



13 **A1** THIRTEENTH
ELEMENT
ENCYCLOPEDIA



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Without dreams society dies...

Paco Rabanne

Many people may find it peculiar that a book about aluminium has the words of a famous French designer as the epigraph. However, let us remember that twelve dresses of his first collection were made from materials that “modern technology offers to us,” to use his own words. To readers who know his style, it will come as no surprise that one of these dresses was a mini-dress made of aluminium plates.

Aluminium is a unique metal. Everywhere you look you will see its applications. Here is a new building. It is huge, but it looks airy; large glass panels are framed with a light metal. It is aluminium. A young girl is walking along the street wearing smart, slightly shimmering shoes. Obviously, they are not made of metal, but they shine because they are covered with a thin sheen of aluminium powder. In the window of a jewelry store rubies, sapphires, and topazes shine. They are aluminium minerals. At home, in the office, in cafes and restaurants you can find this softly shining metal everywhere. Chairs and cans with soft drinks, ballpoint pens and kitchen utensils, a music center and a reading lamp, a laptop, an airplane, a candy wrapper, a car, a cell-phone – we can go on and on, listing all things made of this amazing metal, aluminium. Their advantages are equally numerous – they are easy to use, light, practical, functional, elegant, strikingly beautiful...

“Among beautiful things, especially the ones beautiful in their meaning, in what they symbolize, life becomes better,” says trend-setting furniture designer Philip Stark who also used this metal with a silver shine. Talking of silver, the metal that was named “aluminium” only two hundred years ago was once valued more than silver and gold. It was used to make jewelry that smart ladies of Paris wore. Emperor Napoleon ate off aluminium dishes. But gradually aluminium turned from an exotic metal into an indispensable material for architects, engineers, designers. It allowed many of them to realize their dreams and made us look at the world of usual things differently.



Fiat Panda Barchetta, concept-car of 2007 with aluminium frame and its prototype *Fiat 500 Barchetta* of 1947

Chapter 1 | The History of Aluminium Before the 19th Century

Aluminium Metal in Antiquity – Myth or Reality?

It is impossible to imagine the modern world without aluminium, the most widely used metal today. Aluminium use ranges from the ordinary spoon to the latest aircraft. Aluminium was named the Metal of the Future in the 19th century, when it was first discovered. Although aluminium was discovered quite recently, in the

the craftsman stated, was obtained from clay. Potters separate clay into light and heavy types, a division based both on outward appearance and physical sensation. Heavy clay is spreadable, like butter, and is used in ceramics. If you run a finger across the surface of heavy clay, it shines, whereas light clay stays dull. Furthermore,



Clay

“Once a certain Roman jeweler was allowed to show the Emperor Tiberius a chalice made of a new metal. The chalice was remarkable for its unusually light weight, and it shone just as brightly as silver. The goldsmith told the emperor that he made this metal from ordinary clay. He also assured the ruler that the means of obtaining this metal from clay was known only to him and the gods. The emperor was intrigued by the craftsman’s words, and the financial side of the matter did not concern him much. But soon he was struck by the thought that if people master the production of this bright metal from ordinary clay, all the stores of gold and silver in his treasure trove would instantly become worthless. Therefore, instead of the expected reward, the craftsman lost his head.”

Pliny the Elder. *Natural History*: Tiberius Claudius Nero, 1st Century

19th century, references to an unusual, silver-like metal can be found in the writings of ancient Roman historians.

In *Natural History* the Roman scholar and naturalist Pliny the Elder recounts a legend dating back to the first century AD: a craftsman came to the palace of the Emperor Tiberius bearing a gift of a shiny, silvery chalice. When asked what the chalice was made of, the craftsman responded: from clay. The emperor accepted the gift, but he ordered that the craftsman be executed out of fear that the spread of this new metal would devalue silver and lead to an economic crisis.

Judging by the descriptions of ancient writers, the mysterious metal most resembled aluminium and, as

light clay is difficult to mould and is therefore unfit for pottery. It is easy to confuse it with *bauxite*, a substance used as raw material for metal production today. When heated to high temperatures, bauxite releases aluminium oxide, which is used to yield pure metal with an electric current. However, the Roman legend is about a time long before the invention of electricity.

Even if the mention of clay is fiction, the craftsman could not have found a nugget of “soft, silver-like metal,” since aluminium is more chemically volatile than gold, silver, bronze and iron, and therefore is virtually impossible to find in pure form in nature. Upon coming into contact with water and oxygen, aluminium quickly forms oxides.



Tiberius Claudius Nero



Calcium and aluminium embedded in the Efremovka meteorite

In the 19th century scientists discovered that heating a mix of aluminium oxide (obtained from bauxite) and carbon to high temperatures yields an easily oxidized vapor, which transforms into tiny spheres of metal when cooled. They do not shine, and therefore do not resemble pure metal, but acquire a dull color because aluminium quickly oxidizes when exposed to air, and the exterior of each sphere is covered with a crust of oxide which forms on the spheres' exterior. That is why the metal obtained by combustion with carbon does not shine, and, far more importantly, cannot become an ingot or be used to fashion chalices. Scientists made several attempts to avoid oxidization, such as creating a reaction in a carbon-rich environment. But these efforts did not yield the desired result, and instead of spheres or a nugget of pure aluminium, the scientists found in the furnace yielded a gray powder, or *carbide* (Al_4C_3).

In 1887 in the United States, the Coles brothers proposed adding other metals to aluminium oxide, such as bronze or iron, to prevent the transformation into carbide. They achieved their goal, but obtained a predominantly aluminium alloy. Perhaps this was the method used by the craftsman who brought Emperor Tiberius the chalice.

Unfortunately, no aluminium objects made in antiquity have been discovered by archaeologists. But some

Pure Aluminium in Nature

Although it is well-known that pure aluminium is never encountered in nature, nano-particles of pure aluminium less than 100 microns large have been discovered in iron residue and clay in the eastern Pacific, as well as on the bottom of the Red Sea and in gabbro-doleritic rocks of the Siberian platform. Particles from the bottom of the Pacific Ocean are virtually pure aluminium (98-100%) with minor impurities of iron, titanium, calcium, silicon and also chloride. Micro-particles of aluminium look yellow-orange, because their exterior is covered with a thin film of partially oxidized iron and silicon. Scholars completely exclude the hypothesis that aluminium nano-particles appeared on the bottom of the ocean as a result of human activity, since these particles do not exhibit impurities of copper and manganese, which are inevitable traces in industrially-obtained aluminium. The idea of aluminium falling on the ocean floor from outer space is also unlikely, although particles of pure aluminium have also been found on the Moon. For example, a soil sample taken from the continental area between the Sea of Crises and the Sea of Abundance contained three small, oblong grains of this metal, 0.22 mm, 0.15 mm and 0.1 mm in length (like particles of earth aluminium, they had a matte finish and only revealed a metallic sheen and the characteristic silvery-white color when freshly cut, and the crystal



Surface of the Moon

structure of moon aluminium is in no way different from the structure of its earthly counterpart). Some scientists have also hypothesized, proposed by scientists, a biogenic process for the creation of metal compounds, including aluminium compounds, under the influence of microorganisms that create a restorative environment. However, as a result of the bacteria's activity, metals take shape in a so-called cryptocrystalline form, while the aluminium micro-particles discovered on the ocean floor have a complete crystal structure. We can only guess that aluminium compounds are restored to pure metal by endogenous processes that occur at high temperatures and high pressure without access to oxygen, for example, in a hydrogen- or methane-heavy atmosphere. In these conditions, contact with alkali and ultra-alkali substances with quartz (SiO_2) and halite ($NaCl$) may form the volatile chloride ($AlCl$), which breaks down



The tomb of the first Emperor of a united China, Qin Shihuangdi (246-210 BC)

interesting finds have been made in ancient Chinese tombs. In 1959, the Chinese archaeologist **Yang Ken** published information about a clasp he found in the tomb of Chiansu, dated to the 3rd-6th century AD and made from an alloy that contained 85% aluminium, 10% bronze and 5% manganese. Ornaments in the tomb of the great Chinese commander Zhou Zhu, who died in the early 3rd century, were also made of aluminium alloys. These facts suggest that ancient Chinese metal workers discovered the secret of obtaining aluminium alloys long before the Coles brothers.

We can only wonder why products made of this metal did not become widespread sooner. Whatever the case may be, for centuries mankind used various compound substances with aluminium, never imagining what they contained.

into small crystals of aluminium chloride ($AlCl_3$) as it passes through the layers of geological deposits. Scientists suggest that there is more pure aluminium on the surface of the Moon than on the Earth. They say that the small crystals of metallic aluminium could appear not only during the collapse of the volatile chloride $AlCl$, which is stable only at high temperatures, but also as a result of cosmic rays bombarding the Moon's surface. Under the effect of neutrons and protons flying to the Moon from space, some connections in natural minerals of aluminium come apart, which could lead to the appearance of small particles of free metal. A detailed study of these processes remains to be written by the scientists of the future. ■

Alum in Antiquity and the Middle Ages

Aluminium is a truly amazing metal. It is light and malleable, and therefore has an extraordinarily wide number of uses in modern industry. Pure aluminium is virtually impossible to find in nature, though the metal cannot be called rare since it is part of many compound substances. The most significant of these are *salts* (the result of partial or full substitution of hydrogen acid with metal), particularly alum, known in Russian as *kvastysy*. That is the name given to minerals that are double aluminium sulfates (sulfuric acid salts), alkali metal or ammonia (a compound of nitrogen and oxygen). “Alum is a double salt of sulfuric corundum

them from other types of alum – ammonium alum (*churmigite*) and nitric alum (*mendozite*), which occur much more rarely. They are all highly water soluble, and the solvent gives off crystals in regular octahedra. Describing the properties of salts, **Mikhail Lomonosov** said: “When released in pure water they do not reduce its transparency, and yet in fire some do not burn, but merely melt.”

In nature alum can be found in slate deposits as white fibrous solids; they often form veins, and sometimes films and crusts on clayey minerals. Pliny called these formations “rock sweat.” Fibrous salts were called *stystos*

“Alum has a very strong sour taste, which gave it its name in the Russian tongue. To dissolve, it requires more than ten times its own weight in water. It foams in fire... it combusts in a white, opaque and brittle substance, and the effect of the fire releases through the neck of a boiler into an adjacent vessel a very strong and sour spirit, which differs little from the sulfurous, for not only does it fix the dissolution and corrosion of metals, but can also be used to make sulfur instead of sulfur spirit.”

M.V. Lomonosov. Pervye osnovaniya metallurgii ili rudnykh del. 1763

with a sulfuric alkali – kali, natron, ammonia,” **V. Yuzvikevich**, the Russian technologist, wrote in the mid-19th century.

In most European countries the name of this chemical compound is derived from the Latin *alumen*. In England it is known as *alum*; *alun* in Danish, Swedish and French; *alaun* in German; and, *allume* in Italian. Romanians borrowed the term from German: *alaun*. Even in Ukrainian they are called *halun*. But in Russian these aluminium salts, sour to the taste, were given the name *kvastysy*, from the Slavic root *kysati*, “to sour.” These salts gave aluminium its name.

A book about aluminium, its history and its possible uses would be incomplete without the story of alum, which since the 16th century has been one of Europe’s main strategic products. To this day it is widely used in diverse sectors of industry: in the leather and photography industry as a tanning agent, in the dye industry as a mordant for dyeing cloth, in the paper industry as glue. Alum-based aluminium drugs are indispensable in medicine, be it dermatology, cosmetology, dentistry or ophthalmology.

The most common sort is potassium alum, or the mineral *kalinite*. Ancient geologists barely distinguished

by the Greeks, a word than can be translated as “layered,” or *trichitos*, or “hairy.” Alum deposits can be found near volcanoes, where they form under the influence of sulfurous gas. This is the origin of the alum discovered on the Lipari Islands in the southern Tyrrhenian Sea, on the slopes of Vesuvius and in the outlying regions of Naples, in Pozzuoli.

A hydrous solution of alum is sour to the taste, since it contains an acid formed by the salt’s reaction to water. The sour taste is also related to the Russian name of the substance, which comes from the ancient Slavic root *kisl* or *kvas* – acid. Interestingly, in Polish the word *kwas* means “acid” to this day. In medieval Russian documents the word *kvasety* and later *kvastysy*, referring to alum and alum salts, can be found starting from the 15th century.

The first mention of alum can be found in the writings of **Herodotus** (in the 5th century BC). A detailed description of its properties and applications is known to have been contained in the lost tract of the Greek philosopher **Theophrastes** (372–288 BC). In antiquity alum was used in medicine, as well as in leather trimming, as a mordant when dyeing fabric and to prepare chrysocolla dyes. The ancients knew that alum adds sheen to dull, earthy colors.



Mikhail Vasilyevich Lomonosov (1711–1765) was born in the village of Denisovka in the Arkhangelsk province. In 1730 he set off for Moscow to receive an education. He matriculated in the Slavic, Greek and Latin Academy in January 1731 by passing himself off as the son of a nobleman. As one of the most outstanding pupils, he was sent to Petersburg in 1735 to enroll in the Academic University, and in 1736 he went to Germany to study chemistry and metallurgy. Upon his return, Lomonosov became an adjunct in the physics department, and in 1745 he was named a professor of chemistry and elected as a member of the Academy of Sciences. In 1748 Russia’s first chemical research laboratory was built for his use. Lomonosov’s research in chemistry and physics were based on the kinetic molecular theory.



Gaius Plinius Secundus (ca. 23–79), commonly known as **Pliny the Elder**, was a Roman politician, naturalist and historian. He was born in the city of Como in northern Italy. At an early age he moved to Rome, where he became a lawyer. He took part in military campaigns against Germanic tribes, as well as in Gaul and Spain. Under Emperor Vespasianus he was a procurator in Gallia Narbonensis and Hispania Tarraconensis, and, later, prefect of the Roman navy at Misenum. In 79, wanting to observe the eruption of Vesuvius up close, he disembarked from his ship and was killed by the volcano's poisonous gases. Pliny wrote 160 works, but only his *Natural History* has survived to our time. It contains information about astronomy, physics, geography, mineralogy, medicine, and the history of arts and crafts. This book systematizes the knowledge of Pliny's contemporaries, and uses materials that he collected during his many journeys and observations.

Archelaus, a general of King **Mithridates VI of Pontus**, discovered that wood submerged in an alum solution becomes flame-retardant. This was often used by the Romans to protect their fortresses from possible enemy arson attempts.

Thanks to the high acidity of its solutions, alum was used to polish metals and to cleanse them from oxide film.

In Alexandrian manuscripts, alum was mentioned as one of the substances used for *iosis*, a treatment that colored the surface of an alloy gold. The great French chemist **Pierre Eugène Berthelot**, in his study on alchemy, wrote that French jewelers employed this method in the 19th century.

The Variety of Alum

In modern chemical literature alum is commonly called a double sulfate, not only of potassium aluminium or ammonia aluminium, but of certain other single- and triple-charge ions as well. The generalized formula for alum can be expressed as $M^I M^{III} (SO_4)_2 \cdot 12H_2O$, where M^I is a single-charge cation of potassium, ammonium, rubidium, cesium or thallium, while M^{III} is a triple-charge cation of aluminium, titanium, vanadium, manganese, iron, cobalt, rodium, gallium, indium or thallium. In some cases sulfate ions can be replaced by remnants of selenic acid. All these substances have a cubic



Alumo-ammonium alum crystals

crystal lattice, the corners of which contain sulfate ions and cations of the metals, each of which is surrounded by six water molecules. The only naturally occurring substances are alum with cations of potassium and ammonium, and even these are rare. That is why since ancient times alum has been obtained from *alunite*, which is the basic sulfate of potassium and aluminium. Alum forms in nature when pyrite-rich slate is exposed to air. It can also come from reactions of sulfur oxide solutions (of volcanic origin or products of oxidized sulfides) and aluminium silicates. Often alum can be found in the form of stains on clay-like minerals.

Ammonium alum occurs much less commonly in nature than potassium. Interestingly, mineralogists sometimes use the term alum or halotrichite for double sulfates of aluminium and double-charge cations, for example, or pickeringite (magnesium alum) $MgAl_2(SO_4)_4 \cdot 22H_2O$, *halotrichite* (iron alum) $FeAl_2(SO_4)_4 \cdot 22H_2O$, *apjohnite* (manganese alum) $MnAl_2(SO_4)_4 \cdot 22H_2O$, as well as iron sulfate $FeFe_2(SO_4)_4 \cdot 22H_2O$.

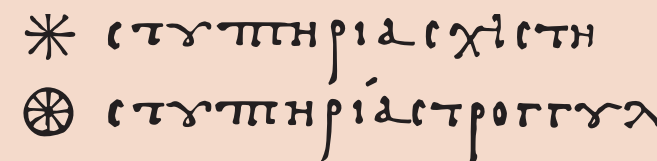
All kinds of alum are highly water-soluble, and their solubility increases with heat. A hydrous alum solution has an acidic reaction environment, which means it is sour to the taste. Alum detaches from alum solutions in the form of beautiful crystals, the shape of which resembles a right octahedron. The slower the evaporation, the larger the crystals are. Commonly alum has a characteristic coloring, often very beautiful. It depends on the type of the triple-charge cation.

Aluminium alum is colorless, titanic alum is indigo, vanadium is violet, chromic alum is dark purple, ▶

In some fields, such as cosmetology and dermatology, it was more convenient to use burnt alum, which was used by fashionable ladies for skin care since ancient times. They were described by Pliny as being: "...melted in bowls until they are no longer liquid." (XXXV, p. 186)

In ancient times the main suppliers of alum were Egypt and the island of Melos, and later, around the 1st century BC, the Lipari Islands, located in the Tyrrhenian Sea. In his *Geography*, the Greek scholar **Strabon** described the largest of these islands, Lipari, mentioning

ALUM MENTIONED IN A BYZANTINE MANUSCRIPT, MARCIAN LIBRARY, VENICE



not only the fertile soils and hot springs, but the profitable alumstone mine (Strabon, *Geography*, VI, II, 10).

Medieval chemistry tracts drew information about alum from the writings of ancient thinkers. Some of them mention *flos alunis* (or *Fleurs d'alun* in Berthelot's works), or alum flowers, along with alum proper. This was apparently the term for the fibrous alum crystals, which resemble small feathers (hence *feathery alum*, *alume minute*, in Russia they were called "fluffy alum" or "stone oil"). The appearance of alum flowers differs from that of other substances that alchemists included among "flowers," the volatile substances that form crystals during condensation (the "red flowers of antimony" were antimony sulfide, the "flowers of arsenic" were arsenic oxide, etc.). In medieval tracts alum was often drawn as rays emitting from a single center, sometimes enclosed in a circle.

Alchemy gradually faded into the past. Abstract philosophical discourse and mysterious quests for the recipe of

To effect this mode of gilding, the copper is first well hammered, after which it is subjected to the action of fire, and then cooled with a mixture of salt, vinegar, and alum. It is then cleansed of all extraneous substances, it being known by its brightness when it has been sufficiently purified. This done, it is again heated by fire, in order to enable it, when thus prepared, with the aid of an amalgam of pumice, alum, and quicksilver, to receive the gold leaf when applied.

The Method of Gilding. Pliny the Elder. *The Natural History*, 1 century



Mining alum minerals. A miniature from the manuscript *Tract on Plants* by the Greek doctor Dioscorides. 16th century

▶ manganese alum is cherry red, rodium alum is yellow, and iron alum is the color of amethyst.

We have already noted that all types of alum are structured identically, which means one metal in them can be replaced by another. Scientists call this phenomenon *isomorphism*. Isomorphism makes it possible to grow a single crystal that consists of several layers. To do this, scientists select a right octahedral crystal of aluminium potassium alum and place it in a saturated solution of chromic potassium alum. The surface of the crystal is covered with a layer of chromic potassium alum, which gives it a violet color. If the same crystal is then placed in a solution of aluminium potassium alum, the violet layer grows a new colorless one. If solutions are alternated for a long time, the resulting crystal in cross-section resembles a zebra-print pattern.

Certain types of alum – such as titanic, vanadic and manganese – are instable and break easily. Not every scientist is able to produce them, even in small quantities. But aluminium, iron and chromic alum are much simpler to produce. These compounds have applications. When heated, alum melts easily, and dissolves in crystallized water. At a higher temperature the detached water evaporates, leaving a powder of burnt alum. A solution of aluminium potassium alum is able to dissolve a considerable quantity of hydrated alumina, yielding *neutral alum*, or the main salt used ▶



▼ as a mordant. This substance is usually obtained by adding soda to an alum solution until the resulting white sediment of hydrated alumina continues to dissolve. Chromic alum has an interesting feature: when boiled, it is destroyed, and the color of the solution turns from violet to green. ■

One of the most important representatives of this movement was **Philippus Theophrastus Aureolus Bombastus von Hohenheim**, better known as **Paracelsus** (1493–1541). In place of earlier medicine, which consisted almost exclusively of herbal infusions and plant essences, Paracelsus introduced drugs made in chemical laboratories. It was the dawn of the era of pharmacists, who manufactured medicines in apothecaries using methods written down in clear detail, unlike their alchemist predecessors, who strove to hide their experiments from others and complicated their descriptions. Great pharmacists made a number of significant discoveries: they perfected and multiplied methods of obtaining chemical drugs. Many substances already known to science entered the arsenal of medicine, including alum. In one of his writings, Paracelsus describes three types of salt – sodium chloride, vitriol and alum – each of which has its own “spirit.” The scholar suggested using alum to treat rashes. “*Aer alumen sanat pruriturum:*” the spirit of alum cures this ailment.

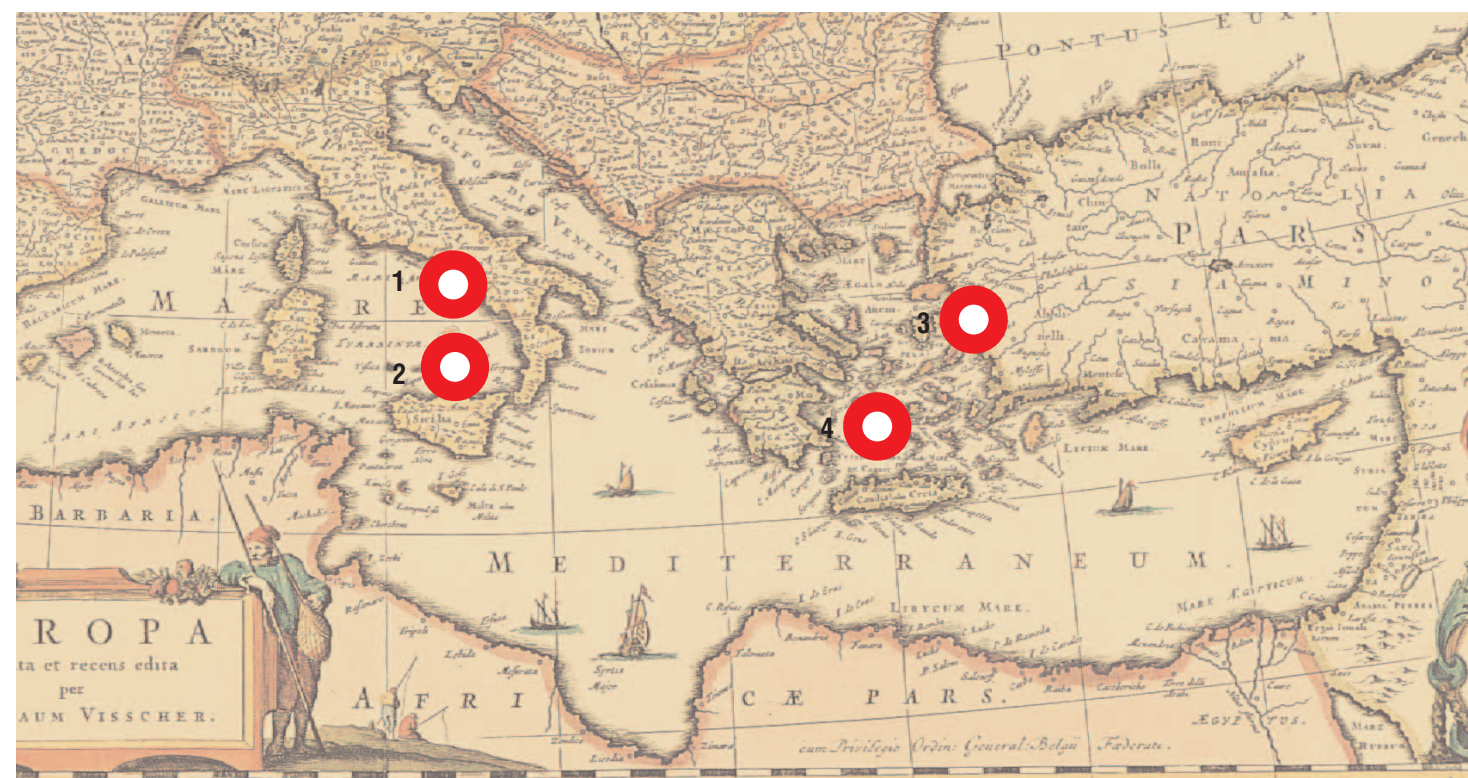
Until the 16th century, alum was brought to Europe from the East, where it had been mined since ancient times. After the Crusades, alum was an important trade item for Genoese and Venetian merchants. In 1177 Genoese merchants traded their goods for alum that the **Saladin** brothers imported from Egypt. A particularly important event for Genoese trade came in 1275, when the Byzantine emperor **Michael Paleologos** offered citizen **Manuel Zaccaria** the right to use mines in Focea (now Foca), near Smyrna. Along with the Pontiac deposits, these mines were the most important sources of alum for many years. As a result, Focea became one of the reasons for the struggle between Genoa, Venice and

Paracelsus (1493–1541), MORE PROPERLY THEOPHRASTUS PHILIPPUS AUREOLUS BOMBASTUS VON HOHENHEIM, A SWISS PHILOSOPHER, NATURAL SCIENTIST, A RENAISSANCE PHYSICIAN, ONE OF THE FOUNDERS OF IATROCHEMISTRY, WAS BORN IN THE CANTON SCHWYZ. HE RECEIVED HIS EDUCATION IN ITALY’S FERRARA AT ONE OF EUROPE’S OLDEST UNIVERSITIES FOUNDED IN 1391. AROUND THE YEAR 1515 HE ATTAINED HIS MEDICAL DEGREE. UPON HIS RETURN TO SWITZERLAND HE TAUGHT AT THE UNIVERSITY OF BASEL (1526) AND WAS THE CITY PHYSICIAN. PARACELUS TRAVELED A LOT ACROSS EUROPE. HE DENIED THE ANCIENT TEACHING OF THE “FOUR JUICES” OF THE HUMAN BODY, AS HE BELIEVED THAT ALL PHYSIOLOGICAL PROCESSES ARE CHEMICAL IN NATURE. HE USED PLANT EXTRACTS AND ELIXIRS TO TREAT HIS PATIENTS AND DEVELOPED A NEW CONCEPT OF DOSAGE AND THE USE OF MINERALS FOR MEDICAL PURPOSES. THE MATERIALISTIC VIEWS OF PARACELUS AND HIS PRACTICE WERE NOT COMPLETELY FREE OF MEDIEVAL MYSTICISM: HE DEVELOPED THE TEACHING ABOUT ARCHAEUS, THE SUPREME SPIRITUAL PRINCIPLE ALLEGEDLY GOVERNING THE WHOLE LIVING BODY.

transmutation slowly gave way to carefully planned experiments. Many chemists at the time directed their gaze to medicine. It was replaced by a new movement called iatrochemistry (from the Greek *iatros* – “doctor”) to underscore its link to medicine. Iatrochemists viewed all bodily processes as chemical phenomena, understood diseases as a result of a disruption of chemical balance, and made their goal the search of chemical substances for treatment.

Take sour vinegar, or any acid as long as it is extremely acidic. And you will have a pipkin with liquid. And you will sprinkle in it a handful of alum. And if it is not enough, add some more. Boil it until the alum melts. And heat the iron on a fire. And test the metal with water, until it makes a sizzle. And if it sizzles, you will take a cloth and soak it in the acid where the alum boiled, and rub it on the metal while it is hot, until it is like a shining copper cauldron. And you will rub it with mercury until it shines golden, as the gold masters do.

15th century Gilding Method



the Byzantine Empire. Other suppliers of alum for the European market were Syria, the part of Fraceea adjacent to Constantinople, Egypt and Yemen.

As we can see, the import of alum to Europe was significant. Focea alone supplied 14,000 centers annually of this raw material, which was transported to European countries on vessels under various flags. By some calculations, the West paid about 100,000 guilders to Asian merchants for alum daily. In those times, a simple person could live for a year on eight guilders, while the great German artist **Albrecht Dürer** received a pension of 100 guilders.

Alum was divided into several types, the finest of which was considered *alume di Rocca*, or alumstone. The name may come from *al Ruga*, the Arab name for the city of Edessa, near which it was mined. Other products in the trade included *alume minute*, or “small alum” from Egypt, “feathered alum” and many more.

The ever-expanding use of alum, mainly for dyeing fabric, required organized manufacturing. The first alum factory in Europe is believed to have been founded by the Genoese merchant **Bartholo Pedrix** on the island of Ischia in the Tyrrhenian Sea. The date of the factory’s founding has not been determined. Some documents suggest it already existed in 1192, while other sources say it only started working in the mid-15th century. By

Major alum deposits in antiquity and the Middle Ages

- 1 Ischia Island
- 2 The Lipari Islands
- 3 Focia
- 4 Milos Island

that time, the Italian cities of Ischia, Vellano and Agniano were all alum suppliers. There is evidence that in 1227 Genoa had alum delivered from Monte Argentaro. In around 1462 an alum factory was built in Tolfa in the Papal States, and in the next century in Tuscany (Volterra, 1558).

A legend retold by the Italian scholar **Vannoccio Biringuccio** (1480–1538) says that the factory in the Papal States was established by the merchant **Giovanni de Castro**, who was banished by Turks from Constantinople and Smyrna. He found the deposits with the help of holly bushes, which supposedly grow in alum-rich soil. Pope **Pius II** welcomed the organization of his own alum manufacture, and immediately canceled imports from Asia Minor, which was under control of the Turks. The Italian alum, called Roman, long played an important role in Europe’s pharmaceutical trade. The papal government set high prices for Roman alum, which led other states to build their own production facilities.

In Spanish Majorca, Algiers and Morocco, alum was mined in the 14th century, and in Bohemia (now the Czech Republic) starting in 1407, although large-scale



Georg Agricola.
On Mining and Metallurgy
Basel, 1557

mining only arrived there in the mid-16th century. The German scholar **Georg Agricola** (1494–1555) listed sites of alum production in Duben near Leipzig, Dippoldiswalde and Lobenstein on the Saale, and Mattesias in the Ellenbogen region. In the late 16th century, factories sprang up near Luneburg, Saafeld, Plauen, Nederlanguenau near Glaz, and a factory in Oberkaufungen in Hessen, which was often mentioned in specialized literature. In England alum factories appeared only under **Elizabeth I** (1533–1603), for example, the factory in Guisborough in Yorkshire county.

Means of alum production used in the 15th and 16th centuries are described in detail in the technological tracts of Biringuccio and Georg Agricola. An important

Georg Agricola on Alum

Now I propose to describe the methods of making alum,¹⁰ which are likewise neither all alike, nor simple, because it is made from boiling aluminous water until it condenses to alum, or else from boiling a solution of alum which is obtained from a kind of earth, or from rocks, or from pyrites, or other minerals.

This kind of earth having first been dug up in such quantity as would make three hundred wheelbarrow loads, is thrown into two tanks; then the water is turned into them, and if it (the earth) contains vitriol it must be diluted with urine. The workmen must many times a day stir the ore with long, thick sticks in order that the water and urine may be mixed with it; then the plugs having been taken out of both tanks, the solution is drawn off into a trough, which is carved out of one or two trees. If the locality is supplied with an abundance of such ore, it should not immediately be thrown into the tanks, but first conveyed into open spaces and heaped up, for the longer it is exposed to the air and the rain, the better it is; after some months, during which the ore has been heaped up in open spaces into mounds, there are generated veinlets of far better quality than the ore. Then it is conveyed into six or more tanks, nine feet in length and breadth and five in depth, and afterward water is drawn into them of similar solution. After this, when the water has absorbed the alum, the plugs are pulled out, and the solution escapes into a round reservoir forty feet wide and three feet deep. Then the ore is thrown out of the tanks into other tanks, and water again being run into the latter and the urine added and stirred by means of poles, the plugs are withdrawn and the solution is run off into the same reservoir. A few days afterward, the reservoirs containing the solution are emptied through a small launder, and run into rectangular lead caldrons; it is boiled in them until the greater part of the water has evaporated. The earthy sediment deposited at the bottom of the caldron is composed of fatty and aluminous matter, which usually consists of small incrustations, in which there is not infrequently found a very white and very light powder of asbestos or gypsum. The solution now seems to be full of meal. Some people instead pour the partly evaporated solution into a vat, so that it may become pure and clear; then pouring it back into the caldron, they boil it again until it becomes mealy. By whichever process it has been condensed, it is then poured into a wooden tub sunk into the earth in order to cool it. When it becomes cold it is poured into vats, in which are arranged horizontal and vertical twigs, to which the alum clings when it condenses; and thus are made the small white transparent cubes, which are laid to dry in hot rooms. If vitriol forms part of the aluminous ore, the material is dissolved in water without being mixed with urine, but it is necessary to pour that into the clear and pure solution when it is to be reboiled. This separates the vitriol from the alum, for by this method the latter sinks to the bottom of the caldron, while the former floats on the top; both must be poured separately into smaller vessels, and from these



Alum production
An engraving from Georg Agricola's book
On Mining and Metallurgy

raw material for alum production was the alumstone known as alunite. This mineral naturally forms from volcanic lava under the influence of sulfurous gas, and when exposed to air it can acquire a coating of alum crystals. Alunite was fired in an oven, similar to that used to heat limestone, until it became red-hot and started to decompose, releasing sulfurous gas. Once cooled, the alunite was removed from the oven, stacked in layers on the floor and generously watered. After the prolonged moistening, the solid became soft and flaky, like lime hydrate. A round oven topped with a large cauldron made of sheets of copper was built to evaporate the alum solution. The bowl was filled with water, which was then boiled and used to dissolve the fired solid. As soon as the solution became

into vats to condense. If, however, when the solution was re-boiled they did not separate, then they must be poured from the smaller vessels into larger vessels and covered over; then the vitriol separating from the alum, it condenses. Both are cut out and put to dry in the hot room, and are ready to be sold; the solution which did not congeal in the vessels and vats is again poured back into the caldron to be re-boiled. The earth which settled at the bottom of the caldron is carried back to the tanks, and, together with the ore, is again dissolved with water and urine. The earth which remains in the tanks after the solution has been drawn off is emptied in a heap, and daily becomes more and more aluminous in the same way as the earth from which saltpetre was made, but fuller of its juices, wherefore it is again thrown into the tanks and percolated by water.

Georg Agricola. On Mining and Metallurgy. 1557

transparent, it was spooned out with deep ladles and poured down a chute into thirty oak troughs, where the solution cooled. There it would yield alum.

Besides alunite, alum ore and slate, which contain both *kaolin* and *pyrite*, were used as raw material for producing alum. The raw material was piled in large clumps that were left outside. When in contact with air, the pyrite gradually oxidized. Obtaining alum in this method required alkali, which for many years came in the form of urine; in an aqueous solution, urea turns into ammonia carbonate, which leads to the formation of ammonia alum. The practice of using urine to manufacture alum continued to the mid-18th century, as we know from Mikhail Lomonosov: “the alum alkali is boiled with urine and poured into vessels.”

After urine was added, the solution was poured down gutters into rectangular lead pans and evaporated until sediment remained. Then the concentrated alkali was scooped into wooden vessel equipped with a grate, and alum would gradually crystallize on its bars (as Lomonosov wrote, one has to wait “alum settles into crystals”). The ready product was dried in hothouses. In some cases alum was obtained from alum slates, which consisted primarily of clay mixed with ferrous compounds.

In pre-Petrine Russia, alum was produced in small quantities in pharmacies, like sulfuric acid, high-proof vodka (nitric acid) and hydrochloric acid. The first Russian pharmacy was founded in 1581 in Moscow during the reign of **Ivan the Terrible**, and in order for that to happen the Englishman **James (Yakov) Frensham** was invited to Russia. Under **Mikhail Romanov** a special

pharmacy directorate was founded, which employed alchemists, distillers and pharmacy students. The prices for the medicine they produced were high. A popular saying of the time went: “If you are going to a pharmacy, loosen your purse strings.” In 1674 Moscow had two pharmacies – one in the Kremlin, which served primarily the tsar’s court, and another in the city center, also state-owned.

In medieval Russia, alum was used in icon painting, dyeing and leather tanning, and medicine. It was also used to gild iron. In the 17th century the pharmacy maintained its high prices for alum: two *altyn* (six kopeks) for a pound (the same price as a kilogram of good meat at that time; an entire shipment of melons could be purchased for three rubles), and burnt alum cost 20 *altyn* per pound. Burnt alum along with sulfuric acid comprised ointments

Although now in Russia many sources of alum earth have been discovered, the spread of this matter... is not being taken up with great effort. Places rich in this important salt are located near Shilka and Agruni, in the Nerchinsky mountains, by the Yenisei River, Tom, Iseta, Volga and many places in Ukraine; although near Tambov an alum factory was established several years ago, now state property, it produces alum with very little intensity. Each year Russia purchases 100,000 rubles worth of alum, which makes it clear that few are concerned with their own salt, which can be produced in abundance in many places of Russia.

A. Shchekatov: “Geographical Dictionary of the Russian State”, 1801–1809

diluted with bear fat and wood oil. Such ointments were used to treat gun wounds, venereal diseases (in this case quicksilver would be added to the ointment). Alum was also used to treat toothaches and lice. An alum solution (a *zlotnik* of salt per pound of water in old Russian measurements, or 10.4 grams of alum per liter of water) with a few drops of concentrated sulfuric acid was taken to treat diarrhea and to stop heavy bleeding.

During the Enlightenment the main consumer of alum was the textile industry. In 1768 the Moscow canvas guild went through about 17 tonnes of this salt. Dyeing centers used alum solutions to *enliven* colors, making them more vivid. Before dyeing, fabric would be dipped in an alum solution for greater absorbency. Alum was indispensable for dyeing leather: 6,000 skins took 100 kilograms of alum. On a trip to Astrakhan, the Russian scientist **Pyotr Simon Pallas** observed the process



Ferro aluminium alum



Pharmacist's vessel. 18th century

Alum production technology
(To an engraving from Diderot and d'Alambert's *Encyclopédie*, 1762)

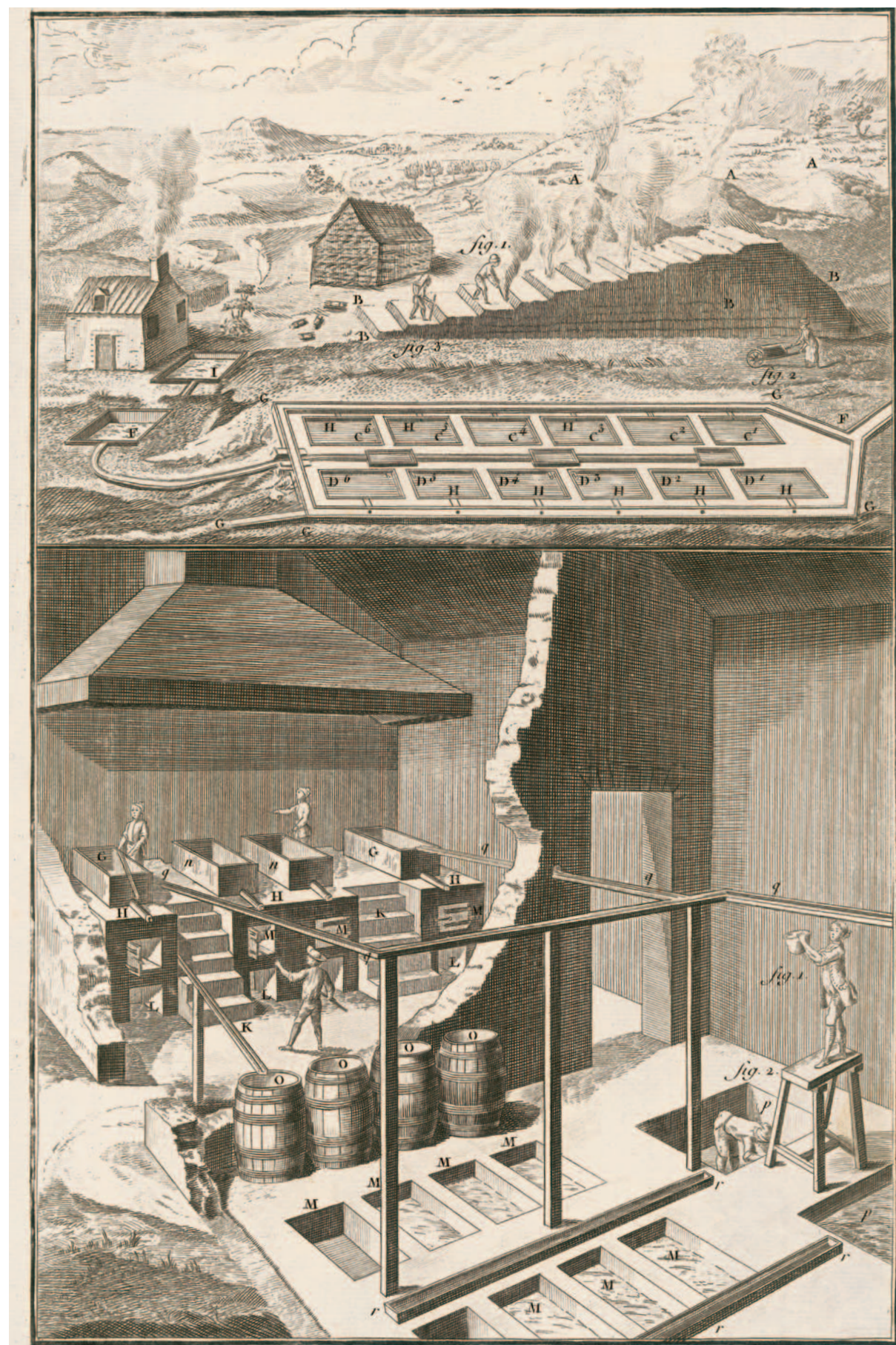
The alum ore is put on an even dry place in piles (A), which look like cut-open pyramids. Under the influence of moisture in the air, it heats up and emits sulfuric gas, then is covered by alum crystals, which sometimes resemble hair in their shape. This ore is ready for desalination.

When using alum shale as the ore, specialists work differently. The shale is gathered on a flat, horizontal plane in the shape of a staircase. Bundles of twigs are placed on each step and lit on fire. As they burn, the shale loses its hardness, crumbles and becomes ready for desalination.

Alum is desalinated in *soaking pits* (C and D). These rectangular pools are a little more than one meter deep, dug in the ground. In these pits the alum in the ore becomes a solution called alkali. The separated alkali is poured into pits placed in the center, from where they are sent to reservoirs (F and I) down a stone-lined canal.

From here the alkali ends up in the boiler, the internal appearance of which is shown in the lower part of the engraving. Inside the boiler, alkali moves down the tubes (Q) to the stoves with pans (G) about 2 meters long. The oven is a parallelogram laid with fire-resistant bricks, with openings for loading firewood (M) and raking away the ash (L). Above the oven, where the steps (K) lead, sits a pan in the shape of a rectangular box, cast in lead.

The total mass of the pans with a depth of 70 centimeters reached 300 pounds, or almost five tons. Transporting such vessels was very difficult, and therefore they were cast right at the factory. As the solution evaporated in the pan, fresh alkali was added. The craftsman had to use his eye to determine the moment to switch to the next operation – pouring the steamed alkali into the barrels (O). There the particles in the alkali settled on the bottom, and the solution became transparent. Then the ready solution was poured into the crystallizers (M), which look like rectangular baths on the level of the floor. Alum crystallized in them, settling on the bottom and on the sides. The crystals were removed, laid on inclined drying boards (R), where the alkali ran off the crystals, and the alum dried out. The alum factory, equipped with seven pans, in ten days could produce up to three and a half tons of alum. ■



Alum production. An engraving from Diderot and d'Alambert's *Encyclopédie* (1762)



Chambers of the 17th-century Pharmacy Directorate in Starovagankovsky Pereulok, Moscow. The second floor was added in the 1920s

Medical Qualities of Alum (Medieval Recipe)

"Say they that alum of different kinds can be found, The fourth degree they contain, dry and hot power, Power is that which stops blood flow and lightens the dark eyes. Alum thins eyelids, eating up the meat excess, Or the meat that is around, when the tissues have died. Dry they also bad ulcers and close wrinkles Add then nut-gall and strong wine grounds to them. Heal they hurting teeth, and should gums swell up help also. Mix strong wine with honey to treat this. Blood when spills from the mouth, stop they the flow. Rub an ulcer with them, the ulcer or itching will pass, Or by dissolving the alum, wash it with water".

Author unknown. Spuria macri
Addition to *De Herbarum* by a French physician
Odo de Meung, 11th century ■

of colouring a wild donkey skin red and recorded the following description: The skin was bleached before coloring, then moistened in a solution of soda obtained in Astrakhan's estuaries, then submerged in "the strongest alum solution," after which it was dyed. Alum was also used to glue canvas and paper, to make wood fire-resistant and to clean the surface of metals. Additionally, alum was put in sealing wax, which from the 19th century was used to seal envelopes and apply stamps.

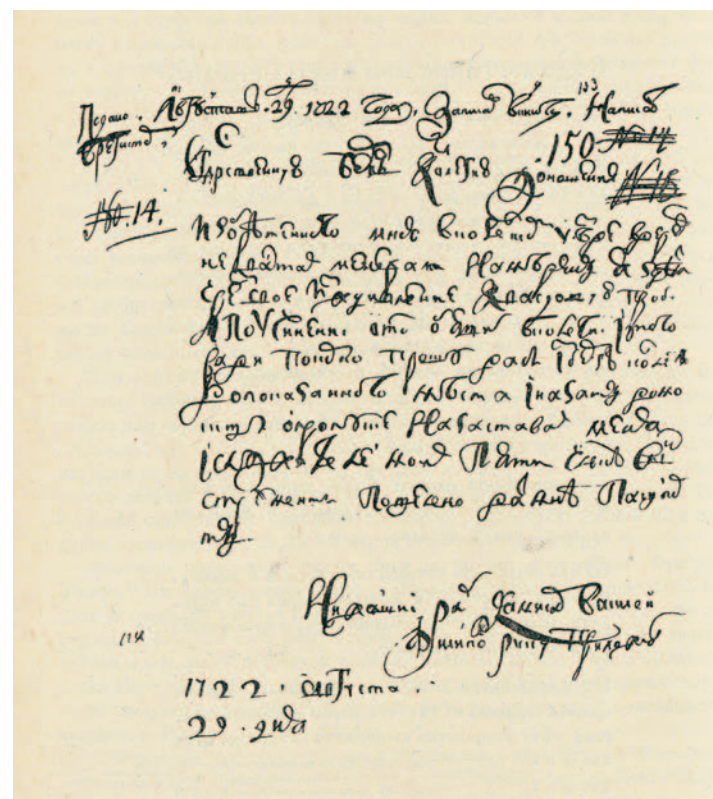
Despite the high demand for alum, Russia did not have its own alum factories in the 16th and 17th centuries. Raw material was imported, primarily from Germany and Holland. In 1547, Ivan the Terrible ordered the Saxon **Hans Schlitte** to recruit masters to work in Russia. Among the hundred men he selected was a "master for boiling alum". However, the craftsmen were unable to enter Russia because of the Livonian Brothers of the Sword, who were way part of the Russian state rein-

forcing its military and economic resources. The Livonian knights jailed Schlitte and arrested the craftsmen.

Under Peter the Great, Russia made its first attempt to organize the industrial production of alum. In 1720, the German **Friedrich Stift** built an alum factory in the Vyborgskaya Storona area of St. Petersburg, not far from a deposit of bauxite ore. In 1722 alumstone was found by **Vasily Filippov** in the Kozel district. The following year, samples of the alum obtained from this deposit were presented to St. Petersburg's Berg Collegium, an industry and trade ministry founded by Peter the Great, along with a request to allow construction of an alum factory, to free it from taxes for ten years and forbid the opening of such factories by other people. Considering no one had opened such a factory before Filippov, the Berg Collegium approved his request. But apparently in the following years not one of his proposed factories was launched. Documents of the Berg Collegium from 1730

Aluminium (alumina) – we know this metal for its local effect, specifically in the form of alumen, a chemical compound of alumina and potassa sulphates. Alumen in their astringency approach the metals discussed above [mercury, zinc, copper, and lead], while also demonstrating a minor antiseptic effect. Alumen is often used as a gargling solution to treat angina (1 teaspoon per cup of water), for scurvy mouth inflammation, for irrigation against the white, etc. Aluminium acetic acid has very strong antiseptic qualities and in a 3-percent solution is used in surgery. Silicate alumina or clay, argilla s. bolus alba, insoluble and nonabsorbable is used to add to pills from easily decomposing elements, such as caustic and other.

Prof. Shapiro, "Pharmacology Textbook", 1890



Vasily Filippov's report to the Berg Collegia on finding an alum deposit. August 29, 1722

attested that "alum is brought from other states for many thousands of rubles, and in Russia no one makes it."

Several years later the situation changed, and by 1737 Filippov's factory in the Kozel district had apparently already started to produce alum. **Fyodor Polunin's** *Geographic Lexicon of the Russian State* (1773) mentions it: "Alum, tar and potash, which go to all areas of the Russian state from here, is made here in the finest good will." Archival documents dated 1735 refer to an alum factory on the river Zhizdre, belonging to the industrialist **Makeyev**.

In the 18th century, alum deposits were discovered not only in Moscow, but also in Kazan, Simbirsk, Nizhe-

gord and Tobolsk provinces. In 1768 the merchants **Grunt** and **Proskurin** built an alum factory in the village of Sosnovka in the Tambovsk vicarate (later a province). By the late 18th century the factory became one of the largest in Russia in this field: it employed 65 men and a laboratory was organized there. In 1788, the factory produced 12.75 tonnes of alum, at a cost of 173 rubles 90 kopeks per ton. However, demand for alum grew in proportion with the development of the textile industry, and continued to exceed supply.

The Russian scientists **Pallas**, **Laksman** and **Gildensedt** undertook an expedition to the Urals, Siberia and the Far East with the intention of finding new alum deposits. **Vasily Severgin** found alum soil on the lower Dniepr, along the shores of the Moksha River near Morskansk, in Tobol, in the northern Caucasus and in Siberia. This was also the time when Zanliksky began to process a deposit in Georgia, which at that time was part of the Russian empire. In Moscow alum was prepared at the **Lepioshkinys'** chemical factory, founded in 1824. Its proprietors also owned the Dmitrovsky factory in Ivanovo-Voznesenk and the Vyskovo factory in the Kovrovsky district. In 1837 a factory was established in Doktorovo, a village in the Bogorodsky district of the Moscow province, later called the Doktorsky factory. In the 1870s the Tentelevsky chemical factory in St. Petersburg (renamed Red Chemist after the revolution) began using French-imported bauxite as a raw material. In the late 19th century alum was produced in 10 Russian factories, and cost from 90 to 100 rubles per tonne. The annual alum production Russia for 1888 reached 3,344 tonnes.

Besides alum, Russia also started producing aluminium sulfate – also called sulfurous alumina – in the 19th century, starting with Tentelevsky's St. Petersburg factory in the 1870s. French-imported bauxite was used as raw material until it was replaced by Russian clay.

A 1798 description of the Tambov alum factory

1 boiler for boiling alum, 2 brick furnaces with 5 ovens each, for boiling the alum sand, 1 cauldron and a spare, 2 for heating, also the reboiling of the alum requires one large cauldron and another small one, a total of 6 lead cauldrons and 1 iron one. A third brick furnace with three ovens. A hothouse for crystallizing alum. 8 wooden bins for separating and washing the alum sand and for [growing crystals] of vitriol, including 1 collective with a standing valve, and a bin. A urine hothouse with vats, a water wheel and 6 pumps for pouring water into the boilers and hothouses in the bins and cauldrons of water. A boiler for boiling potash, with 2 brick ovens and an iron cauldron.

GADA, fond Berg-kollegii. No. 2709. Delo 5. Leningrad: 390–391.

Aluminium Earth

As we know, aluminium metal is virtually impossible to find in nature. Yet ancient and medieval naturalists knew about the substances that contained it, included alum. But until the 18th century scientists did not know how to distinguish aluminium compounds from other similar chemical compounds. This required a rigid, academic approach, so a scientific system for classifying various compounds was devised. One of its classes was “earth,” which included alum earth, or *aluminium earth*.

In order to make sense of the terminology and understand what *aluminium earth* means (and our narration cannot be complete without its history), we must go back in time and look at the world of substance through the eyes of the intellectuals and encyclopedists of the Enlightenment.

Until the mid-18th century, theoretical ideas about matter were based on the medieval theory of *phlogiston*, a volatile substance emitted during combustion and oxidation in the form of heat and fire. This theory, which appeared in the Middle Ages, was articulated by **Georg Ernst Stahl** (1659–1734), a German doctor and chemist. Curiously, the ubiquitous theory of phlogiston could not explain why rusting (a process that Stahl compared to burning wood) made iron heavier, even as phlogiston was emitted from it. To the chemists of the 18th century this contradiction did not seem very important; they mainly cared about explaining changes in the appearance of the substance.

In the classification system of the time, scientists isolated salts as a special group of chemical substances, or *bodies*. In addition to sodium chloride, it included sulfuric acid, alum, ammonia salt (ammonium chloride), Epsom salt and Glauber’s salt.

Bodies at the base of salts that form when they are heated were called *earths*. Several kinds of earths were known: lime earth (burnt lime), obtained by burning lime or marble and used in construction, bitter earth (magnesium earth), which is formed by heating Epsom salt. Sometimes the concept of soil was interpreted more broadly: “Soil is a mineral body, simple, hard, fragile, constant in fire, does not melt or dissolve in water, spirits, oil or air” (**Herman Burgave**, 1732). A similar defini-



Georg Ernst Stahl (1659–1734) was a German physician and chemist who invented the theory of phlogiston, which claimed that all combustible bodies, as well as metals, contain a common essence (phlogiston is derived from the Greek *phlogistos*, or flammable), which is lost in combustion of metals. He was born in Ansbach. From 1673 to 1679 he studied medicine and chemistry at the University of Jena, and after graduation he received a post as a private docent, and then a professor of medicine. In 1687 he was appointed the court physician of Duke Johann Ernst of Saxon Weimar. In 1694 he became a professor of medicine in the new University of Halle. In 1715 he was invited to Berlin as the court physician to the Prussian King Friedrich Wilhelm I. Stahl was the president of the Medical College, the highest medical institution in Prussia. The College of Medicine and Surgery for the preparation of military physicians was founded in Berlin due to Stahl’s efforts.

tion is given by the Russian scientist **Alexander Sherer** (1807): “Soil in water without a constant body does not dissolve, in the strongest fire does not change, does not have color, odor or flavor.”

The English physicist and chemist **Robert Boyle** (1627–1691) established that the effect of bodies on two other groups – acids (also the name given to sour-tasting substances) and *alkali* (substances that form when soapy

solutions are dissolved in water) – yield salts. This intrigued many natural scientists. The Swedish scientist **Torbern Ulaf Bergman** (1735–1784), who studied the components and properties of many inorganic salts, for many years tried to understand the makeup of alum. In a 1767 article he described the crystallization of alum from a solution obtained by boiling alunite with sulfuric acid and added *potash* or ammonium. He also obtained alum through the reaction of solutions of potassium sulfate (which he called vitriolated vegetable alkali, or potash, processed with sulfuric acid) and aluminium. Thus the scientist proved that alum is a double salt.

Metals at that time were considered to be complex bodies that consisted of a type of *calx* and phlogiston (scientists believed that during combustion iron lost phlogiston and became “iron calx,” known to us as iron scale, while the white powder resulting from burning zinc was called zinc calx). In ancient times there were seven known metals – gold, silver, iron, mercury, lead, copper and tin. In the Middle Ages three more appeared – zinc, antimony and bismuth, discovered by Agricola in 1529. Metals differed from other bodies primarily in their physical properties – metallic sheen, plasticity and heat conductivity. Scientists noted that iron, copper, zinc, tin, lead, antimony and bismuth became dull and lost their metallic sheen when heated in air. Unlike them, metals such as gold, silver and mercury did not change in the air. These metals came to be known as noble.

Chemists long believed that there was some sort of original earth, and all the earths they knew were varieties of it. However, that confidence gradually subsided, since it turned out that each earth has its own special properties. The earths that are somewhat water-soluble came to be called alkali. Among them were lime, and also the hard soil *barite*, discovered in 1774 by the Swedish scientist **Carl Wilhelm Scheele**, and strontian, obtained in 1792. Some scientists included silicon dioxide, or quartz among the soils.

The theory that alum is a salt of a special alum soil was first expressed by Paracelsus in 1530. **Andreas Libavius** proved that alum and sulfuric acid were formed by the same acid, but different soils. In his writing we first encountered the name of another soil – *alumina* (from the Latin *alume*). “Alum follows sulfuric acid, but the alumina in it is not perfect [like iron earth]. Thus, heating pyrite and alumina expels the spirit of alum, which is

Ceramics

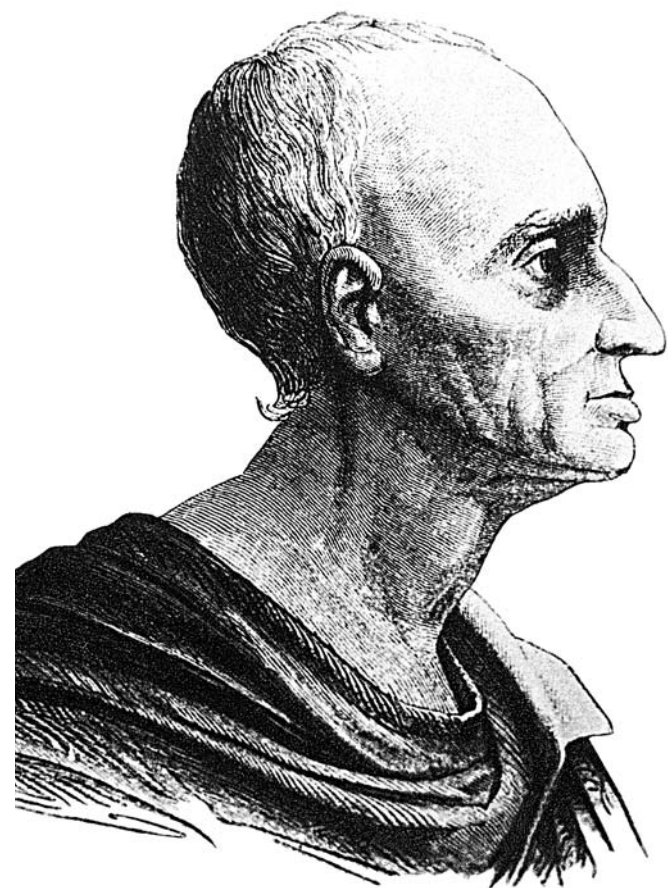
In the Stone Age, long before the smelting of bronze and iron was discovered, mankind mastered the production of clay flatware. Products from fired clay are widely used nowadays: bricks, tiles and shingles are used as construction materials, while porcelain and faience are the basis of objects of *dé cor* and tableware. Yet any clay contains aluminium. Even the ordinary clay we walk on is an aluminium deposit. And the wondrous properties of the most diverse products from clay are to a large extent due to their aluminium content.

Clay, or *kaolinite*, is a white, crystal-like substance. Kaolinite crystals are fine, six-cornered plates approximately 0.00005 cm in size. When wet, they stick to each other like sheets of wet paper. In this condition clay is able to retain water in the gaps between crystals. Water, which is contained in moist clay, acts like a lubricant – the crystals easily

THE SYSTEM OF CHEMICAL COMPOUNDS IN THE TIME OF THE PHLOGISTON THEORY

I Class	Metal 1) Noble: gold, silver, mercury 2) Ignoble: iron, copper, zinc, tin, lead, antimony
II Class	Calx Iron calx [Fe ₃ O ₄], copper calx [CuO], zinc calx [ZnO]
III Class	Earth Calx earth [CaO], bitter earth [MgO], alum earth [Al ₂ O ₃]
IV Class	Salt Common salt [NaCl], ammonia salt [NH ₄ Cl], vitriol [CuSO ₄ · 5H ₂ O, FeSO ₄ · 7H ₂ O], alum [KAlSO ₄ · 12H ₂ O], Epsom salt MgSO ₄ · 7H ₂ O, Glauber’s salt Na ₂ SO ₄ · 10H ₂ O
V Class	Alkali 1) Weak: potash K ₂ CO ₃ 2) Caustic: caustic potash KOH, caustic soda NaOH 3) Volatile: ammonia spirit NH ₃ · H ₂ O
VI Class	Acids 1) Mineral: sulfuric [H ₂ SO ₄], hydrochloric [HCl], nitric [HNO ₃], phosphoric [H ₃ PO ₄], boric [H ₃ BO ₃] 2) Vegetable: acetic [CH ₃ COOH], oxalic [H ₂ C ₂ O ₄] 3) Animal: lactic [CH ₃ CH(OH)COOH]
VII Class	Water, sulfur, phosphorus
VIII Class	Gases Carbon dioxide [CO ₂], sulfurous gas [SO ₂], hydrogen [H ₂], chloride [Cl ₂], oxygen [O ₂], nitrogen [N ₂].

sulfuric acid,” he wrote. The French chemist **Etienne Geoffroy** (1672–1731), studying alum, also came to the conclusion that it is based on a special alumina earth in a compound with sulfuric acid. However, the scientist erroneously believed that heating alumina could yield quartz. This led to confusion among scientists and delayed the discovery of how the new earth could be obtained in its pure form. Scheele first demonstrated that alumina, like quartz, comes from clay. The difference between these two soils was discovered by the German senator, pharmacist and chemist **Johann Wiegleb** (1732–1800), who



Andreas Marggraf (1709–1782) was a German chemist and metallurgist who studied in Halle and in the Freiberg Mining Academy. He worked in Berlin at the pharmacy of the royal court, then headed the chemical laboratory of the Berlin Academy of Sciences. His work employed the newest equipment and analysis methods. Marggraf was one of the first to work with the microscope, using it to prove the existence of sucrose crystals in the roots of the sugar beet. After obtaining gypsum from a reaction of sulfuric acid and lime, he concluded that the substance was a hydrated sulphate of lime. In 1750 he perfected his method of obtaining phosphorus by replacing the urine commonly used for this with natural phosphates. He studied alum and isolated the new alumina earth.

▼ slip against each other. Whoever has walked on damp, clayey soil knows how hard it is to maintain balance. The plasticity of moist clay recalls plasticine; even complex shapes can be molded in it with ease. When the clay dries, individual crystals of kaolinite stick together, forming a rigid and hard mass, which maintains the resulting form. After drying the ceramic products are fired in a kiln, and individual crystals are joined in a single hard mass, which consists of mullite ($3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$) crystallised in the shape of needles, and firm solutions based on it. These pointy mullite crystals make ceramic wares durable.

Ceramics is the common name of products from kiln-fired clay. It is supposed that the origin of the name is linked to a region of Athenian potters (from the word *keramos*, or potters' clay) on the shores of the Eridan River. Depending on the impurities in the clay, ceramics has either a yellowish-brown or indistinct gray color after firing. To make a pattern, finely ground metal oxides are used then applied to porcelain and faience. During firing, they react with mullite, forming brightly colored substances. In order to avoid this and give the product a beautiful color, before firing the product is covered with a thin layer



Porcelain plate. France, 19th century

of high-quality colored clay called *engobe*, or glass glaze.

Firing unpurified clay, colored yellow or brown with iron compounds, produces bricks, shingles and fire-retardant materials.

Ceramics based on aluminium oxides are used more and more actively in modern medicine and are taking over one of the most important fields in the medicine of the future: implants. Ceramic implants to replace and restore bone are superior to metal ones for several reasons: they are more durable, last longer and are not rejected by the body.

Ceramic with a nonporous structure is called *porcelain*. It is made from very pure, white clay with no impurities. When fired, porcelain becomes porous, and therefore is usually covered with glaze and decorated with patterns. Both *overglaze* and *underglaze* ►

proved that quartz cannot be transformed into alumina by an alkali alloy, as was believed earlier. In 1739 the French chemist **Jean Gello** proved that quartz soil, obtained by the reaction of alkali and alum, was identical to the earth in clay.

The first person to obtain pure alum earth was the German scholar **Andreas Marggraf** (1709–1782). In an attempt to isolate alum earth, he boiled clay with sulfuric acid, but nothing came from the solution. Success came when the scientist accidentally added potash to the drum where the reaction was taking place. After some time the scientist discovered crystals alum at the bottom of the drum, which he recognized by its characteristic octahedra. “Alumina earth [*Alaun-Erde*] is a special earth, which is present in clay along with quartz,” he wrote. The scholar also discovered that to obtain this earth he only had to add alkali, soda or potash to an alum solution. After drying, aluminium oxide, or alum earth, retains its ability to dissolve in acids, like lime, which made it possible to include it among alkali earths. Only in 1789, after the death of Marggraf, the German chemist **Martin Henrich Claproth** discovered that settled alumina dissolves in alkali, unlike alkali earths. This led scholars to study it separately. Marggraf prepared salts of alumina earth, or aluminium salts. He described chloride and aluminium nitrate, which are secreted in the form of colorless crystals, as well as a gel-like acetate, which turns into white powder when dried.

The first study devoted solely to alumina appeared in 1801; it was written by the Swiss chemist **Horatius B. Saussure**. In Russia aluminium oxide was called “clayey earth” (N. Sokolov, 1788), alum earth (V. Severgin, 1796), clay (A. Scherer, 1807). The term *glinozem*, or “clay-earth,” was introduced by Ya. Zakharov in 1810.

Aluminium salts were studied by Marggraf's contemporary **Thomas Henry** (1734–1816). He obtained an aluminium acetate solution by processing alumina with acetic acid. This salt turned out to be a very good mordant, and it was used to this end in the 20th century. For many years aluminium acetate was widely used in the production of water-resistant fabrics. For this the fabric was soaked with soap solution or a casein solution in soap, and then processed with aluminium acetate. Wood soaked with a solution of this salt becomes resistant to flame and rot.

In order to conclude this classification of substances that was current in chemistry in the mid-18th century, it is also worth remembering substances that were studied

▼ decorations are used. In the first case, paint is applied to the glaze's surface, while in the second it is applied directly to the porcelain. Since application of glaze is related to firing wares at high temperature, underglaze uses only pigments with a high thermic durability, such as solutions of salts of transitional metals, which color the ware in mild, translucent, watercolor tones. Underglaze decorations often employ *cobalt blue*, or cobalt aluminate CoAl_2O_4 , familiar to every Russian from Gzhel ceramic ware.

Only a small amount of *biscuit* porcelain (i.e., unglazed) is released. The white, matted surface of biscuit porcelain effectively conveys the volume, therefore it is used as a material for sculpture, medals and reliefs.

China is considered the birthplace of porcelain. It appeared there sometime between the 4th and 6th centuries CE when the recipe for preparing ceramic mass was perfected. Beginning in the 16th century, a material very similar to Chinese porcelain called *soft porcelain* was produced in Western Europe. It was made in a spreadable silicate mass, similar in composition to opal glass. Like porcelain wares, it was covered by a transparent leaden glaze



Teapot, bowl, casket. Mayolika, gzhel, 1980-s

and decorated. One variety of soft porcelain is bone porcelain, which is produced by adding bone ash to the clay. The Chinese successfully kept the secret of creating true porcelain (sometimes called “hard porcelain”) from foreigners for centuries. Only in 1708 did the Saxon craftsman **Johann Friedrich Betger** discover the secret, and the German city of Meissen began to produce porcelain that to this day is considered classic. In Russia regular porcelain manufacturing was established in the mid-18th century by **Dmitry Vinogradov**, who also independently discovered the secret of making porcelain clay.

Faience is outwardly similar to porcelain, but is more porous, less dense and completely opaque. Faience has been made in Europe and in the Middle East since antiquity. Dishware produced from it is heavier than porcelain and does not let light through.

Majolica is the name given to highly porous goods from colored, fired clay. Water can pass through unglazed majolica because of its large pores, ►

separately from others. They include: water (scientists did not know if it was a simple or compound body), and also sulfur and phosphorous, mistaken for a combination of sulfuric and phosphoric acids with phlogiston. Phosphorus, which was later used to manufacture matches, was discovered in 1669 by the alchemist **Hennig Brandt** in urine as a result of his searches for the philosopher's stone.

Starting from the mid-18th century, scientists paid special attention to studying gases, which were long known as *types of air*. Besides the aforementioned flammable air (oxygen) scientists knew of constant air (carbon oxide gas), sulfur gas, and chloride, which was considered a hydrochloric acid without phlogiston. The English chemist **Joseph Priestly** and Carl Wilhelm Scheele proved that air is not a homogenous body, but consists of two gases – oxygen (air without phlogiston) and nitrogen (phlogistic air).

As practical chemistry developed, scientists accumulated facts that contradicted their beliefs about phlogiston. Working with the experiments of Priestly and Joseph Black, who proved that burning phosphorous expends a certain amount of air, and that burning coal releases carbon oxide, the great French chemist **Antoine Laurent Lavoisier** (1743–1794) made the brilliant conclusion that burning is “not the decomposition of burning bodies into elements, but the union of the burning body with oxygen in the air.” Thus, phlogiston does not exist, metals, and also carbon and sulfur, are simple bodies, and their products of combustion are metallic calx, carbon oxide and sulfuric gases, or compounds of simple substances with oxygen. The scientist also discovered that the mass of a substance formed during combustion is exactly equal to the mass of the burnt body plus the mass of the spent oxygen. He famously phrased this finding as follows: *la nature ne fait rien de rien, et la matière ne se perd point* – “In nature nothing is made of nothing, and matter does not disappear.” “No one dared to disturb it [the theory] until a man appeared who destroyed the whole beautiful building with one wave of his hand. Not by negating it or proving its incorrectness, but simply by replacing it with a new theory – a better one, for it was simpler and more precise. That was Lavoisier.” (M.G. Zentnerschwer. Essays on the History of Chemistry). The great Russian chemist Mikhail Lomonosov came to the same conclusion independently of Lavoisier, when he experimented with heating metals in vacuum-sealed boilers.

▼ and therefore majolica wares are always covered by opaque enamel. Pigments are applied to the surface of raw enamel before firing. Majolica has been known in Ancient Russia since the 11th century (called *izraztsy*). Majolica tiles were used to decorate the walls of buildings, ovens, and fire places. Traditional Gzhel ceramics use the same majolica technology.



A vase for flowers. Bisquit. Dmitrov Porcelain Factory. 1950s

Many Russian artists adopted the majolica technique in the late 19th – early 20th centuries. Using Mikhail Vrubel's sketches and with his involvement, in 1899–1903 the Dream Princess mosaic picture was created on the front of the Metropol Hotel. Products of the Gzhel masters are also examples of majolica. Firing ceramic masses at high temperatures



A stove tile. Russia, 18th century

yields a dense material called *stone mass*. Wares from stone mass are usually decorated with a thin relief and glazed. Technological equipment uses special ceramic materials that are heat-resistant metal oxides. For example, alundum furnaces, which only become hot at high temperatures, are made from aluminium oxide. ■



Antoine Loran Lavoisier (1743–1794) WAS BORN TO THE FAMILY OF AN AFFLUENT LAWYER. HE GRADUATED FROM THE LAW FACULTY OF THE UNIVERSITY OF PARIS. ALONG WITH JURISPRUDENCE, HE STUDIED MATHEMATICS, ASTRONOMY, BOTANICS, MINERAL GEOLOGY AND CHEMISTRY. HE WON FAME AMONG CHEMISTS BECAUSE OF HIS WORK ON MINERAL ANALYSIS. IN 1768 HE WAS ELECTED AS AN EXTRAORDINARY ADJUNCT OF THE ACADEMY OF SCIENCES FOR CHEMISTRY, AND BECAME AN ORDINARY ACADEMIC IN 1778. ON MAY 8, 1794, LAVOISIER WAS GUILLOTINED BY ORDER OF A REVOLUTIONARY TRIBUNAL FOR BEING A FORMER TAX COLLECTOR. HIS MOST SIGNIFICANT ACHIEVEMENT WAS TO REFUTE THE THEORY OF PHLOGISTON, WHICH HAD PREVAILED FOR MANY DECADES, AND CREATE THE THEORY OF COMBUSTION. HE VIRTUALLY CREATED A NEW PHILOSOPHY OF CHEMISTRY, A NEW SCIENTIFIC SYSTEM.



Mikhail Vruble Day-dreaming Princess.
Mosaics, Moscow, 1899–1903

The principle of the preservation of matter was stated by Lomonosov with complete clarity and awareness of its general significance: “All transformations that occur in nature happen such that if something arrives somewhere, than simultaneously it departs from another place in equal measure. Consequently, if some matter is added to a certain amount of matter, then another body loses the same amount of it.”

Earth’s resemblance to the metallic oxides studied by Lavoisier led him to the conclusion that earths are

also oxides. However, Lavoisier had no direct proof of this. That came several decades later, when in 1807 the English chemist **Humphrey Davy** broke down alkali with an electric current and obtained pure potassium and sodium. Soon after that metals that formed earths were discovered: calcium, magnesium, strontium, barium and aluminium. Curiously, even the great English chemist **John Dalton** (1766–1844), a contemporary of Davy, for a long time mistakenly put alumina beside soda and potash as an element, based on the fact that it

Aluminium and oxygen form a compound long known as alumina. This oxide, combined in various proportions with silica, forms important compounds called clays; it also is part of a large number of minerals <...> Many precious stones, such as rubies and sapphires, are composed of alumina and colored with certain metallic oxides. The same is true for pure colorless and crystallized alumina, and emery, colored by iron oxide. All of these substances, like hardened alumina, are unaffected by acid and alkali. Alumina can be either anhydrous or in a compound with water. It is easy to produce in the latter form; or by the decay of papermaker’s alum or alum dissolved in water with ammonium, or better still with ammonium carbonate, forms a gelatinous residue of hydrous alumina. If this substance is heated to close to a red-hot temperature it loses its crystallized water and forms anhydrous alumina. Anhydrous alumina can also be obtained by using heat to isolate papermaker’s alum and ammonia, or ammonia alum. The smelting pot where the heating is done retains a white, very light mass that consists of hydrous alumina <...> Hydrous alumina is not water-solvent, but dissolves easily in acids and in a solution of potassium or soda; in the latter case, when the liquid slowly evaporates, a crystal compound results, expressed by the formula KOHAl₂O₃ and creates aluminium potassium. The solubility of alumina in ammonia is barely significant, but given a certain amount of alumina this reactor cannot be used to precipitate alumina. <...> Anhydrous alumina, heated until red-hot, becomes insoluble in both acids and alkalis. Hydrous alumina with organic dyeing substances forms compounds of very diverse colors, called varnishes in painting. Alumina does not melt in the strongest fire of our furnaces, but melts in the flame of oxyhydrogen. Subjecting alum mixed with a small quantity of chromoxide potassium to the this temperature results in false rubies, which due to their small size cannot be used.

August Cavure. “A course in elementary general chemistry”. Paris, 1860



Jöns Jacob Berzelius (1779–1848) WAS A SWEDISH CHEMIST AND MINERALOGIST. IN 1802 HE COMPLETED A DOCTORAL DEGREE IN MEDICINE AT UPPSALA UNIVERSITY. HE BECAME A PROFESSOR AT STOCKHOLM UNIVERSITY IN 1807, IN 1810 BEGAN WORKING AT THE MEDICAL SURGERY INSTITUTE. IN 1810 HE BECAME HEAD OF THE SWEDISH ACADEMY OF SCIENCES. THE FOUNDATION OF BERZELIUS’ THEORETICAL VIEWS WAS THE POSTULATE ABOUT THE ELECTRICAL NATURE OF CHEMICAL AFFINITY. THE MAJOR ACHIEVEMENT OF THIS SWEDISH SCIENTIST WAS HIS EXPERIMENTAL SUBSTANTIATION OF ATOMISM, ITS DEVELOPMENT AND IMPLEMENTATION IN CHEMISTRY. WHEN STUDYING VARIOUS MINERALS AND DEPOSITS WITH W. HISINGER, HE DISCOVERED CERIUM (1803), SELENIUM (1817) AND THORIUM (1828); HE WAS THE FIRST TO ISOLATE SILICUM, TITANIUM, TANTALUM AND ZIRCONIUM. HE GAVE THE FIRST FORMULAE FOR SEVERAL ORGANIC ACIDS.

does not decompose when heated. The scientist depicted each atom as a region marked by a special symbol or equipped with special signs. In his 1810 book *The New System of Chemical Philosophy*, he presented an image of alums in the form of compounds of potash, four atoms of aluminium, five atoms of sulfur and 15 atoms of oxygen. Several years later the Swedish chemist **Jacob Berzelius** (1779–1848) restored justice by marking aluminium in the series of elements and putting alumina among the complex bodies and oxides. At first the scholar gave it the formula AlO₃. The correct formula of the compound Al₂O₃ was determined by **Eilhard Mitcherlich** in 1821. It led Berzelius to include in his new system of atomic weights the atomic weight of aluminium, a value of 27, which corresponds to the modern value, rounded up. We should note that it was Berzelius who proposed the modern designations of chemical elements, which replaced the confusing atomic symbols of Dalton. Indexes in the



Chemical transactions of the 18th –
beginning of 19th century

chemical formula were at first written superscript, like degree indices: for example, Al²O³. These conventions survived in some books until the early 20th century. An example is the last (eighth) edition of Mendeleev’s *The Bases of Chemistry* to be published in his lifetime, which came out in 1906. The accepted indication of the number of atoms of an element in the formula in the lower right corner was first proposed by the German chemist **Justus Liebig** in 1834.

SYMBOLS OF CHEMICAL ELEMENTS AND COMPOUNDS PROPOSED BY JOHN DALTON			
⊙	Hydrogen	⊙⊙	Water
⊖	Nitrogen	⊙⊖	Ammonia
●	Carbon	⊙●	Ethylene
○	Oxygen	○●	Carbon monoxide
⊕	Sulfur	⊙●○	Carbonic acid
⊗	Phosphorus	⊙⊕	Sulfuric acid
⊙⊕	Alumina (aluminum oxide)	⊙⊕⊕	Potassium alum
⊕	Soda (sodium carbonate)		
⊕⊕	Potash (carbonate of potash)		
⊙	Copper		
⊖	Lead		

Source: J. Dalton. *The New System of Chemical Philosophy*

Chapter 2

How the Metal Was Discovered

The First Attempts to Produce Aluminium

The study of complex chemical compounds, including salts and *earths* (as they were called in the 18th century), led scholars to the brink of discovering aluminium, as we mentioned in Chapter 1. Antoine Lavoisier suggested that alumina, or aluminous soil is an oxide of a new unknown metal.

In the early 19th century chemists have discovered a long-awaited and strong instrument, electrical power that made it possible to break down complex substances into simple ones. *Electrolysis* – the process of breaking down a complex compound with electricity – became widely popular.

Humphry Davy, an English chemist, came very close to solving the problem of extracting aluminium in 1808. He was the first to extract sodium and potassium using electrolysis. All was ready to make a new metal, and Davie even thought of a new name, *aluminium*.

In 1791 a pamphlet by the Bolognese anatomist and physiologist **Luigi Galvani** (1737–1798) shook the scientific community. It described a remarkable phenomenon that Galvani had accidentally discovered in the course of an experiment: dissecting a frog in his laboratory, while an assistant physicist conducted experiments with an electrostatic machine nearby, Galvani was astounded to see that the frog's muscles contracted when he touched its exposed nerve with a metal scalpel. He noticed that the frog "came to life" when a spark was generated by the machine. He later noted that the frog's legs also began to twitch during a thunderstorm.

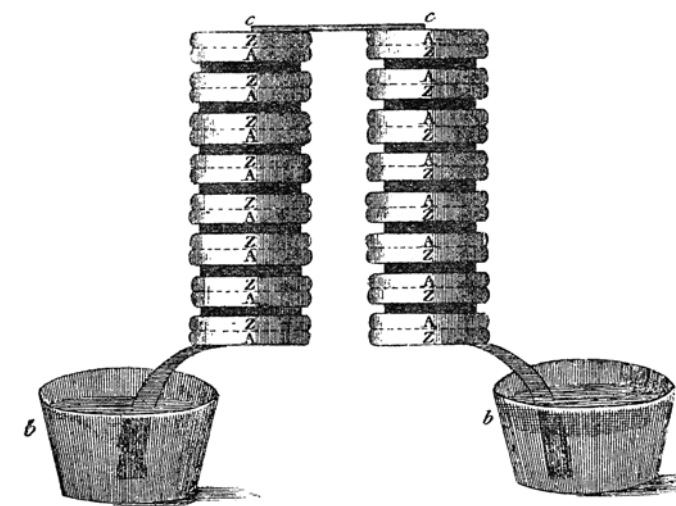
Galvani's experiments attracted the attention of many scholars but it was the Italian physicist **Alessandro Volta** (1745–1827) who discovered the cause of the mysterious behavior of the frog's muscles. While Galvani had mistakenly believed that the current was derived



Humphry Davy [1778–1829] WAS AN ENGLISH CHEMIST, PHYSICIST, AND INVENTOR. HE WAS BORN IN THE TOWN OF PENZANCE IN SOUTHWESTERN ENGLAND IN THE FAMILY OF A POOR WOOD ENGRAVER. HE STUDIED CHEMISTRY ON HIS OWN WHILE WORKING AT A PHARMACIST'S SHOP. IN 1798, DAVY WAS INVITED TO THE PNEUMATIC INSTITUTE IN BRISTOL AND THEN TO THE ROYAL INSTITUTE, WHERE HE STUDIED THE IMPACT OF ELECTRIC CURRENT ON DIFFERENT SUBSTANCES, INCLUDING MOLTEN SALTS AND ALKALIS. HE ISOLATED SIX PREVIOUSLY UNKNOWN METALS (POTASSIUM, SODIUM, BARIUM, CALCIUM, MAGNESIUM AND STRONTIUM) AND ALSO PROVED THE EXISTENCE OF ALUMINIUM AS THE METAL BASE OF ALUM AND GAVE IT ITS NAME. USING ELECTROLYSIS, HE ISOLATED BORON FROM BORIC ACID, WHICH WAS ONE OF THE MOST REMARKABLE EVENTS IN THE HISTORY OF THE DISCOVERY OF NEW CHEMICAL ELEMENTS. DAVY WAS KNIGHTED FOR HIS SCIENTIFIC ACCOMPLISHMENTS IN 1812 AND BECAME PRESIDENT OF THE LONDON ROYAL SOCIETY (ENGLAND'S ACADEMY OF SCIENCES) IN 1820. DURING THIS PERIOD, HE DEVOTED A GREAT DEAL OF TIME TO POETRY AND BECAME A MEMBER OF THE GROUP OF ENGLISH ROMANTIC POETS KNOWN AS "LAKE POETS."

from "animal electricity" (i.e., from the frog itself), Volta determined that it was the combination of different metal conductors that led to the appearance of electric charge on their ends. Volta noticed that a layer of moist cloth (especially when soaked in a salt or acid solution) increased electrolyzation, which formed the basis of his most important invention – the voltaic pile. This device, consisting of alternating magnesium and zinc disks separated by cloth pads moistened with sulfuric acid, produced current of such strength to generate sparks. The greater the number of disks in the pile, the stronger the current produced.

Volta's research on electricity sparked keen interest not only among scientists but also among politicians, public figures and intellectuals. Volta's and Galvani's studies even inspired the English writer **Mary Wollstonecraft Shelley** to create the literary character Frankenstein – a person assembled out of dead organs



Metallic Sodium

Voltaic Pile

and brought to life with electricity. Moreover, Napoleon Bonaparte, who was still consul of the French Republic, invited Volta to give a talk on his experiments in *galvanic electricity* (the name used to denote electricity generated by chemical processes taking place between different substances such as metal plates in a voltaic pile). In Europe it became the fashion to make voltaic piles out of copper and silver coins. People believed that galvanic electricity cured different diseases, giving credence to the idea of 'noble' metals.

Volta's experiments also secured the interest of chemists. Sir Humphry Davy, the future founder of the new science of *electrochemistry*, immediately recognized

Spectral Analysis

In the 1860s, aluminium was discovered as a chemical element. It finally ceased to be invisible and soon occupied the thirteenth cell in Mendeleev's periodic table. This important event took place thanks to spectral analysis.

The refraction of sunlight passing it through a glass prism was first described by **Isaac Newton** in a series of works on optics in 1666. He showed that ordinary white light consists of a large number of light rays of different colors. As we now know, each of the colors results from electromagnetic waves of a certain wavelength. White light is made up of rays of different colors, which are refracted by different angles when they pass through the prism. Thus, if we put a screen behind the prism, we see a color picture that is called a continuous spectrum. Such a spectrum is produced by incandescent liquids and solid bodies that emit rays of all the different colors. The spectra of different bodies differ only in brightness.

In the early 19th century, the German physicist **Joseph von Fraunhofer** (1787–1826) invented a device consisting of an optic tube and a glass prism that split sunlight in such a way that the resulting spectrum was not continuous but made up of a large number of lines. These lines were stable, did not change their relative position, and had a characteristic color. The German physicist **Gustav Robert Kirchhoff** and chemist **Robert Wilhelm Bunsen** made use of Fraunhofer's results in the 19th century. By this time, chemists were aware of the fact that the light-blue flame produced by ethanol or natural gas acquired a characteristic color after the salts of certain metals were added. For example, sodium salts give the flame a bright yellow color, potassium salts – a violet color, and calcium salts – a brick-red color. From 1854 on, Kirchhoff and Bunsen studied how metals color the flame by adding metal salts on the tip of a platinum wire to the flame of an alcohol burner. Sodium gave such an intense color that Kirchhoff and Bunsen began to use pieces of blue glass as light filters for neutralizing the yellow color in order to detect potassium in the presence of sodium. Kirchhoff had an unexpected idea. He proposed using the optic device invented by Fraunhofer to study flame coloring. The scientists made a triangular prism out of three identical glass plates that were connected to each other and whose edges were fastened to a glass base. The prism was filled with water, and the light from the burner flame was directed at one of its facets. This resulted in spectra that consisted of separate lines as in Fraunhofer's experiment. Such spectra came to be called *discrete* or *linear* spectra. Although different metals gave different spectra, compounds of the same metal (e.g., sodium) gave spectra with an identical arrangement of lines. Thus it was shown that gases and vapours (in contrast to solid bodies and liquids) give linear spectra



Alessandro Volta demonstrates his galvanic battery to Napoleon I

that electricity can be used to break up complex bodies into elementary ones and, in particular, to isolate pure metals, which occur only in the form of compounds in nature.

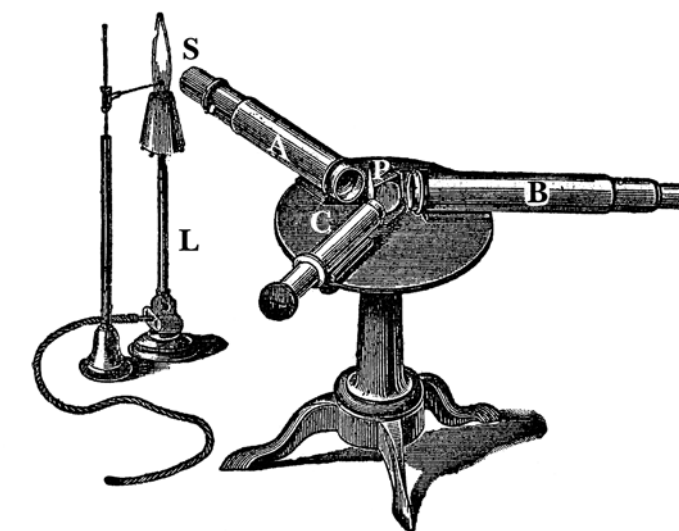
Davy began by passing electric current through water. He found that electricity breaks water down into hydrogen and oxygen, which are generated at the ends of two submerged platinum wires. Similarly, Davy used electric current to break down a solution of caustic soda (NaOH). However, when he replaced the platinum wire serving as a *cathode* (i.e., the negatively charged electrode) with a layer of liquid mercury, virtually no gas was generated. At the same time, the mercury acquired special properties: it slowly reacted with water and generated hydrogen after the experiment with the electric current was complete. This supported the idea that electrolyzing caustic soda solution created a new and previously unknown metal as a deposit on the mercury cathode. In order to obtain this metal in pure form, Davy electrolyzed caustic soda that had been dissolved in a small amount of water. He noticed that metal globules formed on the cathode and that they rapidly oxidized when exposed to air and combusted in the presence of water. When he conducted similar experiments with caustic potash (KOH), Davy obtained a different metal that had analogous properties yet was even more active. Davy proposed that the substance obtained by electrolyzing caustic soda be called “sodium” and that the substance obtained from caustic potash be called “potassium”. These names are still used today. Two decades after Davy’s experiment these technologies were deployed for producing pure aluminium.

Then Davy began to work on the electrolytic breakdown of alkaline earths. Their component metal oxides are extremely refractory and do not conduct electricity when solid, which complicated things further. So in order to isolate calcium, strontium, and barium in pure form, Davy mixed their oxides with mercury and placed the mixture in an electrolytic cell.

Alum-earth was the next in line. In 1808 Davy concluded that a new metal can be produced from it by electrolysis and gave it the name that we still use today – aluminium. Davy wrote: “Had I been so fortunate as to have procured the metallic substance I was in search of, I should have proposed for it the name of aluminium.” Davy, therefore, is rightly heralded as the ‘father’ of the modern aluminium industry: all companies producing the metal today use the electrolytic method.

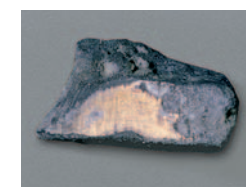
▼ consisting of a set of color bands separated by dark intervals. For example, a flame colored by the vapours of sodium or its compounds gives a spectrum with two yellow lines; lithium gives a red and an orange line; and potassium gives a red and a blue line. Thus every element has a well-defined spectrum that belongs to it alone and differs from the spectra of neighboring elements.

This property of elements lies at the foundation of the *spectral analysis* of substances developed by Kirchhoff and Bunsen in 1859. This method is highly sensitive, for one needs only a minute quantity of a substance in order to get a spectrum. For example, it can be used to identify even 10^{-6} mg of sodium. In the 19th century, *spectroscopes* were used to perform spectral analysis.



Kirchhoff and Bunsen's spectroscope

A spectroscope consists of a round base supporting a triangular prism P made out of *flint glass* (lead glass with a high refractive index) and three optical tubes (see diagram). Tube A, which is called the *collimator*, ends in a movable vertical slit, before which the glowing body or flame is placed. The rays entering the slit pass through the lenses inside the tube, become parallel, and fall on prism P. The rays refracted by the prism, which make up the spectrum, are viewed through tube B, called the *ocular*. Tube C has a horizontal slit with a transparent glass scale, which is used for determining the position of spectral lines. When the glowing flame illuminates the scale, the latter is reflected by the surface of the prism and passes into tube B when tube C is oriented in the right way, so that the substance’s spectrum and the scale are simultaneously visible in tube B.



Strontium

To view the spectrum of a metal, a platinum thread dipped into the solution of a compound of this metal is inserted into the burner flame. The flame becomes a plasma with trace quantities of neutral atoms even of such active metals as sodium and potassium.

In 1824 the great Danish physicist **Hans Christian Ørsted**, a professor at the University of Copenhagen, took the next step forward. He heated a mixture of alum earth and carbon in a chlorine atmosphere, which resulted in the formation of crystals of anhydrous aluminium chloride AlCl_3 . This substance resembled white or yellowish scales that immediately bloated when they

The compound of chlorine and the flammable constituent of clay [aluminium chloride] is volatile at temperatures slightly above the boiling point of water. This substance is slightly yellowish (which may be due to a small admixture of carbon) and soft. Although it is crystalline, it readily absorbs water and easily dissolves, releasing a lot of heat. When it is rapidly heated together with potassium amalgam, it breaks down into potassium chloride and aluminium amalgam. This amalgam readily dissociates in the presence of air. When distilled in an airless environment, it produces small chunks of metal that resemble tin in color and luster.

H.C. Ørsted, Oversigt over det K. Danske. Videns – kabernes selskab Torhandling, 1824–1825, p. 15.

came into contact with moist air, absorbing water vapour. Reacting anhydrous aluminium chloride with potassium amalgam (a term used to refer to an alloy of a metal and mercury), Ørsted obtained in 1824 potassium chloride and aluminium amalgam. After boiling away the mercury, Ørsted saw that a metal remained.

On 25th March 1825, Ørsted announced the results of his work at a meeting of the Danish Academy of Sciences and on 8th April he demonstrated the resulting product, which he considered to be metallic aluminium. In a brief note published in 1825, he reported that his experiments led to the production of “bits of metal that resembled tin in color and luster.” No one knows whether it was pure aluminium or an alloy. However, in 1826 Ørsted published a chemistry handbook in which he wrote that “aluminium has a metallic luster and somewhat grayish color and breaks down water very slowly.” These properties show that the substance obtained by Ørsted was an aluminium–potassium alloy rather than pure aluminium.

The German chemist **Friedrich Wöhler** tried to repeat Ørsted’s experiment. He meticulously prepared anhydrous aluminium chloride, isolated pure potassium, and ground it with mercury. However, he failed to obtain aluminium. It may be that the aluminium chloride used by Ørsted in his experiment had contained



Hans Christian Ørsted [1777–1851] was a Danish physicist. He was born on 14th August 1777, in Rudkøbing. His father was a pharmacist. He graduated from the University of Copenhagen in 1797 and received a Ph.D. in 1799. He was appointed professor at the University in 1806 and also became director of the Copenhagen Polytechnical School in 1829. Ørsted’s most prominent achievement was establishing the relationship between electricity and magnetism. He showed that a conductor with a current flowing through it deflects a magnetic compass needle. Ørsted’s experiments stimulated a lot of other research that finally led to the creation of electrodynamics and electric engineering. In 1822 Ørsted invented the piezometer, which he used to study the compressibility of fluids. In 1825 he managed to obtain fairly pure aluminium. Ørsted did a lot to popularize science; he founded a society for the spread of scientific knowledge in 1824, and set up the first physics laboratory in Denmark.

▼ These atoms form out of the ions of the metals contained in the salt and electrons. Refractory metals are converted into vapour by a hydrogen-oxygen flame or a voltaic arc between two pieces of metals acting as electrodes.

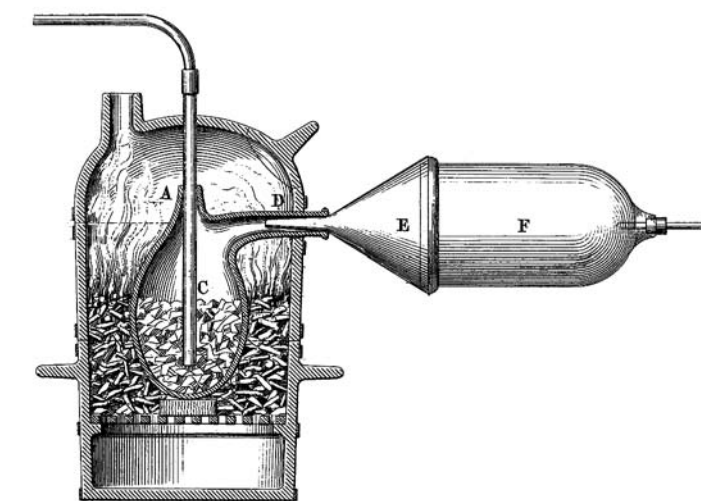
The spectroscope led to the discovery of several new elements. Bunsen discovered *rubidium* and *cesium* by studying the spectra of alkali metals in the mineral lepidolite and in samples of mineral waters from Durkheim springs. In addition, in 1860–1863 he discovered *indium* and *thallium*, which are located in the same group as aluminium(III) in the periodic table. ■



Friedrich Wöhler [1800–1882] was a German chemist. He was born in Eschersheim near Frankfurt. His father was a doctor. In 1823 he graduated from the Medical Department of the University of Heidelberg. He was appointed professor at the University of Göttingen in 1836, a position that he retained to the end of his life. In all, over 8,000 students attended Wöhler’s lectures on chemistry at Göttingen. He wrote a number of textbooks that were used by several generations of chemists. Most of Wöhler’s work lay in the domain of inorganic chemistry. After extensive efforts, he managed to isolate a small amount of aluminium in the form of a gray powder. It took him another 18 years to obtain small globules of aluminium. Wöhler discovered beryllium and yttrium in 1828 and, later, boron and silicon.

water or that his potassium amalgam had had some caustic potash or too little mercury. Wöhler did, however, succeed when he replaced the potassium amalgam in Ørsted’s experiment with pure potassium vapour which he passed over anhydrous aluminium chloride.

On 22nd October 1827 Wöhler obtained only about 30 grams of aluminium in the form of a powder whose color resembled platinum. Yet he did not leave it at that – instead he continued to conduct experiments, varying the proportions of reactants and the experimental con-



Device for Obtaining Anhydrous Aluminium Chloride

Aluminium powder, obtained by heating ammonium alum, is mixed with carbon and a small amount of vegetable oil, which yields a mixture with the consistency of dough. The resulting mass is placed in a retort [C] with a volume of 10 L. The retort is put in an iron furnace. A stream of dry chlorine (obtained by reacting the mineral pyrolusite MnO_2 with hydrochloric acid) is fed along a pipe through hole A into the retort. During the first minutes of reaction, water vapour is emitted from tube [D] of the retort, for aluminium readily absorbs moisture from the air. As soon as aluminium chloride vapour comes out of the retort tube, the ceramic funnel [E] is placed in the retort hole. The funnel is connected by the bell jar [F] to the opening into which the chlorine outlet tube is inserted. As soon as the bell jar fills up with aluminium chloride, it is replaced by a new one. ■



Anhydrous aluminium chloride

ditions. Eighteen years later in 1845 he finally managed to obtain small globules of aluminium and determine the metal’s basic properties.

In a letter to his friend, the German chemist Justus von Liebig, he proudly wrote, “I have found a way of obtaining aluminium in the form of grains the size of a pinhead. They are malleable, tin white, and highly soluble in a solution of caustic potash, generating hydrogen.”

Describing the properties of the new metal, Wöhler noted that it is refractory like iron. This shows that

the resulting grains were not pure aluminium but an alloy of aluminium and platinum, of which the tube and tray were made. In addition, according to Wöhler, the resulting metal broke down boiling water and generated hydrogen. Therefore, it contained a small amount of potassium. Thus both Ørsted and Wöhler obtained an alloy of aluminium, mercury, potassium, and platinum rather than pure aluminium.

Many other scholars besides Wöhler tried unsuccessfully to reproduce Ørsted's experiments and concluded that their results were erroneous. Only in 1921, almost a century later, the Danish chemist **Fogh** showed that the success of Ørsted's experiment depends upon the use of a large amount of excess aluminium chloride and an amalgam with low potassium content. If one respects these conditions, one obtains a pure metal that can be fused into globules. Other scientists showed that mercury can be fully removed from the recovered aluminium only by heating the resulting sample at red heat (approx. 700°C) for a long time in a hydrogen atmosphere. Yet it was Wöhler who minutely described not only the method of obtaining the metal but also some of its properties.



Aluminium cuttings

► Properties of Aluminium

"Aluminium was obtained in the form of a gray powder with a metallic luster, yet a closer study (which we described above) showed that it consists of a large number of small molten metal globules, visible to the naked eye and white as tin. Most of them are no bigger than a large pinhead. Using a microscope with a magnification of 200x, one sees that all of the powder consists in actual fact of such molten metal globules. The metal is sometimes obtained in the form of a compact spongy mass that consists, all the same, of sintered metal globules. All of this goes to show that aluminium melts at a temperature below its temperature of reduction. Further experiments showed that this temperature is not particularly high and that aluminium melts in the flame of a soldering torch. "Aluminium in the form of pure molten globules resembles tin in color and luster. It is very plastic. Aluminium globules can be beaten into thin plates. Aluminium has a relative weight of 2.50 as measured using two globules with a total weight of 32 mg and 2.67 as measured using three globules with a total weight of 34 mg. "Due to the insignificant amount of mass, these figures are naturally approximate. Aluminium is not magnetic. It retains its luster in air. Although it does not break water down at room temperature, it slowly releases hydrogen from water already at 100° even in such compact form. In even a dilute caustic potash solution, it dissolves completely, violently releasing hydrogen."

Friedrich Wöhler, Liebig Annals of Chemistry and Pharmacy, vol. 58, 1845. ■



Aluminium in globules

The Beginning of Industrial Aluminium Production in France

Wöhler's method for producing aluminium made it possible to obtain small quantities of the metal in the form of globules the size of a pinhead. This was not suitable for the purposes of commercial production. Many scholars searched for new ways of producing aluminium. **Henri Étienne Sainte-Claire Deville**, a Professor at Ecole Normale Supérieure in Paris, was successful. In 1854, he announced his discovery in a lecture at the Paris Academy of Sciences.

In contrast to Wöhler, who was a great chemist with profound scientific erudition, Deville was a great engineer. He used Wöhler's method as a foundation and built upon it. Deville replaced potassium, used as a reducing agent, with the less expensive sodium and found the optimal temperatures of reaction.

In his first experiments, Deville placed a few hundred grams of aluminium chloride into a thick-walled glass tube housing trays with metallic sodium. Then he filled the tube with dry hydrogen and heated it. The resulting reaction and subsequent sublimation (i.e., transformation from the solid to the gaseous state without becoming a liquid) of the byproduct, a double chloride of sodium and aluminium, led to the formation of several globules of aluminium in the tray. They frequently fused into one large globule under the double chloride layer.

In subsequent years, Deville improved his technology for producing aluminium. Anhydrous aluminium chloride readily absorbs water and water vapour, which are always present in air. Thus, if a bottle with this substance is kept open even for a short time, aluminium chloride crystals begin to stick together, gradually forming a viscous mass. Deville proposed to replace aluminium chloride by its double salt with sodium chloride, which is less reactive in air and melts at a lower temperature.

This improvement paved the way for a totally new type of breakthrough in developing a commercial process for producing aluminium. Deville conducted his first experiments in this field at a chemical plant in the Parisian suburb of Javel. The double chloride of aluminium was reduced with metallic sodium in furnaces with stirrers. Under these conditions the process took place more gradually. The sodium chloride that formed



Henri Étienne Sainte-Claire Deville [1818–1881] WAS A FRENCH CHEMIST. HIS FATHER WAS THE OWNER OF A SHIPPING COMPANY. IN 1843, HE GRADUATED FROM THE MEDICAL DEPARTMENT OF THE UNIVERSITY OF PARIS AND, THE SAME YEAR, GOT A PH.D. IN MEDICINE AND A PH.D. IN CHEMISTRY FOR RESEARCH ON OILS EXTRACTED FROM EXOTIC PLANTS. IN 1845–1850 HE WAS PROFESSOR OF CHEMISTRY AND DEAN OF THE DEPARTMENT OF NATURAL SCIENCES AT THE UNIVERSITY OF BESANÇON. IN 1851 HE BECAME PROFESSOR OF CHEMISTRY AT THE ÉCOLE NORMALE SUPÉRIEURE IN PARIS AND LECTURED FOR 10 YEARS AT THE SORBONNE. SAINTE-CLAIRE DEVILLE BECAME FAMOUS AFTER INVENTING IN 1854 A CHEMICAL METHOD FOR THE COMMERCIAL PRODUCTION OF ALUMINIUM BASED ON THE DISPLACEMENT OF ALUMINIUM BY METALLIC SODIUM FROM A DOUBLE CHLORIDE OF SODIUM AND ALUMINIUM. IN 36 YEARS OF APPLICATION 200 TONNES OF THE METAL WERE OBTAINED USING THE DEVILLE METHOD. DEVILLE IS RIGHTLY INCLUDED AMONG THE FOUNDERS OF THE ALUMINIUM INDUSTRY.

on the surface of the aluminium was removed mechanically or washed away with water.

In 1856, the long-awaited event finally occurred: Deville together with **Moran** and the **Rousseau** brothers organized the first commercial production of aluminium. They began their work at the smelter of the brothers **Charles and Alexandre Tissier** in Rouen.

All the substances needed for producing aluminium were manufactured at the smelter. Aluminium chloride was derived from alum earth by heating ammonium alum. The double chloride of sodium and aluminium was produced by passing dry chlorine over a hot mixture of alum earth, ordinary salt, and coal.

In his book on aluminium, Sainte-Claire Deville devotes an entire chapter to the production of sodium.



Sainte-Claire Deville giving demonstration

This was an important technical matter, for in the 19th century it was impossible to obtain aluminium without sodium. Sodium was initially produced by reducing caustic soda with iron – this method was developed in the early 19th century by the French scientists **Louis Jacques Thenard** and **Joseph Louis Gay-Lussac**.

Sainte-Claire Deville proposed a different method that was considerably cheaper and a lot more practical. It involved heating a mixture of calcined (anhydrous) sodium carbonate, coal, and chalk to extremely high temperatures in iron retorts. Sodium was obtained in vapour form at the reaction temperature and was subsequently condensed in refrigerators. “After I conducted these experiments, the Rousseau brothers expressed a keen interest in using their results to set up commercial production of the metal at their chemical plant. I gave them

detailed instructions on how to proceed. Following these instructions, they set up a production process that made it possible to obtain sodium at a lower cost and in greater quantities,” wrote Sainte-Claire Deville in his memoirs.

According to the well-known French chemist **Jean Baptiste André Dumas**, one gram of sodium obtained by the Gay-Lussac–Thenard method cost seven francs in the early 19th century. In 1857 one could buy a kilogram of sodium at the same price. The cost of aluminium was 300 francs per kilogram – 10 times less than in 1854. The Rouen smelter produced two kilograms of aluminium daily. At this time, it cost 20 francs a month to rent a room in Paris, and, for 10 francs, an artist could buy a supply of paints and canvases that would last him a long time. In 1857 Leo Tolstoy gambled away a fortune playing roulette in Baden-Baden: 3,000 francs.



Bauxite

Bauxite is a rock consisting mainly of alum earth (Al_2O_3) mixed with other mineral components. It is fairly common in nature. Bauxite varies in structure. It may be hard and dense, or loose and crumbly. Bauxite also varies in colour: ordinarily it is brick-red, reddish, or brown. Such hues result from the presence of iron oxide (in some countries, bauxite is even used as a pigment – the base of red mineral paint). Bauxite with a low iron content is gray or white in color. Yellow, dark green, and even multicolored (with light blue, red-violet, and black striate) bauxite also occurs. Color is not a criterion of quality for bauxite, for it says nothing of the percentage composition of different admixtures in the rock). High-quality bauxite is composed of over 50% aluminium oxide. They contain less than five grams of silica (silicon dioxide, SiO_2) per hundred grams aluminium oxide; silicon dioxide is the most harmful of all bauxite admixtures. Rock species that are similar to bauxite yet contain more iron occur in the tropics. These rocks are called laterites and are produced by the erosion of tropical forest soils. They are less dense than the bauxite in chalk rocks. ■

Varieties of red bauxites. Leningrad The Urals (above and in the middle)

White bauxite. France (below)

The smelter was soon moved from Rouen to La Glacière and then to Nanterre, where raw materials could be brought more easily. At the same time, the technology for producing aluminium continued to be improved. At Moran’s suggestion, fluorspar (CaF_2) was added to the mixture of double chloride of sodium and aluminium with metallic sodium; the fluorspar played the role of a *flux* (a substance added to metals in a furnace to promote fusing). The mixture of double chloride, fluorspar, and metallic sodium was heated in a coal furnace. The molten metal was collected in a special cavity on the bottom of the furnace rather than in trays. The production capacity of the Nanterre smelter increased. Sainte-Claire Deville believed that it was possible to increase the smelter’s output of aluminium by a factor of four. However, the low demand for aluminium and its high cost slowed down the growth of production.

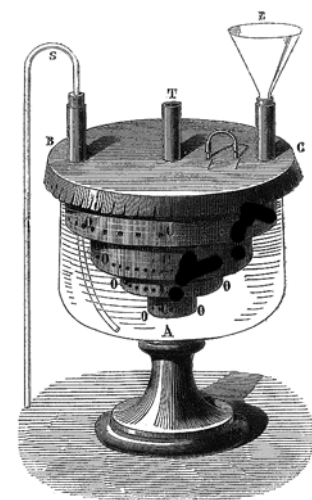
In 1857 the production of aluminium was moved from Nanterre to a smelter in Salindres near Alès. This smelter, which was subsequently acquired by the French company *Pechiney* and the *Compagnie d’Alais et de la Camargue*, went down in history as the world’s largest company engaged in chemical aluminium production. In 1872 it manufactured 1,800 kilograms of aluminium – 900 times more than in Nanterre.

The principal raw material for producing aluminium at Salindres was bauxite, i.e., aluminium ore. The French geologist **Pierre Berthier** discovered deposits of this reddish argillaceous mineral in the south of France in 1821. Bauxite took its name from its place of discovery – Les Baux.

Bauxite was mixed with powdered soda and heated in a furnace to remove admixtures. In the process, aluminium oxide reacts with soda, turning into sodium aluminate (NaAlO_2), while silica turns into silicate. The *sinter* (the solid mass remaining after heating) was leached. (*Leaching* is the removal of soluble constituents from a solid substance with an aqueous or organic solvent or often gas.) Carbon dioxide was used to disassociate the pure aluminate solution.

To dissociate sodium aluminate, Sainte-Claire Deville constructed an apparatus consisting of several coaxial cylinders submerged into a vessel with water. A major innovation in the fusion process was the use of cryolite (sodium hexafluoroaluminate) as a flux. After the process was complete and the aluminium was reduced, the liquid metal accumulating on the bottom of the furnace was poured into iron forms to make aluminium ingots. The production cycle was then complete.

The cost of producing aluminium at Salindres during the first year of the smelter's operation was approximately 80 francs per kilogram, 56% of which was spent on sodium. The metal was sold at a price of 100 francs per kilogram.



Device for Breaking Down Sodium Aluminate with Carbon Dioxide

The apparatus consists of several concentric cylinders [C] of different heights placed in a glass bell jar [A]. Each of them has several holes in its upper part: the longer the cylinder, the smaller the holes. The bell jar is closed with the zinc lid [BC]. The lid contains the small tubes t and t connected by a rubber hose, the tube [T] for the inflow of carbon dioxide, the funnel [E] for the inflow of fluid, and the siphon [S] for removing alum earth. The holes [O] are strictly horizontal. Only in this case does the carbon dioxide break down the aluminate uniformly, and alum earth is obtained in the form of a powder rather than a gel. ■

The Roots of Aluminium Production in Other Countries. The Use of Cryolite

Sainte-Claire Deville's success inspired scientists and technologists in many other countries to launch their own aluminium production. In 1888 the first smelter based on the Sainte-Claire Deville method opened in England. It was located in Oldbury near Birmingham. The smelter's founder was the chemist **Karl Friedrich Wilhelm Gottlob Kastner** (1783–1857), who six years earlier had developed a new commercial method for manufacturing sodium, which was essential for aluminium production. Kastner proposed that the molten caustic soda be reduced with a carbon-iron mixture. This new technology for producing sodium lowered the price of aluminium to half its previous value at Saint-Claire Deville's smelter in Salindres. The Oldbury smelter produced up to 250 kilograms of metal daily.

Kastner went even further and obtained sodium using electrolysis in 1890. However, this metal soon stopped being used for producing aluminium, which also began to be obtained electrolytically.

Nevertheless, before the production of aluminium based on electrolysis was introduced and became widespread, scientists from different countries continued to improve upon the Sainte-Claire Deville method. Here, cryolite played a key role.

In 1800 – long before Ørsted's experiments – deposits of a rare aluminium mineral were discovered in Greenland at a place called Ivigtût. The mineral, which resembled white agglomerations of ice, was called *cryolite* (from the Greek words $\chi\rho\nu\omicron\varsigma$ "frost" and $\lambda\iota\theta\omicron\varsigma$ "rock," i.e., icy rock). In its composition, cryolite (Na_3AlF_6) resembles the mixture of sodium and aluminium chloride Na_3AlCl_6 used in the Sainte-Claire Deville method. Despite its rarity, cryolite aroused the interest of scientists.

In 1854 this mineral began to be shipped to Europe in large quantities. Soon the English scientists **Percy** and **Dick** repeated Sainte-Claire Deville's experiment, substituting cryolite for the mixture of sodium and aluminium chloride. They obtained an ingot of aluminium, which they demonstrated at the London Royal Institute the following year.

In 1855, **Gustav Rose** (1798–1873), a German mineralogist and crystallographer and professor at the Uni-

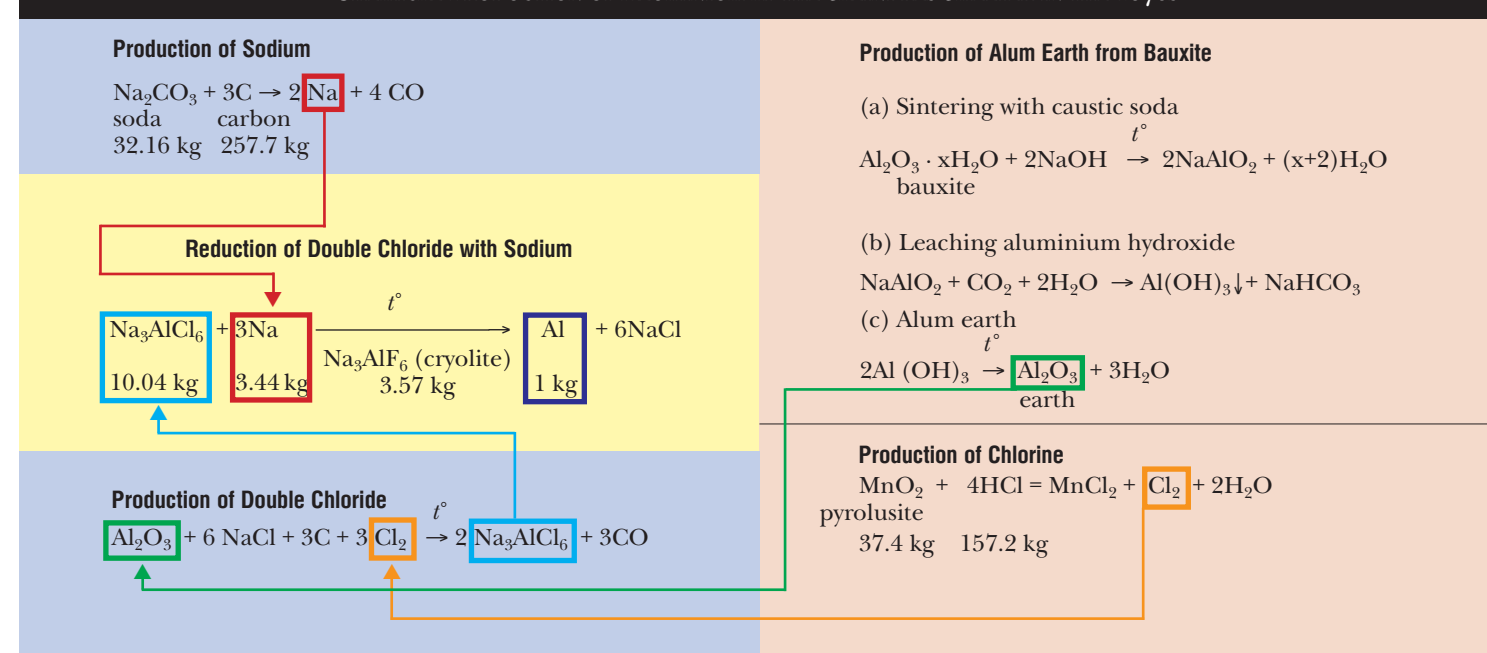


Native cryolite

versity of Berlin, conducted a similar experiment. He put a mixture of cryolite and metallic sodium in a small iron crucible and covered it with potassium chloride. The sinter that was obtained after the crucible was heated for half an hour was treated with water and ground. The reaction products contained globules of aluminium, each weighing about half a gram.

Sainte-Claire Deville also tried to use cryolite as a raw material for producing aluminium, yet he did not consider this process to be particularly viable. In addition, he feared that ordering cryolite from Greenland would make the French aluminium industry dependent on imports.

CHEMICAL PRODUCTION OF ALUMINIUM AT THE SALINDRES SMELTER IN THE 1870S



Source: Belyaev A. I. The History of Aluminium

It should be remarked that cryolite is not an ideal raw material. In contrast to the double chloride of sodium and aluminium, it dissolves poorly in water, and therefore its residue is harder to separate from aluminium.

The use of aluminium chloride and its compounds with the chlorides of alkali metals is particularly inconvenient on account of their volatility and hygroscopicity. Cryolite is non-volatile, easily ground into a very fine powder, anhydrous, and non-hygroscopic. As a result, it presents considerable advantages over the aforementioned compounds.

Gustav Rose, Pogg. Ann., vol. 96, 1855.

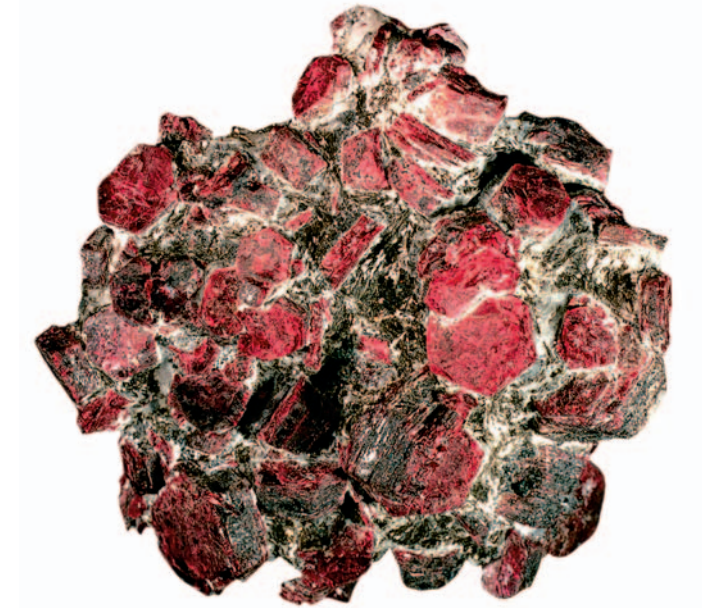


Artificial cryolite

Cryolite

Cryolite (from Greek – “frost” and – “rock”) is a rare mineral belonging to the group of natural fluorides with the composition Na_3AlF_6 . It takes on different hues from colorless or white, grayish white, and sometimes smoky gray to virtually black or reddish brown. It is fragile and melts easily. It is visibly soluble in water, making cryolite outcrops resemble outcroppings of rock salt. It occurs very rarely in nature. Deposits of cryolite have been found at Kaffo (Nigeria) and in granite rocks at Invgutt (Greenland). In Russia, the principal deposits of cryolite are located in the Ilmen Mountains near the town of Miass. Cryolite was the only aluminium ore before bauxite began to be used. Cryolite is less used in industry today. It is employed in aluminium electrometallurgy, although artificial cryolite is used more often. Artificial cryolite is a white fine-grained powder. It is usually produced from hydrofluoric acid, aluminium hydroxide, and caustic soda. It is used in the production of aluminium, glass, enamels and flame-resistant and abrasive materials, and for recycling non-ferrous metals. ■

In 1891 the German chemist **Ludwig Grabau** proposed using aluminium fluoride for producing aluminium. In the aqueous solution of an aluminium salt, e.g. sulfate, aluminium fluoride precipitates in the presence of cryolite. It is then reacted with sodium to produce aluminium. Grabau’s method made it possible to obtain a metal with only 0.2% of impurities – a lot less than the



Native corundum crystals

aluminium produced by the Sainte-Claire Deville method.

In the Grabau method, metallic sodium was isolated by electrolyzing a mixture of the molten chlorides of sodium and potassium. This is undoubtedly the best of all the chemical methods. However, it did not gain wide acceptance, for it was not significantly better than already existing methods.

The curious aluminium fashion of that time did not bypass America whose scientists began to take an interest in the new metal very early on. As far back as 1856 *Mining Magazine* published a story describing the experiments of Sainte-Claire Deville and his followers. It also reported that **Alfred Monier** from Camden, New Jersey, obtained fairly pure aluminium by using sodium as a reducing agent. Samples were exhibited at the Franklin Institute. Newspapers reported that Monier also planned to launch his own aluminium production. However his plans were not realized.

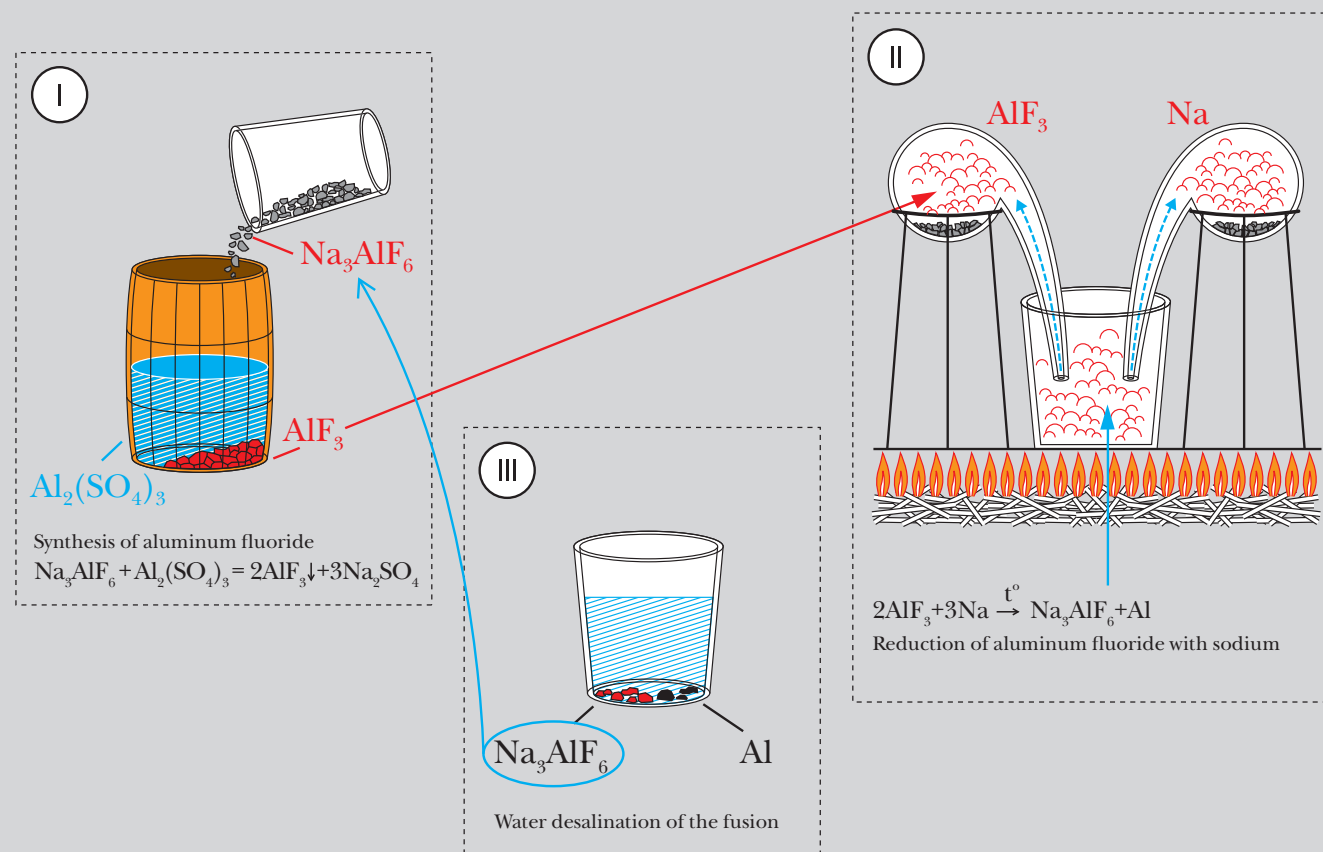
The American inventor **William Frishmuth** made a significant contribution to the history of aluminium. He obtained 12 patents, some of which were directly related to aluminium. On 15th November 1884 the *Philadelphia Evening Star* wrote, “Colonel William Frishmuth, well known in this city for many years, has discovered a method for producing aluminium at reduced cost. Comments were made in various quarters as to the real value of the discovery, some of which even questioned the pos-

sibility of producing the metal by this process, which is stated to produce it from South Carolina *corundum* (natural anhydrous alum earth Al_2O_3), using sodium as a reagent. Meanwhile patents have been taken out in this and foreign countries, and preliminaries are fairly under way to test the process in practice.”

Frishmuth showed that one of the disadvantages of the Sainte-Claire Deville method was the use of metallic sodium, which combusts in contact with water and sometimes even air on account of its high chemical activity. In addition, the isolation of metallic sodium was a laborious and expensive process, which considerably raised the price of aluminium itself. Frishmuth proposed that sodium vapours be produced directly in the course of aluminium production. He united the production of sodium, aluminium chloride, and aluminium (a product of the reaction of the first two substances) in a single industrial cycle.

Frishmuth was the only person in the US to launch the chemical production of aluminium, albeit on a modest scale. The aluminium produced by Frishmuth was used to make the apex of the Washington Memorial as well as various devices and instruments (e.g. geodesic instruments), some of which are still used today. His smelter soon closed, for it could not compete with the new electrolytic method of aluminium production, which became widely used in the United States.

SCHEME OF GRABAU'S METHOD



Source: Belyaev A. I. The History of Aluminium

Applications of Aluminium in the 19th Century

The general public first learned about aluminium at the Exposition Universelle in Paris in 1855 where small ingots of the new metal along with the raw materials used for its production were presented. Surprisingly enough, aluminium, which is employed today in one way or another by virtually all branches of industry, was judged unsuitable for industrial use.

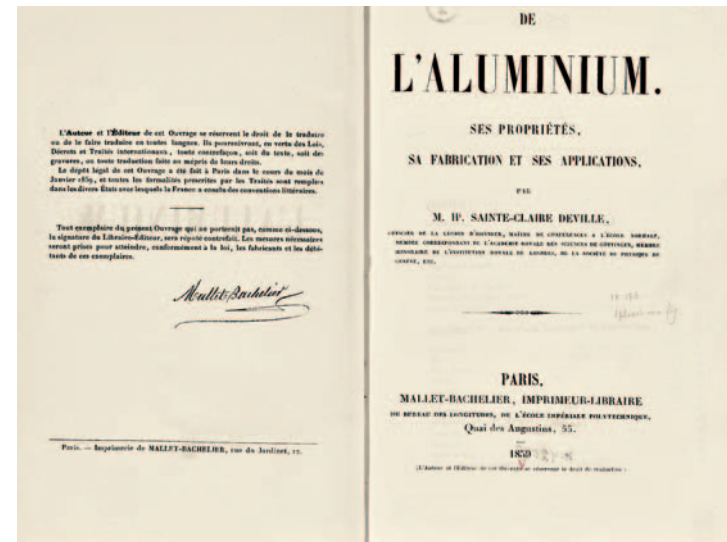
Newspapers wrote: “The Parisian expo put an end to the fairy tale of the silver from clay. Aluminium was shown in public there, and it became clear that most of what was said about it was the product of fantasy and the gullibility of the masses. Instead of the expected heaps, there were only 12 small ingots of aluminium with a total weight of perhaps about a kilogram. Of course, this is not a lot for a discovery that was said to turn the world upside down.” After the Exposition Universelle, the name “silver from clay” became widely used for aluminium.

Sainte-Claire Deville’s work on aluminium received the generous support of the French Emperor Napoleon III. Even before Sainte-Claire Deville began his first experiments on aluminium production, the emperor granted him an unlimited subsidy for conducting his work. Sainte-Claire Deville used 36,000 francs (in comparison, the average annual income of an ordinary family was 1,500–2,000 francs during these years).

The emperor’s interest in *silver from clay* was explained by his desire to use aluminium for making weapons, helmets, armor, and other equipment for the French army. Napoleon III ordered the eagles adorning the poles of standards to be made of aluminium. They resembled silver in outward appearance yet weighed a lot less, as aluminium has a much smaller density.

The chemist Dumas demonstrated an aluminium helmet for the Napoleonic army at a meeting of the French Academy of Sciences in 1856, when he reported on the breakthroughs in aluminium production. The academicians attending the meeting agreed that the helmet was indeed strong and beautiful yet too expensive.

Napoleon III’s grand plans to manufacture military equipment out of aluminium did not materialise. Aluminium was very expensive, and only a few hundred kilograms were produced in the world annually. The overwhelming majority of manufacturers were unwilling



First Book on Aluminium

Title page and book cover of the book «Aluminium» by Sainte-Claire Deville



The history of aluminium in the 19th century is full of paradoxes and quasi-detective stories. If one asks who was the author of the first book on aluminium, most historians would say Sainte-Claire Deville. Yet this is not true. The Tissier brothers published their book *Study of Aluminium* in 1858, a year before Sainte-Claire Deville. The two brothers worked in Sainte-Claire Deville’s laboratory in Paris and then suddenly left without notice, taking some documents and drawings along with them. Sainte-Claire Deville was angry and indignant. Sainte-Claire Deville had been gathering materials for his book for several years. He had worked conscientiously and unhurriedly, as he was sure that no one besides him could write a serious work on the production of aluminium.

The publication of Tissiers’ book was a complete surprise for Sainte-Claire Deville. He did his best to explain to the scientific community that his former collaborators had acted dishonestly; he wrote open letters that were published in leading scientific journals. However, he was no longer able to claim primacy in writing a book on aluminium. Nothing was left for him but to finish and publish his work as quickly as possible. He did not mention the Tissier brothers in his book. ■

to abandon the production of tried and tested metals such as iron, bronze, and brass for experimenting with the new metal. Another difficulty stemmed from the fact that metallurgists had not yet learned to produce aluminium with a constant composition. Every new batch of aluminium had a different purity and different mechanical properties.



Emperor Napoleon III (1808–1873)



Jean-Auguste Barre.
Eagle-shaped Standard Tip
of the Ninth Cavalry Regi-
ment during the Second
Empire (1852–1870).
Aluminium, bronze.

Henri Étienne Sainte-Claire Deville summed up his knowledge on aluminium in his book *On Aluminium, Its Properties, Production, and Applications*, published in Paris in 1859. He wrote that aluminium is a pretty white metal with a barely visible bluish tint and is outwardly very similar to silver. As the reader has undoubtedly already noted, the comparison between aluminium and silver was frequently made. “To determine its true color, I made [out of aluminium] a well-struck medal that was annealed and treated with nitric acid, similar to what Mr. Enfer, Inspector of Coins at the Paris Mint, does in our time. If we compare an aluminium medal to a silver one, the two metallic surfaces are so similar that it is virtually impossible to see any differences in color,” wrote Sainte-Claire Deville in the first chapter of his book. He continued, “When stored in air, aluminium, similar to silver, tarnishes and becomes lusterless. This can be brought about by dipping the metal for a short time in



Prayer Book with an aluminium cover.
Late 19th century.
Morisot Printer, France



Opera-glasses
Aluminium, glass
France, 1865–1875

a very dilute caustic soda solution, washing it with water, and putting it into hot concentrated nitric acid.”

The constant comparison between aluminium and silver speaks to both the status of the new metal and to its sphere of application. Outwardly similar to silver, surprisingly light, and expensive, aluminium was viewed as an elite material that was suitable for making jewellery and *objets d’art*. The first objects made of the new metal are traditionally considered to be the medals with the bas-reliefs of Napoleon III and Friedrich Wöhler, as well as the rattle of the crown prince Louis-Napoleon.

Napoleon III strove to stress France’s priority in the discovery and production of aluminium. He ordered the fabrication of aluminium table utensils, which were used by the emperor himself and the most honored guests at state banquets, while other guests used utensils made of traditional precious metals such as gold and silver. A curious incident took place during a reception at the imperial palace when Napoleon III ate from an aluminium plate, while an African prince ate from a gold one. Parisian ladies adorned their clothes with aluminium buttons, and jewelers began to use aluminium along with gold and silver.

Interest in aluminium grew gradually. At the next Parisian Exposition of 1867, the new metal was no longer a curiosity. For example, aluminium wire and foil, with which we are so familiar today, were presented to the public. Certain items were engraved, while others were polished so finely that they shone as brightly as silver. The new alloy aluminium bronze was exhibited for the first time.

The Parisian Exposition of 1878, which presented technological innovations from all over the world, generated enormous interest: 16 million people visited it over



Charles Rambert
Prince Louis-Napoleon’s
Rattle. Aluminium, gold,
corals, emeralds, diamonds.
France, 1856

194 days. Visitors were astonished by the hydraulic elevator, telephone, telegraph, underwater telecommunication cable, and electric headlights. One can hardly overestimate the importance of these inventions. Nevertheless, it was aluminium that was considered to be the biggest scientific and technological breakthrough that opened up new horizons for mankind.

The world of the future, as described in the literary works of that time, was unthinkable without aluminium. Nikolai Chernyshevsky’s and Jules Verne’s characters dreamt of aluminium cities, palaces, and household fixtures.

When used for the production of trinkets, aluminium acquires a white hue and a very pleasant luster. This property makes for a wonderful effect in engraving: certain details executed in aluminium cannot be executed in silver on account of its overly high luster.

“Given that aluminium can be used as a substitute for precious metals, it ranks between common and noble metals. I am convinced that aluminium will soon be used everywhere where the need for inoxidizable metal arises.

“A lot of people have tried to make use of aluminium’s low specific weight. Telescopes with aluminium frames are quite common nowadays. An aluminium sextant for finding coordinates by the sun weighs less than a third of a copper sextant. One will never believe that spyglasses for voyages and military and even theatrical binoculars made of aluminium can be so light unless one holds them in his hands; the feeling of weightlessness is so unusual that a blindfolded person who picks up one of these objects will never imagine that it is made of metal.

Sainte-Claire Deville, “On Aluminium: Its Properties, Production, and Applications”, Paris, 1859

► Nikolai Chernyshevsky, *What Is to Be Done?*



Nikolai Gavrilovich Chernyshevsky (1828–1889)

“Yet this building – what is it? What architectural style? Such a style no longer exists – although there is one building that resembles it: the palace on Sydenham Hill that is made of iron and glass, iron and glass, and nothing else. No, there is something else: this is only the hull of the building, its exterior walls. There is a real house inside, an enormous house which this iron and crystal building encloses like a case, forming wide galleries around it on all the floors. The architecture of this inner house is extremely light, the partitions between the windows are very thin, and the windows are tall and very wide – as wide as the floors! Its stone walls resemble a series of pilasters that serve as frames for the windows facing the gallery. Yet what are these floors and ceilings like? What are the doors and window frames made of? What is this material? Silver? Platinum? Most of the furniture is also similar. Wooden furniture is like a caprice here, which exists only for the sake of variety. Yet what are the rest of the furniture, ceilings, and floors made of? ‘Try to move this chair,’ says the elder princess. This metal furniture is lighter than furniture made of hazel. Yet what metal is this? Ah, yes, now I know: Sasha showed me such a platter – it was as light as glass. Now similar earrings and brooches exist. Yes, Sasha said that aluminium would sooner or later replace wood and perhaps even stone. Yet how splendid everything is! Aluminium is everywhere, and even the walls between the mirrors are decorated with enormous mirrors. What carpets lie on the floor! In this house, half of the floors are bare, and one sees that they are made of aluminium. ‘As you see, the floor is matte so as not to be too slippery: children play here, and adults along with them. In this room, the floor is also uncarpeted – for dancing.’ Southern trees and flowers are everywhere; the entire house resembles an enormous winter garden.” ■



Arture Martin. Medallion for a new-born baby. Aluminium. France, before 1860

Sainte-Claire Deville was one of those who understood that the future of aluminium was not bound up with jewellery. In his book, he wrote with bitterness: “There is nothing more difficult than to make people use the new metal. Luxury items and jewellery cannot be its only domain of application. Essential things used in everyday life change extremely slowly. I hope that the time will come when aluminium will be used to satisfy people’s daily needs.”

One could hardly overestimate Sainte-Claire Deville’s role in establishing the commercial production of aluminium and promoting its use. However, Sainte-Claire Deville himself said that all his activities in this domain were a continuation of Friedrich Wöhler’s work. As far back as the time of the construction of the first aluminium smelter, he wrote: “As to me, I do not expect that the fortune that I have spent on aluminium will ever return to my children. If I am successful, I will be happy to know that my integrity was proven to the public and that I managed to build upon the extensive work of a man whom I’m proud to call my friend – the famous Wöhler.”

As if in corroboration of his words, Sainte-Claire Deville cast a commemorative medal from the metal that he produced and sent it to the great scientist. The medal was adorned with Wöhler’s portrait and denoted the year when the latter managed to obtain relatively pure aluminium: 1827.



Vase. Aluminium. France, ca. 1875

Chapter 3

A Precious Metal Becomes Industrial

The Electrolytic Method of Producing Aluminium

The reader no doubt recalls that the English chemist Sir Humphry Davy was the first to use electric current to break down moistened alumina to produce aluminium. Forty-five years later, the German chemist **Robert Wilhelm Bunsen** continued Davy's work and managed to isolate a number of metals in pure form. A particularly important result was Bunsen's production of magnesium from its chloride in 1852, which brought him closer to the brink of the electrolytic production of aluminium. Bunsen's cell consisted of a ceramic crucible with a diameter of five centimeters that was heated to approximately 800°C in a furnace.

In 1854 Bunsen used the same electrolytic apparatus to obtain metallic aluminium. At first he tried to use its chloride, but without success. He was unable to melt the salt, because it sublimated when heated, turning instantly into a vapour. Bunsen then tried to use a double chloride of aluminium and sodium as a salt, which melted at a much lower temperature than magnesium chloride and yielded the desired result. Electrolysis took place at a temperature of 200°C and aluminium was obtained in the form of small crystals. In order to fuse the crystals into a globule after electrolysis, Bunsen added sodium chloride to the cell, which raised the mixture's melting point to approximately 950°C. In these conditions, the small aluminium crystals turned into large droplets, which congealed into globules when cooled. They were then melted down into an ingot.

The French chemist Sainte-Claire Deville conducted experiments on the electrolytic production of aluminium at the same time as Bunsen. He also took the double chloride as his initial material, yet he used platinum electrodes that became coated with a thin layer of aluminium during the reaction. The aluminium was then



Robert Wilhelm Bunsen [1811–1899] WAS A GERMAN CHEMIST. BORN IN GÖTTINGEN, HE WAS THE SON OF A UNIVERSITY PROFESSOR WHO SIMULTANEOUSLY WORKED AS THE UNIVERSITY LIBRARIAN. HE BEGAN PERFORMING CHEMISTRY EXPERIMENTS ALREADY AT THE AGE OF TEN AND MADE THE NECESSARY APPARATUS FOR THESE EXPERIMENTS HIMSELF. HE STUDIED CHEMISTRY, PHYSICS, AND MATHEMATICS AT THE UNIVERSITY OF GÖTTINGEN. HIS MASTER'S THESIS WAS DEVOTED TO NEW MEASUREMENT INSTRUMENTS. HE WAS APPOINTED PROFESSOR AT THE UNIVERSITY OF MARBURG IN 1838 AND PROFESSOR AT THE UNIVERSITY OF HEIDELBERG IN 1852. BUNSEN WAS ONE OF THE CREATORS OF PHOTOCHEMISTRY AND A NUMBER OF NEW METHODS FOR STUDYING CHEMICAL SUBSTANCES, INCLUDING SPECTRAL ANALYSIS. TOGETHER WITH THE PHYSICIST GUSTAV KIRCHHOF, HE USED SPECTRAL ANALYSIS TO DISCOVER THE CHEMICAL ELEMENTS CESIUM AND RUBIDIUM. HE INVENTED MANY DIFFERENT INSTRUMENTS FOR CHEMICAL EXPERIMENTS. ALMOST HALF A CENTURY AFTER HUMPHRY DAVY'S EXPERIMENTS, BUNSEN OBTAINED METALLIC ALUMINIUM USING ELECTROLYSIS. THESE EXPERIMENTS OPENED A NEW ERA IN THE HISTORY OF "SILVER FROM CLAY."

removed and melted down into an ingot. The structure of Sainte-Claire Deville's cell made it possible to perform electrolysis virtually without a stop.

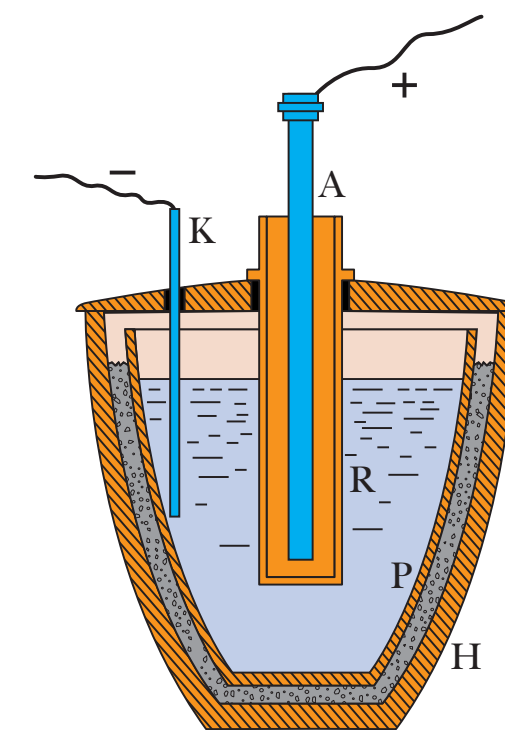
Curiously enough, both experiments were successfully performed in 1854. This date marks a turning point in the history of aluminium. Both scientists worked on the electrolytic method of aluminium production virtually simultaneously and independently of one another, making it difficult to ascribe the metal's discovery to a single one of them. Bunsen was the first to publish a report on his work, while Sainte-Claire Deville was the first to present samples of the resulting metal.

During the same period, Sainte-Claire Deville devised a way of using electrolysis to obtain silicon from quartz. The decision to replace quartz with alumina came to mind naturally. After all, if it was possible to obtain silicon from quartz, it was probably also possible to obtain aluminium from alumina. Sainte-Claire Deville seemed to be on the verge of discovering the modern method of aluminium production. However, his attempts ended in failure: the cathode only generated sodium, the vapors of which combusted when they came into contact with air, while fluoride came from the anode. The technology turned out to be flawed: the alumina dissolved poorly in the electrolytic fluid used by Sainte-Claire Deville, hindering the production of aluminium.

Meanwhile, other scientists were trying to break down molten salts of other aluminium compounds, in particular cryolite. In 1855 Rose discovered that alumina is highly soluble in molten cryolite. However, his attempts to electrolyze this solution were unsuccessful for unknown reasons.

The experiments on the electrolytic production of aluminium conducted by Bunsen, Sainte-Claire Deville, Rose, and several other scientists remained confined to the laboratory. This was due to the fact that the voltaic pile was still used to generate electric current and its capacity was insufficient for the purposes of commercial production. In effect, one could say that chemists spent several decades waiting for physicists to discover a more powerful electrical supply.

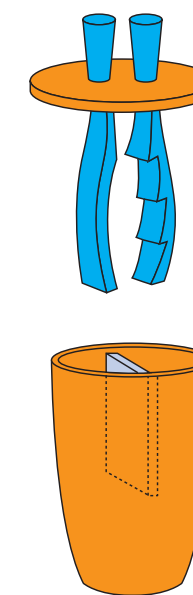
This finally took place in 1870 when the Belgian engineer **Zénobe-Théophile Gramme** invented the dynamo, which could continuously generate a large amount of electricity. In 1889 the Russian engineer **Mikhail Osipovich Dolivo-Dobrovolsky** discovered the three-phase current, which made it possible to transmit electric power over large distances. Now all the necessary



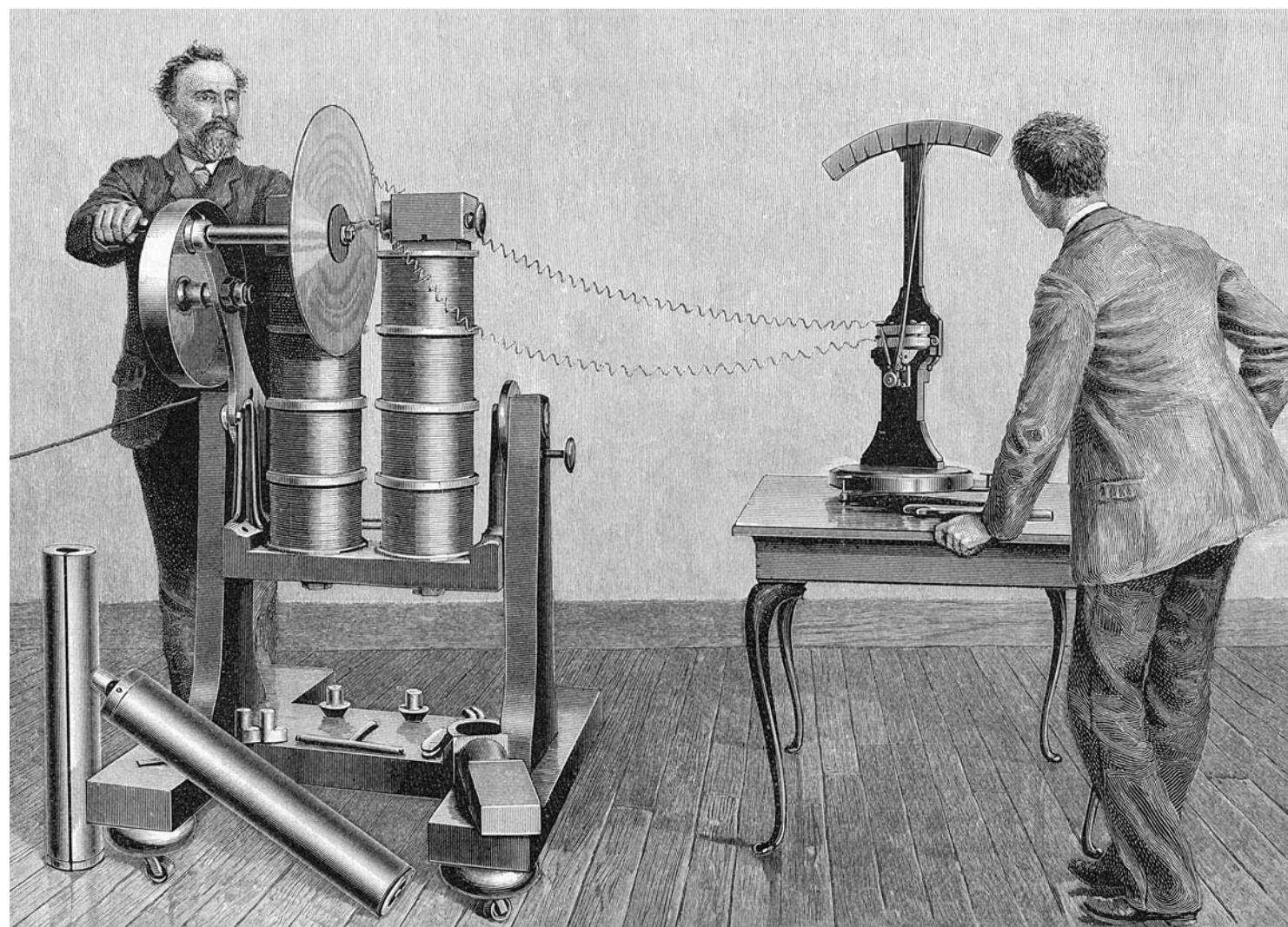
Sainte-Claire Deville's cell

"The apparatus consists of the ceramic crucible, P, placed in the Hessia crucible, H, and fitted with the lid, D, which has a slit for the platinum sheet, K, serving as the negative electrode and a large hole for the porous clay vessel, R. The latter contains the suspended rod, A, made of retort carbon and serving as the positive electrode. The bottom of the porous cylinder is located several centimeters above the bottom of the crucible. The crucible and clay vessel are filled to a common level with the molten double chloride of aluminium and sodium. Decomposition begins after the electrodes are submerged in the melt, for which a small number (two) of elements suffices. The platinum plate is continually removed from the melt, cleaned of the congealed mixture of metal and salt, and put back in place. The salt containing the metal is melted in the ceramic crucible, treated with water, and then melted several times with the double chloride until the entire molten metal fuses into a globule. The double chloride is obtained by mixing and heating two parts of dry aluminium chloride and table salt."

Sainte-Claire Deville, *On Aluminium, Its Properties, Production, and Applications, Paris, 1859* ■



Bunsen's cell



The manual dynamo

preconditions were met for the development of electrochemical (and, in particular, aluminium) production.

A major technological problem had to be overcome before molten salts could be electrolyzed on a commercial scale. Many of the materials that are used for electrolytic baths cannot withstand prolonged contact with molten salt solutions, including cryolite. One proposed solution was to pass a current through the fluid to heat it internally. In such a case, the highest temperature was attained inside the bath and the lowest temperature on the walls, which became covered with a crust of congealed electrolyte that protects them from corrosion. The German physicist **Ernst Werner von Siemens** (1816–1892) first applied this principle in 1878 in his electric arc furnace, which melted substances using the thermal effect of the electric arc.

The principle of internal heating as applied to cryolite was first described in **Charles Bradley's** patent

application of 1883 (he was granted the patent only in 1891). Only one year later in 1892 this principle began to be used for the commercial production of aluminium alloys. The Cowles brothers changed their process of aluminium production and began to conduct it in electric furnaces in the presence of another metal (copper or iron). This yielded aluminium alloys rather than pure aluminium – aluminium bronze with up to 17% aluminium by mass or aluminium iron with up to 20% aluminium by mass. It took 37 kilowatt-hours of electric power on average to obtain one kilogram of aluminium (in comparison to approximately 15 kilowatt-hours today).

This method was used for several years at the Cowles brothers' smelters in England and the United States, yet it could not withstand competition with the electrolytic method for producing pure aluminium, which was dis-

covered a few years later. In 1892 all of the Cowles brothers' smelters shut down.

The electrolytic method of aluminium production, which is still used today, was invented in 1886. The French metallurgist **Paul Louis Toussaint Héroult** and the American chemical engineer **Charles Martin Hall** worked on this method independently of one another. They made the same discovery and patented it almost simultaneously. Yet the remarkable coincidences did not end here. As fate would have it, both scientists were born in the same year (1863) and died in the same year (1914).

Héroult had begun to take an interest in aluminium in his childhood after reading Sainte-Claire Deville's book. Already at the age of 20, he thought about the possibility of using electrolysis to obtain aluminium. This is tellingly shown by the image of a cell drawn with a quill in the margins of his workbook and dated 1883.

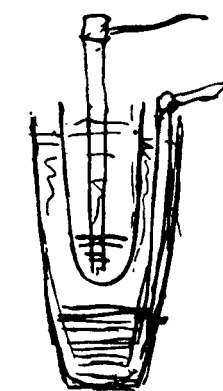
In his first experiments, Héroult electrolyzed hydrous solutions of aluminium salts, yet this metal is too active to precipitate out of an aqueous environment. After his first failures, Héroult tried to dissociate cryolite with electric current. Cryolite melts at a temperature of 1,010°C. Héroult carried the experiment out in an iron crucible that he heated to a temperature of about 1,100°C in a furnace. A carbon rod submerged in molten cryolite served as the anode and the iron crucible as the cathode. The crucible melted during the experiment and the cryolite inside leaked out. Héroult had not expected such a result, as the melting point of iron was about 400°C higher than the temperature of the furnace. The globule resulted from the destroyed crucible contained both iron and aluminium, i.e., it was an iron-aluminium alloy.

Héroult carried out a new experiment in which he added the double chloride of aluminium and sodium to the cryolite to prevent the crucible from melting. He had learned about this technique from Sainte-Claire Deville's book. Héroult knew that this substance melts at a much lower temperature than cryolite.

After completing the experiment, Héroult was surprised to see that the graphite anode was scorched. This indicated that oxygen was present in the experiment. Yet where had it come from? The answer turned out to be simple: Héroult thought that he was using the double chloride of aluminium and sodium, yet this compound absorbed moisture from the air and turned into hydrous alumina, which released oxygen. Thanks to this "mistake"

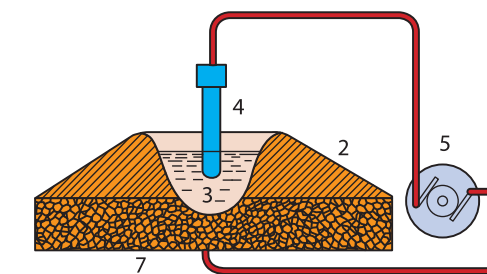
Bradley, US Patents, USA, 1883

«...The greatest difficulty has been found that in the case of cryolite especially, which is a double fluoride of aluminium and sodium, the fused ore unites or fluxes with the crucible itself and that the gas liberated in the process of reduction (fluorine gas) attacks the material of which the crucible is composed, and the consequence is that the crucible is quickly destroyed. [...] The main object of my invention is to dispense with the application of heat outside the basin or receptacle containing the mass of ore or compound under treatment. I employ an electric current to effect electrolytic decomposition, and I maintain the state of fusion by the combined heating effects of such current and a flame or like auxiliary source of heat which, like the heat due to the current, acts directly on the ore next to the electrodes rather than through the walls of a furnace or crucible. [...] By my invention, the current is employed to perform two distinct functions, one of these being to keep the ore melted by having a portion of the electrical resistance offered by the fused ore, and the other being to effect the desired electrolytic decomposition, by which means the heat being produced in the ore itself is concentrated at exactly the point where it is required to keep the ore in a state of fusion. [...] In order to fuse the ore at the start, I take two electrodes connected, respectively, to the two poles of a dynamo-electric machine or other source of current, bring the said electrodes into contact, separate them sufficiently to produce an electric arc, and then thrust them down into the ore lying at the bottom of the cavity or basin, when the ore soon fuses by the heat of the arc and becomes a conducting-electrolyte.



Drawing of the cell from Héroult's notebook

The arc of course ceases to exist as soon as there is a conducting liquid – the fused ore – between the electrodes, and the passage of the current then takes place through the fused ore by conduction and the heat is produced as in an incandescent lamp. [...] As soon as the ore melts, aluminium settles on the cathode, and fluoride is left on the anode. ■



The cell from Bradley's Patent

The ore 2 is placed on the carbon plate 7, which serves as the cathode. The anode 4 is located above; like the cathode, it is connected to the power source 5. At the start of the process, an arc arises between the two electrodes, causing the ore to melt (3 is the molten ore). ■

Hérault realized that the presence of alumina in the molten cryolite lowers its melting point, making it possible to obtain aluminium by electrolysis.

One may think that Hérault was simply lucky and that any other scientist would have done just the same in his place. Nevertheless, Hérault's erudition, his ability to painstakingly analyze the results of his experiments, and his keen observational skills show that this is not the case.

Hérault began to conduct new experiments on electrolysis using alumina. In 1886 he got patents in several European countries simultaneously for his electrolytic method of producing aluminium using a solution of alumina in cryolite.

Nevertheless, pure aluminium did not meet with demand and Hérault decided to work on aluminium alloys. He replaced the graphite crucible that had served as the cathode by a metal (copper or iron) crucible, similar to what he did in his first experiment on the electrolysis of cryolite. During the course of the reaction the aluminium formed an alloy with the material out of which the cathode was made.

For his method of producing aluminium alloys, Hérault got a second patent (French patent number 170,003) titled "Method for Obtaining Aluminium Alloys by Applying the Heating and Electrolyzing Effect of Current to Aluminium Oxide." As the title shows, Hérault also introduced major changes to the method of heating the cell, replacing the external heat source with an electric current to heat the bath internally.

However, as often happens, no one took an interest in Hérault's discoveries in his native country. The aforementioned smelter in Salindres manufactured aluminium by the Sainte-Claire Deville method and its management did not want to improve the process. Moreover, aluminium alloys (just like pure aluminium) had very limited applications at that time. Hérault lacked the opportunity to apply his inventions in practice and was forced to move to Switzerland, where he directed the implementation of aluminium bronze production at a metallurgical smelter in Neuhausen (1888). Here Hérault's discoveries left the confines of the laboratory and began to be applied commercially. The smelter was located next to the Rhine Falls – not on account of the beautiful view but because the falling water drove the smelter's powerful dynamos.

The German metallurgist **Martin Kiliani** (1858–1895) was Hérault's faithful companion who put the latter's



Paul Louis-Toussaint Hérault [1863–1914] was a French metallurgist. While still a student at the École Nationale Supérieure des Mines in Paris, he took a serious interest in the problem of the electrolytic production of aluminium. His research led him to discover in 1886 the modern commercial electrolytic method for producing aluminium. His invention was used to set up the first (1888) commercial production of aluminium at a smelter in Neuhausen (Switzerland). Hérault cast the foundations of the electrochemical production of calcium and alloys of chrome (ferrochrome) and wolfram (ferrowolfram). He invented the electric furnace which became widely used in iron and steel metallurgy. Hérault became director of the aluminium smelter at Froges, France, and subsequently headed a number of other bauxite refineries and aluminium smelters.

ideas into practice and subsequently became director of the Neuhausen smelter. Kiliani already began to conduct experiments on electrolyzing molten cryolite and a mixture of cryolite and alumina before he met Hérault.

The history of aluminium is full of legends and myths. As one story goes, Kiliani made the same discovery as Hérault by accidentally adding alumina to cryolite. This came to light when the smelter's owner **Emil Moritz Rathenau**, who also took an interest in the new metal, came to the workshop after the cryolite electrolysis experiment in order to take a look at the resulting aluminium. Kiliani separated the shiny ingot from the layer of cryolite and presented it to Rathenau. Kiliani did not have time to clean the ingot well, and several flecks of cryolite got caught on Rathenau's clothing. Interestingly enough, these flecks differed in luster: some were shinier and others duller. Kiliani immediately took an interest in this phenomenon and came to the conclusion that the

molten cryolite contained an admixture. Analysis showed that alumina had accidentally got into the cryolite.

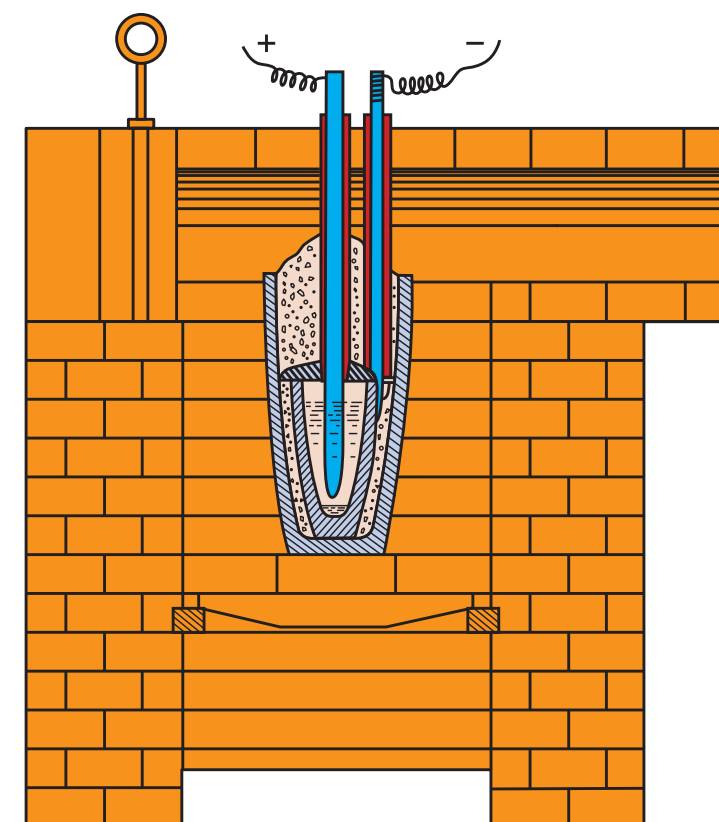
In order to check whether his conjecture was right, Kiliani electrolyzed the cryolite once again, adding alumina. Aluminium was indeed obtained when a solution of alumina in cryolite was used. According to this story, Kiliani also independently proposed using the principle of internal heating to maintain the electrolyte in a molten state. However, these claims have not been confirmed, and so it is still too early to rank Kiliani among the pioneers of the modern electrolytic method.

After Hérault moved to Neuhausen, the smelter began to manufacture aluminium bronze, which became the first industrial aluminium alloy. However, it ceased to be produced a year later. This was partly due to technological problems (Hérault's method was unable to produce alloys with a fixed aluminium content). Another reason was apparently low profit margins: the demand for aluminium bronze was still extremely small.

At the same smelter, Hérault tried to produce pure aluminium on a commercial scale. He did it using the process described in his second patent. Molten alumina was electrolyzed without the addition of cryolite. Nevertheless, major difficulties resulting from the refractoriness of alumina arose during production: a temperature of over 2,000°C had to be maintained during electrolysis. Many experiments at the Neuhausen smelter ended in failure. Nevertheless, the foundations of the entire modern aluminium industry were laid there.

Neuhausen began producing aluminium bronze in the same year, on November 18, 1888. The same year the Swiss Metallurgical Society and the German industrialist Rathenau signed an agreement on the establishment in Neuhausen of the Aluminium Industry Joint-Stock Company with a total capital of ten million Swiss francs. It was later renamed the Society of Aluminium Smelters. Its trademark depicted the sun rising from behind an aluminium ingot which, according to Rathenau, symbolized the birth of the aluminium industry. As figures show, the society grew rapidly: over five years the output of the smelter increased by over ten times. In 1895 Neuhausen produced 450 tonnes of aluminium compared to only 40 tonnes in 1890.

In addition to the smelter at Neuhausen, the Aluminium Industry Joint-Stock Company owned a smelter in Rheinfelden (Baden), built in 1907 on the right bank of the Rhine River. It produced up to 800 tonnes of aluminium annually.



The cell from Hérault's first patent

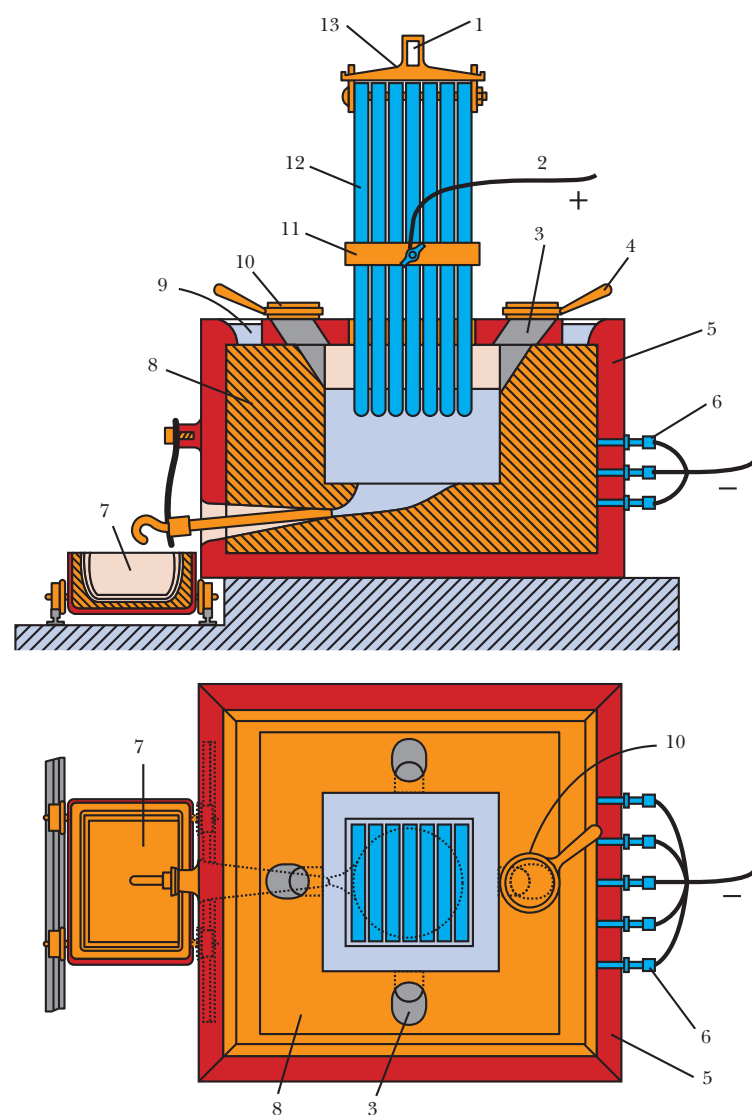
From Hérault's first patent

"I make a claim to the invention of a method for producing aluminium that is based on the electrolysis of alumina dissolved in molten cryolite. The current can conduct through any types of electrodes – for example, a carbon anode submerged in a molten electrolyte, while the electrolytic vessel itself serves as the cathode. The anode is incinerated by the oxygen that is liberated on it, while the metal disengaged at the cathode gathers on the bottom of the crucible. Cryolite is not consumed in the present process, and it suffices to replace the alumina that decomposes during electrolysis to assure the continuous production of metal..."

The molten cryolite is contained in a dense crucible made of pure carbon and placed in a large graphite crucible. The latter stands on a support, which, in turn, rests on a grate.

The installation described above and depicted on the drawing only serves to give an example of my new method, and I reserve the right to make technical changes in the installation."

Paul Louis-Toussaint Hérault, French Patent 175,711, 1886 ■



The cell from Héroult's second patent

From Héroult's second patent. France, 1887

"In the apparatus, the positive electrode is a package of carbon plates, while the negative electrode is the molten metal on the bottom of the carbon crucible. The bottom of the crucible has a tap hole [hole for emitting metal] for assuring a continuous process. The attached drawing shows a cross-section of the apparatus. The iron vessel, 5, whose interior is lined with carbon blocks, 8, is placed on an isolated base. The vessel's walls are connected to a negative electric conductor with screws, 6, that come into contact with the graphite blocks, serving as the cathodes. To make this contact as secure as possible, the inner lining is first prepared and put in a mold, and then the space between the form and the mold is filled with iron or copper. The congealed metal forms the walls and bottom of the box that closely adjoin the inner lining. The anode is a bundle of internal plates, 12, that are connected above by the frame, 13, with hole, 1, which makes it possible to suspend it from a chain. The electrodes are submerged in the bath and removed from it with the help of the chain. The carbon rods are surrounded in the middle by the copper ring, 11, which is connected to a positive electric conductor. The cell is closed above with lid, which contains a hole for inserting anodes and four holes, 3, for the inlet of substances and the outlet of gases emitted during electrolysis. The edges of the holes are beveled, while the upper edge of the lining contains grooves that connect the holes to the interior of the bath. The holes are fitted with lids 10 with handles, 4, which make it easy to remove the lids and to put them back onto the holes. The space between the edges of the lids and the metal walls of the box 9 is filled with powdered charcoal. At the start of the operation, copper (preferably in powdered form) is introduced into the reservoir, the lid is put on, the anode is lowered into the copper, and the current is switched on. Some time later, the copper melts from the action of the current. Alumina is then added to the bath, the anode is raised higher, and the current is switched on once again. Now the current passes through the alumina, which melts and decomposes with the production of oxygen at the anode and aluminium at the cathode. The aluminium dissolves in the copper bath, while the oxygen incinerates the carbon of the anode so that bluish flames of carbon monoxide emerge from the hole, 3. During the electrolytic production of the metal, copper and alumina are added to the bath continuously or at intervals... When a sufficient quantity of aluminium is produced, the molten metal is poured from the bath into mold, 7, to obtain ingots of aluminium bronze."

Paul Louis-Toussaint Héroult, French Patent 170,003, 1887 ■



Trademark of the Society of Aluminium Smelters at Neuhausen

Paul Héroult stayed less than a year at Neuhausen. During this period, changes took place in his native country: people adopted a completely different attitude towards his inventions. On 17th October 1888 the National Electrometallurgical Society was founded in Paris. Its first step was to purchase Héroult's patents and to begin to build an aluminium smelter. It also convinced Héroult to return to France. The smelter was inaugurated already in April 1889 at Froges in the Isère Valley near Grenoble (Isère Department).

Héroult was appointed the smelter's director, which (like the smelter in Neuhausen) specialized during its first few months in the production of aluminium bronze and an iron-aluminium alloy containing up to 30% aluminium. Yet, already in late 1889, the smelter switched to the production of pure aluminium.

Initially, electrolytic baths with a single anode were used, and a DC current supply of 4,000 A was supplied to

the anode. An enormous amount of electric energy (42 kWh) was needed to produce a single kilogram of aluminium. This was due to a poor cell design in which a high current density (over 6 A/cm²) arose at the anode. Héroult retained the same current yet used four electrodes instead of one. This made it possible to decrease the current density by a factor of four and lower the cost of production of aluminium.

In 1893 another smelter opened under Héroult's direction. This took place in La Praz on the Arc River in the foothills of the French Alps (Savoy Department). Here electrolytic baths with six anodes working at a current of 5,000 A were used.

Many technical minds in Europe and America tried to improve the electrolytic method of aluminium production in the 1880s. Even before the details of the Héroult process became known to a wide circle of specialists, the German engineer **Johannes Borchers** proposed his own version of the cell with a new method of cooling the outer walls of the apparatus: the continuous circulation of the cooling mixture prevented the metal from being contaminated with the material of the cell, as the walls were coated by a crust of congealed cryolite from the inside. The obtained metal was thus enclosed by the congealed electrolyte, which prevented it from coming into contact with other substances. Borchers' ideas turned out to be pertinent even many years later and were used for building commercial cells in subsequent decades.

New aluminium factories continued to go up in France. Most of them were located in the southeastern part of the country – the French Alps – where mountain rivers made it possible to obtain electricity inexpensively. In 1903 a smelter opened at Saussaz, and, seven years later, a smelter with an even greater capacity at L'Argentière-la-Bessée on the Durance River (Hautes-Alpes department).

The chemical company *Compagnie d'Alais et de la Comargue*, which owned the Salindres smelter, also decided to switch to the electrolytic method of aluminium production (the Salindres smelter had previously employed the Deville chemical method). Nevertheless, all the rights to Héroult's patents belonged to the French Electrometallurgical Society. They expired only in 1901. To overcome this obstacle, the management of the *Compagnie d'Alais et de la Comargue* made use of Hall's American patents (the reader will recall that Hall and Héroult simultaneously developed the electrolytic method of commercial aluminium production). The company's

From the memoirs of Paul Louis-Toussaint Héroult

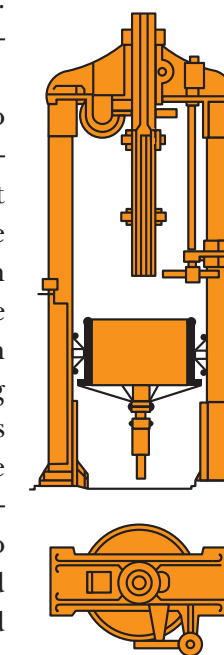
"My father died in 1885 while I was still a student. He had been the owner of a small tannery in Gentilly. Since that time, Gentilly (a suburb of Paris and a summer resort) became my home. I had no intention to continue the tanning business.

I sold some of the equipment at a low price to my father's friends and used the money to buy a small Gramme dynamo. There was a steam engine at the tannery. The dynamo and steam engine sufficed for conducting experiments on the electrolysis of various aluminium compounds.

As I was convinced that aluminium could be obtained by electrolysis, I tried to decompose aqueous solutions of aluminium compounds with electric current. Nothing good came of these attempts – only numerous failures. My knowledge in chemistry was limited. What else could one expect of a twenty-three-year-old student who did not specialize in this field? Yet, after a lot of effort, I embarked upon the right path. Alumina and cryolite were melted by the electric current of my dynamo and finally gave me metallic aluminium...

After I got the patent, I did not know what to do with it. I began to ask specialists in the field. One of them, whom I had asked for advice, told me, 'Aluminium is a metal with limited demand, and, no matter whether you sell it for 10 or 100 francs per kilogram, people will not buy an extra kilogram of it. If you could produce aluminium bronze, that would be a different matter altogether, for it is used in substantial quantities.'

Putting aside the production of pure aluminium, I launched a new series of experiments and obtained aluminium alloys. I turned to industrialists and capitalists for financial support. However, no one was interested in helping me in France. With a bitter feeling, I left Gentilly, where I had come to feel at home, and went to Switzerland. Why Switzerland? It is difficult for me to say. I was ready to go to the ends of the earth only to get the opportunity to continue my work on aluminium. My country, which had done more for aluminium than any other, did not want to offer me even a little bit of support. Very well, I will look all over the world for people who would buy me and my invention." ■



Design for electrolytic baths at the Neuhausen Smelter, 1889

first electrolytic smelter was located in Calypso (Savoy Department). In 1895 the smelter began to employ the new method. The company built a new smelter in Saint-Jean-de-Maurienne (Savoy Department) in 1907.

Hall patented his electrolytic method for aluminium production two months after Héroult. It took Hall three years to prove the originality of his method with respect to that of Héroult (Hall filed his patent application on 9th June 1886, yet was granted the patent only in 1889). Like Héroult, Hall was greatly influenced by Sainte-

Claire Deville's book. He read it while still at college and began to take a serious interest in finding a way of producing aluminium, starting with naïve schoolboy experiments that would eventually culminate in a major discovery.

At first, he tried to reduce alumina with carbon. When this attempt failed, he looked for another substance that could be added to alumina to achieve the desired effect. Determined to obtain aluminium at all costs, he tried all the substances that he could lay his hands on, somewhat like a medieval alchemist. He tried soda and the salts of barium, calcium chloride, and magnesium. Realising the futility of these attempts, Hall began to experiment with electric current. Yet the desired white metal did not appear: experiments with aqueous solutions of alum and aluminium chloride only led to the appearance of a precipitate resembling jellied meat. Yet Hall not only conducted experimental work but also read books and meticulously analysed his prior experiments. He wanted to find a substance that would "make alumina dissolve just as salt and sugar disappear in boiling water." He tried calcium fluoride, magnesium fluoride, and sodium fluoride. However, these substances melt at very high temperatures. Step by step, he reached the idea of using cryolite. First of all, cryolite easily dissolves in water without requiring a lot of heat. Secondly, molten cryolite is an excellent solvent of alumina. Hall kept adding alumina to the solution, and the latter remained as clear as glass.

Hall could now turn to electrolytic experiments. He faced the problem of selecting a material for the crucible. Initially, he had conducted his experiments in a ceramic crucible made of fired clay. However, they were not successful. Once again, Hall was not daunted by failure but continued to analyze, think, and make conclusions. What could hinder the production of the metal? Could it be the silica contained in clay? Hall recalled his repeated attempts to reduce alumina with carbon. He decided to replace the ceramic crucible by a carbon one, taking the final and decisive step on the road to success. On 23rd February 1886, Hall electrolyzed a solution of alumina in molten cryolite and finally obtained aluminium.

Confident of success, he continued his investigations. He tried replacing cryolite by mixtures of fluorides of different metals, experimented with the cell design and varied the crucible material. For an unknown reason, he externally heated the electrolyte in



Charles Martin Hall [1863–1914] was an AMERICAN CHEMICAL ENGINEER AND TECHNOLOGIST. HE WAS BORN IN OBERLIN, OHIO. AT THE AGE OF 13 HE HEARD ABOUT ALUMINIUM, A METAL WITH REMARKABLE PROPERTIES THAT IS PRESENT IN COMPOUNDS IN ALL TYPES OF CLAY, AND WAS CARRIED AWAY BY THE IDEA OF FINDING A MEANS OF PRODUCING IT. WHILE STILL AT COLLEGE, HALL TOOK UP THE STUDY OF CHEMISTRY AND SET UP A LABORATORY AT HIS HOME, WHERE HE CARRIED OUT EXPERIMENTS TO REDUCE ALUMINIUM FROM ITS OXIDE. IN 1886, HE INVENTED THE ELECTROLYTIC METHOD OF PRODUCING ALUMINIUM SIMULTANEOUSLY WITH HIS COEVAL PAUL LOUIS-TOUSSAINT HÉROULT WHO WORKED ON THE SAME PROBLEM IN FRANCE. HE SUBSEQUENTLY WORKED ON THE DEVELOPMENT OF A TECHNOLOGY FOR OBTAINING PURE ALUMINA AND THE IMPROVEMENT OF THE CELL.

a furnace. Hall proposed two cell designs in his patent. However, it was still too early to rest on his laurels: although the cell designs were suitable for conducting experiments in a laboratory, they were unfit for commercial use. Hall was faced with the uneasy task of putting a theoretical discovery into practice.

Hall's invention was applied for the first time at the Cowles brothers' smelter in Lockport but only a few kilograms of aluminium could be obtained there. It was necessary to make radical changes in the entire technology to increase the scale of production, yet the smelter owners were not willing to do so. Letters from Edwin Cowles, the company's president, have been preserved. He understood that the introduction of Hall's method would lead to a sharp fall in aluminium prices. This naturally discouraged him from making reforms. To save his firm from bankruptcy, he even fostered plans of buying Hall's patent for a low amount in order to prevent



First particles of aluminium obtained by Hall

competitors from making use of his invention.

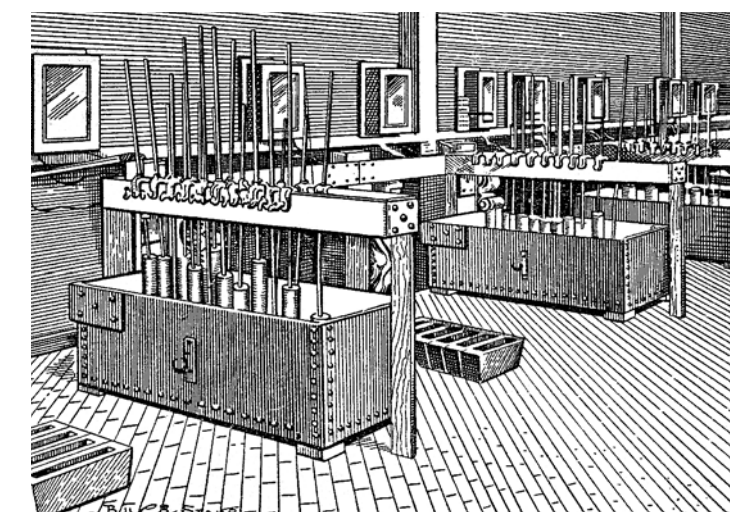
The joint work foundered and Hall left the Lockport smelter. With the support of friends he founded the Pittsburgh Reduction Company. Its first smelter was inaugurated on 18th September 1888 at Kensington near Pittsburgh. It made use of iron electrolytic baths that were rectangular in shape (60 cm long, 40 cm wide, and 50 cm high). Two dynamo machines generated the electric current. Each bath contained approximately 100 kg of electrolyte (a solution of alumina in molten cryolite).

The baths were initially designed to be heated externally. To this end, each bath was mounted on a brick pediment with a furnace inside. However, engineers noticed that during electrolysis the heat emitted by the current passing through the electrolyte sufficed for the process, and decided to dispense with the external heat source. Hall then applied the principle of internally heating the

baths that had been patented by Bradley and it was the Cowles brothers that owned Bradley's patent. The lawsuit lasted for 12 years and Hall's company was finally ordered to pay a large indemnity to the Cowles brothers (1903).

During its first few months, Hall's Pittsburgh smelter produced 50 pounds (about 22.5 kilograms) of aluminium daily. The aluminium cost \$10 per kilogram, i.e., half the price of the aluminium produced by the Cowles brothers. Nevertheless, even such an inexpensive metal did not meet with sufficient demand. The Pittsburgh smelter was forced to lower the price by 20% and later even by 40% for quantities over 1.5 tonnes.

The scale of production gradually increased. By 1890

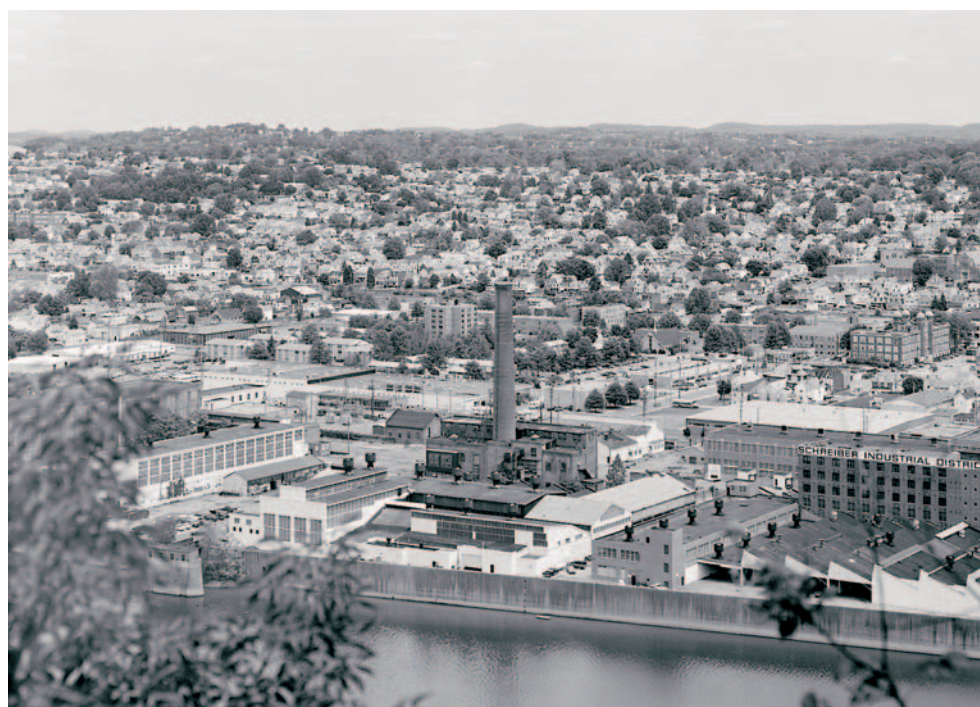


Smelter in New Kensington

the smelter already produced 240 kilograms daily. To this end, it had to buy two new dynamos and increase the number and the size of the baths. The new baths were 1.8 meters long and 1 meter deep. Another new feature was an opening in their bottom for extracting aluminium.

The premises of the Pittsburgh smelter soon became too small for the rapidly expanding company. Even more importantly, the smelter began to experience a shortage of electric power. In March 1891 it was moved to New Kensington near Pittsburgh where a hydroelectric smelter had been built on the Allegheny River. The smelter began to produce 500 kilograms of aluminium daily in 1893 and twice as much the following year.

Under Hall's leadership, the Pittsburgh Reduction Company rapidly expanded. Several new smelters were founded in New York State near the recently constructed Niagara Hydroelectric Smelter. One of them (*Niagara*



Falls) is still operating today. In 1907 the Pittsburgh Reduction Company was reorganized to become the American Aluminum Company. Today, it is called Alcoa and is a leader in the US aluminium industry.

By the end of the 19th century, two world leaders had emerged in aluminium production: France and the United States. Scientists from these two countries – the European Héroult and the American Hall – are rightly considered to be the founders of the modern aluminium industry. For the sake of fairness, it should be noted that, three years before Héroult and Hall, Bradley had proposed to use a solution of alumina in cryolite for obtaining aluminium by electrolysis. He also discovered the principle of internally heating the electrolyte by electric current, on which modern cells are based.

Virtually all science historians believe that Héroult, who worked in France, was not familiar with Bradley's experiments. Yet there are different views with regards to Hall, who, like Bradley, worked in the United States.

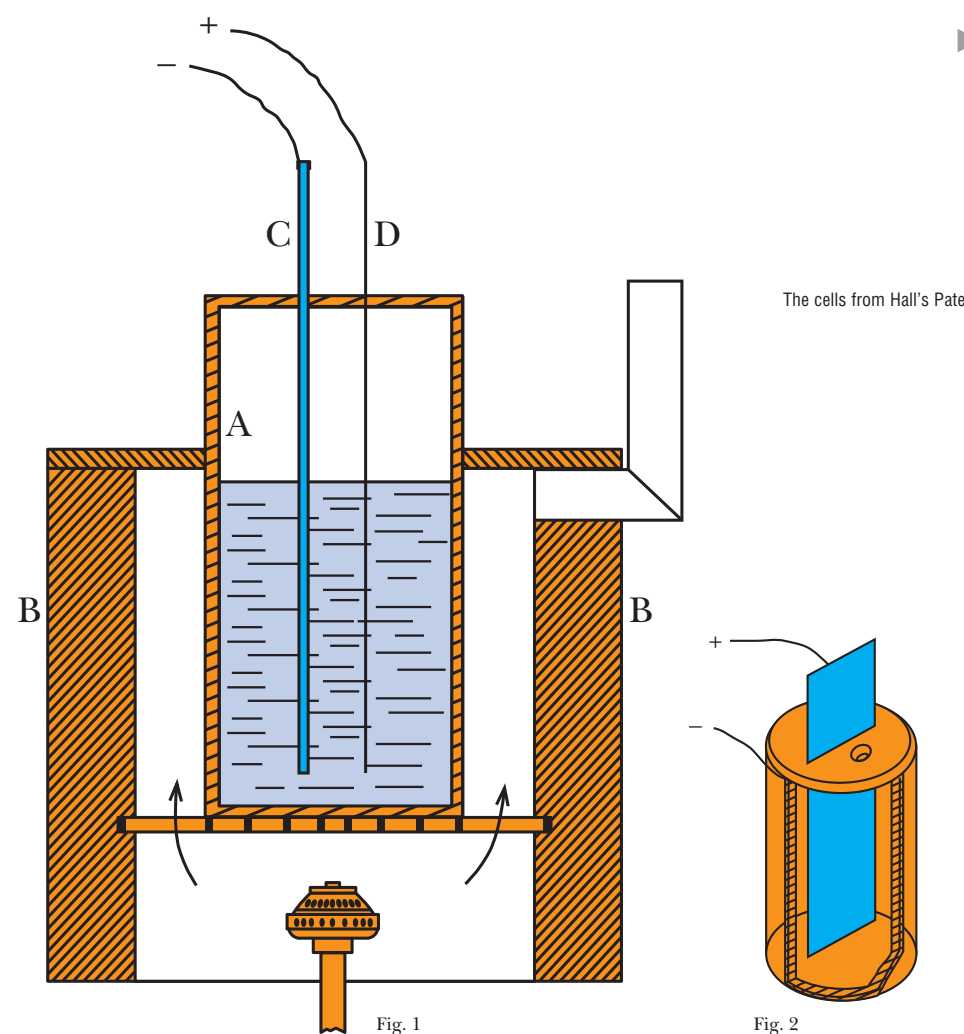
In his book "Aluminium Industry", **Rudolf Debar** conjectured that Hall intentionally did not mention the principle of internally heating the electrolyte, as he feared that his invention would be rejected. After all, this principle had already been patented by Bradley. However, the latter had not patented his discovery of the electrolytic method of aluminium production itself. This may explain why he has been relegated to a secondary role in the history of aluminium.

Pittsburgh Reduction Company's smelter in New Kensington (left)

Power plant building in New Kensington (right)

From the memoirs of Charles Martin Hall

"Little by little I mastered thermochemistry and I got the idea that alumina could be dissolved in a substance that did not contain water: a solvent more chemically stable than alumina. Thus there would be a solution that could yield aluminium by electrolysis... I hastily constructed a small electrical battery. In the clay crucible I fused some cryolite, dissolved alumina in it and passed an electric current through the fused mass for a duration of approximately two hours. When I poured out the fused mass, I could not find any aluminium... It occurred to me that this operation could be hampered by extraneous substances, primarily quartz from the clay crucible. It was then that I decided to fashion a crucible from carbon. Passing the current for approximately two hours, I poured out the mass and found several small globules of aluminium. That was how I became confident that I discovered the process I had been looking for... Our advertisement of aluminium for \$2 per pound with the purchase of 1,000 pounds of the metal apparently interested no one. I realize that many are frightened by such a large amount. Many believe that the total consumption in the United States barely exceeds 1,000 pounds annually. Many say even we do not have 1,000 pounds. They are wrong about that, but they are correct in thinking that finding someone willing to purchase 1,000 pounds is quite difficult, for no one needs aluminium in this quantity." ■



The cells from Hall's Patent

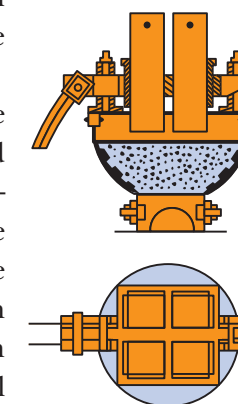
Fig. 1

Fig. 2

The encyclopedia *Promyshlennost i tekhnika* (Industry and Technology) published in St. Petersburg in 1904 makes the following conclusion, which strips Hall's method of all originality: "Hall copied the electrolytic apparatus and the principle of production from Héroult. Thus his method cannot be considered to be original but only a variation of Héroult's method."

Debates will undoubtedly continue for a long time on who was the first to develop the electrolytic method for the commercial production of aluminium. However, it is a lot more important for us here to discuss the results of this discovery, which are very impressive. The electrometallurgical aluminium industry emerged in only a few years' time. The production of aluminium grew by a factor of magnitude, while its price fell sharply.

This is the end of the history of "silver from clay" and the beginning of an entirely different story of how a quasi-precious metal became accessible virtually to all – accessible, ordinary and irreplaceable.



Design of electrolytic baths at the Neuhausen Smelter (1892-93)

From Hall's Patent, 1889

"The invention described herein relates to the reduction of aluminium from its oxide by dissolving such oxide in a bath containing a fused fluoride salt of aluminium and then reducing the aluminium by passing an electric current through the bath; and in general terms the invention consists in the electrolysis of a solution of alumina in a fused fluoride salt of aluminium, substantially as hereinafter more fully described and claimed.

In the accompanying drawings, forming a part of this specification, Fig. 1 is a sectional elevation of a form of apparatus applicable in the practice of my invention; and Fig. 2 is a view, partly in section, of a modified form of apparatus. In the practice of my invention I prepare a bath for the solution of the alumina by fusing together in a suitable crucible, A, the fluoride of aluminium and the fluoride of a metal more electro-positive than aluminium – as, for example, the fluoride of sodium potassium, or – these salts being preferably mingled together in the proportions of 84 parts of sodium fluoride and 169 parts of aluminium fluoride, represented by the formula $\text{Na}_2\text{Al}_2\text{F}_6$. A convenient method of forming the bath consists in adding to the mineral cryolite 338/421 of its weight in aluminium fluoride. To object of thus adding aluminium fluoride is to secure in the bath the proper relative proportions of the fluorides of aluminium and sodium. To this fused bath is added alumina or the oxide of aluminium in sufficient quantities, and the alumina being dissolved by the fused bath an electric current is passed through the solution, by means of suitable electrodes, C and D, connected with a dynamo-electric machine or other suitable source of electricity and immersed in the solution.

By the action of the electric current, which preferably has an electro-motive force of about 4-6 V, oxygen is released at the positive electrode D, and aluminium is reduced at the negative electrode C, which, on account of the affinity of aluminium for other metals, is formed of carbon when it is desired to produce pure aluminium. The positive electrode D may be formed of carbon, copper, platinum or other suitable material. When formed of carbon, the electrode C is gradually consumed, and must therefore be renewed from time to time but when formed of copper an oxide coating is formed over the surface of the electrode from further destruction by the action of the oxygen, but does not interfere materially with the conducting qualities of the electrode. On account of the affinity of aluminium for other metals, and also the corrosive action of the materials forming the bath on earthly materials, I prefer to form the crucible or melting-pot A of metal – as iron or steel – and protect the same from the action of the aluminium by a carbon lining. This crucible is placed in a suitable furnace, B, and subjected to a sufficient heat to fuse the materials placed therein, such materials fusing at approximately the same temperature as common salt. In lieu of the electrode C, the carbon lining may be employed as the negative electrode, as shown in Fig. 2, the conductor from the negative pole of the electric generator being suitably connected, to such lining.

Charles Martin Hall, US Patent 400766, 1889 ■

Applications of Aluminium in the Late 19th and Early 20th Centuries. Aluminium Alloys

After Hall and Héroult invented the electrolytic method for the commercial production of aluminium, prices on the metal dropped. By the early 1890s, metallic aluminium was already very widely used. After it became more accessible, it began to be applied in a lot of different fields. It was used for jewellery and objets d'art, everyday items, cosmetic flasks, eyeglass frames, and optical instruments (binoculars, spyglasses, theodolites, and sextants), to name just a few. Aluminium tableware, which is an essential part of daily life today, began to be produced in the late 19th century. In the first decades of the 20th century, it gradually supplanted copper and cast iron tableware. Aluminium pots and pans are light, resistant to edible acids, heat up quickly, and do not rust.

Aluminium foil, another basic object today, also appeared at that time. It replaced tin foil and was first used to package candy and chocolate. Today, aluminium foil is employed in virtually all the domains of the packaging industry and has many advantages from its excellent protective qualities to its striking and festive outer appearance.

Aluminium has become essential in chemical laboratories, too. It is used to manufacture articles for air and water baths, gas burners, and hot filtration funnels. As one sees from the account of the applications of aluminium in the ten-volume encyclopedia *Industry and Technology* translated from German and published in St. Petersburg in the early 20th century with additions by Russian scholars, aluminium already had a wide variety of applications at that time.

The fashion for pure aluminium jewelry that arose in the 1850s soon passed, and its use as a basis for various types of ornaments also met with difficulties: it turned out that it was difficult to coat aluminium with a layer of another metal. For example, in order to gild or silver aluminium, nineteenth-century specialists first covered it with a layer of copper and then plated the noble metal on the copper. It was a laborious process: the aluminium article was etched with an alkaline solution or a mixture of nitric and hydrofluoric acid, washed, immersed in hot hydrochloric acid, washed once again, and only



Aluminium postcard
Spain, 1906

then immersed in a solution of copper sulfate. As a result, a layer of copper covered the article, which became orange-red in colour. Finally, the article with the thin layer of copper was placed in a galvanic bath for silvering or gilding. Nevertheless, whereas the task of plating aluminium with a layer of another metal was difficult though possible, the inverse problem was virtually insoluble. Aluminium film did not adhere to metal surfaces and flaked off quickly.

Aluminium articles are difficult to solder. Due to the high chemical activity of aluminium, a galvanic current arises between it and the soldering alloy, greatly deforming the soldering joint. This explains why aluminium articles began to be manufactured by casting and stamping already in the 19th century. At the same time, aluminium could be used as an additive. For example, film made from an alloy of zinc and a small amount of aluminium was stronger than ordinary zinc film. The addition of aluminium to brass also produced a denser and stronger material.

Aluminium easily forms alloys with many other metals. This property of aluminium makes it possible to improve its hardness and other mechanical characteristics (strength, ductility, flexibility and malleability) while preserving its main property – lightness.

The universality of aluminium stems from this ability to form alloys easily. The history of the use of aluminium in the late 19th and 20th centuries is, above all, a history of its different alloys. Scientists and engineers



Alfred Eduard Berrage
K3 aluminium tea kettle from
the Picault kitchenware collection.
Great Britain, 1937



Vase made of lead and cast,
stamped and engraved
aluminium. France, 1945



Aluminium box for antiseptic
shave stick. France, 1910s

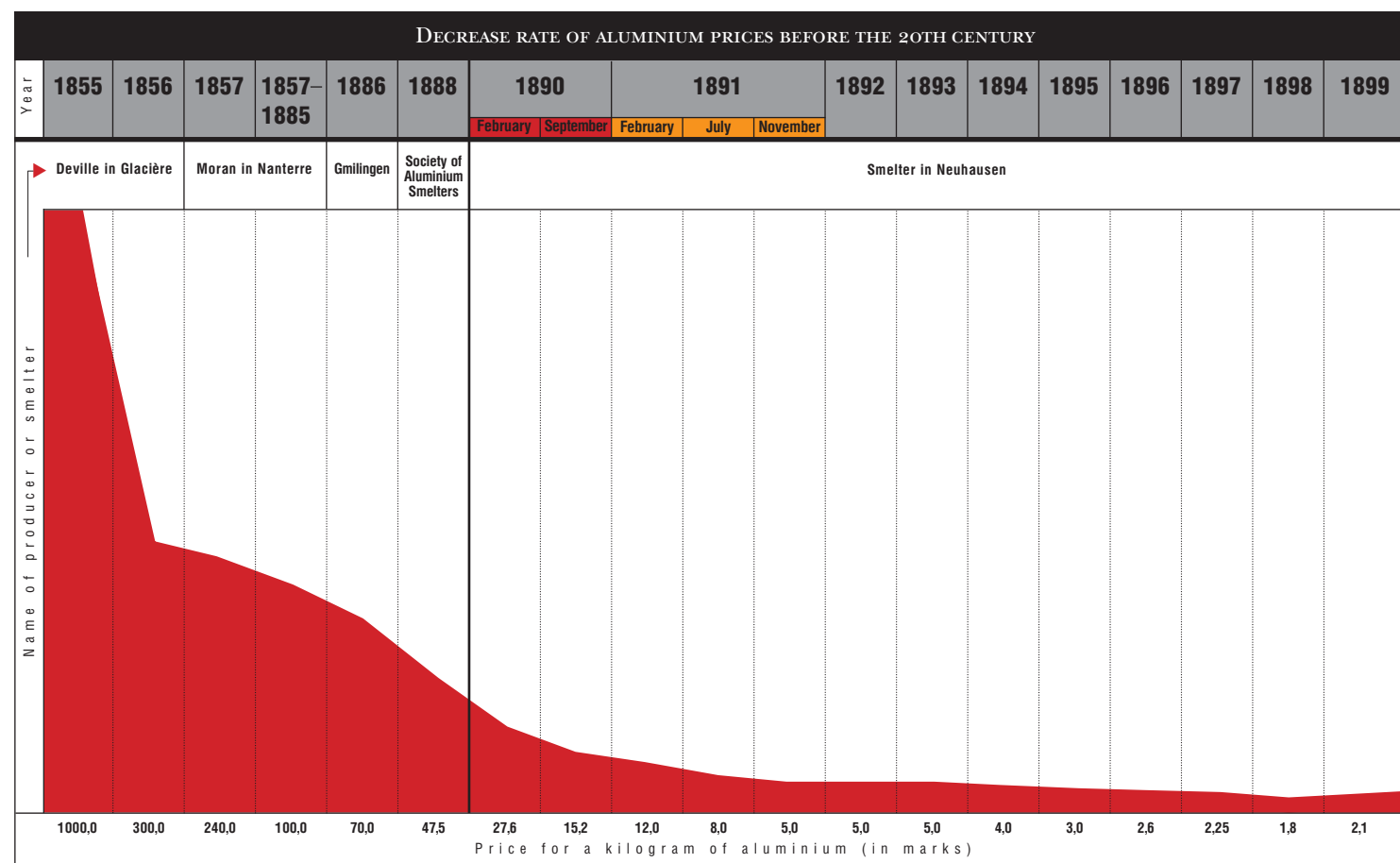
immediately noticed that the new metal is very soft and malleable. However, when it is smelted with other metals, it acquires the necessary hardness without losing its key property of lightness.

Already Wöhler and Sainte-Claire Deville remarked aluminium's ability to form alloys; the latter devoted a whole chapter of his book to this topic. The Tissier brothers prepared a number of aluminium alloys in 1856. Two years later, Hirzel produced about thirty new alloys and described their properties. Aluminium bronze was the first alloy to be applied in practice. The reader will recall that this alloy of aluminium and copper was presented at the Paris Exposition of 1867 alongside other technological achievements. This is a fairly inexpensive alloy with excellent mechanical properties. It is resistant to seawater and even dilute hydrochloric acid. It is used to make flexible bands, sheets, and wire and is widely employed in the shipbuilding and aviation industries. In the USSR, one, two, three, and five-kopeck coins were struck from aluminium bronze between 1926 and 1957.

In the late 19th century metallurgists discovered that adding even a small amount of aluminium to steel considerably improves the latter's properties. This method is used to assure smoother cooling, decrease the size of shrink holes (cavities in ingots that arise during solidification), improve durability, prevent corrosion, and make the surface denser and more homogeneous. Indeed, aluminium that is added to steel reduces the



nickel-plated steel.
France, ca. 1906–1908



Source: The Mining and Metallurgical Engineering, SPb., 1904

small quantities of ferrous and other oxides that it may contain. As a result, aluminium began to be applied in steelmaking by adding approximately 100 grams of aluminium per ton of steel.

When the price of aluminium dropped, and experiments with aluminium became affordable, many researchers began to work on the invention of aluminium alloys. This was done in a haphazard fashion, however. Aluminium was often alloyed with everything at hand. Every scientist strove to give a name of his own to his new alloy, and these names rarely provide information on the component added to the metal. The names of these strange alloys have come down to us in history books: *argentarium*, *chromalium*, *nickalium*, *iontanium*, *wol-*

framium, *cerium*, *tatanium*, *cimalium*, *reformium*, *cruselium*, *voidrium*, *partinium*, *alcenium*, *asperalium*, *ciscon*, *albidur*, and many others.

Scientists were looking for an alloy with a similar density to pure aluminium yet with better mechanical properties (hardness, strength, and flexibility) and chemical inertness. In 1903 the German materials scientist **Alfred Wilm** (1869–1937) finally succeeded after seven years of hard work at the laboratories of the Central Research Station at Neubabelsberg near Berlin. His alloy, which was a mixture of aluminium with copper (3.5–4%), magnesium (0.5%), and manganese (0.5%), was called *duralumin*, i.e., hard aluminium (from the Latin word *durus* ‘hard’). Duralumin has a low density that is virtually

It suffices to take a look at the world aluminium production over the last decade to conclude that the yield of aluminium is growing with each passing year, while its price is systematically falling. The growth of the production of aluminium is due not only to its extensive use in metallurgy and electrical engineering but also, without a doubt, to the remarkable development of aeronautics and the use of aluminium in the production of tableware and certain military equipment.

N. Pushin, E. Dishler, and M. Maksimenko, “On the Production of Aluminium from Russian Minerals,” *Izvestiya Petrogradskogo Elektrotehnicheskogo Instituta*, no. 10, 1914

equal to that of pure aluminium, yet it is hard and flexible like soft steel.

Duralumin turned out to have very unusual property: it *ages*. Wilm made this discovery accidentally. One evening, he left the laboratory, leaving a few samples of the alloy on the testing machine. The next day, he discovered to his surprise that the alloy became stronger by itself. After mechanical treatment and heating to about 500°C, duralumin began to improve spontaneously its mechanical properties – in other words, it became even stronger. Wilm analyzed what had taken place and made the necessary experiments to substantiate his discovery. He published the results in 1909.

The first commercial production of duralumin was set up at the Düren Metallurgical Smelter in Germany, whose documents mention the name of the alloy for the first time. In the 1920s, the Soviet metallurgical engineer **Vladimir Butalov** developed a Russian version of this alloy, which was called *kolchugaluminium*. While the word *duralumin* may stem from the name of the town of Düren, as certain historians of technology believe, the word *kolchugaluminium* certainly comes from the village (and now city) of Kolchugino, in the Vladimir region, where this alloy was manufactured. The first Soviet all-metal aircraft ANT-2 designed by **Andrei Tupolev** was made from this alloy.

During the pre-war years, other deformable aluminium alloys of great industrial importance besides duralumin were produced in Russia. The alloy D 1, which contains the alloying *elements* (a term used to refer to chemical elements, mostly metals that are added to alloys to give them certain properties) copper and magnesium, was used in particular for making aircraft propeller blades. During the war, when pilots sometimes had to land on makeshift runways or directly on the fuselage without letting down the landing wheels, propeller blades often bent upon impact with the earth. They bent without breaking! They were straightened out in the field, and the plane continued to fly with the same airscrew. Another alloy from the same duralumin family (D 16) is used by the aviation industry for a different purpose: manufacturing the lower panels of wings.

Another important aluminium alloy – *silumin* – contains 12–13% of silicon and a small amount of sodium, which gives it a fine crystalline structure as well as additional hardness and strength. Silumin was discovered by **Aladar Patch** in Cleveland in 1920 (USA) and then

Kerosene lamp. Silumin



Alfred Wilm. Method for aging magnesium-bearing aluminium alloys

“The goal of the new method is to age magnesium-bearing aluminium and its alloys with other metals such as copper, manganese, and nickel. The resulting alloys have higher strength, toughness, and hardness. In this method, the alloy, after being heated during the final treatment, is heated once again to a temperature of at least 420°C and then slowly cooled or hardened and left to age by itself for a certain time...

The process improves all the material's properties, such as yield point, strength, elongation, and hardness, which were attained by mechanical treatment... The most important thing for the attainment of this goal is the presence of magnesium in the alloy. The simultaneous presence of other metals such as copper, manganese, nickel, titanium, etc., also substantially raises the alloy's strength.”

German Patent 244554, 1909 ■

improved by the chemist Professor **Jan Czochralski**, founder of the Warsaw Institute of Metallurgy and Metal Science. In the United States, this alloy is called *alpax*.

Silumin is an excellent cast alloy: articles made of silumin are not wrought on a lathe but cast in molds. It virtually does not shrink during cooling and renders minute details of form. At the same time, silumin has high mechanical strength and is resistant to corrosion. In the early 20th century, this alloy was used to make barrels, tanks, and the bodies of cars, trains, airplanes, and airships.

Ferro aluminium, an alloy of iron and aluminium, plays an important role in steel metallurgy. The lithium-aluminium alloy *scleron* is very strong. Other aluminium

alloys with good casting properties were also developed in the first half of the 20th century.

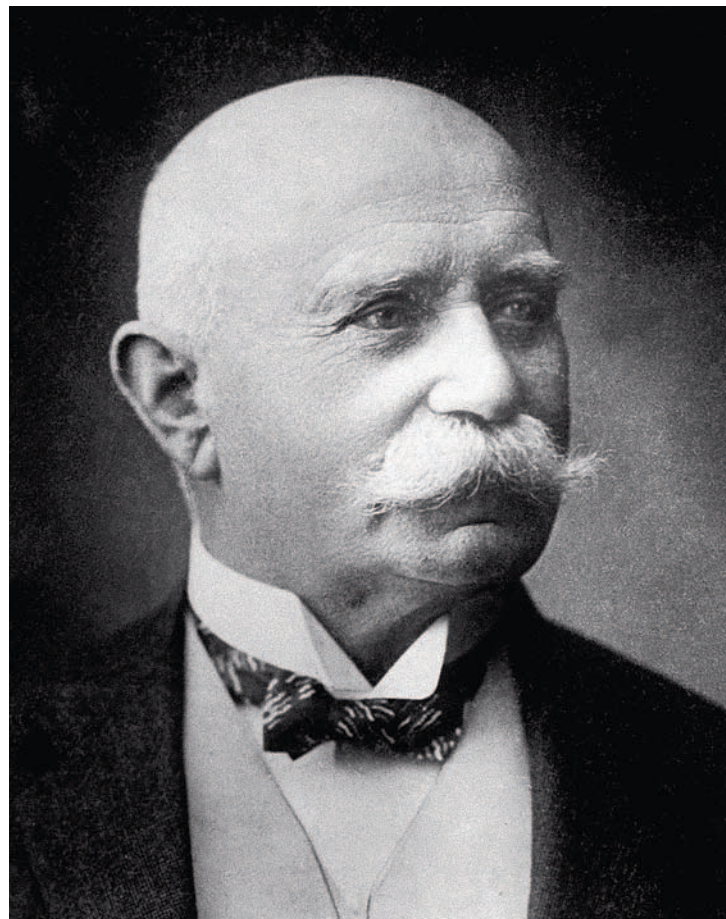
The rapid growth in aluminium production and the sharp drop in prices continued in the first half of the 20th century. These factors led to a considerable rise in aluminium consumption. Whereas the world's per capita aluminium consumption amounted to 4.7 grams in 1900, it rose to 251.2 grams by 1937 – an increase by more than a factor of fifty. (In developed countries the figure is now at 30 kg.) In comparison, the same indicator increased by only a factor of three for other nonferrous metals (i.e., all metals except for iron).

Manufacturers realized the advantages of aluminium and its alloys, which are light, fairly hard, good heat and electric conductors, and corrosion-free. Aluminium became an essential part of the rapidly developing aeronautic and car industries.

In the second half of the 19th century, hot air balloons were replaced by airships that floated thanks to the buoyant force of gas (as a rule, hydrogen or helium) enclosed in an envelope. In a number of cases, the envelope was placed in a rigid hull that was usually made of wood. As far back as 1887, the outstanding Russian scientist **Konstantin Tsiolkovsky** designed an all-metal frameless airship made of aluminium. In 1892 Tsiolkovsky described his design in detail in the work *Metal Steerable Aerostat*.

Nevertheless, the government rejected Tsiolkovsky's proposal, and the first airship with a rigid hull was built in Germany in 1900 by **Ferdinand Zeppelin**, whose name came to stand for such aircraft. The airship's hull with an area of 11,300 square meters, the casing of the gondola, and the airscrews were made of aluminium. The airship made its maiden flight on 2nd July 1900. Only ten years later, all airships would have hulls made of the strong aluminium alloy duralumin.

The bodies of the first airplanes were made of wood, plywood, and canvas and contained virtually no metal. Only in 1916, French Breguet airplanes (named after the aeronautical pioneer **Louis-Charles Bréguet**) began to incorporate sheets of aluminium and duralumin, which were used for the load-bearing surfaces of the fuselage. This increased the strength of the fuselage by an order of magnitude with only a slight increase in weight. Moreover, virtually all French planes were equipped with engines with aluminium pistons already a year later.



Ferdinand von Zeppelin (1838–1917), GERMAN AIRSHIP CONSTRUCTOR, WAS BORN IN THE SOUTH OF GERMANY IN KONSTANZ, (LAND BADEN-WÜRTTEMBERG). IN 1854 HE GRADUATED FROM THE LUDVIGSBURG MILITARY ACADEMY. HE VOLUNTEERED TO GO TO THREE WARS, FIGHTING FOR THE NORTH IN THE U.S. CIVIL WAR (1861–1865), IN AUSTRO-PRUSSIAN (1866), AND FRANCO-PRUSSIAN (1870–1871) WARS. IN 1891 HE RETIRED IN THE RANK OF GENERAL AND DEVOTED HIMSELF TO AIRSHIP CONSTRUCTION. HE HAS DEVELOPED A STIFF AIRSHIP STRUCTURE WITH A METAL CARCASS COVERED WITH FABRIC; THERE WERE GAS CYLINDERS INSIDE. THE FIRST AIRSHIP TOOK TO THE AIR ON JULY 2, 1900 (SOON TO BE DESTROYED BY A STORM). IN 1905, THE SECOND SHIP WAS BUILT, AFTER WHICH AIRSHIPS OF HIS CONSTRUCTION STARTED TO BE CALLED *Zeppelins*. SINCE 1906, MOST MACHINES WERE PURCHASED BY THE MILITARY. BY 1914 THERE WERE 25 ZEPPELINS, INCLUDING SIX THAT CARRIED PASSENGERS. MILITARY ZEPPELINS WERE USED IN WORLD WAR I (1914–1918). IN 1928 (AFTER THE CONSTRUCTOR'S DEATH), THE COUNT ZEPPELIN AIRSHIP WAS BUILT. IT MADE SEVERAL LARGE FLIGHTS AND WAS USED TO CARRY MAIL AND PASSENGERS ACROSS THE ATLANTIC. IN 1930 IT WAS DEMONSTRATED IN MOSCOW. GINDENBURG (1936) WAS THE LAST PASSENGER OF ZEPPELIN. IT MADE 63 FLIGHTS AND BURNED DOWN IN 1937.

The day bomber and spy plane Bréguet-14 was almost entirely made of aluminium except for the wooden ribs (elements forming the outer line of the wing) and fillets (an aeronautical term referring to the front of the horizontal stabilizer of the airplane near its junction with the fuselage). Bréguet-14 was the principal airplane of the French army from World War I up to the 1920s; the American Expeditionary Force had sixteen squadrons of these bombers. In 1925, aluminium made up 10% on



Louis Charles Bréguet [1880–1955] WAS BORN IN PARIS. HE GRADUATED FROM THE ÉCOLE SUPÉRIEURE D'ÉLECTRICITÉ AND THEN WORKED IN A CONSTRUCTION FIRM THAT BELONGED TO HIS FAMILY. IN 1907 HE PILOTED THE FIRST FLIGHT ON THE GYROPLANE THAT HE INVENTED (A PREDECESSOR OF THE MODERN HELICOPTER). HE WAS ONE OF THE FIRST TO BUILD A METAL AIRPLANE. HIS FIRST MODEL (1910) HAD A WING WITH ONE SPAR IN THE SHAPE OF A STEEL PIPE OF LARGE DIAMETER. THE BRÉGUET-14 DAY BOMBER AND SPY PLANE WAS MADE OF ALUMINIUM WITH THE EXCEPTION OF THE WOODEN WING RIBS AND FILLETS AND THE CANVAS SKIN. IN 1919, BRÉGUET FOUNDED THE *Compagnie des messageries aériennes*, the future *Air France*. IN 1927 HE MADE THE FIRST NONSTOP FLIGHT OVER THE SOUTH ATLANTIC AND, IN 1933, THE LONGEST TRANSATLANTIC FLIGHT UP TO THAT TIME. IN 1935 BRÉGUET RETURNED TO THE HELICOPTER ONCE AGAIN AND DESIGNED A CONSTRUCTION WHOSE BLADES EXECUTED A COMPLEX ROTATIONAL-FLAPPING MOTION. HE WORKED ON THE DEVELOPMENT OF MILITARY AVIATION DURING WORLD WAR II AND CONSTRUCTED SEVERAL TRANSPORT PLANES AFTER THE WAR.

average of the mass of airplanes; 15 years later, this figure had risen to 75% and even reached 90% in certain types of planes. On the eve of World War II, the average plane contained 2.5 tonnes of aluminium and duralumin. Today it takes 75 tonnes of aluminium to produce a Boeing 747-400.

Aluminium alloys were used to make not only airplane bodies and engine parts but also propellers, which had previously been made of wood. Fuel and oil tanks, radiators, and wheels were also made of aluminium. *Seaplanes* designed to land on water were equipped with aluminium pontoons and floats. Aluminium sheets and panels were used in the fuselage interior. Flight navigation instruments had aluminium frames.

High-altitude balloons (lighter-than-air aircraft used to study the upper layers of the atmosphere) required materials with very low densities. Aluminium offered the necessary properties. The gondola (basket) of the first high-altitude balloon (built in 1932, it rose to an altitude of 16.6 kilometers) was made of aluminium. Aluminium has been indispensable ever since for building aircraft for



Bréguet-14 Bomber

studying the Earth's atmosphere. We should mention in passing that the body of the first space satellite, launched by the USSR in 1957, was also made of aluminium.

The car industry actively experimented with aluminium from almost the very beginning. The small Dürkopp with an aluminium body was presented at the Berlin Motor Show of 1899. Five years later, French Darracq cars began to be equipped with aluminium crankshafts. In 1909, the American company Pierce-Arrow, which manufactured exclusive cars together with Aluminium Casting Co. in Buffalo, built a car with an all-aluminium body. One of these cars was subjected to a crash test. The car was accelerated with a steam locomotive and pushed off a high railroad embankment at high speed. The results were beyond all expectation: only the hood was seriously damaged, while the passenger compartment remained virtually intact! This was the result of the high flexibility of aluminium and duralumin.

Nevertheless, aluminium was not adopted for the time being in mass automobile production for the simple reason that fairly expensive aluminium alloys are required for cars. Even the manufacturer of exclusive Pierce-Arrow cars hesitated to produce cars with an aluminium body up until 1923, when a few Series 81 cars were released. In Germany, the famous aerodynamics specialist **Wunibald Kamm** built the first aluminium car in 1924 at the commission of the company South German SHW (this car is now displayed at the National Museum in Munich). The Austrian company NSU (Neckarsulm, Swabia), the predecessor of today's Audi, produced an aluminium car in 1913. Some of these models had ultra-light bodies that were manufactured

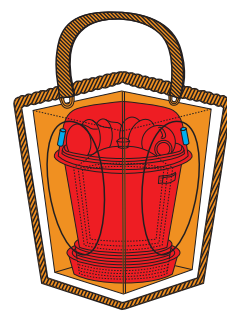
of unpainted aluminium and seemed to be made of silver from a distance, which was unusual at that time.

In the late 19th century, powdered aluminium became an essential ingredient in the production of *ammonal* – an explosive substance for artillery shells, bombs, and mines. In 1924 the Soviet scientist and inventor **Friedrich Arturovich Zander** proposed using aluminium as a fuel, as it releases a considerable amount of heat when combusted in oxygen. Fine powder of this metal is now used in high-efficiency hard fuels for rockets.

Aluminium articles began to become an indispensable part of everyday life in the mid-20th century. We have already mentioned aluminium tableware. In subsequent chapters, we will speak about the use of aluminium in interior decoration and for making furniture. The light weight of aluminium and its alloys led to their use in the production of the bodies of vacuum cleaners, refrigerators, tanks, cans, samovars, washing machines, and many more useful devices. It would be virtually impossible to list all of its applications.



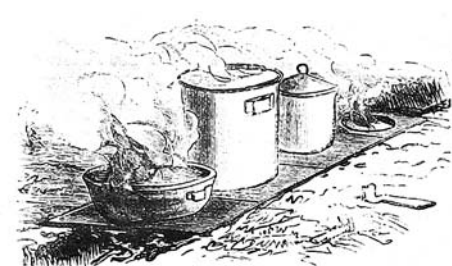
Pierce-Arrow car with an aluminium body, 1909



Aluminium field canteen, assembled and unassembled

Dr. Dymuz's aluminium field kitchen

“For many, it would have been strange and incredible to hear a few years ago that we would begin to use our old clayware once again, though in a new form, and that it would prove to be extremely useful, particularly in conditions where extremely high strength is required, as, for example, an expedition. After all, aluminium is essentially alumina that is electrolyzed and purified until it becomes a metal. Aluminium tableware can easily compete with tableware from any other



metal in strength and ruggedness, even if it is only a millimeter thick. When one also adds that aluminium does not rust and is extremely light, it becomes clear why people came up with the idea of using it to make a field kitchen. As aluminium is an excellent heat conductor, the very first trial led to wonderful results: the food cooked very quickly, which is quite important during an expedition. Another major advantage of the kitchen is that it can be carried by hand and, thanks to its convenient form, can be quickly and easily folded and transported. To this end, it comes in a wicker basket between 30 and 38 centimeters high. An iron board divided into four parts and equipped with holes is used for cooking; it is placed on the raised edges of a dug-out pit. The field kitchen consists of two pots, a pan, a meat bowl, a coffee pot, a coffee strainer, a ladle, a skimmer, a cutting knife, and three boxes with canned goods, as well as the respective number of plates, knives, and spoons with forks and other accessories (such as a cork screw). All of the articles are made of top-quality aluminium. Taken together, the items (including the iron board and basket) weigh 12 pounds for 4 people and 24 pounds for 10 people. The field kitchen will also prove useful to hunters, tourists, and travelers, especially in the steppes – in a word, everywhere where it is necessary to cook food quickly, to transport it conveniently, and to clean tableware easily.”

Niva, 1894, no. 1 ■

Chapter 4 Aluminium Production in Russia and the USSR: the Late 19th and Early 20th Centuries

The Development of Aluminium Production in Russia

Although Russian aluminium production was established later than in France, Britain and the United States, today Russia is a world leader in manufacturing the metal. Here is how it all began: the first aluminium smelter was founded in 1885 by the industrialist **A.A. Novoveisky** near the Troitsa-Sergiev monastery north of Moscow. It was a small enterprise in a one-story house. Here aluminium was obtained using the Sainte-Claire Deville chemical method, with clay as the raw material, specially mined from the Glukhov deposit in the Chernigov province.

The Russian chemist **Nikolai Nikolayevich Beketov** took up the study of cryolite. His doctoral dissertation, which he defended at Kharkov University in 1865, was devoted to a study of the mutual displacement of various metals from their salts. While studying this phenomenon, the scientist discovered that aluminium (called *gliny* in Russia at the time) could be displaced from cryolite by magnesium. Magnesium is less reactive than chloride – it does not burn when it comes in contact with air and does not react to cold water. It is far simpler and safer to work with than chloride. Therefore Beketov had every reason to believe that the reaction he discovered would find a practical application. But at that time Russia had no aluminium industry, and Beketov's discovery was not in demand. The process he invented for the magnesium reduction of cryolite was implemented only 22 years later.

In 1882 *Gorny Zhurnal* published an article entitled “A New Means for Obtaining Aluminium.” This article also addressed the process of obtaining metal aluminium from cryolite. It used an iron shaving as the reductive agent.

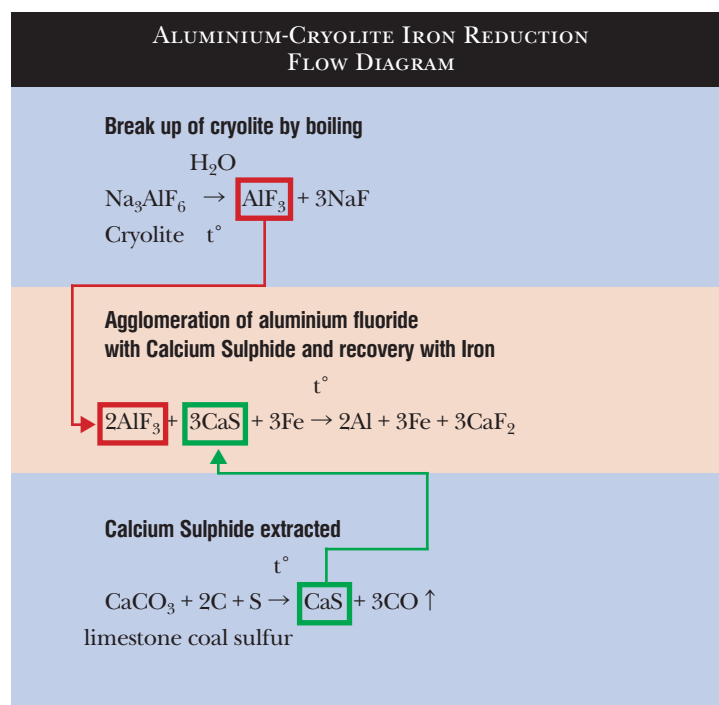
An 1883 issue of *Tekhnika* announced that Moscow researchers were examining the possibility of obtaining aluminium in a more economic way – with electrolysis.



Nikolai Nikolayevich Beketov [1827–1911] was a Russian physical chemist. He graduated from Kazan University in 1849. He worked at Kharkov University as an adjunct professor from 1855–1859, and then as a professor. In 1865 he defended his doctoral dissertation on “STUDIES OF THE PHENOMENA OF DISPLACEMENT OF CERTAIN METALS FROM OTHERS.” Starting in 1886, he worked at the Academic Chemical Laboratory in St. Petersburg and taught advanced women's courses. In 1890 he began a lecture series at Moscow University on “THE FUNDAMENTALS OF THERMOCHEMISTRY.”

Beketov discovered that at high temperatures and under pressure magnesium and zinc displace other metals from their salts. He also demonstrated that at high temperatures aluminium restores metals from their oxides; later at these experiments provided a starting point for the science of *aluminothermy*.

Beketov's enormous achievement was the development of physical chemistry as an independent discipline in science and education. In 1860 in Kharkov, the scientist read a lecture entitled “THE RELATIONSHIP OF PHYSICAL AND CHEMICAL PHENOMENA,” followed by “PHYSICAL CHEMISTRY” in 1865. In 1864, at Beketov's urging, Kharkov University established a physical chemistry department and conducted physical chemistry research.



Unfortunately, the article did not give the names of the scholars or any specific information about experiments.

The first book in Russian about “silver from clay,” titled *Aluminium, Its Properties and Technical Processing, Alloys of It with Other Metals*, was published in 1884. In 1885 the Russian metallurgist **Nikolai Zhukov** printed a brochure called *Electrometallurgy and Metal Processing with Electric Current*, and several years later, in 1893, he wrote a monographic study called “Aluminium and Its Metallurgy,” dedicated exclusively to the aluminium production. However, it was primarily about foreign experience.

1888 saw the publication of **A.I. Korenblit’s** voluminous book *Aluminium, Its Mining, Properties, Processing, Alloys and Compounds*. A technical engineer at a Moscow sugar refinery, Korenblit achieved fame as the author of a popular reference work on the preparation of various chemical reactions. His book about aluminium devoted a great deal of attention to the metal’s properties, its mechanical processing and application, as well as its alloys – aluminium bronze and ferro aluminium.

Among Russia’s scientific intelligentsia the interest in aluminium grew. Russian scholars and industrialists realized the necessity of creating their own aluminium electrolytic production. In 1914, the Russian metallurgist **N.A. Pushin** wrote in his article *On Obtaining Aluminium from Russian Minerals*: “Russia, which consumes 80,000 pounds of aluminium annually, does not produce a single gram of this metal and buys all of its alu-

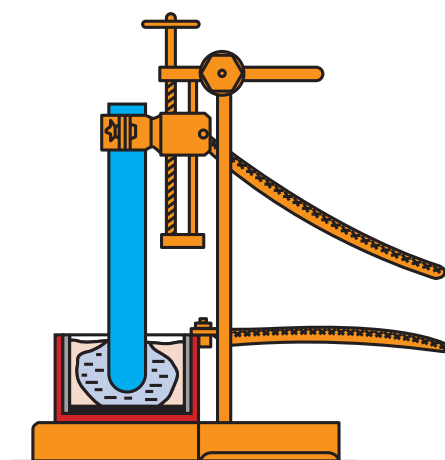


Advertisement for aluminium delivery from N. Zhukov’s book “Aluminium and its Metallurgy”, 1893

minium abroad. For a large, cultured country, which ought to aspire to satisfy all its own needs with its own means when possible, this situation can hardly be called normal, and therefore it is unsurprising that in recent years the issue of introducing aluminium production to Russia has been raised more and more insistently.”

Much effort was made to established aluminium production in Russia by the great chemist and engineer, **Pavel Pavlovich Fedotyev**, a professor who became the head of the department of technical electrochemistry at

► The laboratory electrolytic bath of N.A. Pushin



“For the small bath we used a four-cornered iron box welded with an acetylene flame, with dimensions of 22x22x14 cm. The box’s bottom and sides were lined with carbon sheets. On the bottom, above the carbon there were slabs of graphite, since the lower carbon ones were destroyed during the first fusion and polluted the electrolytic solution. All the openings were carefully rubbed with a graphite plaster.

The bath itself served as the cathode, or to more precise, its bottom did. The anode was the 6-centimeter carbon rod, held up on a stand. To melt the freshly loaded electrolytic solution, a carbon rod 1.5 cm in diameter and 6 cm long was inserted between the cylindrical anode and the bath’s bottom. When heated with a final current of 150–200 A, the carbon stick became white-hot and melted the freshly sprinkled mass surrounding it. When the electrolytic solution was melted, the stick was removed, the carbon anode was submerged in the electrolytic solution, and electrolysis began. During the melting process the solution zone was directly under the anode, taking up a space approximately 12–14 cm in diameter, so the bath’s sides always had a layer of unfused electrolytic solution...”

N. Pushin, E. Dishler, M. Maximenko, “On Obtaining Aluminium from Russian Minerals,” 1914 ■

the Petersburg Polytechnic Institute in 1904. He nurtured an entire generation of Russian and Soviet electrochemists. His studies in aluminium’s electrometallurgy were groundbreaking and led to the creation of Russia’s own aluminium industry. He also contributed to the design of the electrolytic bath.

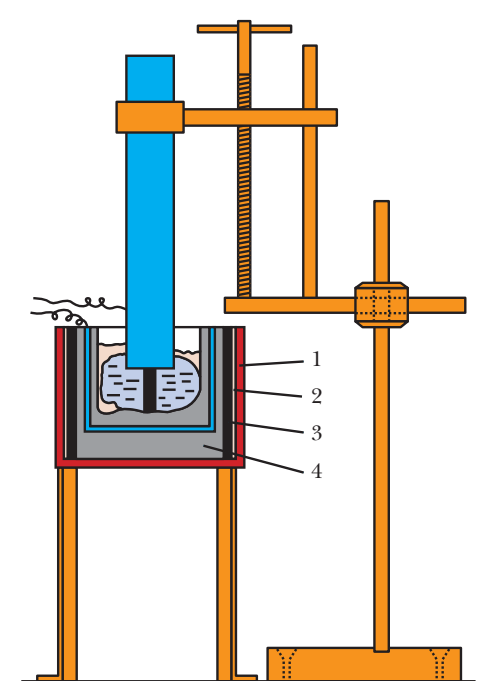
The discovery of a domestic bauxite deposit played a major role in the formation of the Russian aluminium industry. It was discovered in 1916 outside the city of Tikhvin (now in Leningrad region) by a local resident, the former sailor **P.N. Timofeyev**, who presented samples to the Chief Artillery Agency.

The Tikhvin deposit was explored in detail, in the early 1920s. The result of the expedition was not encouraging: the large stores of bauxite were useless for industrial use because of their high quartz content. It was impossible to extract alumina from them with any of the methods known at that time.



Pavel Pavlovich Fedotyev [1864–1934] WAS A GREAT RUSSIAN ELECTROCHEMIST AND METALLURGIST. HE GRADUATED FROM THE METALLURGY DEPARTMENT OF THE ST. PETERSBURG TECHNOLOGICAL INSTITUTE, WORKED AS AN ENGINEER AT THE KRASNYY VYBORZHETS SMELTER. HE LAID THE SCIENTIFIC FOUNDATION FOR MANY TECHNOLOGICAL PROCESSES IN THE FIELD OF HYDROELECTRIC METALLURGY. HE ORGANIZED EXPERIMENTAL PRODUCTION OF ALUMINIUM AND SEVERAL OTHER NONFERROUS METALS. HE DEVELOPED A THEORY ABOUT TRANSFERRING CURRENT IN AN ALUMINIUM BATH. FEDOTYEV WAS THE FIRST TO PROPOSE THE DISSOCIATION (BREAKDOWN INTO COMPONENT PARTS) OF CRYOLITE AND ALUMINA DURING FUSION TO FORMED IONS THAT TRANSFERRED THE ELECTRIC CURRENT TO ELECTRODES. HE STUDIED POTASSIUM AND LITHIUM ANALOGUES OF CRYOLITE. IN 1929 FEDOTYEV FOUNDED A DEPARTMENT OF TECHNICAL ELECTROCHEMISTRY IN THE TECHNOLOGICAL INSTITUTE AND DIRECTED IT UNTIL 1930. HE WAS ONE OF THE FOUNDERS OF RUSSIA’S ALUMINIUM INDUSTRY.

► Pavel Fedotyev’s laboratory electrolytic furnace (1912)



“The following iron furnace was built for electrolysis. An inner space of 25 cm square and 20 cm high was tiled with carbon sheets and next to them, thin tiles of graphite. A thick carbon sheet 7 cm thick was laid on the bottom, with a graphite sheet inserted in it. Thus, the electrolytic bath was a graphite melting pot 15 cm square and 12 cm deep. A carbon anode 7 cm in diameter was affixed to a stand with a screw for easy regulation. The cathode cable was connected directly to the clamp on the iron furnace. The side surface of the furnace was lined with thick asbestos.

The current for electrolysis was provided by a generator with an independent power source, connected by cables directly to electrodes without intermediate resistance... Natural cryolite powder, pure sodium fluoride and aluminium fluoride and industrial alumina served as the raw materials for electrolysis. Aluminium fluoride (hydrate) was heated in preparation... The materials were carefully mixed in the appropriate proportions, and that mixture was put in the furnace for fusion... The fusion was performed with resistance carbon pressed between the electrodes, 6.5 cm long and 1 cm in diameter... When the quantity of fused electrolyte seemed sufficient, the resistance carbon was removed and electrolysis began.”

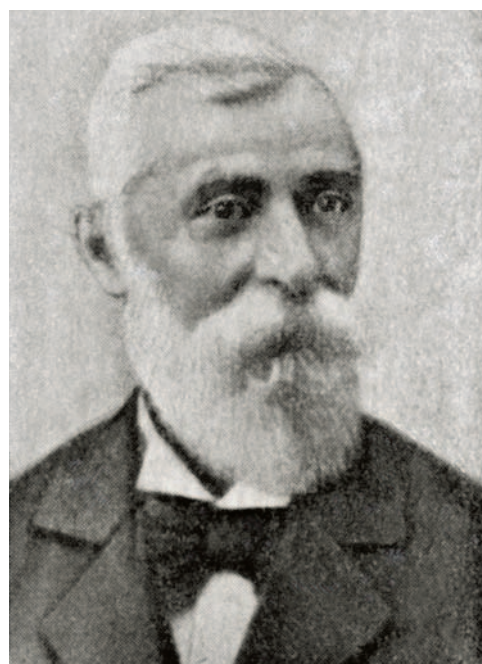
P.P. Fedotyev, V.P. Ilyinsky, Eksperimentalnoye issledovanie po elektrometallurgii aluminia ■



Advertisement for aluminium delivery from N. Zhukov’s book “Aluminium and its Metallurgy”, 1893

The elimination of quartz impurities from alumina was the main technological problem that had to be solved when reworking bauxite into raw material for the aluminium industry. The French chemist and metal expert **Henri Louis le Chatelier** (1850–1936), the first to propose a method for processing bauxite, was unable to come up with a solution.

The Austrian chemist **Karl Joseph Bayer** developed another method. He sintered bauxite with a corrosive alkali, and leached the resulting substance with water (leaching is the use of a solvent to extract individual components of a hard material). Observing the solu-



Karl Joseph Bayer [1847–1904] was an Austrian chemical engineer. After an unsuccessful attempt to become an architect, he found work in the laboratory of Fresenius, then worked with Bunsen at Heidelberg University, where he defended his doctoral dissertation in 1871. In the early 1880s he moved to Russia, where he worked at the Tentelevsky factory in Petersburg, in charge of producing aluminium sulfate to be used as a mordant for applying red dye to cloth. He was famed for his discovery of the spontaneous decomposition of sodium aluminate solutions in the presence of a mordant of freshly settled aluminium hydroxide (his patent of 1889). In the second patent (1892) he formulated the potential for dissolving aluminium oxide contained in bauxites, when processing them with a solution of corrosive alkali under pressure in an autoclave. Bayer actively implemented his inventions into production during trips to various countries of the world. In 1894 the scientist returned to Austria, where he finally settled in Ruetzdorf (Lower Styria). Here he also studied local bauxite, hoping to manufacture alumina from it. However, he was unable to do it in time.

important discovery. The subject of the scientist's study was the alkali solutions that remained after the isolation of alumina solids. In one of the experiments, the scientists added bauxite, and then heated it in a closed vessel. He discovered that the bauxite dissolved, but not entirely. Studying the contents of the insoluble remnants, Bayer could hardly find any aluminium in it. In fact, when treated with the alkali solution, all the aluminium in the bauxite went to the solution! Thus he discovered a highly technological, industry-friendly method. "The apparatus required for this purpose needs an autoclave made from a half-inch sheet of iron and equipped with the necessary armature, a safety valve, a mixing device, a manometer, a conduit and hatches for adding bauxite. Even for significant productivity, this apparatus may have relatively small dimensions," reads Bayer's second patent.



Krasny Khimik Factory
(formerly known as
Tentelevsky Factory), 1932

tions resulting from leaching, he noted that when he mixed and primed them, they emitted aluminium hydroxide, and in a pure form, since the compound of iron and quartz still remained in the solution.

We should note that the place of this discovery was St. Petersburg, where Bayer worked in the 1880s at the Tentelevsky Factory. After patenting his invention (patent of Germany 43,947, 1889), the scientist received the privilege to produce alumina in this way, a right that was valid from 1891 to 1901.

Bayer also designed a machine that could break down the original solution without interruption. In the early 1890s Bayer went to work at the Bondyuzhsky Chemical Factory, located near Elabuga. There he made another

In the late 19th century, Bayer's method, invented for the needs of Russian textile production, was taken up at French, British and American refineries to extract alumina from bauxite. The first major alumina refinery that worked with the Bayer method was built in France near Marseilles in 1893. Its first director was the inventor himself.

In 1895 the Russian chemical engineer **D.A. Penyakov** patented a sulfate method of extracting alumina from bauxite. The novelty of the method proposed by the Russian engineer was primarily that it substituted Bayer's alkali or soda with cheaper raw materials – sodium sulfate. Penyakov's sulfate method was a successful competitor for Bayer's method at several enterprises. Two alumina



Laying explosives
in demolition shafts
at Tikhvinsky bauxite
mines, 1936

refineries were set up in France and Belgium with Penyakov's method. The Belgian refinery was destroyed by German forces during World War I.

Some scientists noted the problem of extracting alumina from low-quality raw aluminium. In the 1880s the German scientists **G. Müller** and **A. Tedesco** patented a method of extracting alumina from aluminium silicate, but it did not find practical usage. In 1916 Penyakov designed a method used in industry. He suggested a technique of firing a clay and lime mixture, dissolving the alumina in a hot soda solution.

To avoid confusion and to distinguish it from the Penyakov method, it is nominally called the *calcium method*. During World War I it was used in Germany. The calcium method is known to have been employed in French at the Gardanne refinery, near Marseilles, from 1911 to 1925.

Frauds and Speculators in the History of Aluminium

"Without its own aluminium industry, Russia spent monstrous, foolish sums on purchasing aluminium abroad.

... Everyone tried to make money on trade deals, from the Entente Allies, ending with Russia's own industrial dealmakers. In this perspective, the mystery of *K. Shpan and Sons*, a trade company, is quite symptomatic. With the blessing of the defense ministry, the head of the ministry (the elder brother, Boris Shpan) set off to deliver a large quantity of foreign aluminium to Russia's artillery. Swiftly sent to Sweden, the company's trade representative hid in his shoe fictive documents asserting that a certain German company was selling aluminium that rightfully belonged to the Russian company through neutral middle men. But at an enormous price, of course – almost 8,000 rubles per tonne. In fact, the full amount of the indicated product was stored at K. Shpan and Sons' warehouses in Petrograd, and the company needed the false trade operation to fetch a fabulous sum for the strategic metal. A military counterespionage operation of the Northern front, which followed each step of the false salesman, apprehended him on his return trip. The company was liquidated, its owners exiled to Siberia, and the whole dirty story was highly publicized.

The major public scandal of the aluminium machinations forced the tsarist government to announce a nationwide confiscation of aluminium in all its forms: in slabs, in products, in powder, even in dirty shavings. After that in 1916, an Agency for the Construction of Aluminium Smelters headed by A.P. Kurdyumov (a metallurgy teacher at the Artillery Academy) under the auspices of the Chief Artillery Agency of the Russian Empire. However, there were nine more months of bureaucratic red tape to draw up the necessary documents for all the decisive instances. Only by the end of September were the assignments released (in a reduced form)...

At the same time the clever government officials were able to sign an aluminium supply contract with Norwegian Nitrides on January 27, 1916. The new contract was drawn up to virtually obligate Russian to pay an additional 225 million to 300 million rubles in gold for aluminium deliveries (in addition to already exorbitantly high prices). Dozens of aluminium smelters could deliver for the same sum.

To the merit of Russian scientists and the most important aluminium engineers, despite the bloody and meaningless civil unrest that led to mass emigration, despite the general collapse of domestic production that threw the country back to 19th-century levels, none of them abandoned their homelands. They devotedly continued their work in the new economic and political conditions of Soviet Russia. We are in debt to these people for the powerful aluminium industry that our country has today."

Nikolai Golden. Rossiyskiy aluminii. Istoki ■

The impossibility of processing the Tikhvin bauxite seemed to bury plans to develop an aluminium industry in the USSR. However, researchers at a small but experienced refinery at the Leningrad State Institute of Applied Chemistry (GIPKh), headed by Professor **Alexander Yakovkin**, designed a method for obtaining alumina from low-quality bauxite.

Note that in 1931, Tikhvin was the only deposit in Russia that yielded bauxite in industrial quantities and the new method came to be called the GIPKh method. Subsequently it was used at Russia's first alumina refinery in Volkhov, then in Tikhvin as well.

Meanwhile, a group of scientists at the Leningrad Mining Institute led by Professor **Alexander Nazarovich Kuznetsov** and engineer **Evgeny Ivanovich Zhukovsky** designed an alternative method for processing low-quality bauxite. The bases of this method (electrothermal fusion of bauxite with barite and carbon) were formulated by Kuznetsov and Zhukovsky in 1915.

However, the patent "Method for obtaining pure alumina and its salts from alumina silicate, simple clay, etc." was obtained only 10 years later (Soviet patent No. 280, May 30, 1925). Historic events – world war, revolution, civil war – did not encourage the development of science and industry. The first experiments were made at a laboratory of the Mining Institute, and later at the half-industrial equipment of Tsaritsyno, near Moscow, by an experience station of the Institute of Applied Mineralogy. There the Kuznetsov-Zhukovsky method was perfected especially for the future Dnepr Aluminium Smelter in Zaporozhye, where the cheap electricity from the Dnepr Hydroelectric Station (Dneproges) made its application economically feasible. Dneproges was one of the symbols of the power of the communist system, victoriously presented to all the world. Alongside it stood aluminium smelters of the industrialization era, which also boasted the most advanced technologies.

The First Russian Aluminium

Russia's first experiments in obtaining aluminium by electrolysis were conducted by Fedotyev, the professor of the Petersburg Polytechnic (then Leningrad Industrial) Institute, in the early 20th century. But the high energy costs were an insurmountable obstacle to realizing his scientific and technological discoveries at the time.

In 1920 the state adopted the plan of GOELRO (State Commission for the Electrification of Russia), the first long-term government program to develop the economy, in which electrification was stated as the primary foundation, the locomotive for the economy. Thanks to this plan, the country got cheap electric energy. This was of principal importance for the development of the aluminium industry, since its basic manufacturing processes involved major expenditures of electricity – a third of aluminium's production cost is spent on electricity.

In November 1920, issues of aluminium production were discussed at the 1st All-Russia Congress of Metallurgists in Moscow. At the 2nd All-Russia Congress in 1924, special sessions devoted to aluminium production were held at the Krasny Vyborzhets Smelter in



View of the Krasny Vyborzhets Smelter, 1930-1931

Leningrad. At national conferences on nonferrous metals, held in 1925 and 1927, the development of the aluminium industry was a constant topic of discussion, for which the country had the necessary raw materials base, and the necessary energy resources. As a result, the conference delegates adopted a decision to arrange

experimental production and additional exploration of bauxite deposits. As the country developed at rapid rates, it needed its own highly developed aluminium industry.

However, to realize full-cycle aluminium production, the country needed one more important component – cryolite. In 1923 this problem was addressed by employees of the Institute of Applied Mineralogy, which was directed by the Soviet chemist and metallurgist, **Ergard Viktorovich Britske** (1877-1953). They were able to isolate cryolite

Mikhail Ivanovich Kalinin among the workers and administrators of the Krasny Vyborzhets Smelter, 1924



from fluorite. To analyze the effectiveness of this method, in 1927 the Tsaritsyno Experimental Station launched a new tool. After some time, industrial production of cryolite was launched at the Polevskoy Refinery in the Urals.

1927 was a banner year in the history of Russian aluminium. In the laboratory of the Leningrad Polytechnic Institute, Fedotyev became the first to obtain aluminium through electrolysis of alumina extracted from Tikhvin bauxite. The scientist used a small, 200 A electrolytic bath, the design of which is still used today in laboratory practice.

Fedotyev directed the first industrial experiments to obtain aluminium metal by electrolysis in Russia. This occurred from March 25 to 2nd July 1929 at Krasny Vyborzhets.

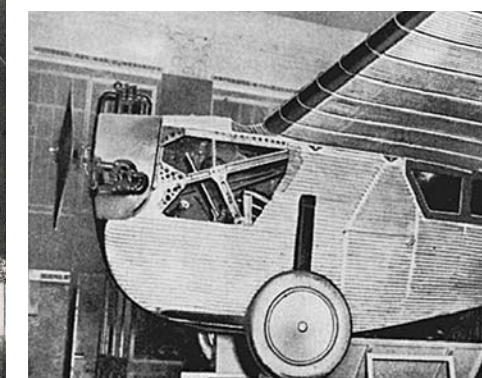
Six baths were mounted for the experiments, and they were designed to handle a 2,000 A current. The baths were lined inside with fire-resistant bricks, which served as a warmth insulator, and then with carbon tiles.

I. N. Friedlander. Memoirs about making aviation, space and atomic equipment from aluminium alloys, 2005

"In October 1922 TsAGI [Central Aero-Hydrodynamic Institute] established a commission for all-metal airplane construction. It included A.N. Tupolev (chairman), I.I. Sidorin (deputy chairman), G.A. Ozerov and E.I. Pogossky (commission members).

In Tsarist Russia wood was used as the primary construction material for aviation. Defenders of traditional airplane construction methods said, "Do you want to doom our country? Do you want to leave it without an air fleet? There is no metal in Russia, but there is an ocean of lumber!"

A.N. Tupolev replied to these sharp attacks just as sharply, "Yes, we would like to build airplanes from a nonexistent material, because the all-metal monoplane is the plane of the future. If there is no aluminium, that means we must start to manufacture it.



ANT-2, the first fully metal Soviet airplane

If there is no duralumin, then we must make it." One of the most vocal advocates of all-metal plane construction was I.I. Sidorin. With the active participation of professor Sidorin and the smelter's chief metallurgist, V.A. Butalov, the Kolchugino Metal Works mastered production of Soviet duralumin, which came to be called kolchugaluminium. The construction of ANT-2, the first all-metal airplane made from kolchugaluminium, was carried out on Ulitsa Radio, where the N.E. Zhukovsky Museum now stands. On the 1st of May, 1924, ANT-2 led the air parade." ■

Copper pipes were tucked into the anodes to supply the current. Six anodes were lowered into each bath. Two or three baths worked at the refinery simultaneously. At a current force of 1800 A to 2000 A each of them yielded from 10 to 11 kilograms of aluminium daily.

It is important to note that the apparatus and all the substances needed for electrolysis did not come from abroad, but were produced in the country. Alumina was delivered to Krasny Vyborzhets from an experimental

smelter of the State Institute of Applied Chemistry, located in Leningrad, where it was extracted from Tikhvin bauxite. Cryolite was brought from the Tsaritsyno Experimental Station, and carbon electrodes were prepared at the Kudinovskiy Factory.

The first Soviet aluminium was obtained on 27th March 1929 in a quantity of eight kilograms. Fedotyeu, who led this production, would later write: "This moment can be considered the appearance of aluminium production in the USSR using Volkhov energy, entirely from materials of our own production." The smelter used energy from the Volkhov Hydroelectric Dam, the first one built according to the GOELRO plan. In its first days, the process met with substantial difficulties. Moisture and impurities of volatile fluoride compounds were found in the cryolite, and when fused it emitted choking gases, which even in small volumes created serious problems. The low quality of the cryolite affected the quality of the metal: aluminium contained a significant quantity of silicon, and the first baths also had iron impurities. At first the smelter produced third-rate metal, then second-rate that was 98% aluminium. Krasny Vyborzhets was unable to meet the standards of first-rate aluminium (99–99.5% Al), but the resulting metal was malleable enough to roll and stamp.

The first Soviet aluminium was used to produce household objects – kitchen flatware and table settings. They were manufactured at the smelter. These objects are easy to be distinguished from later ones by their considerable thickness; they were more massive than contemporary counterparts.

Thus began the industrial production of Soviet aluminium. The Soviet press wrote that the first museum-quality ingot of aluminium should be preserved as a monument to one of the greatest achievements of Soviet technology.

The capacity of Krasny Vyborzhets was not high. Realizing the acute need to develop the aluminium industry, the highest organs of state power – the Central Execu-



Spoons made at the Krasniy Vyborzhets Smelter

tive Committee and the Soviet of People's Commissars of the USSR (TsIK and SNK SSSR) on 12th June 1929, ordered that another industrial plant be organized in Leningrad – the Experimental Aluminium Smelter (OAZ). In September of the same year a former weapons smelter in the Vyborgskaya Storona area of Leningrad was reequipped for this purpose.

The enormous initiative demonstrated by the comrades from Leningrad in developing methods of aluminium production made it possible for them to produce a batch of aluminium in laboratory and minor industrial scales. In connection with this we propose now, in 1929, to begin building an experimental smelter in Leningrad to manufacture aluminium so that when the problem is finally resolved in semi-factory scales, we may resolve the issue of the construction period for the Leningrad Region Smelter.

From a speech by V.V. Kuibyshev, chairman of the Supreme Soviet of the People's Economy (VSNKh), about the first five-year plan at the 5th National Congress of Soviets



Aluminium spoons and forks, 1930s



► Pavel Fedotyeu.
Experiments to obtain aluminium
at the Krasny Vyborzhets Smelter, 1933

"In issues of organizing our own production of aluminium we had to work not only with economic principles. Hopes for foreign technical assistance seemed rather problematic when taking into account the organization of aluminium industry in Europe and America... In late October, 1928, an initiative of the chairman of LOSNKh (Leningrad Regional Soviet of the People's Economy) planned major experiments to obtain aluminium metal in Leningrad at Krasny Vyborzhets... The presence of quite a large quantity of iron in the first batches can be explained by the immoderate use of iron ingots to break through the crusts and mix the electrolyte. The first ingots also contained copper. Its presence can be explained by the heating of cryolite in a furnace used for smelting copper; in some cases they applied graphite melting pots formerly used for copper alloys. The copper content was gradually decreased, but it was always found. Furthermore, sometimes the anode clamps were ruined by overheating. Some clamps fell in the bath and added copper and zinc to the aluminium. The first batches of aluminium contained 5% Si and more than 3% Fe. The content of these elements over the course of work significantly decreased, but the purest metal of the final baths contained no more than 97.5% to 98.0% aluminium. The lowest extreme content of silicon possible given the quality of the materials used was not achieved." ■

this odd competition the victory went to the French electrolysis bath.

The responsibility of the Experimental Smelter was not only industrial-scale aluminium production, but also training of qualified aluminium workers and engineers. The smelter worked with domestically mined cryolite, which as before was delivered from the Tsaritsyno Experimental Station. As the reader will remember, it was here that scientists designed an original way of obtaining cryolite to equip Krasny Vyborzhets.

The smelter yielded its first product on 6th June 1930. Part of the smelted aluminium was rolled, which resulted in a 0.05 mm-thick foil with a shining surface and good mechanical properties that could compete with foreign samples. To this day, this foil is used in construction for heat insulation.

In 1930 OAZ yielded a total of 90 tonnes of metal. At that time it was a good volume of production. (For comparison, today this figure ranges from 300,000 to 800,000 tonnes at various smelters.) Production was directed by

On 12th October 1929, the Supreme Soviet of the People's Economy (VSNKh) established a special agency, "Aluminstroy", to manage the construction of aluminium smelters. Zhukovsky, the aluminium metallurgy specialist, was appointed the chief engineer.

Production at OAZ required developing a new, modern electrolysis furnace. The smelter, built under the direction of Fedotyeu in just six months, was equipped with 20 electrolysis baths of various structures, adjusted for a 6,000 A current (remember that at Krasny Vyborzhets this figure was about 2,000 A). Some baths were created according to models of foreign companies, while others were designed by Soviet engineers. The best of them would become the prototypical apparatus for Russian industrial electrolysis. In

the talented young engineers **Alexander Zheleznov** and **Pavel Elizarov**. Specialists from France and Germany were invited to organize aluminium production.

After the electrolysis baths of OAZ yielded their first aluminium in the summer of 1920, construction was started on the Volkhov Aluminium Smelter (1930), the working plan of which included alumina refinery and reduction area. Alumina production was intended to process up to 12.5 tonnes of low-quality Tikhvin bauxite per year using the GIPKh method.

Of course, this rapid development of the aluminium industry required new sources of raw materials. In the early 1930s exploration was launched for more Tikhvin bauxite deposits. This resulted in the construction of a new Tikhvin Alumina Refinery, later called the Bauxitogorsk Refinery. At this refinery, which started working in 1938, bauxite was processed using an improved GIPKh method, called the *wet method*. It involved a preliminary baking of a moistened mixture of bauxite with lime and soda, a technique borrowed from cement production, which ensured a more homogenous dry mix and simplified the production process. (“Dry mix” is a mixture of raw materials in a certain proportion, later processed in metallurgical, chemical and other aggregates.) Mills cut their volume and expenditures of electricity and water, and the milling process was streamlined.

On 14th May 1932, two years after intense labor of a 9,000-strong construction team, the Volkhov Aluminium Smelter obtained the first kilograms of Soviet industrial aluminium. This event was one of the greatest achievements of the first five-year plan.

The second aluminium smelter built by command of the SNK SSSR, was the Dnepr Aluminium Smelter, supplied by electricity from Dneproges. The smelter complex included an alumina refinery with a capacity for processing 30,000 tonnes of bauxite, a reduction area able to yield 15,000 tonnes of metal a year, and an electrode factory intended to produce carbon anodes and tiles, necessary for fettling the electrolytic baths. All these facilities were located adjacent to one another.

The smelter’s construction began with a ceremonious event. On 3rd September 1930 the foundation of the first workshop was laid with three red cement blocks with five-pointed stars and an inscription: “1930, IX, Aluminkombinat.”

Memoirs by witnesses of the construction convey the special romance of the first five-year plans. They tell of



Entrance to the territory of the Kirov Aluminium Smelter in Volkhov, 1932

► **Arkady Gaidar. Dalnye strany (Distant Lands). 1931**

“Ivan Mikhailovich did not see Pet’ka either. Vas’ka became upset and sat down next to him. ‘What is that you are reading about, Ivan Mikhailovich?’ he asked, peering over Ivan Mikhailovich’s shoulder. ‘You are reading, but smiling. Is it some sort of story, or what?’ ‘About our places. Here, brother Vaska, it says that there are plans to build a smelter along our junction. An enormous smelter. Aluminium – that’s a kind of metal – will be mined from clay. It says here that we’ve got places rich in aluminium. And we always thought it was just clay. Now that’s clay for you.’ And just as Vas’ka heard this, he instantly leapt up and ran to Pet’ka to be the first to share with him this amazing news. But remembering that Pet’ka had disappeared somewhere, he sat down again, and asked Ivan Mikhailovich about what they would build, in what place and if the smelter’s smokestacks would be tall. Where they would build it, even Ivan Mikhailovich did not yet know, but as for the pipes he explained that there would not be any, because the smelter would work on electricity. For that they also wanted to build a dam across Tikhaya River. They would put in turbines that would turn from water pressure and spin generators, and those generators would send electric current down the wires.” ■

the great enthusiasm of construction workers employed at the industrial sites, about the spirit of collectivism that helped realize grandiose projects. In just a few years an entire city appeared on the bare steppe of Zaporozhye. Engineers arrived in Ukraine from Leningrad and from OAZ, headed by the reputable Zheleznov and Elizarov. They were assisted by specialists of the venerable French *Compagnie d’Alais et de la Camargue*, who had been contracted to work in the Soviet

Union. The reader will probably remember that this company owned the first smelters to produce aluminium with the Sainte-Claire Deville method at the dawn of aluminium production.

All the smelting furnaces of the giant smelter released products separately. The reduction area began working first. That happened 10th June 1933. By 6:00 a.m. on 12th June 40 baths were already working, and 40 more were launched in July and August of 1933. In the first month of work, each bath yielded 112 kilograms of aluminium per day. In August this figure rose to 120 kilograms, and to 140 kilograms in October.

At first the smelter operated on imported materials. But on 20th May 1934 it yielded the first 230 kilograms of aluminium from the smelter’s own materials, when the alumina refinery produced its first yield. Electrode production had been established even earlier.

Now only bauxite and cryolite were needed to smelt aluminium at the Dnepr Smelter; these were produced in the Urals, 50 kilometers from Sverdlovsk (now Ekaterinburg), at the Polevskoy Chemical Factory, and later at the specially built Polevskoy Cryolite Refinery.

Early in 1934 the smelter faced a difficult task – to master production of *wire bars*, or billets to be stretched into wire. They must meet strict demands: the metal should be of the highest sort, and the surface of the ingot should be ideally smooth. Aluminium smelted at the Dnepr smelter suited the quality needed for these objectives. But the first ingots were “coniferous,” or had a wrinkly surface. This problem was resolved using a double smelting process. Starting in 1934 the Dnepr Aluminium Smelter supplied the Soviet Union with aluminium wire.

In 1990, the Dnepr Smelter became the Zaporozhsky Aluminium Smelter (ZAIK).

In 1931 Aluminstroy became Soyuzaluminy, and later Glavaluminy. In the same year a specialized Scientific Research Institute of the Aluminium Industry was established in Leningrad; it later became the All-Union Aluminium Magnesium Institute (VAMI), renamed the All-Russia Aluminium-Magnesium Institution in 1993.

As the reader can see, the state devoted a great deal of attention to the growth of the aluminium industry. To expand the geography of production, bauxite exploration was organized around the country.

Finding valuable raw materials is never easy, but this time success was aided by some good luck. The geologist **Nikolai Karzhavin** studied a mineralogy collection



Stone-laying ceremony at the Dnepr Aluminium Smelter, 1930

► **Memoirs of an electrician of the Dnepr Aluminium Smelter, Mikhail Kol’chak**

“In 1930 I worked on the dam as a stonecutter. After work a man came to our barracks and invited us to a demonstration, for the stone-laying ceremony of an aluminium smelter. I was interested and plus I was drawn to working at a smelter. I went to the steppe where the aluminium smelter would be. Autumn was approaching so people all around were gathering corn. Many people came... The orator crawled right up on a mound of earth dug out of the foundation pit and started talking about what a powerful and beautiful aluminium smelter there would be and how strongly important it is for the Soviet Union. Leaving the demonstration I got the idea to go to that smelter and get myself a qualification. In 1931 I went to work at the aluminium smelter and signed up to be a digger at the personnel department. Construction was already boiling like water in a pot. All around where the mills would be up went scaffolding, foundation pits were dug. And so I started digging pits...”
From the archives of the Dnepr Aluminium Smelter ■

View of the reduction area of the Dnepr Smelter, 1935



in a laboratory made by the great crystallographer **Evgraf Fedorov** at the Turin copper deposits of the Northern Urals. Karzhavin discovered that the rock called ferrous sandstone in fact contained more than 50% aluminium oxide; in other words, it was bauxite that greatly surpassed the Tikhvin sort in quality.

In 1931 the scientist organized an expedition to explore bauxite deposits in the Urals. Samples of the minerals in Fedorov's collection were discovered by him in the taiga on the Vagran River in the region of the city of Serov. The river banks, where the rock stuck above the surface, were characterized by a red-brown color, and therefore the deposit was called "Little Red Riding Hood." It was the first in the Northern Urals bauxite pool, where in 1931 and 1932 geologists discovered more promising deposits of raw materials for the aluminium industry. The Northern Urals Bauxite Mine (SUBR) was established on 2nd April 1934, on the base of the "Red Riding Hood" deposit. In 1935–1936, the geologist **A.K. Belousov** discovered bauxite deposits in the Southern Urals, in modern-day Bashkiria, which determined the construction of a new, powerful aluminium smelter in the Urals.

The first line of the Urals Smelter was launched in 1939, near the city of Kamensk-Uralsky on the Iset River. The fuel base of the enterprise was stone carbon, which was also mined in the Urals. The quality of local bauxite was in no way inferior to that of French sorts, which meant they could be processed by the Bayer method, which was perfected in the first years of the smelter's operation. Engineers were able to increase the percent of alumina in aluminate solutions and extract the maximum amount of alumina. Specialists simultaneously sought new sources of alumina. The scientists set their sights on cinder produced in blast furnaces. Research showed that some of them contain up to 24% alumina. Subsequently the Dnepr Smelter processed them to produce alumina.

The demand for aluminium was high. As Soviet industry developed at rapid rates, the products of the three smelters – in Volkhov, Dnepr and the Urals – was not enough. The metal still had to be imported. In 1940 the Stupin Aluminium Smelter began to operate; at the moment it was the biggest in the world. In May 1941 its first line entered full power. On 11th October 1940 a decision was made to build the Bogoslov Aluminium Smelter near the Turya River and a settlement. Today that smelter is Russia's largest producer of alumina and



Worker at the Dnepr Aluminium Smelter collects molten aluminium, 1934



Pouring aluminium into molds at the Dnepr Aluminium Smelter, 1937



Finished products at the Dnepr Aluminium Smelter, 1937



View of a reduction area at the Bogoslov Aluminium Smelter, 1947

one of the leaders of Russia's aluminium industry. At the start of spring 1941 a plan to create the Kamensk-Uralsky smelter was confirmed.

Fascist Germany's invasion of the USSR halted operations at the Volkhov and Dnepr aluminium smelters, as well as alumina production in Tikhvin. The State Defense Committee adopted a measure to evacuate the most valuable equipment of the Volkhov and Dnepr aluminium smelters to the Urals. Some facilities of the Stupin Smelter were transferred to the Kamensk-Uralsky Smelter, which was still under construction. In August 1941, the Ural Aluminium Smelter was the only enterprise in the Soviet Union that released alumina, as well

as aluminium and its alloys, which were important for defense needs. In the war years the Ural Aluminium Smelter produced more than 224,000 tonnes of aluminium and almost 500,000 tonnes of alumina.

A complex plan was devised to maintain production in war-time conditions: the Bogoslov Aluminium Smelter manufactured aluminium hydroxide, which was brought to the Ural Smelter and smelted there, and the resulting alumina was sent to the Novokuznetsk (then Stalinsk) Smelter, which started operations on January 7, 1943.

During the war, Soviet industry lost more than half of its capacity to produce alumina and aluminium, and



Urals Aluminium Smelter, 1942

the production of silumin, an alloy that contains silicon, virtually stopped. This created major hardships for the weapons industry – silumin was extremely important in the production of aviation, tank and automobile motors. "Give me 30,000 tons of aluminium, and I will win the war," **Stalin** wrote to **Roosevelt** in 1941. Despite the dire economic position of the country, all possible funds were found to develop aluminium metallurgy. On 17th June 1943 aluminium hydroxide was obtained at the alumina mill of the Bogoslov Smelter, which was founded in 1940 and built during the war. And on 9th May 1945 at 4:00 a.m., a few hours before news about victory arrived, the smelter released its first aluminium.

Russian Aluminium Industry and the Progress of Aviation on the Eve of the War

The main consumer of aluminium in the 1930s was aviation. Despite the existence of an aluminium industry, there was not enough metal to satisfy its needs. Many parts of airplanes were still made from wood, but it could not replace aluminium. A significant amount of the metal was purchased abroad. In 1930–1933 an average of 10,000 tonnes were imported (the peak came in 1931, when more than 20,000 tonnes were purchased). In 1935–1936 there was a decline caused by the opening of the Dnepr Aluminium Smelter. But soon the import volumes began to climb again – the country needed more and more of the "winged metal," as aluminium came to be called. Only in the late 1930s did the share of imports gradually fall. "A sector that involves as many other sectors as aviation construction is rare. Without exaggeration one could say that the whole country is working for aviation, and it uses only the best. We took everything or almost everything. For example, we took almost all the aluminium." These are the words of Alexey Ivanovich Shakhurin, the people's commissar of the USSR aviation industry in the pre-war years, who correctly assessed the situation. Even to support the volume of airplane construction and maintain the number of airplanes manufactured, they had to increase aluminium production at least threefold, which meant bringing it up to 145,000 to 150,000 tonnes of aluminium per year. The growth plan for the people's economy of the USSR for 1941 stipulated "smelting... 100,000 tonnes of aluminium and an increase of the aluminium industry's capacity by no less than 175,000 tonnes of aluminium, counting the smelting of 1942." For comparison, Germany in 1941 produced 324,000 tonnes of aluminium.

The main exporters of aluminium to the USSR were France and Norway. However, since 1939, at the start of World War II, the supply stopped coming from France. Its place was taken by the United States, and then Norway, which increased its export volumes. But soon they, too, sharply cut deliveries.

The Soviet Union sought new aluminium suppliers. On 28th November 1940, **Vyacheslav Mikhailovich Molotov**, the people's commissar of foreign affairs, told the German ambassador to the USSR **Werner von der Schulenburg** about the Soviet leadership's intention to purchase 30,000 tonnes of German aluminium. Soon the corresponding contract was signed. It was a serious miscalculation. Now any interruption in deliveries of the metal threatened the import-dependent Soviet aviation industry with a stand-still. ■

Chapter 5 | The Modern Aluminium Smelter

Production of Alumina and Cryolite

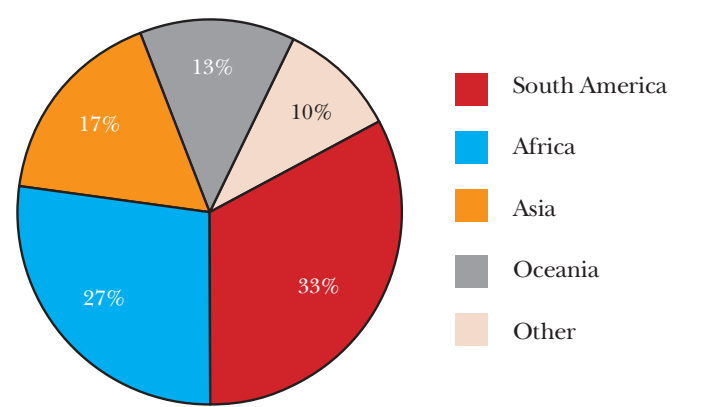
Our history of aluminium draws closer to modernity. From the 19th century laboratory experiments that began to develop our knowledge of how to produce aluminium, and the start of its industrial production we move on to the present-day aluminium industry, where the global annual production volume reaches several million metric tons. In this chapter, we will explore sections of the various plants that make up the single complex of the aluminium industry, learn about the latest technologies, and follow all the process stages, from raw material to the end product.

Modern aluminium production consists of three stages: mining the ore (primarily bauxite), processing it into alumina, and finally, obtaining the primary metal. The aluminium industry has developed in many countries, but few have plants handling all three stages of production.

The world's total confirmed resources of bauxite – the raw material for the aluminium industry – are estimated at 18.6 billion metric tons, which at the current mining rate can satisfy demand for more than a century. About 90% of the world's bauxite stockpiles are concentrated in the earth's tropical and subtropical zones. 73% of them are in Guinea, Brazil, Jamaica, Australia and India. The most bauxite is in Guinea and is of a high quality, which means it contains a minimal amount of quartz impurities.

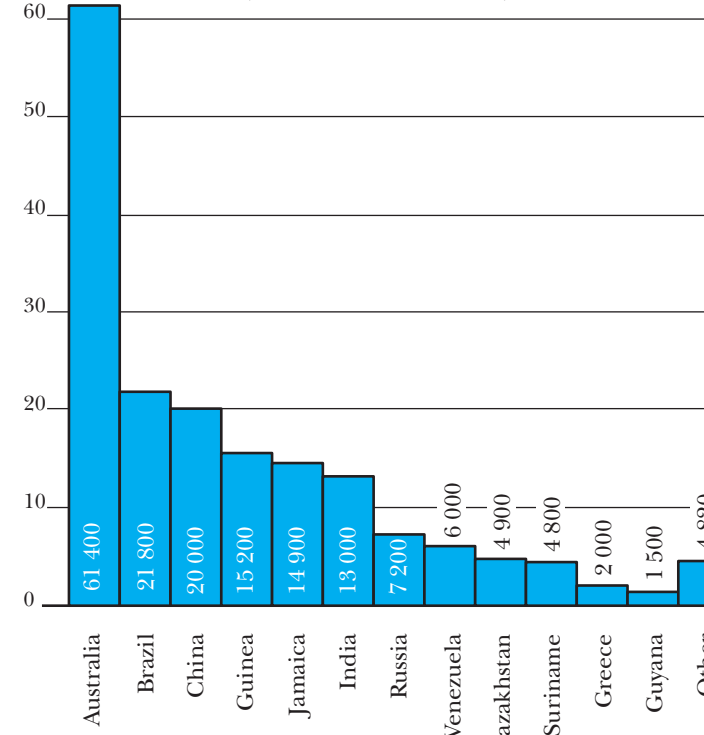
The rate of mining in these countries is affected by several factors such as the geographical location of deposits, their depth, the sophistication of the country's infrastructure and the domestic economic and political situation. In view of all of these considerations, the most favorable situation is in Australia, which is the world's

DISTRIBUTION OF THE WORLD'S BAUXITE DEPOSITS IN 2006



Source: International Aluminium Institute (IAI)

WORLD VOLUMES OF BAUXITE MINING IN 2006 (IN THOUSANDS OF TONS)



Source: International Aluminium Institute (IAI)



Mining bauxite at deposits in Guinea (top, left)

Wagons transporting bauxite (top, right)

Guinean bauxite before being sent for processing



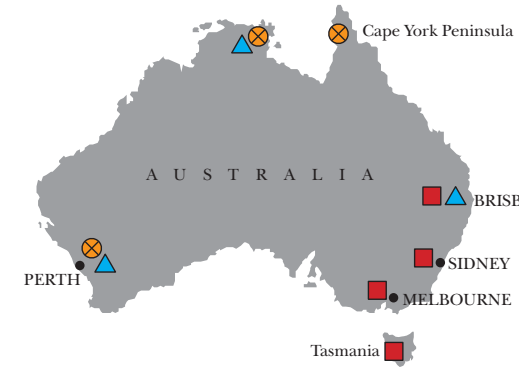
Africa aluminium industry

- Bauxite deposits
- △ Alumina refineries
- Aluminium smelters

largest producer and exporter of bauxite. It accounts for more than a third of the raw material mined for the aluminium industry. The cost of Australian bauxite is only \$10 per ton, which is why many countries are eager to buy it. Australia's most important bauxite deposits are along the coasts in the south-east (the Darling Range to the west of Perth), the north (the Mitchell plateau in the Kimberly region) and the north-east (near Weipa on the Cape York Peninsula).

In contrast, significant bauxite reserves remain untouched in several countries. Supplies in Ghana (780 million tons), Sierra Leone (130 million tons) and Malawi remain unexplored due to distances from main roads and other problems with underdeveloped infrastructure.

Despite the wide geography of bauxite sources, it is mined primarily in coastal regions. Specialists consider Africa to be the closest and most promising reserve of raw materials for the aluminium industry, despite the infrastructural issues. North and Central America,



Australia aluminium industry

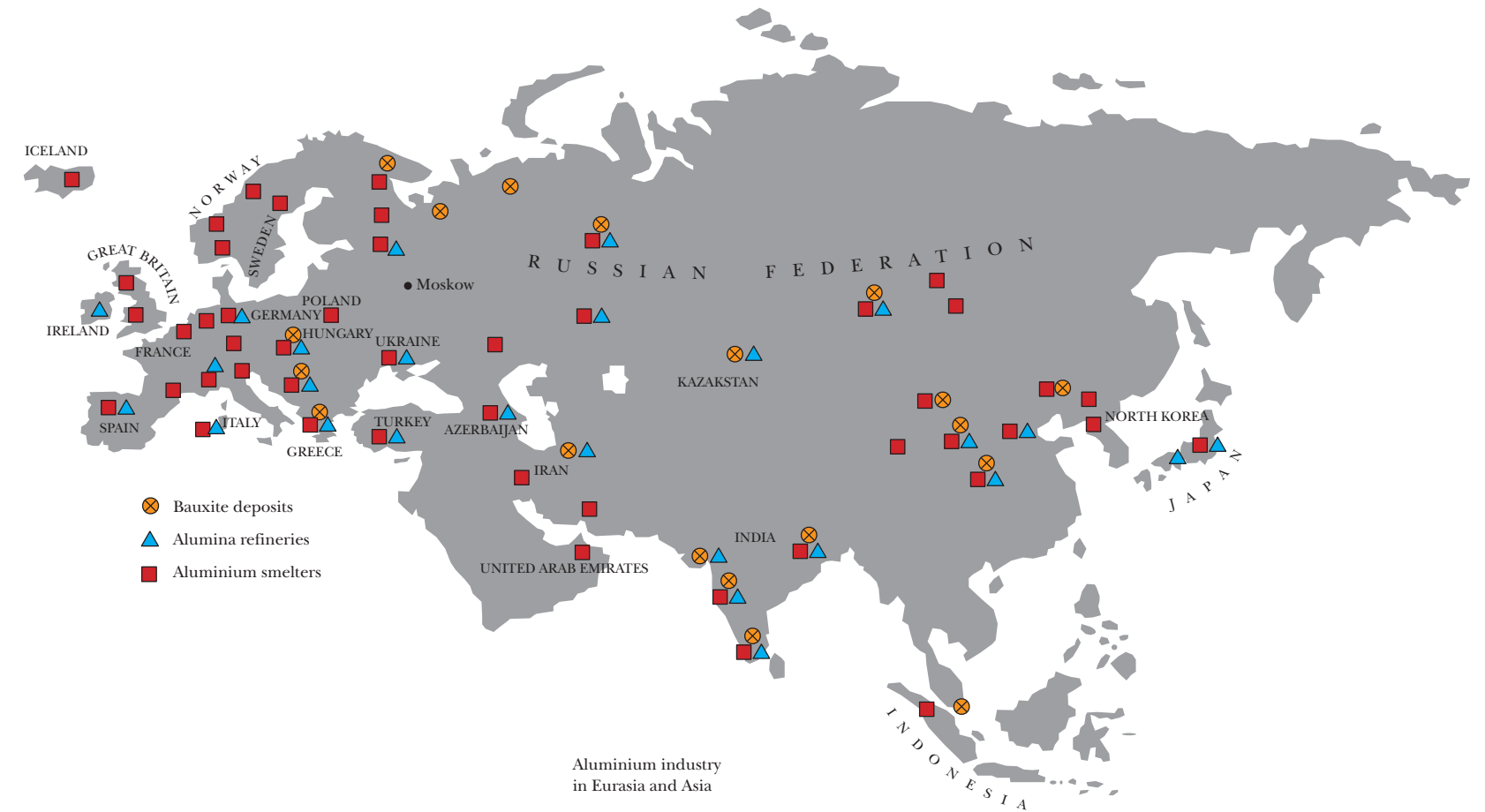
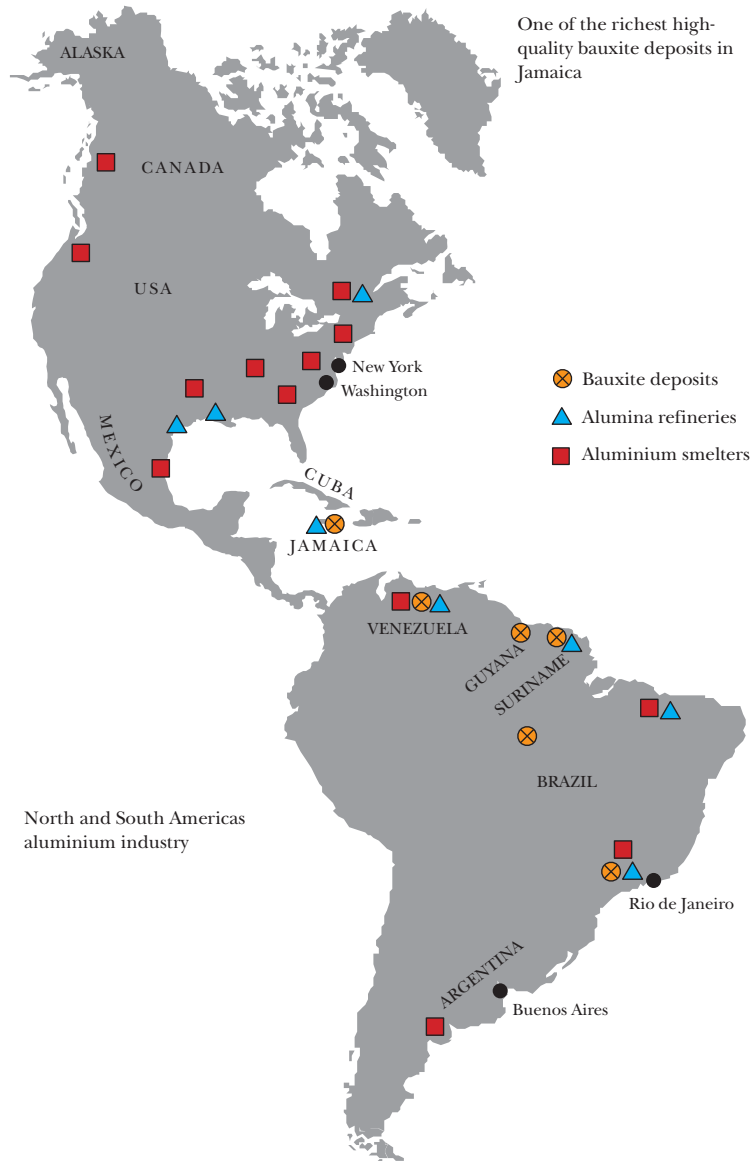


the United States and Caribbean Islands (Haiti, Jamaica) are also rich in bauxite. In the United States, most of the bauxite is deposited in southern states: Arkansas, Georgia, Mississippi and Alabama. In Latin American countries such as Brazil, Venezuela and Guyana, bauxite is deposited in valleys, among the savannahs, right on the surface of the earth. In Asia, major bauxite supplies are in India, China, Indonesia and Turkey.

Some suppliers of raw material for the aluminium industry, such as Australia (which leads the world in this regard) process bauxite to make alumina, which they also export. However, this high-tech process involves major expenses that not every country can afford – for example, in Africa, the only country that exports alumina is Guinea. There are also middle men such as the United States, which sell some of the alumina produced from imported bauxite to third parties.

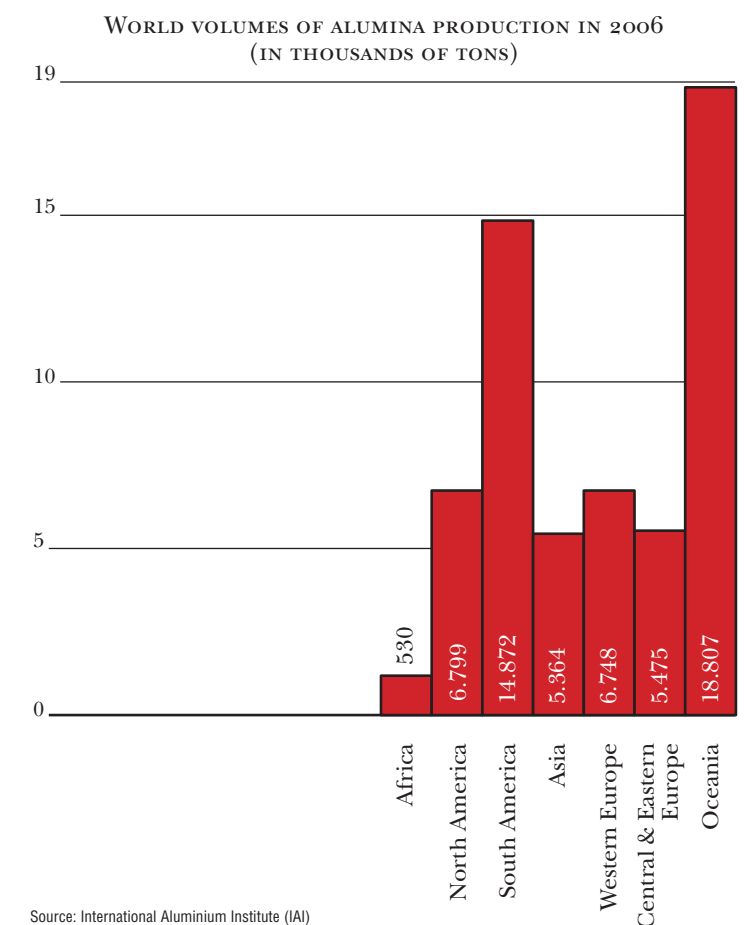
In Western Europe, the largest bauxite deposit is on the territory of Hungary, in the foothills of Vertes, to the west of the country's capital, Budapest. The sheet of ore can lie up to 30 meters deep. In many places the layers of bauxite reach the surface or lie beneath a thin layer of clay or limestone. This deposit provided Germany with bauxite for many years.

There are also many bauxite deposits in the Balkan nations, such as Greece, Albania, Bosnia, Herzegovina, Croatia and Montenegro, as well as in Spain and Italy.



Russia is one of the few countries that has all three stages of aluminium production but they are not developed to equal extent – there are not many deposits of high-quality bauxite on Russian territory. That is why Russia, along with China, Canada and the United States, is one of the world's biggest importers of the raw material.

We discussed some Russian bauxite deposits in the previous chapter, which described the birth of the aluminium industry in Russia and the Soviet Union. The first was discovered in 1916, near Tikhvin in the Leningrad region. Another was found in the Sverdlovsk region in 1938, in the Northern Urals. It became the basis for the Northern Urals Bauxite Mine (SUBR), which is being worked to this day and supplies the Bogoslov and Ural aluminium smelters with high-quality ore. However, this quality comes at a high price. Here bauxite can be found in layers up to 1 kilometer below the earth's surface. It is the only facility in Russia where minerals are mined underground in extremely complex technical and hydro-geological conditions. Although the cost of mining bauxite and processing it to produce alumina significantly exceeded similar expenses in





▶ A New Bauxite Deposit

View of the open bauxite deposit at Vezhaya-Vorykvinsky deposit of Sredny Timan (top right)

Hewer in mine at the Severouralsky deposit (top left)

Detraining bauxite at the Severouralsky deposit (left)

In 1997 mining began at a deposit in Sredny Timan in the Komi republic, in the taiga (boreal forest) to the northwest of the town of Ukhta. Even the most modest estimates say that the bauxite supplies here are enough to produce approximately 2 million tons of alumina for over 40 years. Unlike the Northern Urals lode, bauxites at Vezhayu-Vorykvinsky – Sredny Timan's largest deposit – can be mined on the surface.

The bauxites mined at the Sredny Timan deposit can be used to produce not only alumina, but also abrasive and fire-proof materials. A railroad track in use since 2002 connects the deposit to the Moscow-Vorkuta line. ■

many European countries, the volume of Northern Urals bauxite mined in 2006 reached 3.13 million tons.

In parallel with the exploitation of old deposits, Russia is exploring new sources for its aluminium industry. Bauxite mines have been cultivated primarily in Western Siberia and Belgorod, Arkhangelsk and Krasnoyarsk regions. In the past 70 years, no new technology for extracting alumina from bauxite has been invented. At present, two main methods are used: *the Bayer method* (the “wet” method) and *sintering* (the “dry” method). Several facilities combine these methods making it possible to use needed reactive substances more effectively, decreasing the cost of alumina. Both methods are being constantly perfected, but the main principle remains unchanged. The previous chapter covered the history of the development of these methods and their significance

in the growth of the Soviet aluminium industry – now the time has come to make sense of their chemical features.

The Bayer method is less expensive and brings more economic advantages, but is more specific about the raw materials: it is only good for processing high-quality bauxite with low quartz content. Overall about 90% of the world's alumina is produced using the Bayer method, but in Russia, where most bauxite contains high quantities of quartz, its application is limited. Of the facilities in the former Soviet Union, only the Nikolayev Alumina Refinery and Zaporozhye Aluminium Combine, as well as Gyanzha Alumina Refinery in Azerbaijan, in Ukraine works using a modified version of the Bayer method.

To produce alumina by the Bayer method, the bauxite is crushed, dried and ground in mills with a small

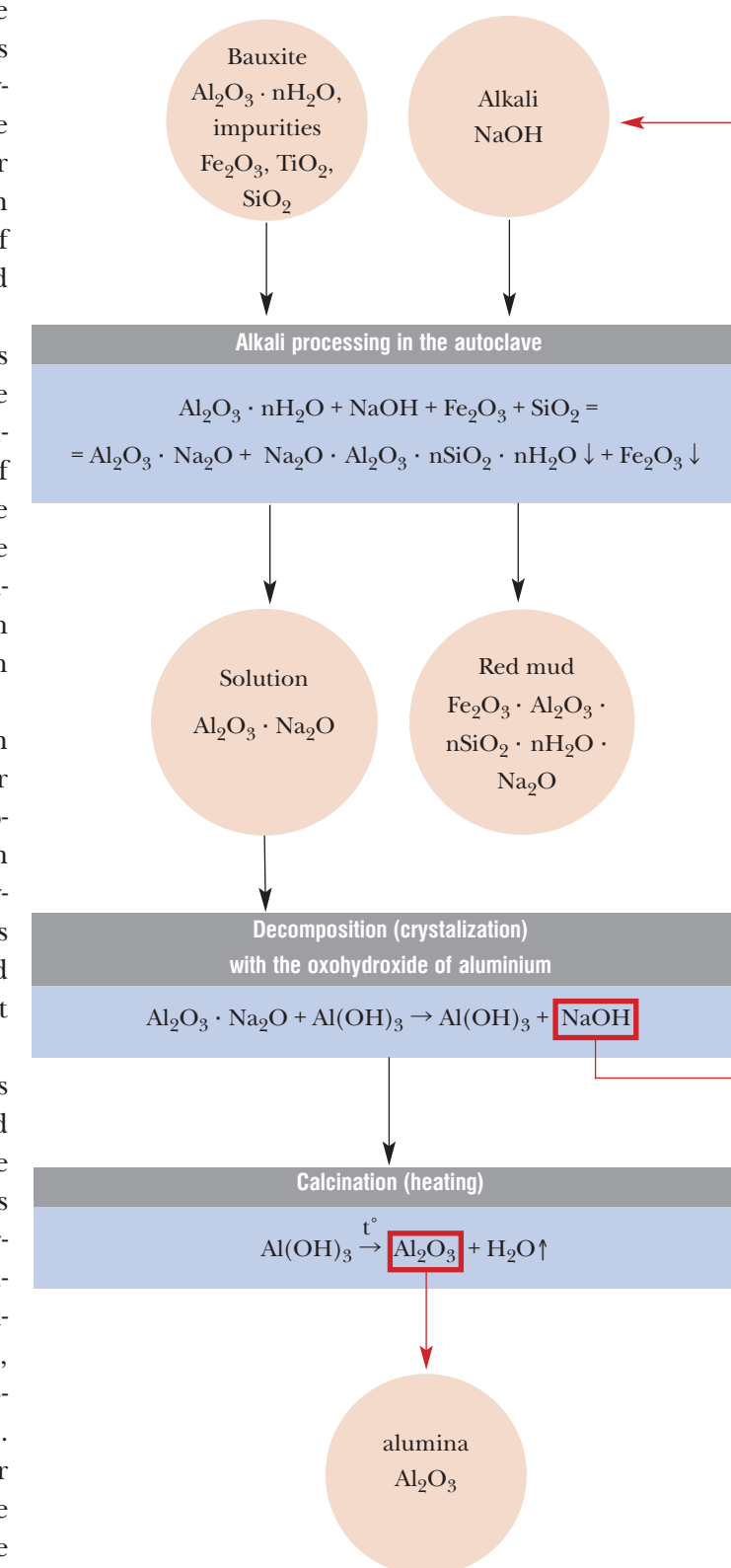
amount of water. The resulting thick mass, the pulp, is gathered in special containers and steamed. This operation makes it possible to bind most of the silicon in the bauxite into an insoluble aluminosilicate. Then a valve is used to pump the pulp into an autoclave (a hermetically-sealed cauldron for pressure heating at a temperature higher than boiling point), where they are processed for several hours with a concentrated solution of sodium hydroxide. Some types of bauxite require an addition of lime. Usually a facility uses ten sequentially connected autoclaves.

An engineer constantly observes the process throughout its duration. The worse the leaching, the more time it takes and the higher the pressure and temperature in the autoclave. Usually only 85% to 95% of alumina passes into the lye from the bauxite. Losses are inevitable because part of the aluminium in the bauxite forms compounds with the insoluble sodium aluminosilicate. Along with aluminium, oxides of silicon, iron and titanium, or other elements in alumina, end up in the solution.

From the final autoclave, the pulp flows into a steam trap, where the solution cools, and the steam is used for the processing of a new portion of pulp. In order to separate foreign impurities, the solution is diluted with water and thickened again. This process forms a ruddy-coloured sediment, called red mud. Its colouring comes from iron compounds, primarily the oxide Fe_2O_3 and the oxhydroxide FeOOH . In addition, the sediment contains titanium dioxide and quartz.

After the red mud has been removed, the solution is cooled to 70°C in a heat-exchanging apparatus and then transferred to large vats with decomposers. (The first vats were designed by Bayer and described in his patent.) The decomposer mixes the solution for several days at a temperature of $40\text{--}70^\circ\text{C}$. The sodium aluminate gradually dissociates, and aluminium hydroxide falls into the solid. This method of dissociation, called precipitation is, along with holding in autoclaves, a characteristic feature of the Bayer method. Contemporary tools have an automated process for controlling the fluid decrease in temperature. At the beginning of the operation, mordant is added to the solution to speed up the process. Aluminium hydroxide is used again as the mordant. As a rule, the amount of mordant exceeds the amount of alumina in the solution by 150%.

PRODUCTION OF ALUMINA BY THE BAYER METHOD



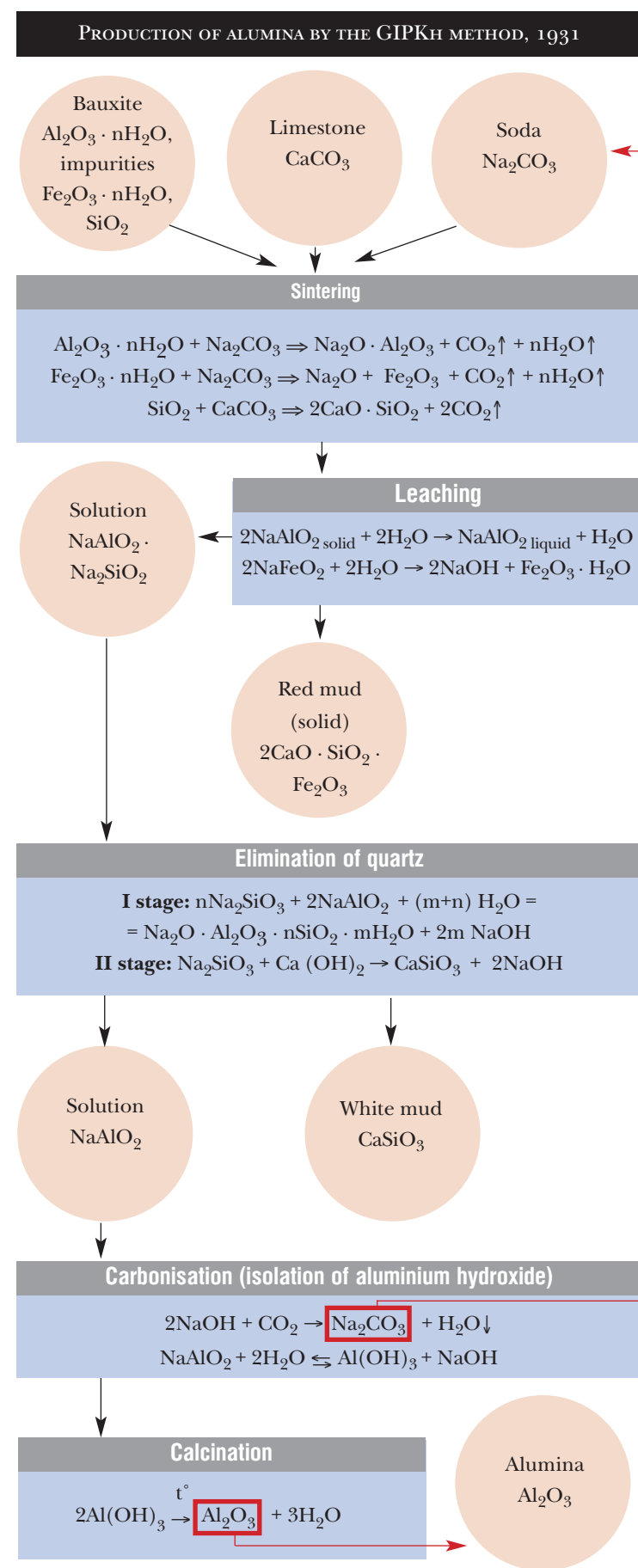
The precipitation results in a solid of aluminium hydroxide, or hydrated alumina. Large chunks of solid alumina can easily be filtered from the solution, and they are washed with water, dried, and calcinated, or heated to eliminate water.

Small particles of aluminium hydroxide are difficult to isolate from the solution, but they can make an excellent mordant. They are separated from large fractions of aluminium hydroxide and returned to the decomposer. The *mother solution* is concentrated following filtration and used again for leaching.

The second method of obtaining alumina from bauxite currently used is the sintering method. Sintering is a process of obtaining hard and porous materials from powder and dust at heightened temperatures. It is more expensive than the Bayer method, but at the same time it gives an opportunity to process bauxite with a high quantity of quartz impurities, which is commonly encountered on Russian territory. This method was invented earlier than the Bayer method by the French chemist Louis Le Chatelier in 1859. Le Chatelier started to obtain alumina from bauxite, sintering with soda, and then breaking up aluminate solutions with carbon dioxide gas. In 1880, Muller proposed adding lime, magnesium carbonite or dolomite to ore containing quartz during sintering – this bound the quartz in non-water soluble silicates, thus simplifying the process of isolating it from alumina. In 1902, Pacard was able to determine how much lime must be added to the solution to isolate quartz. His dry mix is still used today for processing in metallurgical, chemical and other industries.

Soviet scientists made a major contribution to improving the sintering method. In 1931 researchers at the State Institute of Applied Chemistry (GIPKh) developed a method of sintering with wet mix to process low-quality Tikhvin bauxite. A slightly modified version is used at present-day Russian alumina refineries.

The sintering method involves carefully mixing ground bauxite with ground soda and lime (or limestone) and heating it in tubular spinning furnaces at 1,000°C to 1,200°C. The resulting pitch is cooled, crushed and leached with water. As a result of these procedures, the solution retains sodium aluminate and silicate, and precipitates all of the impurities, which as in the Bayer method is called *red mud*; its reddish-brown colour comes from iron hydroxide(III).



The next step is to eliminate the quartz. Lime milk, a suspension of calcium hydroxide in water, is added to the solution and heated under pressure in autoclaves. A large part of the quartz forms white calcium aluminosilicate, which precipitates. The remaining sodium aluminate is broken up by the addition of carbon dioxide. This stage, called *carbonatization*, involves carbonizers, or deep reservoirs with mixers. The result of this process is the isolation of solid aluminium hydroxide and the formation of soda, which remains in the solution. Aluminium hydroxide is not fully removed from the solution, since its final portions are taken from the solution of hydrated quartz, which is polluted by the solid. The aluminium hydroxide isolated from the solution is settled, filtered, washed and heated until it becomes alumina, similar to the process described in the Bayer method. In the dry version of the sintering method, the soda solution obtained in the carbonization process is steamed and used for sintering new portions of bauxite.

The sintering method of processing bauxite is used at the Bauxitogorsk Alumina Refinery, located in the Leningrad region, 240 kilometers from St. Petersburg. The refinery, which was opened in 1938, in 2006 yielded 148,500 tons of alumina.

Scientists and engineers are working to perfect bauxite processing method and propose new technologies. The implementation of the results of their research makes it possible to use raw material more thoroughly,

decrease production losses, save electricity and improve working conditions. It was earlier believed that ore with a high quartz content could not be processed as alumina. But practice shows that aluminium oxide can be isolated from ore that is almost 50% quartz.

Russia's largest alumina facility is the Achinsk Alumina Refinery (AGK), which started production in 1970. It uses technologies developed by the All-Russia Aluminium and Magnesium Institute (VAMI), which is a part of UC RUSAL. The technology is based on sintering the ore with lime and a following hydrochemical processing of the pitch. The Achinsk refinery is a contemporary complex of industrial facilities that occupies dozens of hectares. Just the sintering block of the alumina refinery takes up 78,000 square meters (the equivalent of 11 football fields). This multi-purpose industrial complex includes nepheline and lime mines in addition to alumina refineries, soda and cement factories.

Bauxite is the most common, but not the only raw material for producing alumina. It is also obtained from aluminosilicate nepheline ((Na, K)₂O·Al₂O₃·2SiO₂). In nature it can be found in apatite, a mineral from the group of phosphate salts of calcium (3Ca₃(PO₄)₂·Ca(F, Cl)₂), which form apatite-nepheline mines. They are mined on the Kolsk peninsula, in the Kemerovo region and in the Krasnoyarsk region. Along with alumina, potash and soda are also obtained from nepheline, as is the rare



Achinsk Alumina Refinery



Nepheline

metal gallium, and high-quality cement is produced from the manufacturing residue. On average, one tonne of alumina requires 4 to 4.1 tons of nepheline and 7.5 tons of limestone. The only refinery in the world that uses residue from apatite-nepheline mines (nepheline concentrate) as a complex raw material is the Pikalevo Alumina Refinery, in the city of Pikalevo in Leningrad region. The refinery uses a unique technology of producing alumina from nepheline concentrate, developed by specialists at UC RUSAL's VAMI institute. For electrolytic production of aluminium, cryolite is needed in addition to alumina. For a long time the aluminium industry widely used natural Greenland cryolite, mined from the world's only major mine in the region of Ivigtut. The ore mined there contained approximately 80%



Pikalevo Alumina Refinery

Metallurgy as part of Russian Economy

Metallurgy is one of the fundamental sectors of Russia's economy. It has a 16% share in the country's industrial production, more than a third of which is accounted for by non-ferrous metals. More than 35% of rail shipments around the country involve metallurgy; it consumes 30% of all the electricity designated for industrial use and 25% of the natural gas. The industry's products are used in many strategically important sectors, such as machinery, fuel and energy, the military industrial complex, construction and more. Metallurgy is one of the few sectors of Russian industry integrated in the international economy. Russia's metallurgy industry is distinguished by a high degree of concentration of production: about 90% of products in ferrous metallurgy are produced by six major companies, and five dominate the production of non-ferrous metals. The most important Russian companies working with aluminium production are Rusal and Sual.

Russia is the world's second-largest aluminium producer, with a 12% share of overall production, and is the largest exporter of the metal. Approximately half of all export products of non-ferrous metals and aluminium and products made from it. The majority of that is pure aluminium, although in recent years the export of aluminium alloys has grown substantially. The share of semifinished materials and aluminium products (mill products, foil) is insignificant. Russian aluminium is mostly consumed by Japan (29.5% of exports), the United States (19%), the Netherlands and Portugal (9.5% each). The quality of the Russian metal complies with international standards. The share of highly pure metal in the overall production of aluminium is constantly growing. Russia's main competitors on the international market are *Alcoa* (based in the United States) and *Alcan* (based in Canada).

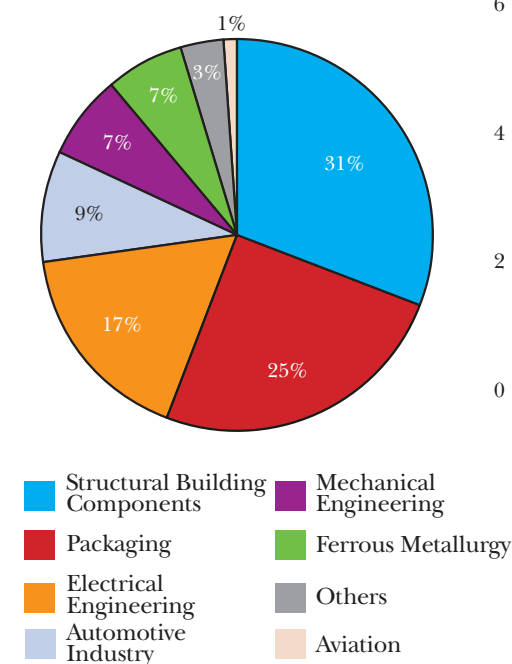
Russia's sources of raw material are presently able to provide for only 50% of the needs of the country's aluminium industry. Most of the supplies of bauxite are either low quality or are mined in complex geological conditions, which increases production costs. Russian companies find it more profitable to import high-quality bauxite from Guinea, Australia and Guyana. In addition, manufactured alumina is imported from Kazakhstan, Ukraine and more distant countries to Russia. A colourful term for aluminium is conserved electricity, since electrolysis, the method used to produce it, requires major energy expenditures. That is why it is advantageous to build aluminium smelters near sources of cheap electricity, such as hydroelectric stations (currently 82% of aluminium in Russia is produced with hydropower). Aluminium smelters located directly near sources of electricity save approximately one third of the cost of converting and transporting energy.

However, this distribution of reduction facilities increases transportation costs on delivering

cryolite with impurities of quartz, fluorite, pyrite, sphalerite, galena and other minerals. Enriching the ground ore yielded a very pure product, with only traces of quartz and ferrous compounds. But as a result of heavy use, the mine's resources dwindled and in 1975 the cryolite mine shut down. Since that time, the aluminium industry all over the world switched to artificial cryolite. It is obtained by a reaction of hydrofluoric acid and aluminium hydroxide (or sodium aluminate) and soda. Cryolite, which dissolves poorly in water, remains a solid.

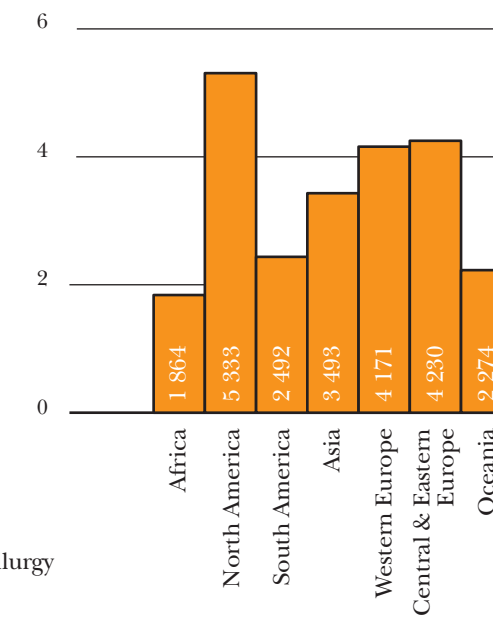
Cryolite used in the electrometallurgy of aluminium is synthesized at cryolite refineries. They also specialize in producing other fluoride compounds – hydrofluoric acid, fluoride and sodium hexafluorosilicate, aluminium fluoride – which are used in the glass industry as a mordant for glass, crystal production, and optics. In Russia, cryolite refineries are located in Kuvandyk, in Orenburg region, and Polevsky, in Sverdlovsk region.

STRUCTURE OF ALUMINIUM CONSUMPTION IN RUSSIA, 2006



Source: UC RUSAL

ALUMINIUM PRODUCTION IN THE WORLD (IN THOUSANDS OF TONS), 2006



Source: International Aluminium Institute (IAI)

alumina and transporting primary aluminium. Russian aluminium smelters are in the centre of the country, a significant distance from the ports of the Far East, the Baltic and Black Seas. This increases the cost of the metal marked for export. The share of transportation costs in the price of aluminium in 2004 was 12.1% on average.

In the 1980s, the Soviet Union was a world leader in producing and consuming aluminium. The country produced 15 kilograms of aluminium per capita annually, on the level of the most developed world powers. In the early 1990s, Russia's aluminium production sharply dropped, which led to a fall in aluminium consumption to 3-4 kilograms per capita. This was comparable with similar figures for underdeveloped nations. Then a large amount of Russian metal started to go abroad: the export of aluminium in the short period from 1991 to 1993 grew more than threefold: from 700,000 to 2.2 million tons. In subsequent years the intensive growth of the Russian economy brought a greater consumption of aluminium, mainly in the spheres of electronics and packaging. In the latter category, Russia reached the 1990 level of aluminium consumption only in 2003, and in terms of the amount of machinery in use it remains ten times lower than the 1990 level.

Today domestic aluminium consumption in Russia increases by 5% every day. This growth comes on the background of increased prices for metal, related to increased prices for energy carriers and raw materials. Often high prices for electricity make aluminium production unprofitable even at facilities near hydropower plants.

Compared to many European countries, the United States and Canada, Russia does not use aluminium scrap to its fullest potential. Russia is estimated to create approximately 650,000 tons of scrap a year, the greater part of which (approximately 500,000 tons per year) leaves the country as secondary aluminium alloys. The consumption of secondary aluminium in Russia is only 15% of the volume of the primary consumed metals. ■

In the Reduction Area

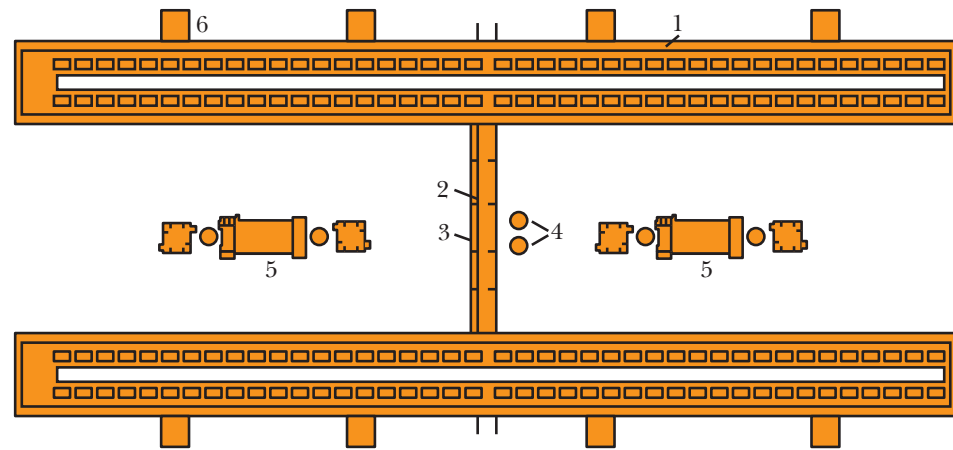
Aluminium is obtained from alumina and cryolite at the reduction area (or at an electrolysis plant). It is unlike the departments at other metal works that produce, for example, cast iron or steel, and usually consists of several rectangular structures. To provide better ventilation they are always built facing the dominant wind direction. The corpuses are connected: a single corridor passes through the center of their long sides.

Alumina and cryolite arrive by rail to the raw material storage house, located in immediate proximity of the reduction area. From the warehouse's compressor department the material is pumped with compressed

Plan of the reduction area:

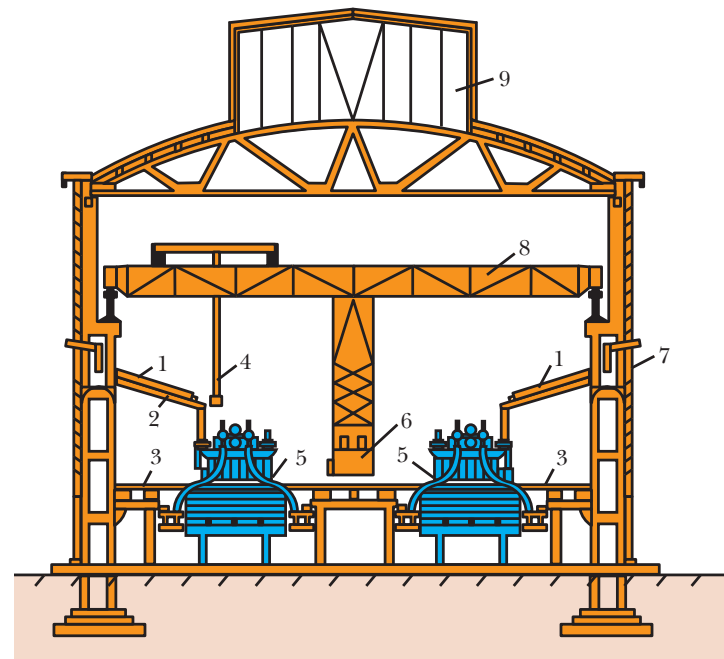
Bird's eye view:

- 1 – body of the electrolytic bath,
- 2 – connective corridor
- 3 – service area
- 4 – towers of alumina
- 5 – gas-cleaning modules
- 6 – break room



Side view:

- 1 – gas vent pipes
- 2 – trestle for cables
- 3 – grates
- 4 – bar for moving studs
- 5 – electrolysis bath
- 6 – cabin for the bridge faucet
- 7 – windows
- 8 – truss for the bridge faucet
- 9 – lamp



Alternate Methods of Obtaining Aluminium

The electrolytic process of obtaining aluminium invented by Héroult and Hall, which is used in contemporary industry, suffers significant drawbacks. While it expends great amounts of electricity, it yields a relatively small amount of the metal, the electrolytic baths last only a short time, and many hazardous substances are emitted into the atmosphere. Environmental pollution is a serious problem even with contemporary technologies. Over the last few decades, scientists and engineers have been developing alternative methods, some of which have been implemented in production, but were unable to withstand competition with the traditional method of electrolysis.

In 1960, specialists at the Canadian aluminium company Alcan developed a *carbothermic subhalogen process*, based on reducing aluminium to its monochloride (AlCl). If a mix of ferro aluminium power and anhydrous aluminium chloride is heated in a closed vessel, then crystals of pure aluminium form in the unheated part. The aluminium monochloride emitted during the reaction process is stable at high temperatures, but when cooled breaks down into aluminium trichloride and metallic aluminium, which takes the form of crystals. Ferro aluminium can be obtained by reducing clay with carbon.

During the subhalogen process, low-quality bauxite or other aluminium ore is reduced with coke in electric furnaces, as the Cowles brother did. The resulting metal contains a significant carbide impurity and cannot be used without further purification, which happens during the process of forming the monochloride, which is stable only at high temperatures. The energy expended on this process turned out to exceed the amount used in electrolysis. Also, electrolytic equipment heated to high temperatures in the presence of chloride and chloride compounds rapidly went bad due to considerable corrosion.

A subhalogen process may be of interest as a method of producing silumin or use for refining aluminium alloys.

From 1966 to 1973, the American company, Toth, worked on a carbothermal technology of producing aluminium from clay. Chloride is passed through a heated, carefully ground mixture of clay and coke. The aluminium in the clay becomes a volatile chloride (AlCl₃), which is reduced by manganese. Aluminium and manganese chloride also form, and heating in oxygen turns the latter into an oxide. Reduction of the manganese oxide with carbon in electric furnaces yielded manganese to restore the next portion of aluminium chloride. But the high cost of equipment became an obstacle to the use of this method on an industrial scale.

air to the warehouse's silos, where they are then distributed into baths. The centre of the reduction area is the large hall, where several rows of baths covered with shutters (bonnets) are partially buried in the earth to help maintain heat.

In some Russian facilities, the electrolysis buildings are two stories high. The workspaces are on the top floor, which improves ventilation and assists in more completely eliminating the gases formed during electrolysis. Massive copper wires that lead the current to the bottom of the furnace and up to the anodes are a constant reminder of the amount of electricity consumed during the process.

The aluminium industry is no longer labour intensive – the entire process of aluminium production is mechanized, everything is automatically controlled, and there are few workers in the department.



Reduction area at a modern aluminium smelter (Khakas Aluminium Smelter)

The baths are located five meters from each other and stand more than 2.5 meters from the walls of the building. The reduction area from above looks like a miniature city landscape – it has its own roads, the transportation corridors along with faucets and freight carts move along. Special bridge faucets, the supports of which are located above the baths, serve to replace the anodes (during electrolysis anodes are regularly used up, burning out from the oxygen released during the reaction). Vacuum buckets are fixed to these faucets, and remove metal from the bath. Alumina and cryolite are delivered to the baths in automatic bunkers. The most modern facilities have an automatic system of delivering alumina. Just like the

In the 1970s, the American company, *Alcoa*, invented an *electrochemical* method of producing aluminium from trichloride. Obtaining anhydrous trichloride was meant to chlorify the mixture of alumina and the reductive agent, and coke was used for this purpose. Sainte-Claire Deville obtained anhydrous trichloride with approximately the same method. An electrolytic bath made of a steel shell and fittled with fire-resistant bricks (also known as fire-clay bricks) that can withstand temperatures up to 1600°C as well as the effects of chloride alloys. The side walls of the electrolytic baths are cooled with water. At the bottom of the bath is a graphite reservoir that collects the molten metal. Curiously, the chloride method does not use up graphite electrodes, since carbon barely reacts with chloride, which means the emission of toxic gases is decreased. This is the principal difference of the chloride method from the process invented by Héroult and Hall. The electrolysis process uses not pure aluminium chloride, which when heated sublimates practically without melting, but a molten metal mixture of aluminium chloride with lithium and sodium chlorides. However, electrolysis of this liquid requires greater pressure than electrolysis of an aluminium oxide solution in molten cryolite. In order to avoid a decrease in pressure, the design of the electrolytic bath employs bipolar electrodes – additional electrodes located between the cathode and the anode. Their upper part carries a negative charge, while the lower part is positive. This makes it possible to decrease expenditures of electricity by approximately 30%.

The chloride method is undoubtedly the best alternative to the electrolysis process invented by Héroult and Hall. Alcoa spent \$25 million researching this direction. Work went on for 15 years and ended in 1976 with the creation of the first industrial complex to produce aluminium with the chloride method. It was built in the city of Palestine, Texas, USA. ■

transportation of raw materials from storage to the silos, this tubular system uses compressed air. Every half hour, a new portion of raw material for aluminium production is loaded into the bath.

The metal is electrochemically reduced in cells, metallic baths which are put beneath fire-proof material



Automated production process

and carbon blocks. The bath's bottom serves as the cathode, and the hanging corner blocks are the anodes, partially submerged in the electrolytic fluid.

The molten cryolite-alumina mixture is very aggressive; it corrodes most metals, including steel – this is why the electrodes are made from carbon. The inside of the electrolysis bath, which comes in direct contact with the mixture, is also lined with sheets of carbon. During normal work, the carbon floor of the bath is always covered with a layer of aluminium 10 to 15 centimetres thick, which forms the cathode. Metal aluminium reacts with carbon on the bottom of the bath, as well as with the car-

bon dust in the electrolytic fluid that results from the destruction of the anodes. Sometimes a layer of carbide sediment (Al_4C_3) several centimetres thick forms, which leads to overheating and excessive use of electricity.

The dozens, even hundreds of baths installed in the department are subsequently connected to the

One ton of aluminium requires:

Alumina	1,925–1,930 kg
Carbon (for the anode)	500–600 kg
Cryolite.....	50–70 kg
Electricity.....	14,500–17,500 kW/h

source of constant electricity to account for tension on electrodes equal to 4–6 W. Electrolysis occurs at a temperature of about 950°C. If the first electrolytic baths were designed to handle a current of 0.6 kA, then contemporary tools work at a current of 300 kA or 400 kA. Furthermore, experiments are currently underway to create electrolytic baths that consume a 500 kA current. Although engineers already know of so-called *inert* anodes, which do not change during electrolysis and do not require frequent replacement, at present aluminium facilities use *carbon anodes* exclusively, which need to be replaced and significantly increase the cost of production. The use of these anodes has another negative side – their combustion releases a considerable amount of poisonous gases, the emission of which the industry is developing new technologies to reduce.

Technology of Carbon Anodes

There are two main types of expendable anodes. The first is the self-firing anode, the second – the previously formed, or burnt, anode.

The self-firing anodes, often called Soderberg anodes, after the inventor who designed them in the 1920s. Their main advantage is that they can work without interruption – as the anode burns up from the bottom, new portions of carbon grow on the top. The cost

of production 1 metric ton of aluminium using Soderberg anodes is 5.2% lower than with the previously formed ones.

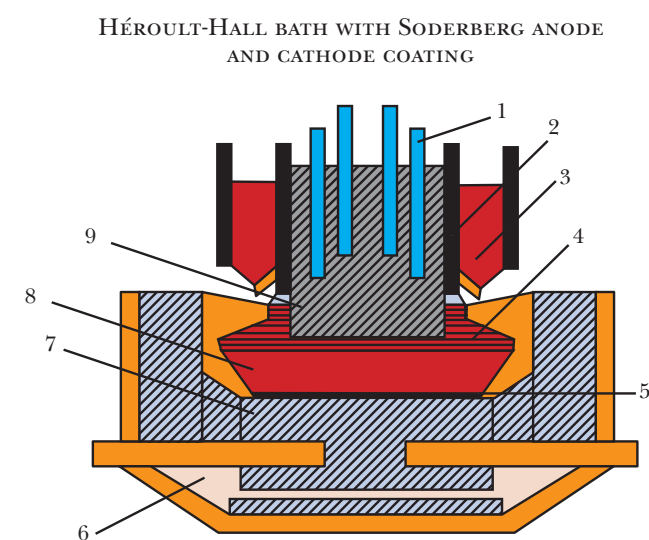
Self-burning anodes easily form directly during the process of the bath's work and tk. Their preparation does not require special equipment or furnaces. However, the combustion of this anode is accompanied by an emission of fine carbon soot and dangerous vapors,

which besides carbon dioxide contain coal gas and several other highly toxic fumes. Resinous, semi-liquid pitch, used to form the anode, is the source of many of these compounds. When heated it released many tarry substances that possess carcinogenic properties.

Despite the fact that the use of the burnt anodes considered to be more progressive, the Soderberg technology adherents are confident that the technical capabilities of electrolytic baths with the self-firing anodes is far from exhausted. The main challenge currently facing manufacturers is the environmental stress-reduction. That's the goal of all the researches conducting in this area.

In Russia, most aluminium smelters built before the mid-1970s are equipped with baths with Soderberg anodes. 18% of aluminium production is based on Soderberg technology.

The aluminium manufacturers that use the Soderberg technology even organized a club after his name, which includes such large companies as: Forberg & Associates Inc. (USA), Elkem Aluminium ANS Research (Norway), UC RUSAL, CBA (Brazil), K+T-ENGINEERS (Switzerland), Madras Aluminium Company (India). The Soderberg Club also includes industrialists from Poland, South Africa and Netherlands. Virtually on every Soderberg Club meeting its members discuss the issues of reducing harmful emissions, ecological modernization and competitiveness of electrolytic baths working on the Soderberg technology.



1 – current source, 2 – anode mass, 3 – alumina supply, 4 – molten electrolytic fluid, 5 – cathode coating, 6 – isolation, 7 – carbon base, 8 – aluminium, 9 – carbon anode.

Inert Anodes

The use of carbon anodes, proposed in Hall's patent, currently seems extremely ineffective. As burnt anodes must be replaced every 22 to 27 days. The consumption cost of anode material increases the manufacturing cost of aluminium by 20–25%; the impurities in the anode pollute the metal, and the gases emitted during combustion create major environmental problems. Scientists search for new materials capable of replacing carbon on commissions from major aluminium companies.

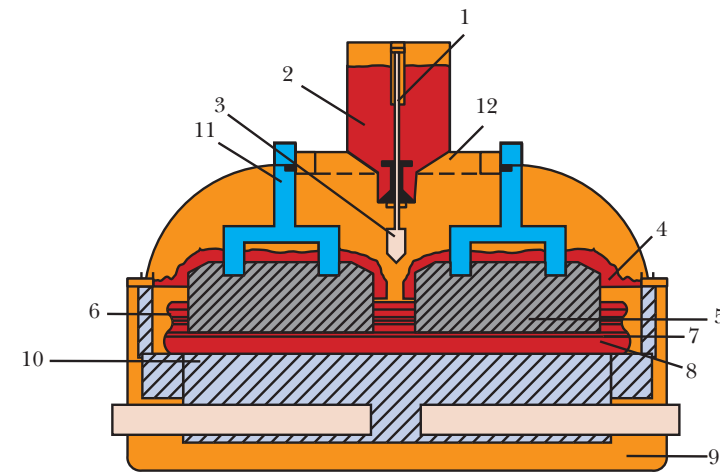
An inert anode should have high chemical stability, not dissolve in molten fluoride, be highly conductive and not pollute aluminium with impurities. From a chemical point of view, the ideal anode would be made of a noble metal, such as platinum or gold. But a simple calculation will show that this solution is not financially feasible, even if the metal is applied in a thin layer on the anode's surface. Many scientists looked to ceramic phases, for example, oxides of metals. However, most pure oxides do not conduct electricity, and conductivity is a necessary condition for an electrode. To increase the conductivity scientists proposed using cermets, or compositional materials made of ceramics and pieces of metal. A matrix of ceramic oxide based on nickel oxide (NiO) or mixed oxide ($NiFe_2O_4$) with the structure of the magnesium aluminate forms a three-dimensional net, so durable that it maintains its structure in an aggressive environment. In the gaps of this matrix are small pieces of metals, such as copper, which gives the entire material conductivity. An electrode in molten cryolite made of cermets sustained only insignificant corrosion – 0.0015 cm per hour. However, its tests in aluminium electrolysis have not yet met success. Since scientists learned that the speed of corrosion is highly dependent on the concentration of alumina, which constantly changes in the course of electrolysis. The Moltech company has developed an inert anode of an iron and nickel alloy with additives of other metals and covered with a thin layer of cerium oxyfluoride. Tin dioxide with various additives has been proposed as an alternative metal. The search for new materials goes on. Unlike anodes, cathodes are not consumed in the electrolysis process; in other words, they are already inert. However, they do not soak up liquid aluminium, and therefore the metal cannot accumulate directly on the cathode's surface. The wettable cathode gathers only a thin film of metal, but its main layer is collected on the metal reservoir at the cathode's bottom, whence it is poured. The search for wettable materials led to the invention of covering from titanium diboride (TiB_2). Such cathodes have already undergone industrial tests. ■

In Western European countries, the United States and Canada the most commonly encountered kind of electrolysis baths are equipped with anodes that have been previously formed at special factories. They are commonly called burnt anodes. They are made from the same material as Soderberg anodes, but they use somewhat less pitch. During the exploitation process, the burnt anodes inflict less harm on the environment, since the tar substances contained in the coke are eliminated earlier, during the anode production process. It is more difficult to make these anodes, but the payback for these expenses is the preservation of the environment.

Russia's aluminium industry is currently quickly reequipping its tools facilities with burnt anodes and all the designed and constructed aluminium smelters are using this technology. At the same time, plants using Soderberg technology are modernized with more effective and environmentally friendly technology – using “dry” anode paste, which allows to reduce the ecologic impact. Soderberg technology electrolysis baths using “dry” anode paste are, by environmental parameters, in between Soderberg technology electrolysis baths using anode paste and burnt anodes technology.

HÉROULT-HALL BATH WITH BURNT ANODE AND CATHODE COATING

1 – pneumocylinder, 2 – alumina, 3 – pin, 4 – alumina crust, 5 – carbon anode, 6 – electrolytic fluid, 7 – molten aluminium, 8 – cathode coating, 9 – heat isolation, 10, 11 carbon base, 12 – anode current source, 13 – gas vent



Last Stage of Obtaining Primary Aluminium

Production of each tonne of aluminium yields 280,000 cubic meters of gases. Therefore, each electrolysis bath, regardless of its design, is equipped with a system to cleanse exhaust gases. Part of the electrolyser is the system of gas collection, which collects the gases emitted during electrolysis and directs them to the gas cleansing system.

At older one-story reduction areas, gases are diverted by a complex system of underground channels, but their disadvantage is that they frequently become clogged with fine carbon dust and need regular cleaning. In contemporary facilities, spacious gas pipes are placed above the tops of electrolysis baths both inside and outside the building. Sometimes the space above the anode is covered with shutters, special bonnets, or a cast iron bell, in which the exhaust gases (primarily coal gas) are combusted in special burners. Fluoride compounds from



Exhaust gases' cleansing block at Khakas Aluminium Smelter

the exhaust gases are eliminated by passing the gases through a sofa solution. This means that the equipment is not only cleaned but the process also yields an additional quantity of secondary cryolite.

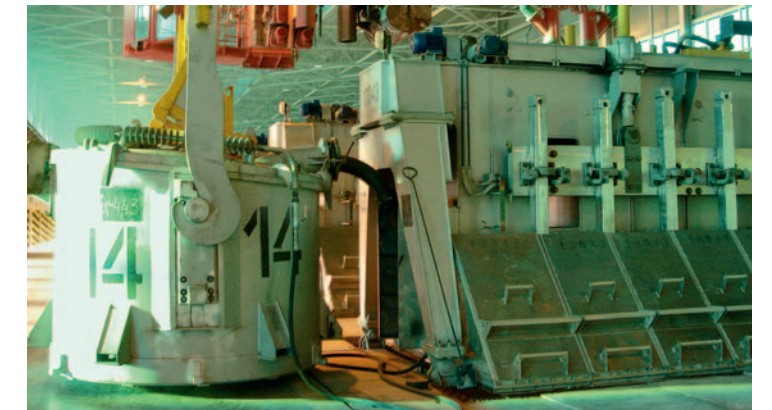
During electrolysis, the bottom of the bath gradually accumulates molten aluminium, since the resulting metal is heavier than the electrolytic fluid. From time to time, approximately once every 2 to 4 days, it is removed. In the early period of the industry, aluminium would be retrieved from the bath using an iron bowl with an opening. Before lowering the bowl into the bath, its opening is plugged with a wooden cork. The cork is removed when the bowl is submerged in the molten metal, and the liquid aluminium gradually fills the bowl through the opening. At this stage, the aluminium can be scooped from the bowl with large iron spoons and poured into casting forms. In further developments, engineers proposed a bath design with tap holes to release the metal. The tap hole is located at the very bottom of the bath's side wall, and during electrolysis it is closed with a carbon cork. The cork is removed, or pushed out, only during the release of the metal. However, the bath design with tap holes did not meet expectations: the opening was often clogged with cryolite, it was difficult to clean, and repeated clogging damaged the bath's fettle. Engineers spent a great deal of effort searching for a more modern means of releasing the metal from the bath – they tried siphoning pipes, valves, vacuums and scoops.

The current method for extraction of aluminium from the bath involves an opening being punctured in the crust of congealed electrolysis fluid on the bath's surface, and a tube is lowered into it. Liquid aluminium is sucked down the tube into a vacuum scoop (air is pumped out of it in advance), which is hung on a bridge faucet. Aluminium is poured from vacuum scoops into casting scoops, which are mounted on the carts that autocars transport to the foundry. There the molten aluminium passes through a special mixer into a pouring line, where it is turned into small ingots intended for subsequent recasting.

The Khakas Aluminium Smelter

The youngest smelter in the Russian aluminium industry is the Khakas Aluminium Smelter, part of UC RUSAL and located in the city of Sayanogorsk on the Yenisey river, near Sayano-Shushenkaya and Main-skaya hydroelectric stations. It is the first aluminium smelter built in Russia in the last 20 years. The production capacity of the smelter is 300,000 tons of aluminium per year, and the overall volume of investment is greater than \$750 million.

The first batch of Khakas aluminium was finished on December 15, 2006; the smelter is expected to reach



Aluminium extraction from the cell with a crucible (Khakas Aluminium Smelter)

full capacity by the end of 2007. The smelter's design is an example of the latest achievements in the Russian and international aluminium industry, and uses contemporary equipment and high-quality raw materials. The facility applies a progressive technology of preliminary burnt anode – the most modern and environmentally safe aluminium production technology that currently exists. The smelter is equipped with powerful Russian electrolytic baths, RA-300, developed by specialists from UC RUSAL's Engineering Technology Centre. In a day, RA-300 produces more than 2,050 kilograms of aluminium and ensures environmental safety and efficient production. Two highly effective gas-purification tools have been built for the electrolysis chamber; they trap more than 99% of fluoride compounds and dust. ■



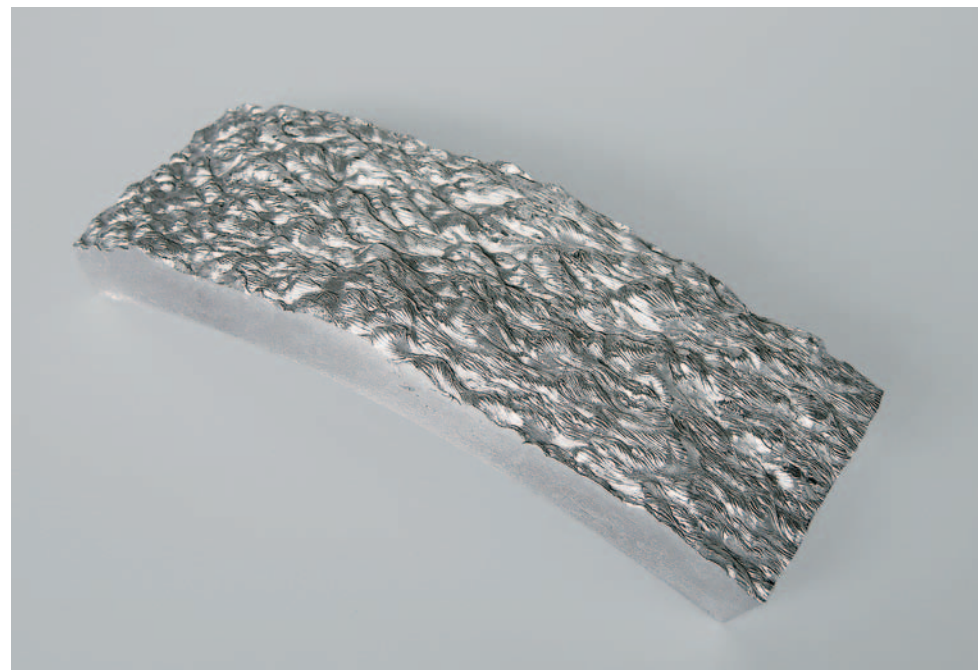
Aluminium ingots

Purifying Primary Aluminium

Aluminium metal obtained by electrolysis usually contains impurities of iron and silicon. In the terminology of engineers, that is “raw aluminium”, or primary aluminium. Mechanical impurities and gases in the metal are eliminated during recasting. To this end, ingots of aluminium are sprinkled with powdered cryolite. The metal is held in the over at a temperature of 800°C – this temperature is enough to melt aluminium, but cryolite remains solid. The molten aluminium is cast again, into ingots weighing 16 and 4 kilograms, as well as tiles for rolling into sheets, or long sticks for making rods and wire.

The plasticity of aluminium decreases drastically when there is even a small amount of impurities. This means that recast primary aluminium cannot be used to make foil. Impurities also decrease the conductivity of aluminium; therefore, this metal also cannot be used in electronics. Purer metal (99.99%) can be obtained by the electrolytic *refinement method* which involves electrolysis of hydrous solutions or molten salt. It is based on the greater chemical activity of the metal that first oxidizes during electrolysis. Therefore, if aluminium containing impurities of iron and copper is used to make an anode and put in an electrolytic bath, then

Refined aluminium ingots



Secondary use of aluminium

Unlike steel, aluminium does not corrode, and therefore materials made from it can be reused as secondary raw materials. Aluminium and many of its alloys can be repeatedly fused with a loss of any mechanical properties. All around the world, dealers collect aluminium refuse, supplying it to recycling factories, where refuse is used to produce new aluminium alloys. Obtaining aluminium from earlier alloys can at times present a difficult challenge. Besides simple substances, many alloys also contain intermetallic compounds, or chemical compounds of two or more metals. Scientists have considered various ways of purifying aluminium from intermetallic compounds. One method proposed to harden the molten metal and then “clean out” intermetallic compounds under a pressure of more than 1,000 bars into a magnetic field with a pressure of more than 300 Tesla. This method turned out to be the most effective when reworking car bodies. The density of most intermetallic compounds is much greater than that of aluminium, and this property can also be used to separate them.

According to the International Aluminium Institute, in 2006 the volume of secondary aluminium production worldwide reached 16.4 million tons, while 33,965 thousands of tons (Brook Hunt) of primary metal were produced.

Over the last decade, the volume of secondary aluminium production worldwide has increased by 64%, while the volume of primary production has only grown by 27%. The International Aluminium Institute estimates that about 400 million tons of aluminium have accumulated in infrastructure, appliances and transport. In 2006, the manufacture of secondary aluminium in Russia reached about 670 thousands of tons (UC RUSAL). Many countries have set up a system for collecting everyday aluminium refuse, including soft-drink cans. Scientists have calculated that recycling one kilogram of aluminium cans saves 8 kilograms of bauxite, 4 kilograms of various fluorides and 14 kW hours of electricity.

At the present aluminium can is the most civilized and effective form of packaging: it is environmentally friendly and has the minimal weight, and it is inexpensive to produce and transport. Each year, more than 220 billions of drink cans are produced worldwide each year. More than 90% of them in Europe and 80% in Russia are processed from secondary aluminium. Every other bank in the world is produced from it. These are the best figures for packaging materials. Processing aluminium packaging makes it possible to reduce the damage that is afflicted on the environment by the perennially increasing disposal of household waste.

Secondary aluminium is used in other sectors as well, such as construction and the auto industry. ■



Pressed aluminium cans

the molten metal will collect ions of aluminium only, and atoms of impurities will gradually settle on the bottom near the anode. During as the process continues, aluminium ions will once again turn into metal as they are charged on the cathode.

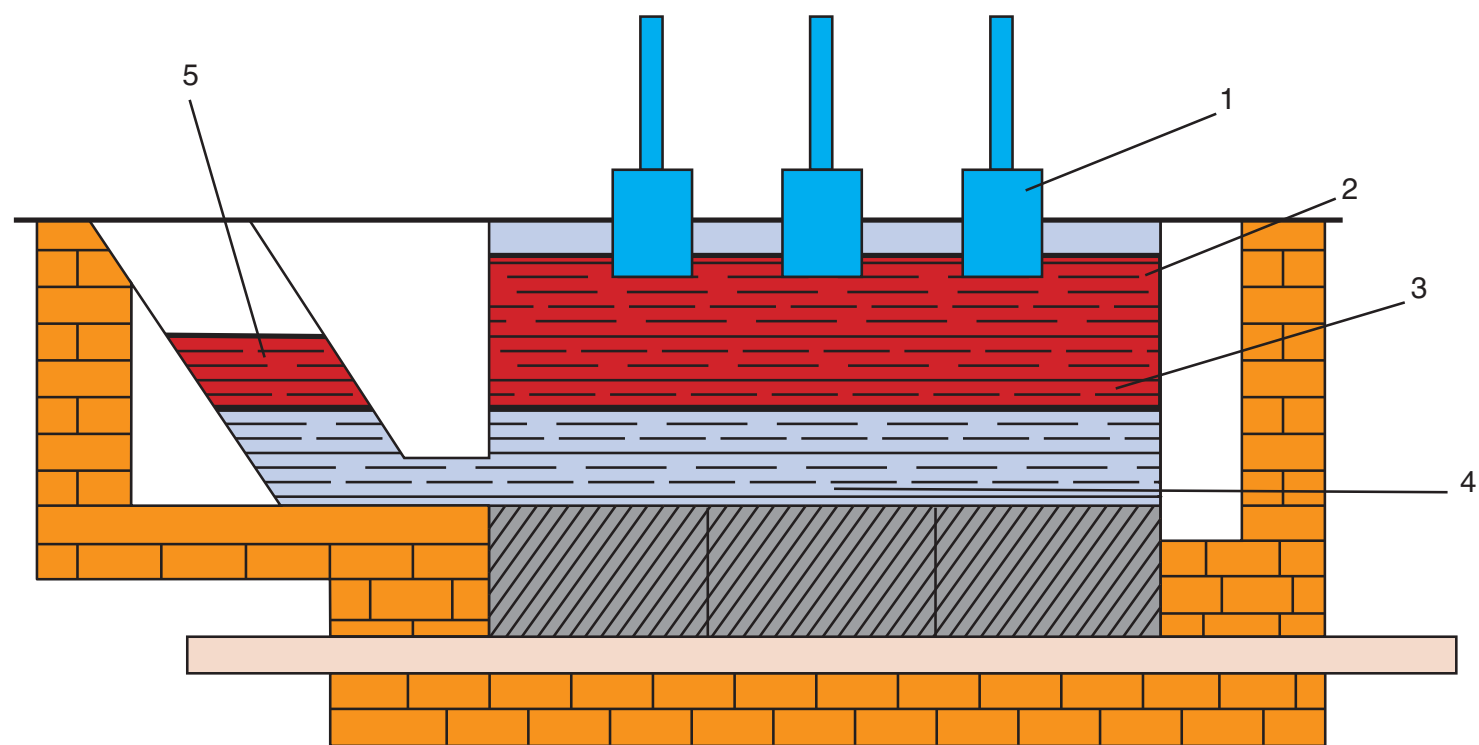
The electrolysis bath used for refining resembles Hall's bath for obtaining metal. The difference is that its cathode is at the top, and the anode at the bottom. Refining with the method of three-layered electrolysis weighs down the raw aluminium with additions of copper, so it sits at the bath's bottom and acts as an anode. Above it is a layer of electrolytic fluid, and even higher – pure molten aluminium, which serves as a cathode. Using this method, first applied in 1919, it is important to select electrolytic fluid of the density, so that it is no lighter than the anode's alloy of aluminium with

copper, but heavier than pure aluminium. The patent of the French company Pechiney from 1932 proposed using a mixture of 17% sodium fluoride, 23% aluminium fluoride and 60% barium chloride as the electrolytic fluid. At temperatures of 950–1000°C with a current of 20 kA, the process yields 99.98% pure aluminium.

To obtain purer metal, smelters use electrolytic fluid containing sodium fluoride and organic metal compounds of aluminium, such as triethyl aluminium. Then technologies apply the so-called molten zone method – they slowly transfer the narrow zone of the molten metal down a long ingot. The recrystallization process results in a redistribution of admixtures, yielding particularly pure aluminium, with a purity of up to 99.999%.

CELL FOR REFINING ALUMINIUM

1 – graphite electrodes, 2 – pure aluminium, 3 – electrolytic fluid, 4 – raw aluminium with copper added (anode), 5 – reservoir for separating pure aluminium



Chapter 6

A Metal Resembling Tin in Color and Luster

Thirteenth Element

Here it is – the most mysterious, surprising, and promising metal! Why is it so? What properties of aluminium have made it play such a special role in history?

It has been known for some time that all substances consist of atoms. The atom resembles a miniature solar system. The atom's nucleus is like the sun. Electrons revolve around it, somewhat like planets revolve around the sun. Like the solar system, an atom consists mostly of empty space. Every substance has a particular number of electrons that revolve around the nucleus or "sun." Atoms also contain positively charged particles called protons and neutral particles. We will return to this a little later.

Initially, Russian chemists used the term alummy (aluminium) instead of aluminium (F. Gize, 1813); I first encountered the word alyuminy (aluminium) in 1820 in I. Dvignubsky's scientific journal Novy magazine published in Moscow. A.I. Sherer (1823) and M.F. Solovyev (1824) also employed this term. Yet N.P. Shcheglov subsequently proposed glinozem (from glinozem "alum earth"), and G.I. Gess, gliny (from glina "clay") in 1834, and these terms were used up to the early 1870s. Alyuminy (aluminium) began to appear in our books in 1862 (cf. Egorov's translation of Regnault's chemistry textbook). Al has always been used as the symbol for aluminium.

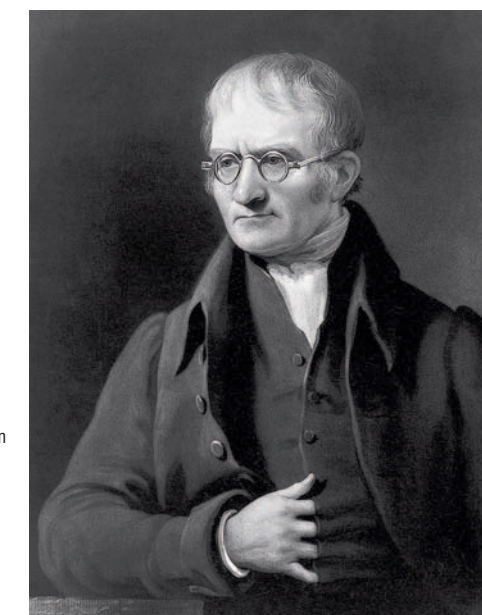
Nikolai Menshutkin, "Analiticheskaya khimiya", 1908

A grouping of atoms of one type is called an *element* in chemistry. Each element has a place of its own in Mendeleev's periodic table; Aluminium occupies the thirteenth cell. One may think, "What an unlucky number!" Yet this is not the case. Firstly, the atomic number is not a simple convention. It indicates the number of protons in the nucleus as well as the number of electrons around it. Thus, an aluminium atom has 13 protons and 13 electrons.

The Size of the Aluminium Atom

How big is the aluminium atom? Although this would seem to be a simple question, the answer is extremely complicated.

In the 19th century, atoms were believed to be spheres of a fixed diameter. This is how John Dalton, the founder of the atomic-molecular theory, imagined them to be. He was the first to construct models of molecules using wooden balls and showed them at his



John Dalton

lectures. One story goes that, when a student of his was asked what atoms are, he answered that they are the wooden balls that were invented by his professor. On paper, Dalton depicted atoms in the form of circles with symbols in the center. However, aluminium was not included in the first table that Dalton drew up in 1803. The second and expanded version of the table mistakenly contained the earth alumina, which for some reason Dalton grouped among chemical elements along with magnesia and certain other substances. The discovery of aluminium, which we

Atoms also have a certain number of neutrons – neutral particles that are also located in the nucleus. The sum of the number of protons and neutrons is equal to the so-called mass number. An atom with a given mass number is called a nuclide. Interestingly, an element can have several different nuclides, each of which contains a different number of neutrons. Such particles are called isotopes.

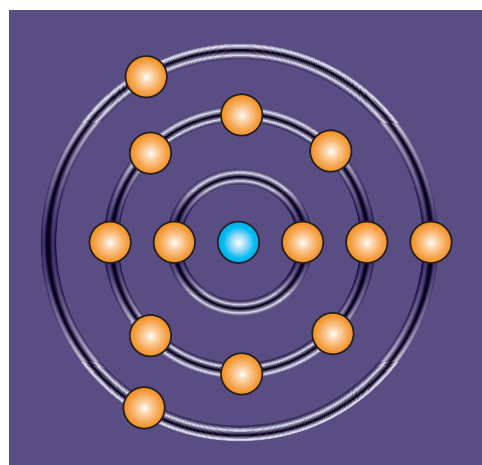
There is only one stable isotope of aluminium in nature; its nucleus has 13 protons and 14 neutrons. Thus it has a mass number of 27.

All the other isotopes of aluminium are unstable, in that their nuclei spontaneously decay over time, turning



Nuclide of aluminium-27

Atom of aluminium
electron
nucleus



the atom's orbital radius – R_{orb} (Fig 1, p. 107). Aluminium has an orbital radius of 0.1312 nanometers (1 nanometer or nm is one-billionth of a meter). There is another way of determining the radius of an atom. If two identical atoms are linked by a chemical bond, their radius is said to be equal to one-half of the distance between them. For aluminium, this radius called the covalent radius – R_{cov} (Fig. 2, p. 107) – is 0.125 nm. Finally, metals have a “metallic radius R_{met} (Fig. 3, p. 107).” It is equal to one-half of the shortest distance between atoms in the metal structure with the most compact arrangement. The metallic radius of aluminium is 0.143 nm. Ionic radii also have different values depending on how they are defined or calculated. However, in the case of aluminium, they are always smaller than the metallic radius, for the radius of an atom always decreases when electrons are lost. ■

described in preceding chapters, allowed the Swiss chemist Berzelius to give it the symbol that we still use today (Al). Dalton's atoms could be measured, for they were spheres with a fixed diameter. But what about the real atom? In its center, it has a nucleus that is surrounded by electrons. In contrast to protons and neutrons, electrons have an extremely small mass and are therefore “spread out” in space around the nucleus; it is impossible to trace their trajectory. Scientists only speak about the probability of finding an electron in a given place around the nucleus. The distance between the center of the nucleus and the most probable location of the electron that is farthest removed from the nucleus is called

into nuclei of other elements. This decay is accompanied by the emission of hazardous gamma rays. This means that aluminium isotopes are radioactive.

Aluminium-26 (aluminium with a mass number of 26) lives the longest. Its half-life (the time it takes for half of its atoms to decay) is almost a million years. Heavier nuclides with mass numbers 23, 24, 25, 28, and 29 live very briefly – from 0.13 to 396 seconds. For example, aluminium-28 atoms spontaneously emit an electron, turning into silicon, which follows aluminium in Mendeleev's periodic table.

Electrons are arranged in an interesting way in the aluminium atom. They are located in three energy shells. Two electrons are located in the first shell next to the nucleus, and there are eight in the second. All of these electrons are inner electrons; in other words, they are closely connected to the nucleus. It takes far more energy to detach them from the atom than any chemical reaction can provide. The remaining three electrons are located in the outer energy shell. They are called valence electrons. The atom can lose them during chemical reactions. During this process, the atom turns into a positively charged ion – a “cation.” The process itself is called oxidation.

It requires energy to detach electrons from their “parent” atom. This energy is compensated by the energy that is emitted during the formation of new chemical bonds. As a result of these constant transformations, the aluminium atom has a positive oxidation number from +1 to +3.

The highest oxidation number of +3 is the most stable. The reason for this is that when the aluminium atom gives up three electrons it receives the electronic configuration of the noble (or inert) gas neon, which has two electrons in the inner shell and eight in the outer shell.

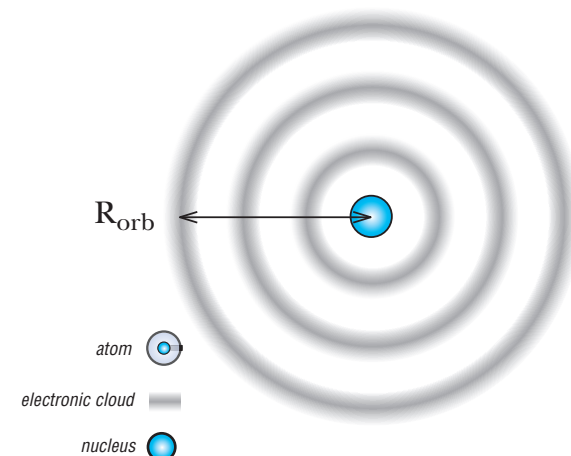


Fig. 1

Atomic radii

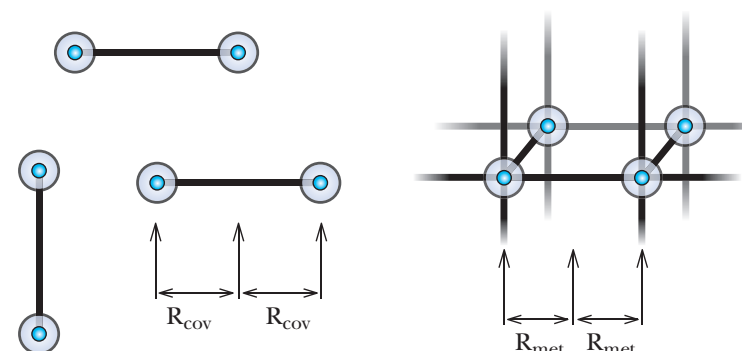


Fig. 2

Fig. 3

The material bodies and objects around us are made of substances. For example, a pot (object) is made of aluminium (substance). Each substance has a unique range of properties, including colour, density, smell, and melting point, which characterise it alone. Every substance is described by a chemical formula that shows the elements of which the substance consists (its qualitative make-up) and the relation in which they stand (its quantitative make-up). For example, aluminium oxide (Al_2O_3) consists of aluminium and oxy-

gen atoms (qualitative make-up) in the ratio 2:3 (quantitative make-up).

A substance consisting of one type of atom is said to be simple, while a substance consisting of different types of atoms is said to be compound. Aluminium is a simple substance, while aluminium oxide (Al_2O_3) is a compound. Metals are simple substances. They have a number of common properties: they are shiny, ductile, and malleable and are good thermal and electric conductors.

Compound substances are called chemical compounds. They are divided in turn into organic and inorganic compounds. Organic substances are compounds containing carbon, except for the simplest compounds such as carbon dioxide (CO_2). All other substances are called inorganic.

A hierarchy exists here, too. The simplest compound substances are binary compounds. They consist of atoms of two different elements only. Compounds with oxygen are called oxides, compounds with nitrogen nitrides, compounds with carbon carbides, and compounds with hydrogen hydrides. Many binary compounds are formed from the interaction of simple substances.

Aluminium Festival at Moscow State University



Memorial badge in honor of the Chemist's Day

For over forty years, the Department of Chemistry at Moscow State University has celebrated Chemist's Day on the second Saturday of May. Every year this festival is devoted to a certain chemical element. Hydrogen was celebrated on the first Chemist's Day, and molybdenum (atomic number of 42) on Chemist's Day 2007. Chemist's Day 1978 was dedicated to aluminium. Meticulous preparations are made for every celebration, particularly for the show which takes place in front of the Department of Chemistry. It is followed by games and contests. Winners get prizes such as pins, tee shirts, and umbrellas bearing the symbol of the element of honor. ■

Physical Properties

Most people know what aluminium looks like. It is a light, malleable and easily fusible silvery white metal. Yet who knows what the crystal lattice of the thirteenth element looks like?

It is a cube with centered faces. The word “centered” means that the aluminium atoms are located not only at the vertices but also in the center of each face. This is the densest arrangement: each aluminium atom has 12 “neighbours” – six in the same plane, three above, and three below. Of course, aluminium can contain admixtures, yet they have an insignificant impact on the size of the aluminium crystal lattice.

The density of aluminium of 99.996% purity measured at 25°C is 2,698.0 kg/m³. When the metal is heated, its density becomes lower. Molten aluminium (a mercurial silvery liquid) is 6.6% less dense than solid aluminium.

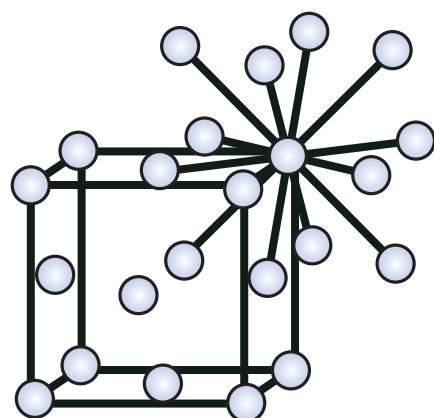
If aluminium foil is held in a flame, it changes form. Aluminium melts yet does not flow. This is because its surface becomes covered with a very thin oxide film that is only 2·10⁻⁵ cm thick and protects aluminium from oxidizing with atmospheric oxygen and from reacting with water. Another important property of this film is high electric resistance. This is no surprise, for aluminium oxide is a dielectric. It has been experimentally shown that it takes around 500 V to break through even a thin film.

Measurements performed in 1968 showed that the melting point of pure aluminium is 660.37°C. Primary aluminium has a lower melting point: 658°C. Aluminium boils at a temperature of 2,494°C. Its boiling point also depends on the metal’s purity.

Aluminium is one of the most popular metals. It ranks second after iron in this respect. Yet, in compari-

son to the latter, it is lighter in weight (almost three times lighter than steel), a better thermal and electrical conductor, and corrosion-free. The electrical conductivity of aluminium is 62–65% (depending on purity) of the electrical conductivity of copper. At the same time, aluminium is three times lighter than copper, and so one needs 2.16 times less aluminium than copper to manufacture electric wire. This means that aluminium

Elementary cell of aluminium



wire is cheaper than copper wire. As Academician Iosif Fridlyander wrote, “The use of aluminium electric wire makes it possible to build electric poles at a great distance from each other, while aluminium electrical coils in the rotors of electric machines reduce their weight.”

Aluminium is fashioned by pressure whether it is hot or cold. It can be rolled, drawn, and stamped. It is ductile: it can be used to make sheets with a thickness of 0.638 microns as well as extremely thin wire. Ultra-thin aluminium foil is three times thinner than a human hair! In his *Principles of Chemistry*, D.I. Men-

Aluminium is typically white in color and similar to tin, i.e., it is greyer than silver; its luster resembles the weak dull luster of tin. Nevertheless, aluminium is fairly hard in contrast to tin and pure silver. It has a density of 2.67 and is therefore almost four times lighter than silver and almost three times lighter than copper. It melts in the lower red heat range (658.7°C, Day and Sosman, 1912), oxidizing little in the process. It tarnishes at room temperature in air due to the formation of a thin layer of aluminium oxide on its surface. It inflames with a lot of difficulty when heated if it is taken in the form not of continuous masses but of thin sheets, into which it can be beaten, or fairly thin wire. It emits an intense white light when it burns, for it forms a refractory and non-volatile oxide. Approximately 350,000 cal are emitted per 102 g of Al₂O₃. It is non-volatile when heated in furnaces. These properties make Al an excellent reducing agent; for example, N.N. Beketov has shown that Al reduces the oxides of alkali metals.

D.I. “Mendeleev, Principles of Chemistry”, 1906

deleev wrote that aluminium is most ductile at a temperature of 100–150°C, at which it “can be easily rolled even into foil; above 500°C, it becomes brittle and can be ground up.”

Aluminium is known for its high reflectivity. It is therefore used in the production of mirrors, reflectors,

and large television screens. However, the formation of an oxide film (which appears as soon as aluminium comes into contact with air) reduces the reflectivity of aluminium. It has been shown that an oxide film with a thickness of 0.1 microns reduces the reflectivity of aluminium by 20–30%.

The Chemical Properties of Aluminium

A thin oxide film instantaneously forms on the surface of aluminium in air. For this reason, aluminium is not subject to corrosion, and aluminium objects (e.g., pots) can be heated over an open flame. However, aluminium powder combusts in a burner flame, releasing a lot of heat and turning into white smoke (the oxide Al₂O₃). This property of aluminium is at the root of the so-called “burning bar”: oxygen and a mixture of aluminium and iron powders are fed under pressure into a steel pipe. The energy released during their combustion is so great that it can be used to cut apart three-meter blocks of concrete. Aluminium powder is also used in fireworks.

Aluminium reacts very violently with halogens (fluorine, chlorine, bromine, iodine, and astatine). The reaction with chlorine is rapid only when heat is added, while the reactions with bromine and iodine take place at room temperature.

The reaction of aluminium with bromine is very striking. It suffices to put a small piece of aluminium foil into a test tube with bromine. A violent reaction will soon begin: the aluminium melts because of the heat released, turning into a white-hot sphere that whirls on

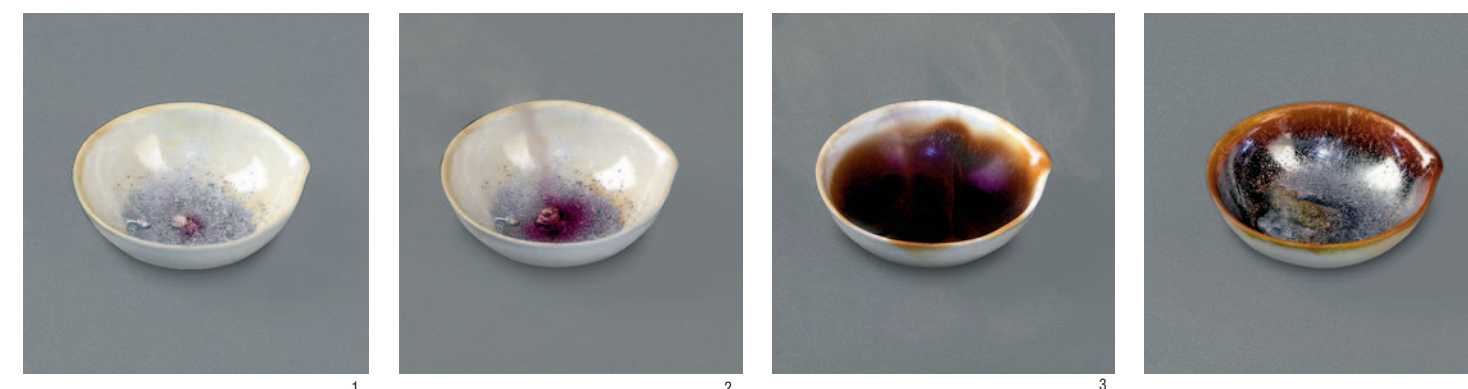
the surface of the bromine and produces white sparks. The bromine in the test tube boils, and a yellowish powder gradually precipitates on the tube walls. This is aluminium bromide (AlBr₃).

To make aluminium react with iodine, a few drops of water are added to a freshly prepared mixture of aluminium dust and iodine powder. A lot of heat and an even larger amount of violet iodine vapor are released in this process, too. The aluminium sometimes ignites.

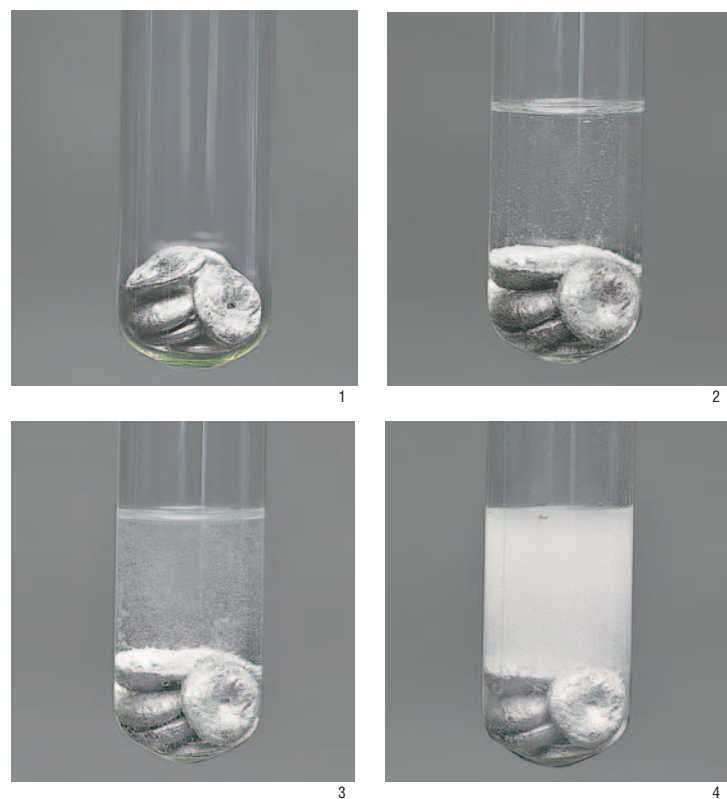
Aluminium reacts rapidly with certain other non-metals such as sulfur and selenium when heated. If a mound of aluminium powder mixed with sulfur is placed on an asbestos plate and ignited, it instantaneously inflames, producing a dazzling flash of light. White powdery aluminium sulfide (Al₂S₃) remains in place of the mixture.

Aluminium reacts with nitrogen only at temperatures above 800°C, forming aluminium nitride (AlN).

The reaction of aluminium with carbon leads to the formation of aluminium carbide (Al₄C₃). Interestingly enough, aluminium carbide was prepared for the first time by heating pieces of aluminium and carbon in



Reaction of aluminium with iodine, accompanied by heat and iodine vapor released

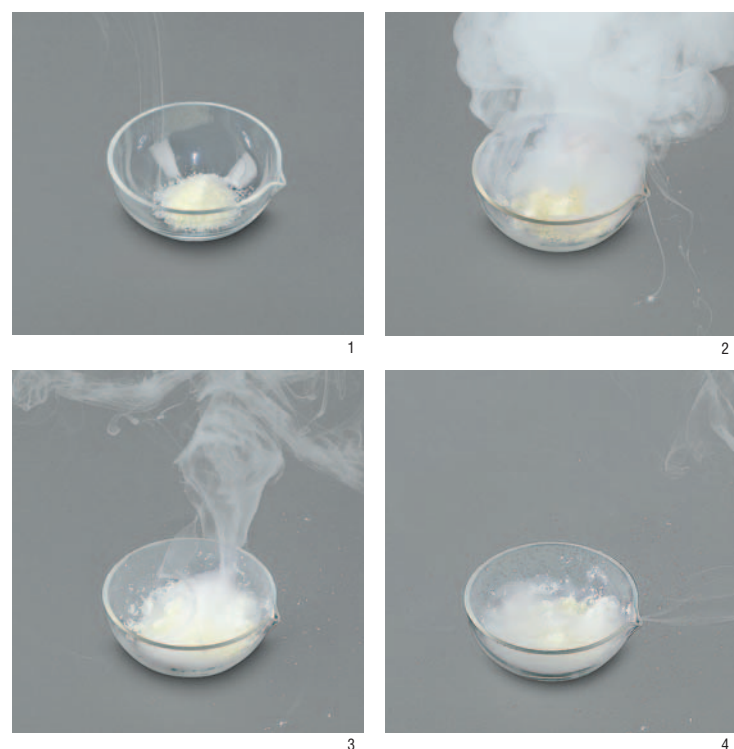


Reaction of aluminium with acids, accompanied by isolation of hot gas hydrogen

Aluminium Chloride

This substance is formally a salt of hydrochloric acid and can be studied along with other salts such as sulfates and nitrates. Indeed, the reaction of aluminium or its hydroxide with hydrochloric acid leads to the formation of a solution from which white crystals of the hydrate $\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$ can be precipitated in a strong acidic medium. Anhydrous aluminium chloride AlCl_3 is another matter altogether. It can hardly be called a salt. This substance has the form of transparent scaly crystals that fume in the presence of air and vaporize when heated to a temperature of 183°C (omitting the melting stage). Water breaks down the crystals, releasing a lot of heat. Anhydrous aluminium chloride is obtained by reacting aluminium with chlorine or gaseous hydrogen chloride as well as by chlorinating mixtures of corundum and carbon. Until the invention of the electrolytic method of aluminium production, aluminium chloride had an important commercial role: it was used to produce the double chloride Na_3AlCl_6 that was reduced by sodium (Sainte-Claire Deville process). When stored for a long time in air, aluminium chloride, as well as the double salt, turn into alum earth. The use of such a dissociated substance is what led people to discover the production of aluminium from alum earth and then from bauxites. The idea of producing aluminium from aluminium chloride continues to attract scientists, who continue to propose new technologies for implementing it. (Some of them have already been described in Chapter 3.) ■

Reaction of waterless chloride of aluminium with water (reaction is so violent that part of water becomes vapor)



a carbon crucible. Aluminium carbide begins to form at a temperature of 650°C , although the reaction is only completed at $1,200^\circ\text{C}$.

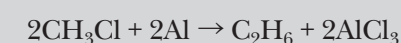
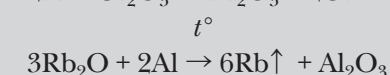
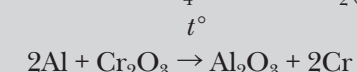
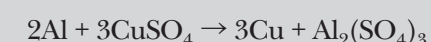
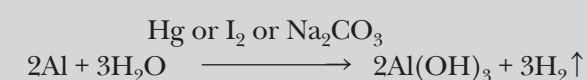
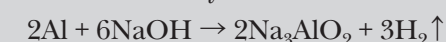
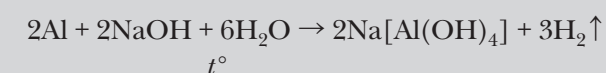
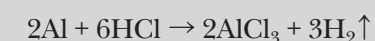
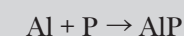
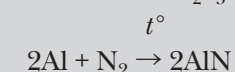
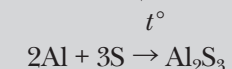
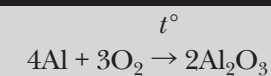
Although aluminium does not react directly with hydrogen, it easily liberates it from acid solutions (e.g., sulfuric and hydrochloric acids). Concentrated sulfuric and nitric acids do not react with aluminium at low temperatures. Aqua regia (a mixture of nitric and hydrochloric acids) easily oxidizes aluminium.

Aluminium is also used to reduce metals. The gist of this method can be described as follows: a mixture of a metal oxide and aluminium is combusted, and the metal is reduced to its pure state. If the oxide is present in excess, the resulting metal will contain almost no aluminium. This method is called "aluminothermy." It is used for obtaining chromium, vanadium, and manganese.

Aluminothermy generates a lot of heat. This property is used for welding pipes, railroad tracks, and other metal structures with the help of Thermit – a mixture of iron scale (Fe_3O_4) and aluminium powder.

The aluminothermic reaction was discovered by Nikolai N. Beketov. He described his experiments on the reduction of aluminium (or "glinium," as it was called back then) by barium and potassium in his 1859

THE FUNDAMENTAL ALUMINIUM REACTIONS



article "On Certain Reduction Phenomena" and then in greater detail in his dissertation. Beketov also used this method for obtaining other chemically active metals. For example, at a meeting of the Chemistry Section of the Russian Physics and Chemistry Society in St. Petersburg, he spoke about the production of metallic rubidium. Later, Beketov used the same method to obtain cesium. In 1894, Goldschmidt in Germany was the first to use aluminium to reduce iron directly from iron ore. To ignite the mixture, he used special cartridges that burned very quickly and violently. Still, it is Beketov who is credited with discovering aluminothermy.

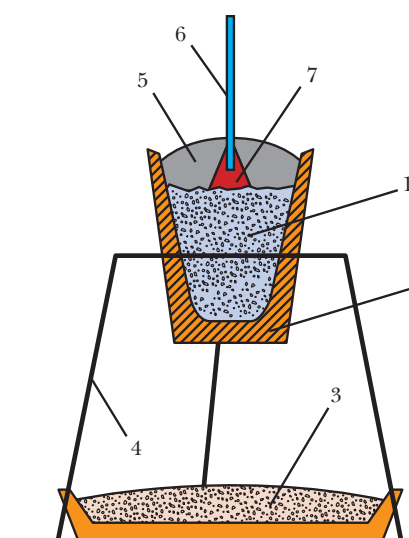
Aluminium reacts very violently with alkali solutions and molten alkalis, releasing a lot of hydrogen. The

Reduction of Potassium by Aluminium

"Just as barium is easily reduced by aluminium, aluminium is easily reduced in turn by magnesium bonded with fluoride (from synthetic cryolite that I produced), as I also know from experience. "Given that aluminium reduces metals from their oxides, one should expect it to have such an effect on potassium oxide. I performed the experiment in a bent rifle barrel, in whose closed end I put pieces of caustic potash and aluminium. Potassium vapors appeared at a fairly high temperature; most of them condensed in the cold part of the barrel. From the latter, I obtained several small pieces of soft metal that floated on water and burned with a violet flame: in other words, they had all the characteristic properties of pure metallic potassium. I did not repeat this experiment on a large scale. Nevertheless, it may turn out to be convenient in practice, for the price of aluminium is fairly low, while the reduction apparently takes place a lot easier even at lower temperatures than the reduction of potassium by iron."

Nikolai Beketov, Research on the Displacement Phenomenon in Metals. Extract from his Ph.D. dissertation. Kharkov, 1865 ■

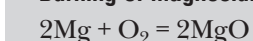
CRUCIBLE FOR ALUMINOTHERMY



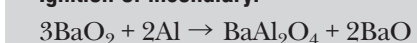
- 1 – Thermite ($\text{Fe}_3\text{O}_4 + \text{Al}$)
- 2 – Chamotte crucible
- 3 – Tray with sand
- 4 – Tripod
- 5 – Flux (CaF_2)
- 6 – Magnesium ribbon
- 7 – Incendiary ($\text{BaO}_2 + \text{Al}$)

ALUMINOTHERMY

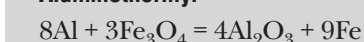
Burning of magnesium:



Ignition of incendiary:



Aluminothermy:



Metallic aluminium does not dissociate water at room temperature. However, if one adds a little iodine or hydrogen iodide and iodine or aluminium iodide and iodine to the water, hydrogen is released in large quantities. This reaction clearly occurs as a result of the temporary formation of AlJ_3 , which combines with water to give alum earth hydrate and HJ , which (along with Al) breaks off hydrogen, forming AlJ_3 once again. ...

"As an example of the easy oxidation of aluminium, let us note that, if mercury gets onto the metallic surface of aluminium and especially if mercury is rubbed into aluminium dipped in a weak acid, Al quickly oxidizes (turns into Al_2O_3). This reaction is accompanied by the striking appearance of a sort of wool (or down) consisting of the threads of aluminium oxide that grow on the metal. ... This instructive and easily reproducible phenomenon results in the formation of alum earth. It does not take place in a nitrogen atmosphere yet occurs in a few minutes in air.

D.I. Mendeleev, "Principles of Chemistry", 1906

reaction takes place fairly slowly at first. However, if the heat supply is not removed in time, the hydrogen may ignite. The products of the reaction of aluminium with alkalis are called aluminates.

When stripped of its oxide film, aluminium reacts actively with water. For this reason, when scientists take aluminium out of the cell, they make sure that there is no moisture nearby. Otherwise, the molten metal can explode. Finely ground aluminium powder actively displaces hydrogen from boiling water.

Can an aluminium spoon, for example, dissolve in water? The oxide film that protects aluminium forms instantaneously in air, and it is virtually impossible to remove it without special equipment. In the laboratory,

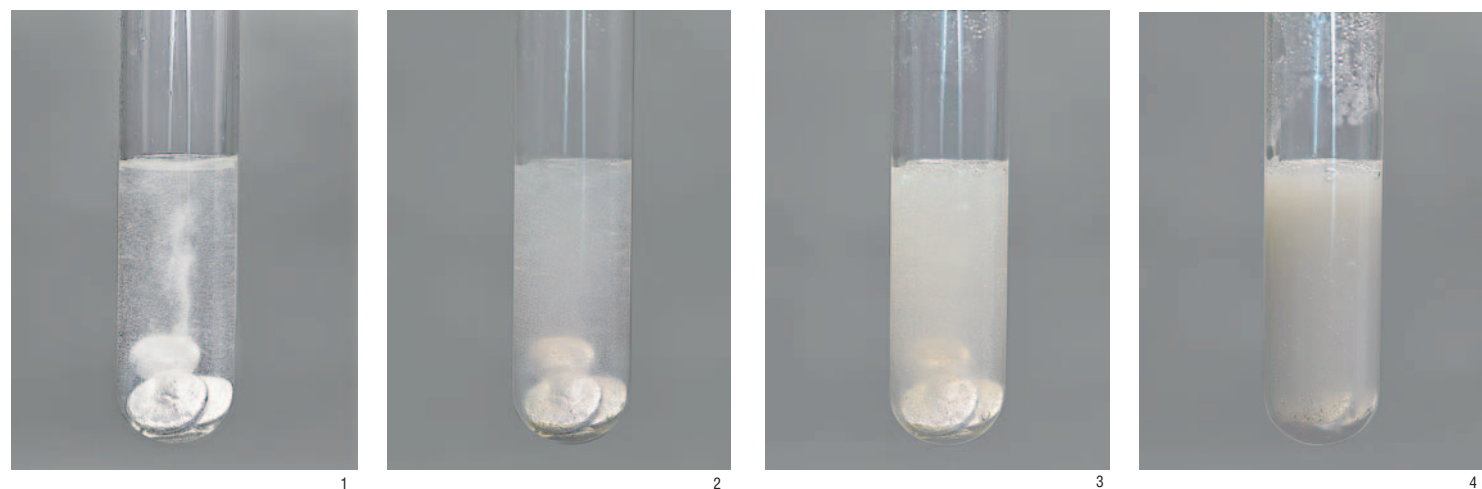
it is removed by amalgamation or by treating the metal's surface with a solution of mercury salt.

The oxide film flakes off easily from the amalgamated (mercury-coated) surface. The metal without the protective film oxidizes quickly in air already at room temperature: white oxide fibers grow on it like a beard. If amalgamated aluminium is placed in a glass of water, one observes the formation of gas bubbles and white flakes that sink to the bottom.

It therefore suffices to remove the oxide film from an aluminium spoon in the laboratory to dissolve the spoon in water. It is a good thing that this cannot be done at home: after all, it would be difficult to eat soup when you know that your spoon can melt at any moment!

It is also possible to remove the protective film from aluminium by reacting it with the salt of copper or another low-activity metal. Russian scientists discovered that aluminium alloyed with gallium, indium, and tin (i.e., aluminium with small admixtures of these metals) does not develop an oxide film, i.e., it is "vulnerable" not only to such strong oxidizing agents as oxygen but also to water. One gram of such an alloy actively reacts with water, displacing over a litre of hydrogen!

On the other hand, is it possible to make the oxide film thicker without damaging the metal's surface? It is, indeed: it suffices to use aluminium as an anode for electrolyzing a dilute solution of sulfuric acid. The oxygen released during electrolysis will oxidize the metal's surface. This process is called anodizing. The thickness of the resulting "oxide armor" can attain 0.15 mm.



Reaction of finely ground aluminium with water (in the process of this reaction hydrogen is displaced, while aluminium particles are covered with white powder of hydroxide $Al(OH)_3$)

The Chemical Compounds of Aluminium

Aluminium is the most widespread metal in the earth's crust. It is chemically active and therefore does not occur in pure form naturally. At the same time, it forms a lot of compounds. It is mostly found in the form of aluminosilicates. Their decomposition leads to the formation of bauxites with which the reader is already familiar.

Let us try to get an idea of the numerous compounds of this remarkable metal.

Oxides. The oxide Al_2O_3 plays an important role in the chemistry of aluminium. It exists in the form of several crystal modifications. The most stable modification is called corundum. This is a white crystalline powder that is insoluble in water and melts at a temperature of over $2,000^\circ C$. When molten corundum congeals, it turns into a transparent vitreous mass. It has a hardness of nine on a ten-point scale (which makes it second only to diamond).

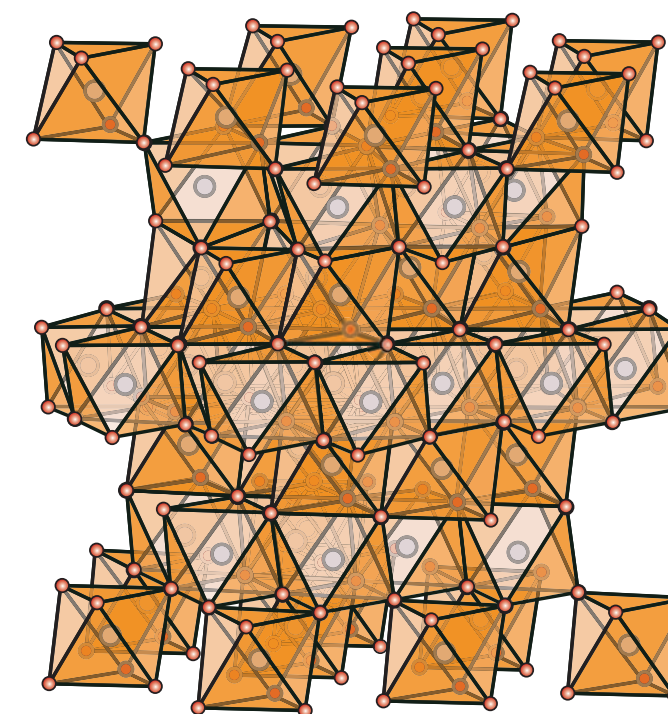
Another modification of aluminium oxide that is called γ -aluminium oxide is similar to it in appearance yet has very different properties. It absorbs water easily. The absorption of water by the surface of the aluminium oxide is accompanied by the release of heat. Even when it looks dry, powdered γ -aluminium oxide is covered by a very thin layer of water that is only a few molecules thick.



Other aluminium-oxygen compounds are known besides aluminium oxide. We are referring to the lowest oxides with the formulae Al_2O and AlO . Both of these





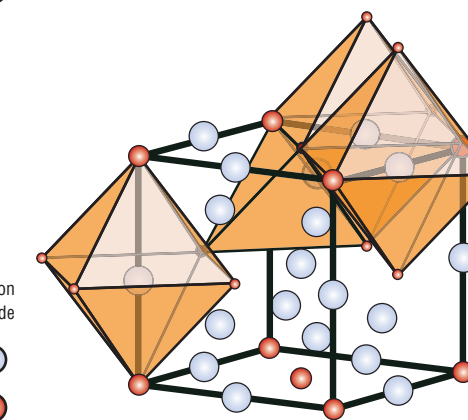
Powder of aluminium oxide

Oxide of aluminium Al_2O_3



Structure of corundum
Aluminium 
Oxygen 
Corundum structure can be displayed as a aluminium-oxygen octahedrons linked by common ribs and vertices in a three-dimensional frame.

Structure γ -modification of aluminium oxide
Aluminium 
Oxygen 



γ -aluminium oxide, compared with corundum, has a loose structure, and that explains large surface area, the ability to absorb moisture from the air and the catalytic activity of this compound. ■

substances were first obtained in the 1950s by reducing corundum with aluminium. Scientists heated a mixture of corundum powder and aluminium. To follow the course of the reaction, they X-rayed the crystalline substance. The X-rays diffracted from the atoms, making a series of sharp lines on the photographic plate (X-ray diagram). Amorphous substances as well as liquids and gases do not give X-ray diagrams: they are X-ray amorphous. The X-ray diagram of each substance is so unique that it allows the substance to be distinguished from thousands of others. Chemists frequently compare it with fingerprints that are used by police officers to identify people.

Hydroxides. Aluminium forms several hydroxides and oxide-hydroxides. Their dissolution in acid solutions leads to the formation of aluminium salts such as alu-



Gibbsite

minium sulfate, aluminium nitrate, and aluminium chloride. The dissolution of aluminium hydroxide in alkali solutions results in the formation of hydroxide aluminates.

The acidification of an aluminium solution leads to the precipitation of aluminium hydroxide. Scientists have identified three modifications of aluminium hydroxide. The most stable modification is called gibbsite. Gibbsite crystallizes out of solutions in the form of very thin hexagonal plates. It occurs in nature in the form of small colourless tabular crystals as well as white crystalline masses with a pearly luster.

All crystal modifications of aluminium hydroxide dissociate when heated, resulting in boehmite, which serves as a source of aluminium oxide (if it is heated further, it turns into aluminium oxide). $\gamma\text{-Al}_2\text{O}_3$ forms at low temperatures. At a temperature of 900°C , it turns into corundum, i.e., $\alpha\text{-Al}_2\text{O}_3$.

More about Bauxites

Bauxite, a major aluminium ore, consists of the three different forms of aluminium hydroxide and oxide-hydroxide: gibbsite (hydrargillite), boehmite, and diaspore. All natural bauxite derives from the colloidal form of aluminium hydroxide (alumina gel). It can contain different quantities of water, which it loses over time, turning into a more stable crystalline substance. Corundum is the end product of the dehydration of bauxites. Thus the type of bauxite depends on the age of the rock. Diaspore bauxites are considered to be the oldest, and hydrargillite bauxites to be the youngest. Hydrargillite predominates in tropical zones. It is the principal constituent of bauxite raw materials stemming from Guiana, west Africa, and Indonesia. French bauxites from Les Baux are composed of virtually pure boehmite. Bauxite raw materials from the Balkans are a mixture of boehmite with diaspore or hydrargillite. Bayerite, which is seldom found in nature, has even been discovered in a Hungarian mine. Bauxites from the north Urals contain boehmite and diaspore. In the middle Urals, only a few fairly small deposits of hydrargillite bauxites have been found. Deposits of boehmite and diaspore bauxites occur in the south Urals. Volkhov bauxites, which served as raw materials for the first Russian aluminium smelters, are low in quality. They have a varying composition, and certain rocks are composed of kaolin with an admixture of boehmite. Raw materials mined in the vicinity of Tikhvin are much better: they contain hydrargillite and boehmite. Certain bauxites contain up to 0.01% of gallium oxide (gallium is the closest relative of aluminium in the Periodic Table). ■

Aluminium salts. The reaction of aluminium oxide with the oxides of metals produces aluminates.

The dissolution of aluminium hydroxide in acid leads to the formation of salts that contain molecules of water. They are colourless crystalline substances that dissolve well in water.

Aluminium sulfate is another important aluminium salt. It is obtained from aluminium hydroxide by dissolving it in sulfuric acid. The salt dissolves well in water, especially when heated. The addition of a solution of potassium sulfate to a saturated solution of aluminium sulfate leads to the formation of crystals of potash alum $\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$. There are also other alums in which

MODERN CLASSIFICATION OF ALUMINIUM COMPOUNDS

I class	Binary Compounds with Compounds with Nonmetals <ol style="list-style-type: none"> 1. Oxides: Al_2O_3, Al_2O, AlO 2. Nitride: AlN 3. Carbide: Al_4C_3 4. Phosphide: AlP 5. Silicide: AlSi 6. Borides: AlB_{12}, AlB_{31} 7. Hydrides: AlH_3 8. Chalcogenides: Al_2S_3, Al_2Se_3, Al_2Te_3 9. Halides: AlCl_3, AlF_3, AlI_3, AlBr_3, AlI
II class	Intermetallics CuAl_2 , Al_2MgLi , $\text{Al}_2\text{Mg}_2\text{Cu}$
III class	Hydroxides <ol style="list-style-type: none"> 1. Hydroxide: $\text{Al}(\text{OH})_3$ 2. Oxyhydroxides: AlOOH
IV class	Aluminium salts <ol style="list-style-type: none"> 1. Sulfate: $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ 2. Chloride: $\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$ 3. Phosphate: AlPO_4 4. Potash alum: $\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ 5. Cryolite: $\text{Na}[\text{AlF}_3]$
V class	Aluminates <ol style="list-style-type: none"> 1. Mixed oxides: MgAl_2O_4, $\text{Y}_3\text{Al}_5\text{O}_{12}$ 2. Saltlike: NaAlO_2, K_3AlO_3 3. Hydroxocomplexes: $\text{Ba}_3[\text{Al}(\text{OH})_6]_2$
VI class	Metallorganic compounds $(\text{CH}_3)_3\text{Al}$

the potassium ions are replaced by univalent sodium, ammonium, rubidium, cesium, or thallium ions and aluminium ions are replaced by trivalent chromium, iron, manganese, vanadium, or titanium ions. All the resulting salts have the same formula and are isomorphic: the crystal of one of these salts continues to grow in the solutions of the other salts.

Potash alum melts at 90°C , dissolving in its own water of crystallization. When heated to a high temperature (150°C), the alum loses water, turning into burnt alum.

Alum and aluminium sulfate are used for dyeing cloth, tanning leather, and gluing paper.

The reaction of an aluminium salt solution with sodium hydrophosphate leads to the formation of the white jelly-like aluminium phosphate precipitate AlPO_4 . When heated to a temperature of $1,300^\circ\text{C}$, the latter turns into a vitreous mass that is used in the production of pottery and optical lenses.

Experiments with Alums

We cite below several experiments that can be easily performed at home, taken from a book published over a hundred years ago. We hope that the modern reader will not try to taste the alum, as the author proposes!

Experiment 213. Obtaining Alum.

"Warm saturated solutions of sulfur-aluminium and sulfur-potassium salts are mixed, and the resulting solution is cooled. Eventually octahedral crystals of the double aluminium-potassium salt of sulfuric acid form."

Experiment 214. Obtaining a Regular Alum Crystal.

"A thread is lowered into a vessel with a weak alum solution. After several crystals form on it, the thread is taken out, and small irregular crystals are removed, leaving only one or two crystal with the regular octahedral form. The thread is immersed in the solution once again, making the crystals grow in size."

Experiment 215. Growing a Large Alum Crystal.

"The largest regular crystal obtained in the preceding experiment is suspended from a thread and immersed in an alum solution that is put for a long time in a warm place. If one keeps adding fresh solution as the old solution is used up, one can grow a huge crystal. One can easily obtain a crystal with a diameter of 2–3 inches."

Experiment 216. Making Ornaments from Crystals.

"The experiment requires a large vessel with a solution of one part alum to two parts water (by weight). A wire framework shaped like an ornament (little basket, frame, etc.) and wrapped in wool yarn is suspended from a thread. Crystals grow on the wires, covering up the framework."

Experiment 217. Obtaining Burnt Alum.

"Finely ground alum powder is intensely heated in a ceramic crucible. The powder dehydrates, swells, and rises out of the crucible in the form of a white puff."

Experiment 218. Alum Reactions.

"Testing the alum solution with litmus paper shows that it is acidic (the litmus paper turns red). Taste the alum to experience its characteristic sour flavor."

V. Ryumin, *Elementary Experiments in Chemistry*, 1907 ■

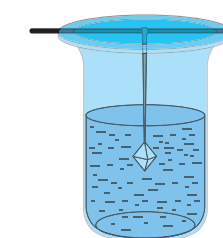


Fig. on Exp. 215



Fig. on Exp. 217

...It has been long since aluminium was considered a precious metal, but some of its compounds remain precious stones. Aluminium oxide monocrystals are the bright red ruby and the shining blue sapphire, the precious stones of the first, highest order. The sapphire gets its blue from the ions of iron and titanium, the ruby gets its red from chrome. Aluminium is also part of tourmaline, colorless leucosapphire, yellow Oriental topaz, and many other precious stones. Read more about this in the next chapter.

Chapter 7

The Earth and Beyond (Aluminium Minerals)

Enticingly colored rubies, deep blue sapphires, laconic pencil leads, and sturdy granites... What do they have in common? All of them are minerals. The mineral kingdom is vast. Specialists have discovered and studied over 2,500 varieties, and several dozen new names appear on this list annually. Minerals containing aluminium are among the most widespread. Aluminium accounts for approx. 8.8% of the mass of the earth's crust. This means that about one of every twenty atoms making up the upper covering of our planet is an aluminium atom.

As we have already said, pure aluminium does not occur in nature. However, aluminium is a constituent of over 250 different minerals. Most of them are oxides and hydroxides (compounds with oxygen and the hydroxyl group OH), silicates (silicon-oxygen compounds), and the salts of certain acids.

The aluminium oxide – corundum – comes first in the table of key minerals for a good reason. It is the mineral with the simplest formula and the highest aluminium content. Corundum has a very stable crystal structure and reacts poorly with both acids and alkalis. Although it is not a good raw material for aluminium production, everyone is familiar with its crystals, *rubies and sapphires*.

Corundum (aluminium oxide) is also used for making emery and grinding wheels and sandpaper. Of the many patented names of corundum, *alundum* is perhaps the best known. It is used for making fireproof and acid-proof articles. Alundum crucibles, which can be heated to high temperatures, are widely used in chemical laboratories. Corundum is insoluble in acids yet can be broken down when melted with bases and carbonates such as soda and potash.

Corundum can also be used for making long thin fibers that are used for strengthening metal alloys and ceramics and making chemically and thermally inert filters and thermal-protective coatings for spaceships.

MAJOR ALUMINIUM MINERALS		
Mineral	Formula	Content of aluminium oxide, %
Corundum	Al ₂ O ₃	100
Diaspore, boehmite	AlOOH	85
Chrysoberyl	BeAl ₂ O ₄	80.0
Gibbsite (hydrargillite)	Al(OH) ₃	65.4
Kyanite	Al ₂ O·SiO ₄	63.2
Kaolinite	Al ₂ O ₃ ·2SiO ₂ ·2H ₂ O	39.5
Muscovite	K ₂ O·3Al ₂ O ₃ ·6SiO ₂ ·H ₂ O	38.5
Alunite	(Na, K)Al ₃ (OH) ₆ (SO ₄) ₂	37–39
Anortite	CaO·Al ₂ O ₃ ·2SiO ₂	36.7
Nepheline	(Na, K) ₂ O·Al ₂ O ₃ ·2SiO ₂	32–36
Spodumene	Li ₂ O·Al ₂ O ₃ ·4SiO ₂	28.0
Cryolite	Na ₃ AlF ₆	23.5
Albite	Na ₂ O·Al ₂ O ₃ ·6SiO ₂	19.3
Orthoclase	K ₂ O·Al ₂ O ₃ ·6SiO ₂	18.4
Beryl	3BeO·Al ₂ O ₃ ·6SiO ₂	14.0

The **sulfate** alunite [KAl₃(OH)₆(SO₄)₂] is also called alumstone. It is one of the few aluminium minerals to be employed in industry. (There are less than ten such minerals.) In many countries, alunite is used for making aluminium oxide as well as alums and other aluminium compounds.

Aluminosilicates are compounds containing aluminium and silicon atoms. Over 40% of all aluminium minerals are aluminosilicates. Many aluminosilicates are widely used in construction and even jewellery making.

Along with other silicates, aluminosilicates form the earth's rocky outer layer that lies beneath all continental

landmasses. Scientists call this layer “sial” – a word formed from the symbols for silicon (Si) and aluminium (Al).

All of these minerals have a crystal structure in that their atoms are arranged in a fixed order rather than chaotically.

Silicon-oxygen tetrahedra bonding along vertices form the mineral quartz (SiO₂) and a multitude of silicates. In addition, they combine with aluminium-oxygen octahedra to form aluminosilicates – feldspars, micas, and many rocks such as basalts, granites, gabbros, and diorites. These rocks (and, in particular, feldspars) decompose under the impact of sun, wind, water, and carbon dioxide (a process called weathering) to form clays as well as aluminium oxide compounds such as bauxites, *diaspore*, and corundum. However, only a small fraction of aluminium compounds get into rivers, seas, and oceans. Scientists have shown that there is very little aluminium in seawater. For example, the Atlantic Ocean has an aluminium content of 9.7·10⁻⁴ parts per million at its surface and even less in its depths.

There are several different varieties of aluminosilicates.

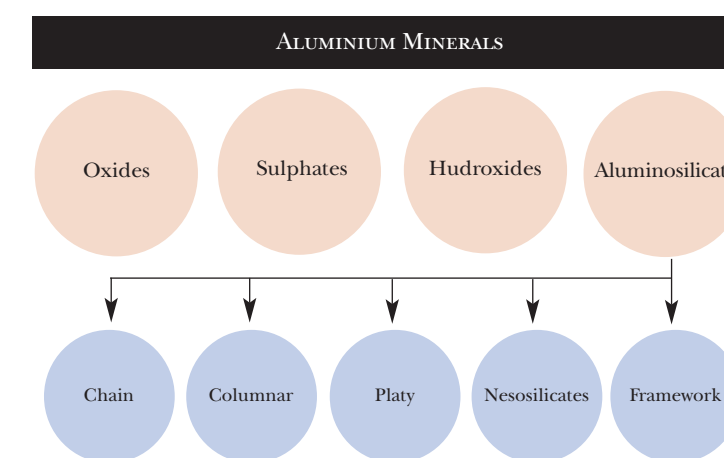
Chain aluminosilicates. Although aluminosilicates are widespread in nature, they are rarely used to make aluminium. Nevertheless, certain aluminosilicates are used as a raw material for producing other metals. A case in point is the mineral spodumene, from which the alkali metal lithium is made. This light green (or even yellow) mineral is a chain aluminosilicate. It consists of endless chains of silicon-oxygen tetrahedra connected by their vertices. The word “spodumene” means “turning into ash” in Greek. The mineral's name comes from the fact that it turns into an ash-grey powder when strongly heated. Spodumene contains lithium and makes a flame turn bright red when it is inserted into it.

There is also a bright green variety of spodumene called hiddenite. Its color stems from the partial displacement of aluminium by chromium atoms. Large hiddenite crystals are used for making jewellery. Certain spodumene crystals have a violet hue due to the presence of manganese and iron ions.

Columnar aluminosilicates. Aluminosilicates consisting of double silicon-oxygen chains occur fairly rarely. One of them is hornblende – a mineral with a very com-



Alunite



plicated chemical structure. Its crystals occur in basalt and diorite rocks.

Platy aluminosilicates. The best-known mineral in this group is *kaolinite*, which makes up white clay (*kaolin*). The mineral's name stems from the Chinese word “Gao-ling,” which means “high hill”; this was the name of the mountain where the mineral was mined. It has been used from long ago for producing china. Kaolinite contains water – not liquid water but “bonded” water that is contained in the mineral's crystal structure. This is why it is called a hydrated silicate.

When immersed in water, kaolin and the related minerals dickite, nacrite, and halloysite become soft, for their crystals begin to slide easily over each other. This

explains why it is difficult to walk over wet clay soil after it has rained. The plasticity of kaolin also explains why it has been used for centuries for making pottery. Small pigment particles can get in between the layers, making it easy to color kaolin.

The largest deposits of high-quality clay are found in the US. They form a belt that stretches for approximately 30 kilometers from central Georgia to South Carolina. The belt is several kilometers wide in some places, while the layers are up to 15 meters thick. The kaolin here is a result of the weathering of the rocks of the Piedmont Plateau that borders upon the Appalachian Mountains from the East.

Another large kaolin deposit is located in the Amazon basin in Brazil. Cornish clay, mined on the Cornwall peninsula in southwest England, has been used in Europe for centuries. In Central Europe, high-quality clay is found in the Czech Republic (Karlovy Vary). There is also a large kaolin deposit in Bavaria.

Russia has numerous clay deposits located in different parts of the country: Central Russia, Karelia, and the Urals. **Dmitry I. Vinogradov** (ca. 1720–1758), the inventor of Russian china, used “Moscow clay” from Gzhel near Moscow and “Andoma clay” from the former Olonets Province.

Heating kaolinite to a temperature of 950°C leads to the formation of mullite. This mineral is used for making high-quality refractory materials, china, composite materials, and ceramic materials of different porosities. Mullite is also used to increase the mechanical strength of metals at high temperatures and their chemical inertness. For this reason, it is used in the steel and iron industry.

Mica is a translucent platy aluminosilicate with a complex structure and a colorless or yellow hue. All



Kaolin

mica can be split into very thin transparent sheets that retain the flexibility, elasticity, and strength of mica. Thin mica plates were formerly used in windows instead of glass. For example, the windows of the Terem Palace in the Kremlin and the mansions of rich boyars were *paned* with mica. It is no coincidence that the word “*muscovite*” stems from “Muscovy,” the former name of Russia. Large sheets of this mica called “Muscovy glass” were once exported to the West. Sheet mica is rarely found in nature. Today, mica is widely used in electric technology, as it is a very good insulator. It is fragile and easily crushed. Finely ground mica is added to paints, varnishes, and fillers and is used for making wall paint, decorating buildings, producing artificial stone articles, plasterboard, and roofing materials. The familiar pearly car enamel that is a constituent of “metallic” paint gets its lustre from small mica crystals. Mica is non-toxic and is therefore used in the cosmetic industry for giving creams

Kaolin clays play a major role in the structure of the earth's upper geosphere. They are found everywhere in the upper layers of the earth's crust: in clays, conglomerates, slates, soils and subsoils, and loess. They abound everywhere, often constituting the main ingredient of sedimentary rocks. They accumulate in glacier moraines, on lake bottoms, in swamps, and in river deltas. They make up silts in ocean depths and cover continental expanses in even greater quantities. They constitute the thick deposits left behind by the last glaciations of Eurasia, North America, and Greenland...

“On average, the transformation of granite rocks into clay releases 120 calories per gram. Thus, a lot of heat is released during the formation of kaolin clays. All of these reactions take place in the biosphere and often at the surface. Reverse complex chemical processes begin at small depths. Here, kaolin clays give rise to new compounds and absorb heat. Most likely an equilibrium exists here: approximately the same number of calories are absorbed and released.”

V.I. Vernadsky, “Geochemistry”, 1934



Muscovite

and ointments a pearly lustre. Baking ground mica produces a material called vermiculite (“swollen mica”) that swells when heated to a temperature of 900–1,000°C, increasing its volume by 15 to 20 times. The layers of air that form between the material’s scales give it a low density and high heat- and noise-isolation properties. Vermiculite is used in construction for making heat insulators, sound-absorbing materials, and mortar. In addition, it can be used as a filler for rubbers, plastics, paints, and pesticides, in the production of antifriction materials, and for improving the structure of soils in agriculture.

Framework aluminosilicates are minerals in which silicon-oxygen tetrahedra and aluminium-oxygen octahedra form a three-dimensional spatial lattice or framework. *Feldspars* are the most abundant minerals in this group. The simplest feldspar *albite* forms colorless or even reddish or greenish crystals. They melt when heated, congealing into a white vitreous mass. Pure albite is used in the ceramic industry.

The potassium feldspar *orthoclase* is a granite mineral. It forms transparent crystals or dense cryptocrystalline masses that are white or have pale yellow, pink, green, or grey hues as a result of admixtures. Albite and orthoclase are often found in granites and basalts. A pretty variety of orthoclase is moonstone, which has a shimmering pearly lustre with a gentle play of color.

Another feldspar is labrador. Its name derives from the place where it was first found in 1770 – the Labrador



Albite

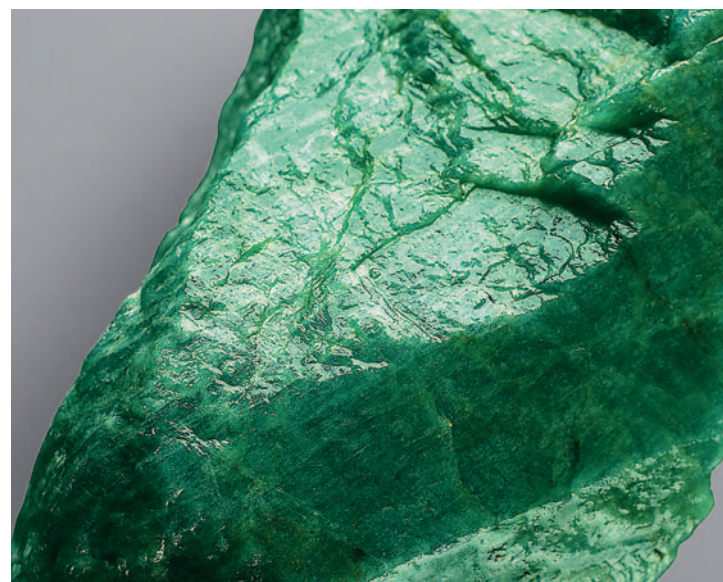


Orthoclase

Peninsula in Canada. Labrador has an amazing capacity for iridescence (a term deriving from the Greek word *iris* “rainbow” and referring to the rainbow play of color on the facets and planes of certain minerals). If one looks at the dark grey surface of the stone from the right angle, it turns light or dark blue or green. For this reason, *labradorite* (a rock consisting of labrador) is frequently used for facing buildings.

One seldom finds bright green stones in nature. An exception is the feldspar *amazonite*. The first specimen of this mineral was found in Amazonian fluvial deposits. Curiously, further attempts to find this stone in the Amazon valley did not meet with success. Amazonite has an unusual green or green blue coloring. Amazonite

rocks sometimes seem to be striped on account of the layers of albite, which have a white coloring of various hues. This makes amazonite particularly appealing. The mineral's color stems from defects in the crystal structure rather than the admixture of other metals. This explains why the mineral loses its color when heated. It regains its color only if it is exposed to radioactive radiation. Thin plates of amazonite are translucent and are therefore used in stained-glass windows and lighting fixtures. Large amazonite deposits have been found in



Amazonite

plex treatment of nepheline also generates soda products such as caustic ash and potash. In Russia, rich deposits of nepheline are found on the Kola Peninsula, in Tuva, and in Kuznetsk Alatau.

Nepheline sometimes occurs together with the framework aluminosilicate *sodalite*. Sodalite was first described in 1811. As its name suggests, sodalite contains sodium. It can take on different hues from green and blue to red. More rarely, white, grey, and colorless stones are found. In Russia sodalite occurs on the Kola



Sodalite

the US (Virginia and Colorado), Canada, South America (Brazil), India, and Madagascar. Amazonite was first discovered in Russia in 1784 in the South Urals and subsequently, on the Kola Peninsula and in Eastern Siberia. However, Russian amazonite is of a much lower quality than Indian and American amazonite.

Nepheline is another important feldspar. When immersed in mineral acids, nepheline loses its transparency and becomes jelly-like and cloudy, which explains its name (the Greek word *nephelē* means "cloud"). In nature nepheline forms grainy or continuous masses; isolated crystals occur more rarely. While pure nepheline is colorless, admixtures of iron, titanium, and other metallic compounds give it a grey, green, or red-brown color. Nepheline (like feldspar) weathers easily on the earth's surface.

Nepheline is sometimes used as a raw material for the industrial production of aluminium oxide. The com-

Peninsula and in the Ilmen, Ural, and Sayan Mountains. Blue sodalite is a precious ornamental stone.

Hackmanite, a violet-red variety of sodalite, was named in 1903 after the Finnish scientist Victor Hackman. When exposed to air, this mineral gradually becomes dull and recovers its original hue only when exposed to radiation. This property, which is called photochromism, leads to the use of certain synthetic varieties of this mineral in radio electronics and television.

Blue varieties of sodalite are sometimes confused with *lazurite*, a dark blue framework aluminosilicate. This is a fairly soft and fragile mineral that is easily cut and polished. Lazurite stones with golden pyrite flecks are particularly valued.

For many centuries, these stones were found at lazurite mines in Badakhshan, a region of Afghanistan adjoining Turkmenistan. These mines were exploited as far back as the Stone Age. Lazurite was later mined by



Lazurite Columns of Isaak Cathedral in St. Petersburg

chipping off huge blocks of marble containing clumps of blue crystals. Miners worked in shackles, while others were prohibited from approaching the lazurite mines on pain of death.

Badakhshan lazurite was used to make the twisted horns, beards, eyes, and necks of goats in the tombs of the ancient city of Ur. These monuments date from the middle of the third millennium BC. Lazurite was also used to make the five-meter-high central columns of the iconostasis of St. Isaac's Cathedral in St. Petersburg. Empress **Catherine the Great** bought the lazurite for the cathedral at a fairly high price: a pound of stone cost a pound of silver (over 300 roubles – in comparison, the annual per capita tax was under a rouble).

After a lazurite mine was discovered in the Baikal region in 1851, Russian stonecutting plants became very skilled in making *objets d'art* from lazurite. There is a

lazurite room in the Peterhof Palace: the panels, fireplaces, and different decorative elements are made from this beautiful stone.

Thanks to its unusual color and its high lustre when polished, lazurite is widely used today for making beads, vases, and ornaments.

Lazurite chips are used in mosaics and in high-quality ultramarine paint. In contrast to many other paints, it does not fade in sunlight and is water and heat resistant. Many famous painters, including Russian artists, used valuable lazurite paint. The walls and ceiling of the Saviour-Transfiguration Church in the Saviour-Mirozhsky Monastery in Pskov are covered with frescoes painted on a bright lazurite background. Executed in the mid-12th century, they remain there today.

As lazurite occurs rarely in nature, scientists have learned to make its synthetic equivalent – *ultramarine*.

It is a sodium aluminosilicate that contains sulfide and polysulfide ions, which give it its color (from blue and violet to green and red).

Ultramarine began to be produced in the 1830s. It is made from kaolin, sulphur, soda, silicon dioxide, and coal tar. The mixture is placed in a furnace and gradually heated. During the first stage, kaolin is dehydrated, while soda reacts with sulphur and carbon, turning into a mixture of sodium sulfide and polysulfides. The final stage of the process (the production of ultramarine) takes place at a temperature of 750°C; to this end, the reagents must be heated in a furnace for several hours. Today, ultramarine is used in the paint and varnish industry for eliminating the yellow hue in white paints and varnishes and making artists' paints. It is also used for coloring plastics, linoleum, and rubbers and bleaching certain kinds of paper.

Zeolites are a separate group of naturally occurring framework aluminosilicates. In contrast to other minerals in this group, the zeolite framework contains voids that are filled with water molecules. When zeolite is gradually heated, the water evaporates without changing the properties of the mineral itself. Anhydrous zeolite can absorb water; the water fills all the voids very quickly, displacing air. It seems as if the mineral boils when it is immersed in water. This accounts for its name: "zeolite" means "boiling stone" in Greek (from the words *zéō* – boil, and *lithos* – stone). Zeolite also swells when it is immersed in acids or heated in a flame. Anhydrous zeolite can absorb other substances such as ammonia and hydrogen cyanide. This is why zeolites are used for absorbing impurities. In nature, zeolites form through the weathering of different aluminosilicates such as feldspars and nepheline. They also arise from volcanic eruptions, forming in lava cavities and different volcanic rocks. In Russia, large zeolite deposits are found in Kamchatka, Buryatia, Sakhalin, and the Primorye region.

Natrolite is a member of the *zeolite* group. It forms colorless prismatic and often elongated crystals. When heated, natrolite whitens, loses its transparency, and then melts, turning into glass when it congeals.

Aluminium nesosilicates. When speaking about jewelry, one should naturally mention *beryl*. This mineral is often used for making ornaments. Beryl crystals can have very different hues depending on the impurities

► **The Youngest Natural Gemstone**



Brooch. Tanzanite, diamonds. Tiffany & Co, 1969

The blue stones of the aluminium mineral tanzanite were first discovered in March 1966 on the Merelani Plateau near Mount Kilimanjaro. One of these stones found by Maasai hunters got into the hands of **Manuel De Souza**, a local businessman who mined rubies. The stone weighed 16,839 carats or over 3 kg. It was called "Mawenzi" after the second highest peak of Mount Kilimanjaro.

The blue stone was initially believed to be a sapphire, yet mineralogists established that it is a variety of zoisite. In the 1970s, Tiffany & Co. began to advertise it actively as a gemstone imitating sapphire. However, according to the company's vice-president Henry Platt, the name "zoisite" sounded a lot like the word "suicide." It was proposed to call the stone tanzanite instead – a name that pointed to its African origins. Tanzanite gradually stopped being viewed as an inexpensive substitute for blue sapphires and became popular in its own right. As it is still only mined in one place (on the Merelani Plateau), the demand for tanzanite has outpaced supply, which has led to a rapid rise in prices. The price of tanzanite has today caught up with the price of blue sapphire. American jewellers have rightly labelled tanzanite the "gemstone of the 20th century."

The stone's color varies from blue to deep violet but is always bright and rich. Certain tanzanites are initially pale, yet their color can be brightened by heating. Like alexandrite, tanzanite has a color that depends on the lighting. When viewed from different angles, the crystal can appear light blue, purple, or brown-yellow (a phenomenon known as *pleochroism*). This effect is interesting for mineralogists, yet not very desirable for jewellers, so virtually all tanzanites are heat-treated. Similarly to other minerals in the same family, tanzanite has a major drawback: it is very brittle. Tanzanite jewelry is not fit for everyday use. ■

that they contain. Green stones are called *emeralds*, yellow and orange stones *heliodors*, red stones *bixbites*, and rose stones *morganites*. The green color of emer-



Natrolite

alds comes from chromium atoms, light blue and blue colors from iron ions, and yellow-orange from manganese ions. Colorless beryls also occur yet are very rare.

Emeralds are the best-known variety of beryl. "It is green, pure, and tender like spring grass, and when you look at it for a long time, your heart becomes brighter," wrote Alexander Kuprin about emerald in his short story "Sulamith." This green stone has been known of for a long time; it is mentioned in ancient Indian epic poems. Emeralds are also found in ancient jewellery.

Africa was the main supplier of emeralds in the ancient world. Here, emeralds were extracted in Nubian mines near the Red Sea as far back as the second millennium BC. American Indians also knew about this beautiful stone. In Russia, emeralds were discovered by chance: on the banks of the Tokovaya River in the Urals, the peasant **Maxim Kozhevnikov** discovered in 1831 fragments of an unusual green stone which turned out to be Ural emerald. Soon after, in 1833, the peasants **Karelin** and **Golendukhin** found emeralds on the Eastern slopes of the Ural Mountains near the village of Murzinka. Several months later, a beautiful green stone was found there; the state counselor **Yaroshevitsky** wrote that this stone "was of the highest quality, had a fairly grassy color, weighed a pound, and was the most precious emerald ever – perhaps even better than the stone encrusted in **Julius Cae-**

► **Discovery of Ural Emeralds**

"A peasant in the Beloyarsk District looking for pitchy pine stumps, deadwood, and brushwood to obtain pitch, found a few small crystals and chips of a green stone between the roots of a tree toppled by the wind. He showed the stone and the place of its discovery to his friends. All of them dug in the roots and found a few more pieces. They took the prettiest of them back to their village and later brought them to Yekaterinburg to sell them there. However, these pieces stemmed from upper layers that were washed out of a disintegrated vein and subjected to all kinds of weathering before they were overgrown by the roots, making them lose their natural color and become covered with cracks. As a result, people mistook them for poor-quality aquamarines.

In the meantime, my assistant informed me about the discovery of stones that were believed to be green aquamarines and, at my request, brought me a small piece of such a stone a few days later... I soon noticed that the stone was not an aquamarine, for it was considerably heavier and stronger, and its fracture was cleaner and glassier. Comparative tests showed that it was stronger than foreign emeralds. These careful observations led me to conjecture that this stone was an emerald.

I immediately took workers and tools and went to the place of discovery. Snow and cold were no obstacles to my painstaking search...

"Upon my return to Yekaterinburg, I had one of the best stones faceted at a stonecutting plant. I showed it to jewellers who confirmed that it was indeed an emerald."

From a report sent to St. Petersburg by Yakov Kokovin, Commander of the Yekaterinburg Lapidary Plant, 1831 ■



Aquamarine



Vorobievite

sar's crown." The rich emerald deposits discovered here were called the Emerald Pits.

The largest emerald ever found was at the Somerset Mine in South Africa in 1956. It measured 14×35 cm and weighed 24,000 carats. Unfortunately, it was cut to pieces and has not survived. The largest Ural emerald was discovered in the Emerald Pits three years after they opened in 1834. It was called the "Kokovin Emerald" in honour of **Yakov V. Kokovin**, craftsman at the Yekaterinburg Lapidary Plant. This stone vanished without a trace. It was most likely also cut to pieces by a stonecutter. However, names sometimes live longer than stones. This name was given some time later to a different Ural emerald that was smaller than its predecessor,

yet quite large all the same – 11,000 carats! Today, this stone is on display at the A.E. Fersman Mineralogical Museum.

Topaz is a very beautiful stone that is also a member of aluminium nesosilicate group. Topazes contain magnesium, chromium, iron, titanium, and vanadium, which give these stones their different color hues. Ruby red topazes are found in Brazil, and bright yellow topazes in Saxony and Volhynia. Variegated stones are often found. They may be partly pink and partly yellow, green, or light blue, for example. Although red and pink topazes are rarely found in nature, certain yellow topazes acquire a pretty pink color when heated. However, heat treatment is not always suitable, for it may cause certain stones to lose their color altogether. Some topazes become paler after prolonged exposure to bright sunlight.

Pliny mentioned topazes in his *Natural History*. However, modern scholars believe that in ancient times this name referred to the silicate *olivine* rather than the modern topaz. Olivine was mined on Isle Topazos (or Topazion, now Isle of Zabargad) in the Red Sea. In this way, the place of origin of olivine gave a completely different stone its name! According to a different version, topaz's name stems from the Sanskrit *tapas* – fire, flame, or heat.

A large blue topaz deposit was discovered in Russia in 1875 near the village of Murzinka. The Ural mines contain many gemstones. Mokrushi is the best-known Murzinka mine; it is a topaz-beryl granite vein with a length of about 500 meters. The largest topaz found in pre-Revolutionary Russia stemmed from Mokrushi: it was a green-blue stone weighing 32 kilograms.

A topaz deposit was discovered in Volhynia during the Soviet period. The stones found there were very large, such as the Alexander Fersman topaz with a sky blue color and a mass of 2,110 grams and the Zolotoe Polesye topaz with a warm yellow color and a mass of 1,850 grams. The largest topaz found in Volhynia weighs 117 kilograms.

Emeralds spread their shine very far, they paint the air, as it were, around themselves. In comparison to them, there is no green thing that can make things greener... They never change either under the sun or in the shade, or beside the lamps, and, judging of their thickness, they have absolute transparency, something we also like in the water.

Academician V.M. Severgin, 1819



Topaz

▶ Village of Murzinka, Urals. Discovery of Russian Emeralds

The village of Murzinka is located in the gently sloping spurs of the eastern flank of the Ural Mountains, 120 km from Yekaterinburg on the Neiva River. Although it was established in the late 17th century as a fortress protecting the Verkhoturksky Highway, its fame does not stem from its role as an outpost in the conquest of Siberia. For everyone who knows and collects gems and takes an interest in the history of mineralogy, this name is linked to the remarkable search for precious Ural stones. History does not tell us who found the first precious stone here and when this took place. However, a document attesting that mines existed near the village in 1669 has come down to us. According to it, at that time “the copper ore smelter **Dmitry Tumashev** sent a petition to our Grand Sovereign, saying that he went to Siberia to search for ores and found precious stones: white crystals, dark red *fetisy*, green *yugi*, and yellow *tumpasy* in the mountains.” This was the beginning of the famous Ural gemstone mines. The mines were apparently abandoned soon afterwards and reopened only in the following century under Catherine the Great. The empress attached a lot of importance to mining precious stones, which were needed for decorating the interiors of St. Petersburg palaces, and sent an expedition to the Urals in 1765 for “quarrying marbles and gemstones in those parts of the state where they are found and working according to pre-existing examples.” Major General **Yakov Dannenberg** was appointed director of the expedition. He was accompanied by craftsmen from the Peterhof Lapidary Plant and the Italian brothers **Gianbattista** and **Valerio Tortori**. One of the discovered mines was subsequently called “Talian” in their honor, and certain gemstones were even given the diminutive names “taliashki.” ▶

Gem-quality topazes have been used since ancient times for making jewellery and, in particular, for decorating royal regalia. A large yellow topaz along with two pearls adorns the “Kazan Cap” – royal crown made by the masters of the Kremlin Armory in 1562 at the order of Ivan the Terrible in commemoration of the conquest of Kazan.

The aluminium nesosilicate *staurolite* is another important aluminium mineral. It forms intergrown crystals resembling crosses. This property led the French scientist De La Mettrie to coin its name in 1792 from the Greek words *stauros* – cross, and *lithos* – stone. Staurolite is also called fairy cross. It can take on dark red, brown,



Staurolite

brown-black, and yellow-brown hues. Red cross-shaped crystals found in the stone are particularly valued. In Russia, staurolites are widespread on the Kola Peninsula and in the Southern Urals. They are also found in other European countries such as France, Germany, Austria, and Switzerland, as well as in the USA in Massachusetts and California. Thanks to its cross-like shape, staurolites have been considered since ancient times to be charms that protect people from witchcraft and hexes. Staurolite cross pendants are often sold as souvenirs.

Another naturally occurring aluminium nesosilicate is *kyanite*. Though pure kyanite is colorless, admixtures of chromium and iron often give it a gentle hue ranging from blue grey and light blue-green to dark blue-green and even yellow. Kyanite forms from the recrystallisation (a term referring to a change in the crystal structure of

▼ The veins that come to the surface near Murzinka usually contain a few gemstones. For example, the Kazennitsa vein that was located 900 m to the east of Mokrusha and that was abandoned in 1938 contained feldspars, quartz, muscovite, topaz, tourmaline, and emerald. The vein had a total length of 150 m, a productive length of 54 m, and a thickness of up to one meter. In 1824 a giant yellow-green beryl crystal with a length of 25 cm and a weight of 2.5 kg was found in one of these veins; it is now in the Mining Institute Museum in St. Petersburg. Scholars have found traces of over 250 mines all around the village of Murzinka along the Neiva, Ambarka, and Alabashka Rivers: emeralds, diamonds, amethysts, topazes, aquamarines, sapphires, and many other gems were mined here. Today, most of the mines are abandoned and are covered with thick undergrowth. Mounds of debris and small ponds on the site of the former pits are the only remaining evidence of the search for gems. ■



Kyanite

solid bodies resulting from heating or cooling that leaves their aggregate state intact) of sedimentary rocks rich in aluminium oxide and is also found in quartz veins. It is a valuable aluminous raw material for making heavy-duty heat-proof and acid-proof articles, aluminium-silicon alloys, spark-plug insulators for internal combustion engines, and technical ceramics. In Russia, large deposits of kyanite have been discovered in the Urals and on the Kola Peninsula.

The aluminium nesosilicate *garnet* (from the Latin word *granum* – grain) is a general name for a group of minerals that includes up to 30 varieties. Some of the minerals of this large family have names of their own: *almandine*, *pyrope*, *grossular*, *andradite*, *uvarovite*, and *spessartine*. Garnets come in a very wide range of colors: from colorless (leucogarnets) to emerald green, yellow,

golden brown, rusty red, black, blood red, and violet. Beautifully colored transparent and semitransparent garnets are used for making jewellery. Jewellers particularly value demantoid, followed by topazolite, grossular, hessonite, and pyrope.

Garnet has been prized for centuries. It has always been surrounded by mystery and an aura of romanticism. Around 1250, the German philosopher and theologian Albert the Great (Albert von Bollstädt, ca. 1193–1280) singled out the stone *granatus* among red stones or “carbuncles” as they were called back then. It was one of 29 stones that supposedly held magical and therapeutic powers. Garnet was believed to bring wealth and power. In Russian literature, it became the symbol of great, sublime, and tragic love thanks to Alexander Kuprin’s story “*Garnet Bracelet*”.

The most widespread garnet is *almandine*. It is found all over the world, mostly in combination with other minerals. As a result, its color varies from red-brown to raspberry red and violet. Large almandine crystals the size of a cannon ball often occur. However, gem-quality almandines are rare: they are imported from India and Ceylon.

Grossular is another garnet that contains aluminium. Its name comes from the Latin word *grossularia* (gooseberry), as it often resembles gooseberries in color and form. In 1968, emerald-green grossulars were found in Tanzania and later in Kenya. They are very expensive.

Yet garnets are not only used as ornaments. Garnets are very hard and break into shards with sharp edges when crushed. They are used as an abrasive material for making sandpaper and grinding wheels. Scientists have produced numerous synthetic minerals that not only imitate garnets but also have valuable properties that are not found in natural minerals. For example, the yttrium-aluminium garnet is colorless, yet the displacement of some yttrium atoms by the rare earth elements neodymium, praseodymium, erbium, or holmium give it a violet, green, pink, or yellow color. These stones luminesce in ultraviolet light – they emit light that differs from their natural color. Large gemstone-quality crystals of yttrium-aluminium and *gadolinium-gallium garnets* (which have similar properties) are used as diamond imitations. Yttrium-aluminium garnet alloyed with neodymium is particularly important for modern technology: it serves as the active medium in powerful lasers. Such lasers can inflame many organic substances.

Other aluminium minerals. *Chrysoberyl* and *noble spinel* (beryl aluminate and magnesium aluminate) are two aluminium collection minerals that do not contain silicon in contrast to aluminosilicates. Chrysoberyl can have a yellow or green-yellow color due to iron ions. A very beautiful gemstone is alexandrite – a chrysoberyl in which certain aluminium atoms are displaced by chromium. This stone is emerald green in daylight yet becomes red-violet under artificial light and shines a bright red color when exposed to ultraviolet rays.

Noble spinel usually forms small yellow, orange, red, violet, blue, light blue, green, or black crystals with a mass of less than 10 carats. The largest pink spinel crystal with a mass of over 5 kg was found in the Pamirs in 1986. Jewellers particularly value bright red spinels, whose color arises from the partial displacement of aluminium atoms by chromium atoms. Such spinels were often mistaken for rubies and pyrope garnets in former times. For example, the Black Prince’s Ruby and the

▶ **Tourmaline**



Tourmaline is a precious mineral with a complex composition. It has a rare variety of colors and is polished like a precious stone. Tourmalines have varying compositions and colors that arise from the presence of transition metal ions. For example, iron ions give them light blue, blue, yellow, orange and brown hues. Emerald green tourmalines contain chromium ions, while pink and red tourmalines have manganese ions. Tourmaline began to be mined in the Urals as early as the 19th century. In Russia, tourmaline deposits are also found in Siberia and the Transbaikalian region. ■

Timur Ruby, which adorn the crowns of English royalty, are actually spinels. The etymology of the word “spinel” is not clear. According to one version, it stems from the Latin word *spinelia* – little thorn, which points to its crystalline form. Yet “spinel” may also come from the Greek word *spinos* – spark. Indeed, faceted spinels reflect light at crepuscule.

Few people know that flame red rubies and blue *sapphires* are varieties of corundum, an aluminium mineral. Large rubies occur more rarely in nature than diamonds. Beautiful faceted gemstone-quality rubies and sapphires were encrusted into medieval reliquaries and imperial regalia. Rubies and sapphires adorn **Monomakh’s Cap** and **Tsar Aleksei Mikhailovich’s** “grand attire” (crown, orb, and scepter). British imperial crowns also have large sapphires.

In addition to aluminium, rubies and sapphires contain atoms of other elements, which give them their color. Red stones containing a small amount of chromium are called rubies, while stones of other colors are called sapphires. The latter are usually blue in color, although light blue, pink, green, violet, orange, brown and even yellow corundum crystals are also called sapphires. The red color of rubies results from the presence of chromium ions. The color of sapphires stems from the presence of the atoms of other elements. For example, pink sapphires contain titanium ions, and yellow sapphires iron ions.

Rubies were first mentioned in Pliny’s *Natural History*. Pliny calls them carbuncles, i.e., garnets. Such confusion



Spiced crystal (double) of the noble spinel

▶ **Synthetic Corundums (Sapphires and Rubies)**

The reader is already familiar with the aluminium oxide corundum. This extremely hard and valuable mineral can be “grown” artificially. The French chemist Auguste **Victor Louis Verneuil** obtained the first large grains of ruby in 1892 and developed a method for producing synthetic rubies and sapphires in 1902. It consisted of melting corundum powder (obtained from the decomposition of ammonium alum) in a hydrogen-oxygen flame. The molten corundum flows onto a sintered corundum rod, which acts as a matrix that incites crystallization. The rod is slowly lowered at a speed of 5 mm per hour. This leads to gradual crystal growth. The crystal has a diameter of 2–3 cm and can reach several dozen centimeters in length. These large transparent columnar crystals often take the form of hexagonal prisms that have a triple axis of symmetry. Coarse-grained corundum without impurities is colorless. Jewellers call it leuco-sapphire. The addition of chromium compounds (whose atoms displace aluminium at crystal lattice sites) to the initial alum leads to the formation of flame red ruby crystals, while the addition of titanium and iron results in blue sapphires.

Later, corundum crystals began to be synthesized using the method developed by the Polish metallurgist and metallographer **Jan Czochralski**. In this method, corundum powder is placed in a refractory crucible made of platinum or molybdenum and heated to melting with a high-frequency inductor. A seed crystal (a small corundum crystal) is lowered into the resulting melt from above. Synthetic corundum grows on this crystal. For good crystal formation, the seed crystal is attached to a revolving rod and slowly raised at a speed of 1–50 mm per hour. The Czochralski method can produce a ruby crystal with a length of up to one meter! It can be also used to grow crystals of different forms, such as sheath, rod, and ribbon crystals.

Synthetic rubies are colored by adding certain metal oxides with concentrations 0.1–2.0% to the initial corundum powder. For example, chromium oxide gives the gem a red color, while the addition of iron and titanium oxides produces blue sapphires. Cobalt oxide is used to obtain a green corundum monocrystal, while nickel oxide gives a yellow color. The addition of vanadium oxide gives rise to a gem that changes its color similar to alexandrite. Today, synthetic rubies and sapphires are produced in many different countries. In Russia, such experiments began to be conducted in the 1920s. The Russian scientist **Khachik Bagdasarov** used directional crystallisation to produce large corundum crystals. The outline of this method can be described as follows. ▶



Sapphire

resulted from the fact that precious stones were mostly classified by color in ancient times. Pliny describes in detail not only the stones' color but also their properties and place of origin. It was his remark that "carbuncles are insensitive to fire" that helped scholars identify them as rubies, for other red stones such as garnets disintegrate in fire. In addition to scientific facts, Pliny cited a story about the existence of male and female carbuncles and said that in Ethiopia these stones were submerged in vinegar for 14 days to give them a special lustre, after which "their lustre lasted for as many months." Ground rubies were believed to heal serious diseases. The modern reader can only smile at such assertions.

Rubies were particularly valued in the Orient and are repeatedly mentioned in ancient Indian epic poems. Today, the best quality stones still come from South and South-Eastern Asia (Thailand, Burma, and Sri Lanka). Deposits of rubies and sapphires are found in other Asian countries (Pakistan and Afghanistan) as well as in America and Australia. In Russia, rubies disseminated in mica have been found in the Polar Urals at Makar Ruz. Although these rubies are up to 10 centimeters long, they are opaque and not fit for making jewellery. As for sapphires, they have been found in Russia in the Ilmen Mountains (Urals) and in the Khibins on the Kola Peninsula.

Synthetic rubies (an artificial variety of corundum) are used in technology. Mechanical watches are still rated according to the number of rubies in them; this number is inscribed on the watch's cover or face. Crystalline corundum plays a major role in certain other pre-



Ruby crystals in rock

▼ A container made of refractory molybdenum metal is filled with corundum powder and placed in a vacuum furnace, which is heated to a temperature of about 2,000°C. Corundum melts at this temperature. The temperature is lowered in certain areas of the



Artificial rubies

furnace. The container is moved there in order to make the corundum crystallize gradually. The slower the cooling process, the larger the resulting crystals. Today, this method is used to produce crystals with a mass of over four kilograms. In 1947, specialists at an American company Linde developed a unique method for producing rubies and sapphires with *asterism* (an optical effect in the crystals of certain minerals in which a star-like figure is produced by light). ►



Crown of the British Empire

cision instruments. Artificially grown ruby crystals are a key constituent of ruby lasers, in which they act as the active medium. The lasers make use of corundum that contains only 0.05% chromium. Its crystals have a pink color, in contrast to the bright red color of rubies used as gemstones. Chromium atoms that give corundum its color play a key role in the laser's functioning. They absorb not only ultraviolet light but yellow and green, letting red and violet rays through. The laser beam has huge energy: it can burn through a metal plate, leaving a deep crater in it.

In contrast to earth minerals, cosmic minerals remain unstudied. This is no surprise, because, for many cen-

▼ Star rubies are found extremely rarely in nature and are highly priced on the market. Asterism can be synthesized by adding approx. 0.3% of rutile to the initial corundum and heating it to melting. One may wonder how is it possible to distinguish synthetic gems from natural ones, which are more precious for the simple fact that they are thousands of years old. On the whole, synthetic gems have no defects, inclusions, or microscopic cracks. Synthetic rubies often contain minute gas bubbles that form characteristic spots or stripes. Yet the main difference lies in the fact that synthetic gems are not homogeneously colored: at closer sight, some of them turn out to be "striped" with alternating bright and dull areas. Nevertheless, it is possible to distinguish natural and synthetic rubies for certain only in a laboratory. ■

turies, scientists could only study meteorites that fell on earth. The beginning of the space age allowed man to take a new look at the kingdom of cosmic minerals. For example, the study of moon soil samples has led scientists to conjecture that the moon contains rich deposits of minerals, including aluminium. Thus minerals may begin to be mined on the Moon in the near future.

Rubies involuntarily remind me of my trip to Paris.

There is a small grubby laboratory in a quiet street in a provincial town near Paris. Several cylindrical instruments with blue apertures stand on the tables among the vapors and hot air in a cramped room. A chemist looks through the apertures to keep track of what is taking place in the furnace and regulates the flame, gas flow, and quantity of white powder blown in. After five or six hours, he switches the furnace off and removes a red transparent pear from a thin red rod. Part of the pear shatters when it is broken off like fragile glass, while the rest remains intact and is sent to a jeweller...

This is the once-famous Alexandère Laboratory near Paris that synthesized rubies. The human genius stripped nature of one of its secrets: beautiful red gems that can be distinguished from natural ones only with difficulty, flooded the market, and whole lots of them were sent to the Orient where they mixed with their rivals – noble Burmese rubies.

One Oriental tale less, and one achievement of scientific thought in the history of mankind more!

A.E. Fersman, "Entertaining Mineralogy", 1928

Chapter 8 | Aluminium Around Us

Aluminium Packaging

Can a metal change the ordinary lives of human beings and their ideas about seemingly ordinary things? Indeed, it can. We have already got used to the fact that food keeps fresh longer in special packaging and cooks faster in certain types of pots and pans. We have become accustomed to light and comfortable furniture and to the modern design of lamps. All of this became possible thanks to the mass production of aluminium.

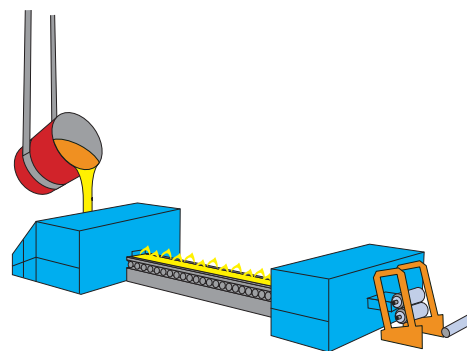
For more than a hundred years, life has been inextricably linked to this metal. Yes, aluminium no longer has the same novel connotation today as it did in the late 19th and early 20th centuries. Yet its significance in the contemporary nevertheless continues to grow. To a large extent this is occurring because aluminium became a substitute for materials such as wood or iron by partially or completely replacing them in various industry sectors. Its discovery is directly related to the appearance of entirely new industrial fields, such as the aviation, rocket and automotive industries. Scientists would not have been able to realise many of their ideas if had not been for the discovery of aluminium.

What are the applications of aluminium in industry? Over 33% of the aluminium produced in the world is used in cars and aeroplanes and about 10% is used in electrical technology. Approximately 24% of aluminium is employed to manufacture packaging materials, primarily aluminium foil. Rail transport, shipbuilding, the chemical and fuel industries, construction, tableware and household items... Aluminium is used everywhere.

Foil is aluminium sheet or, to be more precise, an alloy containing from 92% to 99% aluminium with a thickness from 0.0006 to 0.02 mm. In 2006, production

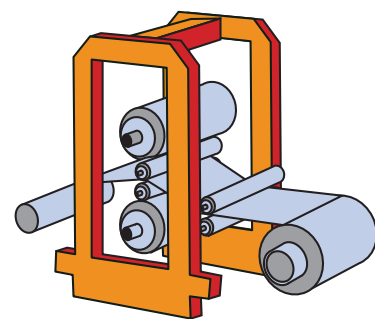
▶ Technology of aluminium foil production

1. Casting



Foil is made out of molten aluminium that is fed into production in crucibles. In the smelting furnace (see left) molten aluminium is improved with covering fluxes, alloyed, refined, and filtered. Once the melt is ready, it is sent to the continuous casting line (see right), where cast section rolls 6–10 mm thick and 1300–1650 mm wide are produced.

2. Prefabrication mill



Cooled rolls are rolled in mills down to 0.3–0.6 mm thick. Readymade rolls is preliminary annealed in nitrogen. ▶



Ready-made foil in the smelter storage



Aluminium packaging

volumes of aluminium foil in the world reached 870,000 tons, and the demand for it grows each year.

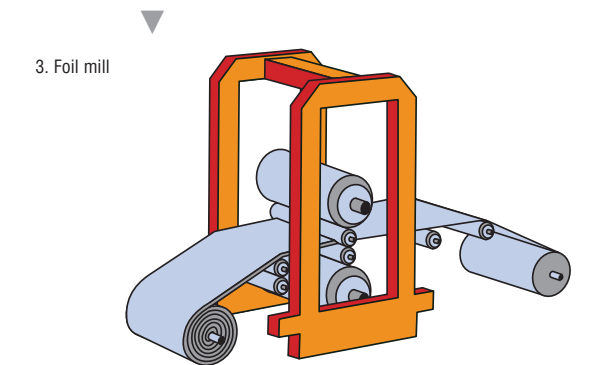
Both matt and glossy foil is obtained by *rolling* (a method of processing metals and metal alloys: the raw material is passed under pressure between spinning rollers on the rolling tool), after which the ready material is cut into sheets.

More thickly packaged foil is used for insulating roofs, floors, attics, pipes, ventilation systems, boilers, sections of walls behind radiators, and also as reflective panels on windows to keep out sunlight.

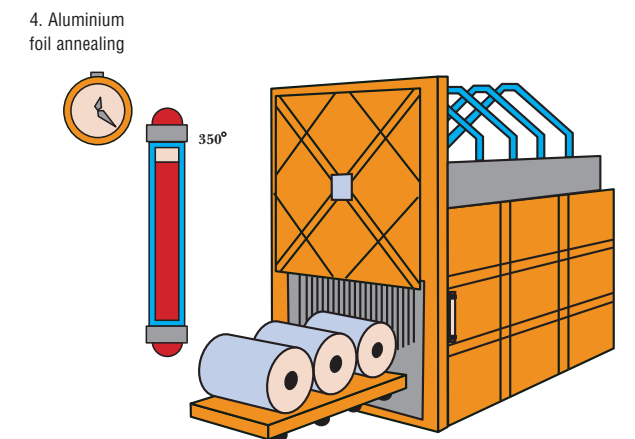
Not even the thinnest aluminium foil can be penetrated by bacteria, oxygen or ultraviolet rays. At a thickness of 0.011–0.012 mm it is impenetrable to sunlight, and at a thickness of 0.025 mm it keeps out steam and gas. The thinnest foil (only 0.009 mm) lets only 0.01 g/m² of steam through over a 24-hour period. Foil reflects light well and therefore barely becomes hot. At high temperatures – a necessary condition for air-tight sealing – it does not melt or deform, and does not give food products a strange smell or flavour. All of this makes aluminium an irreplaceable packaging material. Furthermore, foil is very easy to use – it easily takes the shape of the object around which it is wrapped.

The thinnest foil (0.006 mm) is able to preserve food without freezing it for several months. Foil protects dairy products from the sun because when directly exposed to heat and light they lose their nutritional value and flavour. Some products, such as chocolate and tobacco, are wrapped in foil to prevent them from drying out. In countries with a hot climate, manufacturers use special aluminium packaging to protect sweets from insects.

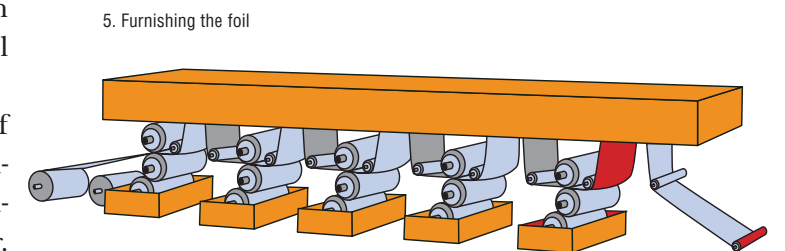
Many foods are wrapped in a combined package of several layers, one of which is foil. To package food containing plant and animal fats, or tea and tobacco products, manufacturers use *backed* foil with pressed paper. The moisture resistance of this foil is three times higher than that of ordinary soft foil. Many years of experience have shown that backed foil preserves tea and tobacco even in hot climates over the course of several weeks. Thanks to its pores, the paper absorbs the moisture which inevitably forms in those climate conditions. *Laminated* foil ensures a long storage period for many products. In such a hermetically sealed package, powdered milk can be stored for up to two years. Laminated foil is used to prepare blister packs, which are used to package medicine.



Cooled rolls (0.3–0.6 mm) are rolled in mills down to 0.2–0.006 mm thick.



Readymade foil is cut, and annealed in nitrogen to remove rolling lubricant and add flexibility. Part of the foil in rolls is supplied to the converting



block to make packaging with the required protective and decorative qualities. Foil there can be laminated, printed on in different colors, varnished, or stamped on. The rolls are then ready to be packed and delivered to the customer. ■

For long-term storage at room temperature, fruit juice, table wine, and condensed or pasteurized milk are poured into opaque packages made from paper, aluminium foil with 6–9 mm thickness and polyethylene film. This combination of materials has several advantages: the paper makes the packaging rigid and durable, while protecting the foil from damage, and thanks to the polyethylene (which has undergone thermal sealing) the casing becomes air-tight.

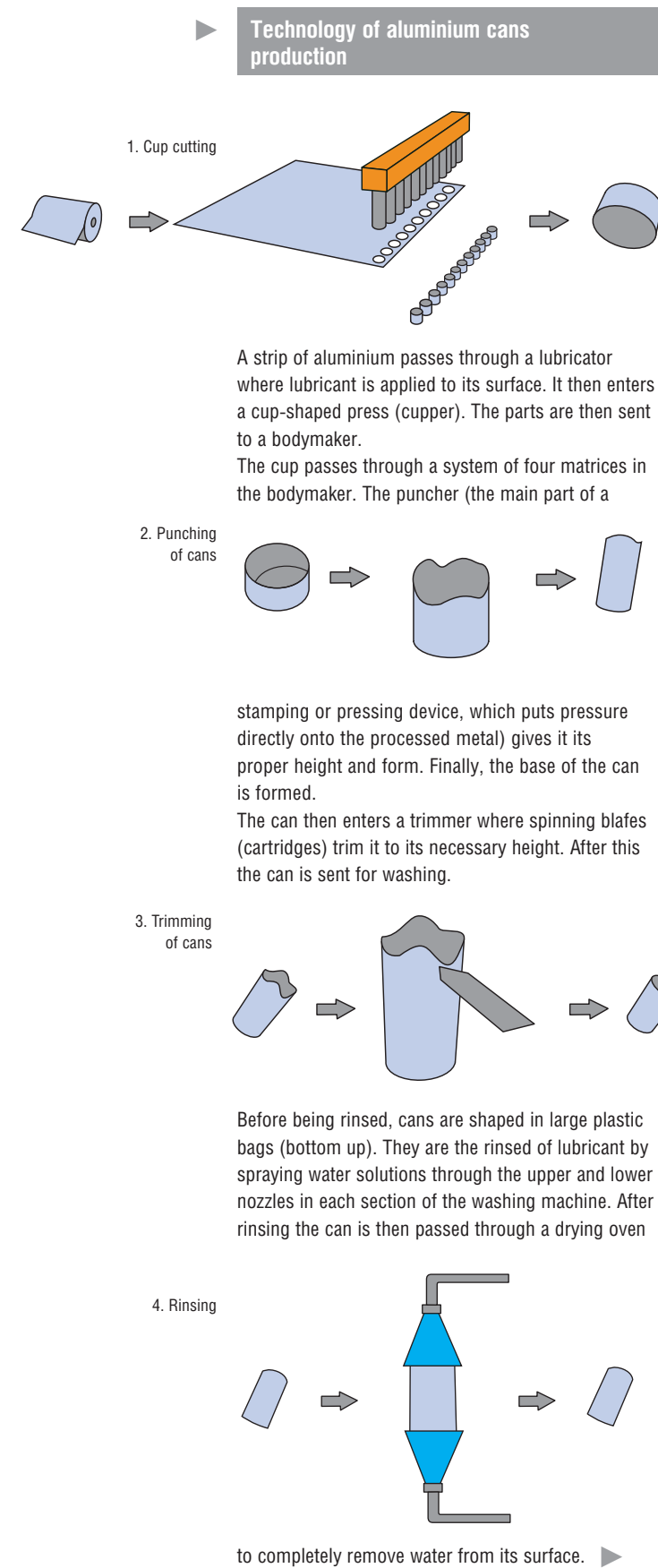
Polymer packages outwardly resemble foil. This is no surprise: they also contain aluminium, but in the form of small particles of metal 20–30 mm thick applied by vacuum dusting on a film. These metallic films are more durable than foil, and are used to pack tea and powdered milk. However, studies have shown that food packaged with a material that contains foil can be stored much longer than packages made of metal-coated materials. Foil which is only 9 mm thick is analogous in its protective properties to a polyethylene film 250–270 mm thick.

Aluminium foil is used in homes. For example, producers recommend using it to carefully wrap delicate cheeses, even when storing them in the refrigerator, since they absorb sharp smells and thus change their flavour. It can also be used when cooking meat and vegetables.

Aluminium cans are considered to be the “cleanest” and most environmentally friendly type of packaging. There is good reason for this. Aluminium cans can be completely recycled, which saves metal and energy in the production of new cans. Moreover, they are very convenient: an aluminium can for carbonated soft drinks weighs a lot less than a glass bottle, which has another considerable drawback – it breaks. Thanks to the high conductivity of aluminium, a beverage cools more quickly in a can than in a bottle. Since aluminium is not affected by corrosion, cans do not rust if they are put in water or ice. For these reasons aluminium cans are in high demand – over the world 230 billion cans are manufactured annually.

Europe, India and Russia produce mainly 330 ml cans. In the United States the standard can has a volume of 335 ml, while in Australia the size is even greater – 375 ml.

Metal cans for food were manufactured long before the invention of aluminium. In 1809, the French chef **François Appère** suggested preserving food products by canning them in white iron (thick steel coated with tin).

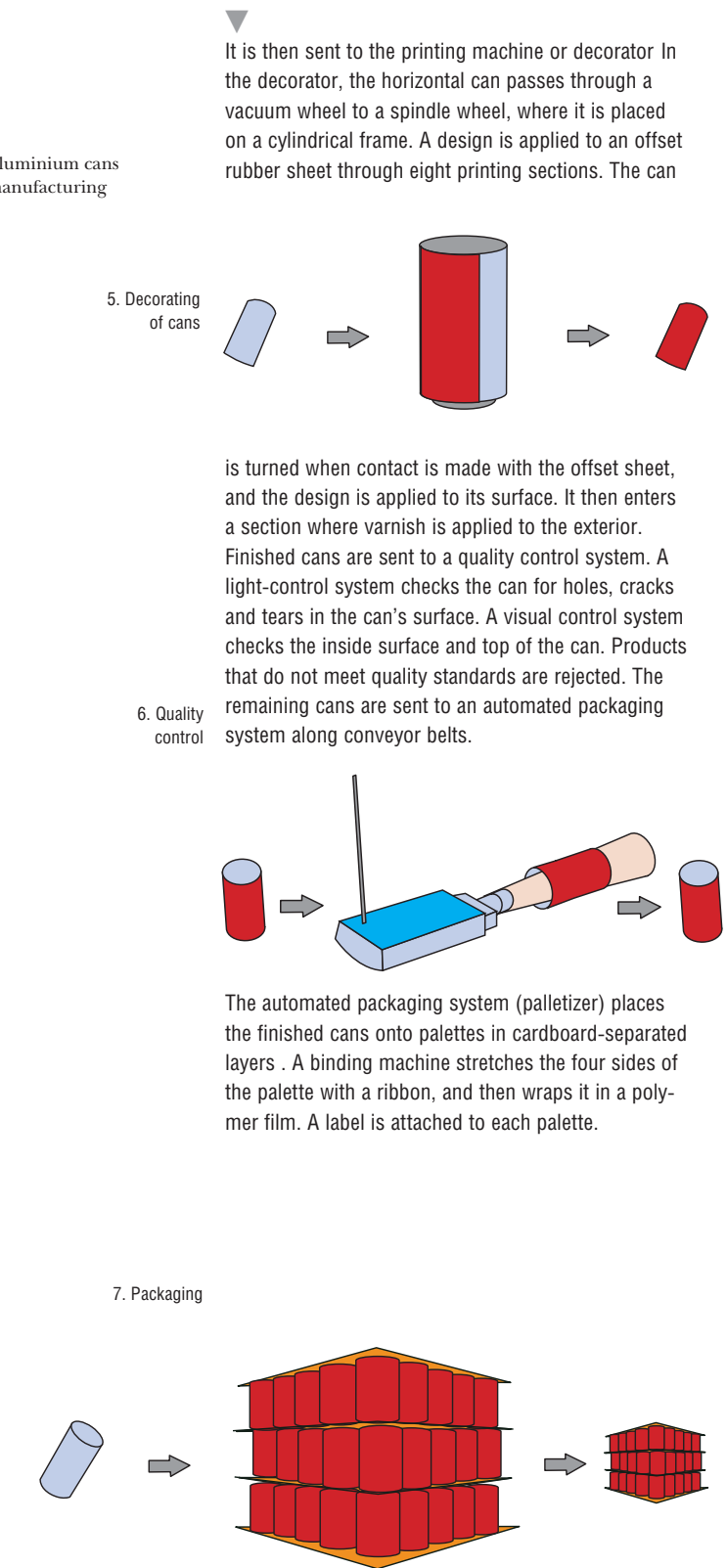


The first country to manufacture aluminium cans was the United States. In 1956 the company Kaiser Aluminium produced the first aluminium can with a volume of about 200 ml, but it was far from perfect. Two years later, in 1958, Adolph Coors Company started selling beer in aluminium cans. The next can model was again made from steel, but the container was given a soft aluminium top that opened easily. The ring top we are used to was only manufactured in 1963 by engineers at the Schlitz Brewing Company.

Unlike food cans, which are made from tin, beverage cans are made from an aluminium alloy. This alloy contains 1% magnesium, 1% manganese, 0.4% iron, 0.2% silicon and 0.15% copper. A significant part of the metal used in can production is manufactured from secondary raw materials. Many specialists worked intensely to create a technology for manufacturing whole aluminium cans. At first they developed a means of high-pressure extrusion. In 1963, the Reynolds Metals Company was the first to employ a method of pressing and constriction used to this day. Since 1967 the Coca-Cola Company and the Pepsi-Cola Company have been packaging their soft drinks in cans.

Curiously, Coca-Cola recently started producing flavoured milk in aluminium cans for American schools. The aluminium package extends this product's shelf-life to nine months without refrigeration. The light, unbreakable aluminium packaging has already won recognition, gradually edging out glass, which was used for beer and wine. Beer is poured into cans with the same technology used for carbonated water, which makes it cheaper than the product in traditional bottles.

Aluminium cans manufacturing



In recent years aluminium has also been used to package wine. The traditional cork has been replaced by an aluminium screw-top that preserves the wine's flavour. The screw-top was used to stop bottles as early as 1926, but at the time no one was ready to switch from the familiar cork.

Many were skeptical about wine bottles closed with an aluminium cap. Public opinion was shaken after a tasting of 11,000 bottles of wine demonstrated that ordinary corks ruined the bouquet of wine in every twentieth bottle. This led to the first comparative tasting of wines closed with corks of various materials. The bark of the cork oak, plastic, and aluminium screw-tops, both embossed and unembossed were all compared. The result was striking: in 21 of 40 cases, tasters preferred the wine with embossed aluminium tops to all others. It turned out that an aluminium screw-top prevents exposure to oxygen in the bottle and can age wine just as well as a cork.

In 2002, Tesco, the Britain's supermarket chain, started selling wine in bottles with embossed aluminium caps. Now each month Tesco customers buy several million aluminium capped bottles of high-quality wine.

Aluminium tubes



Packaging of toothpaste into tubes at a Franch factory, 1890s

The place, the time and the person behind the invention of the tube, a very common form of packaging today, is unknown, however various sources agree on one thing: in 1841 the American scholar and artist **John Rand** patented his invention of tin tubes to prolong the shelf-life of quickly spoiling paint. Of course, they bore little resemblance to modern-day tubes. In 1892, the dentist **Washington Sheffield** from New London, Connecticut, noticed that after an insignificant modernisation such tubes could be

Aluminium tube



used to store ointments, creams, shampoo and toothpaste. The doctor was not an entrepreneur and did not patent his invention, and so **William Colgate** took advantage of of Sheffield's invention. In 1896, his company Colgate Palmolive manufactured toothpaste in modern tubes, and by the early 20th century ointments and creams packaged in tubes were found across America and Europe. Toothpaste in tubes only appeared in Soviet stores in the 1950s. Until then, people used powdered toothpaste in cardboard boxes. In the Soviet Union, the leader in aluminium packaging was Estonia. In 1964, the Pribaltic Chemical Factory began producing aluminium tubes, using hot bottling to package various berry jellies. Curiously, this became the foundation for packaging of food products for space travel. ■

Aluminium Crockery

Many of us recall aluminium pots, spoons, and forks from their childhood. Many continue to use them today. Aluminium is one of the most popular materials for making kitchenware. Aluminium pots, pans, trays, kettles, and Dutch ovens are practical, inexpensive, functional, light and easy to use. Furthermore, aluminium has high heat conductivity, 2.4 times higher than that of steel. An aluminium pot consumes only 7% of its heat (four times less than a steel pot) and transfers the rest to the food.

Aluminium crockery has been produced since the 19th century. To a large extent, this metal has replaced traditional metals like iron and copper, which were used to make kitchenware for centuries. Aluminium pots achieved the widest use because they are light, durable and significantly cheaper than those made of other metals. Formerly, aluminium crockery was a sign of material well-being and a high standard of living: it was a lot more prestigious to use aluminium kitchenware than iron skillets and copper pans.

Over time and use, aluminium pots lose their characteristic metallic sheen, becoming dull and gradually acquiring a residual carbon glaze. Aluminium is easy to clean but requires special treatment. Aluminium crockery should never be rubbed with steel wool or sandpaper, which can scratch and damage the surface and the thin layer of oxide film that restrains the metal's chemical activity. To avoid scratching the soft metal, food in an aluminium pan should not be stirred with sharp implements.

Aluminium spoons, forks, mugs and bowls are essential for instances where every gram of weight counts, such as camping or long journeys. However, it is important to remember that this metal is a good heat conductor. An aluminium mug containing hot tea is hard to hold for long and an aluminium spoon can burn the skin.

Aluminium pans are good for boiling water, cooking potatoes and vegetables, and especially for making porridge. It is well known that porridge and milk virtually do not burn in them. Nevertheless, certain specialists believe that aluminium kitchenware is only suitable for boiling water and baking.



Aluminium mug

Aluminium crockery is made both from pure metal and certain alloys, such as a manganese alloy. It is prepared by rolling or pressing, while traditional thick crockery – such as pans, cast-iron skillets and roasters – are cast. Only 8% of all aluminium manufacturing is from pot casting. The products are expensive and are used by professional chefs, since they last long and meet all the necessary requirements of food preparation.

Inexpensive pressed crockery is used much more often. It differs from cast-iron with its thin sides and bottom (one cast-iron skillet is as thick as three or four pressed ones). The main drawback of pressed crockery is that it quickly deforms and becomes unusable.

One should keep in mind, however, that aluminium reacts easily with acids and alkalis. Thus cabbage soup, berry sauces and jellies, sweet-and-sour meats, and other dishes that include organic acids should not be cooked in aluminium kitchenware. Otherwise, aluminium ions will pass into the food. For the same reason, aluminium kitchenware should not be washed with citric acid, soda,



Aluminium pan



Aluminium frying-pan with anti-stick covering

or vinegar. Eggs, dairy products, pickled goods with sulfur, and foods with a high calcium content leave dark marks on it that are also evidence of oxidation. Nutritionists do not recommend storing food in aluminium vessels. It is not suitable for preparing dietary and children's food.

At the same time, enameled aluminium crockery has none of the many drawbacks of aluminium cookware. The Russian word *emal* comes from the French, and originally meant "fusion, casting." Enamel is a thin and durable glass-like covering (inorganic, primarily made from a silicate oxide). It is applied as a powder on the product's surface and then fired. In some cases the ware is covered with *slurry*, a colloidal solution of enamel components. This is achieved by spraying, pouring or spreading with a brush or immersing the object in the slurry. The applied layer of liquid enamel is dried, after which it is fired at temperatures of 520°C to 560°C. During the firing process the enamel melts forming a smooth, glassy layer adhered to the metal.

Thus the enameled aluminium crockery preserves the light weight and high heat conductivity of aluminium, but is less toxic, since the enamel keeps the metal out of direct contact with food. But enamel is not long-lasting and cracks under repeated use, losing its protective qualities.

The consumer qualities of aluminium crockery were improved with a polymer *anti-stick* covering, commonly called *Teflon* which has been used for more than 50 years. Today almost all pressed aluminium crockery is

manufactured with an anti-stick covering. It is applied to aluminium sheets before pressing, and the surface of the metal is roughened to help the polymer stick to it. The polymer coating is sprayed on the cast crockery. The life span of such products is largely determined by the durability of the covering.

A Teflon pot is better for making soup, gelatin, stewing vegetables or boiling milk than one made only from aluminium or enameled aluminium. Aluminium is protected from contact with food by a layer of fluoropolymer which has an extreme chemical inertia. This substance does not react with oxidizing materials, alkali, acids, and is not corroded by organic solvents. Therefore the covering does not pollute food and is not damaged by cleaning products. However, until recently, a wooden or Teflon spatula was needed to stir food to avoid damaging the bottom of the pan. Contemporary coatings on products from the world's leading companies are significantly more durable and are difficult to scratch even with a knife.

Polymer coating has another useful quality in that its surface is so smooth that drops of oil or water freely slide across it. Therefore, food does not stick to these pans and often oil or butter is not needed to fry food in them. This is theoretically possible, but not advisable – the dish will not be as tasty and the pan will not last as long.

Fluoropolymer coating can be smooth or porous like a honeycomb, which increases the heating surface and makes it more even. To prolong the service period of the crockery, some engineers add small hard particles

of minerals or metals to the anti-stick coating. Therefore, the covering, resembling wet sand, is easy to distinguish from others.

The first polymer coverings had only one layer of fluoropolymer. Now they are made in several layers: the upper layer of the four-layer covering has perfect anti-stick qualities; next comes a layer resistant to scratches and the destructive effect of abrasive substances, the third is designed to tightly attach the polymer to the aluminium and prevent it from warping. The thicker the covering and the more layers it has, the longer the crockery can be used.

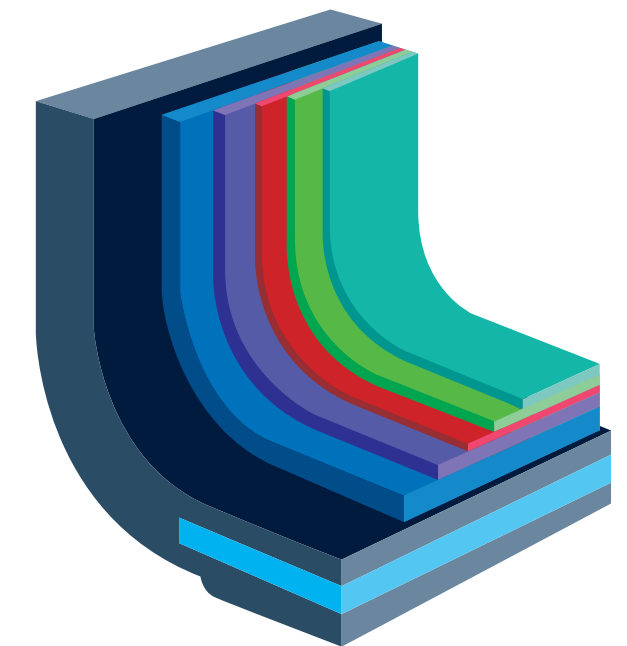
When used carefully, the service period of thin, cheap pans 2–2.5 mm thick is no more than two to four years, while pans with a more durable porous covering can last up to five or six years. But, over time, heat can cause the covering to lose its anti-stick properties and peel, while a thin pan can scorch if splashed with cold water after heating or if very cold food is placed on it.

The most "wearable" are aluminium pans with a base no less than 6 mm thick, sides up to 3.5 mm thick and a multi-layer polymer covering. They can be used for up to 10 years, but even when treated with care the polymer layer is at risk from damage. An accidental scratch can let fat, alkali or acid in food through to the aluminium base, which will lead not only to the contamination of the food, but will also to further peeling of the coating.

Despite its fairly low durability, aluminium crockery with a fluoropolymer-based anti-stick coating is in high demand, and therefore manufacturers try to perfect it by producing materials that are harder than traditional polymers. Recently, a semi-ceramic anti-stick coating was developed from a thin layer of ceramics with a polymer in its pores that makes the inner surface of the crockery even and smooth. This cookware handles damage better and is harder to scratch.

Thanks to aluminium's high heat conductivity it is used to make stainless steel cookware. At first, to make the pot or pan heat faster, an aluminium disk was welded to the steel bottom. However, since the aluminium bottom quickly deformed when heated, specialists developed a "layered" heat-accumulating bottom consisting of a thick sheet of highly conductive aluminium between two sheets of stainless steel. The technology is called Tri-Ply, which is now commonly used to refer to cookware with multiple layers on the base and sides.

ANTI-STICK COVERING



- polymer non-stick coating
- primer coating
- polymer-oxide coating for the better adhesion of the non-stick and primer coatings
- metallic-polymer coating with the high hardness and durability
- gasothermal coating made of corrosion resistant material for the protection of the body frame and its adhesion with the coating
- aluminium disk
- stainless steel body frame

The thickness of the aluminium layer is usually about 4 to 5 millimetres, since the food in it does not touch the aluminium.

Thus, the multi-layered bottom is capable of accumulating warmth, making it possible to significantly decrease the heating time and thus save energy, which once was shown in one commercial: food was cooked in such a pan, lit by the candle. Theoretically this is possible.

Aluminium in Various Sectors of Industry

As we have already said, aluminium is used in virtually all branches of industry, especially in high-tech spheres. The aviation and automobile construction industries consume more than a *third* of all the world's aluminium.

In aviation and space technology, most of the metal is obtained by deforming aluminium alloys of the duraluminium type. In a contemporary aeroplane, 80% of the total weight is composed of aluminium, and, considering the size of the aeroplanes in mind, that is an impressive figure. A Boeing 747, or Jumbo Jet, has 75 tons of aluminium! American space shuttles are made from 90% aluminium.

Russia's current aviation industry actively uses high-strength aluminium alloys reinforced by thermal processing: alloys with zinc, magnesium, and copper and mid- and high-durability alloys are used to bind the fuselage and the wings.

Usually aeroplanes are built from duraluminium sheets and profiles. These are not welded but connected

History of Soviet super sonic Tu-144

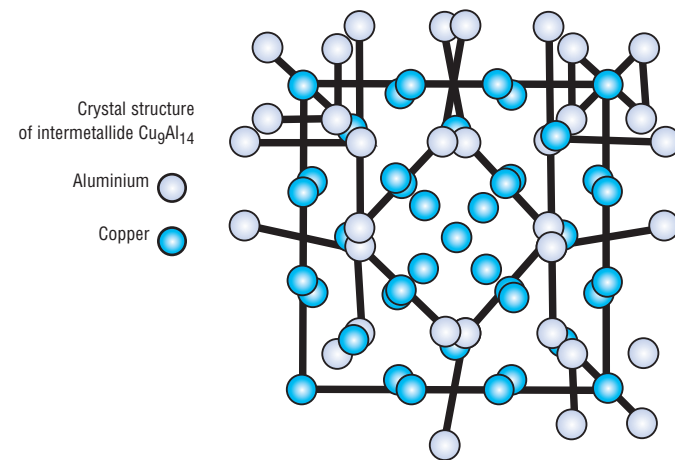
In the 60's it became known that Britain and France resolved to create the supersonic passenger jet, and it was to be called "Concord" <...> Nikita Khrushchev reacted immediately: "We must make our own supersonic jet, and it is supposed to fly faster than 'Concord'."... British and French engineers used the heat-resistant aluminium AU2GN alloy, a mixture of copper, magnesium, iron and nickel. The two latter elements increased its heat-resistance. Russia had long used the analogous AK4-1 alloy for aeroplane motor parts, but also used the new Al-Li VAD-23 alloy. Lithium (Li) is the lightest metal in the periodic table and, correspondingly, the new alloy was much lighter than AK4-1, surpassed it in terms of durability and other features, but it had not yet been applied in manufacturing ...

On December 31, 1968 Tu-144 took off two months earlier than "Concord", which made both A.N. Tupolev, Ministry of Aviation Industry and all the Soviet people quite happy ... In summer 1971, Tu-144 was successfully shown at the Aviation Salon in the La Bourgé, France ... In 1973, another La Bourgé Salon took place, this time, however, it proved quite unsuccessful for us, as Tu-144 disintegrated in the air avoiding the French fighter "Mirage" that appeared quite out of the blue. Thousands viewers watched Tu-144 crash. The crew, as well as several viewers, were killed under the debris of the plane. The reasons of the crash are still unknown, however, in 1977 the first passenger flight of Tu-144 was bounng for Alma-Ata. It was a matter of prestige: "Concords" were in the sky, while Tu-144 was on land, even though it had gone into the air earlier than "Concords." In 1978, there was another crash, this time above Yegoryevsk, and the Tu-144 flights were discontinued. And, as it turned out later, for good... Enormous efforts made to outstrip Britain and France were all in vain.

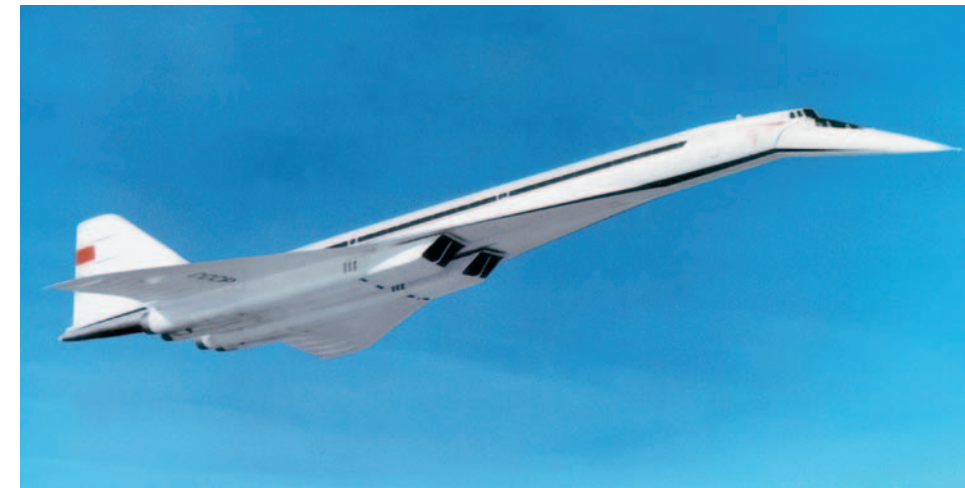
I.N. Fridlyander. "Vospominaniya o sozdanii aviakosmicheskoi i atomnoi tekhniki iz alyuminievykh splavov", 2006

Fastener phases

The high durability of duralumin and other deforming aluminium alloys comes from compounds containing several metals. They form phases in the metal structure's, or fastener phases, which are intermetallics or compounds of various metals. For example, duralumin



contains the intermetallic CuAl_2 , which increases its durability to 5.7 times more than the durability of pure metal. Such compounds often have a variable content, or are characterised by wide region of homogeneity. Crystals extracted from a copper-aluminium alloy in a 1:2 ratio have a more complex make-up – $\text{Cu}_9\text{Al}_{14}$. In this compound, aluminium atoms are connected not only with each other, but also with copper atoms. Interestingly, the distances between aluminium atoms in this compound (0.285 nm) are even smaller than in the metal (0.286 nm). This can be explained by the high durability of the intermetallic. When manganese is introduced to the copper aluminium alloy, the durability of the compound increases; it is the next fastener phase, $\text{Al}_2\text{Mn}_2\text{Cu}$. Aluminium-copper-lithium alloys, with the fastener phase $\text{Al}_{15}\text{Cu}_8\text{Li}_2$ are, almost 10 times more durable than pure aluminium. Alloys containing a fastener phase can age. Usually aging is perceived as being a negative process, one that weakens and destroys, but for aluminium alloys aging brings increased durability. This is due to the reconfiguration of the structure which leads to the formation of special zones in the alloy. We have considered this process in more detail in chapter X which covers the properties of aluminium metal. Here we note that, in some cases, aging can have a negative effect on alloys. Fridlyander wrote that "several years ago, in the coastal waters of the Black Sea, we immersed buoys made of a corrosion-resistant magnalium and duralumin (aluminium with copper and manganese) alloy, which clearly

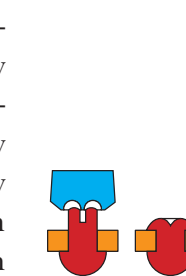


by rivets. Aluminium alloys are also used to make the rivets. The number of rivets can reach several million. Making all-aluminium frames is technically possible, but they do not handle large loads. If a crack appears in the aeroplane's structure during use, then the all-aluminium body will collapse, while in riveted construction the crack only reaches the opening of the rivet. Instead of aluminium sheets, some modern aeroplanes use pressed panels. In this case the crack only reaches the end of the panel. For example, the wing of the Russian aeroplane An 124-100 Ruslan consists of eight such panels, each 9 metres wide. The aeroplane's structure is calculated so that the wing still functions even if two panels are destroyed.

In the automotive industry, aluminium is also used to increase weight resistance, decrease mass and consequently decrease fuel consumption. Apart from the economic aspect, this has a quite important ecological benefit as decreasing fuel consumption leads to a decrease in harmful emissions as transportation emissions are the main polluter in major cities. According to calculations by the Association of Automobile Manufacturers, each kilogram of aluminium used to build an automobile decreases its mass by a kilogram; and for each 1% percent decrease in the automobile's weight, fuel consumption decreases by 1.0% on average. Thus, the use of 100 kg of aluminium in an automobile will save more than 1,000 litres of gasoline over 200,000 kilometres, and accordingly will decrease emissions of carbon dioxide gas by 2,500 kg.

The foresighted European requirements of 2005 for automobiles with gasoline engines limit carbon dioxide emissions to 150 g/km, which can be achieved when the weight of the vehicle does not exceed 1,000 kg. However,

Tu-144



Scheme of riveting

surpasses it in its resistance to corrosion. Six months passed, and the magnalium buoys had rotted. The duralumin buoys also suffered, but much less. What happened to the magnalium? The buoys were heated in the sun to 50°C to 70°C. The heat broke down the saturated, firm magnesium solution and an unbroken chain formed from the secretions of the Mg_2Al_3 phase along the borders of the grains. Between the aluminium grain and secretions of the Mg_2Al_3 phase there is a significant border of electrochemical potentials. Along the borders of the grains it quickly corrodes and the alloy precipitates into separate, unconnected grains. This danger can be avoided if the alloy is first heated for a long period of time at a moderate temperature. Large secretions of the Mg_2Al_3 phase precipitate from the hard solution. These secretions are different from each other, scattered not along the borders, but along the entire section of the grain. In this form, these secretions do not damage the material, which remains unharmed by sunlight and sea water fully justifying its reputation as a corrosion-resistant alloy." Compounds of magnesium, silicon and zinc play a large role in the increased durability of aluminium alloys. Magnesium silicide (Mg_2Si), in the form of separate crystals, dissolves easily in water. However, small additions of magnesium and silicon in molten aluminium lead to the formation of small crystals of magnesium silicide, which are evenly distributed in the cooled aluminium and are therefore resistant to the effects of moisture. The Mg_2Si phase is called the queen of aluminium alloys for construction by metal specialists. Aluminium alloys (AD31, AD33, AD35, AV) are characterised not only by their high durability and corrosion-resistance, but they are also easy to polish.

The aluminium-zinc fastener phase is performed by the intermetallic MgZn_2 and is highly durable but cannot withstand a large number of repeat loads. At first, to prevent cracking, small amounts of chromide, manganese and zirconium were added to the alloy. However, this led to a decrease in the alloy's mechanical properties, primarily its plasticity/ductility. Engineers sought to obtain aluminium-zinc-magnesium-copper alloys which were capable of handling large loads without chromide, manganese and zirconium. This problem was finally solved by adding a small amount of iron to the alloy and varying the aging regime through which engineers found a composition for the alloy with all the required properties. It should be noted that during the production of such materials it is important to closely adhere to a set temperature. Scientists led by Fridlyander discovered that at a specific concentrated region and as the magnesium content increased, the durability, ductility and viscosity of the alloys increased simultaneously, as did their corrosion-resistance. Thanks to successful scientific development, in 1956 the Soviet Union invented the world's most durable aluminium alloy, V96ts, which contained 8.0% to 9.0% zinc,

in the last 20 years the average passenger car has become 150 kg heavier, which can be explained by an increase in dimensions, as well as heightened consumer demands for safety and comfort. Therefore, the use of aluminium in automobile construction keeps growing. Currently an automobile manufactured in North America contains an average of 116 kg of aluminium, while Japanese and Korean cars contain 93 kg, and Western European cars contain as little as 90 kg.

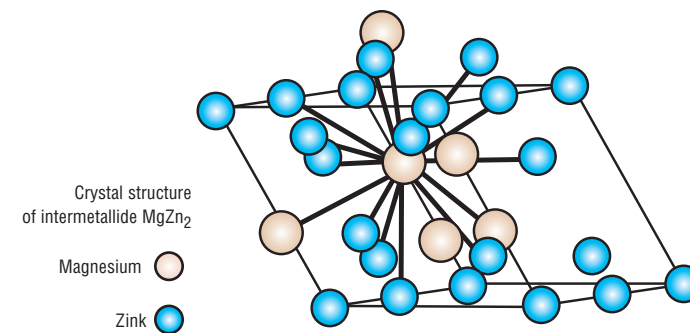
Aluminium alloys are widely used to manufacture many car parts. In passenger cars this is the body of the engine, the caps on the valve-operating mechanism, the hood, the transmission and the door handles. Besides the combustion heads, which account for the dominant part of aluminium consumption in the automotive industry, aluminium's use has grown in the construction of hubcaps, suspensions, chassis and parts of the transmission. Aluminium has one more important quality: it lowers the impact of a collision up to twice as effectively as steel. It is no wonder aluminium is the material used for bumpers.

More than 80% of car parts are cast including valves, parts of transmission and suspension, wheel plates and subframes. However, in recent years, the use of aluminium sheets and strips has increased. Contemporary wheel plates consist of a central part, which is cast, and a peripheral rim made from a stamped sheet.

Forging gives aluminium alloys better mechanical qualities than casting making it possible to vary charac-

ALUMINIUM IN THE AUTOMOBILE COMPONENTS IN THE INDUSTRIALLY DEVELOPED REGIONS, KG PER AUTOMOBILE (SOURCE: "URALS METAL MARKET")			
Components	N. America	Japan and S. Korea	W. Europe
Engine	40.0	36.5	35.2
Transmission and cardan drive	26.5	20.6	15.5
Wheels	18.0	15.5	11.4
Heat-exchanges	14.5	12.0	10.5
Suspension	3.0	0.4	4.4
Steering System	2.8	2.5	2.7
Body	2.2	0.5	2.9
Other	9.0	5.0	7.4
Total	116.0	93.0	90.0

2.3% to 3.0% magnesium, 2.0% to 2.6% copper, less than 0.1% manganese and less than 0.05% chromide. It was used to prepare centrifuges for enriching natural uranium and obtaining fuel for atomic power stations and nuclear warheads. In 1970, scientists obtained the V96ts-3 alloy with a somewhat different ratio of components. Unlike its "predecessor," it contained zirconium. During the Cold War this alloy was used to make the bodies of solid-fuel, mid-range rockets. We should note that information on the alloy's makeup (7.6% to 8.6% zinc, 1.7% to 2.3% magnesium, 1.4% to 2.0% copper, 0.1% to 0.2% zirconium,



less than 0.05% manganese, less than 0.05% chromide, less than 0.2% iron, less than 0.1% silicon) was included in the *Metallovedenie i Termicheskaya Obrabotka* journal and thus became known to the international scientific community. In 1991, American scientists introduced the 7055 alloy, with a composition of 7.6% to 8.6% zinc, 1.7% to 2.3% magnesium, 2.0% to 2.6% copper, 0.08% to 0.25% zirconium, 0.05% manganese, 0.04% chromide, 0.15% iron and 0.1% silicon. It doubled the composition of the V96ts-3 alloy, except it contained copper which may have only been included for patent law reasons. Nowadays improved aluminium-zinc-magnesium-copper alloys are used in many countries in the manufacturing of military and civilian aircraft. ■



Porsche 928



Honda NSX

teristics of the alloy within a certain range. Forged parts are rarely encountered in the structure of mass produced automobiles. On average, only 1.3% of aluminium parts are forged. The Porsche 928, Chevrolet Corvette, Honda NSX and Mercedes S-Class use a forged aluminium alloy in the subframe and in parts of the suspension. Forged wheel plates have a much smaller mass than cast ones, but are no less durable.

Approximately a quarter of the overall mass of aluminium parts in an automobile are made from rolled sheets. Panels for the body are stamped from these sheets, as are small grates and profiles. Aluminium sheets are used to produce the frame of the body. Audi, which in 1994 in the German city of Neckarsulme established the Aluminiumzentrum, released the Audi A8 in 1994, a car with a frame made entirely from aluminium. However, it is limited edition and only 70 are released daily. The Audi A2, the company's second all-aluminium model, was first presented at the 1997 Frankfurt automotive fair. In 1999 it became a series model. The replacement of the steel body with aluminium led to a 43% decrease in mass. As a result, the car weighs only 960 kg, its former mass being nearly 1,700 kg. Moreover, the aluminium body requires almost

SAP and SAAs

The abbreviation SAP stands for "sintered aluminium powder." SAP is made by placing oxidized aluminium powder in an aluminium hull and sintering it or heating it to a temperature slightly below the metal's melting point. While it is still hot, SAP is pressed into moulds to make semifinished products (bars). The pressed material outwardly resembles a metal in that it has a metallic luster, is fairly strong and conducts heat and electricity. However, in contrast to metal, SAP absorbs humidity well as it contains oxide particles. The bars can be pressed and rolled into sheets, rods, and pipes. SAP is at its strongest when it contains 25% aluminium oxide. Such material is six times stronger than pure metal. SAP retains this property even when it is heated to 500–600°C. For this reason, it is used to make articles that are used in high temperatures like car engine pistons. Sintering aluminium alloy granules ranging from several micrometres (10–3 mm) to several millimetres produces materials called "sintered aluminium alloys" (SAAs) or granulated alloys. The initial granules are made by dispersing liquid metal with a gas jet. SAAs are obtained in a similar manner to SAPs: alloy powders and granules are heated in an aluminium hull and then hot-pressed and extruded. The resulting material has a fine-grained structure which makes it strong and heat resistant and gives it a low friction coefficient. In many regards, SAAs have superior properties to cast alloys of the same composition. For example, granulated duralumin D16 is stronger than a cast bar made of the same alloy as its structure contains small particles, including phase strengtheners, which are not present in the cast alloy. SAAs and SAP are widely used in the car industry. ■

150% fewer parts than a similar steel model. A complete aluminium Audi body is heated at 200°C for forty minutes. The company named its aluminium body technology Audi Space Frame (ASF).

The bodies of the Honda NSX, Jaguar XJ220, Ferrari 512GT and the Plymouth Prowler are also made of pure aluminium. Thanks to its aluminium body, the new

BMW Z4 has “thinned down” and now weighs 1,300 kg. Several companies design cars with steel bodies which have some parts made of aluminium alloys. Toyota, Ford US and Porsche use the alloys to make doors, hoods, roofs and boots. Ferrari, Aston Martin and Ford US have actively implemented aluminium alloys to produce all external panels of the body. In the United States alone, the annual sales of cars with these panels exceeds \$1.5 million.



BMW Z4

Cars with aluminium bodies are immune to corrosion and therefore can be used in any climate conditions. Manufacturers use extrusion to reinforce bumpers, protective blocks in the side doors, seat frames, window frames, the aerodynamic spoiler, oil duct, hydraulic conduit and the reservoir. The products are formed by pressuring softened aluminium through a matrix with an opening of a certain section. Extrusion of aluminium alloys can achieve a maximum size precision.

One New Zealand-based company recently used extrusion to make engine parts for internal combustion. Such an engine weighs less, is more durable and works with less noise than an engine made with traditional casting technologies. The sunken profile can produce engines with various bucket speeds and numbers of cylinders.

Another promising method of manufacturing aluminium parts is powder metallurgy, or pressing materials from powders and then firing them. In Japan, this technology is used to prepare parts of the air conditioning's compressor, buckets and cylinders.

Aluminium Alloys

Many alloys have been created using aluminium. The addition of different metals (called “alloying elements”) to aluminium increases its strength and improves its other properties. Aluminium alloys are divided into two different types based on the method of forming articles: casting alloys which are used for casting articles in moulds, and wrought alloys which are used for rolling and drawing.

Casting aluminium alloys are distinguished according to their alloying elements. These may include silicon and magnesium, silicon and copper, copper, and magnesium.

There are several different methods for casting articles from of casting alloys. The simplest method is casting into a die or a steel mould. It must be carried out in an inert atmosphere, for molten aluminium oxidizes easily. A reciprocating pump can be used to make a lighter porous article, as liquid metal foams when poured into the mould. Pump bodies, among others, are cast in this way. Another method is to make an exact model of the intended article (e.g., compressor blades) out of wax. The model is then blasted with ceramic powder, which sticks to the wax and hardens, turning into a durable heat-resistant crust. The model is then heated, the molten wax is removed through a small hole, and the aluminium is poured inside. This method is called “lost-wax casting.”

The most important aluminium casting alloys are silicon alloys or “silumins.” They are characterised by good fluidity in the liquid state as they quickly and completely fill moulds without forming cracks or bubbles. Different series of silumins are used for making cylinder heads and blocks, fuel systems, and household items such as latches and coat hooks. If you bend a coat hook with pliers it will crack: many casting alloys are fragile!

Magnesium is added to increase their strength which leads to the formation of magnesium silicide crystals which strengthen its structure. Several such alloys are said to be heat-resistant, as they can withstand temperatures of up to 400°C and are used



Wheel disk made from aluminium alloy

Many aluminium alloys are so elastic that when heated they can significantly stretch. Thanks to this, parts with complicated forms can be obtained from air-pressing a flat metal sheet, which involves stretching the sheet over the shape matrix or by a moving die which makes it possible to create embossed parts with complex sections, bumps, rivets and openings.

Many aluminium alloys are so malleable that they can stretch considerably during heating. Thanks to this prop-



Audi A8

erty, parts with a complicated design can be made out of a flat metallic sheet.

The use of aluminium in the automotive industry is growing, but high cost is holding it back. A car with an aluminium body is a luxury item. Its cost highly exceeds a car of the same class with a steel body.

To repair an aluminium body is more expensive and complicated than repairing a steel car. A minor dent can be eliminated without difficulty, since aluminium is soft and malleable. However, in the case of more serious damage it is harder to return an all-aluminium body to its original form. Only a special welding technology in an atmosphere of inert argon gas can be used on aluminium and most repair centers do not have it at their disposal yet.

About 10% of all aluminium produced is used in the **electronics industry**. This has an interesting history. In the 1880s, the director of a train station in Chicago noted that an external electric cable made from copper wire quickly failed. Copper, as it turned out, was corroded by substances in steam engine smoke. Several hundred

to cast engine crankcases and other parts working under heavy loads. Aluminium alloyed with silicon and copper is harder and stronger due to the formation of not only magnesium silicide but also the intermetallic phase. Such alloys are used to make instrument cases and for air and car engines parts.

Even a small admixture of iron lowers the strength of silumin and leads to the development of cracks.

Alloys with over 10% of silicon are highly corrosion-resistant and have good welding properties. If silumin contains more than 13% silicon, the alloy loses its strength and malleability but barely increases in volume when heated. The malleability of many silumins can be increased by adding a minute amount (a few hundredths of a percent) of sodium or phosphorus.

Aluminium and magnesium alloys are resistant to corrosion, have a low density and are easily cut. Both of the metals in this alloy oxidize easily so to avoid this, the alloy is fused and poured in the presence of protective fluxes (substances that are specially added to lower the melting point and remove existing admixtures). The alloy is then thermally treated to improve its mechanical properties. Such alloys are highly resistant to seawater and humidity which makes them suitable for use in the shipbuilding, aircraft, and rocket industries. They are used to make instruments, nose and tail gear forks, and steering wheels.

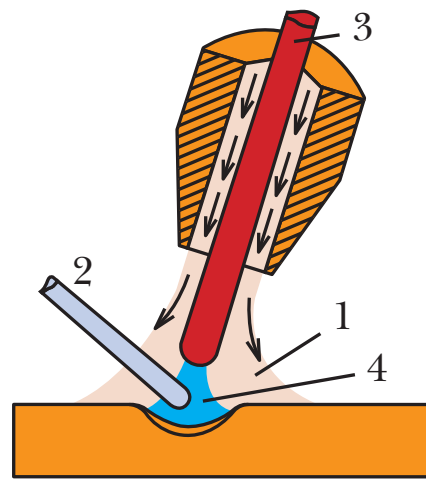
Aluminium-copper alloys are difficult to cast and have a low resistance to corrosion. They are also very strong at normal and high temperatures and are easy to cut and weld. They are used to cast load-bearing parts.

Wrought aluminium alloys are easy to work for they are strong and malleable. At the same time, they have low liquidity and do not fill moulds completely.

Wrought alloys are denoted by special symbols consisting of letters and digits. The letter at the beginning of the symbol represents the type of alloy. For example, D refers to a duralumin-type alloy, F to a forging alloy, and H to a high-strength alloy. Commercial-grade aluminium is denoted by the letter A.

Aluminium-manganese alloy (AMn) is one of the most widespread wrought alloys. This alloy is soft and malleable yet insufficiently strong. The AMn alloy is used for in construction and decoration as well as in manufacturing shop equipment and kitchenware.

Aluminium-magnesium alloys (AMg) are called magnaliums. The strongest alloy among them (AMg6) contains approximately 6% magnesium as well as small amounts of manganese, titanium, and beryllium. The alloy is manufactured into different wrought semi-finished products such as sheets, panels, rods, and sections, and is tough and resistant to corrosion. The alloy AMg6 is easy to weld. It is used to make rocket fuel tanks, gasoline and oil pipelines, ship hulls and masts, hoisting crane parts, railroad car frames, and car bodies. Experiments have even been made using aluminium-magnesium alloys for infantry combat



The argon-arc welding scheme
1. Argon
2. Welding rod
3. Tungsten electrode
4. Electrical arc

metres of copper wire were replaced with aluminium wire. It admirably survived the test of time, even though each year the number of trains on the line increased.

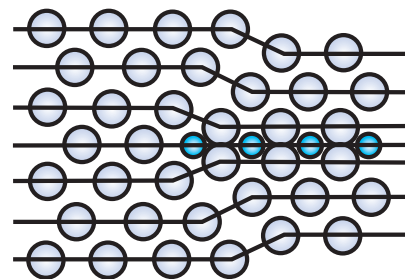
Aluminium wires successfully compete with traditional copper ones, as they are more than three times lighter and much cheaper. The high electric conductivity of aluminium means that it can be used to prepare bare cables for airborne electric wires, structural isolated communication cables, installation wires and winding wire. When conducting a current, bare cables heat up and their surface becomes covered with a durable film of oxide acting as an isolator which protects them from external factors. Sometimes aluminium wires anodise, or their surface becomes covered in a protective oxide film. These wires have such a high chemical resistance that without prolonged isolation they can work in high moisture climates and at temperatures from -200°C to $+500^{\circ}\text{C}$.

Anodic oxide films are used in electric technology as rectifiers. When they come in contact with a metal that cannot be anodised, they form a system that lets current through in one direction only or they act as rectifiers.

Our priority development is permanent search to extend the usage of aluminium in a car in order to efficiently reduce its mass without negative impact on its size and level of security. This is confirmed by the development of car industry in North America, where Alcan works successfully both with the three leaders of American car manufacturers and with the foreign manufacturers in this region. At all events, aluminium is more and more used in cars, in average, in the USA in 2003 128 kilos of aluminium were used compared with 87 kilos 10 years ago... The North American transport is the biggest consumer of aluminium, it uses annually nearly 3.4 million tons of aluminium, out of which about 70% is spent on the production of cars.

Thomas Gannon, vice-president of the branch of industrial and automobile products of Alcan Corporation in Cleveland.

vehicles: shells simply get lodged in the material because of its toughness. Duralumins are the oldest aluminium alloys still used in contemporary technology as they have an effective combination of strength and malleability. However, they are fragile and insufficiently resistant to corrosion. The first such alloy was discovered in 1909 and is still used in technology. Duralumins are widely used in aeronautics and until recently D 1 was used to make aeroplane propeller blades. The best-known alloy (D 16) is a still key material in aircraft manufacturing. Duralumins become a lot stronger after ageing. In so-called natural ageing, the alloy is kept exposed for a long time and in the process copper gathers in disc-shaped zones with a thickness of 1–3 atomic layers and a diameter of 9 nm. Such zones are called **Guinier-Preston zones** after two scientists who independently discovered the accumulation of copper



The model of aging of the aluminium-copper solid solution

in the structure of aged aluminium-copper alloys. The concentration of copper in Guinier-Preston zones is a lot higher than in the surrounding solid solution. The number of such zones in a cubic centimetre of alloy is extremely high: $5 \cdot 10^{17}$. As copper has a smaller atomic radius than aluminium, the crystal lattice becomes deformed around Guinier-Preston zones making the alloy stronger. Thermal treatment is also used to harden aluminium-magnesium-silicon alloys. The American metallurgists **Z. Jeffries** and **R. Archer** made the first such alloy in the 1920s and, in Russia, the well-known metallurgist S.M. Voronov worked with them. ▶



High-tension-line towers



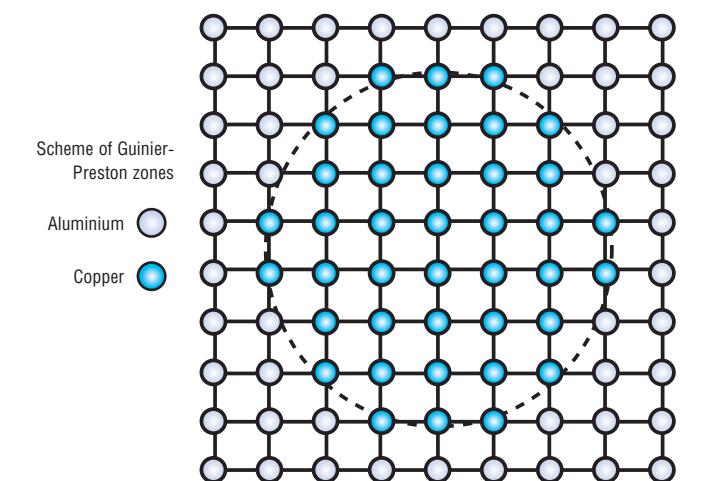
Aluminium wire rod

Aluminium is used to make various types of antennas, including TV aerials and radars. Telephone operators also need aluminium as it makes up telephone cables.

In several countries aluminium is used to manufacture mast supports for electric current lines.

On **railways**, aluminium cars are used to transport bauxite, alumina and grain, while aluminium cisterns are used to transport acids. ▶

These alloys are strong due to the formation of magnesium silicide and ageing processes. The AV alloy and other aluminium-magnesium-silicon alloys are widely used in construction and vehicle engineering. Their surfaces can be easily polished and anodised, which makes them suitable for decorative purposes. For this reason, aluminium-magnesium-silicon alloys are used to make cases for watches and domestic appliances. Other such alloys are used to make pipes, forged products, and window frames. Forging alloys are elastic and resistant to cracking during heat treatment. They have a similar chemical composition to duralumins yet they contain more



silicon. The AS8 alloy with approximately 4% copper is used to make engine mounts, spar booms, and other parts of modern aeroplanes. The AS6 alloy which has a lower copper content is used for making fasteners.

The addition of zinc, copper, and magnesium to alloying elements produces high-strength alloys that are employed in the aviation and defense industries. They are used to make load-bearing parts, including not only aircraft coverings but also bulkheads (transverse bars in aeroplane hulls used for increasing the strength and stability of the sidewalls and base), stringers (longitudinal bars that serve as supports for bulkheads), and spars (bars used for strengthening the wings). Modern alloys are fine "organisms" whose properties are determined by the purity of the initial substances and the meticulous execution of the technology used to make them..

Alloys in which aluminium serves as the main alloying element deserve a special mention. These include aluminium bronze, aluminium brass, and aluminium iron. Aluminium bronze was the first aluminium alloy and replaced traditional tin bronze. Today, bronzes with a 4–11% aluminium content are used in industry. Alloys containing up to 7% aluminium are elastic and can be pressure-treated. Bronzes with a high aluminium content are not malleable and are used as casting alloys. ▶



High-speed TGV train

▼ Aluminium bronzes surpass tin bronzes in many ways as they have a high resistance to corrosion, including in seawater. Articles made of aluminium bronze are used in ships and aircrafts, chemical instruments, and electric technology. Aluminium brass (a copper-zinc alloy containing 1–4% aluminium) has similar uses. Aluminium is also part of certain nickel alloys such as Almel which is heat resistant, elastic, easily forged and drawn, and has magnetic properties. Almel and the chromium alloy Chromel have been used since the 1930s to manufacture thermocouples (devices for measuring temperature). ■

The use of all-aluminium vehicles in public transportation is not financially viable as a rule because of the aluminium's high cost. In France, aluminium alloys are used to make TGV high-speed trains carriages, which reach speeds higher than 500 km/h. Steel parts are replaced with aluminium ones in cars that operate in humid conditions. Some Russian metro cars are made of aluminium alloys. The difference in the mass of the aluminium and steel versions of this car has been calculated at 3,620 kg, which yields a considerable economizing effect during use.

In ship building aluminium is used to make high-speed vessels, like Russia's "Raket", "Meteor" and "Vikhr". Their production makes use of magnalium, an aluminium-magnesium alloy. Aluminium alloys are used to make the bodies of motor boats, yachts and deep-sea vessels. One of the largest such yachts, the 90-metre-long Afina, was built in 2004 from welded 10–15 mm thick aluminium sheets. The same metal is used to make the hulls of ocean liners. Aluminium was first used in ship-building in 1893 when making a torpedo boat.



"Meteor", high-speed hydrofoil boat

Aluminium and its alloys are irreplaceable in the **chemical and fuel industries** to build vats and ducts thanks to their resistance to many acids and alkalis. Aluminium alloys are essential in the serial production of containers for concentrated nitric acid.

For pipelines, especially those in permafrost conditions, aluminium-magnesium alloys are used. The American company Noble Corporation has used aluminium to equip a pipe for deep-water drilling off the shores of Brazil at depths of up to 1,300 metres. Overall, the system was 45% lighter than the steel version.

Aluminium in Construction

Thanks to its high durability, lightness, corrosion-resistance, attractive appearance and resistance to earthquakes, aluminium alloys are widely used in construction. The minimum service period of aluminium constructions is estimated to be 80 years. They resist climate effects and “work” in a wide range of temperatures, from -80°C to $+300^{\circ}\text{C}$ (unlike steel, which breaks down at low temperatures), which is especially

important in the Urals and Western Siberia. For some constructions this factor is no less important than resistance to corrosion or low mass. Although the flexibility module of aluminium is less than the analogous figure for steel as a result of its low density, an aluminium sheet weighs half as much as an equally rigid steel plate. According to foreign scientists, the weight of an aluminium construction is two or three times less than the weight of an identical steel one, and up to seven times lighter than a concrete construction with equal supportive capacity.



Aluminium constructions in industrial development (Khakas Aluminium Smelter)

Aluminium is employed virtually everywhere on account of its excellent properties. Aluminium is used to make frames and coverings for buildings and other structures, including coverings, supports, columns, bridge spans, roof and wall panels, architectural details on façades and interiors, window frames, doors, shutters, garden and balcony grates, parapets and eaves. Each year around the world the volume of

high-rise construction increases. Contemporary façades and shopping, entertainment and office centers are built requiring new construction solutions. In Europe over the last 40 years, the use of aluminium in construction has increased by 15 times, and specialists estimate that the demand will grow annually at least 2% to 3%.

Aluminium was first used in construction in 1896 when the Life Building in Montreal installed an aluminium cornice. A year later an aluminium roof

appeared on a church in Rome. Aluminium was very gradually implemented for use in construction.

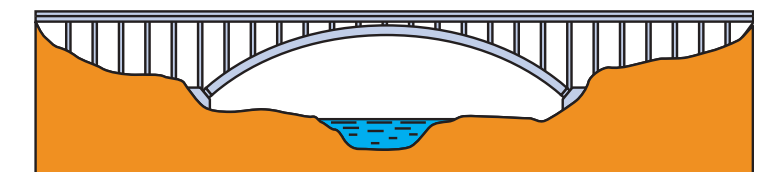
Some of the first weight-bearing constructions were the beams and trusses of the Smithfield Bridge in Pittsburgh (USA) originally made from steel, but in 1933 replaced with aluminium. The frequent use of anti-slick products led to the corrosion of the aluminium structure, but nonetheless the beams lasted more than 30 years and were replaced with new ones from the same material. However, the railings, which were processed with reagents, have been kept in an excellent condition until now proving the longevity of aluminium structures



Smithfield Bridge, Pittsburgh, USA

where they are used properly. The reconstruction of the Smithfield Bridge proved profitable, since the use of aluminium decreased the bridge’s mass by 700 tons, while the supports of the old bridge were used in the construction of the new one.

In 1950 an aluminium bridge was built in Canada across the Saginaw River. Its foundation has a pivotless arch with uncut shore trestles. The bridge’s mass is 180 tons, but this could have been lower if its heavy concrete surface had been replaced with a lighter aluminium version.



Scheme of aluminium bridge across the Saguenay River, Canada

Drawbridges made out of aluminium alloys have numerous advantages. They weight relatively little, which makes the mechanical part simpler and lighter, removes the need for bulky counterbalance, and offers various new options for design. See for example a bridge with an opening span in Sunderland Port, England. It weights 95 tons less than a similar one made of steel would.

After World War II aluminium alloys were used in the construction of high-rise buildings. In the 1950s

Composite Materials (Composites)

Modern car-and shipbuilding, railways and metro, chemical industry, building industry are impossible today without composites. Composite materials are materials consisting of several substances with clear boundaries between them. As a rule, composites consist of a plastic base (matrix), which acts as a binder that contains another substance in the form of fibres, chips, or powder grains. The introduction of the second substance into the matrix makes it possible to transfer certain properties to the latter, making it stronger and more wear-resistant or more elastic and malleable. For example, silver can be strengthened by adding small particles and crystal whiskers of corundum that resemble felt. The resulting material resembles pure silver yet has greater strength, which can be further increased by heating. Composites based on very thin aluminium oxide fibres combine lightness, which is typical of aluminium alloys, with high strength. Composites formed by smelting iron powder and corundum crystal whiskers are three times stronger than steel! ■



Drawbridge made of aluminium in Sanderland, UK, 1950

Cement

Builders have used cement for centuries since the Romans produced it out of lime and volcanic ash. Pliny the Elder wrote that this powdery material "can serve as a bulwark against sea waves: when it is submerged in water, it turns into a hard stone that cannot be overcome by waves and becomes harder with each passing day." Volcanic ash was used for cement production up until the 19th century and subsequently cement was made out of lime and clay. The new material was named after the place in England where the sandstone for the cement was quarried ("Portland cement"). In furnaces, sandstone is broken down at a temperature of 1,400°C into calcium oxide, which interacts with dehydrated clay turning into calcium silicate and aluminate. All of these substances make up the cement clinker which is the solid material produced by the furnace stage. The clinker is cooled, ground, and sifted through very fine sieves. The finer the grind, the stronger the cement. Cement comes in different grades (300, 400, 500 and 600) which serve as a measure of its strength.

The clinker is mixed with water for hardening: on average, 350 millilitres of water are used per kilogram of cement. The resulting suspension, which is called cement slurry, sets over time. When water is added to the clinker, the many substances it contains dissolve and then crystallize over time as hydroxide salts. The latter form the basis of cement stone, which arises from the hardening of the cement solution giving cement its strength and longevity.

When cement hardens, its density grows and its volume decreases (i.e., it contracts). To reduce contraction, sand, gravel, crushed marble, and other fillers are added resulting in a material called concrete. Concrete is used for making building foundations and panels that are used in mass residential construction. It is also used by sculptors: the giant statue of the Motherland on Mamayev Mound in Volgograd is made out of strong reinforced concrete. Although its concrete hull does not exceed 30 centimetres, the 85-metre-high monument has a mass of 6,000 tons. The steel sword measures 29 metres and weighs 14.3 tons. Humidity, carbon dioxide, and changes in temperature gradually disintegrate cement and concrete, causing them to lose their strength a lot faster than natural stone. Water seeps into the pores dissolving and breaking down the calcium bonds that give concrete its strength. ■

large blocks were used for these purposes. Not only did this make it possible to lower the weight of structures in the building's frame, but to also considerably speed up construction. It is a well-known fact that the walls of the 26-story skyscraper in New York were erected in one week by only 15 men.

In Russia, the first domestic specialized enterprises producing aluminium structures for civilian use appeared in the 1970s. Mosmetallokonstruktsiya, the first such factory, was built in Vidnoye near Moscow, followed by factories in Voronezh and Khabarovsk, as well as the Brovar factory in Ukraine which was directed towards the constructing aluminium industrial and civilian buildings.

The first structures made entirely from aluminium were erected in the 1940s, in the USA. Their contours were similar traditional steel ones and differed only in mass. Over time, manufacturing various types of aluminium profiles by pressing became quite common.



The Bercy Stadium in Paris

This made it possible to more effectively make use of the high durability of aluminium alloys, in constructing new buildings.

The round pavilion presented at the London exposition of 1951 was truly innovative. The entire structure is circular and its walls are formed by three-layer arches with trusses turned inwards for maximum rigidity in order to hold up an aluminium dome 109 metres in diameter. The search for the optimal form for the roof was completed by the creation of domes with original constructions. The Bercy stadium in Paris was covered by a multi-faceted dome, the surface of which was formed by bent barrier panels consisting of aluminium sheets. Each panel was strengthened by a piped brace along the curve and stretching to the two opposite corners of the panel. The triangle formed by the braces gave rigidity to the whole system.

How are building structures made out of aluminium? Aluminium bars are fashioned into semi-manufactured



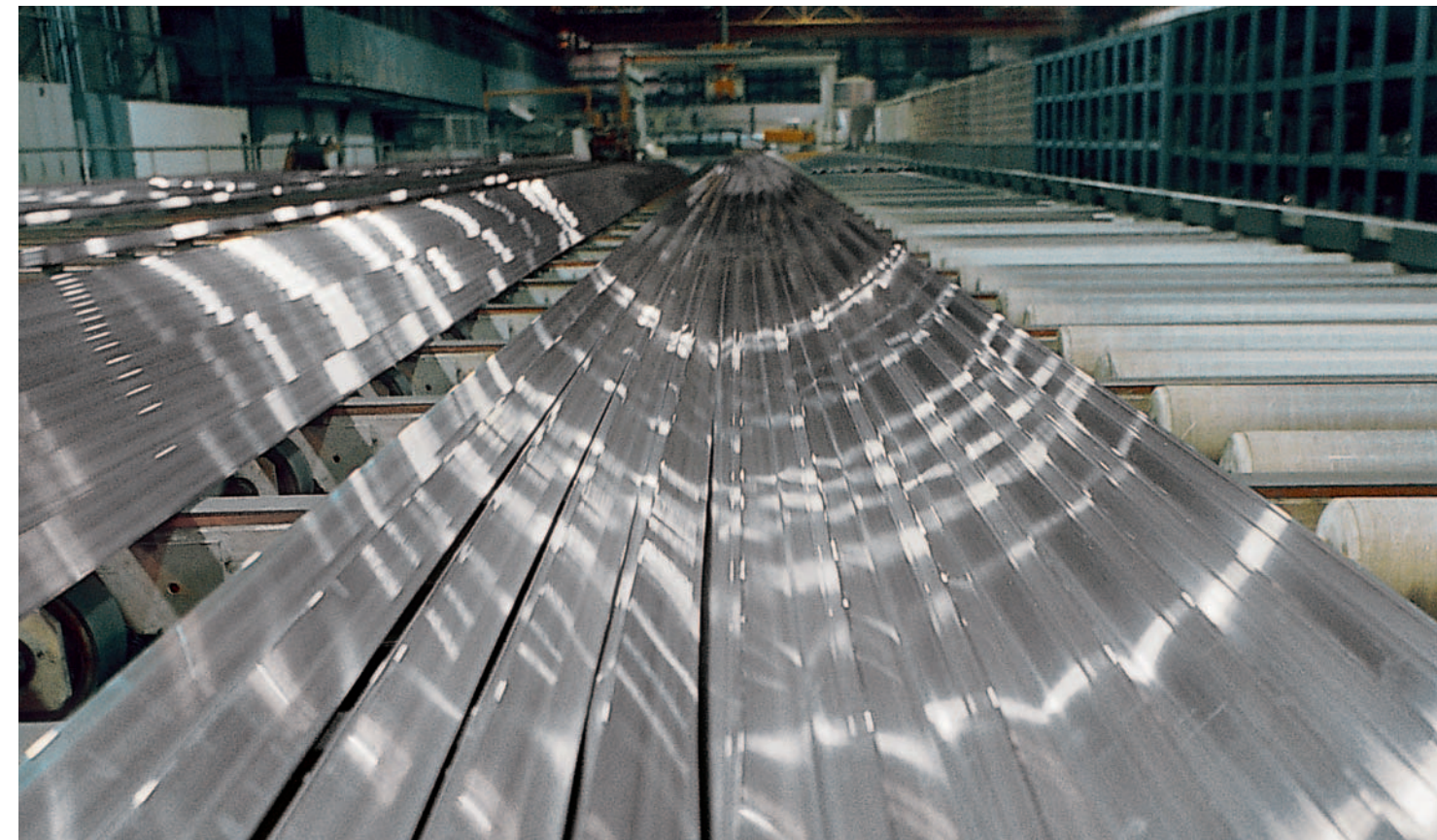
Exhibition Center in London built for the World Expo of 1951

materials for use in construction at specialized factories. Rolling tools make sheets and ribbons, profiles are obtained by pressing, and panels are stamped. These materials are used directly in construction. The manufacturing of aluminium construction profiles and sheets with coverings is carried out by a separate branch of the industry.

Along with traditional single-layer sheets of steel, three-layered sheets are used, consisting of an in-

termediate layer of an ordinary aluminium-magnesium-manganese alloy and two outer layers which are made from an alloy of aluminium and zinc. This material, which is corrosion-resistant, was invented for aeroplane construction.

Aluminium parts are joined using various methods including welding, adhesives, and with rivets and bolts. Welding is very difficult because the metal slightly oxidizes in heat. When installing trusses at a construction site, workers use handheld or arc-jet welders which do not require complex equipment. Before the seam is applied, the parts are heated to 250–300°C with a gas burner to compensate for the increased heat conductivity of the metal. Recently



Aluminium profiles

argon arc welding has been widely used as it produces a durable, smooth seam and has the least thermal effect.

Welding, however, is unreliable as the seam created is not durable and cracks may form, especially on duraluminium. For this reason, duraluminium and other highly durable, thermally processed alloys should not be used in vital structures. As mentioned before, rivets are used in aviation technology. Rivets are inserted into cold metal which excludes the possibility of a thermal effect and subsequent oxidation,

which occurs when seams are welded. Therefore, for thermally fastened aluminium alloys, rivets are the most efficient connections.

In recent years, adhesives have been used more frequently to attach aluminium parts; their durability is starting to compete with that of rivets. Resins are used to adhere aluminium alloys, applied either with hot or cold methods.

One of the methods uses hot resin mixed with a substance which speeds the hardening process and is applied to the glued surfaces which are preliminarily heated. The gluing point is held together for several minutes at a temperature of 280°C and then for two days at 110°C. It is believed that a higher temperature will yield a more durable connection. However, adhesives have several drawbacks. The resin that makes up

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One of the methods uses hot resin mixed with a substance which speeds the hardening process and is applied to the glued surfaces which are preliminarily heated. The gluing point is held together for several minutes at a temperature of 280°C and then for two days at 110°C. It is believed that a higher temperature will yield a more durable connection. However, adhesives have several drawbacks. The resin that makes up



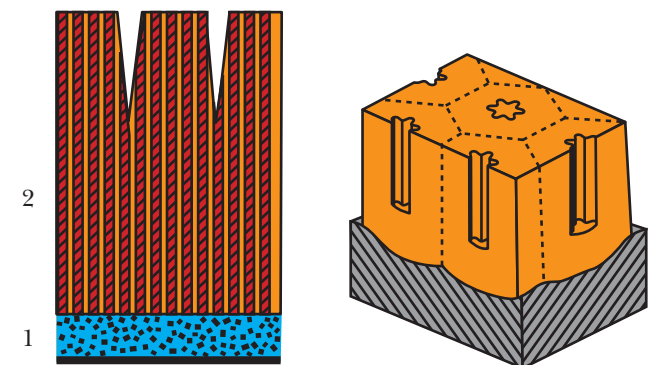
Nikolai Petrovich Sluginov (1854–1897) was a Russian physicist. He was born in Kadnikov, in the family of a merchant, studied in grammar schools of Nizhny-Novgorod and Saratov, and, later on, at the math department of St. Petersburg University. In 1881 he defended his dissertation on the subject "Theory of Electrolysis," and in 1894, a doctorate "Electrical Fluorescence." From 1881 he worked as a teacher in Vvedensky Grammar School, St. Petersburg. From 1884 he read a course in physics in Moscow Technical College, and, beginning with 1884, he was a regular professor at Kazan University.

Sluginov was the author of more than 100 works, mainly of experimental character, published in Russian and foreign journals, among them "A Course in Acoustics" (Kazan, 1894). Sluginov was the first to survey the fluorescence of electrodes and proved the intermittence of current during electrolysis; he found means to cover aluminium with thick layer of waterless alumina, as firm as corundum; he also explained the impact of local currents on the electric capacity of the element.

Anodised Aluminium

Buttons on military coats. Multicolored clock faces and radio dials. Modern chandeliers that seem to be made of bronze. The only way to tell that these objects are made of aluminium is to hold them in your hand. Although they are clearly not covered with paint or enamel, they are far from being silver-grey in color. Yet they are made of aluminium, whose surface is covered by a thin oxide film that retains minute dye particles in its pores and gives the object its color. Recall that the surface of aluminium is always protected by an oxide film so thin it does not hide the material itself and has a metallic luster. This is why anodised articles look shiny. In addition, this thick oxide film can considerably increase the metal's hardness, which can make anodised aluminium stronger than steel.

In 1877, Nikolai P. Sluginov, professor of physics at Imperial Kazan University, was the first to discover a method for obtaining oxide films. This method (along with other methods that were developed subsequently) is still used today. The object is placed in an electrolytic bath filled with 20% sulfuric acid. A graphite rod is lowered into the bath, and a direct current is passed through it. The wire from the positive pole is connected to the article (anode), and the wire from the negative pole to the graphite rod (cathode). This leads



Scheme of anodised oxide film obtained by electrochemical oxidizing

1. The barrier film
2. Porous layer

to the formation of a two-layer film: a thin dense inner layer (called the barrier film) and a thicker outer layer with a loose porous structure. When the current is switched on, the electrolysis of the sulfuric acid begins. During the process, the natural oxide film covering the metal is dismantled, while anions of the electrolyte reach the metal's surface through the resulting voids. A non-porous barrier oxide layer gradually forms on the metal's surface consisting of densely packed cells resembling a honeycomb. The oxide film grows over time and the cells become elongated forming stretched prisms leaning at right angles to the metal's surface. A cylindrical duct forms in the centre of each cell. These ducts are filled



Aviamotornaya station,
Moscow Metro

by water molecules and electrolyte ions. Thanks to its loose porous structure, the film can be dyed by submerging the article in a dye solution. After anodisation, melts (e.g. of salts) are sometimes used as electrolytes instead of solutions. In this case, the bath must be heat-resistant. There is also a plasma anodising method in which aluminium is placed as an anode in a discharge tube filled with oxygen. Anodised aluminium plates with reliefs decorate the ceiling of Aviamotornaya Station in the Moscow subway. From afar, they seem to be made of gold. ■

the adhesive is a fire risk and softens when heated which weakens the structure. Over time, adhesives age and their durability decreases by several times.

The production of aluminium structures is directly related to the process of anodisation, and therefore factories that produce aluminium sheets usually use electrochemical production. The goal of anodising is to protect the metal from corrosion and give it an appealing appearance. Buildings constructed with metal and glass are one of the primary features of contemporary urban architecture. Their facades barely ever have walls as they are entirely constructed from pressed aluminium frames with glass inlays. This is the most common method for covering large surface areas with glass. Pressed frames are the most frequently used technology in glass and metal buildings. In Western Europe there are more than 200 factories producing 2.2 million tons of press products annually.

Thanks to their high durability, pressed profiles are capable of withstanding enormous mechanical loads.

They are used in the construction and renovation of stores, markets, supermarkets and in the production of window displays and display cases. Combining profiles of varying shapes can achieve a wide variety of architectural solutions, including corner and arch constructions. The architectural appeal of constructions made with aluminium profiles is reinforced by the use of tones and mirrored glass. Frame structures based on aluminium profiles are reliable and easy to use and broken or damaged glass can be easily replaced.

Aluminium materials are widely used in monolithic construction. They are the bases of transparent windows, door and window units, systems for false glass facades, and roofs – often in rather complex geometric shapes.

Lowering the weight of a roof also lowers the cost of construction by 12%. For this reason an aluminium sheet roof, will quickly earn its keep during use even if the initial costs are higher than for other types of roofing. Such a roof hardly ever requires protective repair



Moscow State University
building on the Vorobyovy
Hills, Moscow
(the window profiles
are made of aluminium)

and compared to iron it will last much longer. The longevity of an aluminium roof cannot be compared to that of an asphalt sheet as this type of roofing is in constant need of repair. An aluminium roof, produced in thin, wave-like sheets, outwardly resembles tiling and offers numerous decorative opportunities such as anodising to give it color.

Another area of aluminium application is the installation of ceilings. Cleat ceilings are assembled from pressed or bent profiles, while panel ceilings are made of stamped elements, sometimes with a relief.

Aluminium frames are installed when making glass walls for balconies, terraces, galleries and for internal barriers in industrial facilities.

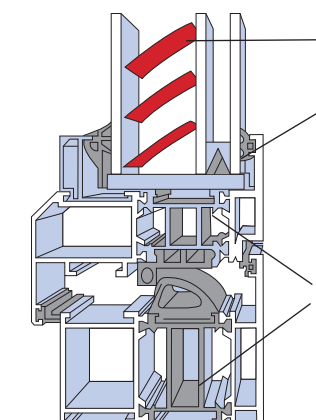
Polished sheets of aluminium alloys were used as early as the 1950s as fencing for the Soviet and Hungarian pavilions at the World Expo in Brussels.

Aluminium Windows

Aluminium windows highlight the architectural modernity of a building and match the style of the modern interior. When restoring old buildings anodised aluminium window frames are used to imitate the styles of any era. Anodising can be used to color sections in different hues. The thin oxide film not only gives the item an attractive outward appearance but also protects it from corrosion. The heat and sound-isolation properties of such profiles are of the highest standard. They were first used in Russian architecture during the construction of high-rise buildings in Moscow such as the Moscow State University on Vorobyevy Hills

Scheme of "warm" aluminium
window profile.

1. Heat barrier, insert made of cold and humidity-resistant polymers.
2. Glazing
3. Spacer



and the Ministry of Foreign Affairs on Smolenskaya Square.

Builders distinguish between two different types of aluminium sections: "cold" and "warm" sections. Cold sections are used for unheated buildings and warm sections, which keep the heat in, are usually used in heated buildings. They contain "heat barriers" which are inserts that isolate the inner (warm) part of the section from the outer (cold) part without changing the section's static properties. The inserts are made of cold and humidity-resistant polymers such as polyurethane and polyamides and should be between 3 and 4 cm thick for a heated room. Heat barriers increase the cost of buildings as both the material itself and the method used for inserting them into sections are expensive. The high cost of windows can be reduced by covering open slits with thin rubber sealant strips which make up a zigzag-shaped "labyrinth" that prevents the cold from coming through. Insulated glazing, consisting of several panes making up a single window, is inserted into the frame. The glazing is equipped with a spacer or aluminium strip that allow the condensate to pass into the humidity absorber through small holes. ■

Aluminium in the Human Body

The body of an adult human has from 50 mg to 140 mg of aluminium exclusively in the form of chemical compounds. There is 0.39 mg of aluminium in one litre of blood, and up to 0.21 mg/g in the heart. The most aluminium is found in the hair: on average, a gram of hair contains 29.3 mg of aluminium and in the hair of casters at aluminium factories this figure reaches 158.5 mg! Aluminium is categorised as a microelement that the body needs in small doses. Aluminium ions activate certain digestive acids and increase a human's reproductive ability.

The wide industrial use of aluminium means that over a lifetime a person's body absorbs aluminium. The lungs of elderly people contain 10 times more aluminium than those of infants (accounting for a change in mass). The adult daily aluminium requirement is estimated to be 2.45 mg. The body's main sources of aluminium are food, water, air and the use of aluminium crockery and deodorant. Studies have shown that in the process of preparing soup in a new aluminium pot the amount of aluminium in the solution increases by almost a third! The more often a pot is used, the duller it becomes (becoming covered with an oxide film) and the less aluminium is absorbed by food.

Aluminium compounds are broken down by acidic

"Today it is still unclear at what stage aluminium penetrates into the brain of someone suffering from Alzheimer's disease. Is it substance that causes disease, or is it substance accumulated because of the disease?"

Most scientists believe that the role of aluminium in the appearance and development of this disease is unimportant. This point of view is based on the fact that aluminium is one of the most widespread elements. It can be discovered anywhere: in water we drink, in dust we breathe, in many substances we use, such as Cola, make-up, food dyes. So, taking into consideration the toxic character of this metal, we could expect a far greater number of people suffering from Alzheimer's disease than they really are. But even if we stop using clay pots (aluminium is part of a chemical compound of clay), pans and deodorants, it will still be impossible to avoid contacts with aluminium."










Zaven Khachaturian,
director of Nancy and Ronald Reagan Research Institute, 1997

Maalox, Almagel, and Other Pharmaceuticals



Aluminium hydroxide is used for removing impurities from drinking water because its gel has a high surface area, easily surrounds colloid particles, and removes them from the solution. This chemical is also used in medicine. The drug Algeldrate (aluminium hydroxide powder) is prescribed to patients suffering from acid indigestion and from injuries of the stomach and the large intestine's mucous coating. Doctors call such substances "antacids", the most effective being Almagel which was developed in the 1960s. Every 5ml of suspension contains 4.75 ml of aluminium hydroxide gel and 0.1 g of magnesium hydroxide. Almagel is a sweet, syrupy white liquid thanks to the sweetener sorbitol (a colorless crystalline sweet substance obtained from glucose and used as a sugar substitute by diabetes patients), which boosts the secretion of bile. In contrast to Algeldrate powder, the gel covers the stomach's mucous coating and thus has a longer-lasting effect. The well-known drug Maalox contains aluminium hydroxide gel, magnesium hydroxide, and the sweetener sorbitol. Every 100 ml of Maalox suspension contains 3.49 g of aluminium hydroxide and 3.9 g of magnesium hydroxide. The new antacid drug Magaldrate has a similar effect to Maalox. Its name comes from the words magnesium hydroxide and aluminium hydroxide. Aluminium hydroxide is also found in many other antacid drugs. For example, Gastal tablets contain 0.45 g of aluminium hydroxide mixed with magnesium oxide and hydroxide. Amorphous aluminium-magnesium silicate is the active ingredient of the drug attapulgit (neointestopan), which helps fight diarrhea, toxicosis and intestinal inflammation. ■

ALUMINIUM CONTENT OF FOODS

			
tea leaves 850–1400 mg/kg	apples up to 150 mg/kg	corn 42 mg/kg	pea 36 mg/kg
			
indian corn 16 mg/kg	beef 1,6–20 mg/kg	sweet pepper 3,2 mg/kg	garlic 1,1 mg/kg
			
			onion 0,8 mg/kg

stomach juices. In the intestine, which has a weak alkali environment, aluminium ions settle in the form of phosphates, and therefore the excessive consumption of aluminium may lead to a deficit of phosphorus in the body.

Aluminium ions affect calcium metabolism which is the main element found in bones. Alunite dust, which contains aluminium, can damage tooth enamel. In places where soil and water are oversaturated with aluminium salts, birds cannot lay eggs due to the increased fragility of the shells. However, a trace of aluminium can have a favourable effect on human health, and aluminium salts are included in mineral and vitamin food supplements.

A debate once existed on whether an accumulation of aluminium in the body led to Alzheimer's disease, a form of senility. In 1965, it was proposed that Alzheimer's disease struck people who used aluminium alloy crockery over a long period of time. This could explain the frequency of the disease in the Unit-

ed States, since aluminium tableware was the most actively used in that country. Experiments with rats have shown that changes in nerve cells under the influence of aluminium salts are different from the changes observed in human patients. As a result of clinical studies, it was found that an increase of aluminium occurred in an Alzheimer's patient's body but it is very likely that this is a result of the disease and not the reason for it. It should be noted that the use of aluminium crockery is not the only way this metal enters the human body. There is, for example, a lot of aluminium in apples and tea, products that are traditionally consumed in Russia.

Chapter 9 | Aluminium and Art

There was a time when human beings only needed a hide on their hips and a piece of raw meat. Only one demand was placed on food, clothing, housing, and weapons: functionality. The main thing was that they kept warm, nourished, and protected from bad weather and enemies. As civilization developed, another criterion became important for mankind: aesthetics. Exquisite table layout, fashionable dress, and designer furniture are all essential attributes of modern life. Those who create the beauty around us keep asking: what next? What will be the aesthetics of tomorrow? What forms and materials will be considered to be the most stylish and convenient by the coming generations?

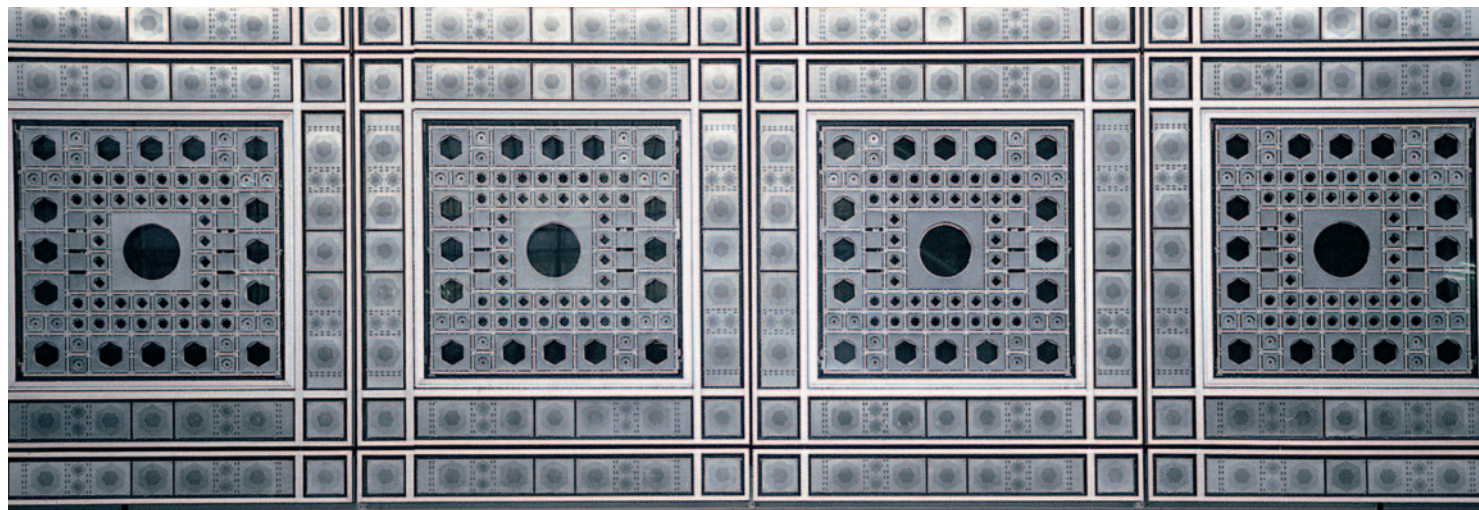
There are a lot of answers to this question. Yet virtually all *maîtres* agree that aluminium will rank high on the list of the materials of the future.

Can a hard metal chair really be comfortable? Or is there beauty in a metal closet? Without a doubt! Can you really be comfortable in a room where most of the objects are made of metal? Don't your eyes get tired from staring at shiny surfaces for too long? Again, you can be perfectly comfortable, as long as the objects in the room are made of aluminium. Is a metal dress fit for wearing at a party? Why not! Today, designers are inventing incred-

ibly effective and stylish clothing, shoes, and accessories that incorporate aluminium. What lies at the heart of the "aluminium aesthetic?"

First and foremost, aluminium allows designers to create many reflecting surfaces; spaces full of aluminium objects are saturated with light. To avoid sharp flashes, surfaces are matted, but they still don't lose their sheen, inspiring optimism and instilling us with new energy. This energy can be found in both the tense yet flexible forms of contemporary furniture and the graceful all-aluminium body of automobiles.

Aluminium's main "competitor" is, of course, stainless steel. But its sheen is so bright that it destroys any impression of the object's integrity. Unlike steel, aluminium is like the double-faced Roman god Janus: it has two "sides." Not only does it have great decorative qualities, but fantastic characteristics for use in construction. Like many other metals, it is durable, but – in comparison to other metals – aluminium is much lighter and more flexible. This is especially valuable when the product's mass needs to be reduced while underlining its stylistic qualities through visual means. Aluminium's surface qualities can also be concealed: anodic treatment can give aluminium the qualities of both grey cast-iron and golden bronze.



Pierre Soria. Aluminium panels decorating the entrance of the Institute of Arab's World in Paris



Jacque Herzog, Pierre de Meuron. Walker Art Center in Minneapolis, USA, 2005 (the building's lining is made of aluminium)

Aluminium in architecture

One could say that the broad use of aluminium in architecture came in through the window. In 1904 the American architect Francis Plym tried to catch a taxi in Kansas City. A hard rain was falling, and all the cars passed him by, so that he sought shelter in an unfinished building. Here he noticed that the wooden window frames had already begun to rot. This gave him the idea to make window frames with non-corrosive metals. After patenting his design for the first metal molding for window frames, the inventive architect went on to found the Kawneer Company in 1906. The company immediately began to mass-produce these frames, at first in bronze and steel, and then, in the 1930s, in aluminium.

In the 1890s, an Italian architect **Raffaele Ingami** has covered the dome of San Gioacchino with aluminium sheets. The church was built in Rome to commemorate the enthronement of **Pope Leo XIII**. *Monadnock Building*, one of the first skyscrapers was built in Chicago in 1889–1892. It was designed by **Daniel Burnham** and **John Welborn Roots**. They planned the staircases, fences for elevator wells, and sliding doors to be made of aluminium.

A drop in aluminium prices happened at the time when numerous new architectural ideas were born. Many architects of the late 19th and early 20th centuries saw the future of architecture defined by the use of metal constructions. Austrian architect **Otto Wagner** points this out in his “Modern Architecture” published in 1895. “The architect must develop artistic forms from construction alone,” he wrote. As possible materials, he mentions steel, reinforced concrete, glass, and aluminium. In the Viennese headquarters of the telegraph agency *Die Zeit*, designed by Wagner in 1902, the Austrian architect planned for the broad use of aluminium in the decoration of interiors and façades. Aluminium panels did not only comprise much of the construction itself, but also became elements of the building’s decor, structuring the wall surfaces and creating a unique rhythm of parallel and perpendicular lines. The matte surface of the aluminium panels contrasted with dark doorways and windows, creating a sense of lightness and transparency. The building’s interior also featured aluminium detailing, such as can be found in the bodies of the lamps. And this was not the only use of aluminium in architecture that Wagner envisioned.



Raffaele Ingami. San Gioacchino in Rome, 1890s (the dome is lined with aluminium)

In the Postal Office Savings Bank building in Vienna, completed a few years later, Wagner used bolts with aluminium heads to hold in place the marble panels of the façade. These bolts fulfilled both constructive and decorative functions, fitting perfectly with the marble veneer.

The greatest architects of the twentieth century – the Frenchman **Le Corbusier**, the American **Frank Lloyd Wright** and the German **Ludwig Mies Van Der Rohe** – rarely used aluminium, if at all. However, it is impossible not to mention them, since their ideas shaped the face of cities around the world in the twentieth century. They



Otto Wagner
Interior of the Postal Office
Savings Bank Headquarters
in Vienna, 1904–1906 (top)

Otto Wagner
Telegraph Agency Die Zeit
Headquarters in Vienna.
Reconstruction, 1985 (right)

envisioned the construction of buildings as a combination of elementary geometrical forms such as cubes, parallelepipeds, cylinders, pyramids and spheres. As elaborate as a building’s design might be, it could always be reduced down to simple spatial elements. Le Corbusier was able to realize many of his ideas by using reinforced concrete. Traditional construction elements were replaced by large slabs upheld by vertical columns, also of massive reinforced concrete. In this way, the wall itself was no longer load-bearing. Rather the columns were placed within the building, while the outer wall became a surface separating the interior from its outer space. Le Corbusier saw glass as the ideal material for walls. In the 1950s Mies van der Rohe introduced his idea of “universal architectural forms,” that is, unified inner spaces, providing the possibility for a maximum of further enhancements to the interior. Glass served as a hard supporting structure and source of light, reflective or translucent surfaces, which later became the basis for all modern architecture. However, Le Corbusier could not ignore the great structural and decorative roles of metals, especially aluminium.





Gregory Johnson (Shreve, Lamb & Harmon Architects). Empire State Building, Manhattan, New York, USA, 1931 (house frame and window frames are made of aluminium)

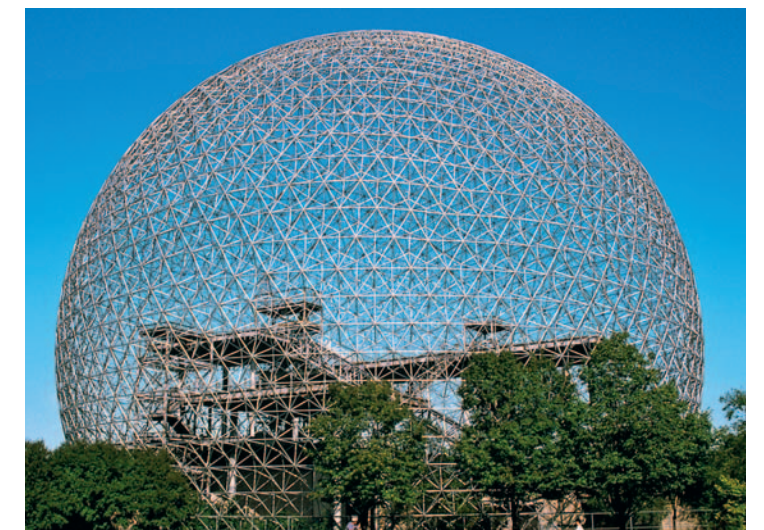
Until then, the use of aluminium as a building material was arbitrary at best. The creation of a needle of aluminium molding on a church in Pittsburgh in 1926 marked the beginning of the material's broader use in architecture. A manifesto of sorts for "aluminium everyday" was to be found in the *Aluminary House*, presented at the Allied Arts Exhibition in conjunction with the Architectural League's annual exhibition in New York in 1931. Designed by the American architect **A. Lawrence Kocher** and the Swiss-born architect **Albert Frey**, the *Aluminary House* served as a prototype for a modern housing unit and even as a paradigm for a modern way of life. For its designers, aluminium was far more than just another material to be used in construction – hence the neologism "aluminaire" in its name, accentuating the metal's etymology in the Latin *lumen* (light). The house was completely constructed of aluminium panels and aluminium framing, so that it was literally saturated with light, both on the outside, due to the matte sheen of the large metal surfaces, as well as on the inside, because of its large window openings. After the exhibition, the architect **Wallace K. Harrison** purchased the house and brought it to his estate on Long Island. Here, it survived into our time, albeit with modifications, and then, in an increasing state of disrepair. Today the Aluminaire House is being restored and reassembled at the campus of the New York Institute of Technology, School of Architecture in Central Islip on Long Island.

Inspired by the Aluminaire House's success, Frey built another "aluminium" house for himself in Palm Springs in 1940. Light enters the round central room through round windows. A table in the center of the living room, as well as stairwell landings literally hang suspended in mid-air, attached to the ceiling with aluminium cable wires.

The Allied Arts Exhibition of 1931 provided an important stimulus to the spread of aluminium construction techniques. Like no other metal, aluminium fits into the aesthetic of the Art Deco style (from the French for "decorative art"), an amalgam of Art Nouveau, Cubism, Constructivism, and Expressionism, among others. Art Deco is characterized by a bold application of zigzags and stepped forms, as well as broad and energetic lines. One of the most grandiose buildings in the Art Deco style is New York City's Empire State Building, a 102-storey skyscraper finished in 1931. The 381.3 meter skyscraper's name derives from New York's alternate name as the "Empire State." At first, the building's spire was designed to be a mooring mast for airships. T-shaped moorings were even attached to the

Fuller's constructions

In 1929, the American architect **Richard Buckminster Fuller** published his model of the Dymaxion House, one of the first pre-fabricated houses of factory-made aluminium parts, resting upon one vertical strut. The idea, originally an architectural utopia, came close to becoming a reality: Fuller had already signed a contract with a Kansas aircraft plant for the production of 60,000 of such homes, but due to disagreements among the partners, the contract fell through. In the end, only one house was assembled in Wichita, Kansas. Six workers put it together in one day. The house weighed no more than one and a half tons. From 1941 to 1947, working to perfect the Dymaxion House, Fuller was able to develop the geodesic dome, a half-sphere composed of tetrahedral facets. This invention was patented in 1954. Geodesic domes brought the architect international recognition, in part due to the U.S. pavilion at the Montreal World's Fair of 1967. In 1957 the aluminium magnate **Henry J. Kaiser** hired Fuller to design a large concert hall in Honolulu. Made with aluminium struts and panels, the dome was



Buckminster Fuller U.S. pavilion at the Montreal World's Fair, 1967

50 meters in diameter; 38 workers assembled it within 20 hours. Fuller is remembered not only as a talented architect but also as an outstanding philosopher. He was convinced that humanity would rely increasingly upon renewable energy sources such as solar and wind in the foreseeable future, bringing an era of "humanity's universal education and propriety." The 1980s saw the discovery of a carbon molecule whose structure is reminiscent of some of Fuller's designs, so that it was named the fullerene in his honor. At present, the fullerene is a term for an entire class of carbon allotropes. ■

skyscraper's outer walls, and are still in place today. However, the idea for the spire was soon abandoned, due to the updrafts and high winds at that altitude that made a safe tie-down impossible. Moreover, by the time the building was complete, the era of the airship was already over.

This grandiose building was immediately considered to be the eighth wonder of the world. This is something that the eight illuminated panels in its three-story lobby reflect, depicting the Seven Wonders of World from antiquity alongside the eighth world wonder – the skyscraper itself.

The skyscraper was completed in record time (14 floors went up in no more than 10 days), which confirmed the colossal possibilities of new technologies. The building was constructed on a two-story concrete foundation. It is held up by a steel frame with a weight of 54,400 tons. (The building's total weight is approximately 331,000 tons.) The stainless chromium-nickel steel girders hold up aluminium panels and aluminium frame with plate glass windows. The width of these panels is around 150 centimeters; their height is around 130 centimeters. These panels enabled the building to be built in record time. However, aluminium largely plays a structural role in the skyscraper. Since large metal surfaces contradicted the *Art Deco* aesthetic, these aluminium panels were covered by a limestone façade. This is why the building appears to be grey, divided into segments by the steel construction of the girder frame.

Later panels with ready-made windows were developed, further accelerating the construction process. A more recent example of such rapidly built high-rises is the headquarters of the Aluminum Company of America (Alcoa). The building's walls consist of aluminium panels supported by a reinforced concrete frame, with imitation diamond faceting and load bearing windows.

In the post-war years, such reinforced concrete frame and aluminium panel constructions found a broad application in high-rise construction. None of these edifices could have been built without aluminium, indispensable in the panels of their façades and inner partitions, door and window frames, stairwell railings, trellises, and suspended ceilings.

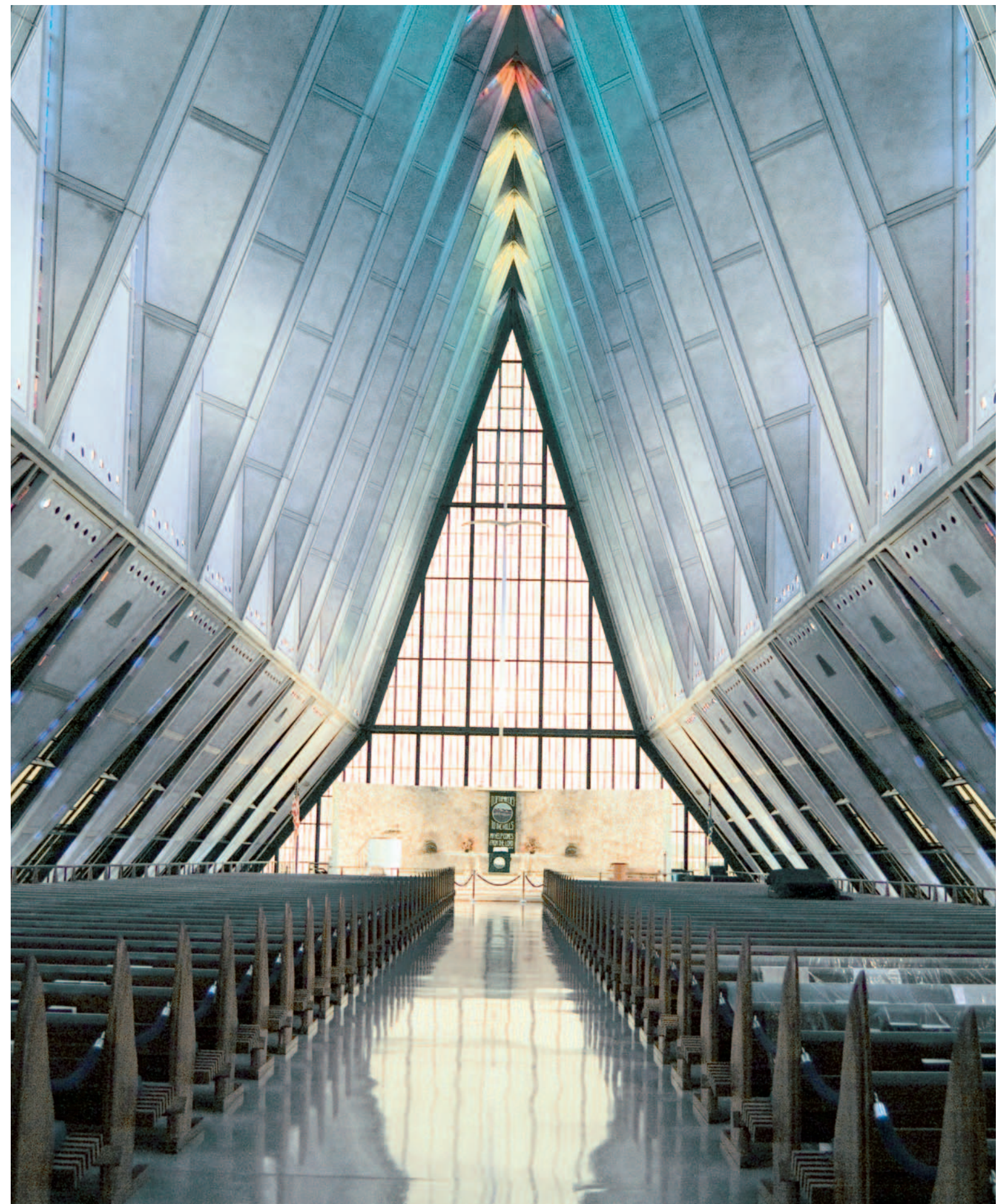
Aluminium is the principal metal used in airplane construction. This is why many of the buildings at the United States Air Force Academy are constructed of aluminium panels. Work on the campus began in 1954 and took about 10 years to complete. The Cadet Chapel is of special architectural interest, symbolizing humanity's



Harrison & Abramovitz. Alcoa Building, Pittsburg, 1950–1953 (the building's walls are made of aluminium panels)



Walter Netsch, Jr. (Skidmore, Owings & Merrill). Cadet Chapel at the U.S. Air Force Academy in Colorado Springs, 1956–1962 (the building's walls are made of aluminium panels)



Interior of Cadet Chapel at the U.S. Air Force Academy in Colorado Springs

connection with the cosmos; its sharpened silhouette literally strains in the sky.

In the years to come, architects directed their efforts toward analyzing various geometrical elements, whose combination could create original and impressive architectural forms. The possibilities of aluminium as a construction material seem almost limitless. Late in life, Mies van der Rohe was somewhat horrified by the prospects of a new “aluminium world,” which threatened to soon become a reality.

Aluminium was introduced into Soviet architecture in the late 1950s. The Soviet pavilion at the Brussels World’s Fair 1958, by architects **A.N. Kondratiev** and **N.Ya. Bulkin**, used an aluminium construction produced by the Belgian firm Chamebel. The walls were made of aluminium sheeting, suspended from the trusses as a counterbalance. The overall mass of the aluminium used in creating the pavilion exceeded 360 tons.

Three years later, aluminium constructions by Chamebel were again used to make an exhibition pavilion in the Moscow park of Sokolniki. Aluminium was also used in the stained-glass windows that decorate the edifice. The success of this pavilion was so great that, in 1968, it was reconstructed at the All-Union Exhibitions of Achievements of National Economy (VDNKh), though its beams and cross sections were now produced by Soviet factories. This building (the Chemical Industry Pavilion) is still in place. The Soviet pavilion at the 1967 World Fair in Montreal also used an aluminium construction. Aluminium was used in the plate-glass window construction, in the pavilion’s inner partitions, and in its suspended ceilings.

In the early 1960s Soviet architects began working on the development of new aluminium structures and their introduction into the construction industry. A good example can be found in the Kremlin’s Palace of Congresses (today the State Kremlin Palace), built between 1959 and 1962 by a group of architects directed by **M.V. Posokhin**. The rectangular concrete and glass design is reminiscent of Mies van der Rohe’s “universal architectural form.” The palace’s face-work uses aluminium panels. One great technical innovation was made in the suspended aluminium ceiling in both the foyer and the 6,000-seat Congress chamber. The plate glass windows, main entrance portals, and railings all use aluminium as well. An original system of aluminium molding was developed for the plate glass windows and the portal with special fittings for sound proofing and moor-



B.S. Vilensky et. al.
Chemical Industry Pavilion at VDNKh (VVTs),
Moscow, 1976 (the house frame is made
of aluminium)



M.V. Posokhin
State Kremlin Palace (Palace of Congresses), Moscow, 1961
(the house frame and interior design are made of aluminium)

ings. The design of the Palace’s banquet hall uses a deck floor of corrugated aluminium sheeting. Built quickly, the Palace of Congresses was to serve as a paradigm for the use of aluminium construction in the Soviet Union for years to come. It was the first time that Soviet architects used outer aluminium constructions anodized to gold and black.

The second half of the 1960s saw a more widespread profusion of aluminium constructions. Aluminium is widely used in the State Planning Commission Building by **L.N. Pavlov** in 1967. Aluminium is the basic material for its clearstory windows between the second and sixteenth floors, as well as the pane glass windows on the first floor. The inner partitions and suspended ceilings are also aluminium. The “Book” houses on the Novy Arbat completed 1962-69, are yet another example of this “triumph” of aluminium constructions. Again, skylights, windows, doors, panels and interior friezes are all made of aluminium. Over 900 tons of the metal were used in the construction of the complex at large.

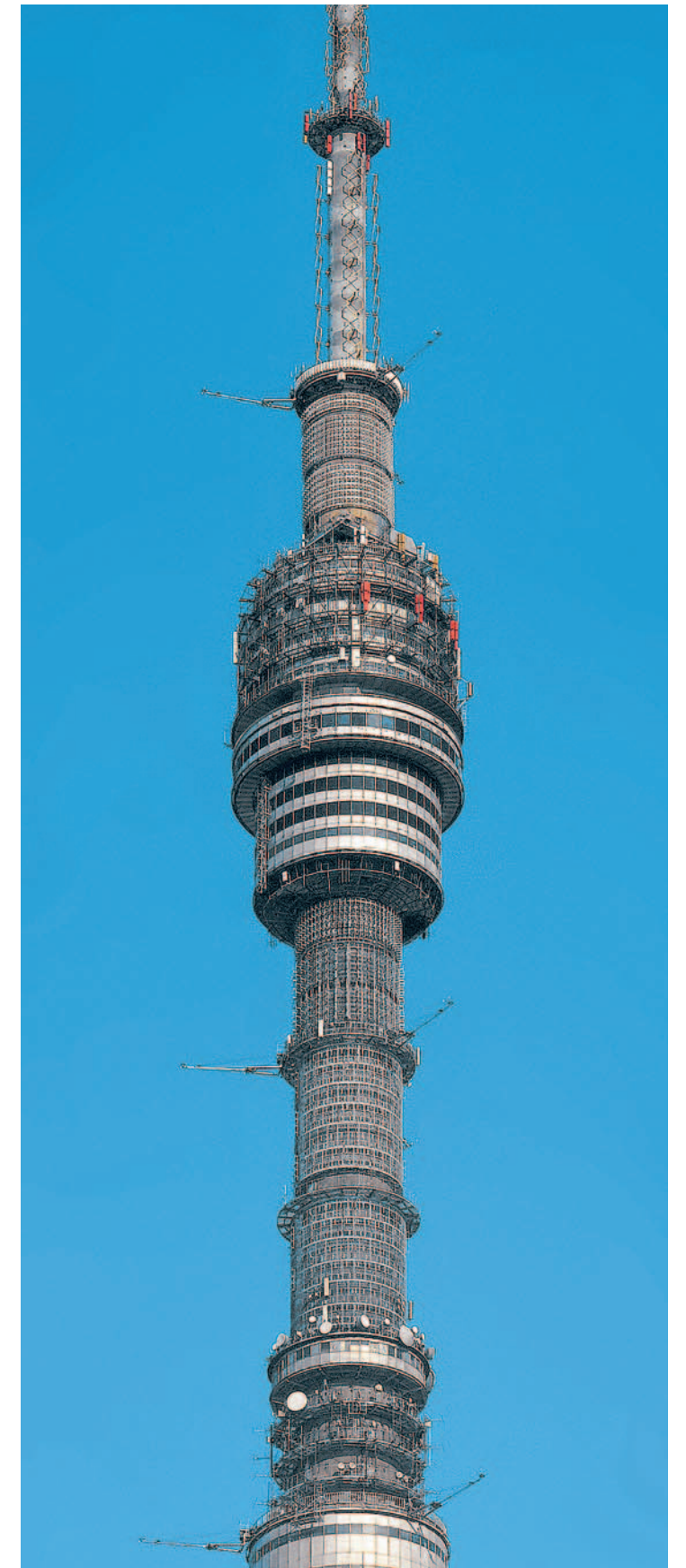
The building of the All-Union (now All-Russian) Institute for Light-Metal Alloys (VILS) was constructed from 1971 to 1973. Its structure is decorated by panels of stamped aluminium sheeting. Employees of the VILS not only designed their own building, but also a number of other major objects. It would have been impossible, for example, to erect the Ostankino television tower without resorting to an aluminium structure. When it was built in



M.V. Posokhin. “Book” buildings
Moscow, 1967 (stained-glass windows, doors and friezes
of the interior are made of aluminium)

1967, the All-Union Institute for Light-Metal Alloys contributed a veneered construction that appears as a broadening of the building’s body. The top floor of the tower’s base is on the level of a ten story building and features the “Seventh Heaven” restaurant, and an observation deck.

In the following years Russian architects began to pay more and more attention to aluminium’s decorative



N.V. Nikitin, L.P. Batalov, D.I. Burdin. Ostankino Television Tower, 1967 (veneered
constructions at a broadening of the building’s body are made of aluminium)



Nickolas Grimshaw.
Southern Cross Station, Melbourne, 2007

qualities, using it as a material in expressive architectural compositions. For the Moscow Olympics of 1980, employees of the VILS designed the “Olympic Flame” complex at the Central Stadium in Luzhniki, where the official opening and closing ceremonies took place. Not only the grandstand railings, but even the Olympic flame’s chalice – alight for the duration of the Olympics were made of aluminium. The smoothly bent railings seem as if they were made of a continual sheet of metal, whose sleek surface mirrored and amplified the light of the Olympic flame.

The 1980s also saw a spread in the decorative use of anodized aluminium. For example, the vaulting of the Moscow metro station “Aviamotornaya” is decorated with reliefs executed in molded sheets of anodized aluminium. This use of aluminium, the “metal of aviators,” is not only decorative but also carries a symbolic function: the metro station is close to a major aviation plant.

Anodized aluminium also found ample use in the execution of the “golden brain,” as the top of the building of the Russian Academy of the Sciences, built under the direction of the architect **Y.P. Platonov**. The most impres-

sive view of the building is from the deck of a sightseeing boat riding on the Moskva river: from afar, glinting in the sunlight, it looks like pure gold.

Aluminium became a symbol of modern architecture. It opened up possibilities for realising the most daring projects. The developments made by scientists and architects not only made it a universal building material but also unveiled its unique aesthetic properties. For example, buildings with fantastic forms, capable of changing their appearance, arose in the world’s cities.

The British architect **Sir Nicholas Grimshaw**, the current president of the Royal Academy of Arts, is one fan of aluminium. In 2007 his company finished the construction of the new Southern Cross train station in Melbourne. The building resembles a giant umbrella covering what appears to be an enclosed city: rail tracks and parking lots for buses, trams, and taxis are located under a single roof.

The construction’s focal point is the roof resembling ocean waves made of steel and aluminium sheets. Aluminium reflects the sky and turns the train station’s roof into a landscape. Due to its thermal properties, the roof transmits

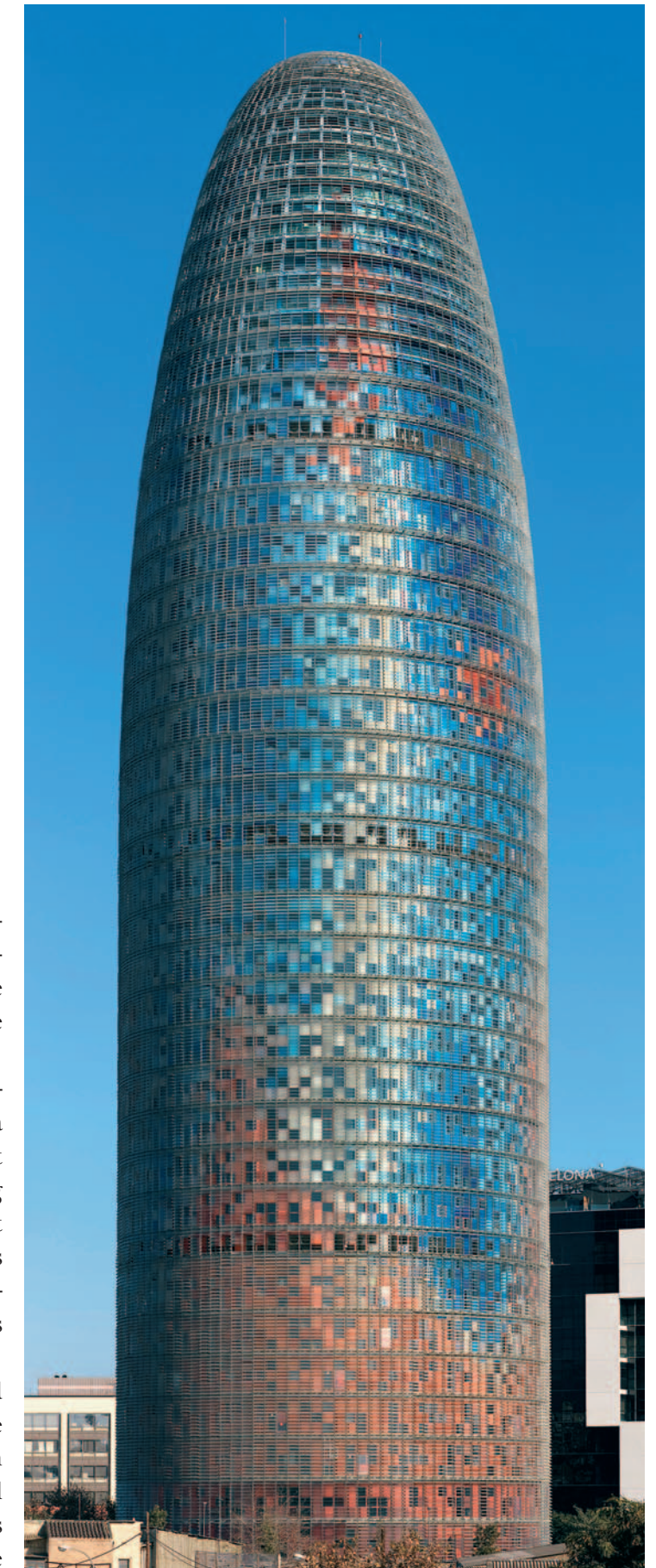


André Vaterceyn. Architectural monument Atomium,
Brussels, 1958. Reconstruction, 2006 (spheres are covered with aluminium plates)

hot air and exhaust fumes into the atmosphere. For this reason, the building has almost no air conditioning and is considered to be one example of “green” architecture. The giant building consumes minimum energy thanks to the unique properties of the roof made of aluminium sheets.

The Dutch architect **Rem Koolhaas** says that aluminium is “real” and “brutal.” He prefers to use the metal as a trimming material and for interior details. In his concert hall Casa da Musica in Porto, the central staircase leading to the auditorium is a cascade of aluminium stairs that contrast with the décor of the main hall (wooden panels with gold foil inlay). According to Koolhaas, such a “collision” of aluminium, concrete, glass, and “live” wood helps to bring out the real nature of these materials.

In the Prada boutique in Los Angeles, Koolhaas used an aluminium barrier at the store entrance instead of the usual glass doors. Each evening, a hidden hydraulic system lifts this barrier to block the store entrance. The unusual entrance was such a surprise, even for the fashionable Los Angeles public, that some people made special visits to the



Jean Nouvel. Agbar Tower, Barcelona, 2005 (lining is made of aluminium sheets)

boutique in the days following its opening in order to touch the aluminium barrier. Thousands of fingerprints were left behind on the metal's surface. Koolhaas explained his choice of materials for the boutique (aluminium, synthetic foam, and polycarbonates) in the following way: "Other boutiques on Rodeo Drive are decorated with gold foil, marble, granite, and travertine. I wanted to create a space with an alternate texture that would be alive, urban, and technological."

The Frenchman **Jean Nouvel** is famous for facing skyscrapers with aluminium sheets. The Aluminium on the façade of the skyscraper Agbar (Aigues de Barcelona) in the Catalonian capital of Barcelona looks expressive. The 144-meter-high conical skyscraper consists of a dense concrete nucleus painted in bright colors and surrounded by a thin shell of corrugated aluminium sheets and glass blinds. The Torre Agbar looks particularly striking at sunset when the aluminium and glass of the outer shell reflect the play of the sky's colors, and the bright colors of the skyscraper's inner nucleus shine through these sparkling red, violet, and rose hues. The skyscraper resembles a giant crystal on these occasions. Nouvel emphasized that no other metal could have replaced aluminium in expressive possibilities, thermal properties, and lightness.

Jean Nouvel used aluminium panels in another well-known project – the Culture Centre on the banks of the Lake of Lucerne in Switzerland (built in 1999). The three buildings that make up the Centre are brought together under one roof, and each building is flanked with large aluminium panels. Looking at the Cultural Centre from the Lake, the main building is hidden by aluminium sheets yet gradually appears as you grow closer. Those who stroll past the Cultural Centre see the reflection of water waves and boat silhouettes in the aluminium panels.

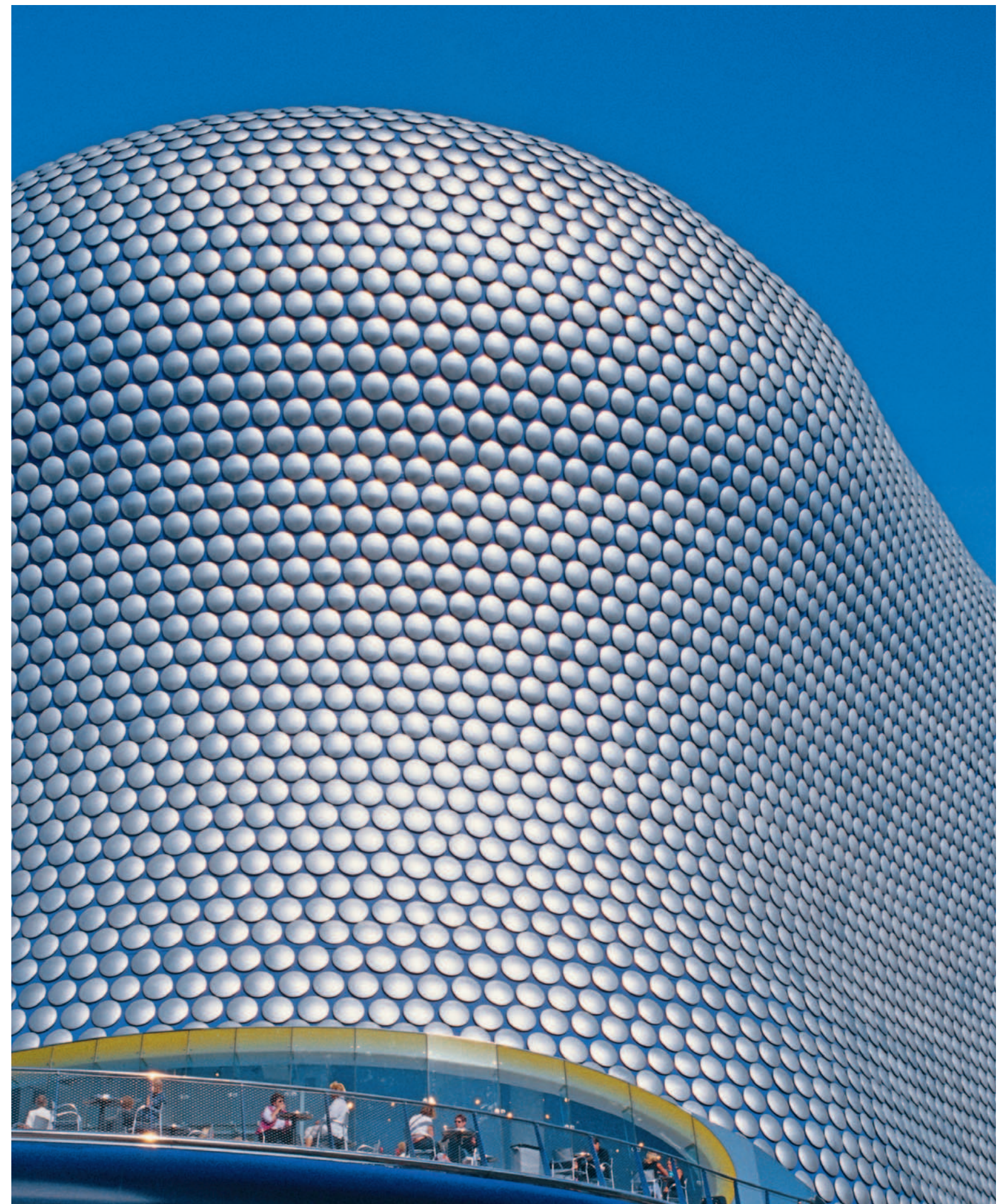
One of the most striking projects of recent years is the Selfridges Department Store in Birmingham, UK, built by Future Systems architectural practice. It drew inspiration for the building from the armour dress made of aluminium plates created by the French designer Paco Rabanne in the 1960s. The silhouette of Selfridges Department Store resembles a giant turtle shell; it has an elegant, smooth form and is faced with 15,000 aluminium disks. After the completion of construction, the Birmingham Tourist Office registered an increase in the number of tourists visiting the city: people came to photograph the building at sunset when the aluminium "armour" reflects the colors of the sky and the light of electric streetlamps.

Sir **Norman Foster**, perhaps the best known high-tech architect (his works were exhibited at the Moscow Museum of Fine Arts in 2006) also uses aluminium. A new City Hall was constructed in London in 2002. Its complex climate control system made of combined glass and aluminium constructions allows cutting power costs by 25% compared to what is spent in a public building of the same size with traditional design. The building with its transparent look (as a symbol of open and transparent city management), the City Hall is 75% covered with glass-coated aluminium panels.

In 2004, a new complex built by Foster for the racing car manufacturer McLaren, The McLaren Technology Centre opened in Surrey, UK. The centre, made of glass and an aluminium framework, is located on the banks of a man-made lake. The main building contains a racetrack for new car models. The tunnel heats up during tests, yet, thanks to the thermally conducting aluminium framework, it is cooled by lake water. Using the same principle, water from the lake cools the entire complex, making it possible to virtually dispense with air conditioning. The McLaren Technology Centre is one of the most environmentally advanced buildings in the world. Norman Foster admits that he borrows many engineering and stylistic techniques from aeronautics. It is therefore no surprise that aluminium is one his favorite materials.



Norman Foster. City Hall (London), 2003 (lining is made of glass-covered aluminium panels)



Future Systems. Selfridges Building, Birmingham, 2003 (the façade is made of 15,000 aluminium plates)



Mounting the aluminium capstone on the Washington Monument. Copperplate after a drawing by S. Nealey, 1884

Aluminium in Sculpture

One of the first experiments in the use of aluminium in monumental art dates to the mid-1880s and is connected to the erection of the Washington Monument in Washington, D.C. The famous obelisk is 169,1 meters tall, took 40 years to build, and was finally finished on October 9, 1888. The obelisk was to be topped by a metal pyramid. Initially, the plan was to cast this pyramid in aluminium bronze – a widely used alloy at the time, with 90% copper and 10% aluminium – with platinum plating. However, William Frischmuth, the major only aluminium producer in the U.S., suggested that by making the pyramid of aluminium, it would not lose its sheen to corrosion. Moreover, many Americans still saw aluminium as a precious metal: not long before, it had cost no less than half the price of silver.

The pyramid was relatively small, only 22.6 centimeters high and 13.9 centimeters at its base, and weighed 2.85 kilograms. If one remembers, however, that in 1885 the U.S. produced no more than 28.3 kilograms of aluminium annually, this is not so little. On November 12, 1884 Frischmuth sent a telegram announcing his success: “After hard work and disappointments, I have just cast a perfect pyramid of pure aluminium made of South Carolina Corundum. Great honor to you, the Monument and whole people of North America, a little to myself lent.”

Before it was mounted, the pyramid was put on display in the showcase of Tiffany’s, one of New York City’s most famous jewelry shops where it attracted a huge amount of attention. After exactly one hundred years of its casting, a perfect copy of the pyramid was exhibited in the same shop window.

The moment of the aluminium pyramid’s mounting was fixed in a copperplate (17×25 cm). Frischmuth is not among the people in the picture; he was not present for the mounting of his pyramid.

During thunderstorms, the Washington Monument attracts lightning, and of course, the pyramid is often hit. An inspection of the monument in 1934 showed that lightning strikes had blunted the tip of the aluminium apex and some globule of metal had fused to the sides. However, it was decided to refurbish the pyramid rather than replace it, since it is a monument to the history of aluminium technologies. (50 years after its mounting, Edgar



George Washington Monument, Washington DC, USA
(on the top there is an aluminium pyramid)

H. Dix, then chief metallurgist of the Aluminum Company of America, called the pyramid “the crown jewel of the aluminium industry.”) A chemical analysis of the material has shown that Frischmuth was not using pure metal (which was impossible to derive at the time), but an alloy of 97.87% aluminium, 1% iron, 0.75% silicon, as well as manganese, copper, tin, and sodium. To be fair, we should note that even sculptors today rarely use pure aluminium, but the alloys Al-8 or Al-13, both containing several percent of silicon.

Sculptural work with aluminium is difficult and labor-intensive, notwithstanding the fact that the metal’s melting point is lower than that of iron or bronze. But since melted aluminium tarnishes easily, the cast must be poured in an inert atmosphere (of nitrogen, argon, and carbon dioxide). This is why aluminium sculptures were initially small in size, most of them tabletop figurines.

One of the first relatively large aluminium casts was made in 1889, and is a miniature copy of the ancient Greek sculpture of the Venus of Milo, whose original is in the Louvre. On the sculpture’s base one can clearly see the manufacturer’s stamp of Barbedienne, a Paris factory founded by

Ferdinand Barbedienne in 1839, and in operation for more than a century. Executed in aluminium, the Venus of Milo makes a much different impression from its ancient original. The sheen of the metal makes it far colder.

In the late 19th century, the muted sheen of aluminium, in comparison to the impressive glint of gilded bronze, attracted the British sculptor and goldsmith **Alfred Gilbert**. In 1886, he worked on the Shaftsbury Memorial Fountain made in honor of **Anthony Ashley Cooper, 7th Earl of Shaftsbury**, a prominent British politician and philanthropist of the Victorian era. Unveiled in 1893 in Piccadilly Circus, one of London's busiest intersections, the memorial fountain consists of a basin on a podium, encircled by marble reliefs depicting sea creatures. The memorial fountain is topped by a statue of the ancient Greek divinity Anteros, a winged, naked youth. According to Gilbert, Anteros is "the god of selfless love." But Londoners soon began to identify the statue as Eros – the god of a completely different type of love: passion. The statue's body is a tense interplay of muscles, and corresponds to the Greco-Roman ideal. The figure is shown in energetic movement; Eros seems to have paused in flight for a moment, marking his next victim in order to take better aim.

The statue of Eros in Piccadilly Circus is rightly considered the first large statue executed in aluminium, with a height of 2.4 meters, and a wingspan of 1.8 meters. Notwithstanding these dimensions, the mass of the statue is only 190.5 kilograms, which is not so surprising when one considers aluminium's lightness. Gilbert assembled the figure from separate parts: the left leg which bears the entire sculpture's load, is cast in solid aluminium, while the rest of the statue is executed in aluminium repoussé.

For many years the statue was an object of constant analysis. Specialists wondered how the new material would behave under the conditions of London's damp climate. The figure was dismantled in the years of the First World War, and then again, in 1931. In both cases, a thorough cleaning revealed its metal to be in excellent condition. We should note that the material used was almost pure aluminium with no silicone added, thus making it more susceptible to corrosion than other alloys. Nevertheless, Eros has survived many a London fog, though he is by now covered with a patina. When the statue was again dismantled for restoration work in 1984–85, the Fine Arts Society in London made a copy of it.

After the statue in Piccadilly Circus, Gilbert turned to aluminium again in 1898 when he made a memorial to



Ferdinand Barbedienne Foundry.
Venus of Milo. Aluminium, 1889

Prince Albert Victor, Duke of Clarence in St. George's Chapel at Windsor Castle. Among the figures that surround the prince's grave, St. George is especially interesting, since he is garbed in an aluminium suit of armor. The sculpture was so successful that two copies were commissioned in the following years, which Gilbert executed as full aluminium casts.

Thus, aluminium gradually came into its own as a sculptural material next to bronze, cast iron, and stone. Objects of bronze are substantial and heavy. Bronze emphasizes the "age" of the figure; taking on a noble patina, it darkens



Alfred Gilbert. Statue of Anteros. Copy, installed
in Piccadilly Circus in London, 1985

over time. Aluminium, by contrast, is light and unchanging. In a sense, aluminium is light-minded and frivolous thanks to its mysterious, slightly muted sheen (so that it is no coincidence that the first large aluminium sculpture was one of a mischievous Eros). At the same time, aluminium radiates coolness, so that there is no temptation to touch the object. Aluminium objects are best contemplated from afar: at a distance, the material can work its magic.

At the turn of the century aluminium came into broader use in the casting of sculptural portraits. The French sculptor **Gabriel-Jules Thomas** used aluminium for his



Alfred Gilbert. St. George.
Aluminium, 1899

bust of Henri Étienne Sainte-Claire Deville, the pioneer of the metal's large-scale chemical manufacture through sodium. The American engineer and chemist Charles Martin Hall, who developed the method of reducing aluminium through electrolysis, was also immortalized in aluminium. The statue was installed in Hall's alma mater, where he had undertaken his earliest experiments in electrolysis.

In the years after World War II, the Soviet sculptor **Viktor Tsikal** used aluminium to make a sculptural portrait of **Nikolai Chernyshevsky**. It may well be that this choice of material was no coincidence: in his novel "What is to be

done?” Chernyshevsky called aluminium the “metal of socialism.” Tsigal worked with aluminium on numerous other occasions, making portraits of fellow sculptors such as P.I. Ustyuzhina, and K.G. Gimadaev, as well as the lyrical composition “Svetlana.”

In Russia, aluminium casting began in 1860 at a former governmental galvanoplastic factory founded in Saint-Petersburg in the mid-19th century. In 1857 this foundry was bought by the company “Genke, Pleske, and Moran.” In 1870, **Moran** took over sole ownership, indelibly connecting his name to the factory’s heyday. A small enterprise, it specialized in bronze casting for various applications such as chandeliers, bells, desk ornaments, lamps, as well as monumental and decorative sculptures. The foundry’s experts probably first encountered aluminium at the Exposition Universelle in Paris in 1867, where they acquired a small ingot of the metal. The stamp “Paul Moran and Co.” on the bottom of a statuette of the Diana of Gabii shows how this factory’s craftsmanship developed in the following years.

The spread of modern means of form casting (detailed in the chapter on aluminium alloys) eventually made it possible to use aluminium in monumental sculpture. In the art of socialist realism, form casting in aluminium was allotted a significant role, as in the sculpture “Foundry-woman” by **Kira Suvorova**, “Virgin Soil” by **Andrei Semchenko**, and the sculpture group “In the Fields” by **Gavriil Schultz**.

In Krasnodar, “Aurora,” a grandiose 14-meter sculptural-architectonic composition by the sculptor **Ivan Shmagan**, was unveiled in 1967. The female figure at its center is not the ancient Greek goddess, however, but a Komsomol girl in a greatcoat, with a rifle on her shoulder. In her left hand raised high over her head, she holds a five-pointed star. The statue is executed in wrought aluminium sheets, thus reflecting sunlight in blinding flashes.

Many readers will be familiar with the “aluminium” sculptures that graced Soviet parks and squares, typical statues like “A Girl with an Oar,” “Runners,” “Swimmers,” or “Divers.” Most of them, in fact, were made of Plaster of Paris and covered with aluminium paint.

One artist to use aluminium extensively was the pre-eminent Russian sculptor and artist **Vadim Sidur**. His choice of material was a matter of necessity. In official Soviet art, Sidur was virtually unknown; his work failed to correspond to the *socialist realism* canon in terms of both form and content. This lack of acceptance made it very difficult for him (and others like him) to access material for cast-



Gabriel-Jules Thomas.
Bust of Henri Étienne Sainte-Claire Deville. Aluminium, 1900

ing. Sidur actually preferred bronze, which he was only able to obtain from workers who smuggled it out of official art workshops. When even this became impossible, friends advised the sculptor to work in aluminium, which could be smelted from the waste products of airplane factories. Sidur accepted the offer readily, all the more since he had little choice. One of his first pieces in aluminium is the sculptural composition “Connections” (1963), two frozen figures that seem to have fused in a unified explosion of feeling. This is why the piece also has a second title, “Gentleness.” The author’s intent, in his own words, was to “avoid the outer dynamism of gesture in favor of inner tension.” Sidur counteracts aluminium’s characteristic coldness by giving the sculpture a grainy, uneven surface.

“Monument to the Victims of Violence” (1974) is another piece from the artist’s cycle of war monuments begun in the early 1960s. Like most of Sidur’s work, both its model



Vadim Sidur. Connections. Aluminium, 1963

and its later cast were executed in aluminium. This sculpture presents a kneeling figure with its hands tied into a noose over its head. The laconic, austere form evokes a vivid sense of tragedy, emphasized by the muted metallic sheen of the aluminium. This quiet sense of tragedy is something that all Sidur’s works have in common; their outer calm expresses the potential of an emotional explosion, a quality that explains their strong effect. Along with many other sculptures, this piece remained in Sidur’s basement studio for quite some time, and was only available to an intimate audience. When Dr. Büettner from Kassel visited Sidur’s studio, he saw the sculpture and immediately exclaimed, “I want this monument in my hometown!” And in the very same year, the sculpture was presented to Kassel and installed in the city’s pedestrian zone. In Germany, in Würzburg, there is one more sculpture by the master, “Monument to Those Killed by Bombs”.



Vadim Sidur. Monument to the Victims of Violence. Aluminium, 1974

In Russia, full appreciation for Sidur’s monuments could only be realized after his death.

Aluminium sculpture can be “painted” through anodic oxidation treatment. Several metro stations in Moscow, such as the Kakhovskaya station, are decorated with anodized aluminium bas-reliefs. Anodic treatments introduce the element of color, allowing the accentuation of various details to great artistic effect. A good example of this technique can be found in a statue of a “Skier” installed in the Swiss Alps. The figure of the skier himself is executed in polished aluminium and retains its natural silver-white coloring, while the skis are anodized, and are black in color. In the collection of the Magen H. Gallery (New York), one can admire work by the contemporary American sculptor **Forrest Myers**. His “Minimalist Composition” (1969) consists of six absolutely identical objects, chairs, each of which is made up of four anodized



Fernando Campana,
Umberto Campana
Sculpture Screen.
Aluminium, 1993

aluminium plates. The light play of color on the violet surface of the metal supplies the composition with a great deal of expressive force.

Anode treatments are not the only way to give aluminium color; in fact, aluminium can be easily painted in a very traditional way. The Odette Sculpture Park in Windsor, Canada, provides a “habitat” for three life-size Emperor Penguins cast in aluminium. The artist **Yolanda Vandergaast** painted them in such natural tones that they seem alive, about to waddle over from their waterfall into the nearby Detroit River.

Contemporary sculptors and object designers do not only use cast aluminium, sheet aluminium, or aluminium foil, but also often work with various aluminium ready-made materials from everyday life, such as wires, antennas, and, of course, soup cans. In 1993 the Brazilian object

designers **Humberto** and **Fernando Campana** used TV antennas to make a composition called Sculpture Screen. This open-work construction flickers in the glinting highlights of its thin, meticulously polished aluminium rods, scintillating cold and mysterious.

Today the sculptor **Elizabeth Berrien** works exclusively in aluminium wire. She is especially known for her animal sculpture, bears, giraffes, rhinos, pelicans, big cats, and even dinosaurs, all of them 2D wire webs. The American artist’s original technique allows one to forget that these objects are actually of metal; they seem weightless and saturated with light. The possibilities of aluminium seem inexhaustible, and there can be little doubt that sculptors will continue to come up with the most unexpected uses for this amazing metal in the future.

Aluminium paint

Among the huge number of pigments, aluminium powder inhabits a rather modest place. To be more precise, it is not actually a conventional pigment powder, but consists of tiny, irregularly shaped flakes of aluminium with an extremely thin oxide layer. Sometimes it is incorrectly called aluminium bronze. Such flakes are not only opaque to light, but are capable of reflecting it. This explains the sheen of surfaces covered with aluminium paint. Since it reflects and keeps out sunlight, aluminium paint is often used to cover railroad cisterns, industrial refrigerators, gliders, and the roves of railway cars. Raw material for the production of aluminium paint usually consists of scraps of foil or finely pulverized metal. First, the foil is ground with special cutting machines. A small amount of paraffin is added to prevent premature corrosion. Then this powder is further refined in mortars, when the foil particles take on the form of fine, flat flakes. To give the paint more brilliance, the flakes are then polished in steel drums with steel ballbearing rotating on the inside. The polished product is then sealed into closed containers where it cools.

Professional artists rarely use aluminium paint, and prefer to depict metallic surfaces with different, less glaring colors. Aluminium paint is, however, used to add silver to works of craftsmanship, made on a lathe, such as the Russian matrioshka doll. To gild such dolls, artisans generally use “false gold,” a powder of titanium nitride. It replaced powdered bronze, which, unlike “false gold,” darkens quickly, thus revealing that it is not actually gold. ■

Aluminium Furniture

In 1930, aluminium bar stools and tables by the architect and furniture designer **Robert Mallet-Stevens** first appeared in a café on the Avenue de Wagram in Paris. In following year, he designed all-aluminium furniture for the villa Cavrois in Croix. At the Autumn Paris Salon of 1930, **Louis Sognot** and **Charlotte Alix** presented a bedroom interior in which all the furniture – closets, bed, chairs, and an armchair – were all made of duralumin. This project was intended for the inhabitants of the French colonies in Africa and



Otto Wagner.
Chair from the *Die Zeit*
Telegraph Agency
Headquarters in
Vienna. Aluminium,
beech, fabric, 1902

Eileen Gray.
Closet from the
project *E-1027*.
Aluminium, wood,
glass, 1923–1928

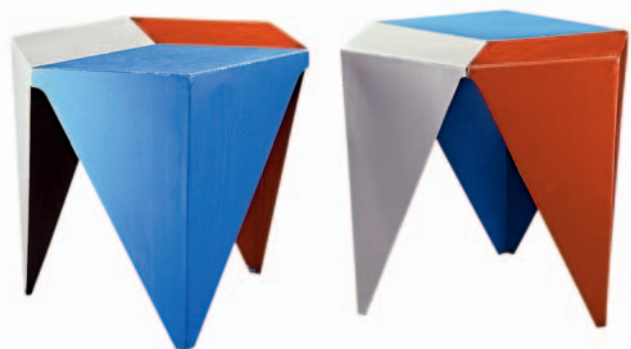
Asia, where the warm, often moist climate tended to other more traditional types of material.

The earliest uses of aluminium in creating furniture are connected to the Jugendstil (from the German *jugend*, meaning youth), a style in European and American art, architecture, and design from the late 19th to early 20th centuries. The unobtrusive sheen of aluminium could not help but attract the Austrian architect and theoretician **Otto Wagner**, one of the founders of the Vienna Secession. For example, when he designed an armchair for the interior of the telegraph company



headquarters of *Die Zeit*, both its feet and its spine were embossed in aluminium.

Aluminium’s role in design slowly spread to other European countries. In the mid-1920s, the furniture designer **Eileen Gray** began to use non-traditional, modern materials in her work, most importantly glass and aluminium. She called aluminium a “great material, generating coolness in a hot climate.” Gray presented her ideas in the high modernist villa E-1027 for which she designed the furniture, some of which – such as the buffet, the rolling tray, and an adjustable table – became



Isamu Noguchi.
Forecast Program coffee tables.
Painted aluminium, 1957



Warren McArthur.
Rainbow Back chair.
Anodized aluminium,
upholstery, 1934–1935



Walter von Nessen
(attributed to).
Desk lamp.
Aluminium, bakelite,
glass, ca. 1935

Forecast Program

In the early 1950s, the aluminium manufacturer Alcoa joined forces with the companies Reynolds and Kaiser to propagate broader use of the metal. Together, they began a massive publicity campaign called the "Forecast Program." Its slogan was "There's a world of aluminium in the wonderful world of tomorrow."

One of the program's principal goals was to find new applications for aluminium. Many designers and artists participated. The sculptor and designer **Isamu Noguchi** was among them. He designed aluminium tables of a hexagonal form painted in red, white, and blue.

The program continued for around 20 years. In the spring of 1965, it even acquired its own airplane. This airplane's cabin was decorated with ornamental aluminium panels, and contained an exhibition that demonstrated the metal's uses in various fields. On their flights throughout the U.S., members of Alcoa's public relations department talked up the benefits of aluminium furniture, beverage cans, and other packing materials, as well as household appliances, with other passengers. In some cases, the airplane would carry out "propaganda bombings," dropping advertising leaflets or presents wrapped in aluminium foil. ■

On the whole, aluminium furniture was considered to be something exotic in pre-war Europe, and usually presented as a unique original. In the United States, aluminium furniture was more wide-spread, thanks to the efforts of the American Aluminum Company.

In 1933, **Warren McArthur** also created aluminium furniture. The parts for his constructions largely came from leftover piping and spacer disks. The tables, armchairs, and chairs that he assembled from these elements were unusually popular. Stars like Marlene Dietrich, Ramon Navarro, and Norma Shearer bought them for their mansions. In 1936, his company's catalogue contained around 600 models of anodized aluminium.

Walter von Nessen and **Donald Deskey** created aluminium furniture using simple geometrical forms. In their work they combined the matte metal with dark, shiny bakelite or glassed steel. **Frederick Kiesler's** furniture stands out through its use of flowing forms and rounded corners. When put together, the two tabletops of his light coffee table form an oval. This piece of furniture is surprisingly comfortable and serves a variety of functions: it can be used as two separate pieces of seating or as a support for house plants. The entire table is made of aluminium, including its dumbbell-like legs that are about 20 centimeters in height.

popular, after its made-to-order serial manufacture was set up in Paris. Gray's furniture designs anticipated many qualities later characteristic of modern furniture: lightness, comfort, and function.

In 1942, the Dutch minimalist architect **Gerrit Rietveld** created an armchair of a whole sheet of aluminium (aside from the back legs). Openings in the back and the sides lighten up the construction both visually and technologically, but not at the cost of hardness.

The wonderful future will have a place for an entire world of aluminium...The time will come when the fur coat your daughter is dreaming of...and the dress her eyes constantly wander to...will be made of aluminium, just like silk emerges from a silkworm's cocoon.

The New Yorker, 1956

In early 1933, the International Bureau for Applications of Aluminium announced the International Competition for the Best Seating in Aluminium in Paris. Two independent juries – one of them comprised of industry representatives, the other of designers and architects – not only evaluated prototypes' aesthetic, but also tested their degree of comfort, and their performance

opening. Coray noted that these openings would not only lighten up the construction at large, but would allow its use in the open air, since water would not collect on the seat. Its legs and armrests are made of continuous aluminium tubing. On the whole, the construction is elegant, practical, durable, and easy to assemble. This is why it went into mass production as early as 1939 under the



Marcel Breuer. Chaise-longue.
Aluminium, 1933



Hans Coray. Landi chair.
Aluminium, 1939

specs. The prototypes were also required to be suitable for mass production. Also, the rules of the competition stipulated that entries could not be copies of existing models but had to be something totally original. The juries evaluated 209 chairs from 14 different countries, and both awarded first place to the American designer **Marcel Breuer** (1902–1981). He entered five models, namely a footstool, two chairs, an armchair and a chaise long. Their frames were made of bent aluminium tubes, while their seats and backs were plywood. The use of steel would have weighed the structure down, while the models Breuer executed in aluminium can rightfully be called portable. They entered serial production in the USA in 1934.

In 1939, at the Swiss National Exhibition in Zurich, the designer **Hans Coray** presented an armchair with a seat and back made of a solid sheet of aluminium with round

name of "Landi" (an abbreviation of Schweizerische Landesausstellung, or Swiss National Exhibition).

Aluminium played an important role in the creation of the swivel chair, something we take for granted today. Its basic design emerged in the late 1930s.

1938 saw the opening of the headquarters of the Italian aluminium corporation Montecatini in Milan, designed by the architect **Gio Ponti**. 350 tons of aluminium went into the construction and decoration of the building. Ponti not only designed the building itself but also worked on its interiors. He created several varieties of swivel-chairs differed from one another in their back attachments, forms, and seat upholstery. The most optimal of these designs provided for regulation of seat height, and well as an adjustment for the back and its tilt. The chair also had rollers, much like the contemporary swivel chair, though it did not yet enter mass production.



Charlotte Perriand,
Jean Prouvé.
Bibliothèque "Mexique".
Aluminium, steel, wood,
1952

Aluminium in lighting fixtures

The first lighting fixtures of aluminium began to appear as early as the 19th century. However, they usually served technical purposes: semaphores at railway stations were often fitted with aluminium reflectors, as were lighthouses and mining lamps.

In the 1920s, aluminium found a broader application in domestic lighting, appearing in several countries at once. Aluminium attracted designers because it softens stark light, unlike mirror glass or stainless steel.

The French designer **Jacques de Chevalier** was soon to become famous for his avant-gardist lighting fixtures of aluminium. From 1927 to 1930, he created several desk lamps inspired by Cubism, the painterly style that had shaped the previous decade. These lamps were of flat aluminium panels, connected by screws. Using the principle of uncovered construction, Le Chevalier anticipated the aesthetic of technicism.

In the 1950s, the French designer Jean Prouvé projected aluminium lighting fixtures with "spotlights." Widely used in industrial buildings and offices, these laconic wall-mounted fixtures are still often used today, a perfect fit for contemporary interiors. ■

In 1944, the American company Emeco began to manufacture an all-aluminium chair for the U.S. Navy. This successful piece of furniture entered the history of design as Navy Chair 1006. Featuring a broad back and a recessed seat, this chair proved so comfortable that it was produced with very few changes until today.

After the end of World War II, the market was flooded with massive amounts of aluminium stemming from the scrapping of military hardware, including airplanes. With the prevalence of metal in the market, metal manufacturers faced a new challenge. One of the solutions lay in mass producing household items, so that the 1950s were a time full of many interesting projects for aluminium furniture. An example can be found in a bookcase by the French designers **Charlotte Perriand** and **Jean Prouvé**, designed for a university campus in Paris. Its horizontal panels and shelves were made of wood, while its vertical partitions and doors were made of painted aluminium.

This striking, multicolored object was called the "Mexican bookcase."

Around the same time, an aluminium folding chair (designer unknown) also reached incredible popularity. Its frame was made of aluminium tubing otherwise used in airplane construction. It is then wrapped with nylon bands, whose interweave form the chair's back and seat. This folding chair was very practical: light, waterproof, corrosion-resistant, and extremely cheap. Its manufacturer advertised it as follows: "Now men no longer need to strain their muscles when they set up chairs for evenings in the garden, bridge parties, or a dinner outdoors." The popularity of the folding chair was further enhanced by the US suburban construction boom. Nevertheless, the folding chair's considerable flaws would soon emerge. The folding chair proved quite uncomfortable; the nylon set would give way to a person's weight, which would then rest upon the aluminium frame, both in the back and on the legs. Americans say that this chair was a product of its time when ease of use and accessibility were more important than comfort.

It was only a matter of time until more optimal folding chair designs began to make their appearance. A good example can be found in the "Toledo" armchair made by the Spanish designer **Jorge Pensi** for the company Amat in 1986–88. The form of this chair's seat and

This is revolution. Future chooses materials that can help new men solve their problems. By "new men" I mean people who keep step with the scientific thought, who understand their age and live in it...

Charlotte Perriand. "Wood or Metal?", 1929



Jacques Le Chevalier. Desk lamp. Aluminium, bakelite, 1927–1930



Jorge Pensi.
Toledo chair.
Aluminium, 1986–1988



Charles and Ray Eames.
Aluminium Group armchair.
Aluminium, vinyl, 1958

back allowed leg and back muscles to relax, and the armrests were comfortable. The armchair's smoothly curving lines make it an ideal fit for a high tech interior. However, the "Toledo" has two drawbacks: it is far more expensive and slightly heavier than its "older brother" of the 1950s. These drawbacks cannot be found in an armchair by the world famous architect **Frank Gehry**, manufactured by Knoll. Its seat and back are made of a solid aluminium sheet with varied thickness, growing thicker at those points where the load will be greatest.

The American designers **Charles** and **Ray Eames**, a married couple collaborating for 40 years, began working with aluminium in 1948, when the Museum of Modern Art in New York announced an international competition for affordable furniture intended for mass production. They presented a chair whose seat and back were made of a thin, stamped out aluminium sheet, while its massive base was a cross-like support cast in

solid aluminium alloy. They were not the first designers to replace the traditional four legs of a chair with a cross beam. In the 1920s, the American Aluminum Company made these types of chairs for the Mellon Bank, similar to Gio Ponti's swivel chair for Montecatini. However, none of these designs ever entered mass distribution due to technical difficulties. It was only when the Eameses took second place in the MoMA competition that their chair went into serial production. Inspired by success, they went on to make several more similar designs for chairs and armchairs, using aluminium frames, and seats, backs, and armrests of polished plastic, and, unlike the 1948 model, with swiveling tops.

In 1962, the Eameses also designed a tandem sling seating for airport waiting rooms. This composite construction of two or more seats on a common frame can be assembled and attached to one another. This tandem seating fit in perfection into waiting room interiors,



Eero Saarinen.
Tulip chair.
Aluminium, plastic, 1955–1956

its aluminium frame reminiscent of a jetliner's silhouette. Its light construction is easy to assemble. This is why tandem sling seating, almost half a century old now, remains popular until today.

In the mid-1950s, designers began to combine aluminium with other materials. The American architect and product designer **Eero Saarinen** was planning a swivel-chair of plastic, but the production technologies of the time did not allow for the creation of a truly durable material. Saarinen gave the chair an aluminium base, covering it with the continuation of a fiberglass frame. The resulting Tulip chair looks like a single form.

In the mid-1980s, aluminium furniture attracted the industrial designer, artist, and architect **Ron Arad**, professor at the Royal College of Art. Arad works with structural honeycomb aluminium, a material whose appearance changes according to the viewing angle; sometimes it seems translucent, spreading a soft, diffuse light. At



Ron Arad.
Tom Vac.
Aluminium, stainless steel, 1997

other times, it is totally opaque. Arad used this aerospace material to great effect in interior objects, including lampshades.

One of Arad's chairs features a sinuous extruded aluminium frame originally supporting a seat/back body of vacuum formed aluminium. When Kartell Spa massproduced this piece, it became famous as the FPE, the Fantastic Plastic Elastic chair, its body now of smooth batch-dyed polypropylene. In his interiors, Arad often uses aviation and spacecraft designs.

In 1997, Arad presented his prototype of the Tom Vac chair, executed as a single cast die of aluminium. This chair can be seen as a contemporary variant of the shell chair, traditional to the epoch of classicism. Its corrugated structure does not only enhance the seat's stability, but also creates an interesting interplay of light on its matte surface. The aluminium "shell" seems to hang in the air on its shiny stainless steel legs. Later Vitra mass



Marc Newson.
Lockheed Lounge.
Aluminium, fiberglass,
rubber, 1985

produced the Tom Vac with a plastic seat shell. The Tom Vac is easy to store and transport, since it can be stacked into a compact “pyramid.” In 1997, at the Furniture Fair in Milan, Arad built a pyramid of 100 Tom Vac chairs, stacked on top of one another in a publicity action for the magazine *Domus*. This structure embodied the intersections of art, design, technology and process, and also demonstrated progressive technologies in the creation of contemporary materials.

In the following year, Arad continued to experiment with the Tom Vac chair using aluminium sheets of different shapes. For example, he designed a chair with extruded, uncut surfaces. The colored prototype was especially striking since its seat body was made of anodized aluminium.

Two important industry trendsetters in fashion and design, namely **Marc Newson** and **Philippe Starck**, also prefer to work with aluminium. One could even say that Starck’s interest in aluminium is hereditary: his father designed aircraft. A rather extravagant use of aluminium can be found in a stool he designed for film director **Wim Wenders** in 1992. One of Starck’s most popular

High-tech interiors

A set of glazed metal shelves takes place of the traditional cupboard. Semitransparent opal glass panels in thin aluminium frames replace standard doors. A bulky table is ousted by a light construction: tempered glass set in metal and placed on metal legs. Abundance of glass and metal fills any space with light. That is what high tech interior design is all about.

The high-tech style was born in Great Britain, and grew out of industrial architecture and the design of industrial spaces in which all functional elements – structural girders and trusses, utility pipes etc. – represent architectural features as well. When they emerged in the 1960s, the pioneers of the high tech style did not write manifestos or programmatic statements, opting instead to realize their ideas in practice. The first building to clearly embody their bold, extremely fashionable ideas in the Centre **Georges Pompidou** built in 1972–1977 in Paris according to a design by **Richard Rogers** and **Renzo Piano**. Over the years, its industrial aesthetic and purposefully utilitarian style took root in the interior of the building as well. The “high-tech” interior is laconic to the utmost; every detail is functional, and every object has been optimized for easy use. The space is reminiscent of both a metal-rolling workshop and the cross-section



Philippe Starck. W.W. Stool. Lacquered aluminium, die-cast, 1990



Marc Newson.
Orgone Chair.
Polished and painted
aluminium, 1993



High-tech kitchen

of a spaceship: pipes, strutting, girders, studs, containers, and other functional objects are not masked, but "exposed," becoming elements of the interior. Tiny details like bolts, rivets, and corner brackets play a prominent role. The abundance of metal makes for a cool atmosphere appropriate to both offices and townhouses, while aluminium plays a fundamental role. Not only does it significantly reduce the weight of the entire structure; its light, reflective surfaces are the perfect complement to glass, another key material in the high-tech style. The abundance of glass and metal visually broaden the interior space. Glassed metal shelving replaces traditional closets. Instead of standard doors, there are translucent surfaces of matted glass in thin aluminium frames. There are no bulky tables, only "airy" structures of glass tops in metal framing on metallic legs. Modern metal furniture combined with plastic, rough monotone fabrics, and leather can be used to create the perfect ambience for both offices and homes. High-tech interiors are usually not multi-colored; usually they are decorated with graphic art or black and white photographs rather than paintings. Most of the lighting fixtures are of metal, primarily of aluminium. Here, there is a great variety of forms, ranging from simple echoes of furniture contours to the most fantastic, reminiscent of flowers, mushrooms, and even gas burners. But almost all of these elements are movable, and a great deal of attention is paid to their variable constellation. To make lighting fixtures less prominent, their aluminium bodies are often anodized to match the color of the ceiling or walls. Shiny metallic elements find their complement in matted, powder sprayed surfaces. Frequently touched objects, such as door handles, doorframes, and the edges of desks and chairs, are matted and thus less likely to bear the traces of fingers or water drops. ■

designs is the Hadson chair, a variation on Navy Chair 1006 produced by Emeco in 1944 (see above). By using a durable aluminium alloy, Starck was able to create a sufficiently strong structure without resorting to the crossbeams used in the original. Starck's contemporary Marc Newson has also worked with aluminium. His Orgone series of aluminium furniture (1993) utilizes a technology developed for the creation of aluminium racecar bodies. These light, fluid objects with shiny, light-reflecting surfaces give one a sense of sitting in a racecar.

In 2000, the American designer Ros Lovegrove created the Go chair. The flexibility of its form and its texture bring it close to Starck's phantasmagoric stool. The Go chair is unusually light, since its seat is executed in polycarbon plastic.

Aluminium in Jewelry

The first aluminium jewelry appeared at the Paris World's Fair of 1855, where the silver-white metal attracted an immediate surge of attention. Thanks to a special treatment, the surface of the metal was so light that many mistook it for silver. However, the sheen of aluminium is softer than silver, and does not tarnish or turn black, making it attractive to jewelers. Ornaments on silver are hard to examine because of the metal's bright sheen. Aluminium does not shine as brightly; it is always matte, even if ever so slightly, and allows one to see even the finest of patterns. Under artificial lighting conditions, matte aluminium settings do not distort the coloring of emeralds or rubies as would silver settings.



Victor Chaperon.
Bracelet. Aluminium,
rubies; repoussé, gold
plating, ca. 1865

Frederic Miliche.
Bracelet. Aluminium;
repoussé, gold plating,
ca. 1865

By the 1860s every fashionable Parisienne immediately had to have at least one piece of jewelry with aluminium. Parisian jewelers such as **Charles Henri Vilmont**, **Pierre Étienne David Longpres**, **Arman Duffet**, **Victor Chaperon**, and others began to make aluminium bracelets, brooches, and earrings. Their creations combined aluminium with gold, silver, enamel, and precious stones. This required no small effort. Since aluminium is poorly suited to soldering, it was fixed with miniature gold and silver studs, producing elegant, winding forms.

The French master jewelers of the second half of the 1860s made elegant chamomile-shaped brooches with insets of mother of pearl or precious stone, decorated with enamel (medallion), gilding, and silver. Jewelers initially tried to interfuse aluminium with gold, using a soldering alloy of tin, magnesium, and silver. In some cases, the body is executed in gold or bronze and aluminium details are mounted later on. For example, Charles Henri Vilmont worked with contrasting colors

Purple gold

Purple gold, the unfulfilled dream of the Byzantine emperors, recently became very popular with the jewelers, who make little inserts of it into cases made of traditional yellow or white gold.

In antiquity, purple symbolized royalty. In Rome and Byzantium, only the emperor had the right to don purple robes, and even signed decrees with purple ink. Tyrian purple was an incredibly expensive dye made from a mollusk that lives in the Mediterranean. The noble color of purple matches well with the sheen of gold. Purple robes combined with a golden diadem decked out with precious stones were reputed to have made an amazing impression, not only on courtiers, but on ambassadors from abroad. Later, people learned how to make purple by mixing other dyes, so that it eventually ceased to be a symbol of royal power, though the awe this color inspires is timeless.

Brilliant gold and noble purple... Can they be combined to give gold a purple hue? Can the metal itself be made purple, and not just its surface (by covering it with purple foil), without sacrificing its noble burnish? For the jewelers of Byzantium, this was an impossible dream. A new page in the history of jewelry opened unexpectedly, when experts in microelectronics experimented with aluminium and gold. They found that prolonged contact of charged aluminium wires with gold produces a purplish residue. Studies showed that this residue is actually a solid solution that contains an inter-metallic compound of gold and aluminium. This served as an impulse for the development of new alloys for the use in jewelry. The deepest purple can be found in an alloy of gold and aluminium (25%), which produces a nearly pure inter-metallic compound AuAl₂. This compound cannot be used in jewelry since it is too brittle. To enhance its plasticity jewelers use an alloy with less aluminium, though enough to produce a purple hue, which only disappears around 15% aluminium. Once the dream of Byzantine emperors, purple gold is now coming into broader and broader use, for example, as a way of adding color to settings in yellow or white gold. Another alloy of 76% gold, 18% copper, and only 6% aluminium has an unusual pinkish hue. It is still being developed by jewelers and is not yet fit for use in jewelry. ■

to great effect, combining a body of gilded bronze with a gothic floral ornament of aluminium. Many pieces were also decorated with complex engravings.

The most famous French jeweler to work with aluminium was **Honoré-Séverin Bourdoncle**, whose work received silver medals at the Paris World's Fairs of 1855

and 1867. His studio made jewelry for the most distinguished socialites of Paris and even worked for the Emperor Napoleon III who have greatly admired the new metal. Bourdoncle even made a rattle-sceptre for the heir to the imperial throne. This object, which is still in the collection of the imperial family's descendents, is more than 20 centimeters long. Designed by the Parisian artist Charles Rambert, this piece is constructed around the contrast between a gray-blue, almost matte aluminium surface and the sheen of gold. A medallion with the emperor's profile is made of aluminium, as are figurines of angels and the female figure on the rattle's base, which is probably a personification of France. Both the rattle's handle and the medallion's settings are decorated with emeralds, while its crown-shaped pommel is made of gold. The rattles on box ends are executed in coral.

Bourdoncle also made a number of bracelets. One of them is now in the collection of the Musée des Arts Décoratifs in Paris. The floridity and elaboration of its sculptural composition is faintly reminiscent of 17th century baroque jewelry. The bracelet's main part – the figures of two *putti*, flowers, volutes, and interwoven bands – are made of aluminium. Aside from the studs that frame the bottom of the medallion, also of aluminium, many of the piece's details are golden, including the rose that deftly serves as a clasp. Bourdoncle's other bracelets imitated figures of angels as well as animals such as doves, snakes, and lizards.

The Parisian jeweler **Charles Christoffe** began to work with aluminium in 1858. The that he founded still bears his name today. On the appointment of Emperor Napoleon III, Christoffe created a desktop ornament with five *putti* symbolizing the prosperity of France. This aluminium sculpture group is on a base of copper-silver alloy, and framed with a decorative band of gilded bronze. A vase on a high foot, executed in solid aluminium, is yet another example of the artist's mastery in working with the metal, which was still new at the time. The techniques used to decorate it – engraving,

"The recent suggestion that aluminium might serve as a metal for artistic uses has presented the lovers of beauty with a new field for the imagination. There have already been reports of hundreds of uses for this material, yet the difficulties of its production have rendered many of them null and void in our time."

Newton's London Journal, 1855



Brooches.
Aluminium, gold plating, silver, mother of pearl.
France, ca. 1865–1870



Armand Duffet. Bracelet.
Aluminium; repoussé,
gold plating, ca 1860



Charles Christoffe.
Centerpiece. Aluminium, copper-silver alloy,
gold-plated bronze, 1858

blackening, and gold-plating – were so difficult to achieve with aluminium surfaces that they were only rarely applied in the century to come. The three graces are die-cast in aluminium and also decorated with engravings. The inner and outer surfaces of the cup – its diameter measuring approximately 25 centimeters – are richly ornamented. The signature engraving tells us that this object was finished in 1858.

Some of the desk ornaments from Christoffe's studio used aluminium bronze instead of pure aluminium, an alloy containing around 90% copper and 10% aluminium.

Increasing aluminium production led the metal's price to fall. From the late 1860s onward, aluminium was no longer considered a precious metal, and the aluminium fashion abated. However, at the turn of the century, jewelers once again turned to the metal, finding a perfect expression of the modern aesthetic in its matte, unobtrusive sheen.

In 1900, at the World's Fair in Paris, the French jeweler **Leon Colon** presented a dovetail shaped diadem of 15 centimeters in height, setting its great many diamonds in aluminium to make the piece of jewelry as light as possible. Moreover, he felt that the matte sheen

of aluminium would not outshine the glittering of the diamonds. The diadem was so beautiful that many people predicted that its designer would win the first prize of the exhibition, but the jeweler could not participate because he was a member of its jury. The saddest part of the story is that the further fate of the diadem is unknown; one can only gain an impression of it by looking at photos made at the exhibition.

The collection of the Musée Lambinet at Versailles contains a diadem by the French jeweler René Jules Lalique made in 1899 for the actress **Julie Bartet**, who played the main role in Jean Racine's "Berenice" at the



Earrings. Aluminium.
USSR, 1980s



Advertising poster for aluminium jewelry.
Italy, 1955

Comédie-Française, France's only state theater. The diadem contains heart-shaped medallions of ivory with reliefs on ancient themes. Set in aluminium, they are combined with ornaments of plamette and lotus decorated by blue sapphires. The outer part of the diadem is formed by stylized figures of angels in ivory. Their widely spread wings are barely touching and form a smoothly curving line. Thanks to the matte sheen of aluminium, the diadem is restrained, and kept in cold, gray-blue tones. Here, aluminium also plays an important functional role; notwithstanding its large dimensions (27×37 cm), the diadem is unusually light.

In the second half of the 1900s, the price of aluminium were so low that Lalique, who was involved in perfume packaging, suggested to replace the traditional glass used in bottles with aluminium. However, only a few of the art deco designs developed for this purpose ever reached mass production.

In the 1920s, some jewelers used aluminium as their principal material. One of them was **Raimond Tam-**

pline, a creator of jewelry and other accessories in the art deco style. In his cigarette cases for socialite Parisiennes, as well as in his other jewelry sets, he combines aluminium with silver and colored lacquering to great effect.

Early aluminium jewelry of the late 19th and early 20th centuries was produced in small quantities and has long since gained historical value as art. Such pieces of jewelry are on display at the major museums of Paris (Musée d'Orsay, Musée des Art Decoratifs), London (Victoria-and-Albert Museum, British Museum) and New York (Cooper-Hewitt Museum), as well as in a number of private collections. Aluminium jewelry is most popular among French collectors, with over 16,000 pieces in various collections.

In the 1960s, jewelry designer once again began to work with aluminium, with each artist developing his or her own approach. The American jeweler **Arlene Fisch** is famous for her volumetric jewelry of painted anodized aluminium. Searching for a material with which to apply the discoveries of avant-garde sculpture

in her rather large jewelry, Fisch eventually opted for aluminium, since any other metal would have been too heavy. At present, Arlene Fisch teaches at the Fine Art department of San Diego State University, but continues to produce jewelry. One of Fisch's favorite techniques is to work in pleated aluminium sheets, through which the metal becomes similar to a fine paper fan.



Gijs Bakker. Bracelet.
Anodized aluminium, 1967

In the 1960s–70s **Gijs Bakker** was to become the most famous European jeweler to work with aluminium. He called aluminium the "metal of nonconformists" and the material of the "real Sixties generation." Combining plastic with aluminium in colliers and bracelets, he felt that these materials "embodied modernity and the poetry of new technologies," seeing aluminium as a symbol of overcoming tradition and the prejudices of jewelers. Bakker was convinced that the future of jewelry lay in the rejection of "precious" metals and use of industrial materials such as aluminium. Many contemporary jewelers share Bakker's idea.

The British jewelry designer **Victoria Howe** makes bracelets that are machine-made. She is certain that "industrial" metals and processes emphasize that jewelry is no longer the domain of affluent connoisseurs. The creation of jewelry is no longer an "artistic" or "individual" process that demands the presence of the artist's "hand." To a degree, the views of Gijs Bakker and Victoria Howe are continuations of the idea of the Italian futurists.

Contemporary designers do not only use aluminium to make accessories and jewelry. The British designer **Nicholas Kirkwood** is famous for his shoes with aluminium heels, many of which have complex forms. This is how he comments his work in aluminium: "Lightness gives aluminium a quality that other metals lack. When worked with a lathe, aluminium allows you to get a very



Michael Peckitt. Fiona's Bangle.
Anodized aluminium, 2006

defined, sharp edges that look great on a heel. With the right instruments, aluminium gives the designer almost limitless possibilities for the creation of forms."

Contemporary jewelers prefer to combine aluminium with other metals and various exotic materials. Artists use a variety of techniques to work with aluminium: repoussé and chasing, engraving, enameling, and anodizing, which allows the application of acrylic paint to the metal's surface. One of the most well known designers to experiment with these techniques is the British jewelry artist **Michael Peckitt**, who translates painterly ideas into abstract jewelry items of aluminium, painting them with acrylic and combining them with steel, silver, and sheet gold encrustations. The jeweler **Jane Adam**, a graduate of the Royal College of Art, also works with anodized aluminium. She is primarily interested in its lightness, using it to create pendants that are nearly weightless, arranging them in pendants that look like clusters of exotic shells or feathers from afar.

Aluminium in Fashion

Fashion designers often say that they are “antennas” tuned into the signals of social fantasies and desires. Clothing is one of the codes that people use to convey information about themselves. For other people to “read” this code, clothing needs to express comprehensible ideas, images of beauty or sexiness that others can share. This is why European fashion designers will tend to emphasize the waist and bust when it comes to women’s fashion; Japanese women almost never show the napes of their necks, since this is seen as an erotic provocation; native Brazilians walk around with no clothes on at all, covering only their ears, the most sacred part of their body. European fashion conveniently codes its information through the nuances of style. One look is enough to tell whether your counterpart is a successful businessman or a computer genius, a socialite or a romantic waif, a Gothic princess or an “athlete, perfect Komsomol member, or, simply, a beautiful girl,” as a quote from an old Soviet comedy puts it. Over the last decade, however, fashion analysts have noted a tendency for styles to mix, leading to surprising new “hybrids,” such as the computer socialite or the athletic princess. What’s more, as society divides into smaller groups and communities, each subculture develops its own style codes and fashion tendencies. Fashion codes become more and more complex; new trends proliferate. Of course, everything new in science, technology, and art finds its place in some fashion niche. This is what happened to aluminium, when it first appeared in the second half of the 19th century.

Aluminium began its path through the history of fashion as a precious metal intended for the creation of unique jewelry items for the divas of the stage and the silver screen. Jewelers combined aluminium with diamonds, emeralds, and beryl. But as the production of aluminium increased, and came into use in the automobile industry, in shipbuilding, and later in aviation, the use of aluminium in fashion underwent a total change. Aluminium was no longer the metal of socialites and film divas, but became one of the symbols of the miracles of technologies, the first silver ray of a “wonderful future,” in which machines would take over human labor, leaving people free to pursue their creativity.



Katharine Hepburn in Metallic Moth Costume in “Christopher Strong” (1933). The costume is made of thin, square aluminium plates.

As the cult of the car arose in the 1910s, so did the cult of aluminium. The Italian Futurists, the poet **Filippo Tommaso Marinetti** at their head, declared that aluminium was the “metal of the future.” They dreamed of a total fashion revolution, introducing garishly bright colors and unthinkably new materials, and even mechanical inventions that could change the silhouette of clothing depending on the person’s mood. In 1916, the Futurist **Bruno Corra** approached an Italian manufacturer with the proposal to make headwear decorated with aluminium sheeting and neon signs. A little later, **Renato di Rosso** presented a necktie of aluminium sheeting. He believed that this necktie would be more

modern than conventional models of silk, and that it would be easier to tie, since aluminium is an “obedient” metal. Last but not least, Rosso suggested that alumin-



Oscar de la Renta. Bathing suit. Aluminium, 1967

um neckties could be made in a variety of unusual forms: they could be twisted into unusual spirals or extravagant twirls, lightly flung over the shoulder. In 1927 **Fortunato Depero** made the typographic album “Depero Futurista,” whose covers were aluminium sheets bound together by aviation bolts.

Shiny textures in garments were considered fashionable, but this was not really the luster of metal, but rather a shimmering twinkle, created by beads, spangles, and paillettes. As in the centuries to come, the tendencies of fashion came down to the use of light, flowing fabrics used to create “streamlined” silhouettes, either through simple geometrical figures or by cutting on the bias.

Couture designers returned to experimenting with aluminium in the 1950s. By the end of the Second World War, the United States and Great Britain had accumulated large stockpiles of the metal that now needed to be utilized in military production and in industrial design. In Britain, designers opted to create furniture from colored aluminium panels, while American designers began to create textiles using bands or threads of aluminium. The textile artist **Marianne Strengell** made carpets of brightly colored wool, viscose, and aluminium bands. She used aluminium as her basic material, making the final product both durable and pliable. But at the same time, she wanted it to look “normal” and not avant-gardistic. This may have been a step back from the bold experiments of the Italian futurists who were not only interested in the functional properties of aluminium, a lightness and plasticity that would allow them to give an item of clothing any form, but also in its aesthetic qualities, a matted silver sheen that could be associated with progress.

As history shows, artists turn to aluminium every time humanity begins to dream of its future. The 1960s were also a decade like this: manned spaceflight, and then, humanity’s first flight to the moon had a tremendous influence on fashion design. Designers enthusiastically set about inventing clothing for 21st century inhabitants of the Moon and Mars. This is how vinyls and plastics made their way into couture. Of course, aluminium was among the new materials. Riding the futurist wave, the American Aluminum Company (Alcoa) announced a competition for the best outfit using aluminium. The fashion designer **Oscar De la Renta** caused a real sensation with his bikini on extremely thin aluminium thread. Today, this model belongs to the Historical Society of Western Pennsylvania in Pittsburgh. According to its keepers, it still continues to stop museum visitors in their tracks. Interestingly, De la Renta did not make anything as radical ever again but his model of the aluminium thread bikini has become one of the key elements of club culture today.

In 1969 **Paco Rabanne** created a mini dress of polished silver and aluminium chain mail, as well as the Atomium Brussels dress based on a combination of aluminium and steel. An architect by education, Paco Rabanne inherited his interest in aluminium and especially objects of standardized aluminium details from his teacher, **Jean Prouvé**. A leading French architect of the 1950s, Prouvé had presented the French government



Paco Rabanne. Mini-dress.
Disks of lacquered aluminium, 1968



Paco Rabanne. Dress.
Aluminium disks, 1999



Emanuel Ungaro. Top and mini-skirt.
Aluminium, 1968



Emanuel Ungaro. Dress.
Aluminium, 1971

with a housing design for French bureaucrats working in the Asian and African colonies, consisting of bungalows of light, perforated aluminium panels. In the late 1960s, Rabanne began to make dresses of disks and another geometrical figures. In 1966, he presented “12 experimental dresses that can be made of modern materials” (of plastic and metals), including a mini of aluminium disks. Paco Rabanne explained his conversion to aluminium as follows: “I was attracted by the lightness, brilliance, and sheen of this metal... I wanted to provoke the public to open itself to new sensations, helping to step beyond the bounds of accepted convention.” One of Rabanne’s dresses inspired the London architectural firm Future System in their design for a new Selfridge’s shopping complex. Its façade is made of 15,000 aluminium disks, imitating a reptile skin of gigantic proportion (see p. 173). Immediately after construction was completed, Birmingham’s tourist authorities noted a sharp increase in visitors who would come to the city to photograph the building in the sunset, when the aluminium “armor” diffracts the hues of the sky and the color of the city lights. Thus, Paco Rabanne’s aluminium experiments served as an impulse to the emergence of a new object which critics cite as a “pearl” of contemporary architecture. And he returned to dresses of aluminium disks. His spring-summer collection of 1999 featured several models of evening gowns of square and triangular fishscales of aluminium and transparent plastic, as well as aluminium chain mail. The Russian supermodel Irina Pantaeva modeled one of these dresses.

André Courrèges, another French couturier, experimenting with aluminium powdersprayed onto plastic, creating models of mini dresses and tops. **Emanuel Ungaro** presented his autumn-winter collection of 1969 and 1970 in a show room decked out in aluminium panels. One of the models presented a cape of grey atlas decorated with thin aluminium tubes, which gave off a melodic ring as the model moved. Under the cape she wore a aluminium string bikini. In the 1960s accessory designers also began to work with aluminium. For example, the Italian house Salvatore Ferragamo used aluminium in models of handbags and shoes.

In the 1970s, the “cosmic” models from the “wonderful world of tomorrow” were replaced by “blasts from the past,” various ethnic styles and retro-themes. The only person who did not forget aluminium was the American radical designer **Rudi Gernreich**. In the mid-1970s, he



André Courrèges. Blouse
with aluminium details, 1960s

created several models of black knitted tube dresses fastened to a broad collar of polished aluminium.

In the 1980s, shiny silver and gold textures once again became fashionable. To create them designers used synthetic materials powder-coated with aluminium. Such fabrics did not only appear in the collections of trendsetting couturiers, such as **Thierry Mugler**, but also in mass-produced models of clothing and shoes, such as gold-powder bomber-jackets or ballet-pumps. Large and striking imitation jewelry came into style, resulting in a huge variety of clip-on earrings and bracelets, many of them in painted anodized aluminium.

In the last 10 to 15 years, fashion and shoe designers, designers of accessories, and textile artists have been experimenting with aluminium intensively. What’s more, each of them has his or her “philosophy of aluminium.” This is a key difference of today’s fashion compared with the fashion of previous decades, in which designer shared a common view of aluminium. (For example, in the 1960s, aluminium was broadly considered as the metal of “outerspace, nonconformists, and the romantics of new technologies.”)



Seetal Solanki. Panel (fragment)

One striking “philosophy of aluminium” is to be found in the work of British fabric designer **Seetal Solanki**. She is interested in materials capable of transforming clothing into architectural objects that keep their own form independently of the body’s natural curves. This is why Solanki feels that aluminium is the ideal material for work: first of all, it is light, and second, it has the necessary pliability. Solanki makes her “fabrics” from thin aluminium disks with tiny perforations. She cuts them into small triangles and attaches them to their basic structure with aluminium screws. From afar, this “fabric” looks like an interweave of exotic feather. “I like working with aluminium because it is light, and because it doesn’t rust in the open air,” she says. Since her fabrics are often designed to decorate architectural objects, she says that “the metal’s resistance to the effects of climatic conditions and the passage of time were one of the most important things. Of course, stainless steel has similar qualities, but it is heavier and far more expensive.”

Solanki is not the only designer to use aluminium in the creation of fabrics. The British textile designer **Sophie Roet** who works with the famous fashion houses John Galliano, Alexander McQueen, and Gianni Versace. Roet likes to use bands of aluminium as a base, and also studs her fabrics with aluminium. Many designers are more interested in aluminium’s sculptural possi-

bilities, and do not set themselves the aim of creating a “futuristic” image. For instance, in their autumn-winter collection 2003–2004, the British duo **Nargess Gharani** and **Vanya Strok** stamped aluminium foil onto velvet, creating a original and impressive new texture.

The British designer **Gareth Pugh** and the Swiss designer **Albert Kriemler** have both “returned” to the themes of futurism, aviation, and space flight, though they give them a new spin. Outfits by these two new technology enthusiasts are reminiscent of space opera costumes and technology epics like the Matrix. Pugh’s spring-summer collection of 2007 featured black-and-white harlequin trench coats with spatters of aluminium. In his autumn-winter collection of 2007/2008, Kriemler presented a cocoon-coat of aluminium sheets.

The spring-summer season of 2007 passed under the slogan of “futurism” and deserves our steadfast attention. A number of fashion houses, including Marc Jacobs, Alberta Ferretti, and Narciso Rodriguez, used experimental fabrics with aluminium coatings, giving them an elegant matte sheen.

The trench coats of **Christopher Bailey**’s collections for Burberry Prorsum had appliquéés of toned aluminium squares. In the same season, **Miuccia Prada**’s collection for Prada used textiles with toned aluminium coatings. A light coat from **Christian Lacroix**’s haute couture collection for the spring-summer season 2007 used golden aluminium foil as the outer layer of its fabric, making the model look like a precious toy. All these designers seem to be attracted by aluminium’s capacity to give off soft reflexes even under harsh lighting condition, making the models’ faces seem younger, softer, and brighter.

Nevertheless, there are other “readings” of aluminium to be found in the collections of today’s fashion designers. In May 2006, New York’s Metropolitan Museum of Art featured the exhibition “AngloMania: Tradition and Transgression in British Fashion” which showcased an evening gown by **Alexander McQueen**, “the hooligan of British fashion” and a master of intricate cuts. The black evening gown integrates a corset construction decorated by an aluminium “rib” that emphasizes its contour’s rigidity. McQueen is famous for his interest in fetishism and his fascination with the aesthetics of cinema. Aluminium, in his interpretation, is full of far more complex emotions, themes of stylistic aggression, a sense of limitation and dependence, which, at the same time, becomes a kind of “artistic preference.”



Christopher Bailey.
Trench coat. Burberry
Prorsum Collection, 2007

Some designers use aluminium because it allows them to bring elements of architecture into fashion design. This is why the Japanese experimental fashion designer **Kei Kagami** works with aluminium, as in a collection she recently demonstrated in Milan. Like Paco Rabanne (see above), Kagami is an architect by training; he studied under **Kenzo Tange**. He studied the basics of tailoring at Bunka Fashion College (Bunka Fukuso Gakuin) in Tokyo and at Central Saint Martin in London, then going on to work with John Galliano. In his autumn-winter collection of 2005/2006, Kagami used aluminated netting that imitated details from the armor of Japanese “bushido” warriors. A year later Kagami’s collection of women’s wear used aluminium rods to a great effect, as clothes hangers for “spare” jackets, or, in a black evening gown, as prosthetic extensions with a finely crafted chandelier with lit candles and bells. The shoes in his spring-summer collection 2007 were weighed down with metal heels screwed onto the outsole; the outfit itself was blown in glass and held in place at the shoulder with a complex construction of aluminium rods decorated with glass ornaments.

The Dutch designer duo Viktor & Rolf (**Viktor Horsting** and **Rolf Snoeren**) have also demonstrated an architectural approach to the use of aluminium. Their women’s wear collection is based on aluminium frames with personalized lighting and a music system. The model first wore a frame which was then draped with clothing. In this way each model presented a “thing in itself,” with her own lighting and soundtrack. The designers could only embody their ideas using aluminium: the models would not have made it down the catwalk in frames of any other metal, since they are all far heavier.

Aluminium is an amazing material. Its various qualities have attracted the interest of designers, finding applications in apparel, accessories, and textiles. Aluminium makes it possible for designers to create various images and to work in different styles and forms. Aluminium is so well-suited to the making of such impressive fabrics that designers don’t even have to worry about complex cuts. Aluminium’s unique possibilities open endless vistas for fashion designers, so that it is certain that the future of fashion will be full of surprises in aluminium.



Viktor Horsting and Rolf Snoeren. Dress, Autumn/Winter 2007/2008 collection

On the Threshold of the Aluminium Age

Nothing stops time. One epoch follows another, and sometimes we don't even notice it. The Stone Age... The Bronze Age... The Iron Age... The world that was once hostile to mankind gradually opened up to man and was conquered by him. Man was determined to make the most of natural resources. Everyday things, tools, vehicles made from natural materials were perfected. People not only discovered new materials but eventually learned to produce them. One of them was especially significant for humankind. It was aluminium. This metal with its surprisingly diverse qualities in just two hundred years managed to conquer the world and become a synonym for technical progress. It is no wonder that aluminium is first and foremost associated with jets and space rockets that could not be made without it. This silvery, "winged" metal symbolized humankind's aspirations to fly, to conquer the skies. Now, in the age of computers and the Internet, many people think that the romanticized time of aluminium has passed, and that plastics, composites and nano-materials have begun to play a bigger part. It is true that the rational serious approach replaced the romance of "conquering the universe." However one may assert that it is now that we stand on the threshold of the Aluminium Age.

This certainty is well-founded. Aluminium is the lightest metal, apart from magnesium, and it does not corrode. It is the ideal material for cars, yachts, airplanes. Do not forget that we owe the expressiveness of many modern interiors to the "aluminium aesthetics." Aluminium is irreplaceable as a packaging material – the production of aluminium foil grows every year. There is no metal better represented on this planet than aluminium. Its resources are estimated at 6,000,000,000 tons. In comparison, there is 200 times less carbon that is part of all organic matter, including various plastics. Even the mass of iron, which is much heavier than aluminium, in the Earth core is two times less. There is a lot of aluminium not only on Earth, its combinations were discovered on the Moon and on Mars. By contrast, the resources of carbon in space are few. Scientists are already developing ways of processing moon soil to extract aluminium from it. As for the resources of aluminium on Earth, they will remain inexhaustible even when all major layers of oil and natural gas are used up, which scientists predict could happen in the not so distant future.

Just a word about fuel. Aluminium really is fuel. Maybe the idea of filling up your tank with aluminium sounds utopist and even absurd. But aluminium powder already is used as rocket fuel. In terms of ecology, aluminium is a green metal, the purest one. Its use in car constructions makes them weigh much less, which lowers fuel consumption and, consequently, reduces air pollution.

We see that aluminium started out as a rival to silver and platinum, but gradually took on a new role and won over some ground from iron, steel, and plastic. The per capita aluminium production rises every year. So, the future belongs to the thirteenth element!

Index/Glossary

A

Abrasive materials (abrasives) – powdery substances used for the mechanical treatment of various surfaces (metal, ceramic, glass, and stone). Abrasive substances are very hard and resistant to compression. The particles (grains) of an abrasive consist of individual crystals or their splinters. The granularity of abrasives is a measure of the size of grains and their homogeneity. Natural abrasives include pumice, corundum, diamond, and quartz sand. Common synthetic abrasives are electro-corundum (corundum fused in electric furnaces), Carborundum, boron carbide, and synthetic diamonds *44, 90, 126, 139*

Acetates – derivatives (salts and compound ethers) of acetic acid *27*

Acetic acid, CH₃COOH – monobasic carboxylic acid. It is a colorless liquid that congeals when cooled into crystals resembling ice. It is soluble in all proportions in water. Acetic acid is widely used in the chemical industry for making solvents, synthetic fibers, and medicinal drugs *22, 27*

Acids – compound substances with hydrogen that can be displaced by metal. Acid solutions have a sour taste, turn litmus paper red, and are neutralized by alkali solutions *12–14, 16, 19, 20, 22, 24–28, 30, 31, 33, 37, 44, 48, 64, 65, 95, 110, 112, 114–116, 116, 120, 122, 125, 137–139, 147, 149, 155, 158, 159*

Aerodynamic spoiler (streamlined cover) – improving the aerodynamic properties of airplanes and automobiles *144*

Aerodynamics – branch of aerohydrromechanics that studies the motion of gases and the forces arising on the surface of a body moving in a gas stream *69*

Aeronautics – aerial navigation *66, 149, 172*

Aerostat – a lighter-than-air aircraft *68; cf. Airship*

Ageing (of metals and alloys) – the process in stored alloys, which results in changes in their mechanical properties *146, 147*

Aggregate states of matter – states of a substance whose transitions are accompanied by discontinuous changes in properties (density, heat capacity, and refraction index) and significant changes in the distance between its smallest particles. One usually singles out three aggregate states: solid, liquid, and gas. Sometimes plasma is called a fourth aggregate state. Not all substances can exist in all three aggregate states, as they can decompose during heating without reaching the melting point. Aggregate states of substance are the states of the same substance within various intervals of temperatures and pressure *125*

Air – mixture of gases making up the lower atmosphere. Mostly consists of nitrogen and oxygen as well as carbon dioxide and inert gases. Contains water vapor and small dust particles *10, 14, 18, 19, 20, 24, 25, 28, 35–39, 45, 48, 53, 56, 64, 68, 69, 71, 77, 97, 98, 101, 108–110, 112, 113, 118, 120, 122, 124, 129, 133, 134, 140, 144, 145, 158, 165–168, 171, 172, 183, 188, 200*

Aircraft – device for flying into the atmosphere or outer space *8, 67–69, 142, 145–147, 165, 190*

Airscrew – *cf.* Propeller *67, 68*

Airship – navigable aerostat with an engine *67, 68, 166*

Albite – sodium-calcium feldspar with colorless crystals that often accrete into serrated forms or grainy aggregates *116, 118, 119*

Alchemy – a stage in the development of chemistry during late Antiquity and the Middle Ages. Its aim was to find the philosophic stone that can change non-noble metals into gold as well as to obtain a youth potion. Although alchemists had erroneous notions about the nature of matter, their experience in working with substances cast the foundations for the modern science of chemistry *14, 15*

Alexandrite – variety of chrysoberyl containing chromium. It is emerald green in daylight and red-violet in electric light *122, 126, 127*

Alkali – a water-soluble base *10, 12, 19, 20, 24, 25, 27, 30, 35, 36, 44, 64, 74, 75, 91, 108, 111, 112, 114, 116, 117, 137–139, 149, 159*

Alkali metals – elements of the principal subgroup of the first group of the periodic table (lithium, sodium, potassium, cesium, and francium). Alkali metals are very active and occur exclusively in compounds in nature *12, 36, 44, 108, 117*

Alloy – a mass created by alloying a few substances. In the broad sense of the word, the same as fusion cake. Alloy is usually a system consisting of two or more metallic components and products of their interaction *10, 11, 14, 27, 36, 38, 49, 54–57, 59, 64–70, 72, 77, 79, 84, 85, 94–97, 99, 102, 104, 112, 116, 125, 126, 130, 132, 134, 136, 140–149, 150–152, 154, 155, 157, 159, 169, 170, 175, 176, 178, 186, 190–193*

Alloy additives – substances added to alloys in small quantities in order to give special properties to the material *64, 99*

Alloying, alloying elements – changing the properties of an alloy through the introduction of small admixtures (alloying elements) *67, 144, 147*

Almandine – red-brown variety of garnet *125, 126*

Alum – general name for salts with the formula M^IM^{III}(SO₄)₂·12H₂O, where M^I is a univalent cation (potassium, sodium, ammonium, rubidium, cesium, or thallium) and M^{III} is a trivalent cation (aluminium, iron, chromium, manganese, thallium, titanium, vanadium, iridium, etc.) Alum forms octahedral crystals. All alums are isomorphic. Aluminium-potassium, sodium-aluminium, and aluminium-ammonium alums occur in nature *12, 14–26, 30–32, 35–37, 39, 41, 42, 45, 60, 105, 110, 112, 114, 115, 126, 127*

Alumina – general historical name for aluminium oxide and aluminium oxide hydroxides *15, 16, 22, 23, 25–27, 30–32, 52, 53, 56–63, 70, 73–77, 80–82, 84–100, 105, 114, 147*

Aluminate solution – a solution containing aluminates *42, 74, 82, 91, 92, 95, 114*

Aluminates – compounds of aluminium and oxygen in which aluminium is a constituent of the anion. Aluminates include salts, double oxides, and oxide-hydroxide complexes *26, 42, 90, 92, 95, 98, 112, 114, 115, 126, 152*

Aluminosilicates – natural or synthetic oxygen compounds containing silicon, aluminium, and certain other metals *113, 116, 117, 119, 122, 126*

Aluminothermy – method of producing metals by reducing their oxides or halides with metallic aluminium *71, 110, 111*

Aluminium brass – copper-zinc alloy with an admixture of aluminium *64, 147, 148*

Aluminium bronze – alloy of aluminium and copper *48, 49, 54, 56–59, 65, 72, 147, 148, 175, 180, 193*

Aluminium acids – name of aluminium hydroxide or oxide-hydroxide in reactions with alkalis or carbonates *42, 44, 74, 84, 85, 91–93, 95, 114, 158*

Aluminium scrap – used aluminium articles or parts *95*

Aluminium-ammonia alum – dodecahydrate double sulfate of ammonium and aluminium. It forms colorless octahedral crystals that are soluble in water. It occurs in nature as the mineral tschermigite *14, 19, 30*

Aluminium-potassium alum – dodecahydrate double sulfate of potassium and aluminium. It forms colorless octahedral crystals that are highly soluble in water. It is used for purifying drinking water and coloring cloth and in medicine *14*

Alundum, Al₂O₃ – technical name for electro-corundum, i.e., corundum produced in electric furnaces. Alundum is used to make crucibles and other articles that must withstand high temperatures. It is also used as an abrasive material *28, 116*

Alunite, KAl₃(SO₄)₂(OH)₆ – mineral of the sulfate class. It forms dense or loose masses with an earthy or brown color on account of the presence of iron compounds. Alunite ore serves as a source of alumina, potassium sulfite, sulfuric acid, and rare earth metals such as gallium and vanadium *14, 19, 25, 116, 117, 159*

Amazonite (Amazon stone) – green mineral of the feldspar group; often occurs together with quartz and albite *119, 120*

Ammonal – mixture of ammonium nitrate and aluminium powder; used as an explosive substance *70*

Ammonia alum, (NH₄)Al(SO₄)₂·12H₂O – double sulfate of ammonium and aluminium. It forms colorless octahedral crystals that are soluble in water.

It eliminates water and disintegrates when heated. Ammonia alum generates ammonia when treated with alkali.

It occurs in nature as the rare mineral tschermigite *14, 19, 30*

Ammonia, NH₃ – simplest compound of nitrogen and hydrogen. This colorless gas with a characteristic pungent odor is easily soluble in water. The aqueous solution of ammonia, called ammonia water, is alkaline and has a characteristic ammonium odor. Ammonia water is used in medicine.

Ammonia is a key product of the chemical industry. Most of the ammonia produced is converted into nitric acid *12, 14, 19, 24, 25, 30, 31, 122*

Ammonium – cation NH₄⁺ resulting from the attachment of a proton to an ammonium molecule. Ammonium does not occur in a free state. The ammonium cation forms salts, similarly to the cations of alkali metals. Ammonium salts often have similar properties to potassium salts, yet, in contrast to the latter, they disassociate when heated and react with alkalis to produce ammonia *14, 25, 30, 115*

Andradite – brown-green variety of garnet; occurs both as individual crystals and continuous masses *125*

Anhydrous alumina – aluminium oxide *30*

Anion – negatively charged ion *155*

Anode – electrode at which oxidation occurs. The anode has a negative charge in a galvanic cell and a positive charge in electrolysis *53, 55, 57–59, 72, 73, 77, 79, 80, 97–99, 100–102, 104, 112, 155, 156, 180*

Anode paste – carbon paste used to make the anode *100*

Anodized aluminium – aluminium covered with a thin oxide film as a result of anodization. It is sometimes colored, for the oxide film can trap small dye particles in its pores *169, 170, 179, 180, 182, 188, 190, 194, 195, 199*

Anodizing – the process of creating a protective oxide film on the surface of metallic articles by electrolysis *112, 195*

Anortite – mineral of the feldspar group, forming white masses and grainy aggregates

Antacids – medicinal drugs lowering the acidity of gastric juice *116*

Antimony, Sb – a chemical element, atomic number 51. It is a metal silver-white in color with a bluish tint. Antimony is a constituent of some fusible alloys *15, 25*

Apatite – calcium phosphate with admixtures of fluorides and chlorides; a key mineral for the production of phosphorous and phosphoric fertilizers *93*

Apjohnite, MnSO₄·Al₂(SO₄)₃·22H₂O – rare mineral, sometimes called manganese alum, forming white fibrous or asbestos-like masses; no practical applications *14*

Aquamarine – light-blue or light-blue-green variety of beryl; gemstone *123, 125*

Arc furnace – *cf.* electric furnace *54*

Argon, Ar – chemical element with atomic number 18. This inert gas is a constituent of air and does not occur in chemical compounds. It is used for creating an inert medium, e.g., in electric lamps *145, 146, 154, 175*

Argon-arc welding – the arc welding in the presence of argon. It is used to weld metals that get easily oxidized in the air *146*

Arsenic, **As** – chemical element with atomic number 33. This crystalline non-metal is gray with a metallic luster and semiconducting properties. Arsenic compounds are toxic; they are used in semiconductor technologies *15*

Art déco (from French *art déco* “decorative art”) – artistic style during the second quarter of the 20th century *165, 166, 194*

Asbestos – general name for a group of naturally occurring hydrosilicates that are capable of splitting into thin fibers.

An important representative of this group is the mineral chrysotile Mg₃[Si₂O₅](OH)₄. Asbestos is widely used in technology for making roof slate, panels, pipes, fireproof cardboard, and sealants *16, 73, 109*

Astatine, At – radioactive chemical element of the halogen group with atomic number 85 *109*

Asterism – capacity of certain minerals in direct or reflected light to emit a certain type of luster in a certain direction in the form of rays that are often arranged in regular figures *128, 129*

Atom – smallest particle of a chemical element possessing its properties. An atom consists of a positively charged nucleus and an electron cloud. The atoms of most elements are stable and can exist eternally, migrating from one substance to another. Atoms do not change in chemical reactions *30–32, 35, 36, 77, 104–108, 114, 116, 117, 122, 126–128, 140, 142, 146, 171, 197*

Atomic mass, atomic weight – an atom’s mass expressed in atomic mass units. Chemists usually use the relative atomic mass that is equal to the ratio of the atomic mass in grams to one-twelfth of the mass of a carbon-12 atom. The periodic table gives the average relative atomic masses of elements *31*

Atomic number – the order of an element in the periodic table of the elements; equal to the number of protons in the nucleus *105, 107*

Autoclave – hermetically sealed apparatus for conducting physical processes and chemical reactions at high pressure and temperature *74, 91*

B

Backed foil – material consisting of aluminium foil, paper and two layers of polythene. It is used for packing dairy products and semifinished products. It withstands freezing *133*

Bakelite – old name for certain synthetic resins *182, 185*

Balloon – a lighter-than-air airborne vehicle. The balloon shell is filled with a light gas. Ballooning – flight on lighter-

than-air aircraft Barite, BaSO₄ – mineral of the sulfate class, sometimes called heavy spar. It forms white masses, is insoluble in water, and is resistant to acids and alkalis. This key barium mineral is used as a filler in the production of paper and rubber *69*

Barium, Ba – chemical element with atomic number 56. This silvery white metal easily oxidizes in air *30, 35, 60, 104, 110, 111*

Basalt – dark effusive rock formed from plagioclase, pyroxenes, and olivine; makes up the ocean floor and the bottom of large lakes *117*

Base – a compound consists of some metal and one or more hydroxyl groups. The bases which are soluble in water are called alkali *24, 33, 41*

Bath – chemical vessel for uniformly heating a reaction mixture with water vapor (water bath), mineral oil (oil bath), or hot quartz sand (sand bath) *20, 64*

Bauxites – important ore for aluminium production. It consists of a mixture of different forms of aluminium oxide-hydroxides and corundum *8, 10, 22, 23, 41, 42, 44, 73–78, 80–82, 86–94, 96, 102, 110, 113, 114, 117, 147*

Bayer method of extracting alumina from bauxites – method consisting of dissolving alumina in an alkaline solution with the subsequent production of the pure product by seeding *75, 82, 90, 91–93*

Bayer improved method of extracting alumina from bauxites – modern technology for processing bauxite ore *74, 75, 91*

Bayerite – *cf.* aluminium hydroxide *114*

Beryl – yellow green, emerald green, light blue, or rosy red mineral with crystals shaped like hexagonal prisms. Large transparent crystals with pretty colors are considered to be precious stones. Beryl ore is as a source of the metal beryllium *116, 122–126, 145, 196*

Beryllium, Be – chemical element with the atomic number 4. This lightweight light-gray metal reacts with both acids and alkalis. It is used in aeronautics and rocketry, as well as for making nuclear reactors. Beryllium bronze is used to make springs and ball

bearings. Binary compounds are compounds of two elements *143*

Biogenic – having an organic origin *10*

Bipolar electrode – an electrode with two poles *97*

Biscuit – white unglazed china with a porous dull surface; used for small sculpture and tabletop ornaments *27*

Bismuth, Bi – chemical element with atomic number 83. Silvery gray metal with a rosy hue. Reacts with oxidizing acids. Used as a constituent of fusible alloys.

Molten bismuth serves as a coolant in nuclear reactors *25*

Bitter [Epsom] salt, MgSO₄·7H₂O – a mineral of the sulfate class. Epsom salt is in the form of colorless bitter crystals soluble in water. It is used in medicine as a laxative. It is found in the sea water *24, 25*

Blast furnace production – production of cast iron from ore of iron and coke *82*

Blister pack – packaging made of thin plastic by vacuum forming *133*

Boehmit – *cf.* γ-AlOOH

Boiling – transformation of a liquid into a gas *18, 22, 23, 25, 36, 38, 60, 72, 81, 91, 108, 112, 122, 137, 138*

Bomber jacket (pilot’s jacket) – short loose jacket gathered into a belt at the waist.

Derives from the insulated coats worn by British bomber crews during World Wars I and II *199*,

Bone porcelain – very fine porcelain containing powdered bone. It is lighter and much more durable than normal porcelain *27*

Boric acid, H₃BO₃ – colorless crystals that are highly soluble in hot water. Boric acid was formerly used in medicine. It is employed for making special kinds of glass, ceramics, and flame retardants. It occurs in nature as the mineral sassolin *25*

Brass – alloy of copper and zinc *46, 64, 147, 148*

Bromine, Br – chemical element from the halogen group with atomic number 35. This red brown liquid with a strong unpleasant smell actively oxidizes many metals. Bromine compounds are used in medicine *109*

Bronze – alloys of copper with brass or other metals, except for zinc. Brass bronzes are the

most widespread. Non-brass bronzes include aluminium bronze – an alloy of copper and aluminium *8, 11, 25, 46, 48, 49, 54, 56–59, 65, 147, 148, 155, 160, 162, 175–178, 180, 191, 192, 203*

Bumper – bar attached to either end of a motor vehicle to absorb impact in a collision *142, 144*,

Burning – heating to high temperature in oxidizing atmosphere (air, oxygen) *24, 25, 28, 97, 98, 109, 111*

Burnt or exsiccated alum – anhydrous potassium-aluminium sulfate that forms during the calcinations of aluminium-potassium alum; used in medicine *15, 20, 115*

C

Calcination – heating a solid substance to a high temperature *91*

Calcite (calcspar) – mineral, natural calcium carbonate CaCO₃; forms chalk, marble, and limestone *72, 92*

Calcium, Ca – chemical element with atomic number 20. This silvery-white light metal slowly disassociates water, producing hydrogen. Calcium compounds make a flame turn brick red *10, 30, 33, 35, 60, 72, 75, 92, 93, 138, 152, 159*

Carbides – compounds of metals and certain non-metals (silicon and phosphorous) with carbon *10, 96, 98, 107, 109, 110, 115*

Carbon dioxide, CO₂ – colorless gas with a “sour taste.” Does not support combustion. Forms during the combustion of organic substances and the respiration of animals and plants. Solid carbon dioxide is called “dry ice.” *25, 28, 32, 42, 92, 93, 99, 107, 117, 141, 152, 175*

Carbon monoxide, CO – colorless poisonous gas without taste or smell. Forms during the incomplete combustion of carbon *31, 58*

Carbon, C – a chemical element, atomic number 6. It has several modifications, of which the best known are diamond, graphite, and coal representing amorphous carbon *10, 31, 36, 37, 42, 43, 53, 55, 57, 58, 60, 62, 63, 72, 73, 78–80, 82, 96–100, 107, 109, 110, 122, 134, 135, 137, 165, 203*

Carbonates – salts and ethers of carbonic acid *18, 30, 31, 40, 116, 134, 135*

Carbonatization – transformation into carbonates *93*

Carbonic acid – an out-of-date name of carbon-dioxide gas *31*

Carbuncle – rare dark red precious stone (obsolete) *126–128*

Carcinogens – substances causing cancer *99*

Casein – protein that is a key constituent of milk and cottage cheese. It is produced when milk turns sour. It is used for making glues and paints. Casein is an important source of phosphorous for the human body *26*

Cast iron – the iron alloy with more than 2% of carbon *64, 96, 100, 137, 160, 176*

Casting – method of making articles by pouring molten material into a form. Casting alloys are used for manufacturing products by founding. As a rule, the casting alloys are brittle and therefore they cannot be processed by rolling or forging methods *64, 68, 69, 101, 102, 130, 137, 138, 142, 144, 148, 175, 177, 178*

Catalytic activity – capacity of a substance to speed up chemical reactions *113*

Cathode – electrode at which reduction occurs. The cathode has a positive charge in a galvanic cell and a negative charge in electrolysis *35, 53, 55–58, 72, 73, 97–100, 104, 155*

Cathode coating – coating on a cathode *99, 100*

Cation – positively charged ion *14, 106*

Caustic potash, KOH – potassium hydroxide, alkali *25, 35, 37, 38, 111*

Caustic soda, NaOH – sodium hydroxide, alkali *25, 35, 40, 42–44, 48*

Cement – a substance that, mixed with water, forms a viscous mixture, after which it gradually turns into a solid stone-like mass *80, 93, 152*

Cement clinker – product resulting from firing a finely ground mixture of limestone and clay; used for making cement *152*

Cement solution – cement in combination with sand and water *152*

Ceramics – articles and materials obtained by firing clays and their mixtures with

mineral additives as well as oxides and other inorganic compounds. Ceramics include terracotta, maj-olica, faience, stoneware, and china *26–28, 37, 52, 53, 60, 99, 115, 118, 119, 139, 144*

Cerium, Ce – a chemical element, atomic number 58. It is silver-grey metal of the lanthanoid family. Cerium loses its luster in the air. It is used in lighters, and in metallurgy as a deoxidizing agent *66, 99*

Chalcogenides – chalcogen compounds *115*

Chalcogens (the chalcogen family) – chemical elements of the IVA subgroup of the periodic system (oxygen, sulfur, selenium, tellurium, and polonium) *115*

Chalk – soft white limestone consisting of small pieces and whole skeletons of microorganisms. Used for making glass and as a filler in paper and rubber industries. Synthetic chalk made of calcium carbonate mixed with gypsum and glue is often used in schools. Such chalk does not write as well as natural chalk *40, 41*

Chamotte – a fire brick made of the SiO₂ and Al₂O₃ mixed in different proportions *111*

Chapel (Italian *cappella*) – in Catholic and Anglican architecture, a small building or room for the prayers of an aristocratic family, for storing relics, for housing singers, etc. Chapels were found in churches as well as castles and palaces. Freestanding chapels were also built (e.g., the Sistine Chapel) *166, 167, 168, 176*

Chassis – the bearing structure that houses the basic units of the automobile *142*

Chemical activity – capacity of a substance to participate in chemical reactions *45, 64, 102, 137*

Chemical element – a collection of atoms of one type with identical charges of atomic nuclei and the identical numbers of electrons in the atomic shell *33, 107*

Chemical formulas – sets of the characters used to define the qualitative and quantitative structure of substances *31, 107*

Chemical industry – a branch of heavy industry processing hydrocarbons, minerals, etc. *151, 168*

Chemical properties – a set of material characteristics defining its ability to interact with other substances *109*

Chemical reaction – process by which one or more substances may be transformed into one or more new substances *72, 106*

Chemical stability – the resistance of substances and materials to aggressive media (acids, alkalis, oxidizers) *99*

Chlorazotic acid – a mixture of nitric and hydrochloric acids in the ratio 1:3. It is able to dissolve gold and platinum *64, 110*

Chlorides – salts of hydrochloric acid *10, 11, 16, 24, 25, 27, 28, 36–39, 41–45, 52, 53, 55, 56, 60, 71, 96, 97, 104, 110, 114*

Chlorine, Cl – a chemical element-halogen, atomic number 17. It is yellow-green suffocating toxic gas with odor of “bleaching powder.” It is used for the disinfecting of water, and also in the production of hydrochloric acid and organic solvents in the chemical industry *36, 37, 39, 42, 109, 111*

Chromium, Cr – a chemical element, atomic number 24. It is a refractory and tough metal silver-grey in color. It reacts with acids. It is used for metal coating (chromium-plating) and also in stainless steel manufacture *14–16, 110, 115, 117, 120, 122, 123, 125–128, 141, 142, 148, 166*

Chrysoberyl – complex oxide of beryllium-aluminium. It is a mineral golden-yellow or green in color. It is found in pegmatitic veins. Some varieties of chrysoberyl are precious stones, e.g., alexandrite *116, 126*

Classicism (from Latin *classicus* “exemplary”) – artistic style and aesthetic movement in European literature and art during the 17th early 19th centuries; a key feature was the imitation of the models and forms of ancient literature and art as an ideal aesthetic standard *187*

Clay minerals – group of aluminosilicates (including kaolinite, montmorillonite, and hydromicas) forming clay rocks *25, 26, 116–118*

Clays – sedimentary rocks consisting of clay minerals. Clays are malleable and used or molding. Clays are classified into different

types depending on their predominant clay mineral *8, 10, 14, 19, 22, 23, 25–27, 30, 36, 46, 53, 60, 62, 63, 71, 72, 75, 76, 80, 88, 96, 97, 105, 117, 118, 152, 158*

Coal – *cf.* Carbon *28, 39, 40, 41, 72, 99, 100, 121*

Cobalt, Co – chemical element with atomic number 27. This heavy silvery metal with a rosy hue reacts slowly with acids. Cobalt compounds often have a rose or blue color *14, 27, 127*

Coke – solid constituents that form during the thermal decomposition of solid and liquid organic materials. Depending on the raw materials goes under various names – petroleum coke, pitch coke, coal coke, etc. *96, 97, 100*

Collimator – optical device for producing beams of parallel rays *35*

Colloidal solution – *cf.* Colloids *138*

Colloids, colloidal systems – systems consisting of particles with a size between 10^{–9} and 10^{–7} m. The properties of these systems are to a large degree determined by the large total surface area of all its constituent particles *114, 138, 158*

Composite materials – *cf.* Composites *118, 151*

Composites – materials composed of several phases, one of which acts as the base, and the others serve as fillers in the form of threads, fibers, or meshes *118, 151, 186*

Compound substances – substances consisting of atoms of different types *11, 12, 107*

Compressor – device for compressing and delivering gas at high pressure *96, 144*

Concentrate – product of mineral enrichment that is better suited for use or further processing than the primary raw material *19, 20, 48, 55, 91–94, 110, 140*

Concrete – solid mass that forms from the solidification of a dense mixture of a binding material, water, fillers, and certain additives *109, 150–152, 162, 163, 166, 168, 172*

Condensate – liquid that forms from the condensation of gas or steam *157*

Condensation – transition of a substance from a gaseous state to a liquid state *15*

Conductivity – the property of a material that indicates its ability to conduct an electric current *25, 99, 102, 108, 134, 137–139, 146, 154*

Copper alloys – (bronze and brass) are widely used in industry *79, 141, 143, 145, 146*

Copper copperas, CuSO₄•5H₂O – pentahydrate copper(II) sulfate. Forms blue crystals that dissolve easily in water. Used as a pesticide in agriculture *25*

Copper, Cu – chemical element with atomic number 29. Soft and ductile red metal that loses its luster in air as a result of oxidation. Excellent thermal and electrical conductor *10, 15, 16, 19, 22, 25, 31, 33, 50, 54, 56, 58, 63–67, 77, 79, 82, 97, 99, 102, 104, 108, 134, 137, 140–142, 144–148, 174, 175, 192, 193*

Corrosion – oxidation and disintegration of metals and alloys through chemical or electrochemical interaction with the external (corrosive) medium *12, 54, 65, 67, 68, 96, 99, 108, 109, 134, 139, 140, 141, 144–146, 175, 176, 180, 184*

Corrosion resistance – the resistance of a material to oxidation in the air *141, 145, 148, 149, 150, 200*

Corundum – crystalline aluminium oxide. This hard mineral is used as an abrasive. Certain large corundum crystals are considered to be precious stones (rubies and sapphires) *12, 45, 110, 113, 114, 116, 117, 127–129, 151, 175*

Covalent radius – a measure of the size of atom which forms part of a covalent bond *106*

Crankshaft – part of an internal combustion engine that transforms the up-and-down motion of its cylinder pistons into rotational motion *69*

Crucible – a bowl made of a fire-resistant material, is intended for melting or tempering substances *43, 52, 53, 55–58, 60, 62, 63, 110, 111, 115, 116, 127, 130*

Cryolite, Na₃AlF₆ – mineral of the fluoride group. The major cryolite deposit in Ivigtut, Greenland, is almost completely exhausted. Cryolite is synthesized today. It is used in aluminium production *42, 43, 44, 53, 54, 55, 56, 57, 59, 60, 61, 62, 63, 71–73, 77, 78,*

79, 81, 86, 94, 95, 96–99, 101, 102, 111, 115, 116

Cryptocrystalline – form of a mineral that outwardly seems amorphous but actually has a crystal structure. Usually, such minerals are formed by very fine crystals indistinguishable to the naked eye *10*

Cryptocrystalline modification – a form of a crystalline substance with very small crystals that are indistinguishable to the human eye *119*

Crystal – solid body in which atoms, molecules, or ions form an ordered periodic structure called a crystal lattice *10, 11, 12, 14, 15, 19, 20, 23, 25, 26, 27, 30, 36, 39, 43, 50, 52, 67, 82, 91, 95, 96, 104, 108, 110, 113–120, 123–128, 140, 141, 142, 144, 146, 151, 152, 158, 172*

Crystal lattice – spatial structure constituted by the particles of a crystal *14, 108, 127, 146*

Crystal modification – a form of a crystalline substance with a certain crystal structure *113, 114*

Crystallization – growth of crystals out of a solution, melt, or vapor *25, 104, 115, 127*

Current strength – a value equal to the electric charge flowing through cross-section of the conductor for a time unit *33*

Cylinder (motor-car) – a component of internal combustion engine. It transforms energy of fuel into mechanical movement *144*

Cylinder head – engine part that covers the cylinder block from above *42*

Decomposition reaction – a chemical reaction, a fragmentation of a chemical compound into smaller ones *28, 53, 55, 74, 91, 113, 127*

D

Demantoid – yellow or green garnet whose color stems from the presence of iron and chromium ions; emerald green demantoid is a precious stone *125*

Density – ratio of the mass of a substance to its volume *46, 59, 66, 122, 104, 107, 108, 145, 150, 152*

Deposit – natural accumulation of minerals *11, 12, 16, 17, 18, 22, 23, 25, 35, 42–44, 55, 71, 73, 76, 77, 80, 82, 86, 87, 88, 89, 90, 114, 118, 120, 122, 123, 124, 125, 126, 128, 129*

Deposition – a layer of powder substance spread over a surface to make the goods with some special physicochemical, mechanical or decorative properties *134, 190, 199, 200*

Diadem (Greek diadema) – women’s head ornament shaped like a small open crown *191, 193, 194*

Diamond – modification of carbon *113, 122, 125, 126, 127, 166, 193, 194, 196*

Diaspore – modification of aluminium oxide-hydroxide that is contained in certain bauxites *114, 116, 117*

Diborides – compounds of elements and boron with the formula EB₂ *99*

Dickite – a mineral that is a polymorphous modification of kaolinite; forms colorless thin plates and packets (“books”) of such plates *117*

Die – instrument with a hole used for molding metal stock in stamping, pressing, and drawing *144, 162, 181, 187*

Dielectric, isolator – substance that virtually does not conduct electric current *108, 146*

Diorite – intrusive rock consisting of plagioclase and hornblende; may also contain biotite, quartz, and other minerals *117*

Dioxides – compounds of elements and oxygen with the formula EO₂ *25, 41, 42, 91–93, 99, 107, 117, 121, 141, 152, 175*

Direct current – constant electric current whose strength and direction does not change *155*

Displacement – chemical reaction between a simple and a compound substance leading to a new simple and a new compound substance *71, 111, 117, 126*

Dissociation – disintegration of a substance. The dissociation of an electrolyte into ions is called electrolytic dissociation, while the disintegration of a substance when heated is called thermal dissociation *73, 91*

Dissolving – process to get a homogeneous mixture *22, 63, 74, 75, 114, 115, 152*

Dolerite – principal igneous rock, which is made of plagioclase, pyroxene, olivine, and titanomagnetite. Dolerite has a dark gray color and a grainy structure. It is close to basalt *92*

Dolomite, CaMg[CO₃]₂ – natural mineral from the carbonate group. It is a double

carbon trioxide salt of calcium and magnesium. It serves as a raw material for making limestone *92*

Double salts – the salts containing several types of cations *12, 25, 39, 110*

Drawing – pulling metal stock through holes (draw dies) for reducing its cross section *144*

Ductility – capacity of a material to withstand hammering and other types of pressure treatment (rolling, drawing, and stamping) *64, 141*

Duralumin – alloy of aluminium, copper, magnesium, and manganese. It can be tempered and aged. It is a major structural material in aeronautics *66–69, 77, 140, 141, 143, 145–147, 154, 181*

Dynamo – former name for a direct current generator *53–56, 59, 61, 63*

E

Earth’s crust – upper solid part of the lithosphere (outer sphere of the “solid” earth) with a thickness between 5 km (beneath the ocean) and 75 km (beneath continents) *113, 116, 118*

Elasticity – the ability of bodies to return to their original shape after external forces stop *118*

Electric arc, voltaic arc – arc-shaped discharge in a gas. It has the shape of a narrow bright plasma cord. When the electrodes are arranged horizontally to one another, this cord assumes the shape of an arc under the impact of rising streams of gas heated by the discharge. It is used to melt and weld metals *36, 54, 55, 146*

Electric battery – *cf.* Galvanic electricity *62*

Electric charge – the intensity of the electromagnetic interaction of charged particles. Electric charge of an electron is named elementary electric charge. It is the least possible quantity of electric charge.

All other electric charges are multiples of it *14, 33, 35, 74, 97, 104–106, 156, 191*

Electric conductor – a substance that readily conducts electricity. There are metals, solutions and melts of electrolytes (salts, acids and bases) that demonstrate the conductivity *58, 68, 107*

Electric current – an ordered motion of charged particles. Current carriers can be either electrons or ions 8, 30, 32, 35, 52, 53, 55, 56, 59, 60, 61, 62, 63, 72, 73, 80, 147

Electric energy – the quantity of power that power stations direct to an electrical network system or the quantity of power that is received by consumers from the network 59, 76

Electric furnace – a furnace where high temperature is generated with electric current or the electric arc 54, 96

Electric resistance – opposition to the flow of an electric current through a circuit (or its section) 55, 73, 108,

Electrical engineering – comprises the application of electric and magnetic phenomena for the purposes of energy transformation, the production of substances and change of their chemical composition, the manufacture and processing of materials, and information transfer, including problems of power production, transformation and use 66, 95

Electricity – a set of the phenomena caused by the existence, movement and interaction of electrically charged bodies or particles 8, 32, 33, 35, 53, 59, 63, 76, 80, 93, 94, 96–99, 102, 143

Electrochemical potential – electromotive force of a galvanic element made of an electrode and a standard reference electrode provided that the activities of all components equal to 1 141

Electrochemistry – a part of chemistry, which studies the properties of solutions and fused baths, and also the phenomena arising from an electric current passing through the solutions 35, 73

Electroconductivity (electrical conduction) or conductivity – the ability of a body to energize under the influence of electric field. It is also the physical value quantitatively describing this ability 99, 102, 108, 146

Electrode – a part of an electrical device, which connects a section of the electric circuit of the device with an external circuit 35, 36, 52, 53, 55, 57, 58, 59, 63, 73, 78, 81, 97, 98, 99, 104, 146

Electrolysis – the process of passing a direct electric current through an electrolyte in order to produce chemical changes in the latter 32, 35, 43, 52, 53, 55, 56, 57, 58, 59, 61, 62, 63, 71, 72, 73, 76, 77, 79, 80, 81, 84, 94, 96, 97, 98, 100, 101, 102, 104, 112, 155, 177, 178

Electrolyte – a substance, solution or liquid melt, which electricity can pass through. Among electrolytes are acids, bases and salts. In addition, some oxides (in molten form) can be electrolytes 54–57, 59, 60–63, 73, 79, 155, 156

Electrolytic aluminium-making technique, or electrolytic method – the reduction of aluminium from aluminium compounds by means of electric current. The technique was practically the only industrial method for more than hundred years 36, 45, 52, 53, 55, 56, 57, 59, 60, 63, 64, 110

Electrolytic bath – a large bowl used for electrolysis or electroplating coating 54, 59, 61, 63, 72, 73, 77, 80, 96–98, 101, 102, 155

Electrolytic refining – a method to refine materials with electrolysis 104

Electromagnetic waves – electromagnetic field propagating with the velocity depending on the properties of a medium. Electromagnetic waves in vacuum have the greatest velocity (velocity of light, about 300 000 km/s) 33

Electrometallurgy – the branch of metallurgy where metals are produced by electrolysis 44, 72, 73, 95,

Electron – a negatively charged elementary particle 36, 105–107, 120, 145

Electronic cloud – a set of points of the near-nucleus space in which an electron can be found 107

Electrostatic machine – device for generating static electricity by friction or using an external source of charge 32

Electrothermal melting, or fusion-melting in electric furnaces 76

Emerald – green variety of beryl 122–126, 191, 192, 196

Emery – a fine-grained rock consisting of corundum. It is used as an abrasive 30, 116

Enameled aluminium – aluminium with an enamel coating 138

Enamels – strong vitreous coatings on metals, fixed by glazing 28, 44, 118, 138, 155, 159, 191, 195

Endogenous – derived from within; said of a geological process that originates within the Earth (tectonic processes, magmatism, metamorphism, seismic activity) 10

Energy carriers – minerals (oil, gas, coal) and the products of their processing, used as energy sources 95

Engobe – coating made of white or colored clay; applied to ceramics before firing in order to smooth out their surface and give them a color 26

Engraving – process of creating a drawing or inscription on a hard material in a manual mechanical manner using a chisel or in an electronic manner using a laser; the resulting drawing or inscription 19, 20, 21, 50, 191–193, 195

Erbium, Er – a chemical element, atomic number 68. It is a metal of the lanthanoid family. Erbium is constituent of some magnetic alloys 126

Ethyl alcohol, ethanol, C₂H₅OH – a colorless liquid with a specific smell. In everyday language it is medical or wine spirit. It is an important product of organic synthesis, which is used in manufacturing solvents, glues, varnishes, and medicines 33

F
Façade (French *façade*, from Italian *facciata*, from *faccia* – *face*) – is the outside of the front wall of a building 62, 166, 172, 173, 199

Faience – glazed fine-pored dense ceramics 25–27

Fastener phase – the phase whose formation in an alloy results in higher durability of the material 140, 141

Feldspars – a group of the most widespread rock-forming minerals making about half of the weight of the earth’s crust. Feldspars are composed of the aluminium silicates of sodium, potassium, calcium, and less often barium. There are white, grey, yellow, pink, red, and green minerals 117, 119, 120, 122, 125

Ferrous metallurgy – production of ferrous metals 94, 95

Fillets – panels covering the front parts of airplane wings to protect them from damage by the air stream 68

Filter – a porous partition for removing insoluble admixtures from a substance passing through the filter 116, 130

Filtering – the process of removing of solid particles from a liquid or gas using the filter detaining solid particles 91, 93, 130

Flint glass – glass containing lead and possessing a high refractive index; used in optical devices 35

Fluidity – the ability of solids to become either plastically or viscously deformed in response to mechanical stress 144

Fluorides – salts of hydrofluoric acid 44, 53, 55, 60, 63, 72, 73, 78, 95, 99, 100, 101, 102, 104, 111

Fluorine, F – a chemical element, halogen, atomic number 9. It is yellow-orange gas with a strong odor, a very strong oxidizer. Water and quartz glass ignite in the presence of fluorine 55, 109

Fluorite – calcium fluoride. It is a mineral of the fluoride group and serves as raw material for fluoric acid production 77, 94

Fluoropolymer – a polymer containing atoms of fluorine, e.g., teflon 138, 139

Fluor-spar, or fluorite, CaF₂ (calcium fluoride) – wide-spread mineral of the fluride group. Poorly soluble in water, colorless, green or red-violet crystals of fluorite are decomposed by acids. It is used as a raw material in the production of fluoric acid, and also as a flux in metallurgy 41, 72, 73

Flux – a substance put in batch so that slag forms 41, 42, 55, 111, 130, 145

Foil – a thin sheet or tape of metal and alloy 49, 64, 79, 94, 102, 108, 109, 190, 133, 134, 149, 172, 180–182, 191, 200, 203

Food acids – acids that are found in foods (e.g., apple, acetic, and citric acids) 25, 133, 139, 164

Food colorings – natural or synthetic chemical substances, that are added to food to change its color. They are nontoxic 70

Forge alloys – the alloys used for manufacturing products by forging 143, 147, 148, 180

Foundry – making goods of cast iron, steel, base metals by molding 101

Fraction – a part of a mix, which is isolated by a specified attribute. Thus, crushed stone is divided into fractions by the size of fragments, and oil, by the boiling temperature 92, 117

Frame – a transversal rib of the ship board or the fuselage of the airborne vehicle used for the strength and stability of sides and bottom 69, 141

Fuel – combustible substances that are burned to produce heat energy 69, 70, 82, 94, 130, 141, 142, 144, 145, 149

Fuel and energy complex – includes the fuel industry, electric power industry, and fuel and energy delivery facilities 94

Fuselage – the main part of an airplane where cockpit, passenger cabin, baggage-and-cargo space are accommodated 67–69, 140

Futurism (from Latin *futurum* – the future) – avant-garde art of the 1910th – early 1920th in Italy and Russia 200

G
Gadolinium, Gd – chemical element with atomic number 64. Metal of the lanthanide series with a very high chemical activity. Constituent of certain magnetic materials 126

Gallium, Ga – chemical element with atomic number 31. This soft silvery-white metal melts at the temperature of the human body. It is used for making semiconductors 14, 93, 112, 114, 126

Galvanic electricity – the electric current resulting from the activity of a galvanic element. It was discovered by Italian physicist A.Volta 33

Gamma rays – short-wave electromagnetic rays with wavelengths below 10⁻¹⁰ m 106

Garnet – group of minerals of the subclass of nesosilicates with the general formula R₃²⁺R₂³⁺(SiO₄)₃, where R²⁺ is Ca, Fe, Mg, or Mn and R³⁺ is Al, Fe, or Cr 125–127

Gas burner – laboratory instrument that generates a steady flame (torch) 64, 154, 190

Gas purification system – a complex of devices intended for the cleaning of gases emitted by hazardous substances 101

Gaseous phase, or gas – aggregate state of matter in which particles move freely and have a far greater kinetic energy than potential energy. Gas does not have a form of its own but fills up the entire volume that is accessible to it 39

Gaseous state of substance – *cf.* Gaseous phase 39

Gasoline – mixture of hydrocarbons obtained from oil refining; used as an automobile fuel 141, 145

Gels – colloidal systems with a liquid dispersion medium in which particles of the dispersion phase form a spatial lattice. Gels are capable of maintaining their form and are strong and jellible. Examples of gels are jelly and jellied meat 27, 42, 114, 158

Gibbsite – *cf.* γ-aluminium hydroxide 114, 117

GIPKh improved method for extracting alumina from bauxites – a sintering method in which the furnace charge is prepared in a “wet” manner from bauxite, soda, limestone, and white sludge 76, 80

GIPKh (Gosudarstvenny institut prikladnoi khimii) – State Institute for Applied Chemistry 92

Glass – a transparent solid amorphous material formed from the melt containing glass-forming components (oxides of silicon, boron and phosphorus) and oxides of the following metals: sodium, potassium, lead, and calcium 7, 26, 27, 33, 35, 39, 42, 44, 49, 50, 60, 95, 112, 118, 120, 122, 129, 134, 135, 138, 156, 157, 162, 163, 165, 166, 168, 169, 172, 181, 182, 184, 190, 194, 201

Glauber’s salt, mirabilite, Na₂SO₄·10H₂O, – a mineral of the sulfate class. Glauber’s salt represents colorless bitter crystals soluble in water. It is used in the manufacture of glass, in the chemical industry and medicine 24, 25

Glaze – vitreous decorative and protective coating applied to ceramics before firing. Glaze can be colorless or colored, transparent or non-transparent. In contrast to biscuit, glazed china is waterproof. For this reason, china dishware is always covered with glaze 26–28, 137

Globule – metal ingot in the form of a small sphere or drop of congealed metal *35, 37–39, 43, 175, 52, 53, 55, 62*

Gold – chemical element with atomic number 79. This noble metal with a yellow-golden color does not alter in air. Gold reacts with halogens and aqua regia and is a good heat and electrical conductor. It is used in electric technology and jewelry *7, 8, 14, 15, 16, 25, 49, 75, 99, 156, 169, 170, 172, 180, 191–193, 199*

Granite – igneous rock consisting of quartz, orthoclase, plagioclase, and mica; used as a decorative material *44, 118, 119, 124, 172*

Granules – substance in the form of small dense balls, cylinders or platelets *143*,

Graphite – natural form of carbon; used for making electrodes and pencil leads *55–58, 72, 73, 79, 97, 104, 155*

Grossular – garnet resembling green gooseberries in color; contains calcium *125, 126*

Guinier-Preston zones – zones of solid solution in metals with a greatly elevated concentration of solute; they preserve the metal’s crystal structure *146, 147*

Gypsum, CaSO₄•2H₂O – mineral of the sulfate group. Forms colorless crystals as well as gray or white aggregates. Splits off water when heated, turning into hemihydrate gypsum. Gypsum congeals when water is added to it, slightly increasing in volume. This makes it a good material for copying sculptures (plaster casts) and for making rigid bandages in medicine. Gypsum is also used in construction, mostly for interior decorative work *18*

H

Halides – compounds of elements and halogens *115*

Halite, rock salt, NaCl – mineral of the chloride class. Its colorless cubic crystals are soluble in water. Also known as table salt *10*

Halloysite, Al₄[Si₄O₁₀](OH)8•4H₂O – clay mineral of the laminar silicate group. It has a similar composition to kaolinite, yet a higher water content *117*

Halogens – elements of the main subgroup of Group VII of the Periodic table (fluorine, chlorine, bromine, iodine, and astatine). They are typical non-metals and as simple substances act as powerful oxidizers (especially fluorine and chlorine) *96, 109*

Halotrichite, or feather alum, FeSO₄•Al₂(SO₄)₃•22H₂O – a rare mineral that forms yellowish silky fibers; soluble in water *14*

Hard porcelain – *cf.* Porcelain *27*

Hardness – the resistance of a material to indentation or scratching *20, 64–67, 113, 139, 155, 182*

Heat conductivity – the property of a material to transfer heat through its whole thickness from one surface to another if these surfaces differ in temperature *25, 137–139, 154*

Heat resistance – capacity of a metal to resist the chemical destruction of its surface under the action of air or other gaseous media at high temperatures *140*

Heliodor – transparent yellow variety of beryl *122*

Helium – chemical element with atomic number 2. This inert gas is the second lightest gas after hydrogen. Present in the sun in large amounts. Does not react *68*

Hermetic – impervious *91, 133*

Hessonite – honey-brown variety of grossular Hexafluorosilicates – salts of hexafluorosilicic acid H₂SiF₆ *125*

Hexagonal – consisting of six-sided cells, somewhat like a honeycomb *114, 127, 182*

Hiddenite – blue or green spodumene *117*

Holmium, Ho – chemical element with atomic number 67. This metal of the lanthanide group is very active chemically. Holmium compounds give glass a yellow hue *126*

Homogenous – uniform *28, 80*

Hood – part of a car, apparatus, mechanism, or device for binding and protecting, protruding and moving parts *55, 69, 82, 137, 142, 144*

Hornblende – a green to black mineral occurred in igneous and metamorphic rocks. Its most usual form is amphibole group, containing iron and various calcium, magnesium and aluminium silicates *117*

Hydrargillite – *cf.* γ-aluminium hydroxide *114, 116*

Hydration – addition of water *114*

Hydrochloric acid, HCl – aqueous solution of hydrogen chloride gas. It is one of the most widespread mineral acids. There is diluted solution of hydrochloric acid in our stomachs *19, 25, 28, 37, 64, 65, 110*

Hydrodynamics – branch of hydromechanics studying the laws of motion of liquids and the forces arising on the surfaces of bodies moving in liquids *77*

Hydrofluoric (fluohydric) acid, HF – aqueous solution of hydrogen fluoride. It can dissolve glass and is therefore stored in plastic bottles. Poisonous *44, 64, 95*

Hydrogen cyanide, HCN – a volatile toxic liquid with smell of bitter almond. It is used for the synthesis of polymers *122*

Hydrogen, H – chemical element with atomic number 1. Hydrogen is a gas without color, smell, or taste. Mixed with oxygen, it forms an explosive gas that releases water during combustion. Used as a reducing agent for producing metals from oxides as well as for synthesizing ammonia and hydrogenating fats. Hydrogen may serve as an automobile fuel in the future *10, 12, 25, 30, 31, 35–39, 68, 107, 110–112, 122, 127*

Hydrogeological conditions – the occurrence and distribution of groundwater *89*

Hydroxide salts – salts containing hydroxide groups *152*

Hydroxides – inorganic compounds containing elements along with oxide and hydroxide groups. Hydroxides are divided into acids, bases, and amphoteric hydroxides *114–116*

Hydroxyl group, hydroxyl – univalent OH group present in many chemical compounds *116*

Hydroxyls – *cf.* Hydroxyl group *116*

I

Incendiary mixture – a mixture used for firing. It consists of oxidizing and reducing agents (fuel) *111*

Incrustation – decoration of an object by figurative inlays of other materials to form an image that does not protrude from the surface of the object *18*

Indium, In – chemical element with atomic number 49. Indium is a white shiny soft metal. Its compounds are used in semiconductors *14, 36, 112*

Inert (noble) gases – poorly reactive chemical elements of the main subgroup of Group VIII of the periodic table (helium, neon, argon, krypton, xenon, and radon). No chemical compounds have been obtained for helium, neon, and argon *107*

Inert anodes – anodes that do not associate during electrolysis *98, 99*

Inertness – capacity of a material to withstand the action of different reagents *66, 118*

Ingot – a metal casting block that is alloyed or moulded piece of metal *10, 43, 52, 53, 57, 78, 81, 178*

Inner electron – the electron that atom cannot give away during the chemical reaction *105*,

Inorganic compounds – any compounds except for organic ones.

Inorganic substances – *cf.* Inorganic compounds *15, 107*

Intermetallic compounds – chemical compounds of metals (e.g., LiAg, LiHg, and LiAl) *102*

Iodine – chemical element of the halogen group with atomic number 53. This hard nonmetal has a metallic luster and is soluble in water and alcohol. Iodine vapor has a violet color. The alcohol solution of iodine is used in medicine *109, 112*

Ion – atom or group of atoms with an electric charge. Positively charged ions are called cations, while negatively charged ions are called anions *14, 36, 73, 104, 105, 115, 117, 121, 122, 126, 127, 137, 156, 158, 159*

Iron Scale – iron oxide Fe₃O₄ *25, 110*

Iron, Fe – chemical element with atomic number 26. This shiny silvery-white metal is malleable and ductile. Iron alloys such as steels and cast steels are widely used in modern technology *8, 10, 14–16, 20, 23–26, 30, 36, 37, 40–43, 46, 50, 54–56, 58, 59, 61, 63, 64, 67, 68, 70–74, 78, 79, 91, 92, 96, 68–102*,

108–111, 115, 117, 118, 120, 122, 123, 125–127, 130, 134, 135, 137, 140–142, 145, 147, 151, 156, 160, 175, 176, 203

Isolation – material that protects from electric current (electrical insulation), from the thermal exposure (thermal insulation), from the sound exposure (soundproofing) *45, 74, 92, 93, 99, 100, 110, 119, 146, 157*

Isolator – *cf.* Dielectric *146*

Isomorphism – the property of substances with similar chemical compositions of crystallizing in identical forms *15*

Isotopes – varieties of a chemical element that occupy the same cell in the periodic table yet have different atomic masses as a result of a different number of neutrons in the nucleus *106*

K

Kalinite – mineral; natural aluminium-potassium alum *12*

Kaolin – rock consisting of the mineral kaolinite. Kaolin is used as a filler in paper and rubber production and serves as a raw material for ceramics. Pure kaolin (“white clay”) is used in cosmetics and medicine *19, 25, 26, 114, 116–118, 121, 122*

Kaolinite, Al₄[Si₄O₁₀](OH)₈ – mineral, principal constituent of white clay; makes up the rock kaolin *25, 26, 116–118*

Kerosene – mixture of hydrocarbons, predominantly alkanes, with a boiling point in the range 110–320°C; used as a solvent and as a fuel in kerosene stoves and kerosene lamps *67*

Kyanite (disthene) – an aluminium silicate forming light blue scales. It is used for making refractory materials and electric isolators. Kyanite turns into mullite when fired *116, 125*

L

Labrador – mineral of the plagioclase group with a color ranging from gray and dark gray to black and with a bluish irisation *119*

Labradorite – rock containing the mineral labrador *119*

Lacquers – substances forming a thin transparent colorless or colored film

on the surface of an article when dry *189, 194, 198*

Lactic acid, – CH₃CH(OH)COOH – 2-hydroxypropanoic acid. Lactic acid forms in pickled cabbage and sour milk. It is an important intermediary product in the metabolism of animals, plants, and microorganisms *25*

Laminated foil – foil covered with a layer of plastic, e.g., polypropylene *133*

Laser – abbreviation of “Light Amplification by Stimulated Emission of Radiation.” Source of optical radiation with a high coherency and a high energy density *129*

Lava – red-hot liquid mass (sometimes very viscous) consisting of silicates and aluminosilicates. Expelled onto the earth’s surface during volcanic eruptions *19, 122*

Lazurite – blue or light blue mineral of the subclass of framework silicates. Used as an ornamental stone. Powdered lazurite has been used to make ultramarine *120, 121*

Leaching – extraction of certain constituents of a solid substance, usually with the help of water *42, 74, 91, 92*

Lead, Pb – a chemical element, atomic number 82. It is a bluish-grey, heavy, very plastic and soft metal (it is cut by a knife and scratched by a nail). Lead compounds are toxic. It is used in rechargeable batteries *8, 18, 19, 22, 23, 25, 31, 35*

Lepidolite – lithium mica. Consists of aggregates of short rosy-red or yellowish prisms, often with rounded faces. Used for producing lithium compounds *36*

Leucosapphire – white sapphire *115*

Lime – conventional name for calcium oxide and hydroxide *19, 24, 25, 27, 75, 80, 91–93, 152*

Lime milk – suspension of calcium hydroxide in water *92*

Limestone – sedimentary rock consisting of calcite, often with an admixture of dolomite, clay, and quartz sand. Used in construction. Limestone is fired to make unslaked lime *19, 72, 88, 92, 93, 166*

Liquid aluminium – impure metal that forms during electrolysis *99, 101*

Liquid phase or liquid – aggregate phase of matter that combines the properties of solid and gaseous phases; like solid bodies, liquids retain their volume, yet, like gases, they do not retain their form *15, 16, 30, 33, 35, 39, 42, 55, 75, 97, 99, 101, 108, 114, 117, 138, 143, 144, 145, 158*

Liquid state of substance – *cf.* Liquid phase *144*

Lithium, Li – chemical element with atomic number 3. Silvery white alkali metal. Reacts with water and enflames when heated in air. Lithium compounds make a flame turn crimson red. This leads to lithium being used in fireworks. It is also employed as an additive to alloys of light metals *35, 67, 73, 97, 117, 140*

Litmus – a coloring substance of plant origin whose solution turns blue in an alkaline medium and red in an acidic medium *115*

Litmus paper – strip of filtered paper permeated with a litmus solution; changes color in the presence of acids and alkalis *115*

M
Magnesium, Mg – chemical element with atomic number 12. Magnesium is a silvery-white lustrous, light, soft, malleable, and ductile metal. It dissociates water when heated, producing hydrogen, and displaces hydrogen from acids. Enflames when heated in air. Burning magnesium has a very bright flame, making it suitable for use in photography. Magnesium alloys are used in aeronautics *14, 24, 30, 33, 52, 60, 66, 67, 71, 81, 92, 93, 99, 111, 123, 126, 135, 140–142, 144, 145, 146–149, 154, 158, 191, 203*

Magnetic properties – the properties of substances and materials that determine their behavior in magnetic field (magnetic susceptibility, intensity of magnetization) *148*

Majolica – ceramics of colored fired clay with a porous body covered with glaze *27, 28*

Manganese, Mn – chemical element with atomic number 25. Heavy silvery white metal. Actively displaces hydrogen from

acids. Used as a reductant in the steel industry *10, 11, 14, 15, 66, 67, 96, 110, 115, 117, 122, 126, 135, 137, 140–143, 154, 175*

Mantle (Ancient Greek *mantion* – “cover, cloak”) – long cloak; ceremonial attire of monarchs, senior clergy, and, in some countries, judges, lawyers, and members of learned societies and academies *155, 176*

Marble – metamorphic rock consisting of calcite *24, 120, 124, 152, 162, 172, 176*

Mass number – sum of the number of protons and neutrons in an atom *106*

Mechanical properties – a set of the indices defining the ability of a material to resist the load acting on it, as well as the deformability of the material and its behavior during destruction. The mechanical properties are estimated in mechanical tests *65–67, 79, 102, 141, 145*

Mechanochemical polishing – a process for using the mechanochemical polishing abrasive to polish the surface of a hardened workpiece *14, 49, 141, 147, 157, 180, 186, 190, 197, 199*

Melt – a liquid state of some substance or mix, which is solid at room temperature *12, 24, 30, 52, 53, 55, 60, 72, 102, 112, 119, 127, 130, 133, 154*

Melting – a process that results in the change of a substance from a solid to a liquid. Metals are extracted from ore by melting in blast furnaces *25, 30, 55, 56, 63, 72, 73, 79, 81, 85, 97, 107, 108, 110, 127, 129, 130, 143, 145, 151, 175,*

Melting point – the temperature at which a substance passes from a solid state to a liquid, i.e., melts *52, 55, 56, 107, 108, 143, 145, 175*

Mendozite – a variety of sodium-aluminium alum; a rare natural mineral *12*

Mercury, Hg – chemical element, atomic number 80. Mercury has a silver-white appearance and it is the only common metal existing as a liquid at ordinary temperatures. It is used in thermometers. The vapor of mercury and its compounds is toxic and cumulative *16, 22, 25, 35, 36, 37, 38, 112*

Metal polymer – plastic material with metallic admixtures for improved strength and other properties *134, 138, 139*

Metallic aluminium – *cf.* Aluminium

Metallic radius – in a metal, the radius of an atom calculated on the base of the distance between the nuclei of the two nearest neighbor atoms in the solid *106*

Metallurgy – heavy industry engaged in producing (smelting) metal from ores and other materials, manufacturing alloys, and giving the desired shapes to metal stock by pressure treatment *18, 19, 66, 67, 72, 73, 75, 79, 85, 94, 95, 144*

Metals – simple substances with a number of common properties such as luster, ductility, malleability, and thermal and electrical conductivity *10, 12, 14, 22, 25, 27, 28, 30, 33, 35, 36, 41, 44, 46, 49, 50, 52, 60, 63, 64, 65, 67, 68, 71, 72, 73, 76, 95–95, 98, 99, 102, 106–112, 114, 117–119, 133, 135, 137, 139, 140, 144, 145, 160, 162, 165, 195, 199*

Methane, CH₄ – simplest compound of carbon and hydrogen. Key constituent of natural gas *10*

Mica – the general name of a group of layered aluminium silicates able to split easily into thin plates *118, 128*

Microscope – device producing enlarged images of small objects *38*

Mineral – natural body with largely homogenous chemical make-up and physical properties that is described by a chemical formula. Minerals are formed as a result of physical and chemical processes in the depths of the earth and on its surface *11, 12, 14, 15, 18, 19, 24, 25, 30, 36, 37, 41–44, 63, 66, 72, 76, 77, 81, 82, 89, 93, 94, 116, 117–120, 122–129, 139, 159*

Mineral acids – inorganic substances with the properties of acids *120*

Mineralogy – science studying minerals, including their make-up, properties, structure, and occurrence in nature *76, 77, 81, 124, 129*

Mining – extraction of ore, minerals, etc., from a mine. The mines could be 3.5–3.8 km deep *15, 18, 19, 35, 45, 71, 72, 76, 86–90, 106, 124, 125, 184*

Mining conditions – the structure and occurrence of ore, which influence a choice of mining method and a complex of

technical means of the development of ore deposit *86, 90, 125*

Mixed oxide – an oxide of more than one element *99*

Modern (from French *moderne* – “latest, contemporary”) – style in European and American art during the late 19th and early 20th centuries *162, 165, 170, 178, 181, 182, 186, 193, 199, 203*

Modification – qualitatively different state or variety of something *113, 114*

Moisture resistance – property of a material to resist the penetration of water *133*

Mold – metallic form for casting metal ingots *58*

Molding – the process of manufacturing the casting molds *162, 165, 168*

Molecule – smallest particle of a substance with its chemical properties *14, 105, 113, 114, 122, 156, 165*

Molybdenum, Mo – chemical element with atomic number 42. This transition metal is hard and refractory and reacts only with oxidizing acids. It is used as an alloying element to make very hard, corrosion-free, and refractory alloys *107, 127, 128*

Monochlorides – chlorides with the formula ECl *96*

Monocrystal – isolated crystal with a continuous crystal lattice; has a regular geometric form *115, 127*

Monoplane – airplane with one wing *77*

Monumental art (from Latin *monumentum* – monument) – type of fine art whose works are marked by considerable ideological content and generalized forms. It includes monuments; sculptural, painterly, and mosaic compositions for buildings; stained glass windows; urban and park sculpture; fountains; etc *175*

Morganite – rosy variety of beryl containing admixtures of alkali metals *122*

Mullite – aluminium metasilicate Al₆Si₂O₁₃ that forms during the calcinations of kaolinite; constituent of ceramics *26, 118*

Multiple glass pane, – composed of several glass sheets joined along the perimeter by a spacer frame. It is used for glazing

buildings and provides an insulated glazing *157*

Muscovite – aluminosilicate of the mica group. Forms colorless laminar crystals that are used as a dielectric in electrical and radio technology *116, 118, 119, 125*

N
Nacrite – a macrocrystalline modification of kolin. It is noted for the pearl reflection *117*

Nanometer (nm) – 10–9 meter *106*

Nanoparticle – a microscopic particle with dimension about a few nanometer *10*

Natrolite – an aluminium silicate of zeolite group. It forms colorless, but sometimes reddish or yellowish crystals *122, 123*

Neodymium, Nd – a metallic chemical element, atomic number 60. It is one of the lanthanides, rare earth metals. Neodymium is somewhat reactive. Neodymium shows typical properties of an active metal.

Neodymium is one of several metals in an alloy commonly used in aircraft construction *126*

Neon, Ne – a chemical element; atomic number 10. It is an inert *107, 196*

Nepheline – an aluminosilicate to form alkaline igneous rock. One of the sources to get aluminium *93, 94, 116, 120, 122*

Nesosilicates (island silicates) – silicates with isolated oxygen-silicon tetrahedrons *117, 122, 123, 125*

Neutron – an elementary particle with no net electric charge and atomic mass unit 1. It weights about 1 amu. Nucleus of all atoms (except the lightest isotope of hydrogen with mass number 1) contain them *11, 106*

Nickel, Ni – a metallic chemical element, atomic number 28. Nickel is silver-white metal, malleable and ductile. Many of nickel salts are green colored. It is used to protect steelworks from corrosion *65, 67, 99, 127, 140, 148, 166*

Nitrates – salts or esters of nitric acid *27, 110, 114*

Nitric acid, HNO₃ – colorless volatile liquid that is soluble in all proportions in water. Concentrated solutions of nitric acid gradually turn yellow or brown due to the disinte-

gration of part of the molecules of nitric acid. Nitric acid is a strong oxidizer. It reacts with metals without generating hydrogen, reducing to nitrogen oxides or molecular nitrogen. Metals can reduce highly dilute nitric acid to ammonium ions. Nitric acid is a key product of the chemical industry. It is used for making fertilizers, pharmaceuticals, explosives, and plastics *19, 48, 110, 149*

Nitrogen, N – chemical element with atomic number 7. Colorless gas without smell or taste. As a simple substance it exists as diatomic molecules. Such molecular nitrogen is a key constituent of air (78% by volume). Nitrogen does not support combustion and respiration and reacts poorly. In contrast, many nitrogen compounds are chemically active *12, 25, 28, 31, 107, 109, 112, 130, 133, 175*

Noble metals – metals that do not oxidize in air (such as gold, silver, platinum, and platinoids) *33, 50, 64, 90*

Noble spinel MgAl₂O₄ – natural mixed magnesium- aluminium oxide; large crystals are used in jewelry *115, 126, 127*

Non-ferrous metals – all metals with the exception of iron and its alloys *44, 94*

Nozzle – a device with one or several apertures for dispersion of a liquid *134*

Nuclide – a nuclear species which is characterized by the number of protons and neutrons which the atomic nucleus contains or energy state of the nucleus *106*

Nugget – a naturally occurring piece of a metal or few metals. There are just low-active metals, as gold, copper, silver and metals of the platinum group which can be found in nuggets *8, 10*

O
Octahedron – a regular polyhedron which has 8 triangle faces, 6 vertices and 12 edges. Octane – a saturated hydrocarbon that has formula C₈H₁₈; a colorless liquid with specific smell *14, 113*

Ocular – the eyepiece of an optical instrument used to magnify the image creating by the objective *35*

Oleum – fuming sulfuric acid, a solution of sulfuric anhydride SO₃ in sulfuric acid 35, 50, 64

Olivin, peridot – a silicate mineral with magnesium, iron and manganese in its composition. It is known as a refractory material. It forms large olive-green crystals of gem-quality (chrysolite) which are used for jewelry 124

Open-pit, or open mining – a method of extracting rocks or minerals from the earth by their removal from an open pit 90

Ore – metal-bearing mineral mass that can be profitably mined 18, 19, 20, 22, 42, 44, 55, 86, 87, 88, 93, 94, 96, 114, 124

Ore deposit – accumulation of ores that are suitable for mining on account of their high mineral content, accessibility, and economic profitability 16, 17, 22, 23, 42, 43, 44, 71, 73, 76, 77, 80, 82, 86–90, 114, 118, 120, 122–126, 128, 129

Organic compounds – organic compounds are carbon compounds except for the simple substance and its oxides, carbonic acid and its salts 107, 115

Organic substances – *cf.* Organic compounds 107, 126

Orthoclase – potash feldspar. It can be colored white, pinkish, yellow-brown. It is common constituent in granite 116, 119

Overhead crane – type of crane with a mechanism that runs along a horizontal beam that travels along two widely separated rails 145

Overhead passing – a bridge built over lowland, motorways or water bodies so that people and vehicles can cross from one side to the other, as well as passing engineering communications 150, 151

Oxalic acid, H₂C₂O₄ – simplest dibasic carboxylic acid. Its colorless crystals are highly soluble in water. This poisonous substance is a constituent of certain detergents 25

Oxidation – the loss of electrons by an atom or an ion 24, 106, 107, 112, 138, 154, 179

Oxidation rate – the oxidizing number i.e., the numerical value of the electrostatic charge attributed to an atom in a molecule, proceeding on the assumption that all links in the compound are ionic 107

Oxide – a chemical compound of oxygen and some other chemical element, where oxygen has oxidation rate 2 8, 10, 14, 15, 27, 28, 30–32, 41, 42, 56, 63, 74, 82, 91, 93, 96, 97, 99, 107–117, 120, 125, 127, 137–139, 143, 146, 151, 152, 154, 155, 157, 158, 180

Oxyfluoride – compound contains some element, fluoride and oxygen 99

Oxygen, O – chemical element with atomic number 8. In its simplest form oxygen consists of diatomic molecules. Oxygen is a key constituent of air. It supports combustion and the respiration of plants and animals. In industry oxygen is produced from air 8, 10, 12, 25, 28, 30, 31, 35, 36, 55–58, 63, 70, 96, 97, 107, 109, 112, 113, 116, 117, 119, 127, 133, 136, 154, 156

Oxyhydrooxide – compound that contain a metal and Oxy and Hydro groups 115

P

Pallet – a pan 135

Pallet placing machine, or palletizer – an equipment for automatic palettization of goods 135

Papermaker’s alum – aluminium sulfate.

Its colorless crystals are soluble in water. It is used for treating drinking water 30

Parallelepiped – a hexahedron with three pairs of parallel faces, it has 8 vertices, 12 edges 163

Patent – a formal document which certifies the authorship of inventors and their exclusive right to exploit the product or process they have created 45, 54, 55, 56, 57, 58, 59, 60, 61, 63, 67, 74, 75, 76, 91, 99, 104, 116, 136, 142, 162, 165

Patina (Italian *patina*) – film of varied colors (from green to brown) that appears on articles of copper, bronze or brass, as a result of corrosion or patination, when the article was heated or treated with some oxidizing agent 176, 177

Periodic table – chart of the elements arranged according to the periodic law discovered by Dmitri I. Mendeleev 3, 33, 36, 105, 106, 114, 140

Phase – an equilibrium state of a substance, which differs from other equilibrium states (other phases) of the same substance in its physical properties 53, 99, 140, 141, 143, 145

Phase, gaseous – *cf.* Gaseous phase

Phase, liquid – *cf.* Liquid phase

Phase, solid – *cf.* Solid phase

Phosphates – the salts and ethers of phosphoric acid 93, 115, 159

Phosphoric acid, H₃PO₄ – colorless crystals that are highly soluble in water. One of the most important mineral acids 28

Phosphorus, P – a chemical element, atomic number 15. It forms several elementary substances. One of the best known is red phosphorus painted on matchboxes. Burning phosphorus leaves bad burns on skin 25, 28, 31, 145, 159

Physical chemistry – the science explaining chemical phenomena and establishing their regularities on the basis of the general principles of physics 71

Physical properties – a set of the characteristics of the substance of which the material is made, including color, density, thermal conductivity and electroconductivity, temperature of fusion, etc. 5, 25, 108

Pickeringite, MgSO₄·Al₂(SO₄)₃·22H₂O – magnesia alum. A rare mineral, which is a fibrous mass of white or yellow color, soluble in water. It has no practical application 14

Pigment – a fine powdered substance which imparts color to plastics, rubber, paper, and used for producing oil-paints, printer’s inks, etc. 27, 28, 41, 117, 180

Piston – a cylindrical part tightly fitting and moving within a cylinder. It transforms mechanical work into energy of gas pressure or vice versa 68, 143

Plagioclase – sodium-calcic feldspars.

Plasma – gaseous mixture of negatively and positively charged particples in such proportion that the common charge is neutral 35, 156

Plastic – material made of polymer, with the ability to flow into a desired shape and keep it 119, 122, 134, 136, 151, 186–188, 190, 191, 195, 197, 199

Plasticity – the propensity of a material to undergo permanent deformation under load 25, 27, 102 117, 141, 191, 197

Platinum, Pt – metallic chemical element, atomic number 78. It is a precious metal of silver-white metal color. It is used as a catalyst 33, 35, 37, 38, 50, 52, 53, 63, 99, 127, 175

Pleochroism – the change of coloring of substances depending on the direction for propagation of light 122

Poles – the opposite ends of an electric circuit or a magnet 18, 55, 46, 108

Polyamides – synthetic polymer containing repeated amide groups. Capron is the wellknown among them 157

Polyethylene – a polymer of polymerized ethylene (hydrocarbon H₂C–CH₂) used for production of pipes, packaging, containers, disposable dishes 134

Polymer – a compound formed from repeated molecular groups 134, 135, 138, 139, 157

Polyurethanes – synthetic polymers containing the group NHCOO: used for production of varnishes, glues, etc. 157

Porcelain (china) – a water-proof substance that is made by heating clay. It is white on fracture and translucent if thin 25–27

Portland cement – a powder produced by fine grinding clinker and calcium sulfate (usually gypsum) with some additions. It is used as a construction material 152

Potash – potassium carbonate, used in glass manufacturing 23, 25, 27, 30, 31, 35, 37, 38, 93, 111, 114–116, 120

Potassium, K – chemical element with atomic number 19. This silvery-white alkali metal is very light, soft, and fusible. It actively reacts with water and enflames in air. Potassium compounds make a flame turn violet 12, 14, 15, 25, 30–39, 43, 45, 63, 73, 110, 111, 114, 115, 119

Powder metallurgy – production of refractory metals by sintering their powders using electric current 144

Praseodymium, Pr – metallic chemical element, atomic number 59. Praseodymium is a chemical active metal of lanthanide group. It is used as an addition for special steels and non-ferrous metals alloys 126

Precipitation – in chemistry – process in which a solid is separated from a solution 30, 55, 60, 91, 92, 44, 109, 110, 114, 115, 141

Press shears, or scissors – mechanically workloaded shears 154

Primary aluminium – aluminium obtained by the alumina-cryolite melt reduction 95, 100, 102, 108

Primary metal – metal made from ore 86, 102

Profile – a metallic billet with some special cross-section (corner, channel, double tee) 140, 143, 144, 152, 153, 154, 156, 157

Propeller, airscrew – a device which transmits power by converting rotational motion into thrust for propulsion of a vehicle 67, 69, 146

Proton – a positively charged (+1) elementary particle that is a fundamental constituent of all atomic nuclei. It has atomic mass about 1. The number of protons is the number of the element in the periodic table 11, 105, 106

Pulp – a mix of fine crushed ore with water 90, 91

Pumice – porous volcanic rock formed by the solidification of lava permeated with gas bubbles. It does not sink in water. Pumice is used is an abrasive and being poured as an additive for cement 15

Pump – device to lift, transfer, or increase the pressure of a fluid (gas or liquid) 91, 144

Punching – *cf.* Stamping 134

Purity of a metal – the index (in percentage) of impurity content in metal 46, 104, 108, 147

Putti (singular putto) – figures of babies, almost always male, often winged, found especially in Renaissance art 192

Pyrite, or fool’s gold – the disulfide of iron, FeS₂. It forms pale brass-yellow mineral cubic crystals . Pyrite chief use is as a source of sulfur in the manufacture of sulfuric acid 14, 19, 25, 94, 120

Pyrites – ores made up predominantly of sulfide materials. They are used as raw materials for producing certain non-ferrous metals such as copper, lead, and zinc, and sulfuric acid 18

Pyrope – a garnet of dark red color, contains magnesium. It is a gem 125, 126

Q

Qualitative make-up of a substance – set of chemical elements constituting a substance 107

Quantitative make-up of a substance – quantitative ratio of atoms of elements in a substance 107

Quartz – natural mineral, crystalline silicon oxide. Quartz forms large transparent crystals (rock crystal). Small quartz crystals make up fluvial sand. Quartz is used for the production of glass and concrete and as a building material 10, 25–27, 53, 63, 73, 74, 86, 90–94, 117, 125

R

Radioactivity – spontaneous transformation of the nuclei of some unstable isotopes into nuclei of other isotope 106, 120

Raw materials – *cf.* Minerals 8, 17, 19, 22, 23, 41, 42, 43, 44, 46, 71, 73, 74, 75, 76, 80–82, 86–89, 90, 93–95, 98, 101, 102, 114, 116, 117, 120, 125, 133, 135, 180

Reaction product – substances resulted by a chemical reaction 43

Reagent – a substance used in a chemical reaction 45, 151, 122

Recrystallization – a repeating crystallization of some matter from a solution or melt 104, **Rectifier** – device transforming alternating current into direct current 146

Reduction – acceptance of electrons by the atoms of a chemical element 38, 42, 44, 55, 61, 62, 63, 71, 72, 96, 99, 110, 111

Refining – the finer processes for separating impurities from materials in metallurgy, chemical industry, food industry, etc. 96, 104

Reinforced concrete – combination of concrete and a steel framework that are joined into one and work together in the structure 152, 162, 163, 166

Resinous substances – organic substances that congeal in air. Resins are viscous substances gradually hardening in the air 99

Rib – forming elements of the structure of a wing, emmenage and other parts of an aircraft to make them in the airfoil

shape. Ribs are attached to stringers, longerons and the skin of the aircraft is fastened to them. **γ** are the base *68, 200* **Rivet** – single-piece fastener *141, 145, 154, 155, 188*

Rock – a naturally occurring aggregate of minerals that have similar chemical compositions. By the processes that formed them they are separated into igneous, sedimentary and metamorphic. *8, 10, 11, 18, 19, 41, 81, 82, 93–95, 114, 115, 117–119, 122, 125, 128* **Rock salt** – *cf.* Halite *44*

Rollers – revolving cylinders in a roll mill *133, 183*

Rolling – shaping of metals by reduction with a pair of rolls of a rolling mill *102, 133, 137, 144, 153, 181, 188*

Rotor – a rotating part of an electrical device *109*

Rubbers – group of industrial polymers that are processed into rubber products *42, 119, 122, 135, 157, 188*

Rubidium, Rb – metallic chemical element, atomic number 37. One of the alkali metals. It is extremely reactive, combining violently with water and may ignite when exposed to air. This element is kept under kerosene, in a sealed vacuum tube *14, 36, 111, 115*

Ruby – a crystalline variety of corundum, containing minor impurities of chromium that colors it from crimson to red. It is used as a gem *115, 123, 126–129*

Rust – iron oxide-hydroxide(III), a brown-red coating that forms on the surface of iron or alloys when exposed to air and moisture *10, 12, 18, 54, 55, 64, 70, 79, 100, 101, 112, 161, 118, 123, 125, 127,*

Rusting – oxidation by atmospheric oxygen during the long-term storage or use of an article *24*

Rutile – a mineral of oxides, one of the forms of titanium dioxide. It is a source of titanium. SAA (sintered aluminium alloys) – the alloys sintered from an alloyed aluminium powder or granules *129*

S
Sand – *cf.* Quartz sand *23, 139, 152,172* **SAP (sintered aluminium powder)** – a powder produced from sintered

aluminium with participles of aluminium oxide to be uniformly distributed in *143* **Sapphire** – gem variety of corundum, colored in blue or pale blue by the addition of amounts of titanium and iron impurity *122, 115, 127*

Saturated solution – solution which is in equilibrium with solid phase *114, 115*

Scale – the product of iron oxidation in the air as a result of iron and ferro-alloys heating in the process of mechanical treatment *25, 110*

Scleron – aluminium alloy of zinc, copper, manganese, lithium, silicon and iron. It is applied in mechanical engineering and aviation industry *68*

Secondary aluminium – aluminium derived from the recycling of secondary materials (scrap metal) *94, 94, 102*

Secondary cryolite – cryolite made from recycled materials *101*

Seed – small particle of a substance introduced into a solution to induce crystallization *127*

Seismic activity – qualitative measure of the seismic setting determined by the average number of seismic centers in a certain energy range arising in the vicinity of the point under consideration per unit of space and unit of time *150*

Selenic acid, H₂SeO₄ – strong mineral acid that is a powerful oxidizer (an even stronger oxidizer than sulfuric acid) *14*

Selenium, Se – a chemical element, atomic number 34. It is grey nonmetal powder with metallic lustre. It has semiconductor properties. Selenium compounds are toxic *109*

Shale – a rock capable of splitting easily into thin plates *20*

Shell – case, box isolating the material within it from external factors *97, 149, 172, 187, 199*

Silica – silicon oxide. Usually the term “silica” refers to hydrated silicon oxide that forms through the disassociation of silicates by acids *30, 41, 42, 60*

Silicates – oxygen compounds of silicon *14, 22, 27, 42, 75, 76, 90–93, 95, 113, 116, 117, 119–125, 126, 138, 152, 158*

Silicides – compounds of metals with silicon *115, 141, 144, 145, 147*

Silicon, Si – chemical element with atomic number 14. This non-metal takes the form of gray fragile crystals with a metallic luster. It has semiconducting properties. It reacts with oxidizing acids and alkalis and is used as a semiconducting material (e.g., in solar cells) *10, 25, 41, 53, 67, 78, 79, 85, 90, 91, 102, 106, 116, 117, 119, 121, 125, 126, 135, 141, 142, 144, 145, 147, 175*

Silumin – aluminium casting alloy of magnesium, manganese and silicon *67, 84, 96, 145*

Silver, Ag – a chemical element, atomic number 47. It is a white plastic precious metal that takes a polish well. When stored for a long time in the air, it gets covered with a sulfide film and turns black. It is used in electrical engineering and jewellery *8, 15, 25, 33, 63, 70, 48, 49, 50, 108, 121, 151, 155, 175, 180, 191–197, 199*

Simple substances – substance consisting of atoms of one type *28, 102, 107*

Sintering – (dry) method of alumina recovery from bauxites – the method of the sintering of bauxites with limestone and soda and the subsequent leaching and carbonization *90, 92, 93, 143*

Siphon pipes – pipes through which liquids flows from a vessel with higher liquid level into a vessel with lower liquid level *42*

Slurry – a powder-like product containing, as a rule, precious metals that precipitate as a result of electrolysis of copper, nickel, zinc and other *138, 152*

Socialist realism – a literature and art method. It represents an aesthetic expression of the socialist concept of the world and man, which is determined by the epoch of struggle for the establishment and creation of the socialist society *178*

Soda – the general name of sodium carbonate and hydrocarbonate *16, 22, 25, 27, 30, 31, 35, 40, 42–44, 48, 60, 75, 80, 93, 95, 116, 120–122, 137*

Sodalite – aluminium silicate forming granular mass grey, dark blue or green in color. It is found in volcanic rocks and pegmatites *120*

Soderberg anodes – *cf.* Self-baking anodes *98–100*

Sodium (Latin Natrium) – a metallic chemical element; atomic number 11. Sodium is a soft, silver-white metal. It is one of the alkali metals. Sodium oxidizes rapidly in air and used as a reducing agent in chemical industry *11, 24, 30, 31, 33, 35, 43–45, 52, 53, 55, 56, 60, 63, 67, 73–75, 91, 92, 95, 97, 104, 110, 115, 120–122, 145, 177*

Soft porcelain – porcelain made of fusible silicate mass. it is similar to usual porcelain (hard porcelain) in appearance. It was made in Western Europe in the 16–18th centuries *27*

Solder – any of various alloys fused and applied to the joint between metal objects to unite them *64*

Soldering – the process in which two details metals are joined together by means of some melted alloy *64, 38, 191*

Solid fuel – a fuel in a solid state, e.g., coal, peat, slate coal, wood *142*

Solid phase, or solid, – such a state of aggregation of matter as the latter retains a stable form. There are amorphous and crystalline solids. The former has an ordered structure of atoms, and the latter, a chaotic one *19, 33, 35, 39, 42, 65, 74, 91–93, 95, 102, 108, 125, 142, 146, 152, 176, 183, 186, 191, 192*

Solid solution – a homogenous mixture of one or more substances which is in solid state. It could be exemplified by ferro-alloys *146, 191*

Solid state of substance – *cf.* Solid phase **Solution** – homogeneous mixture of two or more substances *53, 54, 56, 57, 60, 61, 62*

Solvent – a substance (a fluid or a mixture of fluids, generally) that dissolves another to form a solution. Well-known solvents are water, ethyl alcohol, chloroform, gasoline *12, 30, 42, 60, 62, 74*

Spar – the general name of thin-layered minerals. It comprises calc-spar, fluor-spar and feldspar *147*

Spectral analysis – a physical method of qualitative and quantitative determination of the atomic and molecular composition of a substance, based on its spectra *33, 35* **Spectroscope** – a device used for splitting light radiation into components with

various wave-lengths. An elementary spectroscope is a prism that disperses light into rainbow colors of visible radiation spectrum *35, 36*

Spessartine – garnet bright yellow to pink and orange in color. It contains manganese. It is found in pegmatitic veins *125*

Sphalerite – zink sulfide, the chief ore of zink *94*

Spindle – the rotating shaft of the metal-cutting machines with a product or cutting tool restraining device; a connecting shaft for transferring power from motor ro mill rolls; a driveshaft *135*

Spinels – compounds with the structure of noble spinel mineral *126, 127*

Spodumene – chain aluminium silicate. It is found in granitic pegmatites. It is the main lithium raw material *116, 117*

Spyglass – an optical device for examining distant objects *64, 50*

Stable isotopes – isotopes whose nuclei are not subject to radioactive decay *106*

Stained glass window – ornamental or figural decorative composition (in a window, door, or partition or as an independent panel) made of glass or other translucent material *120, 186–189*

Stainless steel – the steel containing about 12% of chromium. It is not liable to corrosion *139, 160, 184, 187, 188, 200*

Stamping (punching) – the making of relief images on a sheet metal, a stamping is a product with such an image *64, 134*

Staurolite – nesosilicate; frequently it crystallizes in the form of stars. It occurs in some shales *125*

Steam – water in the gaseous state at temperature which is lower than critical temperature *20, 59, 69, 90, 91, 93, 133, 145*

Steam engine – device for transforming the heat energy (pressure) of water vapor into mechanical work *59, 145*

Steam separator – a device to separate steam *91*

Steel – iron carbon alloy containing less than 2% of carbon. Usually it contains also additives of alloying elements *63, 66, 67, 96, 97, 102, 108, 109, 118, 134, 135, 137, 139, 142–145, 148, 149, 150–152, 154, 155, 160,*

162, 166, 171, 180, 182–184, 187, 188, 195, 197, 200

Stringer – the longitudinal stiffening rib of an airborne vehicle *147*

Strontia (strontianite), SrCO₃ – a mineral of the carbonate class. It forms colorless acicular crystals and beamy minerals. Strontianite, along with celestine (SrSO₄), is the main ore mineral of strontium *25*

Strontium, Sr – a chemical element, atomic number 38. It is a highly chemically active metal silver-white in color. It decomposes water with hydrogen liberation. Thanks to the fact that compounds of strontium paint a flame in red color, it is used for fireworks and salutes *30*

Sublimation – process of the transition of a solid substance into a gas without passing through the liquid phase. An example of sublimation is laundry drying in the cold: ice crystals in the fabric gradually turn into vapor without melting. Sulfates are salts and ethers of sulfuric acid. Sulfides are salts and organic derivatives of hydrogen sulphide *39*

Sulfur, S – a chemical element, atomic number 16. It is light-yellow fusible nonmetal powder insoluble in water. When heated in the air, it takes fire and emits suffocating sulphurous gas. Sulfur is used for vulcanization of rubber. In medicine it is a raw material for sulfuric acid production *115*

Sulfuric acid, H₂SO₄ – heavy oily liquid that is soluble in all proportions in water. To dilute it in water sulfuric acid should be poured in a thin stream into water while stirring intensely. Adding water to sulfuric acid can result in serious injury. Concentrated sulfuric acid is a strong oxidizer and a powerful dehydrant. Sulfuric acid is one of the key products of the chemical industry *110, 112, 114, 155*

Suspension – a colloidal system, with solid particles uniformly distributed in the liquid *92, 152, 158*

Suspension, in automobiles – system of details and mechanisms to join the bearing elements with the frame. Its principal purpose is to lessen the dynamic loads

and providing uniform distribution of the load *142, 143*

Synthesis – the process of producing chemical compounds *95, 127, 129*

T

Table salt – the sodium chloride *53*

Tank – a large structure for holding a liquid or gas *18, 19, 67, 69, 70, 85, 145, 170*

Tanzanite – a variety of zoisite, is aluminium nesosilicate grayish white to blue in color. Blue crystals are used in jewellery *122*

Tap holes – holes for emitting molten metal from a furnace *58, 101*

Teflon – a polymer. It results from polymerization of tetrafluoroethylene CF₂–CF₂. Fusion makes its surface smooth. It is nonflammable *138*

Test-tube – a tube sealed at one end used in laboratories *109*

Textile industry – the branch of industry producing fabric, yarn, knitted garments *20, 23,*

Thallium, Tl – a chemical element, atomic number 81. It is a glittering reactive metal grey in color. It liberates hydrogen from acids. Thallium and its compounds are very poisonous, which limits their use *14, 36, 115*

The refractive index of a medium – a measure for how much the speed of light (or other waves such as sound waves) is reduced inside the medium *35*

Thenard’s blue – cobalt aluminate CoAl₂O₄. It is a powder of blue color, insoluble in water, and decomposable by acids. It is used as a pigment in painting and ceramics manufacture *27*

Thermal decomposition – the breaking down of the complex substances in the process of heating *28, 91*

Thermal, or heat insulation – the protection of buildings and plants against undesirable thermal exchange with the environment *79*

Thermochemistry – part of physical chemistry, which studies the release and absorption of heat during chemical reactions *62, 71*

Three-phase circuit, a three-phase system – a set of three single-phase electric circuits (named phases) of alternating current, in which alternating voltage of the identical frequency are out of phase relative to each other *53*

Tin, Sn – metallic chemical element, atomic number 50. It is silver-white, metal, heavy, soft and malleable; it is used for soldering, and production the material for cans *25, 36–38, 64, 99, 105, 108, 135, 136, 147, 148, 175, 191–203*

Titanium nitride – one of the most stable and extremely hard compounds, with metallic color, slightly more reddish than gold *180*

Titanium, Ti – a chemical element, atomic number 22. It is a refractory low-density metal siver-white in color. It reacts with acids. Heated in the open air, powdered Titanium ignites. Ingots of the metal are practically not oxidized, though. It is used as an important structural material in aircraft and space engineering *10, 14, 15, 67, 91, 115, 120, 123, 127, 145, 18*

Topaz – nesosilicate of different colors. Transparent crystals wine-yellow, blue, and red in color are used in jewellery. It is found in granitic pegmatite. Topazolite is the rock formed by topaz *7, 115, 123–125*

Tourmaline – a mineral, boron-containing aluminium silicate of complex and variable composition. Beautiful colorful transparent tourmalines (pink or cherry-red rubellite, bluegreen Brazilian sapphire, etc.) are used in jewellery *115, 125, 126*

Transition metals – chemical elements whose atoms have incomplete inner electron shells; elements of secondary subgroups of the Periodic table *27, 100, 126*

Transmission – a device transferring mechanical energy from the engine to effectors of the machine or to other machines. Clutches, gearboxs, driveshafts and other gears in automobiles are named transmissions *142*

Travertine, or calcareous tuff – a porous cellular rock formed as a result of sedimentation of calcium carbonate from thermal or cold springs *172*

Trench coat – a raincoat. It was originally used in the Great Britain as an element of the military form in the World War I *200, 201*

Treasures of the soil, minerals – inorganic and organic natural materials which could be effectively used for production *7, 11, 12, 14, 15, 18, 30, 66, 72, 82, 94, 95, 116, 117, 119, 122, 125, 126, 128, 129, 139*

Tripod – a device that is used to support operating instruments *111*

Trusses (girders) – components of bar system of a floor with hinged joints *150, 151, 153, 154, 168, 188*

Turbine – an engine with a revolving rotor, which converts the motional energy of steam, gas, water into mechanical work *80*

U

Ultramarine – a pigment either green or dark blue, resulted from fusing kaolin, soda and sulfur together *121*

Ultramarines – a group of aluminium tectosilicates, found in the form of a blue-green mineral, lazurite *121, 122*

Ultra-violet radiation – electromagnetic radiation in a range of 400–10¹⁰ nm. It is invisible to the naked eye. Long-term exposure to ultraviolet radiation harmfully affects the human organism *126, 129, 133*

Urea – carbamide of carbonic acid, CO(NH₂)₂. White powder that is soluble in water. Gradually turns into ammonium carbonate in an aqueous solution. Used as a nitrogen fertilizer as well as in the plastics industry *19, 75, 166, 182, 199*

Urine – waste product secreted by the kidneys in animals and humans. Liquid with a pale yellow color with a characteristic taste and smell. Consists of water, mineral salts, urea, ureic acid, and a number of other substances *18, 19, 23, 28, 175, 192*

Uvarovite – chrome-containing garnet bright green in color. It is of no jewellery value because the crystals are small. It is a distinctive mineral of chrome iron ores *125*

Vacuum – highly rarefied gas at low pressure *28, 70, 97, 100, 101, 134, 135, 187*

Valence electron – the electron that an

atom can give away during the chemical reaction *106*

V

Vanadium, V – chemical element with atomic number 23. This steel-gray metal reacts with oxidizing acids. Many vanadium compounds have bright colors. Vanadium is added to special kinds of steel, e.g., for making armor *14, 110, 115, 123, 127*

Vapor – gaseous state of matter under conditions when a gas phase is in equilibrium with liquid or solid phases of the same matter *33, 35–37, 39, 40, 45, 52*

Vermiculite – aluminosilicate with a laminar structure. Water molecules are present between the layers, as a result of which vermiculate plates turn into wormlike columns when heated. This accounts for the mineral’s name (from Latin *vermiculus* “worm”). Vermiculite is used as a filler for rubbers, plastics, and paints and for soil amelioration in agriculture *118, 119*

Vinegar – 5–10% solution of food acetic acid. It is used for preparation of marinades *15, 16, 128, 138*

Viscosity – resistance of fluid bodies (liquids and gases) to the displacement of one of their parts with respect to another *141*

Volatility – measure of the capacity of a liquid or solid body to transform into a gas *44*

Volcanic lava – red-hot viscous silicate mass expelled onto the earth’s surface during volcanic eruptions *19*

Voltaic arc – *cf.* Electric arc *36*

Voltaic pile – several voltaic cells connected in series. This was the first chemical source of current with practical applications. The diskshaped electrodes in the voltaic pile are separated by pads made of spongy material (cloth or paper) saturated with an electrolyte *33, 53*

W

Water of crystallization – water contained in a crystalline substance *115*

Water, H₂O – key chemical compound of hydrogen and oxygen; occurs widely in nature *8, 12, 14, 15, 16, 18, 19, 20, 22, 23, 24, 25, 27, 28, 30, 31, 33, 35, 36, 37, 38, 39, 42, 43, 44, 45, 48, 49, 53, 56, 60, 62, 64, 65, 69, 71, 74, 80, 81, 90–92, 95, 97, 108–113, 115, 117, 121, 122, 124, 134, 137, 138, 140, 141, 145, 149, 152, 156, 158, 159, 180, 183, 184, 190, Weathering – disintegration of rocks on the surface of the earth or immediately underneath it by the action of temperature changes and the chemical and mechanical impact of water and the atmosphere *116, 118, 122, 123**

Welding – the process of the creation of permanent connection of machinery parts by heating their edges. Substances of welding surfaces mutually penetrate into each other in the place of contact. Welding is carried out by the arc welding technique, laser welding or cold welding techniques *110, 145, 146, 154*

White iron – steel sheet coated with tin; used for making packaging (tin) cans *134*

Wire – a slender, stringlike piece or filament of metal, circular, oval, triangle or polygonal in section *33, 35, 49, 65, 80, 81, 97, 102, 108, 115, 145, 146, 147, 155, 165, 180, 191*

Wire bars – aluminium or copper billets casted by the semi- or continuous method using the water cooled crystallizers *81, 83*

Wire rod – usually round hot rolled wire 5–19 mm diameter *147*

Wolfram, W – chemical element with atomic number 74. Gray-silver refractory and very hard metal. Used for making filaments in light bulbs and as an alloying element for strong and heat-resistant alloys *66*

X

X-rays – invisible electromagnetic radiation with a wavelength of 10⁻⁵–100 nm. Makes photographic film darken. Also, an image of an object on some light-sensitive material (a film or a photographic plate) created by x-rays *114*

Y

Ytterbium, Yb – chemical element with atomic number 70. This lanthanide metal is chemically active. It is added to certain

alloys. Yttrium garnets are widely used in electronics *126*

Z

Zeolites – a group of natural and artificial aluminium silicates. Their structure is a threedimensional skeleton with channels and cavities. Zeolites are used as a molecular sieve and catalysts *122*

Zinc, Zn – a chemical element, atomic number 30. Zinc is a silver-grey metal with weak bluish tint. It is used in some galvanic elements, and also for protection of steel products against corrosion (zincd iron) *22, 25, 33, 42, 64, 71, 79, 140, 141, 142, 147, 148, 154*

Zirconium, Zr – a chemical element, atomic number 40. It is very hard and refractory metal grey in color. It is used in nuclear reactors and also in the chemical instrument-making industry *141, 142*

Zoisite – *cf.* Tanzanite *122*

***α*-alumina**, corundum – the most stable form of aluminium oxide; occurs in nature *113, 114*

***γ*-Al₂O₃** – a form of aluminium oxide with a high surface area. It is used as a catalyst substrate. It turns into corundum when heated *114*

***γ*-AlOOH**, boehmite – a form of aluminium oxide-hydroxide *114–116*

***γ*-aluminium hydroxide**, gibbsite, or hydrargillite – crystal modification of aluminium hydroxide; occurs in nature *114, 116*

***γ*-aluminium oxide** – *cf.* *γ*-Al₂O₃ *113*

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