History of Astrophysics:
From Stellar Spectroscopy to Nucleosynthesis

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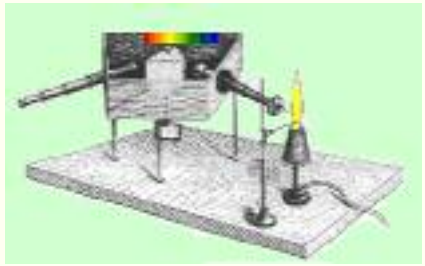
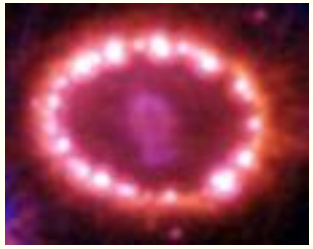


Detection and transmutation of elements:

Then

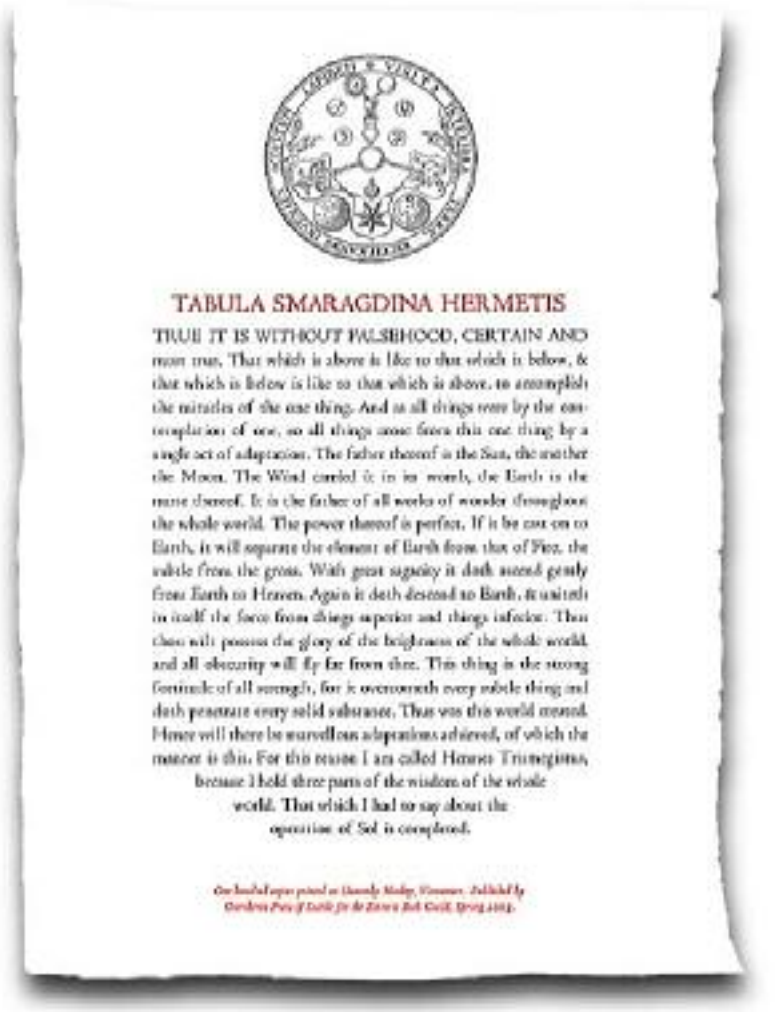
> Was die Sterne sind, wissen wir nicht
> und werden es nie Wissen! ?
> Heinrich Wilhelm Dove, um 1860



and now.

Introductory remark

Quod est superius est sicut id quod est inferius.



TABULA SMARAGDINA HERMETIS

TRUE IT IS WITHOUT FALSEHOOD, CERTAIN AND most true. That which is above is like to that which is below, & that which is below is like to that which is above, to accomplish the miracles of the one thing. And as all things were by the contemplation of one, so all things arose from this one thing by a single act of adaptation. The father thereof is the Sun, the mother the Moon. The Wind carried it in its womb, the Earth is the nurse thereof. It is the father of all works of wonder throughout the whole world. The power thereof is perfect. If it be cast on to Earth, it will separate the element of Earth from that of Fire, the subtle from the gross. With great sagacity it doth ascend gently from Earth to Heaven. Again it doth descend to Earth, & uniteth in itself the force from things superior and things inferior. Thus thou will possess the glory of the brightness of the whole world, and all obscurity will fly far from thee. This thing is the strong fortitude of all strength, for it overcometh every subtle thing and doth penetrate every solid substance. Thus was this world created. Hence will there be marvellous adaptations achieved, of which the manner is this. For this reason I am called Hermes Trismegistus, because I hold three parts of the wisdom of the whole world. That which I had to say about the operation of Sol is completed.

There is a long tradition in regarding everything in the world as highly interconnected, a **“Holistic View”.**

Alchemy, astrology, medicine were part of the **“Hermitean philosophy”,** as compiled in the Gnostic **“Corpus Hermeticum”.**

Up to the 19th century, the vast majority of scientists took part in these believes (not all in public).

Hermes Trismegistos

Uraniborg: astronomy and alchemy

Then came the time of specialisation!

Now we start “interdisciplinary institutes” like JINA or VISTARS in order to bring together scientists from different specialised fields of research.

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Age-old wisdom?

Ibis-headed Thoth
Patron of the scribes

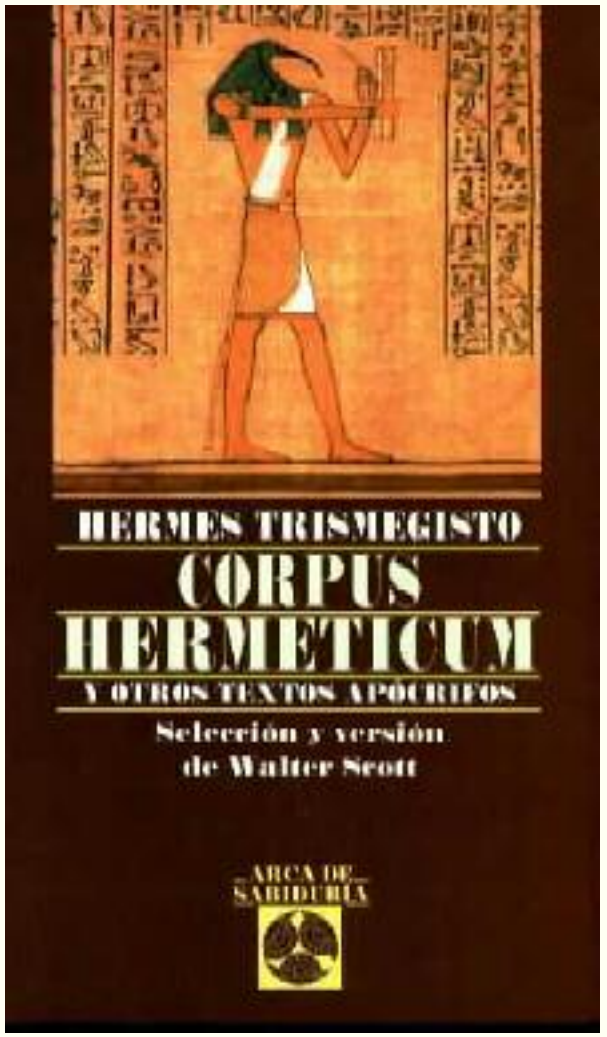
Esoteric circles pretend that their “wisdom” can be traced back at least to the beginning of Egyptian history (the pessimistic view, optimists date it at least to Atlantis, as the followers of Edgar Cayce, the “Sleeping Prophet” and his “Hall of Records” under the paws of the Sphinx at Gizeh).

The Tabula Smaragdina and the Corpus are based on Gnostic texts of late Hellenistic era which seem to have originated in Alexandria. Might-be these texts preserved (lost) teachings from Pharaonic times. They are a syncretism of neo-platonism, judaism, mystery religions etc.

Imhotep, c. 2700 BC
Architect of the step-pyramide of Djoser

The Tabula can be traced back to Arabic texts which give as origin the Jewish community of Alexandria.

The texts of the Corpus were lost to Europe. In the actual form, they were composed at the court of Cosimo de Medici in the beginning of the 15th century.



1945 near Nag Hammadi were found original Coptic texts. Codex VI contains 3 hermetic texts.

13 of the 18 books can be found at http://www.gnosis.org/library/hermet.htm

Codex II contains the “Gospel of Thomas”. It has not been canonized, perhaps because its emphasis on individual spirituality apart from the Church was deemed contrary to the interests of organized religion.

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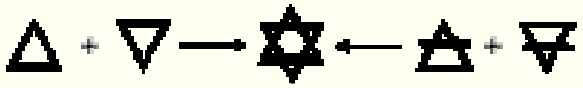
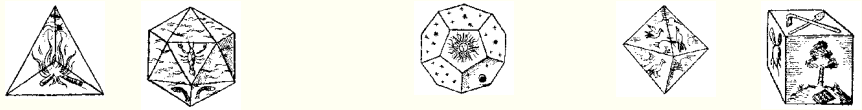
Since a long time, humans try to understand the world surrounding them.
One way is to **dissect complex structures** and search for **simpler, basic constituents**.

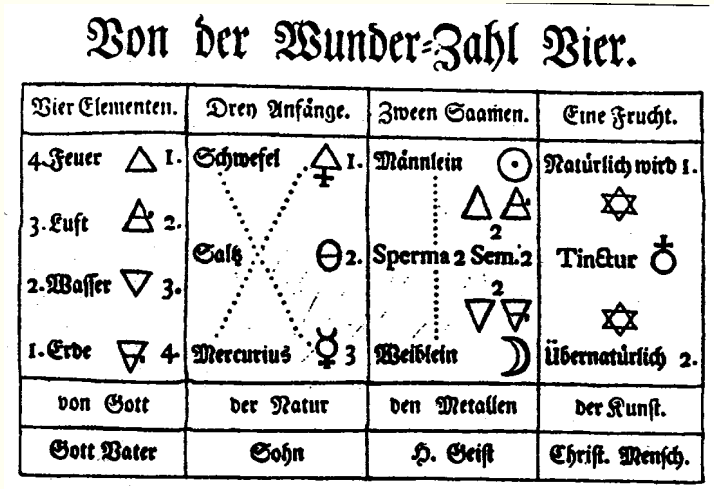
Already in the 5. century B.C., Empedokles of Agrigent assumed that all material things are composed of only **four basic constituents**, the elements **earth, water, air and fire**.

Aristoteles added a fifth element:



Fire Water **Quintessence** Air Earth





Geheime Figuren der Rosenkreuzer (1758)

For some natural philosophers the “atoms” of the elements corresponded to the five regular Platonic bodies.

An element is a body into which other bodies may be analysed, present in them potentially or in actuality (which of these, is still disputable), and not itself divisible into bodies different in form.
Aristoteles, *On the Heavens and Earth*, Book III, Chapter 3

The alchimists believed that elements can be **transmuted, not created!**
So there was no theory of the
origin of elements.
Also in most cosmogonies, the act of creation only introduces **order into chaos**.

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Medieval university textbook for beginners

THE FOUR ELEMENTS. –
The machine of the universe is divided into two, the ethereal and the elementary region. The elementary region, existing subject to continual alteration, is divided into four. For there is earth, placed, as it were, as the center in the middle of all, about which is water, about water air, about air fire, which is pure and not turbid there and reaches to the sphere of the moon, as Aristotle says in his book of *Meteorology*. For so God, the glorious and sublime, disposed. And these are called the "four elements" which are in turn by themselves altered, corrupted and regenerated. The elements are also simple bodies which cannot be subdivided into parts of diverse forms and from whose commixture are produced various species of generated things. Three of them, in turn, surround the earth on all sides spherically, except in so far as the dry land stays the sea's tide to protect the life of animate beings. All, too, are mobile except earth, which, as the center of the world, by its weight in every direction equally avoiding the great motion of the extremes, as a round body occupies the middle of the sphere.

"De Sphæra", Chapter I, Iohannes de Sacrobosco, early 13th century

Translated by Lynn Thorndike, 1949

http://www.esotericarchives.com/solomon/sphere.htm

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This book contains not a single formula. It was in use for centuries.

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Prelude

Transmutation at the Oklo natural nuclear fission reactors

Fossil Reactor 15, located in Oklo, Gabon (West Africa).

Already about 2 billion years ago, some natural nuclear reactors were working in Oklo in Gabon.

Oklo by-products are being used today to probe the stability of the fundamental constants over cosmological time-scales and to develop more effective means for disposing of human-manufactured nuclear waste.

About the fundamental constants, you may ask our lecturer Peter Möller, coauthor of Y. Fujii et al., Nucl. Phys. B573 (2000) 377.

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http://www.physics.isu.edu/radinf/oklo.htm

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A little bit of local color: Johann-Joachim-Becher Weg on Mainz Campus

J. J. Becher, 1635 – 1685
Prof. Dr. med. 1663 Mainz
Kommerzienrat Wien 1666

Astrophysics deals a lot with "metals".
Already the alchemist's main concern was the transmutation of metals, especially to silver and gold.
The general conviction was that this transmutation occurs naturally over extended time spans in metalliferous lodes.
One proof was the observation that silver often is contained in lead veins.
The task of the alchemist was to reproduce the natural process in the laboratory in much shorter time. As a sort of "catalyst" the "Philosophical Stone" was sought for.
[It should also cure all illnesses and endow eternal life.]

J. J. Becher,
Natur-Kündigung der Metallen,
Frankfurt, 1661.

A more or less positive example of a late alchemist is Professor Becher. He has written many books on alchemy (partly on demand), starting with "Metallurgia Becheri" in 1660. He was called to the Imperial Court in Vienna 1666 as the head of a new commission to further industry. In reality, he alone was the commission and his main task was to study claims of itinerant alchemists to "make gold".
And astonishingly, he himself found a receipt to make gold from the alluvial sand of the Vienna region and silver. As has been the case with many examples before, the gold was finely dispersed in the sediment, invisible to the unaided eye, and/or in the silver! The Brabant Talers used in a demonstration in Holland contain a little gold.
[In 1936 a large-scale extraction was started.]

J. J. Becher,
Opuscula chymica rariora,
Nürnberg, 1719

Becher proposed that "terra pinguis" (fatty earth) was present in all flammable materials; this substance was given off during burning and the resulting ash was the true material. Georg Stahl developed from this the **"Phlogiston Theory".** [He is also the founder of the "Animistic Medecine":*The True Theory of Medicine* (1708).] Phlogiston was quite influential.
J. Priestley called oxygen "dephlogisticated air" (1774), and the "Carnot Cycle" was based on it: Sadi Carnot, *Réflexions sur la Puissance Motrice du Feu* (1824).

After a tumultuous life he died impoverished in London where he lies buried close to Robert Boyle in "St. Martin in the Fields" near Trafalgar Square.

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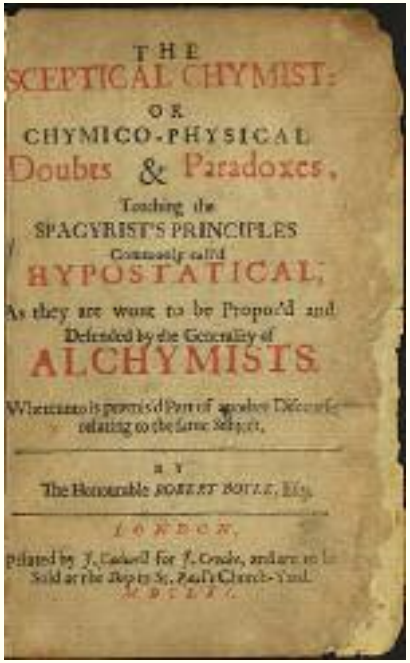
From alchemy to chemistry


THE
SCEPTICAL CHYMIST:
OR
CHYMICO-PHYSICAL
Doubts & Paradoxes,
Touching the
SPAGYRIST'S PRINCIPLES
Commonly called
HYPOSTATICAL;
As they are wont to be Propos'd and
Defended by the Generality of
ALCHYMISTS.
By
The Honourable ROBERT BOYLE, Esq.
LONDON,
Printed by J. Cadwell for J. Crooke, and are to be
Sold at the Sign of the
Robert Boyle, 1661

The transition from alchemy to chemistry was a long process. Modern historians like to find **"the decisive moment".** In the text books, it was Boyle's "Sceptical Chymist" and the "Doubts & Paradoxes Touching the Spagyrist's Principles" formulated therein. But these historians have (or want to) overseen that Boyle's concern regards the many charlatans and impostors benefiting from the cryptic hermitean language of the alchemists. He calls for an **intelligible notation**, so that untaught windbags no longer find an audience. One of his concerns was to clarify the definition of elements, which resulted in renouncing the "Four-Element" theory as not verifiable by experiments.
But he was convinced of transmutation of the elements!


Boyle, ca. 1705

http://oldsite.library.upenn.edu/etext/collections/science/boyle/chymist/

$$p_1 \cdot V_1 = p_2 \cdot V_2$$

Law of Boyle-Mariotte

Boyle's work on gases is well known. It was possible due to the development of effective air pumps by Robert Hooke. It is less known that Hooke communicated his assumption of an inverse square law for gravitation to Newton. Once, Hooke, Wren and Halley discussed orbits of planets in a London pub and sent Halley to Newton, who then convinced him to publish the "Principia".
Later, Newton burnt the only known portrait of Hooke.


NEW
EXPERIMENTS
PHYSICO-MECHANICAL,
Touching
The Spring of the Air, and its Effects,
(Made, for the most part, in a New
Pneumatical Engine)
Written by way of
To the Right Honorable CHARLES Lord
Viscount of DUNGARVAN,
Eldest Son to the Earl of CORK.

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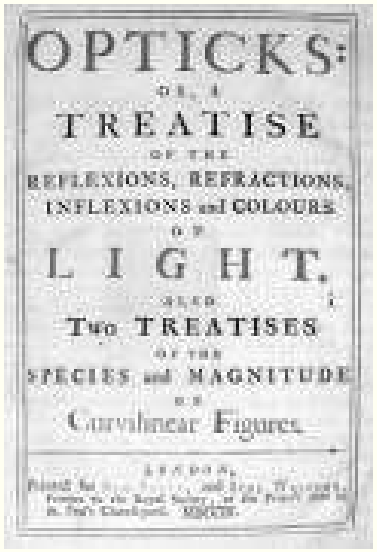
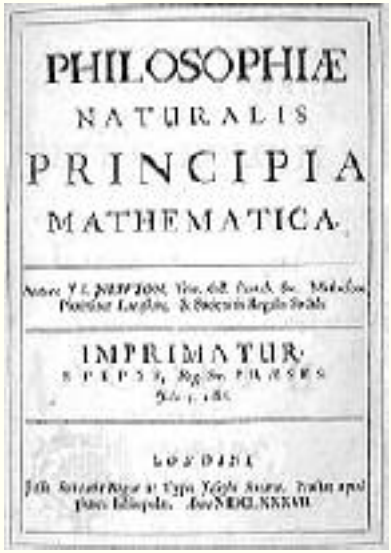
The transitional character of the 17/18th centuries is personified in Sir Isaac Newton

Alchemist, theologian (anti-trinitarian heretic?), astronomer, chronologist, prophet of doomsday (A.D. 2060)
and scientist
(even as an alchemist)

J. Vanderbank (1726)

Many of his remaining notices were sold by his family 1936 by Sotheby's and are dispersed in many collections.
Quite a number are still unpublished!





Not "the first of the age of reason", but rather "the last of the magi"?
J.M. Keynes, 1946

Newton intended to develop an
“exact alchemy”,
an alchemy arranged according to
“number, quantum and weight“.

(All masters of the mint had to perform quantitative chemical analysis of Ag and Au since a long time.)

After Demokrit and Epikur, matter was composed of varying parts of particles and empty pores, leading to different specific weights.
One of the tasks in making gold was therefore to augment the density.

Newton never published his experiments, he feared that they might lead to **unforeseeable consequences**.
(Letter to R. Boyle 1676)

A result of his experiments is Newton‘s Alloy (Pb, Sn, Bi 5:3:8) with a melting point of 96° C.

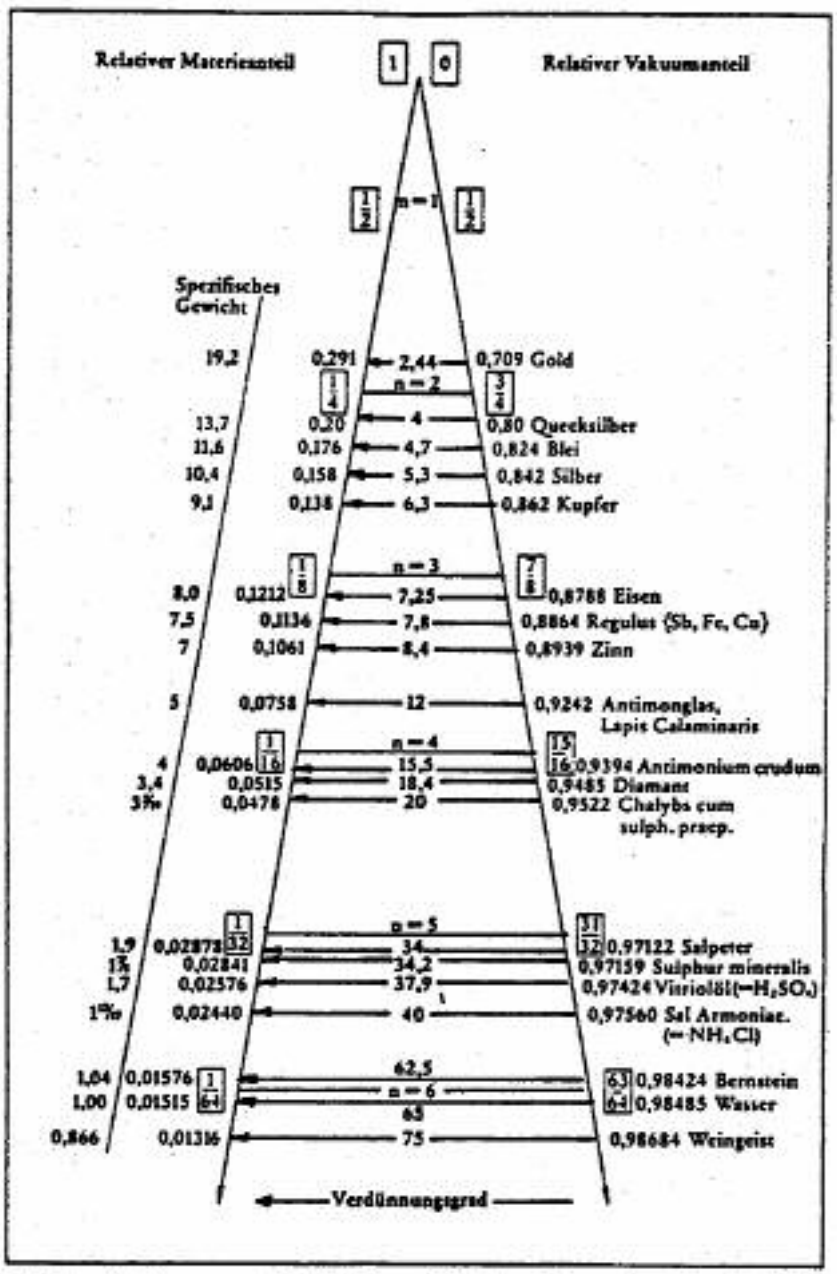


Abb. 90. Verdünnungsgrad der Stoffe nach Newtons Kompositonstheorie. Links sind die spezifischen Gewichte angegeben. (Aus: Figala, 1964, S. 168)

Periodic system of the elements

Over time, the (al)chemists had discovered more than the 4 (5) classical "elements".
Their cryptic works are difficult to understand and often their names stand for compounds or even more general principles:

- "antimony" was Stibnit (Sb_2S_3),
- the element Sb was known as "antimony regulus"

Modern chemistry is said to begin with R. Boyles "*The Sceptical Chymist*" (1661), where he found no confirmation of the "Four-Element" theory.

Decisive was the shift from "quality" to "quantity", the use of precise balances.

T. Norton, *Ordinall of Alchemy*, 15th cent.

Remark: It was difficult to find balances on old depictions of medieval laboratories.

J.L. Proust (1794) and J. Dalton (1804) recognised that elements combine only in **fixed relations** corresponding to even numbers.

As an explanation, Dalton revived Demokrit's atoms:
A New System of Chemical Philosophy
J. Dalton, 1808

Based on these principles, 1868/9 D.I. Mendeleev and L. Meyer developed the Periodic System of the Elements.

TABELLE II

REIHEN	GRUPPE I. — R^2O	GRUPPE II. — RO	GRUPPE III. — R^2O^3	GRUPPE IV. RH^4 RO^2	GRUPPE V. RH^3 R^2O^5	GRUPPE VI. RH^2 RO^3	GRUPPE VII. RH R^2O^7	GRUPPE VIII. — RO^4
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —

Figure 2.5 Dmitri Mendeleev's 1872 periodic table. The spaces marked with blank lines represent elements that Mendeleev deduced existed but were unknown at the time, so he left places for them in the table. The symbols at the top of the columns (e.g., R^2O and RH^3) are molecular formulas written in the style of the 19th century.

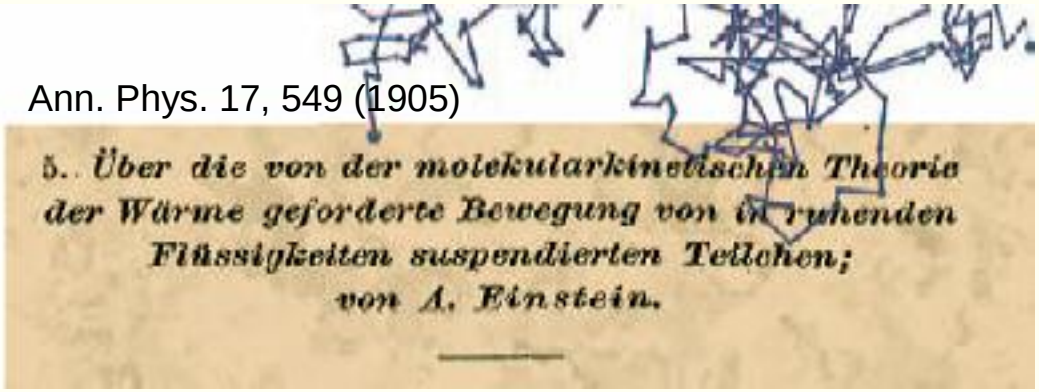
Acceptance of atoms

Until the beginning of the 20th century the existence of atoms was denied by many scientists. The breakthrough was one of the 3 articles of Einstein on Brownian motion in his “annus mirabilis” 100 years ago.

Der Botaniker Robert Brown (1773–1858), hier auf einem Gemälde von Henry Pickersgill, erforschte 1828 die zufällige Zitterbewegung von kleinen, in einer Flüssigkeit suspendierten Teilchen. (Quelle: National Library of Australia)

Ludwig Boltzmann (1844–1906, li.) und Ernst Mach (1838–1916, re.) gehörten zu den wichtigsten Akteuren in der Debatte um die Existenz der Atome. Mach bestritt die Existenz von Entitäten, die der Sinneswahrnehmung nicht direkt zugänglich sind, Boltzmann vetrat eine atomistische Position. (Quelle: Deutsches Museum).

Ann. Phys. 17, 549 (1905)



5. *Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen;*
von A. Einstein.

J. Renn
“Die atomistische Revolution”
Physik Journal 3 (2005) 53

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But what about the nature of the heavenly bodies?

Most people worshipped the stars (including the planets) as their gods.

Natural philosophers from the Greek cities in Asia Minor (Persian satrapies) had contact to all parts of the Persian Empire as Mesopotamy and Egypt.
They started to divert from this view.

Anaxagoras (ca. 500-428 BCE) introduced this philosophy to Athens.
He taught that the stars are not different from Earth. After the meteorite fall of Ægos Potamoi 467 BCE, he behold the Sun as a red hot ball of rock the size of the Peloponnes.
He was accused of impiety and only due to political protection from Pericles escaped death penalty.

Aristoteles later stated that there is a
strict separation of the **sub- and translunar** worlds.

Whereas the Earth is composed of the four elements, the planets and stars are made of quintessence (ether).

The teachings of Aristoteles, the Spagyrist, dominated Natural Philosophy for more than a millenium. Critical views on Aristoteles are regarded by many historians as the first step to science.

Apianus, Cosmographia (1524)

Extraterrestrial Matter

Men has used since long time extra-terrestrial materials, as iron from meteorites or the extremely seldom “lybian desert silicate glass”, as evidenced by an iron dagger and a scarabaeus in the tomb of Tuth-ankh-amun.

Under the lasting influence of Aristoteles science denied the cosmic origin of meteorites. In 1772, a committee of the French Academy of Science headed by Lavoisier “explained” the fall of Lucé 1768 as a stone hit by a stroke of lightning:
“…que ce sont des pierres ordinaire frappées par la foudre, ***malgré*** *les témoignages de personnes* ***dignes de foi****….”*

A first indication gave the high Ni content of the Pallas meteorite.

Über den kosmischen Ursprung der Meteorite und Feuerkugeln
E.F.F. Chladni, Riga, **1794**

And in 1803 J.-B. Biot was sent to L‘Aigle to inquire about a new meteorite fall. His report ends with:
“Il est tombé des pierres aux environs de L’Aigle le 6 Floréal an 11”

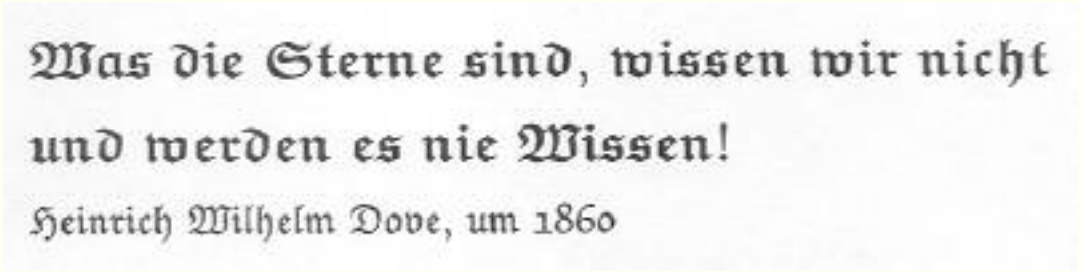
Remark: On **June 16, 1794**, a group of young English travellers witnessed the fall of the Siena meteorite. Unfortunately, a day before there had been an eruption of Vesuvius.
Conclusion: Stones may fall from the sky, but they are of terrestrial origin.

Can we now determine the nature of the heavenly bodies?

„Parmi les trois sens propre à nous faire apercevoir l'existence des corps éloignés, celui de **la vue est evidemment le seul** qui puisse être employé relativement aux corps célestes: ….
Nous concevons la possibilité de déterminer leurs formes, leurs distance, leurs grandeurs et leurs mouvements; tandis que **nous ne saurions jamais étudier par aucun moyen leur composition chimique, ou leur structure minéralogique**, et, à plus forte raison, la nature des corps organisés qui vivent à leur surface, etc. …"

Auguste Comte (1798 – 1857), Cours de Philosophie Positive, 6 Vol., 1830-1842

Or less philosophical:



End of a discussion on new methods in astronomy between Friedrich Zöllner and Dove in "preussischem Korporalston".

F. Zöllner, Wiss. Abhandlungen, Vol. 4, Leipzig 1881, p. 35

Beginning of stellar spectroscopy

Fraunhofer, an instrument maker, applied the dark lines in the solar spectrum primarily as standards for characterising optical devices (as the refractive index of glasses).
Experiments with diffraction gratings 1819 yielded precise wavelengths.

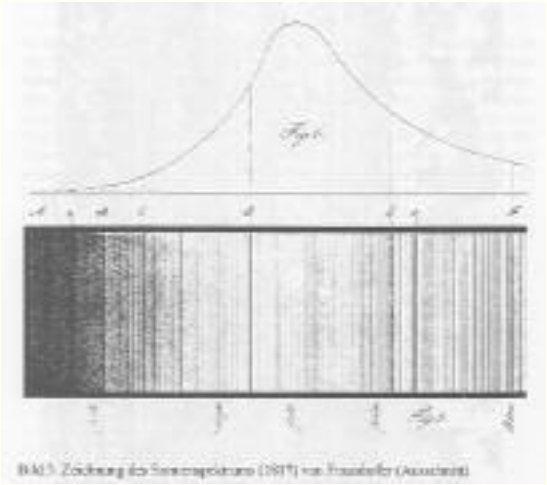


Tabelle 1: Fraunhofers spektroskopische Beobachtungen mit seinem 10 cm-*Prismafernrohr*, oben: cf. [5], unten: Ergänzungen cf. [4]

Stern/Planet	Bemerkung	Typ	V
Mars, Venus	Linien wie im Sonnenlicht, am gleichen Ort (D, E, b, F)	-	-2.02, -4.4
Sirius/ α CMa	Im Orange und Gelb keine fixen Linien; im Grünen ein sehr starker Streifen und im Blauen zwei andere ungemein starke Streifen, keine Ähnlichkeit mit Planetenspektrum	A1 V	-1.46
Castor/ α Gem	Spektrum gleicht dem des Sirius, Messung des Streifens im Grünen: gleicher Ort wie bei Sirius	A1 V	1.59
Pollux/ β Gem	Viele schwache Linien, die wie bei der Venus aussehen, Linie D sehr gut zu erkennen, gleicher Ort wie bei Planeten	K0 III	1.14
Capella/ α Aur	An den Orten D und b dieselben fixen Linien wie im Sonnenlicht	G5 III+ G0 III	0.08
Beteigeuze/ α Ori	Zahlreiche fixe Linien, D und b identifiziert	M1.5 Iab	0.50
Procyon/ α CMi	Einige Linien mit Mühe zu erkennen, möglicherweise D im Orange	F5 IV-V	0.38
Sirius/ α CMa	*Gegens Ende im Roten eine Linie sehr gut zu erkennen (5.4.1819). Im Orange und Gelb keine fixen Linien. Ein großer Streifen am Ende des Grünen (März 1819), mit F der Venus an einem Ort (5.4.1820). Zwei Streifen im Blauen (März 1819). Ein breiter Streifen noch tiefer im Blauen (15.3.1819). Messung der Abstände des Streifens im Blauen von der Linie D des Venusspektrums (26.3./30.3./5.4.1820).*	A1 V	-1.46
Rigel/ β Ori	*Scheint viele Streifen zu haben*	B8 Ia	0.12
Algol/ β Per	*In dem veränderlichen Stern sah ich mit Mühe, daß er einige Linien enthält. Ich glaube am Ort D etwas gesehen zu haben.*	B8 V	2.12

Fraunhofer observed also planets and brilliant stars up to 1820.
He already noticed that the dark D lines correspond to two intense emission lines in flames.

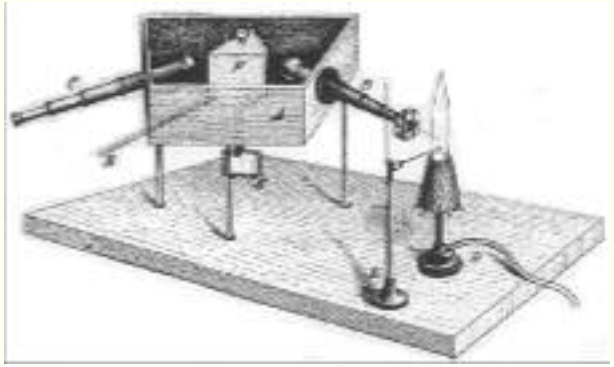
But his experiments were not followed up by astronomers.

They were still mostly interested in precise position measurements, not in the nature of stars.

The beginning of astrophysics

In 1859, Kirchhoff explained the idendity of dark Fraunhofer and bright lines in flames as

absorption and emission of light by chemical elements.



1860. ANNALEN №. 6.
DER PHYSIK UND CHEMIE.
BAND CX.

I. *Chemische Analyse durch Spectralbeobachtungen;*
von G. Kirchhoff und R. Bunsen.

Seiten 161 - 189

This time, the new technique was immediately applied by astronomers. In 1863 first results were published by A. Secchi from the Collegio Romano and two well-equipped amateur astronomers: L.M. Rutherford (New York) and W. Huggins (London)

During a solar eclipse in India August 18, 1868, Jules Jansen observed in the corona a line not known in any one of the (then) known elements: **Helium**

Kirchhoff und Bunsen

Some other elements were postulated later-on by astronomers as Coronium and Nebulium.
Coronium is highly ionized iron, Nebulium are forbidden transitions in nitrogen observed in clouds as the Orion nebula.

Law of conservation of energy

Anaxagoras of Clazomenae (500-428 BCE): “Ex nihilo nihil”
“Nothing can be generated out of nothing and nothing can be annihilated”

René Descartes (1596-1650):
“The overall sum of all products of *quantitas materiae* and velocity in the world is constant”

J.R. Mayer
„Bemerkungen über die Kräfte der unbelebten Natur“
Liebigs Annalen der Chemie und Pharmacie, 1842

H. Helmholtz
„Über die Erhaltung der Kraft“
Physikalische Gesellschaft, Berlin, 1847

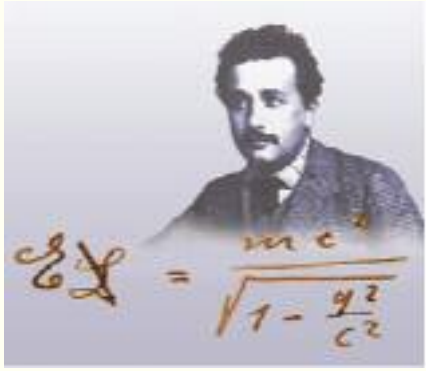
The Annalen at first refused to publish this article. The observations of different colours of venuous blood in Europe and in Batavia as basis and a reasoning according to (hermitean) philosophy were no longer regarded scientific.

Energy source and content of stars?
How long can they shine?

- Chemical reactions: burning of carbon lasts for several thousand years
  Mayer 1842 (the last age estimate in accordance with Scripture)
- Gravitational energy: Helmholtz (1854) / Lord Kelvin ~20 million years
  (now timescale for proto-stars)

It is to mention that for a long time the Earth was much older than the stars!

Cooling experiments:
- G. Buffon ~75000 years
- Lord Kelvin 1862 ~400 million years



New physics around 1900:
1896 discovery of radioactivity by H. Becquerel
1905 Einstein
1903 G. Darwin and J. Joly: contribution of radioactivity to heat content of Earth, much longer cooling times
1907 B. Boltwood: Pb/Th/U chronometry of rocks, up to **2.1 Gy**

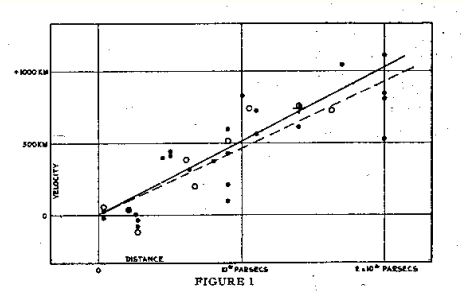


FIGURE 1

To be compared with the original „Hubble time“ of **1.5 Gy** derived from a Hubble constant H = 500 km/s/Mpc

VISTARS

Reactions to post-Newtonian physics in the last century

Many scientists disliked (or even refuted) parts or the totality of physical theories such as thermodynamics (statistical mechanics), relativity, quantum mechanics, expansion of the Universe, …..

A common theme relating quite different people concerned Helmholtz‘s 1854 prediction of a cosmic **“Wärmetod”** (heat death) as a consequence of the second law of thermo-dynamics. Or as W. Nernst called it: “Götterdämmerung des Weltalls“.

Cosmologies based on this principle were presented by James Jeans in the 1920s: Young stars consisted mainly of transuranic elements which would spontaneously transform into radiation. The cosmic processes were unidirectional, from the complex to the simple, and governed by the second law. As Jeans expressed it in 1926 *“the universe is melting away into radiation“,* occasionally leaving pockets of dead ashes such as terrestrial matter. (Nature 68 (1926) 29, 72 (1928) 463)

In this pessimistic view, life was an accident and the Universe destined to die in the far future. It was a view to which many scientists such as MacMillan, Millikan, and Nernst strongly objected.

As an alternative, they proposed “Steady-State Cosmologies“ based on a **Perfect Cosmological Principle** and some form of **continous creation of matter**.

H. Kragh „Cosmology between the wars“, JHA 26, 93 (1995)

The ”Arrow of Time” ?

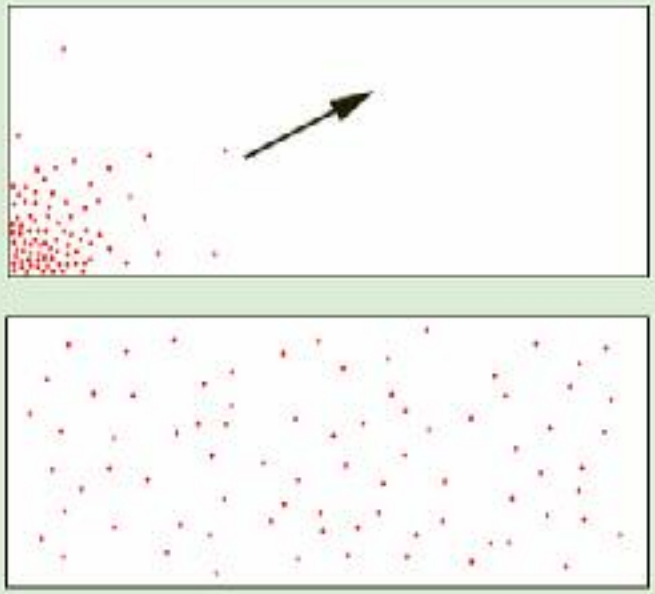
The “heat death”, the unidirectional transition from order to disorder, imposes on the Universe a pervasive “arrow of time”. The problem is that the underlying laws of physics (then Newton’s laws of mechanics) are symmetric in time.
This stark contradiction is illustrated most forcefully in the set-up shown right. If one starts with molecules confined in one corner, they will rapidly diffuse throughout the whole volume and attain an equi-librium state. The reverse process has not been observed.
Boltzmann demonstrated 1872 that inter-molecular collisions redistri-bute energy chaotically among the molecular population and that this leads to a rise in entropy.

But there is a paradox. Every single collision is reversible. So the entire evenly distributed population of the box could be send back to the corner. Although technically implausible, there is nothing in the laws of physics to rule it out.

This lead Poincaré to the “Recurrence Theorem” (mentioned this morning), who showed that, given long enough, the gas ***would*** revisit its initial state. A rough measure of time is 10^N with N the number of molecules.

I suppose that such problems strengthened critical scientists in their refusal of these concepts.

Actual solutions comprise to accept a special initial state of the Universe or some sort of anthropic argument.



1: A gas is isolated in a rigid box. Initially the molecules are confined to one corner of the box (top picture), but as a result of the inter-molecular collisions, the gas rapidly expands into the available space, eventually filling it uniformly (bottom picture). The reverse of this process (bottom picture followed by top picture) would be considered preposterous.

Boltzmann L 1872 Sitzungsber / *Math. Naturwiss. Classe* **66** 275.

Poincaré H 1893 *Les méthods nouvelles de la mécanique céleste* vol. II (Gauthier-Villars, Paris).

Russbach05

P.C.W. Davies: “Whitrow Lecture 2004”, Astonomy and Geophysics 46 (2005) 1.26

BP

MacMillan-Millikan cosmological scheme

In 1918 W.D. MacMillan from Chicago speculated that “the radiant energy from the stars was partly absorbed in the ether and there converted into new matter“.
1925 he postulated that it was unnecessary “to suppose that **the universe as a whole has ever been or ever will be essentially different from what it is today**“

1915 MacMillan discussed his ideas of atom building by condensation of radiation with Millikan. Later at CalTech, Millikan started an experimental program to determine the nature of the mysterious Cosmic Rays (starting in 1922).
Together with G. Harvey Cameron he extended the cosmic ray studies into a grand cosmological scheme: Space is filled with a gas of electrons and protons, which will occasionally combine into heavier nuclei and thereby produce the cosmic ray photons, the **“birth cry of the elements”.**
To circumvent the “Wärmetod“ he demanded that “These building stones are continually being replenished by condensation with the aid of **some as yet wholly unknown mechanism** of radiant heat into positive and negative electrons“ *[“positive electrons” means protons*].

The metaphysical foundation – an evolving universe revealing the Creator‘s continual activity – was essential to their spiritual outlook and view of science.
Millikan and Cameron ended their paper of 1928 pointing out that
“*modern philosophers and theologians have also objected* [to a running-down universe] *on the ground that it overthrows the doctrine of Immanence and requires a return to the middle-age assumption of a Deus ex Machina“.*

R.A. Millikan and G.H. Cameron, „The origin of the cosmic rays“, Phys. Rev. 32 (1928) 533

Walter Nernst and “Die Götterdämmerung des Weltalls”

Similar ideas were developed independently by Walter Nernst in Germany.
[The proponents of these non-mainstream ideas never cited each other.]
Svante Arrhenius, a good friend of Nernst, also refuted the “heath death”.
Physico-chemists around 1900 were interested in reactions at extreme energies and soon got involved in radioactive decay studies. They were interested in the synthesis of elements, also in cosmological scales.
Nernst regarded Eddington’s fusion processes as energy sources for stars as a ”highly fantastic hypothesis“ and proposed the radioactive decay of a “Urmaterie“, a form of primordial matter consisting of hyper-radioactive, transuranic elements formed by the ether.

W. Nernst
1864 - 1941

He urged chemists to search for **“this most important element“,** which might exist on Earth.

Already in 1916, he assumed that the ether, the endproduct of radioactive decay, was a huge energy reservoir with the energy stored as zero-point energy. And fluctuations would, over long spans of time, form radioactive atoms. Eternal recycling of radioactivity would prevent the “Wärmetod“ and secure a stationary state of the universe:
“Our eyes need not, in the far future, have to look at the world as a horrible graveyard, but at a continual abundance of brightly shining stars which come into existence and disappear.“

It is to be noted that he applies quantum theory: fluctuations in the vacuum energy (zero-point energy). Nernst is quite selective in his refutation of modern physical theories!

Cosmological world view as substitute religion?

C.F. von Weizsäcker was once confronted by Nernst. 1938 in Berlin, Weizsäcker had given a talk on energy production in stars (now known as Bethe-Weizsäcker cycle). He mentioned a limited time span for energy production by the Sun and that this was in accord to the age of the Universe derived from the red-shift of galaxies.

Nernst got very angry and stated:

“Die unendliche Dauer der Zeit ist ein Grundelement allen wissenschaftlichen Denkens; wer dies leugnet, verrät die Grundlagen der Wissenschaft.”

Weizsäcker later interpreted the emotional reaction of Nernst in remarking that Nernst was not religious and *”dass in seinem Fühlen das immerdauernde Universum an die Stelle sowohl des ewigen Gottes wie auch der unsterblichen Seele getreten war.“* A contradiction to this quasi-religious belief was felt like a “heresy”.

Weizsäcker, C. F. v.: Die Sterne sind glühende Gaskugeln und Gott ist gegenwärtig. Über Religion und Naturwissenschaft. Herausgegeben und eingeleitet von Thomas Görnitz. Freiburg, Basel, Wien: Herder 1992 (= Herder Spektrum Bd. 4077).

http://www.iguw.de/texte/weltbild.pdf

Although being popular until the late 30‘s, mainstream science refuted these cosmologies. One reason might be, that the proponents of these alternative cosmological theories presented their concepts mostly at meetings of physics and chemists, but seldom to astronomers.

Steady-State Cosmologies

In 1948, Hoyle and Bondi-Gold published two papers on Steady-State Cosmologies.
[F. Hoyle, "A New Model for the Expanding Universe", MNRAS 108 (1948) 372]
These theories use not only formulations of the pre-war cosmologies but are based partly on the same principles, as the **"Perfect Cosmological Principle".** This principle is the extreme consequence of the **"Copernican Principle"** which states that humankind does not occupy a

privileged central position in the Universe in any regard.

The permanent creation of matter is introduced in the latter models to compensate for the thinning-out of matter due to the universal expansion (refuted by Nernst-Millikan) and not to circumvent the consequences of the Second Law.

1. *The perfect cosmological principle*

1.1. The unrestricted repeatability of all experiments is the fundamental axiom of physical science. This implies that the outcome of an experiment is not affected by the position and the time at which it is carried out. A system of cosmology must be principally concerned with this fundamental assumption and, in turn, a suitable cosmology is required for its justification. In laboratory physics we have become accustomed to distinguish between conditions which can be varied at will and the inherent laws which are immutable.

H. Bondi and T. Gold, "The Steady-State Theory of the Expanding Universe", MNRAS 108 (1948) 252

Bondi insisted that the steady-state cosmology was **scientific** because, following Popper, it was **falsifiable**. He even specified what evidence would falsify the theory. H/He ratios and CMB convinced him to give up his theory.
G. Gale, "Milne, Bondi, and the 'Second way' to Cosmology"; in "The Expanding Worlds of General Relativity", 1999

Russbach05

Historians presume that the post-war theories were developed totally independent of the earlier unorthodox ideas.

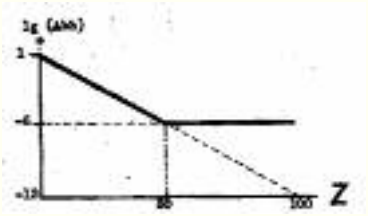
The Anthropic Principle

Brandon Carter developed the first version of the Anthropic Principle as a
“reaction against exaggerated subservience to the Copernican Principle”.
The first publication, ironically, is part of the proceedings of the
Symposium On Copernicus’ 500th Birthday, Krakow:
“Large number coincidences and the anthropic principle in cosmology”
IAUS 63 (1974) 291

At the beginning, there had been no connection to the triple-α-reaction. Fred Hoyle‘s prediction of a doorway-state for the production of carbon was not based on this principle.
[An introduction to the Anthropic Principle in Nuclear Astrophysics can be found in
“Kerne und Sterne” from Heinz Oberhummer.]

The principle had, however, been invoked before then, e.g. in 1957, R.H. Dicke wrote: 'The age of the Universe "now" is not random but conditioned by biological factors ... [changes in the values of the fundamental constants of physics] would preclude the existence of man to consider the problem.'
(R.H. Dicke, *Principle of Equivalence and Weak Interactions*, Rev. Mod. Phys. 29, 355 (1957).)
Even earlier statements of the principle may be found in Alfred Russel Wallace's book *Man's Place in the Universe*, which was first published in 1903. For example: "such a vast and complex universe as that which we know exists around us, may have been absolutely required ... in order to produce a world that should be precisely adapted in every detail for the orderly development of life culminating in man." (pp. 256-7 in the 1912 edition).

Later discussions of transuranic elements



For fusion reactions exponential up to highest Z.

In Gamow's original version of Big-Bang cosmology, the initial state was hypothesized to consist of **super-heavy, radioactive elements**. Light elements from ternary/quaternary fission.

G. Gamow, „Concerning the origin of chemical elements" Journal of the Washington Academy of Science 32 (1942) 353-5

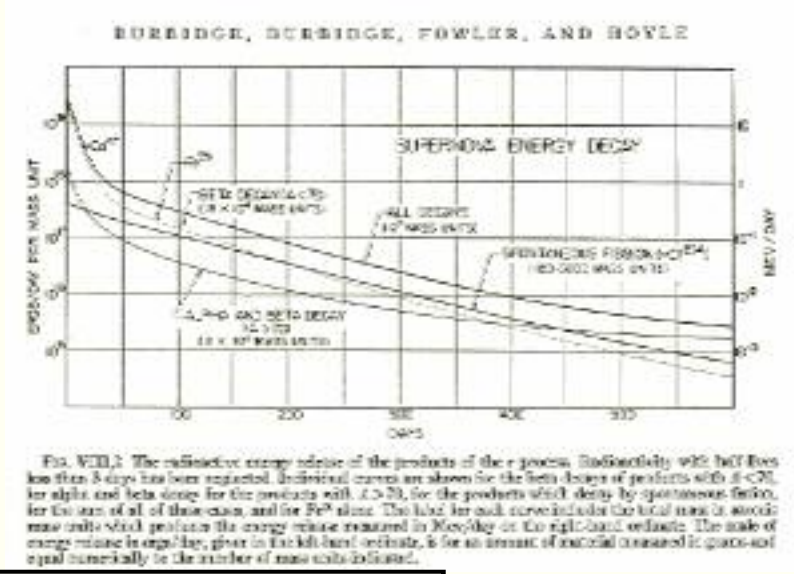
Mayer and Teller explained the origin of the heavy elements as fission-like breakup of a primordial neutron-rich nuclear fluid of transuranic elements the size of a star.

Maria G. Mayer and E. Teller, „On the Origin of Elements", Phys. Rev. 76 (1949) 1226

Burbidge et al., (Phys. Rev. 53 (1956) 1145) explained the light curves of SNe I by the spontaneous-fission decay of ^{254}Cf ($T_{1/2}$ = 55 d).

They remark that

„The presence of Tc in red giant stars and Cf in Type I supernovae appears to be observational evidence that neutron-capture processes on both a slow and a fast time-scale have been necessary to synthesize the heavy elements in their observed cosmic abundances."

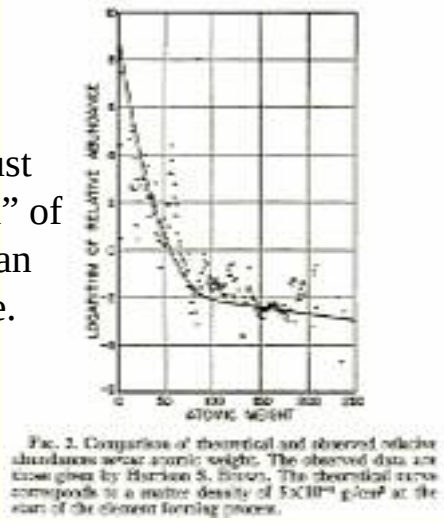


The observation of Cf in stars was a mistake.
Isotopic I and Xe anomalies in chondritic meteorites are explained by Kuroda et al. as ^{244}Pu fission products.

Hot Big-Bang Nucleosynthesis

Lemaître, Einstein
Pasadena, 1933

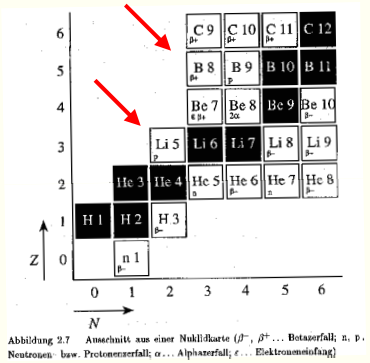
Following the discovery of the expansion of the Universe, Lemaître proposed 1927, that the Universe at the beginning must have been concentrated in a "Primæval Atom". The "explosion" of this atom (later nicknamed "Big Bang" by Fred Hoyle) means an extremely dense and hot early phase of the expanding Universe.



R.A. Alpher, R.C. Herman
Phys. Rev. 74 (1948) 1737

In the late 40's, Gamow, Alpher, Herman, Bethe et al. developed a theory of nucleosynthesis in the first hour after the Big Bang.
But, the neutron captures proposed cannot overcome mass 5 and 8.
And, in addition, the result was based on wrong assumptions on neutron capture rates.

After the discovery of the Cosmic Background Radiation by Penzias and Wilson **1965**, G. Gamow insisted that his group had **predicted** the temperature of the CBR prior to the measurement.
This is regarded in many textbooks as a "proof" of the Big Bang cosmology.



R.A. Alpher, R.C. Herman, Phys. Rev. 75 (**1949**) 1089	about 5 K
G. Gamow, Da. Acad. Math,-Phys. Section 27 No. 10 (**1953**)	7 K
G. Gamow, The Creation of the Universe, **1961** (1952)	50 K

Russbach05

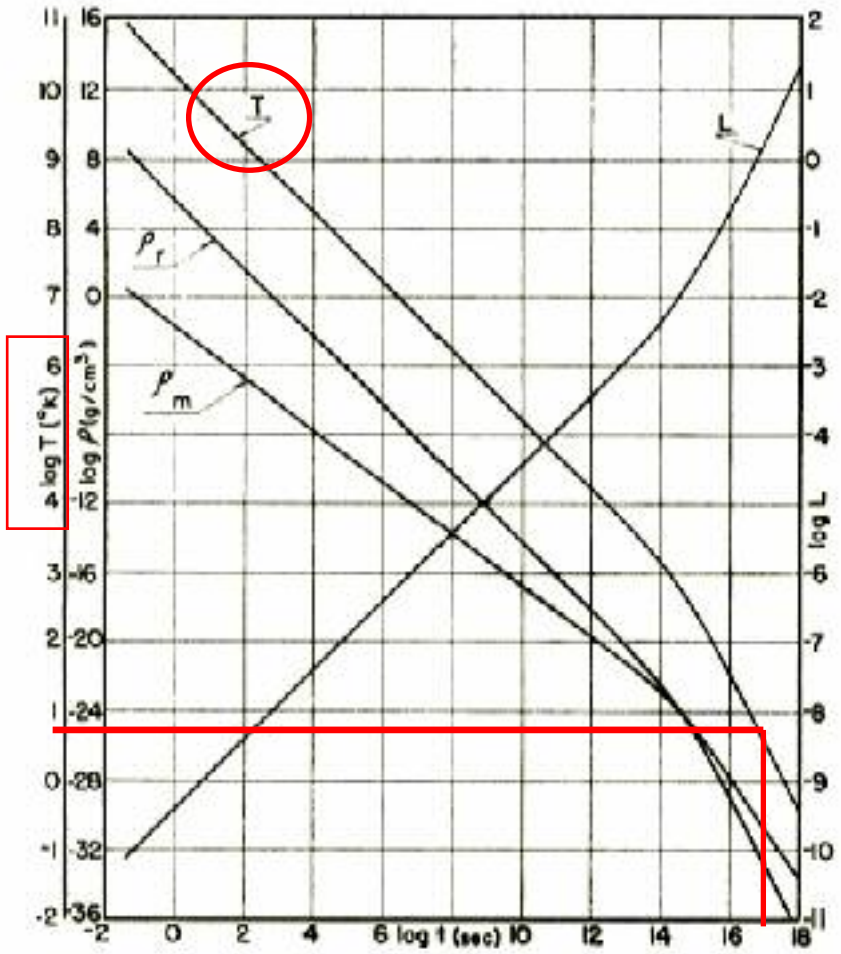


FIG. 1. The time dependence of the proper distance L, the densities of matter and radiation, ρ_m, and ρ_r, as well as the temperature, T, are shown for the case where $\rho_{m'} \cong 10^{-29}$ g/cm³, $\rho_{r'} \cong 10^{-32}$ g/cm³, $\rho_{m'} \cong 10^{-6}$ g/cm³, and $\rho_{r'} \cong 1$ g/cm³. [See Eq. (12).]

R.A. Alpher, R.C. Herman, Phys. Rev. 75 (1949) 1089

Russbach05 “Prediction“ of temperature of background radiation: the end of a myth ?

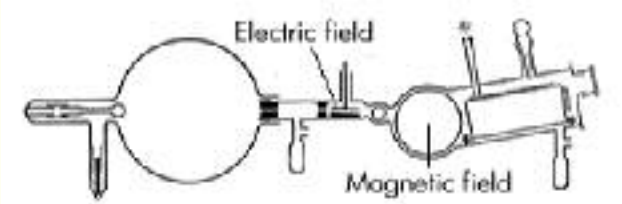
Stefan-Boltzmann law applied to

Energy density of starlight	
• C.-E. Guillaume, “La température de l’espace”, La Nature 1215 (**1896**) 234 [1214, p.210]	**5.6 K**
• A.S. Eddington, "The internal constitution of the stars“ Cambridge, **1926**) 371	**3.18 K**
Cosmic rays	
• E. Regener, "Der Energiestrom der Ultrastrahlung", Z. Phys. 80 (**1933**) 666 energy flux 3.53×10^{-3} erg/s/cm^2	**2.8 K**
• W. Nernst, "Die Strahlungstemperatur des Universums", Ann. Phys. 80 (**1933**) 666 Against Doppler interpretation of redshift. Photons loose energy and are absorbed by ether.	**.75 K**
Interstellar diatomic molecules	
W.S.Adams "What lies between the stars", PASP 53(312) 73 (1941) Observation of CH and CN lines (predicted by McKellar) with 100" Hooker telescope.	
• A.McKellar, Dominion Astrophysics Observatory Journal II, 251 (**1941**) and	
• G. Herzberg, Molecular Spectra and Molecular Structure. Vol. I: Spectra of Diatomic Molecules "…a rotational energy of 2.3 K follows, which has of course only a very restricted meaning."	**2.3 K**
Tired-light model: Finlay-Freundlich, Max Born **1953/4**	**1.9 < T < 6.0 K**

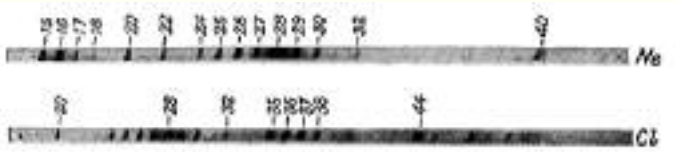
Proponents of Steady-State-Cosmologies accuse Gamow et al., to have derived the conditions for their model from extrapolating back in time the known actual temperature.

Atomic masses

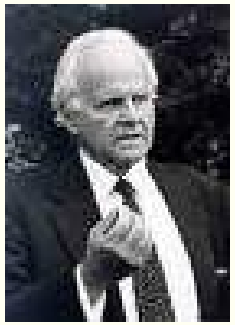
- The physician William Prout determined atomic weights and postulated 1815 that all weights are multiples of hydrogen.
- Sir William Crookes hypothesized 1871 that deviations from this rule indicate to “isotopes“.
- J.J. Thomson / F.W. Aston observed 1912 with cathode rays, that Ne had two isotopes of mass 20 and 22.
- After the war, F.W. Aston measured isotopic masses (1919).
- Based on these masses, Arthur Eddington explained 1920 the energy source of stars as fusion of H to He.



Aston's design for the mass spectrograph.



Based on the liquid drop model
C.F. v. Weizsäcker *[Z. Physik 96 (1935) 431]* and
H.A. Bethe and R.F. Bacher *[Rev. Mod. Phys. 8 (1936) 82]*
developed a semiempirical mass formula, that served as basis for nucleosynthesis models for a long time, as the CNO- or Bethe-Weizsäcker-cycle:
C.F. v. Weizsäcker, *Z. Physik 39 (1938) 633* and
H. Bethe, *Phys. Rev. 55 (1939) 434*



Some authors modified this formula to better fit new data as
A.G.W. Cameron, Canad. J. Phys. 35 (1957) 1021; 36 (1958) 1040

On return from the Workshop, I got to know that Hans Albrecht Bethe had passed away the day of my presentation:
July 2, 1906 (Strassburg) – March 6, 2005 (Ithaca, NY)

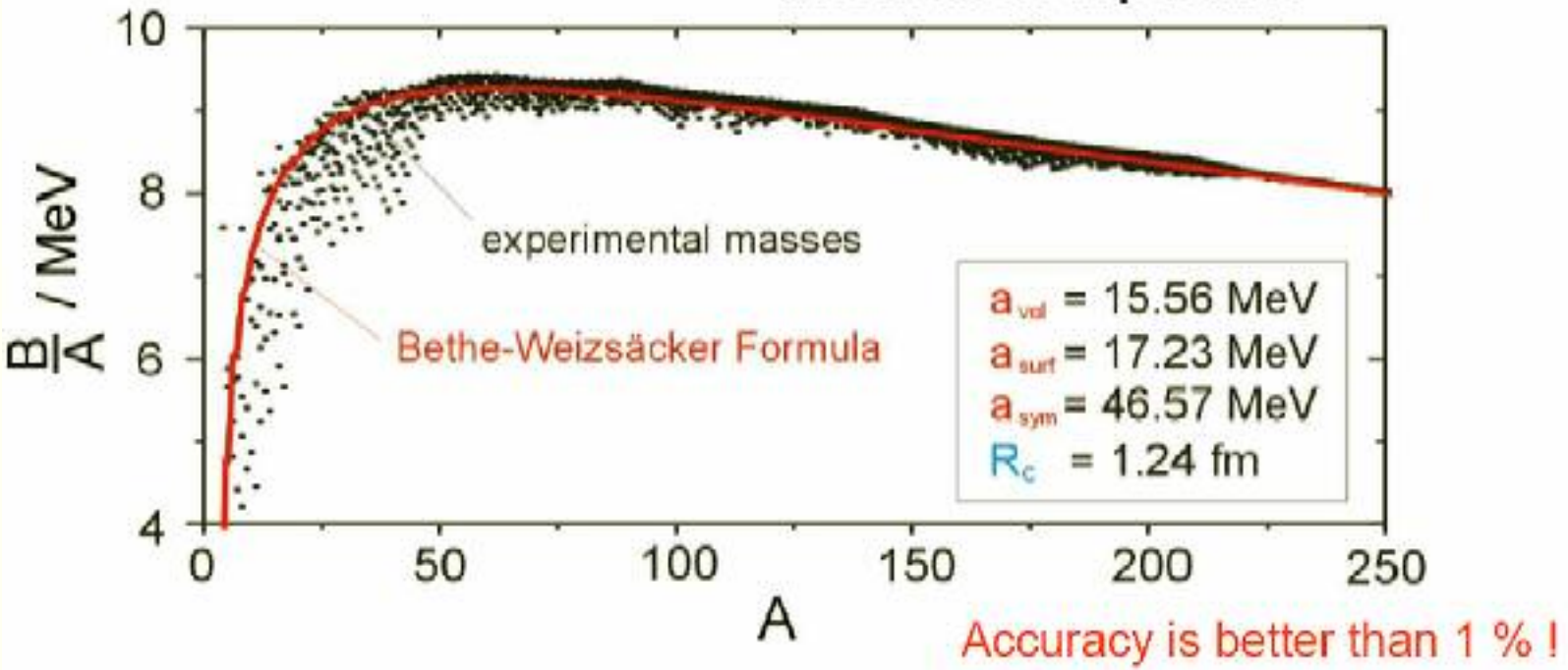
Macroscopic description

Nuclei are treated as a classical liquid drop

Bethe-Weizsäcker Formula: Z. Phys. 96, 431 (1935)

$$B(N, Z) = a_{vol} A - a_{surf} A^{2/3} - \frac{1}{2} a_{sym} \frac{(N-Z)^2}{A} - \frac{3}{5} \frac{Z^2 e^2}{R_c}$$

deformation dependent



Accuracy is better than 1 % !

Courtesy H. Geissel

TheTriple-α or Salpeter Reaction

As there are no stable nuclides with A=5 and 8, nucleosynthesis cannot work with neutron-capture reactions for the light and middle-heavy isotopes.

Already in 1939 H. Bethe in his paper on the CNO-cycle (Phys. Rev. 55 (1939) 434) had discussed possible reactions to form new elements in stars (as the triple-α). He concluded, that there is **no permanent production of nuclei heavier than He** in stars, the fusion reactions deliver **only energy**.
The carbon seed nuclei for the CNO-cycle must be produced somewhere else.

E.E. Salpeter and E.J. Öpik reanalysed the charged particle reactions and found that the triple-α process is the most probable way to overcome the A=5 and 8 gaps (ApJ 115 (52) 326; Proc. Roy. Irish Acad. A54 (51) 49).
F. Hoyle remarked 1954 that the (statistical) reaction rate is too low to produce the carbon observed in the Universe.
He postulated the existence of an excited 0^+ state which would enhance the rate.
This state was then discovered by William Fowler.

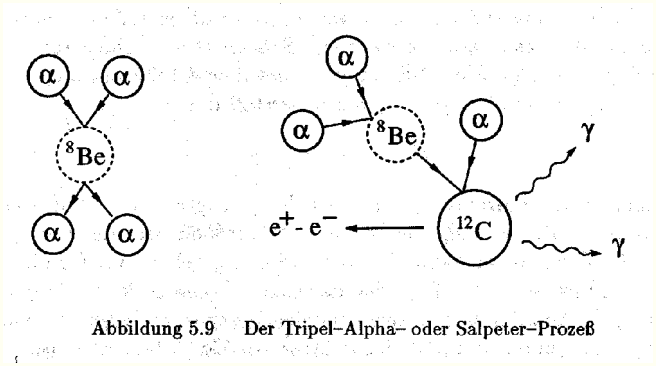


Abbildung 5.9 Der Tripel–Alpha– oder Salpeter–Prozeß

One may regard this state as a cluster of 3 α-particles. Feldmeier, Neff: Phys. J. 4/1 (2005) *29*

The proponents of the Strong Anthropic Principle take this state as proof for their (religious) ideas.
It should be mentioned that this principle originally was developed for cosmological purposes:
B. Carter, Symposium Krakow 1973 [IAUS 63 (1974) 291], Clifford Memorial Meeting Princeton 1970

Stars as the site of nucleosynthesis

Already R. d'Escourt Atkinson and F.G. Houtermans realised that element formation by nuclear collisions required **conditions corresponding to those in the interior of stars**.
[„Zur Frage der Aufbaumöglichkeiten in Sternen", Z. der Physik 54 (1929) 656]

The observation of **unstable Tc** in several variable S stars showed that nucleosynthesis processes are still ongoing and that the site is the interior of stars [P.W. Merrill, ApJ 116 (1952) 21].

Stephen Hawking in a TV documentary said that Fred Hoyle got strongly interested in nucleo-synthesis when the synthesis in the "Big Bang" was used as an argument against Steady State Cosmologies.

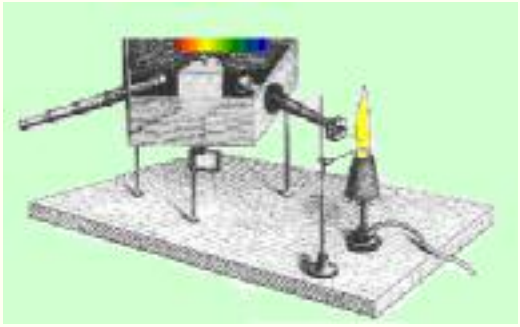
In B^2FH, the synthesis of all elements heavier than He is shown to take place in stars, **not in a singular event** just after the Big Bang, but as a **continuing process**.

For proponents of Steady-State Models still rests a serious drawback:
Helium is still synthesized in the Big Bang!
But, Burbidge/Hoyle remark that the energy content of the CBR is of the same order of magnitude as the energy released when all He is derived from H. In the frame of the Quasi-Steady-State Model they synthesize all elements from H in stars.
[see, e.g., G. Burbidge and F. Hoyle, Ap. J. 509 (1998) L1]

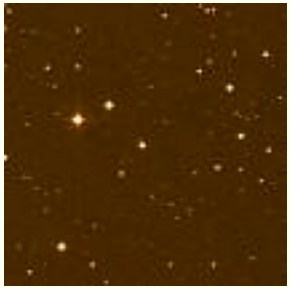
Stephen Hawking studied at Cambridge to do his PhD under the supervision of Fred Hoyle. But there were already too many students in the group of Hoyle.

Hawking's „No-Boundary Cosmology" applies the Perfect Cosmological Principle as Hoyle.

Composition of extraterrestrial matter
Galactical chemical evolution
Old and new observables



Optical spectroscopy: Bunsen/Kirchhoff
Birth of astrophysics 1863: 9 elements detected in Aldebaran and Betelgeuse



CS 22982-052

•Spectroscopy of ultra-metal-poor Halo stars
Interstellar matter (ISM) 13 Gy ago

•Elemental and isotopic composition of meteorites
Interstellar Medium 4.6 Gy ago

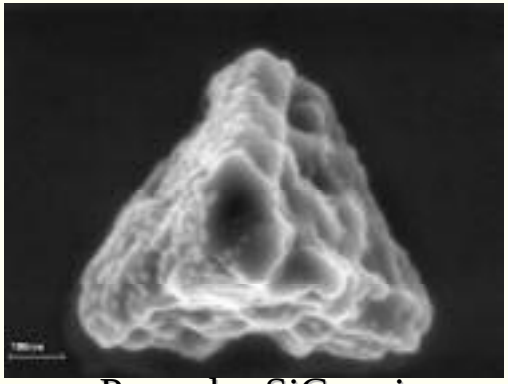
Carbonaceous Chondrite
Murchison

•Pre-solar grains in meteorites and high atmosphere
ISM prior to formation of Solar System

•Ultra-heavy component of cosmic rays
Recent nucleosynthesis events

•STARDUST at comet 81P/Wild 2 and collection of interplanetary and sideral dust
(Jan. 2, 2004; return Jan. 15, 2006)

Nucleus of 81P/Wild 2

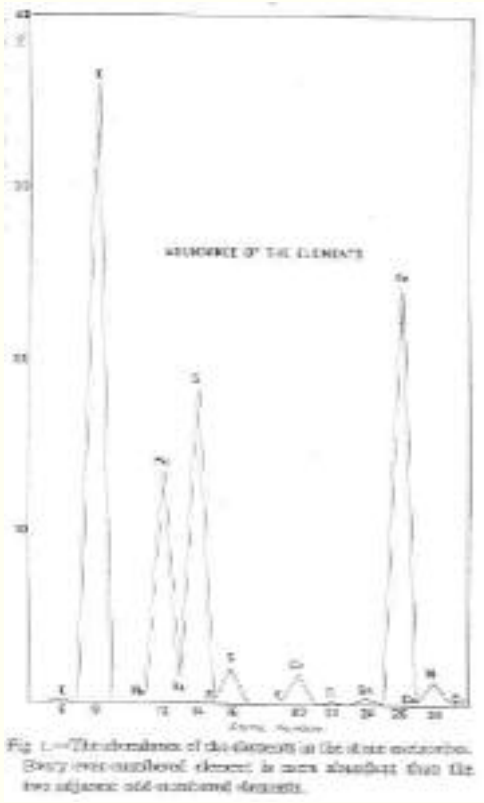


Pre-solar SiC grain

Murchison contains praebiotic molecules with enhanced chirality.

Solar System Abundances and Nuclear Structure

Already in 1917, Harkins connected elemental abundances and nuclear structure.

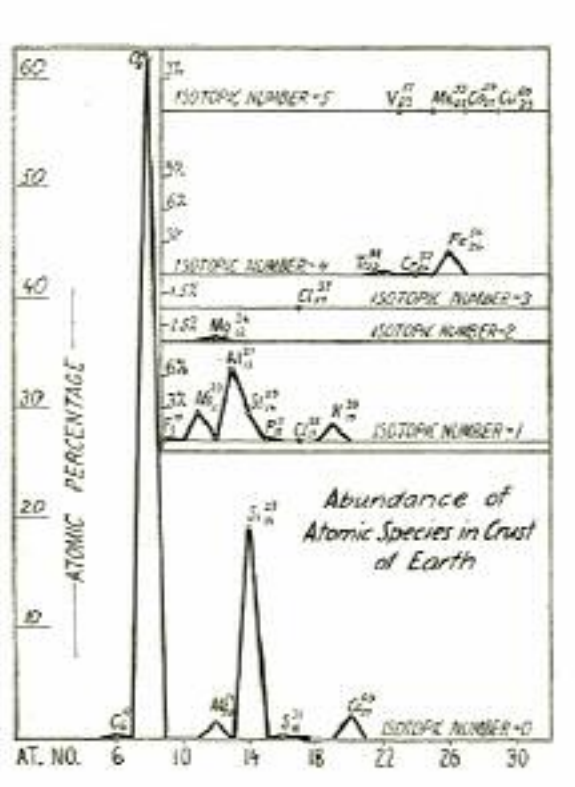


W.D. Harkins
J. Am. Chem. Soc. 39 (1917) 856

Harkins noted an **odd-even effect** in meteoritic elemental abundances and related it to the structure of the (just discovered) nuclei of atoms.

He developed a “natural” system of elements in forming the nuclei from hydrogen, helium and electrons as an alternative to Mendeleev‘s derivation from chemical properties.

Without the neutron, the scheme worked only for light elements.



W.D. Harkins and S.L. Madorsky,
Phys. Rev. 19 (1922) 135

Oliver Manuel bases his theory of the Sun composed of iron (formation by the infall of the ejecta of a supernova on the neutron star) still on the cosmic abundances of Harkins, who (naturally) did not observe H and He in meteorites.

Up to the mid-50‘s, elemental and isotopic solar abundances (called cosmic abundances) were determined with high precision by combining optical spectroscopy with mass measurements by several groups (as Russell, the Noddacks, Elsasser, Goldschmidt, Brown, Goldberg).

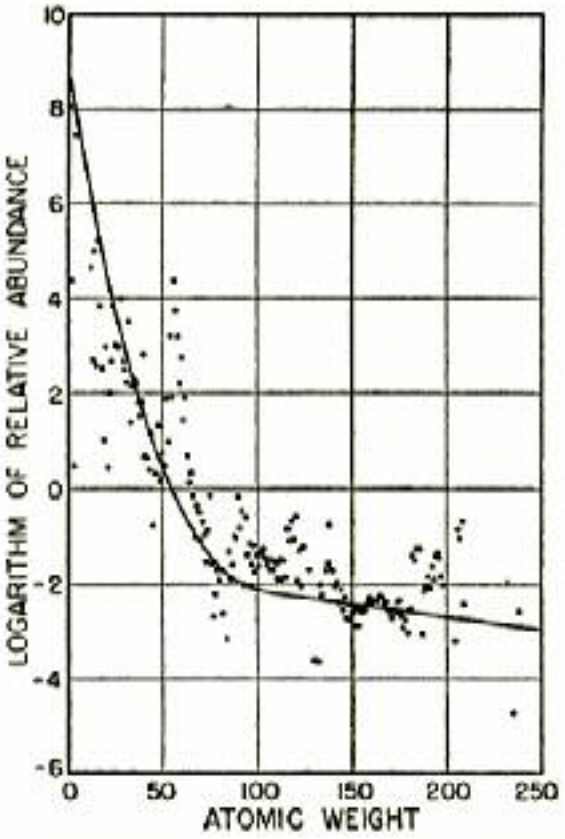
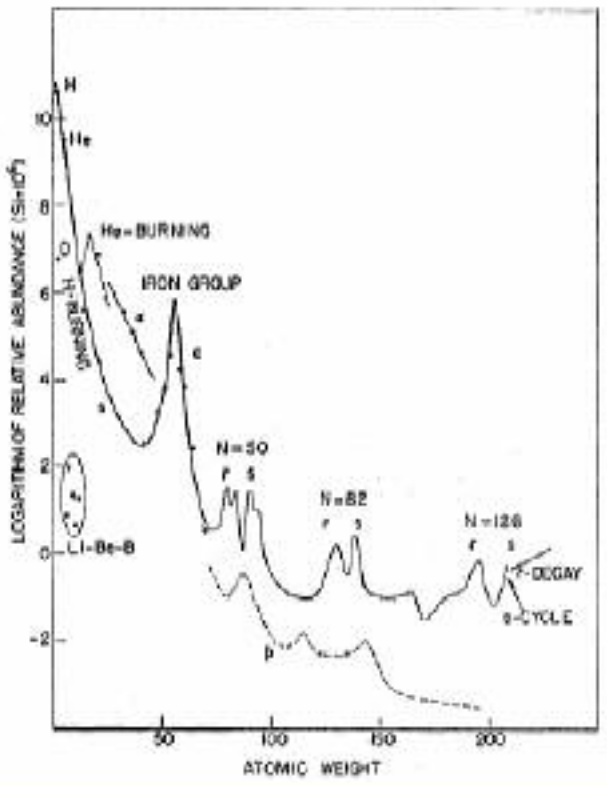


FIG. 2. Comparison of theoretical and observed relative abundances *versus* atomic weight. The observed data are those given by Harrison S. Brown. The theoretical curve corresponds to a matter density of 5×10^{-9} g/cm^3 at the start of the element forming process.

R.A. Alpher, R.C. Herman Phys. Rev. 74 (1948) 1737



Suess and Urey
„Abundances of the Elements“
(Rev. Mod. Phys. 28 (1956) 53)

Elements and isotopes known in 1956

TABLE I,1. Table of elements and isotopes [compiled from *Chart of the Nuclides* (Knolls Atomic Power Laboratory, April, 1956)].

Elements		Isotopes	
Stable	81	Stable	272
Radioactive:		Radioactive:	
Natural ($Z \leq 83$)	1[a]	Natural ($A < 206$)	11[d]
($Z > 83$)	9[b]	($A \geq 206$)	44
Natural:		Natural:	
Stable and Radioactive	91	Stable and Radioactive	327
Radioactive:		Radioactive:	
Artificial ($Z \leq 83$)	1[c]	Artificial ($A < 206$)	702
($Z > 83$)	10	($A \geq 206$)	169
Total	102	Total	1198
Neutron	1	Neutron	1
	103		1199

[a] Tc, observed in *S*-type stars.
[b] Including At and Fr produced in weak side links of natural radioactivity
[c] Pm, not observed in nature.
[d] Including H^3, C^{14}, and Te^{99}.

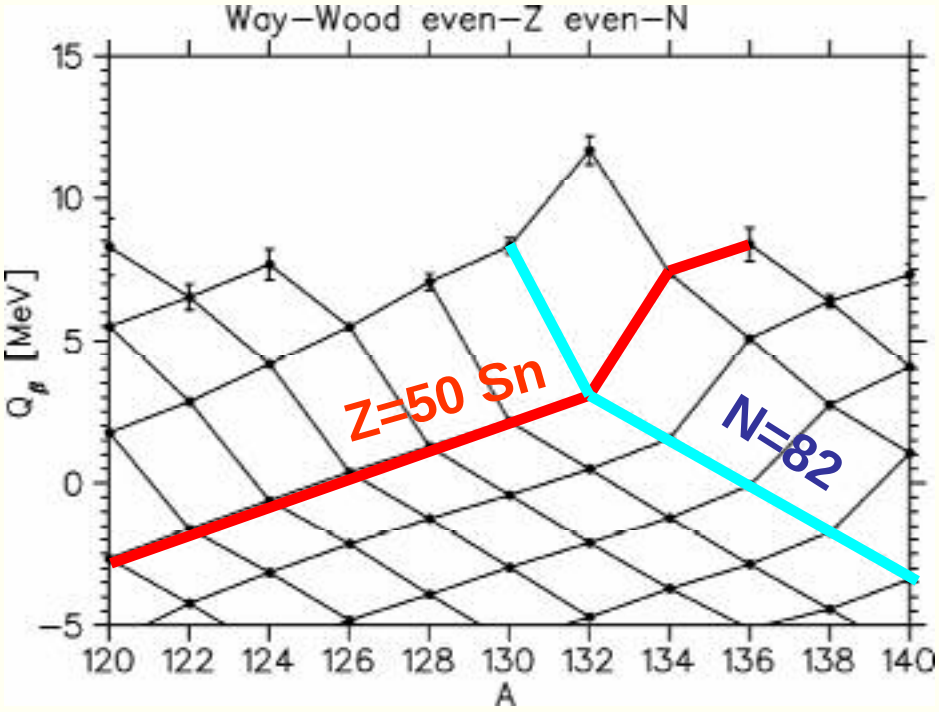
and now

There are only 80 stable elements left, but the total number approaches 120.
Instead of 1200 nuclides observed, the total number approaches 3000
out of about 7000 particle-stable ones.

The decay of ^{209}Bi by 3.137 MeV α–particles with $T_{1/2} = (1.9 \pm 0.2)10^{19}$ y has been reported by P. De Marcillac et al., Nature 422 (2003) 876

Magic numbers

At “magic” proton and/or neutron numbers, nuclear properties can change abruptly.



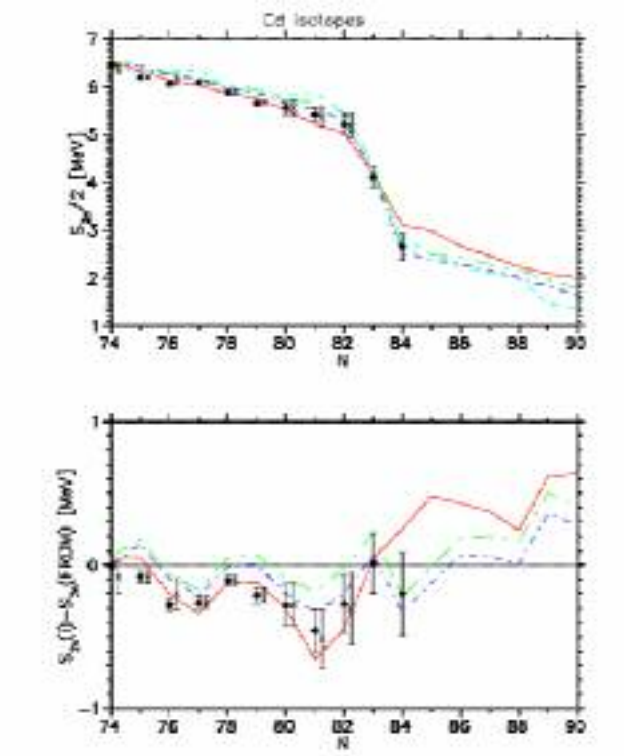


Figure 1: The two-neutron separation energies (S_{2n})across the shell gap at N=82 for Cd-isotopes (upper part) and the differences to the FRDM model (lower part). Experimental values: crosses from 1995 mass evaluation [3] and circles from 2003 evaluation [4]. Theoretical masses: FRDM: cyan, ETFSI-1: green, ETFSI-Q: blue, HFB-2: red

The occurrence of these numbers can be explained by a strong spin-orbit coupling.
The development of the nuclear shell model was essential for the explanation of the maxima in the solar abundances.

Maria Göppert Mayer, Phys. Rev. 75 (1949) 1969; Phys. Rev. 78 (1950) 16
O. Haxel, J.H.D. Jensen, H.E. Suess, Phys. Rev. 75 (1949) 1766; Z. Physik 128 (1950) 295

Experiments on termination of r-process

Isaiah 2:4

> And he shall judge among the nations, and shall rebuke many people:
> and they shall beat their swords into plowshares, and their spears into pruninghooks:
> nation shall not lift up sword against nation, neither shall they learn war any more.

Projects for non-military, peaceful use of nuclear power were initiated by President Eisenhower in his address to the UN.

Eisenhower
Dec. 8, 1953

Experimental data on the fission rates of transuranium elements were obtained by digging out samples from subterranian thermonuclear explosions. No isotopes heavier than A=257 were detected.

A clause in the test ban treaty seems to offer the possibility for underground explosions for non-military purposes after 2006.

TRIGA at Mainz

One of the first projects was stimulated by Teller asking for a research reactor that was **“not only idiot-proof, but PhD proof”** resulting in General Atomic’s TRIGA reactors.

The group developing the TRIGA was also working on Project ORION, a space-ship propelled by nuclear explosions.

(It resurfaced recently in connection to Bush’s ambitions.)

Russbach05

BP

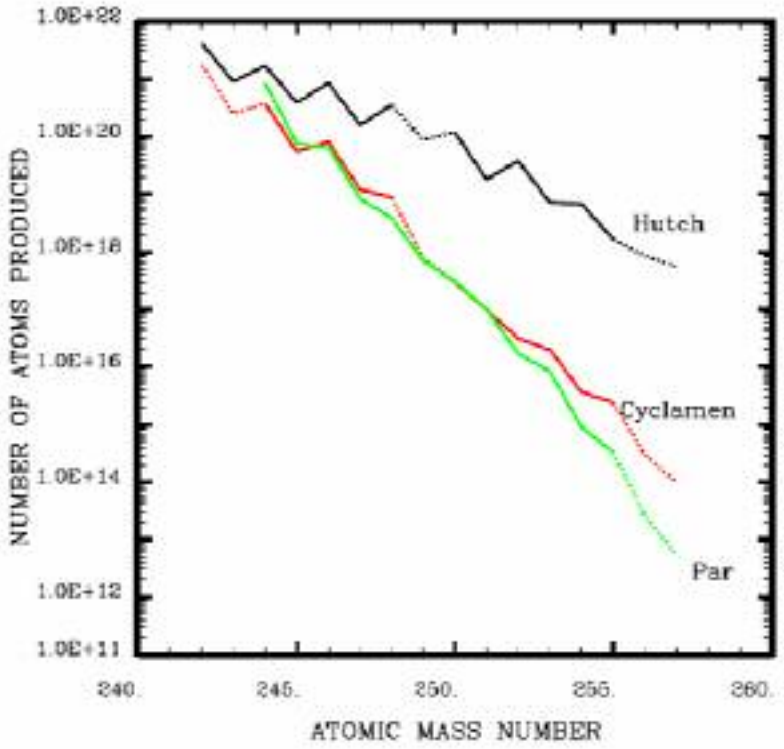
Approximating the *r*-Process on Earth with Thermonuclear Explosions: Lessons Learned and Unanswered Questions

S. A. BECKER
Los Alamos National Laboratory

From 1952 to 1969, 23 nuclear tests involved experiments on the “prompt capture” process. The “US Heavy Element Program” was partly performed in the frame of the “Plowshare Peaceful Nuclear Explosion Program”. Similar experiments were performed by the USSR from 1966 to 1977. Einsteinium and fermium were first discovered in the debris of these explosions. Up to 19 successive neutron captures (Fm-257) could be achieved.

Element	Isotopes
Pu	244, 245, 246
Am	246
Cm	246, 247, 248
Bk	249
Cf	249, 252, 253, 254
Es	253, 255
Fm	255

Mike test on 10/31/52: 10.4 Mt
(17 captures up to Fm-255)



Russbach05

http://www.octw.edu/octw/symposia/series/symposium4/proceedings.html)

BP

PROJECT CHARIOT: HOW ALASKA ESCAPED NUCLEAR EXCAVATION

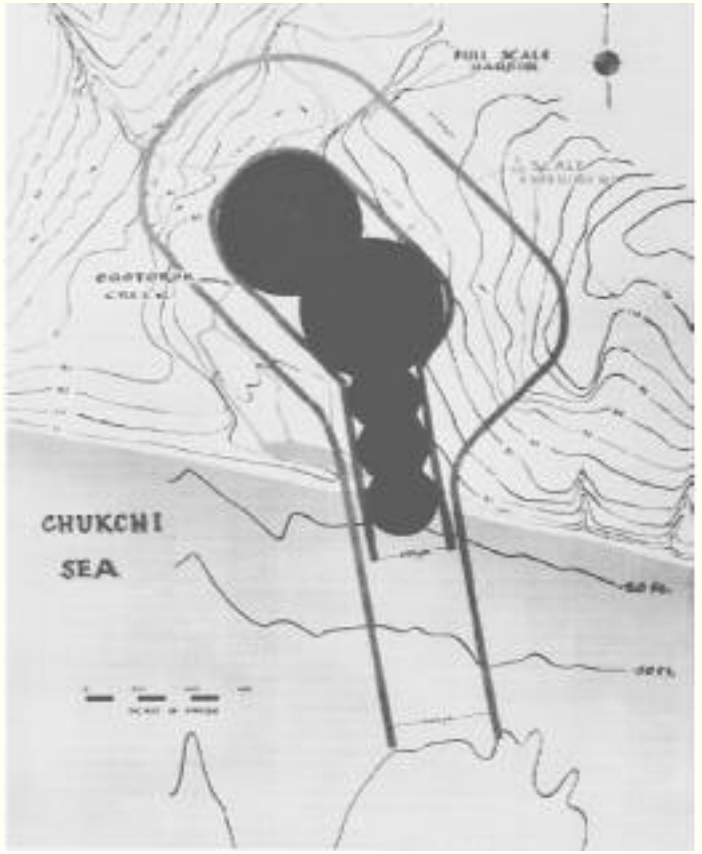
Underground thermonuclear explosions were also performed in Project Plowshare (under the guiding of Edward Teller) intended to create cavities for storing gas or excavating harbors or canals as a new sea-level Panama canal.

Bulletin of the Atomic Scientists
December 1989, Volume 45, Number 10, pp. 28-37

Edward Teller, center, at Kotzebue in the summer of 1959 on one of his many trips to Alaska. At one point Teller suggested the Eskimos could become coal miners if Alaska had a harbor to ship out its "black diamonds."

Edward Teller set out to carve a harbor into the Alaskan coast with nuclear explosives. Instead, he accidentally helped launch the environmental movement.

Sedan test (July 6, 1962) 104 kt
1280 feet across, 320 feet deep



2 1 Mt and 3 100 kt explosions
c. 40% of firepower in WWII

http://www.thebulletin.org/pdf/temp/045_010_021.pdf

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BP

In the early 50`s, the development of the nuclear shell-model (Göppert-Mayer and Jensen, Haxel, Suess) was the basis for the understanding of nucleosynthesis.

Several groups worked out a detailed picture, as
- Suess and Urey
- A.G.W. Cameron
- C.D. Coryell
- B^2FH

July 1971, Fowler's 60th birthday

REVIEWS OF
MODERN PHYSICS

VOLUME 29, NUMBER 4 OCTOBER, 1957

Synthesis of the Elements in Stars*

E. MARGARET BURBIDGE, G. R. BURBIDGE, WILLIAM A. FOWLER, AND F. HOYLE

Kellogg Radiation Laboratory, California Institute of Technology, and Mount Wilson and Palomar Observatories, Carnegie Institution of Washington, California Institute of Technology, Pasadena, California

"It is the stars, The stars above us, govern our conditions";
(*King Lear*, Act IV, Scene 3)

but perhaps

"The fault, dear Brutus, is not in our stars, But in ourselves,"
(*Julius Caesar*, Act I, Scene 2)

B^2FH, the „Bible" of Nuclear Astrophysics

Charles Coryell

Al Cameron

Necessity of primordial, explosive synthesis processes?

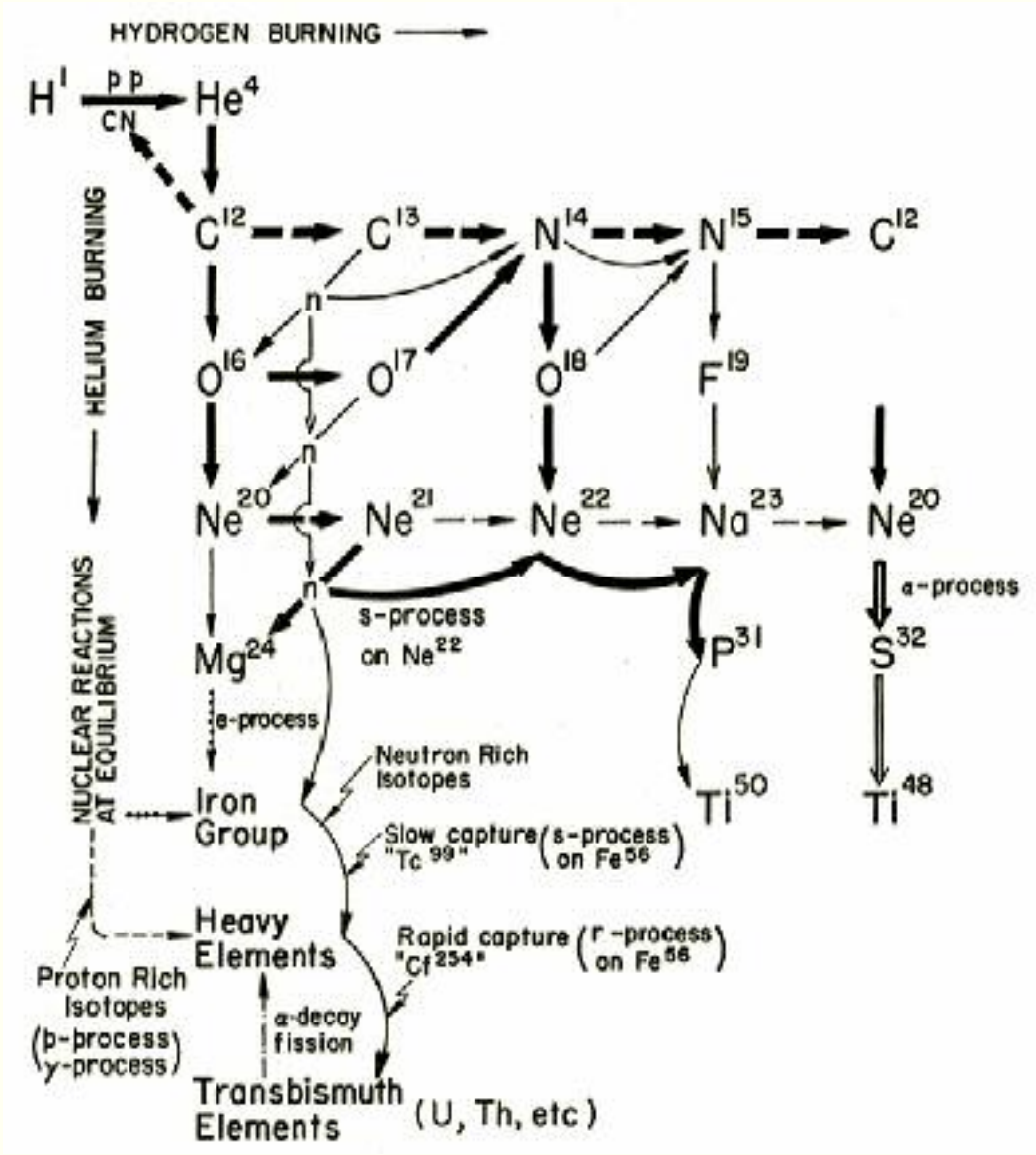
The authors cite a review for alternative processes
(R.A. Alpher and R.C. Herman, Ann. Rev. of Nucl. Sci.2 (1953) 1)
and continue:

It is not known for certain at the present time whether all of the atomic species heavier than hydrogen have been produced in stars without the necessity of element synthesis in a primordial explosive stage of the universe. Without attempting to give a definite answer to this problem we intend in this paper to restrict ourselves to element synthesis in stars and to lay the groundwork for future experimental, observational, and theoretical work which may ultimately provide conclusive evidence for the origin of the elements in stars.

B^2FH (1957)

"...it appears that in order to explain all the features of the abundance curve, at least eight different types of synthesizing processes are demanded..."

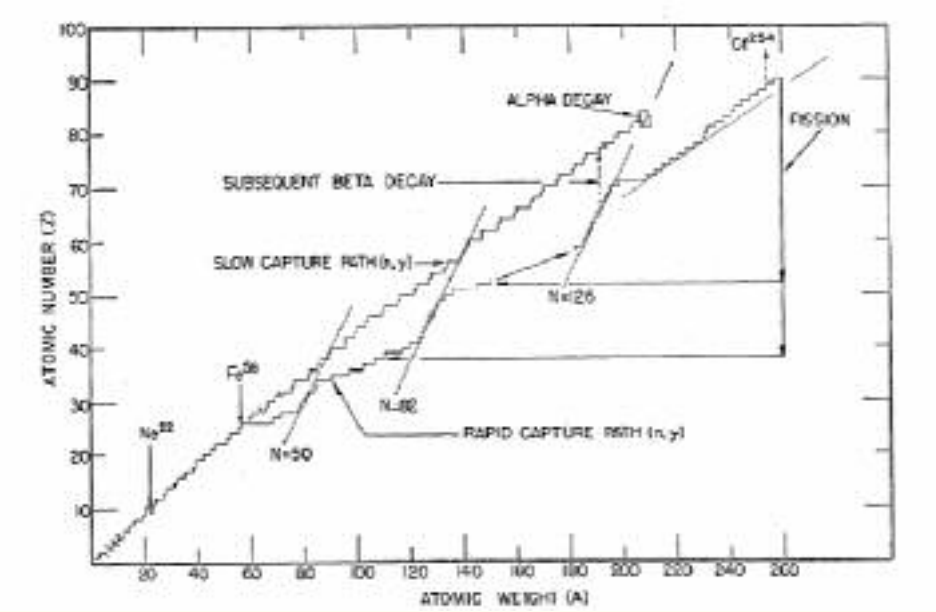
1. H-burning
2. He-burning
3. α-process
4. e-process
5. s-process
6. r-process
7. p-process
8. x-process

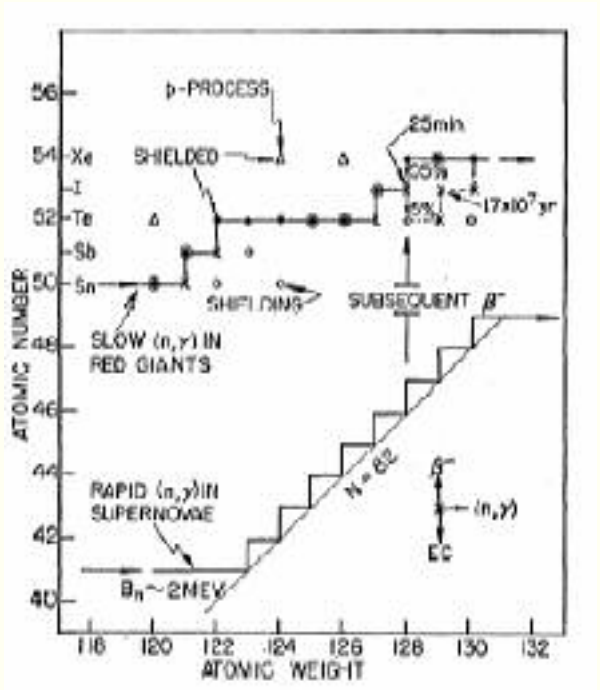


R-Process

"... The process is that of very rapid capture of neutrons in a supernova explosion, where atoms in the Fe region suddenly are exposed to a tremendous flux of fast neutrons of short duration, and hundreds of neutrons may be captured.
Subsequent radioative decay of these products gives us the elements we know now..."

(Charles D. Coryell, 1960)





Already in 1957 even the detailed behaviour at N=50, 82 and 126 was predicted correctly. The *„climb up the staircases"*, the major waiting-point nuclei involved, as well as the *„break-through pairs"*, and their *„association with the rising sides of major peaks in the abundance curve for the r-process"* are still today important properties to be studied experimentally and theoretically.

B^{2}FH concluded that a

„reasonable but not exact agreement with observed abundances is obtained“.

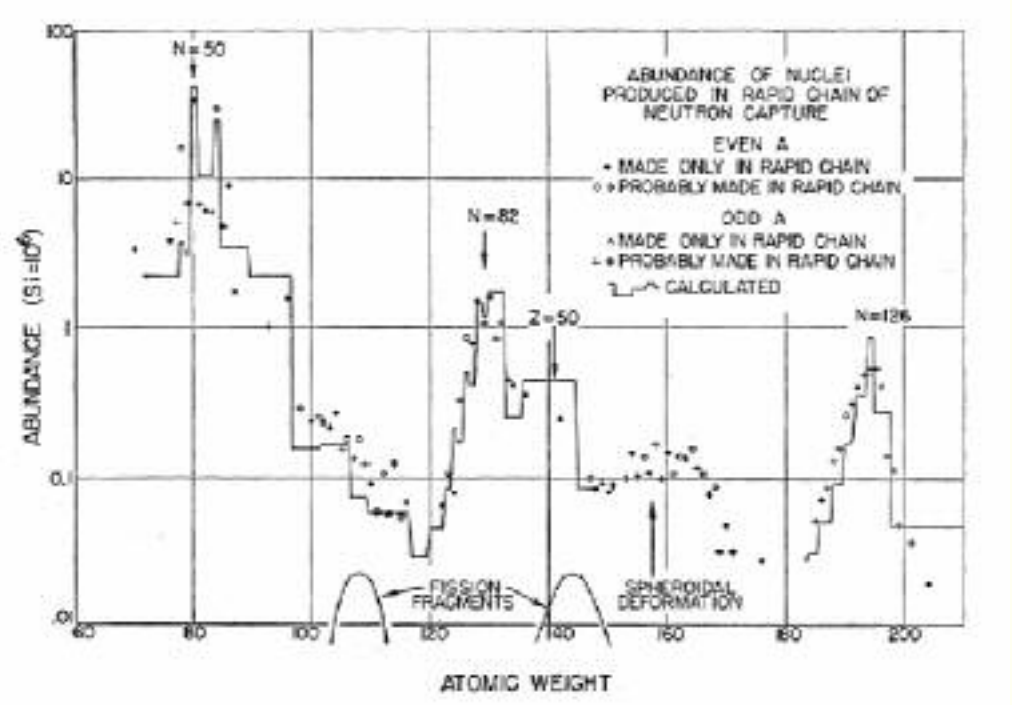


Fig. VII,3 of B^{2}FH: Classical static r-process calculation compared to observed abundances of Suess and Urey.

A fine example of British understatement!

Quite some work had to be invested to get better results, as we will see this week.

Neutron-Capture Reactions

Following the discovery of Tc in Red Giant Stars, Al Cameron studied the possibility of neutron-captures and neutron-producing reactions as the $^{13}C(\alpha,n)^{16}O$.

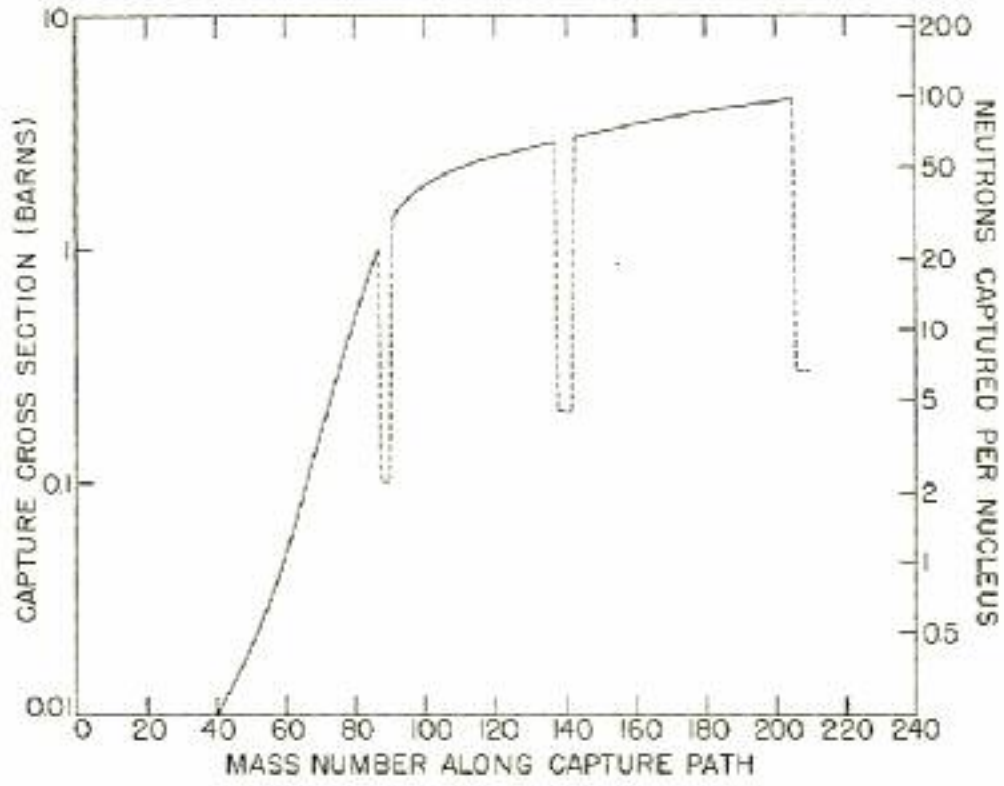


FIG. 1.—The neutron-capture cross-section of the nuclides lying on the main neutron-capture path. The scale on the right shows the number of neutrons captured per nucleus as calculated by the "static" method, which does not make allowances for the changing abundances.

A.G.W. Cameron, ApJ 121 (1955) 144

State of the s-Process 1957

In the past 50 years, most of the relevant capture cross sections could be measured.
As we will see later this week, this has changed the figure at bottom left considerably.

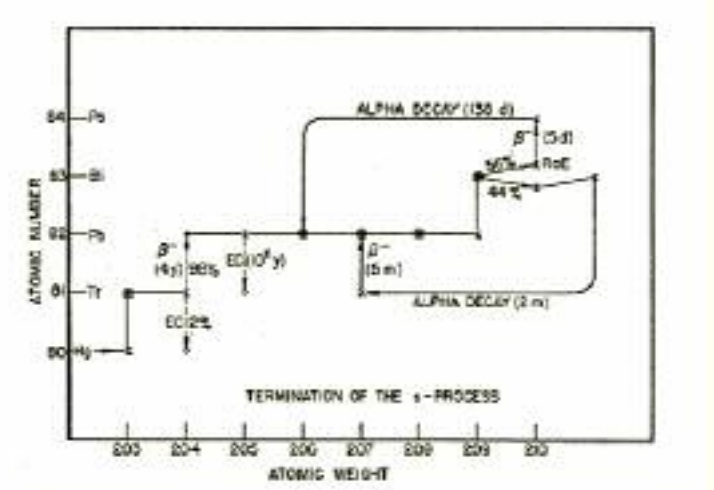
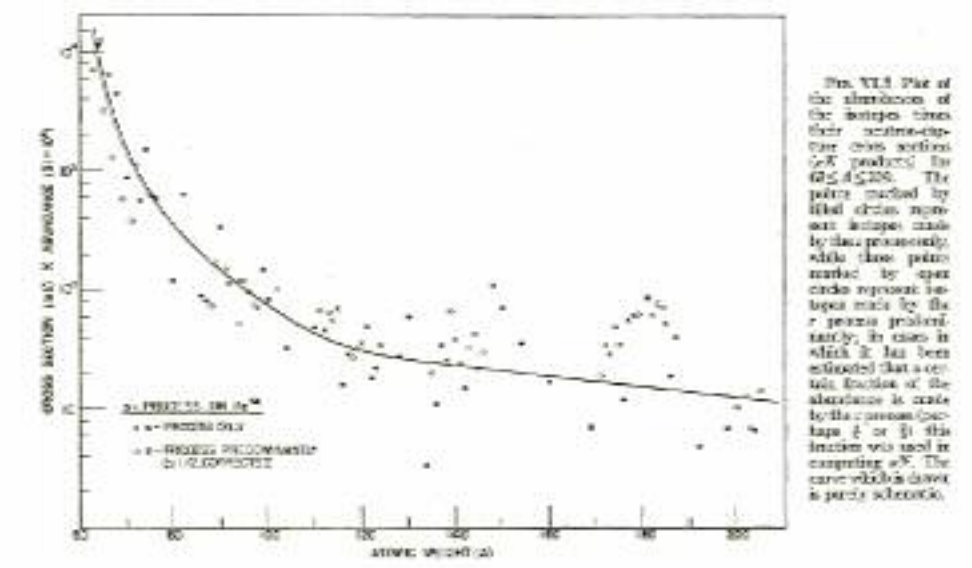
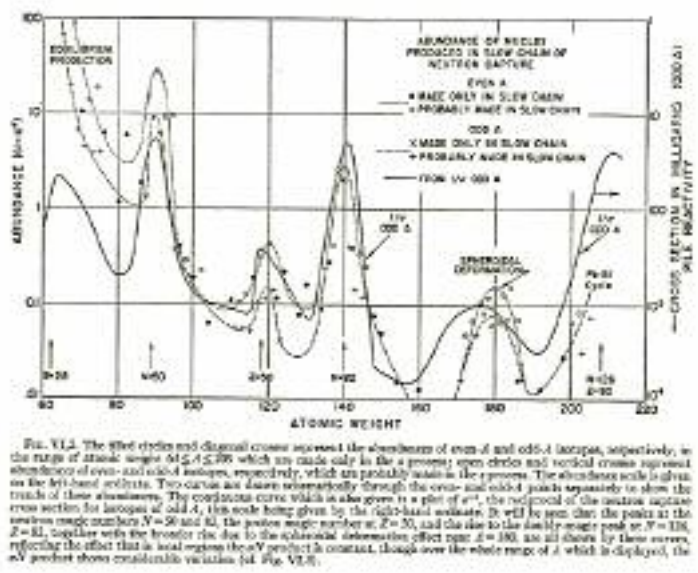


FIG. VIII,5. This diagram shows the details of the termination of the *s* process. The half-life for electron capture in Pb^{205} should be changed to $\sim 5 \times 10^7$ years.





The p-Process

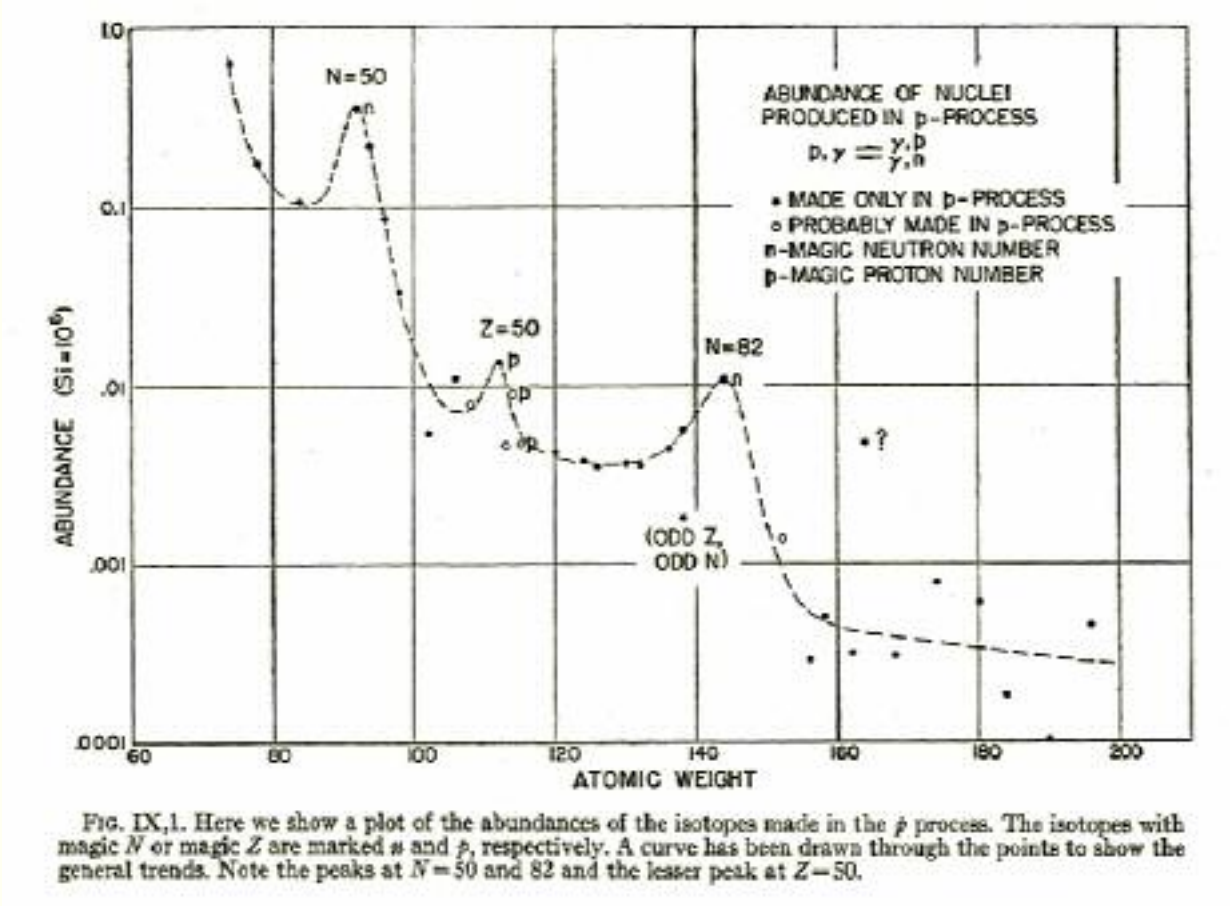


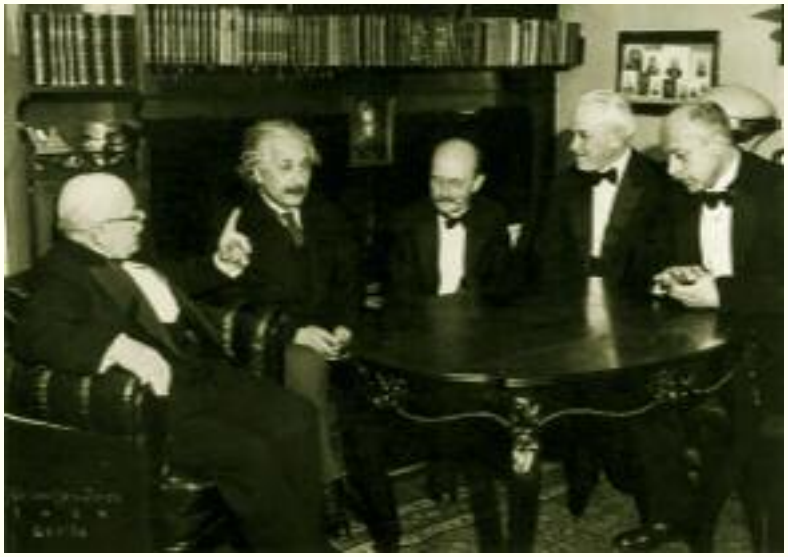
FIG. IX,1. Here we show a plot of the abundances of the isotopes made in the p process. The isotopes with magic N or magic Z are marked n and p, respectively. A curve has been drawn through the points to show the general trends. Note the peaks at $N=50$ and 82 and the lesser peak at $Z=50$.

As we will see the next days, this process has undergone quite substantial changes since 1957.

1920 chemistry

We followed the development of science for more than 2000 years. Contrary to many textbooks, it was not always a straightforward progress. Many concepts later on had to be discarded and were replaced by „better“ ones.
Even Nobel awards developed „strange“ ideas. Others made many outstanding contributions to physics, but were not rewarded due to out-of-the-field contributions.

1923 physics



Nernst, Einstein, Planck, Millikan, von Laue
Berlin, 1928

Remark:
Nernst and Millikan did not cite each others cosmological work.
But at least they made conversation.

What will future historians think about our works?

Sir Fred Hoyle