XU Guangxian: Father of Chinese rare earths chemistry

By XIN Ling (Staff Reporter)

Decades ago, he invented a cascade extraction theory and technique that have greatly facilitated the production of the so-called "industrial vitamins," shifting China's role from a low-profit exporter of raw ores to the world's dominant supplier of separated individual rare earth compounds and metals in high purity. Now, long past retirement age, he is still actively engaged in the development of China's rare earth industry by calling for planned exploitation and resource conservation. Prof. Xu Guangxian (Kwang-Hsien Hsu), 89, a CAS Member and laureate of the 2008 State Supreme S&T Award, is among the most outstanding scientists of our time.

Prof. Xu shakes hands with Chinese President Hu Jintao at the awarding ceremony of the State Supreme S&T Award on 9 January, 2009 in Beijing.

Reshuffling world's rare earth market

A native of southeast China's Zhejiang Province, Xu was born a curious and diligent boy. In the 1940s, though tossed by warfare and family decline, the young man took up chemistry at Shanghai Jiao Tong University and became a technician to support his family after graduation.

Before long, Xu got a chance for postgraduate studies in the US. Thanks to his outstanding academic performance at Columbia University, he was elected a member of the Honorary Phi Lambda Upsilon Chemistry Society in 1949 and the Honorary Sigma Xi Science Society in 1951. In the spring of 1951, he received his PhD with a major in quantum chemistry and returned to China with his wife GAO Xiaoxia, a chemist who received an MS degree in analytical chemistry at New York University.

In the same year Xu and Gao both joined the faculty of the Chemistry Department, Peking University. Xu became the first to teach physical chemistry at Peking University and quantum chemistry at Yanjing University. In 1957, he was appointed deputy director of the newly-established Department of Technical Physics at Peking University, which consisted of two specialties: nuclear physics and radiochemistry. Xu was in charge of radiochemistry.

The professor might have never expected his career to reach climax in an entirely unacquainted field. It was in 1972 that Xu, already in his fifties, was assigned a mission – to separate praseodymium (Pr) and neodymium (Nd).

According to Prof. Xu, Pr and Nd belong to a unique class of metal elements in the periodic table called the "rare earth elements" (REE). The REE, due to their particular photoelectronic, electrical and magnetic properties as well as catalytic and medical functions, are of vital importance to the development of high technology and national defense. They are also indispensable in our daily life as a component of energy-saving light, mobile phone, television, camera, etc.

However, most of the REE, 17 of them in all, naturally intergrow with one another. With similar atomic

What are rare earth elements?

Rare earth elements (REE) refer to a collection of 17 metallic elements which form the largest chemically coherent group in the periodic table. They include scandium (Sc), yttrium(Y) and 15 lanthanoids: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb) and lutetium (Lu).

The REE became known to the world with the discovery of the black mineral ytterbite by Lieutenant Arrhenius in 1787, in a quarry in the village of Ytterby, Sweden. The term "rare earth" arises from the minerals from which they were isolated, which were uncommon oxide-type minerals (earths).

High-tech and environmental applications of the REE have grown dramatically in diversity and importance over the past decades. For instance, Y_2O_3 is a sort of white powder used in color TV phosphors to help the screen show red. La_2O_3 plays a key role in camera lens. The yellowish CeO_2 is good at decoloring and polishing material for glass. On the contrary, the pale purple powder of Nd_2O_3 is a coloring agent for glass and ceramics. When Ce-Zr composite oxide works as the catalytic converter for cars' exhaust gases, ZrO_2-doped artificial precious stones have always been loved by girls.

With REE, the guidance system of missiles will be more accurate and the armor of tanks more solid. Seeing their significance in national defense, countries like the US and Japan have already put the REE in a list of "strategic elements" and prescribed "a minimum reserve of REE" in law. ■

structures and chemical characteristics, they are difficult to separate. “In Latin, praseodymium means ‘the green twin’; neodymium ‘the new twin’. They were the most inseparable ‘twins’ at that time,” Xu smiled.

At a time when key separation techniques were monopolized by developed nations like the US, France and Japan, China, despite its largest proved REE reserves in the world, could only sell raw ores at a cheap price and buy back refined metals from overseas producers.

Without delay, Prof. Xu set about collecting data. “He made boxes of cards, and conducted a comprehensive classification, summary and abstraction of all literature available on separation techniques,” said Dr. YAN Chunhua, director of the State Key Laboratory of Rare Earth Materials Chemistry and Applications, Peking University, an expert in functional materials chemistry who got his PhD under Xu’s supervision.

The professor discovered that Pr-Nd separation was not a readily solved problem around the world. Most producers were still using the traditional ion exchange method, which was time-consuming and costly. As a matter of fact, the theory for REE extraction seemed to be just emerging and immature. Xu decided to start with setting up a systematic extraction theory.

Nothing was easy at the beginning. Prof. Xu and colleagues had to follow traditional practices for a while. In the daytime, they shook separatory funnels and recorded extraction data. Late into the night, the chemist continued to probe into rules behind the figures.

“Those days, we worked above 80 hours a week,” Xu recalled. Even with such painstaking efforts, an entire experiment process would still cost “dozens of technicians about one year and a half to complete, not always with optimal results”, according to HUANG Chunhui, renowned rare-earth chemist, CAS Member and Xu’s former student.

Xu said to himself, “I don’t feel like shaking funnels any more!”

Xu finally got inspiration from some “push and pull system” already abandoned by scientists at the US Bureau of Mines, and, thanks to his talent in theoretical calculation and rich experience in Uranium and Plutonium extraction, established his own “cascade theory of countercurrent extraction ” for separating REE. With this theory, the purity of rare earth products could hit a record high of 99.999%.

Hurray. But in Xu’s eye, it was just a minor victory. He understood that the next, decisive challenge was how to apply the novel theory to industrial production.

At that time, even at Rhodia, the world’s largest rare earth producer, the extraction techniques were empirical and feasible only for some constituent-specific ores. “It wouldn’t do for China. The composition of our deposits usually varies against geographic distribution – from Inner Mongolia in the north, to Shandong in the east and Sichuan in the west.” Therefore, if Xu could design a new technique to separate all REE including the Pr-Nd twin, it could be a perfect fulfillment of his assignment.

Once majoring in quantum chemistry, Xu is endowed with a strong background in theoretical calculation and induction. Based on countless experiments at laboratory and in rare earth factories, he worked out over a hundred formulas to express the complicated process of extraction. He also simulated the process of shaking funnels using a computer. In this way, the best technical procedure for ingredient-diverse raw materials just came under control.

“After that, we need no more than a week to design a whole production procedure,” Dr. Yan emphasized. For operators at the workshop, all they have to do is to press a few buttons and punch data into the machine, which will then figure out the optimized technical parameters all by itself.

Prof. Xu’s invention was soon adopted by some domestic factories, put into production, and became popular across the country. In 1978, a nationwide training course on countercurrent extraction was hosted free of charge at Peking University. Technicians and chief engineers from chemical plants, as well as scientists from research institutes and universities swarmed to learn Xu’s magic know-how. Rare earth separation and extraction techniques, a hard nut to crack for too long, became a widespread skill in underdeveloped China.

Xu’s legendary success eventually reshuffled the world market. The price of pure rare earth metals plunged by some 70%. This is known as the “China impact”.

Meanwhile, China’s rare earth industry turned over a new leaf. Ever since the 1990s, China’s export quota of high-purity rare earth products has been rocketing. Now over 90% of the world's annual consumption of REE comes from Chinese chemical plants. It brought about billions of dollars of income to the nation.

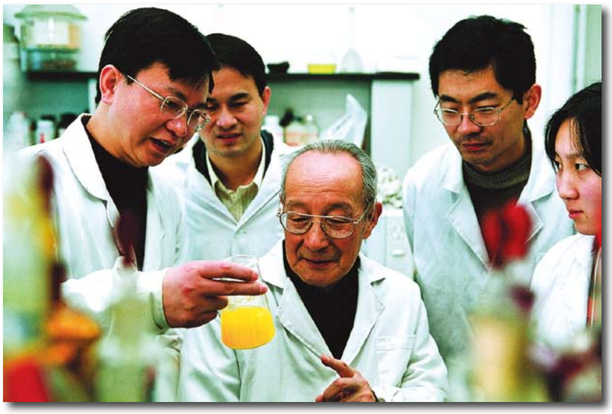
Today, the cascade theory of countercurrent extraction is still the keystone of China's rare earth industry.

"My work is far from complete"

The cascade theory of countercurrent extraction has brought Xu Guangxian many glories and honors. For instance, he has been awarded twice by the Ho Leung Ho Lee Foundation. On 9 January, 2009, he became one of the two laureates of the State Supreme S&T Award, the top prize for Chinese scientists and engineers.

At the ceremony, the chemist, 89, was neat in his white shirt and navy blue suit. White hair, sagacious forehead, gold-rimmed glasses, a lank but elegant figure. He looked so happy to shake hands and whisper with Premier WEN Jiabao, with a childlike smile on his face.

"Except for bad hearing, I'm in good health," he told a crowd of journalists. "Every day I work for five hours, searching online information and writing research papers. Then I take a walk around my residence, and read my favorite kung fu novels."



Prof. Xu (center), Prof. YAN Chunhua (1st left) and other colleagues.

Xu Guangxian, a dedicated and successful educator

As a university professor, Xu Guangxian once mentioned that "nothing is more important than teaching", a career to which he has devoted the best part of his life. In class, he presents the essence of theoretical chemistry in simple language. *Structure of Matter,* a collection of Xu's early lectures, boasts one of the most popular and lasting textbooks in China that has enlightened generations of chemists.

And nothing can make him happier than to see the students grow up into healthy and useful people. Some followed in his footsteps to become CAS Members, which are the highest honor of lifelong tenure conferred by the Chinese government in science and technology communities, or Cheung Kong Professors, an honor granted by the Chinese Ministry of Education, making active contributors to China's high-tech development. Quantum chemist LI Lemin, photoelectronic materials expert HUANG Chunhui, inorganic chemist GAO Song, founder of microemulsion extraction method WU Jinguang, and YAN Chunhua who improved Xu's countercurrent extraction theory and developed a new process for rare earth separation: they were all Xu's disciples.

Prof. Xu has been respected and loved because he is a kind-hearted and generous man in the first place. He often supports those who need money to continue study. He donated his HLHL prize to fund young talents. The 5-million-yuan ($730,000) supreme award will wholly be used to encourage further research and training, he said.

However, the professor is always strict with himself. He has never been late for class, not even for one minute. Over so many years, he seldom bought himself expensive clothes, and wears the same jacket for over a decade. ■

"I just couldn't get rid of my 'rare earth complex' over the past 47 years," he laughed.

Indeed, Prof. Xu has been concerned with the development of domestic rare earth industry for many years. He feels happy to see it blooming, of course.

Once in a while, people can read worry and anxiety from the old man's face when he talks a lot about ongoing problems undermining the cash-cow trade: unrestrained and unscientific exploitation, resource outflow, environmental crisis and so on.

A few statistics will suffice to explain Xu's worry. For dozens of rare earth factories in China, their total output is some 120,000 tons each year. The world's annual demand stays around 100,000 tons. Severe oversupply leads to excessive competition, low price and marginal profit, reportedly as low as 1% to 5%. The most heart-stricken reality for Prof. Xu is that "though China now corners the world's rare earth production, we still have so little power in pricing."

Seeing the key role of REE in high-tech development and national defense, some countries have been buying rare earth "bargains" from China since years ago. They stock up these "strategic elements" in case of resource shortage. The natural treasure, once sold, will cost manyfold to repurchase when China's deposits run out, Xu warned.

The professor couldn't sit by any more. In 2005, he submitted a joint letter (signed by 15 CAS Members) and in 2006 another letter to Premier Wen Jiabao, appealing for the scientific exploitation and management of rare earths resources in China. The letters were promptly responded by the Premier. In 2006, the Chinese government issued a list of export-forbidden REE products, declaring that starting from 2007 the domestic production of REE will be restrained to under 80,000 tons per year. This news soon boosted the price of Chinese high-quality REE products by one to two-folds in the world market.

Xu also proposed that exploitation be guided by scientific management. Take the Bayan Obo Mine, the world's biggest deposits of rare earth metals situated in suburban Baotou, northern China's Inner Mongolia. Harboring over half of the world's total rare earth reserves, it is a mixed deposit of different mineral elements including ferrum (Fe), the REE, thorium (Th) and niobium (Nb).

"The Bayan Obo Mine has been exploited mainly for its iron ores over the last five decades. However, the rare earth and thorium were largely neglected and wasted," Prof. Xu is upset.

"Things can be worse. Thorium is an important radioactive element for nuclear energy. The mine tailing containing REE and Th may blend with discharged flood after local rainy season, and pose great danger to the water safety for millions of residents in Baotou. Even the Yellow River might be polluted."

"But mismanagement is sometimes beyond what scientists could manage." The anxious look came back on his face.

The 89-year-old man is still on the run, and his name will be remembered forever with the China's chemistry of rare earths. ■