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# RARE EARTH CRITICAL MATERIALS

## CSS DIALOGUE REPORT

THE CENTRE FOR SECURITY STUDIES

# RARE EARTH ELEMENTS

This report is about Rare Earth Elements (RREs), which consist of seventeen metallic elements that play a crucial role in many high-tech devices. These elements are also called Rare Earth Oxides, as most of them are usually sold as oxide compounds. Currently, China is the largest producer of these rare earth elements.

The aim of this report is to analyse some of the Rare Earth Elements such as Cerium, Dysprosium, Europium, etc. Each element is examined based on its availability, applications, extraction and production methods, environmental effects, and more. In recent years, the demand for these elements has increased rapidly due to their critical importance in various technologies. They are particularly essential for producing high-performance magnets used in electric vehicle motors, wind turbines, and military equipment. Despite their significance in modern industry, the exploration, extraction, and sustainable use of REEs present significant challenges. This report also analyses some of the challenges involved in the use of REEs.

This report, divided into 3 parts, is the work of 9 Research Interns at CSS. They have researched rare earth elements that play a crucial role in modern technologies such as clean energy. It aims to provide valuable insights and perspectives to deepen our understanding of these elements.

This report is a product of the Centre for Security Studies, Jindal School of International Affairs.

**Centre for Security Studies**

Jindal School of International Affairs

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# CERIUM

*Madalsa Jain*

## About Rare Earth Minerals

Today because of the COVID-19 pandemic Rare Earth Minerals (REE) are a set of 17 metallic elements that include 15 lanthanoids on the periodic table, excluding scandium and yttrium. They have very similar properties and chemists across the world, tried for more than a hundred years to separate them. William Crookes, the great Victorian inventor and spectroscopist wrote in 1887, "these elements perplex us in our researches; they baffle us in our speculations and haunt us in our very dreams. They stretch like an unknown sea before us, marking mystifying and murmuring strange revelations and possibilities."[1]

These elements are available in abundance in the crust of the Earth. However, they are found across trace impurities. Rare earth elements are used in various applications in a highly pure format. However, converting the rare earth minerals to a product of higher purity requires machinery and processes that are time, money and effort exhaustive. For this reason, they are termed as 'rare'. They are not often found in concentrated enough clusters to make them viable to mine. It was the scarcity of these minerals that led to them being called rare earths.[2]

Rare-earth elements are necessary components of more than 200 products across a wide range of applications, especially high-tech consumer products, such as cellular telephones, computer hard drives, electric and hybrid vehicles, and flat-screen monitors and televisions as well as significant defence applications including electronic displays, guidance systems, lasers, and radar and sonar systems.[3] Although the amount of REE used in a product may not be a significant part of that product by weight, value, or volume, the REE can be necessary for the device to function.[4]

[1] Stephen, B.C. & Hedrick, J. B. (1990). Rare Earth Minerals. *Industrial Minerals and Rocks.* Available at: https://web.archive.org/web/20180722021907id_/http://www.fieldexexploration.com/images/property/1_RareEarths_FLX_02.pdf.

[2] Lynas Corp. (2022, November 29). *What are rare earths?* Lynas Rare Earths. https://lynasrareearths.com/products/what-are-rare-earths/.

[3] *What are rare earth elements, and why are they important?* (2018, February 1). American Geosciences Institute. https://www.americangeosciences.org/critical-issues/faq/what-are-rare-earth-elements-and-why-are-they-important.

[4] Id.

## About Cerium

The atomic number of Cerium is 58, out of 118 elements of the periodic table. The atomic mass of cerium is 140.12g.mol$^{-1}$. The melting point of cerium is at 799 Celsius and the boiling point is at 3426 Celsius. Cerium was discovered in 1803, two years after the discovery of Ceres, the dwarf planet which was named after the Roman goddess of agriculture. Cerium was in turn named after Ceres.

It is a metal that is grey in appearance. It is highly reactive and tarnishes easily when exposed to air.[5] It also reacts with water. It sparks when it is heated, scratched or filed. It is also malleable, soft and ductile. Cerium is slightly harder than lead. It dissolves in acids except hydrofluoric acid (HF) which leads to the formation of the protective fluoride (CeF3) layer on the surface of the metal. It is because of these reasons that Cerium has to be stored in either vacuum or inert atmosphere.

## History of Cerium

Cerium was first identified by Jons Berzelius and Wilhelm Heusinger in the winter of 1803. Martin Klaproth discovered it independently in the same year. The two groups of discoverers engaged in an academic race for the publication of papers proving the discovery of Cerium.

Although cerium is one of the 14 lanthanoids, it was discovered separately and independently.[6] Some minerals are almost exclusively cerium salts such as cerite, which is cerium silicate.[7] A lump of this mineral had been found in 1751 by Axel Cronstedt at a mine in Vestmanland, Sweden. He sent some to Carl Scheele to analyze it but he failed to realize it was a new element.[8] In 1803, Berzelius and Heusinger examined it themselves and proved that it contained a new element. Cerium oxide, which is also known as Ceria, was examined and it is from Ceria, that cerium was extracted using the process of electrolysis.

[5] *Cerium - Element information, properties and uses | Periodic Table*. (n.d.). https://www.rsc.org/periodic-table/element/58/cerium#:~:text=Cerium%20is%20the%20most%20abundant,and%20treating%20with%20hydrochloric%20acid.
[6] Id.
[7] *Cerium - Element information, properties and uses | Periodic Table*. (n.d.). https://www.rsc.org/periodic-table/element/58/cerium#:~:text=Cerium%20is%20the%20most%20abundant,and%20treating%20with%20hydrochloric%20acid.
[8] *Cerium - Element information, properties and uses | Periodic Table*. (n.d.). https://www.rsc.org/periodic-table/element/58/cerium#:~:text=Cerium%20is%20the%20most%20abundant,and%20treating%20with%20hydrochloric%20acid.

It was not until 1875 that William Hillebrand and Thomas Norton obtained a pure specimen of cerium itself, by passing an electric current through the molten cerium chloride.[9]

## Geopolitical Distribution of Rare Earth Minerals

In 1993, 38 per cent of world production of REEs was in China, 33 per cent was in the United States, 12 per cent was in Australia, and 5 per cent each was in Malaysia and India.[10] Several other countries, including Brazil, Canada, South Africa, Sri Lanka, and Thailand, made up the remainder.[11] However, in 2008, China accounted for more than 90 per cent of world production of REEs, and by 2011, China accounted for 97 per cent of world production.[12] Beginning in 1990 and beyond, supplies of REEs became an issue as the Government of China began to change the amount of REEs that it allows to be produced and exported.[13] The Chinese Government also began to limit the number of Chinese and Sino-foreign joint-venture companies that could export REEs from China.

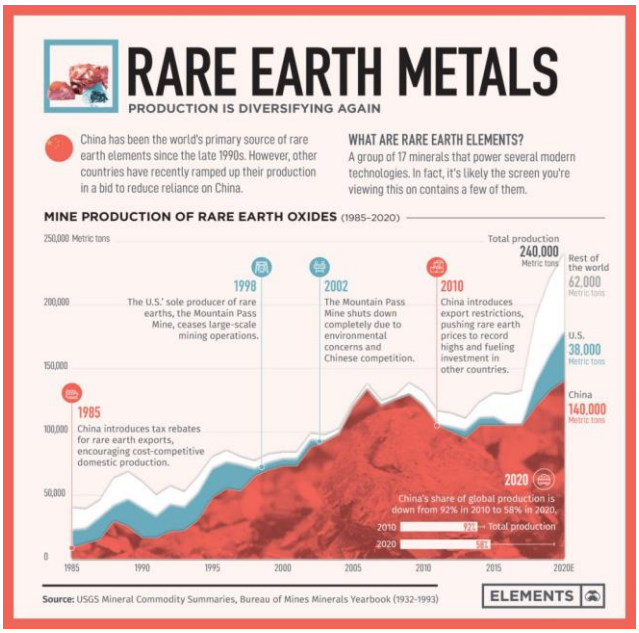


Fig 1[14]

[9] Id.
[10] *What are rare earth elements, and why are they important?* (2018, February 1). American Geosciences Institute. https://www.americangeosciences.org/critical-issues/faq/what-are-rare-earth-elements-and-why-are-they-important.
[11] Id.
[12] *What are rare earth elements, and why are they important?* (2018, February 1). American Geosciences Institute. https://www.americangeosciences.org/critical-issues/faq/what-are-rare-earth-elements-and-why-are-they-important.
[13] Id.
[14] Bhutada, G. (2021, April 2). *Rare Earths Metals Production Is No Longer Monopolized by China*. Mining. Available at: https://www.mining.com/rare-earth-metals-production-is-no-longer-monopolized-by-china/

| Year | U.S. Production (metric tons) | China's Production (metric tons) | ROW Production (metric tons) | U.S. % Share | China's % Share |
|---|---|---|---|---|---|
| 1985 | 13,428 | 8,500 | 17,757 | 34% | 21% |
| 1990 | 22,713 | 16,480 | 20,917 | 38% | 27% |
| 1995 | 22,200 | 48,000 | 9,700 | 28% | 60% |
| 2000 | 5,000 | 73,000 | 5,500 | 6% | 87% |
| 2005 | 0 | 119,000 | 3,000 | 0% | 98% |
| 2010 | 0 | 120,000 | 11,000 | 0% | 92% |
| 2015 | 5,900 | 105,000 | 19,100 | 5% | 81% |
| 2020 | 38,000 | 140,000 | 62,000 | 16% | 58% |

Edit

Fig 2[15]

## Applications of Cerium

Cerium is used as a core for the carbon electrodes of arc lamps for incandescent mantles for gas lighting. It is used in stainless steel as a precipitation-hardening agent and to make permanent magnets. Lanthanum and cerium are used as power sources in hybrid EVs and as battery electrodes in nickel metal hybrid batteries.[16]

Cerium is the major component of mischmetal alloy; a type of alloy that is made only by mixing rare earth minerals. In powdered form, cerium is very reactive, especially when alloyed with iron. It forms a brittle material of ferrous cerium which sparks spectacularly when struck and is the basis of the flints of cigarette lighters and fire steels for chefs.[17] The best-known use for this alloy is in 'flints' for cigarette lighters as discovered by Carl Auer von Welsbach.[18] This is because cerium will make sparks when struck. Iron is the only other element with the same property. It burns fiercely because cerium is electropositive and gives its outer electrons easily. Ceria is very stable.

Ceria is also very hard which is why it makes a good polish for a lens. Cerium (III) oxide has uses as a catalyst. It is used in the inside walls of self-cleaning ovens to prevent the

[15] Bhutada, G. (2021, April 2). *Rare Earths Metals Production Is No Longer Monopolized by China*. Mining. Available at: https://www.mining.com/rare-earth-metals-production-is-no-longer-monopolized-by-china/
[16] Mishra, N. (2022). Defense and Civilian Applications of Rare Earth Elements. *Journal of Air Power and Space Studies*, 17(3), 115 – 143.
[17] *Cerium - Element information, properties and uses | Periodic Table*. (n.d.). https://www.rsc.org/periodic-table/element/58/cerium#:~:text=Cerium%20is%20the%20most%20abundant,and%20treating%20with%20hydrochloric%20acid.
[18] Id.

build-up of cooking residues.[19] The formula for cerium oxide is $CeO_2$ (one cerium and two oxygen). Ceria is interesting in the sense that it misbehaves; in reality, the compound always has slightly less than 2 oxygens; the surface is peppered with defects, and gaps where an oxygen atom should be, and the degree of imperfection varies; it depends very much on how the oxide is prepared or treated.[20]

One of the headline uses for cerium oxide includes as catalytic converters in cars and trucks. Cerium (III) oxide nanoparticles are being studied as an additive for diesel fuel to help it burn more completely and reduce exhaust emissions.[21] A honeycomb of cerium dioxide helps to combust un-burnt fuel coming down the exhaust pipe by releasing oxygen during the oxygen-lean part of the engine's cycle while picking the oxygen back up in the rich stage.[22] As a nano-powder, mixed in with diesel fuel, it can clean up the otherwise sooty fumes produced by trucks and buses.[23] Cerium reduces the impact of internal combustion engines.

Cerium sulfide is a non-toxic compound that is a rich red colour and is environmentally desirable. It is used as a pigment. Cerium is also used in flat-screen TVs, low-energy light bulbs and floodlights.

Cerium has other mysterious properties as well. Cerium loses 4 electrons handing them over to the surrounding oxygen leaving aside defects, this means it has a 4+ oxidation state.[24] But on very close inspection with x-ray spectroscopy, it is clear that the cerium hangs on to at least some of those four electrons and its true oxidation state is in a quantum mechanical limbo somewhere between 3 and 4.[25] Japanese spectroscopist Akio Kotani once wrote that “there is no genuine example of Cerium (IV)”. The potential use of cerium in medicine and as a burn cream is a developing science and a mystery for now.

[19] *Cerium - Element information, properties and uses | Periodic Table*. (n.d.). https://www.rsc.org/periodic-table/element/58/cerium#:~:text=Cerium%20is%20the%20most%20abundant,and%20treating%20with%20hydrochloric%20acid.
[20] Id.
[21] *Cerium - Element information, properties and uses | Periodic Table*. (n.d.). https://www.rsc.org/periodic-table/element/58/cerium#:~:text=Cerium%20is%20the%20most%20abundant,and%20treating%20with%20hydrochloric%20acid.
[22] *Cerium - Element information, properties and uses | Periodic Table*. (n.d.). https://www.rsc.org/periodic-table/element/58/cerium#:~:text=Cerium%20is%20the%20most%20abundant,and%20treating%20with%20hydrochloric%20acid.
[23] Id.
[24] *Cerium - Element information, properties and uses | Periodic Table*. (n.d.). https://www.rsc.org/periodic-table/element/58/cerium#:~:text=Cerium%20is%20the%20most%20abundant,and%20treating%20with%20hydrochloric%20acid.
[25] Id.

Cerium also provides valuable properties when added in small amounts in various alloys; it makes aluminium more corrosion resistant, magnesium more heat resistant and helps reduce sulfur and oxygen content in steel.

## Compounds of Cerium

- Cerium Oxide ($CeO_2$) - It is a pale yellow-white powder with the chemical formula CeO2. It is an important commercial product and an intermediate in the purification of the elements from the ores. Cerium occurs naturally as oxides, always as a mixture with other rare-earth elements. After extraction of the metal ions into an aqueous base, Cerium is separated from that mixture by the addition of an oxidant followed by an adjustment of the pH. This step exploits the low solubility of CeO2 and the fact that other rare-earth elements resist oxidation.
- Cerium Nitrate ($CeNO_3$) - Cerium nitrate refers to a family of nitrates of cerium in the +3 or +4 oxidation state - contains water, hydroxide, or hydronium ions in addition to cerium and nitrate. Cerium magnesium nitrate (also known as cerous magnesium nitrate), is a highly paramagnetic salt and is a possible refrigerant for use in magnetic refrigeration.
- Cerium Chloride ($CeCl_3$) - Cerium chloride, also known as cerous chloride or cerium trichloride, is a compound of cerium and chlorine. It is a white hygroscopic salt; it rapidly absorbs water on exposure to moist air to form a hydrate, which appears to be of variable composition. It is highly soluble in water, ethanol, and acetone.
- Cerium Sulfide ($Ce_2S_3$) - Cerium sulfide is an inorganic compound. The distinctive red colour and chemical stability up to high temperatures have led to some limited commercial use as a red pigment (known as cerium sulfide red).

## Availability of Cerium Across the World

Cerium is the most abundant of the lanthanoids. It makes up 0.0046% of the Earth's crust in weight. Cerium comes mainly from the major lanthanide ores - allanite or orthite, monazite, bastnaesite, cerite and samarskite. It is also found in fission products of uranium, plutonium, and thorium. It is more abundant than tin or lead and almost as abundant as zinc.[26] It is found in many different ores and minerals, the most common of which are bastnaesite and monazite.

Production amounts to 23,000 tons a year, but this amount is likely to increase since more and more cerium is used nowadays. The main mining areas of cerium are in India,

[26] *Cerium - Element information, properties and uses | Periodic Table*. (n.d.). https://www.rsc.org/periodic-table/element/58/cerium#:~:text=Cerium%20is%20the%20most%20abundant,and%20treating%20with%20hydrochloric%20acid.

Brazil, the USA, China, Australia and Sri Lanka. The largest producers of cerium are Russia, China and Malaysia.

Cerium oxide is produced by heating bastnaesite ore and treating it with hydrochloric acid.[27] Metallic cerium can be obtained by heating cerium (III) fluoride with calcium, or by the electrolysis of molten cerium oxide.[28]

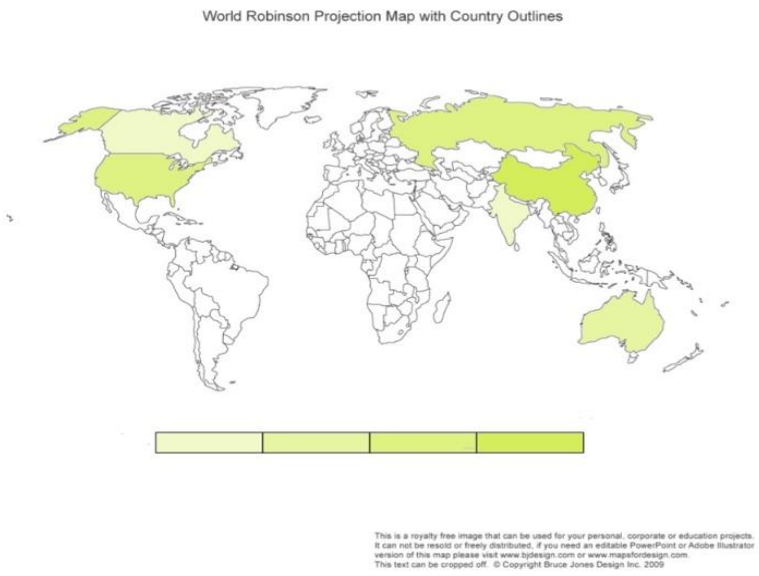


Fig 3[29]

## Environmental Effects of Cerium

Petrol-producing industries use cerium extensively and dump the same into the environment in many different places.[30] It can also enter the environment when household equipment like lamps, glasses and colour televisions are thrown away without proper waste management.[31] Cerium will gradually accumulate in soil and water soils and this will eventually lead to increasing concentration in humans, animals and soil

[27] Id.
[28] *Cerium - Element information, properties and uses | Periodic Table*. (n.d.). https://www.rsc.org/periodic-table/element/58/cerium#:~:text=Cerium%20is%20the%20most%20abundant,and%20treating%20with%20hydrochloric%20acid.
[29] Source: *Locations of deposits*. (n.d.). https://web.mit.edu/12.000/www/m2016/finalwebsite/solutions/deposits.html.
[30] *Cerium (Ce) - Chemical properties, Health and Environmental effects*. (n.d.). https://www.lenntech.com/periodic/elements/ce.htm#:~:text=Environmental%20effects%20of%20cerium,-Cerium%20is%20dumped&text=With%20water%20animals%20cerium%20causes,or%20wherever%20diesel%20engines%20operates.
[31] Id.

particles. With water animals, cerium causes damage to cell membranes, which has several negative influences on reproduction and the functions of the nervous system.[32]

Cerium also has positive effects on the environment. Its role as a catalytic converter helps slowly improve the atmosphere of the cities.[33] One way to reduce particulates emissions is to trap them in a ceramic filter and then burn them off via the addition of a little cerium oxide to the fuel itself, it will catalyze the burning of the particulates and eliminate them.[34]

## Use of Cerium in Military Industry

The US Department of the Interior released a list of 35 minerals it deems essential to economic and national security in 2018 (updated in 2022), amongst them are many REEs.[35] The extent of reliance on imports varies from mineral to mineral. Beryllium is mainly used to create lightweight material used in fighter jets, lithium is essential for modern battery production and tin is used in electronics, including soldier semiconductors, a sector that is projected to reach a value of $17.5bn by 2030.[36]

Cerium is used in batteries, and in most devices with a screen and magnets forged from neodymium and samarium are impervious to extreme temperatures that are used in fighter jet fin actuators, missile guidance, control systems, aircraft and tank motors, satellite communications and radar and SONAR systems.[37]

Today, an estimated 85% of the global rare earth oxide supply is produced in China.[38] Historically, because of market domination, individual producers of specific materials,

[32] *Cerium (Ce) - Chemical properties, Health and Environmental effects.* (n.d.). https://www.lenntech.com/periodic/elements/ce.htm#:~:text=Environmental%20effects%20of%20cerium,-Cerium%20is%20dumped&text=With%20water%20animals%20cerium%20causes,or%20wherever%20diesel%20engines%20operates.

[33] Id.

[34] *Cerium (Ce) - Chemical properties, Health and Environmental effects.* (n.d.). https://www.lenntech.com/periodic/elements/ce.htm#:~:text=Environmental%20effects%20of%20cerium,-Cerium%20is%20dumped&text=With%20water%20animals%20cerium%20causes,or%20wherever%20diesel%20engines%20operates.

[35] Neumann, N. (2022, March 23). Securing the rare earth supply chain is crucial for defence. Army Technology. https://www.army-technology.com/features/securing-the-rare-earth-supply-chain-is-crucial-for-defence/?cf-view.

[36] Id.

[37] Neumann, N. (2022, March 23). Securing the rare earth supply chain is crucial for defence. Army Technology. https://www.army-technology.com/features/securing-the-rare-earth-supply-chain-is-crucial-for-defence/?cf-view.

[38] Clark, M. (n.d.). *Rare earth elements aren't that rare, but they're vital to national security | The Heritage Foundation*. The Heritage Foundation. https://www.heritage.org/defense/commentary/rare-earth-elements-arent-rare-theyre-vital-national-security.

such as China and Chile, can temporarily sway market prices, causing disruption that free markets eventually correct, but not without doing damage to time-sensitive defence programs.[39] China has attempted to use its dominance in this sector for geopolitical gain. During tensions over the disputed Senkaku Islands in 2010, China unofficially imposed rare earth elements export limits against Japan.[40]

## Use of Cerium in the Medical Sector

In the biological system, cerium and lanthanum are used in bio-membranes to monitor the movement and deposition within the procurement of both plants and animals; and to develop the role of calcium in the cells.[41] It is also used in dental ceramics and medicines, La-based drug for hyperphosphatemia, Ho: YAG Laser for medical surgical procedures, Tm-169 and Yb for portable X-ray machines.[42]

Cerium and its derivatives have been used as remedies for wounds since the early 20th century.[43] Cerium nitrate has attracted the most attention in the treatment of deep burns, followed later by reports of its antimicrobial properties.[44] Cerium nitrate is currently used in wound treatment in combination with silver sulfadiazine as Flammacérium.[45] Cerium oxide, especially in nanoparticle form (Nanoceria), has lately captured much interest due to its antibacterial properties mediated via oxidative stress, leading to an increase in published reports.[46]

Cerium oxide has also found a potential usage in treating cardiovascular diseases. Nanomedicine is being explored to treat these diseases. Among these, Cerium Oxide ($CeO_2$) nanoparticles are gaining attention due to their irreversible oxidative states ($Ce^{3+}$ and $Ce^{4+}$), which provide them with many unique, physiologically important traits like antioxidant properties, anti-inflammatory properties, free radicle scavenging potential etc.[47] All these features make $CeO_2$ an excellent agent for treating many cardiac-related disorders.

[39] Id.
[40] Clark, M. (n.d.). *Rare earth elements aren't that rare, but they're vital to national security | The Heritage Foundation*. The Heritage Foundation. https://www.heritage.org/defense/commentary/rare-earth-elements-arent-rare-theyre-vital-national-security.
[41] Mishra, N. (2022). Defense and Civilian Applications of Rare Earth Elements. *Journal of Air Power and Space Studies*, 17(3), 115 – 143.
[42] Id.
[43] Barker, E., Shepherd, J. & Asencio, I.O. (2022). The Use of Cerium Compounds as Antimicrobials for Biomedical Applications. *Molecules*, 27(9), 2678. Doi: 10.3390/molecules27092678.
[44] Id.
[45] Barker, E., Shepherd, J. & Asencio, I.O. (2022). The Use of Cerium Compounds as Antimicrobials for Biomedical Applications. *Molecules*, 27(9), 2678. Doi: 10.3390/molecules27092678.
[46] Id.
[47] Shurfa, M.K. et al. (2023). Cerium Oxide Nanoparticles Applications in the Field of Cardiovascular Diseases. *International Journal of Pharmaceutical Sciences and Research*, 1(1), 530-537. 10.13040/IJPSR.0975-8232.14(2).530-37.

More uses for Cerium and its compounds in the medical sector are still being explored, among which cerium oxide and cerium nitrates are compounds with many medical properties and are of great potential use in the future.

## Cerium in Water Management

Environmental awareness has heightened across the world, considering the impending global warming and environmental degradation issues. This has resulted in more stringent regulations concerning different aspects of environmental conservation. Superior variations of the existing technologies such as nanofiltration and microwave disinfection as well as newer technologies like peracetic acid disinfection and Salsnes filter are researched to this effect.[48] Cerium oxide and its solid solutions have tremendous applications in several fields such as sensors, catalysts, solid oxide fuel cells, etc. It has also been extensively used in various water treatment processes.[49] There are inherent characteristics of cerium oxide like redox properties and oxidation storage capacity that make it effective in technologies like Advanced Oxidation Processes, adsorption, and filtration.[50]

The widespread usage of nanotechnology in many essential products has raised concerns about the possible release of nanoparticles (NPs) into aquatic habitats.[51] Cerium dioxide (CeO2) has gained the most interest in the worldwide nanotechnology industry of all types of Ce minerals owing to its beneficial uses in a wide range of industry practices such as catalysts, sunscreens, fuel additives, fuel cells, and biomedicine.[52] It was discovered that a large amount of CeO2 from untreated industrial waste could be released into the aquatic environment and affect all living organisms.[53] Thus, there is intended need to identify the optimal technique of synthesized CeO2 nanoparticles in order to assess their beneficial use or their potential ecotoxicological impacts on aquatic organisms and humans.[54]

## Conclusion

Cerium is an extremely important rare earth mineral. While the metal has fairly less

[48] Kurian, M. (2020). Cerium oxide based materials for water treatment – A review. *Journal of Environmental Chemical Engineering*, 8(5). https://doi.org/10.1016/j.jece.2020.104439.
[49] Id.
[50] Kurian, M. (2020). Cerium oxide based materials for water treatment – A review. *Journal of Environmental Chemical Engineering*, 8(5). https://doi.org/10.1016/j.jece.2020.104439.
[51] Naiel, M.A.E. et al. (2022). The Applications of Cerium Oxide nanoform and its ecotoxicity in the aquatic environment: an updated insight. *Aquatic Living Resources*, 35. https://doi.org/10.1051/alr/2022008.
[52] Id.
[53] Naiel, M.A.E. et al. (2022). The Applications of Cerium Oxide nanoform and its ecotoxicity in the aquatic environment: an updated insight. *Aquatic Living Resources*, 35. https://doi.org/10.1051/alr/2022008.
[54] Id.

important uses, the compound Cerium Oxide (CeO2) has been investigated as an element with multiple benefits and applications across various sectors. Geopolitically, what harms the mining of cerium as well as other rare earth minerals, is their concentration within China and ocean beds. Conducting mining processes in ocean beds is very environmentally dangerous. Recent studies have shown that the ocean buds surrounding Hawaii and French Polynesia are rich in Rare Earth Minerals. However, there are substantial issues in establishing a supply of these minerals, including cerium. A way forward for India would be to focus on extraction within its geography since India is blessed with a sufficient supply of Cerium. Given cerium's enhanced properties and usage in different fields including the medical field, military industry and water management, more funding and streamlined processes are required. There should be more encouragement from the government's side to research and examine the role of cerium nanoparticles in medicine.

# DYSPROSIUM

*Jayanti Dhingra*

## Introduction

Dysprosium is a Rare Earth Critical Materials (REE). REEs are those which are considered rare and important for the economy. Lanthanides are the rare-earth elements of the modern periodic table i.e. the elements with atomic numbers from 57 to 71 and they belong to the f-block of the periodic table. There are 15 Lanthanides plus Scandium (Sc) and Yttrium (Y). Dysprosium is a lustrous, silver and soft metal. It is considered to be stable at room temperature but it gets slowly oxidised by oxygen. REEs are the 15 lanthanides on the periodic table (La-Lu), plus Scandium (Sc) and Yttrium (Y).[1]

Dysprosium has the symbol **Dy** and the atomic number 66. It comes from the Greek word 'dysprositos' which means 'hard to get at.' This element is abundantly found in nature and even found in many minerals such as gadolinite, xenotime, euxenite, fergusonite, blomstrandine and polycrase.[2] Howeverit is mostly obtained by isolating the metal from minerals or monazite sand.

## History

Dysprosium was first discovered in 1886 by Paul-Émile Lecoq de Boisbaudran in Paris. Along with dysprosium, he also discovered Gallium and samarium metals. The discovery of Dysprosium came as a result of research into yttrium oxide, first made in 1794, from which other rare earth elements (which are known as lanthanoids) were subsequently extracted, namely erbium in 1843, holmium in 1878, and finally dysprosium in 1886. De Boisbaudran's method involved endless precipitations carried out on the marble slab of his fireplace at home. However, with the discovery, dysprosium was not obtained in isolation. It was mixed with other impurities, which were in impure forms. It was obtained as an impurity in Erbium ores, which contain oxides of holmium and thulium. His procedure for isolation involved dissolving dysprosium oxide in acid and then adding ammonia. He was only able to isolate dysprosium from its oxide after more than 30 attempts. Which is why, on succeeding, he named the element *dysprosium,* coming from the Greek '*dysprositos'* meaning

[1] Nayar, J. (2021, August 12). *Not so "Green" technology: the complicated legacy of rare earth mining*. Harvard International Review. https://hir.harvard.edu/not-so-green-technology-the-complicated-legacy-of-rare-earth-mining/

[2] Eric, R. (2019, May 12). What is Dysprosium? *Earth.com*. https://www.earth.com/earthpedia-articles/dysprosium/

"hard to get".

However, more forms of the element were prepared in 1906 by Georges Urbain. However that too contained certain levels of impurities. A pure form of the element was not produced until 1950, after the development of advanced chemical processes used for separation and distillation such as ion-exchange separation and metallographic reduction techniques by Frank Harold Spedding, a pioneer of rare earth research, and his team at Ames Laboratory.[3]

Earlier it was difficult to separate dysprosium from other rare earth minerals. However, with the introduction of new techniques for separation, it was possible to separate the rare earth elements reliably and efficiently. Earlier methods of separation have now been superseded by liquid-liquid exchange technology.

## Dysprosium Electron Configuration

The electronic configuration of the lanthanoids is $4f^{1-14}\ 5d^{0-1}\ 6s^2$.

Dysprosium is an element with position number sixty-six in the periodic table.

Reduced electronic configuration of Dy is:[4] $Xe\ 4f^{10}\ 6s^2$

## Isotopes of Dysprosium[5]

Dysprosium is composed of seven isotopes: $^{156}Dy$, $^{158}Dy$, $^{160}Dy$, $^{161}Dy$, $^{162}Dy$, $^{163}Dy$ and $^{164}Dy$. They all are stable except $^{156}Dy$, which has a half-life of over $1 \times 10^{18}$ years. Dysprosium has twenty-nine radioisotopes having atomic masses 138 to 173. The most stable is $^{154}Dy$, which has a half-life of around $3 \times 10^6$ years. $^{159}Dy$ has a half-life of 144.4 days and $^{138}Dy$ has a half-life of 200 ms. It also has 11 metastable isomers having atomic mass ranging from 140 to 165. $^{165m}Dy$ has a half-life of 1.257 minutes and $^{149m2}Dy$ has 28 ns.[6]

[3] *Dysprosium - Element information, properties and uses | Periodic Table*. https://www.rsc.org/periodic-table/element/66/dysprosium#:~:text=Dysprosium%20was%20discovered%20in%201886,in%201878%2C%20and%20finally%20dysprosium.
[4] Ibid
[5] Dodos, S. (2018, December 17). *Dysprosium Element | Uses, facts, physical & chemical characteristics*. Periodic Table. https://periodic-table.com/dysprosium/#:~:text=Dysprosium%20is%20chemically%20active%20metal,halogens%20above%20200OC.
[6] Ibid

## Physical Properties

Dysprosium is a bright silver lustrous metal with a soft nature, allowing for machining under controlled heating. The presence of even small impurities can impact its physical properties. At low temperatures, dysprosium exhibits its highest magnetic strength, with ferromagnetic order at 85K. Below this temperature, it transitions into an antiferromagnetic state. Ferromagnetic materials, like dysprosium, display strong magnetism in the direction of an applied magnetic field due to the varied alignment patterns of their atoms. This transition in dysprosium results in a disordered paramagnetic state at 179 K. Dysprosium is represented by the chemical symbol Dy, and has an atomic number of 66, and an atomic weight of 162.5. Its melting point is 1407°C, boiling point is 2562°C, and density at room temperature is approximately 8.540 g/cm³. Additionally, it has a Vickers Hardness of 540 MPa.[7]

## Chemical Properties

At a temperature below 85K, this metal exhibits high magnetic strength and are known to have ferromagnetic power, that is, they have high magnetic strength and usually depend on the varied alignment of atomic patterns and their interaction in the magnetic field. Dysprosium is known to be a chemically active metal.

It is stable in air at room temperature but slowly tarnishes in the air and burns to produce dysprosium (III) oxides, $Dy_2O_3$.

$4Dy + 3O_2 \rightarrow 2Dy_2O_3$

It also reacts rapidly with hot water and slowly with cold water to form dysprosium hydroxide, $Dy(OH)_3$, and hydrogen gas ($H_2$).

$2Dy(s) + 6H_2O(g) \rightarrow 2Dy(OH)_3(aq) + 3H_2(g)$

However, it reacts slowly with cold water. There are various impurities contained in a specific sample of dysprosium, which is removed by chemical reactions.

Additionally, dysprosium exhibits vigorous reactions with halogens above 200°C to form dysprosium(III) halides. So, it reacts with fluorine, $F_2$, chlorine, $Cl_2$, bromine, $I_2$, and iodine, $I_2$, to form respectively dysprosium(III) bromide, $DyF_3$, dysprosium(III) chloride, $DyCl_3$, dysprosium(III) bromide, $DyBr_3$, and dysprosium(III) iodide, $DyI_3$.

[7] The Editors of Encyclopaedia Britannica. (1998, July 20). *Dysprosium | Rare Earth Element, Uses & Properties*. Encyclopedia Britannica. https://www.britannica.com/science/dysprosium

$2Dy(s) + 3F_2(g) \rightarrow 2DyF_3(s)$ [green]

$2Dy(s) + 3Cl_2(g) \rightarrow 2DyCl_3(s)$ [white]

$2Dy(s) + 3Br_2(g) \rightarrow 2DyBr_3(s)$ [white]

$2Dy(s) + 3I_2(g) \rightarrow 2DyI_3(s)$ [green]

In dilute sulfuric acid, dysprosium dissolves quickly, yielding a yellow-coloured solution. The resulting compound, dysprosium (III) sulfate, is paramagnetic. It forms a yellow aquated Dy(III) ion together with hydrogen gas, $H_2$.

$2Dy(s) + 3H_2SO_4(aq) \rightarrow 2Dy^{3+}(aq) + 3SO_4^{2-}(aq) + 3H_2(g)$

Dysprosium oxide, also known as dysprosia, is a white powder that is more magnetic than iron oxide. It forms binary compounds with various non-metals at high temperatures, predominantly existing in the +3 oxidation state, although +2 oxidation states are also observed in compounds like DyN, DyP, DyH2, and DyH3. Dysprosium compounds are generally soluble in water, with the exception of dysprosium carbonate tetrahydrate and dysprosium oxalate decahydrate, which are insoluble.[8]

In general, dysprosium is a chemically active metal and is known to exhibit great magnetic strengths. That is why, it is commercially viable and has wide-ranging applications.

## Extraction of dysprosium

Dysprosium is extracted from minerals containing rare earth elements such as bastnasite and monazite. It is also found in other smaller quantities in other minerals such as xenotime and fergusonite.

However the primary source of dysprosium is monazite sand. Monazite sand is a phosphate mixture. It is obtained as a byproduct of nuclear fission and commercial yttrium extraction. Most undesired metals can be excluded magnetically or through a flotation process when isolating dysprosium. Liquid-liquid extraction or ion-exchange methods are used in the commercial separation of dysprosium from its ores.[9]

Liquid-liquid extraction is a method by which a compound is pulled from solvent A to

[8] Prof Mark Winter, University of Sheffield. (n.d.). *WebElements Periodic Table » Dysprosium » reactions of elements*. Copyright 2024 Prof Mark Winter. https://www.webelements.com/dysprosium/chemistry.html
[9] *Dysprosium | Metallurgy for Dummies*. https://www.metallurgyfordummies.com/dysprosium.html

solvent B where solvents A and B are not miscible, that is, they cannot be mixed. The solute partitions itself between two immiscible phases.

Ions are atoms that bear a positive or negative electric charge. Ion exchange is a chemical process to remove unwanted dissolved ions exchanging specific ions for ions that have the same charge. Certain insoluble materials bearing positive or negative charges on their surfaces react with ionic solutions to remove various ions, replacing them with ions of other kinds. They are used in a variety of ways to remove ions from solution and to separate ions of various kinds from one another.

The steps involved in the extraction of dysprosium are:

1. Mining: Rare earth mineral deposits are mined from the ground in the form of ores, utilizing methods such as liquid-liquid extraction and ion exchange.
2. Crushing and grinding: The mined ores are crushed and ground into a fine powder.
3. Leaching: The powdered ore is treated with a chemical solution, typically hydrochloric acid, to dissolve the rare earth elements in a process known as leaching.
4. Separation: An organic solvent is employed in liquid-liquid extraction to selectively extract dysprosium from other rare earth minerals.
5. Purification: The separated dysprosium undergoes purification through vacuum distillation to remove any remaining impurities.
6. Reduction: The purified dysprosium is then reduced to its metallic form using metallothermic reduction, which involves the reduction of anhydrous halides with alkali or alkaline earth metals. It can be reduced using calcium or lithium metal by the following reactions:

- $3Ca+2DyF_3 \rightarrow 2Dy+3CaF_2$
- $3Li+DyCl_3 \rightarrow Dy+3LiCl$

As and when the reaction progresses, the resulting compounds and molten dysprosium separate due to differences in density. When the mixture cools, dysprosium can be cut away from the impurities.[10] When dysprosium is in solid form, it is a silvery-coloured substance and it can be cut with a knife. But when it is in salt form, it is in a yellowish-green colour.

[10] Ibid

## Production of Dysprosium

Dysprosium is not found free in nature but is found in a number of minerals: mainly monazite and bastnaesite. Commercially, it is recovered from monazite sand and bastnaesite using ion exchange and solvent extraction techniques. Dysprosium metal can be produced by reduction of its trifluoride with calcium metal.

Dysprosium is found in the Earth's crust at an average concentration of about 5.2 mg/kg and in seawater at approximately 0.9 mg/L.[11] It does not exist in its free form in nature but is present in various minerals such as xenotime, fergusonite, gadolinite, euxenite, polycrase, blomstrandine, monazite, and bastnasite. Sometimes, dysprosium is also found in association with erbium and holmium.[12]

China presently produces some 60% of the world's rare earth elements and processes 85% of them.[13] More than 90 per cent of the world's annual production of dysprosium comes from China. Most dysprosium is obtained from the ion-adsorption clay ores of southern China. The dysprosium supply mainly results from mining, with the largest mining contribution in Jiangxi Province of China. Other countries that produce dysprosium include the USA, Australia, and Russia.

It is also produced in certain parts of India. In India, the Rare Earth (RE) resources are reported to account for the fifth largest in the world.[14] Sizable deposits of xenotime that contain the heavier rare earth dysprosium, have been found in the states of Chhattisgarh and Jharkhand. Meanwhile, bastnäsite—a source of cerium—is found in the state of West Bengal, though, over there, dysprosium is obtained in smaller quantities.[15] Countries all over the world majorly rely on China due to its high number of reserves of Rare Earth Critical Metals.

## Uses

Earlier, the problem behind not getting a sole sample of dysprosium was that there were no reliable methods for removing impurities. However the introduction of ion exchange methods and, liquid-liquid extraction methods have simplified the process a

[11] Squadrone, S., Brizio, P., Battuello, M., Nurra, N., Sartor, R. M., Benedetto, A., Pessani, D., & Abete, M. C. (2017). A first report of rare earth elements in northwestern Mediterranean seaweeds. *Marine Pollution Bulletin*, *122*(1–2), 236–242. https://doi.org/10.1016/j.marpolbul.2017.06.048
[12] Ibid
[13] Ezrati, M. (2023, December 11). How much control does China have over rare Earth elements? *Forbes*. https://www.forbes.com/sites/miltonezrati/2023/12/11/how-much-control-does-china-have-over-rare-earth-elements/?sh=283ccde55b21
[14] *Mining of rare earth elements*. https://pib.gov.in/PressReleasePage.aspx?PRID=1914305
[15] Saini, A. (2012). India to reopen mining for rare-earth elements. *Mrs Bulletin*, *37*(9), 792–793. https://doi.org/10.1557/mrs.2012.214

lot and have made dysprosium commercially viable.

Dysprosium (Dy) is a heavy rare earth element (HREE) with significant applications.[16]

- Dysprosium is used in control rods in reactors of nuclear energy plants as they have the potential to absorb neutrons. Dysprosium oxide-nickel cement plays a role in cooling nuclear reactor rods. Even under prolonged neutron bombardment, this cement absorbs neutrons readily without swelling or contracting. It is considered as a 'poison' to neutrons because dysprosium absorbs neutrons and that is why it is used in nuclear reactors a lot. When it is mixed with steel and nuclear rods, it absorbs all of the excess neutrons which stabilizes the reaction, thus helping in the absorption of neutrons.
- Dysprosium, when combined with vanadium and other rare earth elements, has been used in the production of laser materials. Dysprosium-cadmium has been used for studying chemical reactions as they are sources of radium.
- Dysprosium's main use is in alloys for neodymium-based magnets. This is because it is resistant to demagnetisation at high temperatures. This property is important for magnets used in motors or generators. These magnets are also used in wind turbines and electrical vehicles, so demand for dysprosium is growing rapidly.
- Dysprosium iodide is used in halide discharge lamps. The salt enables the lamps to give out a very intense white light.
- Since the magnetic susceptibility of dysprosium is high, it is utilised in applications of data storage systems. Data storage devices such as hard disks, floppy disks, compact disks, and flash drives can be produced with dysprosium alloys.
- Dysprosium alloys can also be employed in infrared devices. Infrared devices can be used for night vision, astronomy, weather forecasting, and communication.
- Due to their magnetic properties, dysprosium alloys can be employed in ships' sound navigation and range systems. It is therefore important to the marine industry.

## The Dysprosium Market

The global dysprosium market is anticipated to create lucrative growth over the forecast period from 2022 to 2032 by registering a CAGR of 5.2%.[17] The global

[16] *Periodic Table of Elements: Los Alamos National Laboratory*. https://periodic.lanl.gov/66.shtml

[17] *Dysprosium market*. (2022, June 29). https://www.futuremarketinsights.com/reports/dysprosium-market

market was valued at US$ 5.3 Billion in 2022 and it is expected to reach a valuation of US$ 8.8 Billion by 2032.[18] Asia Pacific is claimed to be the largest consumer of dysprosium.

The global dysprosium market is expected to increase significantly, owing to ever-rising demand from the automotive and electronics sectors, and also from new inventions of technologies to extract dysprosium effectively. Furthermore, the increased use of permanent magnets in consumer electronics and its wide-ranging applications in devices such as smartphones, televisions, and loudspeakers is boosting the worldwide dysprosium market.

New trends in electric mobility, automation, and energy efficiency are expected to augment the usage of dysprosium, propelling the market growth. Different techniques are also underway to develop dysprosium extraction in the coming years.

## Conclusion

Obtaining dysprosium is challenging. Due to its difficulty in isolation, dysprosium is typically utilized in mixtures with other metals. In comparison to other rare-earth metals, this makes it relatively expensive. As of January 10, 2024, its value amounted to 548 dollars per kg[19]. In terms of its health effects, dysprosium in free or elemental form is non-toxic. From toxicity tests, it was calculated that a dose of 500 grams or more would be needed to put a person's life at risk.[20] Certain salts of dysprosium that are water soluble are mildly toxic, but insoluble salts are not. So even though it is expensive, it is a highly sought-after rare-earth element due to its wide range of applications. It is necessary in a variety of industries including the maritime, automotive, biomedical, and telecommunication ones.

[18] Ibid
[19] *Dysprosium price now - Historical prices - 2024 forecast*. (2024, January 3). Strategic Metals Invest. https://strategicmetalsinvest.com/dysprosium-prices/#:~:text=The%20current%20price%20of%20Dysprosium%20is%20%24548.30%20per%20kg.&text=For%20bulk%20purchases%2C%20whether%20investment,us%20directly%20for%20a%20quotation.
[20] *Dysprosium (Dy) - Chemical properties, Health and Environmental effects*. https://www.lenntech.com/periodic/elements/dy.htm

# EUROPIUM

*Siddhant Kilpady*

## Introduction

In the Earth's crust, rare earth elements are comparatively numerous; cerium ranks 25th in terms of abundance, with 68 parts per million. It implies that it is as plentiful as copper. Rare earth elements (REE) are frequently dispersed due to their geochemical characteristics. In other words, it is rare to find them in dense enough clusters for mining to be profitable. The scarce nature of these minerals explains why they are known as rare earth elements[1]. Rare earth elements (REE) are a collection of seventeen metallic elements, which include the fifteen lanthanides listed in the periodic table as well as scandium and yttrium. Numerous high-tech devices require rare earth elements as components[2].

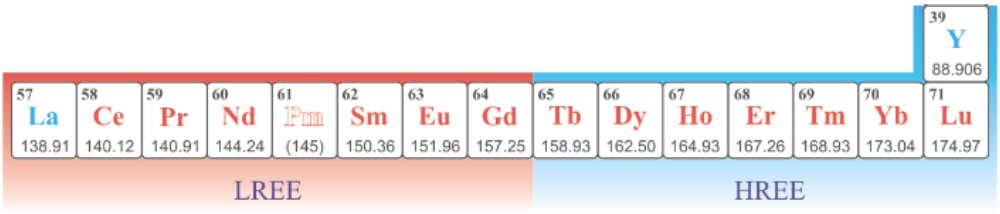


Fig. 4[3]

The lanthanide series refers to a group of 15 elements in the periodic table. Rare earth can be classified into light elements (LREE: lanthanum to samarium) and heavy elements (HREE: europium to lutetium). Owing to their rarity, heavy elements are more costly[4].

## The Discovery and Identity of Europium

[1] Earths, L. R. (n.d.). *What are Rare Earths?* Retrieved from Lynas Rare Earths: https://lynasrareearths.com/products/what-are-rare-earths/

[2] Institute, A. G. (n.d.). *What are rare earth elements, and why are they important?* Retrieved from American Geosciences Institute: https://www.americangeosciences.org/critical-issues/faq/what-are-rare-earth-elements-and-why-are-they-important

[3] Earths, L. R. (n.d.). *What are Rare Earths?* Retrieved from Lynas Rare Earths: https://lynasrareearths.com/products/what-are-rare-earths/

[4] Ibid

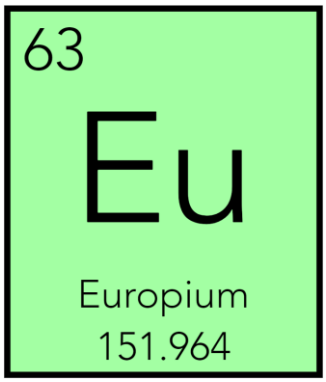


Fig 2[5]

Europium, as the name suggests, is named after the continent of Europe; this metal is rare. It has the symbol Eu (not the European Union) with an atomic number of 63. This metal belongs to the Lanthanide series of metals, with a melting point of 822°C and a boiling point of 1529°C[6]. Europium was discovered by a French scientist, Eugène-Antole Demarçay, in 1901. He had first suspected that the samples of a then recently discovered element, samarium, an element discovered by Paul Emile Lecoq[7], were contaminated with an unknown substance in 1896. Upon further investigation, Demarçay was successful in separating this contamination to finally get a substantial amount of pure europium in 1901[8].

Europium is a soft, silvery metal that discolours rapidly while also being reactive with water[9]. It possesses a distinct fluorescence under the influence of ultraviolet light (UV), which is helpful in manufacturing and legitimising technical instruments and even legal tender (banknotes). This luminescence is due to the element's unique electronic transitions and energy levels[10]. The scarcity of europium in the Earth's crust is one of its distinctive characteristics. It is recognised as a rare earth element, yet it is more abundant than several of its lanthanide parallels. Europium has been detected spectroscopically in the sun and other stars. There are presently 17 recognised isotopes. Because of their superior neutron absorption capabilities, europium isotopes have been researched for potential use in nuclear control mechanisms[11].

[5] Facility, T. J. (n.d.). *The Element Europium*. Retrieved from Thomas Jefferson National Accelerator Facility: https://education.jlab.org/itselemental/ele063.html
[6] Chemistry, R. S. (n.d.). *Europium*. Retrieved from Royal Society of Chemistry: https://www.rsc.org/periodic-table/element/63/europium
[7] Ag, I. F. (n.d.). *Europium, Eu, ordinal 63*. Retrieved from Institut Fur Seltene Erden und Metalle Ag: https://en.institut-seltene-erden.de/seltene-erden-und-metalle/seltene-erden/Europium/
[8] Facility, T. J. (n.d.). *The Element Europium*. Retrieved from Thomas Jefferson National Accelerator Facility: https://education.jlab.org/itselemental/ele063.html
[9] Chemistry, R. S. (n.d.). *Europium*. Retrieved from Royal Society of Chemistry: https://www.rsc.org/periodic-table/element/63/europium
[10] Ibid
[11] Laboratory, L. A. (n.d.). *PERIODIC TABLE OF ELEMENTS: LANL; Europium*. Retrieved from Los Alamos National Laboratory: https://periodic.lanl.gov/63.shtml

Beyond its application in televisions, europium is used in many other electronic applications. It is a necessary component in the production of phosphors for fluorescent lights and compact fluorescent bulbs. The red colour of these lighting sources may be effectively created by using europium due to its distinct luminescent capabilities. Beyond that, europium compounds are used in the manufacture of certain kinds of lasers and as a dopant in semiconductors[12].

Europium has received a lot of interest in the realm of nuclear energy recently. It is employed as a neutron absorber in nuclear reactor control rods to help control the velocity of nuclear fission processes. This application illustrates the flexible use of europium in both consumer electronics and complex technical systems[13]. Researchers in the domains of materials science and chemistry continue to be intrigued by the study of europium. For technology and material development to progress further, it is essential to comprehend its electrical structure, magnetic characteristics, and behaviour in different conditions. Europium's significance in the fields of science and business is expected to grow as researchers continue to explore its special properties and consider more possible uses for it in developing technology.

## Occurrence

The quantity of europium is only around 2 parts per millimetre (ppm) in the crust of the earth. A variety of lanthanide minerals include small amounts of europium; the minerals that contain europium in larger amounts remain uncertain[14]. It is found in cerite earths (a complex silicate mineral group containing cerium) such as monazite and bastnaesite, as well as ytter earths (a complex mineral group containing ytterbium) such as xenotime; the amount of europium generally falls between 0.1 and 0.2%. Up until 1985, the Bastnasite ore at Mountain Pass, California, was the most prominent resource for the extraction of europium. Since then, Chinese mines, specifically the ore deposit in Bayan Obo, have emerged as the most significant[15]. The two minerals that include europium as an impurity are bastnasite and monazite. Mining takes place in the United States, China, Russia, Australia, and India[16].

[12] Chemistry, R. S. (n.d.). *Europium*. Retrieved from Royal Society of Chemistry: https://www.rsc.org/periodic-table/element/63/europium

[13] LennTech. (n.d.). *Europium-Eu*. Retrieved from LennTech: https://www.lenntech.com/periodic/elements/eu.htm#:~:text=Europium%20is%20a%20soft%20silvery,and%20reacts%20readly%20with%20water.&text=Europium%20is%20a%20neutron%20adsorber,in%20nuclear%20reactors%20control%20rods.

[14] Ag, I. F. (n.d.). *Europium, Eu, ordinal 63*. Retrieved from Institut Fur Seltene Erden und Metalle Ag: https://en.institut-seltene-erden.de/seltene-erden-und-metalle/seltene-erden/Europium/

[15] Ibid

[16] Coalition, M. E. (n.d.). *Europium*. Retrieved from Minerals Education Coalition: https://mineralseducationcoalition.org/elements/europium/#:~:text=Europium%20is%20obtained%20from%20bastnasite,Russia%2C%20Australia%2C%20and%20India.

Naturally existing europium is a compound made up of two isotopes: Eu-151 and Eu-153. Eu-153 has the highest natural abundance (52.2%). 35 artificial radioisotopes have also been defined, with the most stable being Eu-150, which has a half-life of 36.9 years. Eu-152 has a half-life of 13.516 years, whereas Eu-154 has a half-life of 8.593. The remaining isotopes have half-lives of less than 4.8 years, with the majority of them lasting less than 12.2 seconds[17].

One of the nations with the highest concentration of rare earth minerals, namely bastnaesite and monazite, is the United States[18].

## Extraction and Preparation

The separation of europium from the other lanthanoids can be hard as a result of their resemblance to the partner metals and their low concentration in the ores, but it is additionally crucial due to the element's usage. Various techniques for separation are available once the primary minerals, such as monazite or bastnäsite, have been decomposed using sulfuric acid or sodium hydroxide solution. The reaction of europium (III) oxide with lanthanum or mischmetal might result in metallic europium. As a result, europium can be extracted from other metals and contaminants if this reaction is conducted in a vacuum[19].

## Uses of Europium

Europium serves in an extensive variety of industrial and medical applications, notably the manufacturing of fluorescent lights, lasers, and X-ray scanners[20]. Food products can have their flavour and colour improved by adding europium. Additionally, food goods can have their shelf life extended by using it as a preservative. Europium is also used as a nutritional supplement, supplying the body with essential minerals and vitamins. Europium is needed for the body to function normally. It regulates metabolism, supports red blood cell production, and improves bone and tooth health. Additionally, it may help lower the incidence of several cancer types and provide protection against oxidative stress. Furthermore, Europium may aid in boosting cognitive function and minimise the risk of Alzheimer's disease[21].

[17] earth.com. (n.d.). *What is Europium?* Retrieved from earth.com: https://www.earth.com/earthpedia-articles/europium/

[18] Metal, A. (n.d.). *Rare earths: resource distribution and production*. Retrieved from Asian Metal: http://metalpedia.asianmetal.com/metal/rare_earth/resources&production.shtml#:~:text=The%20United%20States%20is%20one,ore%20can%20also%20be%20collected.

[19] Ag, I. F. (n.d.). *Europium, Eu, ordinal 63*. Retrieved from Institut Fur Seltene Erden und Metalle Ag: https://en.institut-seltene-erden.de/seltene-erden-und-metalle/seltene-erden/Europium/

[20] DIGICOMPLY, S. (n.d.). *Europium*. Retrieved from Dietary Supplements Database: https://www.digicomply.com/dietary-supplements-database/europium

[21] Ibid

Europium is a common trace element used in geochemistry and petrology for better comprehension of the underlying processes that generate igneous rocks. Furthermore, to distinguish between genuine and counterfeit currency, it functions as a phosphor in Euro banknotes[22]. Europium's propensity to absorb neutrons renders it an ideal material for use in nuclear reactors[23].

## Europium (III) Oxide

Europium oxide is a highly insoluble, thermally stable Europium source that is frequently used for glass, optics, and ceramic applications. When europium metal is ignited, europium oxide, which mirrors manganese oxide in structure, is created. In an acidic reaction, europium oxide yields europium salts. Usually, europium oxide is available instantaneously. Nanoscale elemental powders and suspensions, as alternatives to large surface area forms, may be examined. Europium provides both needed red and blue colours in energy-efficient fluorescent lighting (oxide purity of 99.999%). Europium oxide (Eu2O3) powder mixtures lack the ability to conduct electricity[24]. Due to their high stability and insoluble nature in aqueous solutions (water), these substances find application in everything from basic ceramic structures like clay bowls to sophisticated electronics and lightweight components for electrochemical and aerospace applications like fuel cells. Europium oxide is also available as pellets, chunks, powder, sputtering targets, tablets, and nanopowder[25].

To create a pure red light, europium oxide functions as a phosphor in colour TVs and computer display panels. Because of its red spectrum, europium is additionally used in low-energy light bulbs to provide a warmer and more natural light as opposed to the harsh glare generated by traditional fluorescent tubes. Europium is also added to mercury vapour tubes to make powerful streetlights appear natural-looking. In the medical industry, europium is employed because, when linked as a tag to complex biochemicals, its extremely sensitive luminescence helps with the live tracing of these chemicals during living tissue research. Europium oxide is the most widely traded type because of its luminous qualities, which are used in a variety of practical applications[26].

## Market for Europium

[22] Materials, A. A. (n.d.). *Europium*. Retrieved from Rare Metals: https://avalonadvancedmaterials.com/rare_metals/europium/
[23] Ibid
[24] Manufacturer, A. E. (n.d.). *Europium Oxide*. Retrieved from American Elements: The Advanced Materials Manufacturer: https://www.americanelements.com/europium-oxide-1308-96-9
[25] Manufacturer, A. E. (n.d.). *Europium Oxide*. Retrieved from American Elements: The Advanced Materials Manufacturer: https://www.americanelements.com/europium-oxide-1308-96-9
[26] MMTA, M. M. (n.d.). *Eu - Europium*. Retrieved from Minor Metals Trade Association: MMTA: https://mmta.co.uk/metals/eu/

With a strong compound annual growth rate (CAGR) of 5.5% from 2022 to 2032, the international europium market is expected to offer an absolute dollar opportunity throughout the forecast period. By 2022, the worldwide market was estimated to be worth US$225 million, and by the end of 2032, it was expected to be worth US$385 million. The demand for europium is projected to increase globally over the course of the evaluation period due to several technological advancements in the field of earth metal nanocrystals[27]. The worldwide europium market is being propelled by many key growth drivers, including the expanding civil infrastructure and the growing demand for LEDs and flat panel displays. A multitude of prospective opportunities are also expected to be presented to the worldwide europium market by the increasing demand for the metal in emerging applications for end usage and growing economies like China, India, and others[28].

Due to its growing population, rising living standards, and disposable capital, China is the country that consumes this metal at the fastest rate. Japan's, Korea's, and China's growing demand for consumer electronics is propelling the industry in this area. China is the greatest producer of europium and its byproducts. However, there have been difficulties with supplies due to local demand growth and export constraints. Due to demand from the LED and consumer electronics sectors, North America follows Asia Pacific. New production and exploration sites have been established in this region to meet demand as a consequence of China's decreased exports[29].

Superconducting materials also use aspects of europium. Following the discovery of high-temperature superconductors (HTS) in the late 1980s, the possibility of using these materials in cutting-edge and efficient technological applications gained considerable popularity throughout Europe. In 2020, Europe was the largest regional market for superconductors. The demand for europium is constantly increasing due to the region's growing consumption of electricity. To promote energy appliances like wind turbines and maximise the europium market's income from sales, researchers constantly strive to optimise their power efficiency[30].

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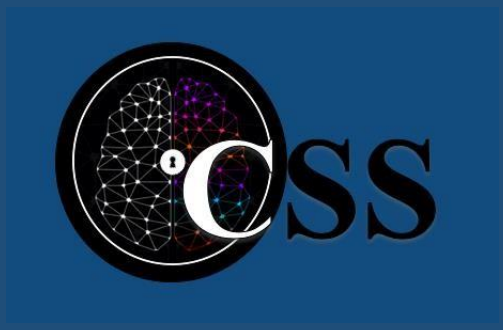


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