

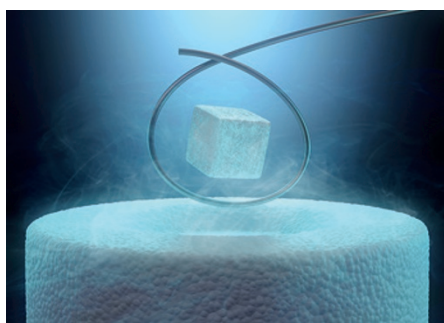
Yttrium from Ytterby

Peter Dinér describes the journey of yttrium from its discovery in a remote mine to high-temperature superconductors and light-emitting diodes.

If you find yourself in Stockholm with some time to spare for a piece of science history, I recommend making a short visit to the village of Ytterby on the nearby island Resarö. It is still possible to visit the abandoned and refilled mine that was the birthplace of four rare-earth elements, whose names all derive from Ytterby: yttrium, erbium, terbium and ytterbium.

The village's scientific story started in 1789 in a quarry, which at the time produced quartz for ironworks and feldspar for the porcelain industry, when Carl Axel Arrhenius — a young lieutenant in the Swedish army with a keen interest in minerals acquired during his time at the Royal Mint's laboratory — discovered a black piece of stone among the leftover gangue. The peculiar black mineral, first presumed to be tungsten, was shipped off to Arrhenius's friend Johan Gadolin, a chemistry professor at the Royal Academy of Turku in Finland (known in latin as *Regia academia aboensis*).

Gadolin identified that the mineral 'ytterbite' (which would later be renamed gadolinite in his honour) contained the oxide of a new rare-earth element¹. The Swedish chemist Anders Gustaf Ekeberg subsequently confirmed these findings and named the oxide yttria². Elemental yttrium, in an impure form, was first isolated in 1828 by Friedrich Wöhler by passing chlorine gas over the gadolinite mineral to form anhydrous yttrium chloride (YCl₃), which was in turn reduced to yttrium using potassium³. In 1843, Carl Gustaf Mosander discovered that yttria was in fact a mixture of a number of metal oxides, which he separated into three parts: yttria (containing yttrium oxide, Y₂O₃), erbia, and terbia⁴. In the end, the black mineral found by Arrhenius was shown to contain oxides of eight rare-earth metals — erbium, terbium, ytterbium, scandium, thulium, holmium, dysprosium, and lutetium. In the 1920s,



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element 39 saw a change in its symbol, when Y replaced the older Yt in the periodic table.

Along with above-neighbour scandium in group 3 of the periodic table, yttrium is chemically similar to the lanthanides and together they form the rare-earth elements. This means that, in the same manner as the lanthanides, yttrium is produced by separation from a mixture of oxides in ores such as monazite sand and bastnäsite. It can then be purified by the preparation of yttrium fluoride, and its subsequent reduction with calcium metal.

Yttrium has a silver-metallic luster and is relatively stable in air. Again, like the lanthanides, it usually exists as a trivalent ion, Y³⁺, and is abundant as yttrium oxide (Y₂O₃). It has many isotopes, with mass numbers ranging from 79 to 103, but the naturally occurring element consists of only one stable isotope, ⁸⁹Y.

Organic chemists are very familiar with trivalent yttrium complexes, which are used as Lewis acid catalysts for a wide range of reactions. For example, a recent highly enantioselective ring-opening reaction of aziridines was catalysed by a bimetallic yttrium complex⁵.

Element 39 also serves in various optical devices, through yttrium aluminate garnets (YAGs). In these materials, a small portion of the yttrium atoms have been replaced by lanthanides, introducing lattice strains that change the optical properties of the material. For example, cerium-doped YAGs (Ce:YAGs) are used as phosphors in combination with

blue light emitting diodes (LEDs). Blue radiation from the LED 'bleeding' through a Ce:YAG phosphor is down-converted to a yellow emission, which in turns combines with the LED's blue radiation to produce white daylight-like light. Other devices include the so-called Nd:YAG lasers that are commonly used both in medical and industrial applications.

Yet perhaps the most important impact of yttrium has been its role in the discovery of high temperature superconductors — those materials with no electrical resistance. In 1986, Bednorz and Müller discovered superconductivity in a lanthanum-based cuprate perovskite material (La₂CuO₃) at a temperature of 35 K, for which they were awarded the Nobel Prize in Physics the following year⁶. Also in 1987, physicists in the United States found that yttrium-based Y_{1.2}Ba_{0.8}CuO₄ (often referred to as YBCO) was superconducting at 93 K — a temperature increase of practical importance as this is above the boiling point of liquid nitrogen (77 K), which makes it a practically feasible cooling temperature⁷. The discovery invigorated research efforts in the quest for superconductivity at even higher temperatures — ideally, above room temperature, though this has remained elusive.

A transition metal close to the lanthanides, element 39 has found its way from a now-abandoned mine to a variety of high-tech devices. □

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