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HALLGARTEN + COMPANY

Metal Review

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Rubidium:

Cesium's Lesser-Known Twin

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Rubidium (Rb)

Cesium's Lesser Known Twin

- + **Rubidium is the more accessible and more widely available alternative to Cesium in some applications where Rb´s similar attributes can be tapped**
- + **Cesium production has effectively ceased from one of the two major mines, while the other is reportedly subject to an ore export ban**
- + **The tight (to non-existent) supply situation for Cesium provides an opening into the market for Rubidium in Formates (used for high pressure gas well workovers)**
- + **Cesium formate is currently under the exclusive control of Sinomines and any move to break its dominance would be welcome**
- + **All attempts to elucidate the real cost of mining and the margins and profits (or losses) for Rubidium and Cesium are elusive**
- + **Rubidium is the lower cost (but less accurate) alternative to Cesium for Atomic clocks**
- + **New applications could produce a sea-change in demand for Rubidium**
- + **China's dominance of production sources over the opportunity for a *de novo* non-Chinese producer to claim strategic status (and thus funding)**
- + **We know of two listed companies with Rubidium MREs**
- ✘ **Rubidium's tendency to explode upon contact with oxygen cramps its potential usages and creates storage and transportation issues**
- ✘ **Pricing is almost non-existent making economics of production/processing problematical**
- ✘ **Current applications for Rubidium are scant**

The Flurry in the Promotorial Classes

The mining equities space has seen an upsurge of companies claiming to have Rubidium in their mineralisations. The managements of said companies know little to nothing about Rubidium and the term "critical mineral" is thrown about with gusto and seemingly lacking awareness that the mineral is NOT on any critical minerals list because it is so little used and certainly the world would not stop turning (and guns would not stop firing) if no Rubidium was ever produced again.

This has not stopped the metal/mineral from being co-opted into the hallowed realms of criticality.

The public know even less about Rubidium than the promoters, though that is difficult to imagine as what is less than zero knowledge? However, from our own long acquaintance with Rubidium we can see a way clear for it to become a metal of some relevance. Even if not pivotal. For us the main upside is as a substitute/alternative to Cesium which, because of Washington incompetence/ignorance, allowed the US's global domination of Cesium to pass to Chinese control as recently as 2020.

In this primer we shall review a few key uses and sources of the metal without giving any mileage to the wannabes furiously arm-waving in the Rubidium space… if there even is a Rubidium space.

A Niche Metal

Cesium and Rubidium are close in the Periodic Table and even closer in real life in their attributes.

Rubidium is used interchangeably or together with Cesium in many uses. Its principal application is in specialty glasses used in fiber optic telecommunication systems. Rubidium's photoemissive properties have led to its use in night-vision devices, photoelectric cells, and photomultiplier tubes. It has several medical and pharmaceutical applications.

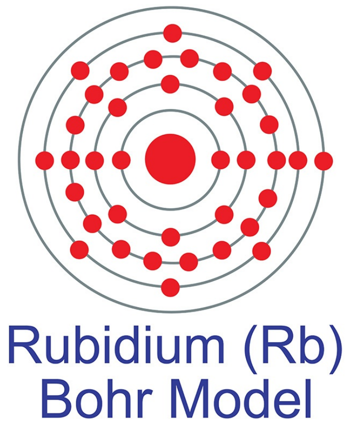
The USGS claims that a dozen, or more, other uses are known, which include use as a co-catalyst for several organic reactions and in frequency reference oscillators for telecommunications network synchronization.

The market for Rubidium is extremely small, amounting to one to two metric tons per annum in the United States. The USGS makes the interesting claim that world resources are vast compared with demand.

Some Basics

Rubidium is the chemical element with the symbol Rb and atomic number 37. It is a very soft, whitish-grey solid in the alkali metal group, similar to Potassium and Cesium. It is the second most electropositive of the stable alkali metals and melts at a temperature of 39.3 °C (102.7 °F).

Rubidium is the twenty-third most abundant element in the Earth's crust, roughly as abundant as Zinc and rather more common than Copper. It occurs naturally in the minerals leucite, pollucite, carnallite, and zinnwaldite, which contain as much as 1% Rubidium oxide. Lepidolite contains between 0.3% and 3.5% Rubidium and is the commercial source of the element. Some Potassium minerals and Potassium chlorides also contain the element in commercially significant quantities.



On Earth, natural Rubidium comprises two isotopes: 72% is a stable isotope 85Rb, and 28% is slightly radioactive 87Rb, with a half-life of 48.8 billion years—more than three times as long as the estimated age of the universe.

Like other alkali metals, Rubidium metal reacts violently with water. As with Potassium (which is slightly less reactive) and Cesium (which is slightly more reactive), this reaction is usually vigorous enough to ignite the hydrogen gas it produces. Rubidium has also been reported to ignite spontaneously in air. It forms amalgams with Mercury (Hg) and alloys with gold, iron, Cesium, Sodium, and Potassium.

It does NOT form an amalgam with Lithium (even though Rubidium and Lithium are in the same group).

History

Rubidium was discovered in 1861 by Robert Bunsen and Gustav Kirchhoff, in Heidelberg, Germany, in the lithium mineral lepidolite through flame spectroscopy. Rubidium was the second element, shortly after Cesium, to be discovered by spectroscopy, just one year after the invention of the spectroscope by Bunsen and Kirchhoff.

Because of the bright red lines in its emission spectrum, they chose a name derived from the Latin word *rubidus*, meaning "deep red".

The slight radioactivity of Rubidium was discovered in 1908, but that was before the theory of isotopes was established in 1910, and the low level of activity (half-life greater than 1010 years) made interpretation complicated.

Rubidium had minimal industrial value before the 1920s. Since then, the most important use of Rubidium is in research and development, primarily in chemical and electronic applications.

Rubidium Mineralisations

Rubidium must be viewed in the light of its close relations with two other metals that are positioned next to it in the Periodic Table of Elements (and frequently in real life). The fundamental difficulty has been that the properties of both Cesium and Rubidium are very similar to each other, and to those of Potassium, which constantly accompanies them in natural compounds.

Rubidium is relatively widespread in nature (clark Rubidium is estimated at 3-8*10-3%), and only its high dispersion, difficulty in concentrating and extracting from mineral raw materials make it a rare element. Rubidium is a typically lithophilic element and occurs in nature only as compounds. It is concentrated mainly in acidic eruptions and sedimentary rocks. During the weathering of rocks and the few minerals in which Rubidium occurs, it is washed out and gets, sometimes in significant quantities, into mineral springs. There is noticeably less Rubidium in lakes, estuaries, groundwater, and seawater, and very little in river water. Rubidium passes from mineral springs and seawater into salt deposits, which explains its presence in saltpetre and deposits of potash minerals, sylvine and carnallite. The number of rocks and minerals in which significant concentrations of Rubidium have been detected is small.

When it comes to Rubidium technology, it is impossible not to mention Cesium, since these are two isomorphically-substituted elements and in all natural sources they are contained together in varying proportions. Most often, they replace Potassium in an isomorphic range of its compounds. This explains why both elements are found in Potassium-rich aluminosilicates, such as feldspars and micas. During the solidification of the magmatic melt, its gradual enrichment with Rubidium and Cesium took place, which, upon crystallization of the residual magma, passed mainly into granite pegmatites.

Minerals in which the content of Rubidium and Cesium reaches a relatively high concentration include: lepidolite, biotite, amazonite, petalite, zinnvaldite, beryl, vorobyovite (a pink Cesium-containing variety of beryl), leucite, triphylline and carnallite. All of these minerals, with the exception of the last two, are aluminosilicates, mainly of Potassium. They occur almost exclusively in pegmatite veins, which correspond to the lowest temperature formations and are characterized by frequent inclusions of Lithium minerals — amblygonite, lepidolite, and spodumene. The possibilities of industrial use of most of them (especially the most common ones) for the extraction of Rubidium and Cesium are limited. The minerals concentrating Rubidium and Cesium also include Potassium minerals that make up salt deposits; among them, carnallite is of the greatest interest.

Among the minerals mentioned above, to extract Rubidium from them, first of all it is necessary to keep in mind lepidolite, which has been mastered in the Lithium industry. This is a first-class raw material for Rubidium, the richest mineral in its content (usually 0.6-0.8% Rb_2O, less often >1%). Rubidium is found in relatively large quantities in zinnwaldite (0.8-0.9 wt.% Rb_2O) and gilbertite (0.3-0.5%). Carnallite and kainite-calibornite rocks of salt domes are becoming promising sources for the extraction of Rubidium. Of particular importance, of course, is carnallite, the enormous reserves of which make it a potentially inexhaustible resource not only of Rubidium, but also of Cesium.

Extraction of Rubidium from other Potassium salts (for example, from sylvanite) may be of particular interest. Films of clay materials from lake bottom sediments and salt rocks should be considered as potential raw materials with, again, almost unlimited reserves of Rubidium.

Cesium is to Pollucite…

Cesium has, in the past, been extracted in considerable amounts from the Cesium-rich mineral pollucite, commercial deposits of which were discovered in the USA (Maine, South Dakota), Sweden (Varutrask, an asset owned in recent times by ourselves), Namibia, ex-CIS states, and other countries.

…. as Rubidium is to Lepidolite

The main form of Rubidium and Cesium raw material for a long time has been lepidolites (or lithium micas). Lepidolites are complex aluminum silicates of lithium and Potassium in which a very small part of the alkali metals is preplaced by Rubidium and Cesium.

These lepidolites, along with small amounts of Rubidium and Cesium (about 0.5%), contain up to 4-5% lithium oxide. Lithium salts were the main product, while Rubidium and Cesium were byproducts.

Carnallites

Rubidium has also been obtained from carnallites. As early as the 1890s it was proved that in spite of the negligible amount of Rubidium in carnallite, this mineral could become a practical source for the production of Rubidium.

Extraction/Production

As noted, the largest producers of Cesium have produced Rubidium as a by-product from pollucite. Rubidium has also been sourced from it being minor component in the Lithium mineral, lepidolite.

Although Rubidium is more abundant in Earth's crust than Cesium, the limited applications and the lack of a mineral rich in Rubidium has, according to the USGS, limited the production of Rubidium compounds to 2 to 4 tonnes per year. We would estimate that this is now closer to zero due to (negative) developments at Bernic Lake (Manitoba) and Bikita (Zimbabwe). The latter is operating under Sinomines control but has been subject in recent months to rancour between the national government and the Chinese operators.

Several methods are available for separating Potassium, Rubidium, and Cesium. The fractional crystallization of a Rubidium and Cesium alum yields, after 30 subsequent steps, pure Rubidium alum. Two other methods are reported, the chlorostannate process and the ferrocyanide process.

From 1958 until about 1975, Rubidium for the U.S. market was supplied largely from a stock of dry mixed alkali carbonates (trade-named Alkarb). This had accumulated at a plant in Texas as a byproduct of the extraction of lithium from imported lepidolite. It contained 20-25% Rubidium carbonate, with the rest being Potassium and a small amount of Cesium.

Technological difficulties, as well as the small scale of production, determine the high cost of Rubidium and Cesium compounds and, consequently, metals. On the other hand, the high cost of materials, as well as the complex technique of working with metallic Rubidium and Cesium, are the main obstacles to the widespread use of Rubidium and Cesium-based materials.

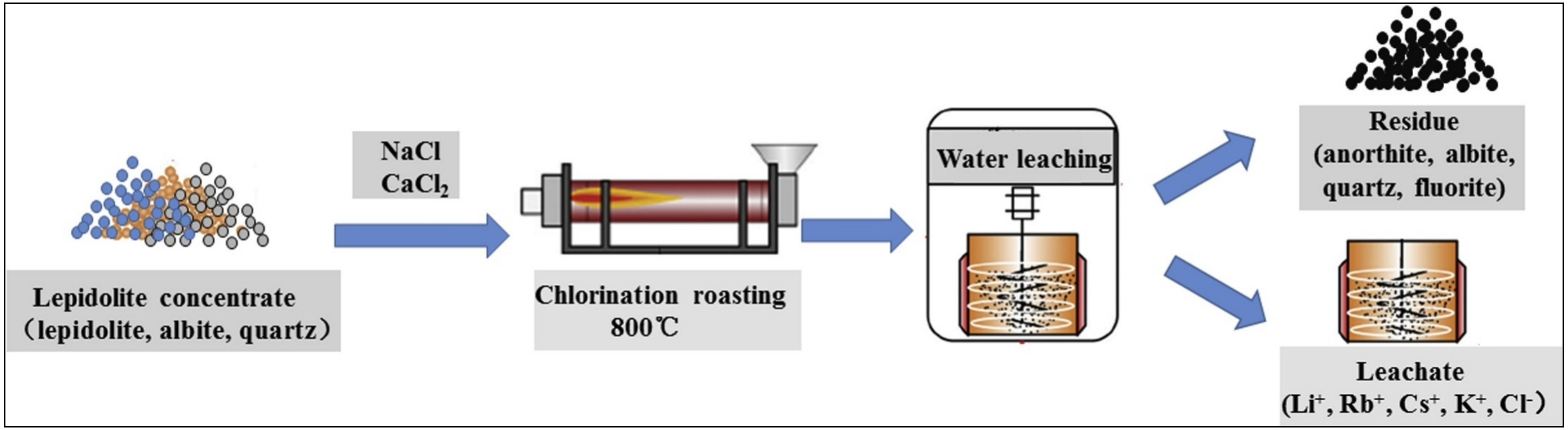
The extraction and further production of Rubidium and Cesium has developed due to the greatly increased use of these metals in various fields of application. However, it should be noted that the release of Rubidium, this highly-dispersed element, makes a significant contribution to the total cost of the project due to the fact that large volumes of raw materials containing very low concentrations of the desired component must be processed to obtain it. The extraction of Rubidium, as well as other rare and dispersed elements, is a complex task, consisting not only in obtaining one element, but also in developing a complete scheme for extracting the largest amount of other elements (precious elements, Ge, In, Sc, REE, Be, Gl, Ta, Tl, etc.). Only in this case will the processing of raw materials containing Rubidium have the greatest economically positive effect.

Cesium has its own mineral, pollucite, which forms clusters of industrial importance in nature. Rubidium is a dispersed element, its minerals have not been found in nature, therefore, the ore technology of Rubidium does not exist. Industrial production of Rubidium boils down to its separation from elements similar in properties — Potassium and Cesium. The task is usually complicated by the fact that the content of impurity elements, especially Potassium, is many times higher than the content of Rubidium, and the concentrations of Rubidium are low.

Creating Concentrates

Next, the known methods for obtaining Rubidium-Cesium concentrate from the most common sources are analyzed:

Processing of lepidolite. When processing spodumene and other lithium silicate minerals, it is necessary to take into account the possibility of associated extraction of Rubidium and Cesium, even in cases where they are present not in the main minerals, but in the accompanying minerals of industrial concentrates. It is all the more important to simultaneously extract Rubidium and Cesium from lepidolite, the richest joint source of raw materials.



Source: Xiufeng Zhang, Tahani Aldahri, Xiumin Tan, Weizao Liu, Lizhen Zhang & Shengwei Tang

Methods for extracting Rubidium and Cesium from lepidolite include those based on decomposition by sulfuric acid with its mixtures, as well as fusion and sintering methods. During acid decomposition, Rubidium and Cesium always pass into solution. Acid decomposition is designed to produce solutions of sulfates of alkaline elements. Alum is converted to chlorides through carbonates, and then Rubidium and Cesium are precipitated as chlorostannates, chloroplumbates, and other ways.

The technology based on sintering lepidolite with gypsum or CaO and $CaCl_2$ implies that the spec is leached out with water and Rubidium and Cesium pass into solution. During sintering of lepidolite with limestone, Rubidium and Cesium accumulate in the mother liquor remaining after separation of the primary product. Hence, they can be isolated in the form of alum, chlorostannates, chloroplumbates, silicovolframates, or, for example, in the form of mixed ferrocyanides.

Fundamentally different ways of separating Rubidium and Cesium, which are already used at the San Antonio plant, are also possible. Initially, a mixture of carbonates of alkaline elements is obtained from spent liquors. Then individual compounds and other products are obtained from the mixture, successfully using ion exchange instead of methods of precipitation of difficult-to-dissolve compounds.

An example of the complex processing of lepidolite with the extraction of Rubidium and Cesium from it is the method proposed in the USSR by E. S. Burkser. According to this method, lepidolite is fused with K_2so_4 at 1000 °C. The float is treated with water. All lithium, partly Rubidium and Cesium, passes into the solution. Most of the Rubidium and Cesium are in the residue. It is decomposed at 100 ° with sulfuric acid. Decomposed sediment is treated with water. Upon cooling, a mixture of Potassium, Rubidium and Cesium alum crystallizes from a concentrated solution, which is enriched with Rubidium and Cesium during fractionated crystallization. Enriched alum is treated by boiling with barium carbonate to obtain carbonates of alkaline elements. From a solution of carbonates, Rubidium and Cesium are precipitated in the form of $(Rb, Cs)_2[pbcl_6]$ (in this way, further purification from Potassium is carried out). The precipitate is hydrolyzed by adding a little ammonia solution. Lead is released as PBO_2 (lead residues are removed with hydrogen sulfide). Cesium precipitates from the filtered solution in the form of $Cs_3[sb_2cl_9]$. The described method makes it possible to obtain Rubidium and Cesium chlorides with a purity of 97%.

Carnallite is an almost inexhaustible and the cheapest raw material source of Rubidium and partly Cesium. It is a valuable natural raw material, the processing of which yields Potassium fertilizer (Potassium chloride, waste electrolyte), metallic magnesium, bromine and edible salt.

The first industrial technology for processing carnallite was developed by Veit and Kubirshsky. The proposed technology of carnallite processing is as follows: natural carnallite is subjected to grinding and processing with continuous stirring with hot mother liquor. In this case, the decomposition of incongruently soluble Potassium carnallite occurs with the release of solid Potassium chloride. Rubidium and Cesium carnallites, congruently soluble, remain in solution. After some settling, the clarified solution is sent to a crystallizer, where Potassium chloride (sludge) is released. The sludge is washed with cold water from NaCl and $MgCl_2$, dried and released as a commercial product (fertilizer). The mother liquor is evaporated in vacuum apparatuses for the separation of sodium chloride, kieserite $MGSO_4 \cdot H_2O$ and langbeinite $kso_4 \cdot 2mgso_4$. Upon cooling of the remaining solution, crystallization of the 1st artificial (or enriched) carnallite occurs, which is a solid solution of Potassium, Rubidium and Cesium carnallites. Step-by-step recrystallization of carnallite under various conditions after several iterations leads to the production of alum enriched with Rubidium and Cesium, and subsequently alum containing no

Potassium.

Separation of Potassium, Cesium and Rubidium. Obtaining pure individual salts.

During the processing of polycyte, lithium and Potassium minerals, radioactive waste and other raw materials, Rubidium-Cesium, Cesium-Rubidium and Rubidium-Potassium concentrates are obtained in the form of alum, chlorides, sulfates, carbonates and other salts. Such concentrates contain impurities of K, Na, Mg, Ca, Si, Al, Fe, Cr, Ti and other elements. Of these, Potassium is the closest in chemical properties to Rubidium and Cesium, so their separation (especially Potassium—Rubidium pairs) is the most difficult problem in the technology of obtaining pure Rubidium and Cesium salts. In this regard, in the future, we will mainly consider methods related to solving the mentioned problem, as well as the possibility of removing other impurities.

Several technological processes have been proposed for the separation of Potassium, Rubidium and Cesium, using slight differences in the conditions of formation and in the physico-chemical properties of some of their simple and especially complex salts: fractionated crystallization, precipitation, ion exchange chromatography, extraction. These processes are unequal for obtaining pure salts and substances of high purity.

Ion exchange chromatography and ion exchange sorption. Obtaining pure Rubidium and Cesium salts on an industrial scale is fundamentally possible using both classical chromatography (i.e. purely adsorption processes) and ion exchange chromatography, in which organic and inorganic ionites are used instead of adsorbents.

Chromatographic purification of Rubidium and Cesium salts, with its relative simplicity, low labor intensity and cyclicity, has one significant drawback: as a result, more dilute solutions are obtained than the initial ones. Dilution involves significant energy costs for evaporation of solutions and the need for large production capacities, and all this dramatically reduces the economic advantages obtained from the use of resins.

Extraction. Due to the fact that alkali metal ions in solutions are highly hydrated, and their ability to form complex compounds with organic citations is limited, the use of extraction for the concentration and separation of Rubidium and Cesium encounters significant difficulties.

As the ability of alkali metals to form complex compounds with organic ligands is rather limited, it should not be surprising that the extraction separation of Potassium, Rubidium and Cesium in the liquid—liquid system has been poorly studied.

Extractants used to isolate and separate alkaline elements are divided into neutral, basic and acidic. Alcohols belong to the first group. It is known to extract carbyl and Cesium fluorides from mixtures of solid halogens with monobasic aromatic and acyclic alcohols. Esters of phosphoric acids belong to the class of neutral extractants. It has been established that Cesium ion is weakly extracted by them from acidic and alkaline solutions. The high selectivity of cyclic and crown polyesters with respect to alkali metals is indicated. Long-chain amines have found the greatest use among the group of main extractants. Di-(2-ethyl) is noted from organophosphoric acids capable of extracting alkaline elements-hexylphosphoric acid (DEEGFC).

The most effective extractants for the extraction and separation of alkaline elements are phenols. Despite the relatively low partition coefficients, phenols have higher partition coefficients of alkaline elements compared to other extractants. The degradation occurs due to 4-s-butyl-2-(a-methylbenzyl) phenol. Analytical data is presented up to 13. The analytical data contains the following values: Li < Na < K < Rb < Cs.

In addition to widely used separation methods, Rubidium technology also uses unique technological techniques based on different volatility, such as Rubidium, Potassium and Cesium chlorides at high temperatures under vacuum. Ultrafiltration and a cascade of reverse osmotic membranes can be used to separate Rubidium and Cesium.

Compounds

Rubidium metal is marketed either as technical grade metal, minimum 99% Rubidium, or high-purity grade, minimum 99.8% Rubidium. Rubidium compounds, which are more important commercially than the metal, are prepared in grades that range from 99- to 99.99% pure

Rubidium chloride (RbCl) is probably the most used Rubidium compound. While other common Rubidium compounds are:

- the corrosive Rubidium hydroxide (RbOH), the starting material for most Rubidium-based chemical processes
- Rubidium carbonate (Rb_2CO_3), used in some optical glasses
- Rubidium copper sulfate, $Rb_2SO_4 \cdot CuSO_4 \cdot 6H_2O$
- Rubidium silver iodide ($RbAg_4I_5$) has the highest room temperature conductivity of any known ionic crystal, a property exploited in thin film batteries and other applications

Rubidium forms a number of oxides when exposed to air, including Rubidium monoxide (Rb_2O), Rb_6O, and Rb_9O_2. Rubidium in excess oxygen gives the superoxide RbO_2. Rubidium forms salts with halogens, producing Rubidium fluoride, Rubidium chloride, Rubidium bromide, and Rubidium iodide.

Uses & Applications

These Rubidium compounds have various chemical and electronic applications. Rubidium metal is easily vaporized and has a convenient spectral absorption range, making it a frequent target for laser manipulation of atoms.

Rubidium and its salts have few commercial uses. The metal is used in the manufacture of photocells and in the removal of residual gases from vacuum tubes. Rubidium salts are used in glasses and ceramics and in fireworks to give them a purple colour. Potential uses are in ion engines for space vehicles, as working fluid in vapor turbines, and as getter in vacuum tubes.

Rubidium compounds are sometimes used in fireworks to give them a purple color. Rubidium has also been considered for use in a thermoelectric generator using the magnetohydrodynamic principle, whereby hot Rubidium ions are passed through a magnetic field. These conduct electricity and act like an armature of a generator, thereby generating an electric current.

Rubidium, particularly vaporized 87Rb, is one of the most commonly used atomic species employed for laser cooling and Bose–Einstein condensation. Its desirable features for this application include the ready availability of inexpensive diode laser light at the relevant wavelength and the moderate temperatures required to obtain substantial vapor pressures.

Rubidium has been used for polarizing 3He, producing volumes of magnetized 3He gas. Rubidium vapor is optically pumped by a laser, and the polarized Rb polarizes 3He through the hyperfine interaction. Such spin-polarized 3He cells are useful for neutron polarization measurements and for producing polarized neutron beams for other purposes.

The resonant element in atomic clocks utilizes the hyperfine structure of Rubidium's energy levels, and Rubidium is useful for high-precision timing. It is used as the main component of secondary frequency references (Rubidium oscillators) in cell site transmitters and other electronic transmitting, networking, and test equipment. These Rubidium standards are often used with GPS to produce a "primary frequency standard" that has greater accuracy and is less expensive than Cesium standards. Such Rubidium standards are often mass-produced for the telecommunication industry.

Other potential, or current, uses of Rubidium include a working fluid in vapor turbines, as a getter in vacuum tubes, and as a photocell component. Rubidium is also used as an ingredient in special types of glass, in the production of superoxide by burning in oxygen, in the study of Potassium ion channels in biology, and as the vapor in atomic magnetometers. In particular, 87Rb is used with other alkali metals in the development of spin-exchange relaxation-free (SERF) magnetometers.

Atomic Clocks

Today the majority of commercial frequency standards are based on Rubidium clock technology. This technology uses optical pumping to prepare and detect the hyperfine ground state of Rubidium atoms in a vapour cell. Rubidium clocks are used to synchronize the time base in telecom networks, power grids, and satellite navigation systems such as GPS and Galileo.

Medical/Pharma Applications

It has several uses in medical science.

Rubidium is not a known nutrient for any living organisms. However, Rubidium ions have similar properties and the same charge as Potassium ions and are actively taken up and treated by animal cells in similar ways.

One rising usage is in positron emission tomographic (PET) imaging. In October of 2020, Bracco Diagnostics Inc., the U.S subsidiary of Bracco Imaging S.p.A., a leading global company in the diagnostic imaging business, announced that the US Food and Drug Administration (FDA) had approved its new CardioGen-82 infusion system to enhance automation, efficiency, and simplicity in cardiac position emission tomography (PET) myocardial perfusion imaging (MPI).

Rubidium collects more in brain tumors than normal brain tissue, allowing the use of radioisotope

Rubidium-82 in nuclear medicine to locate and image brain tumors.

Rubidium has been applied to the treatment of epilepsy, and the ultracentrifugal separation of nucleic acids and viruses.

Rubidium was tested for the influence on manic depression and depression. For example, dialysis patients suffering from depression show a depletion in Rubidium, and therefore a supplementation may help during depression.

The Big Question….

Cesium and Rubidium are close in the Periodic Table and even closer in real life in their attributes.

…. Well, at least for us. As the chemical and physical properties of Rubidium are so similar to those of Cesium that the two elements are often used together or interchangeably in many uses, which begs the question as to whether Rubidium could play any role in the space that Cesium so dominates (and is so strategic) i.e. high-pressure gas well workovers. Rubidium formate exists but is used for other purposes. We have read nowhere of Rubidium's use in gas-wells. Is this because it is unsuitable? Or is it because Cesium (until recently) has been more available (under Cabot's, then Sinomines´, market domination) that thought was not applied to Rubidium being used in workovers?

In most shared applications, Cesium, which is more readily available and at times somewhat cheaper, has been used in preference to Rubidium. But drillers are clearly unhappy with the leasing model that dominates the Cesium formate market.

On Rubidium Formate

Recently, the Rubidium salt with carboxylic (formic) acid formate (RbHCO2) has been of unexpected interest. Rubidium formate is used in various fields, including catalysis, electronics industry, optics and medicine, it is used to produce pure Rubidium, as a component of electrolytes for chemical power sources, as a catalyst in organic synthesis, as well as in analytical chemistry.

Rubidium compounds, including formates, are used in the production of electrolytes for low-temperature chemical power sources, as well as as additives to increase electrical conductivity and operability at low temperatures. Rubidium formate is used as a catalyst in organic synthesis.

Rubidium and its compounds, as a rule, are not independent end products, but are used as components of various materials and devices.

The field of application of Rubidium and its compounds, including Rubidium formate, is constantly expanding with the development of new technologies and scientific research.

Methods for the synthesis of Rubidium formate are based on the interaction of a Rubidium compound (most often hydroxide) with formic acid under certain conditions. And although at first glance it seems that synthesis does not cause any particular difficulties, many related factors should be taken into account when working with Rubidium: synthesis should take place in clean rooms (including those purified from carbon dioxide), formic acid should not contain impurities of alkaline and alkaline earth metals (high-purity acid should be used), all materials of execution They must be made of a special plastic that is thermally and chemically stable to the action of Rubidium.

The main difficulties of working with Rubidium and its salts are its increased reactivity, and when choosing materials for execution, the possibility of a reaction between Rubidium and the execution material should be taken into account. Rubidium formate makes it possible to keep highly reactive Rubidium in the most stable state before converting it to a metallic state for final use.

Occurrences

Because of its large ionic radius, Rubidium is one of the "incompatible elements." During magma crystallization, Rubidium is concentrated together with its heavier analogue Cesium in the liquid phase and crystallizes last. Therefore, the largest deposits of Rubidium and Cesium are zone pegmatite ore bodies formed by this enrichment process. Because Rubidium substitutes for Potassium in the crystallization of magma, the enrichment is far less effective than that of Cesium. Zone pegmatite ore bodies containing mineable quantities of Cesium as pollucite or the Lithium minerals lepidolite are also a source for Rubidium as a by-product.

Mine Production

The USGS stated in 2003 that the market for Rubidium was extremely small, amounting to one to two metric tons per annum in the United States.

Although Rubidium is more abundant in the earth's crust than copper, lead, or zinc, it forms no minerals of its own, and is, or has been, produced in small quantities as a byproduct of the processing of Cesium and Lithium ores.

Two notable sources of Rubidium are the rich deposits of pollucite at Bernic Lake, Manitoba, Canada, and the rubicline ($(Rb,K)AlSi_3O_8$) found as impurities in pollucite on the Italian island of Elba, with a Rubidium content of 17.5%. Both of those deposits are also sources of Cesium.

Another prominent source in recent years has been the Bikita mine in Zimbabwe. Bernic Lake and Bikita are now under the control of Sinomines.

The USGS states that world resources are "vast" compared with demand. It stated that no reliable data was available to determine reserves for specific countries; however, Australia, Canada, China, Namibia, and Zimbabwe were thought to have reserves totaling less than 200,000 tons. This is a fairly unsubstantiated claim as Canada and Zimbabwe were either out of mine life (the former) or did not have scientifically calculated reserves (the latter).

The USGS reported that, during 2020, no Rubidium production was reported globally. Production of Rubidium from all countries, excluding China, ceased within the past two decades. Production in Namibia ceased in the early 2000s, followed by the Tanco Mine in Canada shutting down and later being sold after a mine collapse in 2015.

Bernic Lake, historically the world's major source of Cesium, was long held by Tanco, a subsidiary of the US-based chemical major, Cabot Corp. However, Cabot sold its Specialty Fluids division (its main product being Cesium Formate, for high-pressure gas-well workovers) to Sinomine in a controversial transaction in 2019. Part of the logic of the sale was that Bernic Lake was effectively past its end of minelife and thus that there would be no more additions to the Cesium inventory of Cabot's division (where Cesium Formate is leased, rather than sold) to drillers. It was said that Sinomine were going to try and extract further material from tailings and stockpiles at site. Our source of intelligence on this mine (a veteran pegmatite geo who lives on a road leading to the old mine) says there has been no evidence that they have been able to process material from the "scrapings" left at the mine.

The source in Namibia was not stated, but we believe it was the Tsumeb mine.

The Bikita mine is a storied Lithium operation in Zimbabwe. In recent years it was viewed as being the private fiefdom of a particular minister in the government, who reputedly cut deals with the Chinese for his benefit. The product flow from this mine is Lithium and Cesium but it is reported to also produce Rubidium. The USGS claimed that the Bikita mine was depleted of pollucite ore reserves in 2018. We would not be so eager to accept this claim. However, a ban on export of Lithium ores from Zimbabwe has been in place since late 2023 and reports in Mining Journal indicate that as much as 2 million tonnes of Lepidolite ore may have built up, awaiting export. If true this might indicate that the party in the government that vended Bikita to the Chinese may not have rewarded all who needed rewarding. Moreover, the rationale that Lithium ores should be upgraded in-country presents a major challenge for the Chinese with their attitude that all value-added should drop off at the processing facilities in the "mothership" (i.e. onshore China).

The Sinclair Mine (of Essential Metals – ASX:ESS) in Western Australia completed the mining and shipments of all economically recoverable pollucite ore in 2019. It is worth noting that Sinomine was the exclusive recipient of the Sinclair mine's pollucite output through a deal that was a legacy of an arrangement supposedly made by Cabot, pre-sale.

The USGS makes an, uncharacteristically unsupported statement that "significant" Rubidium-bearing pegmatite occurrences have been identified in Afghanistan, Australia, Canada, China, Denmark, Germany, Japan, Kazakhstan, Namibia, Peru, Russia, the United Kingdom, the United States, and Zambia.

Not unsurprisingly in light of its relationship with Lithium, minor quantities of Rubidium have been reported in brines in northern Chile and China, and in evaporites in the United States (New Mexico and Utah), France, and Germany.

The USGS, in 2020, claimed that "recent reports" indicate that with current processing rates, the world's stockpiles of Rubidium ore, excluding those in China, would be depleted by 2022. We would also take this statement with a degree of scepticism. The Chinese in particular have a vested interest in obfuscating the state of the supply situation in both Rubidium and Cesium.

Market & Pricing

In the United States, the USGS has reported that Rubidium and its compounds were produced from imported raw materials by at least one company, Penn Rare (at Revere, Pennsylvania) that was a subsidiary of Cabot Corporation. However, we would note that Sinomine's purchase of the Specialty Fluids division of Cabot also probably put paid to this activity.

Curiously, while the USGS claims global production to be around 2 to 4 tonnes per annum, it also states that industry information during the past decade suggests a domestic consumption rate of approximately 2,000 kilograms per year. This would imply the US consuming the entirety of the low-end estimate of global production. As we have also noted, we posit that such production has likely collapsed of late.

To say that pricing of Rubidium is opaque is a severe understatement. Recent spot prices for Rubidium metal have ranged from $36.00 per gram up to US$130.00 per gram (US$1080 to US$3640 per ounce) depending on purity. Another source, in early 2022, asserted that the market price of 99.75% Rb_2CO_3 (the most widely used Rubidium chemical) was around US$57 for 10 grams (i.e., US$5,700 per kg).

In 2020, the USGS reported that one company offered 1-gram ampoules of 99.75%-grade Rubidium (metal basis) for $89.00 and 100-gram ampoules of the same material for $1,608.00. The price for 1-gram ampoules of 99.8% Rubidium formate hydrate (metal basis) was $34.70.

The USGS also cited that the prices for 10 grams of 99.8% (metal basis) Rubidium acetate, Rubidium bromide, Rubidium carbonate, Rubidium chloride, and Rubidium nitrate were $50.60, $67.00, $56.80, $61.30, and $47.20, respectively. The price for a Rubidium-plasma standard solution (10,000 micrograms per milliliter) was $49.50 for 50 milliliters and $80.80 for 100 milliliters.

Pricing thus is all over the place with extreme difficulty in comparing "apples to oranges" in the various Rubidium compounds.

Industrial Vendors

The USGS claims that the primary processing plant of Rubidium compounds globally, located in Germany, has reportedly operated far below capacity for the past few years.

Amongst others the leading vendors of Rubidium compounds are:

- American Elements (US)
- Inorganic Ventures Inc. (US)
- LANHIT (Russia)
- Merck KGaA (Germany)
- Otto Chemie Pvt. Ltd. (India)
- Thermo Fisher Scientific Inc. (US)
- MaTeck (Material, Technologie & Kristalle GmbH) (Germany)

The "Competition"

The challengers in the Rubidium space are undoubtedly Sinomines, which as we have mentioned have a strong position, but then there is also Lepidico, with its project in Namibia that it picked up through a merger with a company called Desert Lion in mid-2019.

Sinomines have a problem in that they are now quite severely circumscribed in the fields of international actions. New rules in Canada would block them from actions relating to strategic assets controlled by Canadian companies (they would almost certainly not be allowed to acquire Tanco today, no matter that it was an expired mine). Onshore assets in Australia would be precluded from their reach also. It is unlikely they would get approval for mining acquisitions or even offtakes in Europe.

The US has been exercising suasion in Latin America also with regard to strategic metal moves by Chinese companies. This leaves Africa as one of the last free fields of action open to the Chinese in strategic/critical metals.

Lepidico, a wannabe Lithium producer located in the Karibib Pegmatite Belt of Namibia, undoubtedly also has ambitions as far as Cesium/Rubidium are concerned. The company has also signaled that it plans to develop processing facilities in the Middle East, with cheap energy being a drawcard. There is mineral resource estimate for the Karibib project in Namibia, reporting 8.9mn metric tonnes of Measured and Indicated resources containing 0.23% Rubidium and 302 ppm of Cesium. While Lithium would be the primary product, Lepidico have also signaled a desire to have Cesium, Potassium, and Rubidium as potential byproducts.

Conclusion

We might have said two years ago that the outlook for the entry of a major "new" producer of Rubidium is not promising. As the lesser sibling of Cesium, which has real applications in high-pressure gas-well workovers, Rubidium had very limited applications in atomic clocks and (potentially in) pharmaceuticals but nothing that signals large volumes at high prices. It is more a case of very small (minuscule?) volumes at high prices.

That said, the reigning prices for Rubidium and its associated products is (seemingly) high though, as noted, pricing is opaque. Just as Cabot Corp (and its division's acquirer, Sinomine) was a vertically integrated operation in Cesium, the lesson must be that the way to maximize value-added from any Rubidium production is through further upgrading of mined material.

It is clear that the US government allowing the sale of Cabot's division was a major mistake of epic strategic proportions. While the transaction cannot be reversed (as almost all the assets were outside the US anyway) there is scope for an incipient producer of Rubidium "ore" to create a value-added operation and play to the *Zeitgeist* of strategic positioning in a critical mineral. This would preclude sale of finished products to China but would conversely potentially bring a producer “most favoured status, exclusive access to markets and additionally attract funding for filling the strategic gap presented by Sinomines being effectively *persona non grata* in the US and elsewhere.

Finally, we would note that it appears the most attractive option for a Cesium or Rubidium miner is to enter the downstream and effectively become (and ensure) its own offtake.

Important disclosures

I, Christopher Ecclestone, hereby certify that the views expressed in this research report accurately reflect my personal views about the subject securities and issuers. I also certify that no part of my compensation was, is, or will be, directly or indirectly, related to the specific recommendations or view expressed in this research report.

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