

= 575 pm . However , there is a report of room @-@ temperature hexagonal einsteinium metal with $a =$

398 pm and $c = 650$ pm , which converted to the fcc phase upon heating to 300°C .

The self @-@ damage induced by the radioactivity of einsteinium is so strong that it rapidly destroys the crystal lattice , and the energy release during this process , 1000 watts per gram of ^{253}Es , induces a visible glow . These processes may contribute to the relatively low density and melting point of einsteinium . Further , owing to the small size of the available samples , the melting point of einsteinium was often deduced by observing the sample being heated inside an electron microscope . Thus the surface effects in small samples could reduce the melting point value .

The metal is divalent and has a noticeably high volatility . In order to reduce the self @-@ radiation damage , most measurements of solid einsteinium and its compounds are performed right after thermal annealing . Also , some compounds are studied under the atmosphere of the reductant gas , for example $\text{H}_2\text{O} + \text{HCl}$ for EsOCl so that the sample is partly regrown during its decomposition .

Apart from the self @-@ destruction of solid einsteinium and its compounds , other intrinsic difficulties in studying this element include scarcity ? the most common ^{253}Es isotope is available only once or twice a year in sub @-@ milligram amounts ? and self @-@ contamination due to rapid conversion of einsteinium to berkelium and then to californium at a rate of about 3 @.@ 3 % per day :

<formula>

Thus , most einsteinium samples are contaminated , and their intrinsic properties are often deduced by extrapolating back experimental data accumulated over time . Other experimental techniques to circumvent the contamination problem include selective optical excitation of einsteinium ions by a tunable laser , such as in studying its luminescence properties .

Magnetic properties have been studied for einsteinium metal , its oxide and fluoride . All three materials showed Curie ? Weiss paramagnetic behavior from liquid helium to room temperature . The effective magnetic moments were deduced as $10 @.@ 4 \pm 0 @.@ 3 \mu\text{B}$ for Es_2O_3 and $11 @.@ 4 \pm 0 @.@ 3 \mu\text{B}$ for the EsF_3 , which are the highest values among actinides , and the corresponding Curie temperatures are 53 and 37 K.

== Chemical ==

Like all actinides , einsteinium is rather reactive . Its trivalent oxidation state is most stable in solids and aqueous solution where it induced pale pink color . The existence of divalent einsteinium is firmly established , especially in solid phase ; such + 2 state is not observed in many other actinides , including protactinium , uranium , neptunium , plutonium , curium and berkelium . Einsteinium (II) compounds can be obtained , for example , by reducing einsteinium (III) with samarium (II) chloride . The oxidation state + 4 was postulated from vapor studies and is yet uncertain .

== Isotopes ==

Nineteen nuclides and three nuclear isomers are known for einsteinium with atomic weights ranging from 240 to 258 . All are radioactive and the most stable nuclide , ^{252}Es , has a half @-@ life of 471 @.@ 7 days . Next most stable isotopes are ^{254}Es (half @-@ life 275 @.@ 7 days) , ^{255}Es (39 @.@ 8 days) and ^{253}Es (20 @.@ 47 days) . All of the remaining isotopes have half @-@ lives shorter than 40 hours , and most of them decay within less than 30 minutes . Of the three nuclear isomers , the most stable is $^{254\text{m}}\text{Es}$ with half @-@ life of 39 @.@ 3 hours .

== Nuclear fission ==

Einsteinium has a high rate of nuclear fission that results in a low critical mass for a sustained nuclear chain reaction . This mass is 9 @.@ 89 kilograms for a bare sphere of ^{254}Es isotope , and can be lowered to 2 @.@ 9 by adding a 30 centimeter thick steel neutron reflector , or even to 2 @.@ 26 kilograms with a 20 cm thick reflector made of water . However , even this small critical

mass greatly exceeds the total amount of einsteinium isolated thus far , especially of the rare ^{254}Es isotope .

== Natural occurrence ==

Because of the short half @-@ life of all isotopes of einsteinium , any primordial einsteinium , that is einsteinium that could possibly be present on the Earth during its formation , has decayed by now . Synthesis of einsteinium from naturally occurring actinides uranium and thorium in the Earth crust requires multiple neutron capture , which is an extremely unlikely event . Therefore , most einsteinium is produced on Earth in scientific laboratories , high @-@ power nuclear reactors , or in nuclear weapons tests , and is present only within a few years from the time of the synthesis . The transuranic elements from americium to fermium , including einsteinium , occurred naturally in the natural nuclear fission reactor at Oklo , but no longer do so . Einsteinium was observed in Przybylski 's Star in 2008 .

== Synthesis and extraction ==

Einsteinium is produced in minute quantities by bombarding lighter actinides with neutrons in dedicated high @-@ flux nuclear reactors . The world 's major irradiation sources are the 85 @-@ megawatt High Flux Isotope Reactor (HFIR) at the Oak Ridge National Laboratory in Tennessee , U.S. , and the SM @-@ 2 loop reactor at the Research Institute of Atomic Reactors (NIIAR) in Dimitrovgrad , Russia , which are both dedicated to the production of transcurium ($Z > 96$) elements . These facilities have similar power and flux levels , and are expected to have comparable production capacities for transcurium elements , although the quantities produced at NIIAR are not widely reported . In a " typical processing campaign " at Oak Ridge , tens of grams of curium are irradiated to produce decigram quantities of californium , milligram quantities of berkelium (^{249}Bk) and einsteinium and picogram quantities of fermium .

The first microscopic sample of ^{253}Es sample weighing about 10 nanograms was prepared in 1961 at HFIR . A special magnetic balance was designed to estimate its weight . Larger batches were produced later starting from several kilograms of plutonium with the einsteinium yields (mostly ^{253}Es) of 0 @-@ 48 milligrams in 1967 ? 1970 , 3 @-@ 2 milligrams in 1971 ? 1973 , followed by steady production of about 3 milligrams per year between 1974 and 1978 . These quantities however refer to the integral amount in the target right after irradiation . Subsequent separation procedures reduced the amount of isotopically pure einsteinium roughly tenfold .

== Laboratory synthesis ==

Heavy neutron irradiation of plutonium results in four major isotopes of einsteinium : ^{253}Es (? @-@ emitter with half @-@ life of 20 @-@ 03 days and with a spontaneous fission half @-@ life of 7×10^5 years) ; $^{254\text{m}}\text{Es}$ (? @-@ emitter with half @-@ life of 38 @-@ 5 hours) , ^{254}Es (? @-@ emitter with half @-@ life of about 276 days) and ^{255}Es (? @-@ emitter with half @-@ life of 24 days) . An alternative route involves bombardment of uranium @-@ 238 with high @-@ intensity nitrogen or oxygen ion beams .

Einsteinium @-@ 247 (half @-@ life 4 @-@ 55 minutes) was produced by irradiating americium @-@ 241 with carbon or uranium @-@ 238 with nitrogen ions . The latter reaction was first realized in 1967 in Dubna , Russia , and the involved scientists were awarded the Lenin Komsomol Prize .

The isotope ^{248}Es was produced by irradiating ^{249}Cf with deuterium ions . It mainly decays by emission of electrons to ^{248}Cf with a half @-@ life of 25 (± 5) minutes , but also releases ? @-@ particles of 6 @-@ 87 MeV energy , with the ratio of electrons to ? @-@ particles of about 400 .

<formula>

The heavier isotopes ^{249}Es , ^{250}Es , ^{251}Es and ^{252}Es were obtained by bombarding ^{249}Bk with ? @-@ particles . One to four neutrons are liberated in this process making possible the formation of four different isotopes in one reaction .

<formula>

Einsteinium $^{253}_{101}\text{Es}$ was produced by irradiating a 0.102 milligram $^{252}_{98}\text{Cf}$ target with a thermal neutron flux of $(2.5 \times 10^{14} \text{ neutrons} \cdot \text{cm}^{-2} \cdot \text{s}^{-1})$ for 500–900 hours :

<formula>

== Synthesis in nuclear explosions ==

The analysis of the debris at the 10-megaton Ivy Mike nuclear test was a part of long-term project. One of the goals of which was studying the efficiency of production of transuranium elements in high-power nuclear explosions. The motivation for these experiments was that synthesis of such elements from uranium requires multiple neutron capture. The probability of such events increases with the neutron flux, and nuclear explosions are the most powerful man-made neutron sources, providing densities of the order $10^{23} \text{ neutrons} / \text{cm}^2$ within a microsecond, or about $10^{29} \text{ neutrons} / (\text{cm}^2 \cdot \text{s})$. In comparison, the flux of the HFIR reactor is $5 \times 10^{15} \text{ neutrons} / (\text{cm}^2 \cdot \text{s})$. A dedicated laboratory was set up right at Enewetak Atoll for preliminary analysis of debris, as some isotopes could have decayed by the time the debris samples reached the mainland U.S. The laboratory was receiving samples for analysis as soon as possible, from airplanes equipped with paper filters which flew over the atoll after the tests. Whereas it was hoped to discover new chemical elements heavier than fermium, none of these were found even after a series of megaton explosions conducted between 1954 and 1956 at the atoll.

The atmospheric results were supplemented by the underground test data accumulated in the 1960s at the Nevada Test Site, as it was hoped that powerful explosions conducted in confined space might result in improved yields and heavier isotopes. Apart from traditional uranium charges, combinations of uranium with americium and thorium have been tried, as well as a mixed plutonium-neptunium charge, but they were less successful in terms of yield and was attributed to stronger losses of heavy isotopes due to enhanced fission rates in heavy-element charges. Product isolation was problematic as the explosions were spreading debris through melting and vaporizing the surrounding rocks at depths of 300–600 meters. Drilling to such depths to extract the products was both slow and inefficient in terms of collected volumes.

Among the nine underground tests that were carried between 1962 and 1969, the last one was the most powerful and had the highest yield of transuranium elements. Milligrams of einsteinium that would normally take a year of irradiation in a high-power reactor, were produced within a microsecond. However, the major practical problem of the entire proposal was collecting the radioactive debris dispersed by the powerful blast. Aircraft filters adsorbed only about 4×10^{-14} of the total amount, and collection of tons of corals at Enewetak Atoll increased this fraction by only two orders of magnitude. Extraction of about 500 kilograms of underground rocks 60 days after the Hutch explosion recovered only about 1×10^{-7} of the total charge. The amount of transuranium elements in this 500 kg batch was only 30 times higher than in a 0.4 kg rock picked up 7 days after the test which demonstrated the highly non-linear dependence of the transuranium elements yield on the amount of retrieved radioactive rock. Shafts were drilled at the site before the test in order to accelerate sample collection after explosion, so that explosion would expel radioactive material from the epicenter through the shafts and to collecting volumes near the surface. This method was tried in two tests and instantly provided hundreds kilograms of material, but with actinide concentration 3 times lower than in samples obtained after drilling. Whereas such method could have been efficient in scientific studies of short-lived isotopes, it could not improve the overall collection efficiency of the produced actinides.

Although no new elements (apart from einsteinium and fermium) could be detected in the nuclear test debris, and the total yields of transuranium elements were disappointingly low, these tests did provide significantly higher amounts of rare heavy isotopes than previously available in laboratories.

== Separation ==

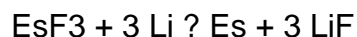
Separation procedure of einsteinium depends on the synthesis method . In the case of light α - α ion bombardment inside a cyclotron , the heavy ion target is attached to a thin foil , and the generated einsteinium is simply washed off the foil after the irradiation . However , the produced amounts in such experiments are relatively low . The yields are much higher for reactor irradiation , but there , the product is a mixture of various actinide isotopes , as well as lanthanides produced in the nuclear fission decays . In this case , isolation of einsteinium is a tedious procedure which involves several repeating steps of cation exchange , at elevated temperature and pressure , and chromatography . Separation from berkelium is important , because the most common einsteinium isotope produced in nuclear reactors , ^{253}Es , decays with a half α - α life of only 20 days to ^{249}Bk , which is fast on the timescale of most experiments . Such separation relies on the fact that berkelium easily oxidizes to the solid + 4 state and precipitates , whereas other actinides , including einsteinium , remain in their + 3 state in solutions .

Separation of trivalent actinides from lanthanide fission products can be done by a cation α - α exchange resin column using a 90 % water / 10 % ethanol solution saturated with hydrochloric acid (HCl) as eluant . It is usually followed by anion α - α exchange chromatography using 6 molar HCl as eluant . A cation α - α exchange resin column (Dowex α - α 50 exchange column) treated with ammonium salts is then used to separate fractions containing elements 99 , 100 and 101 . These elements can be then identified simply based on their elution position / time , using ? α - α hydroxyisobutyrate solution (? α - α HIB) , for example , as eluant .

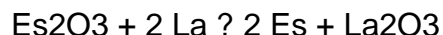
Separation of the 3 + actinides can also be achieved by solvent extraction chromatography , using bis- (2 α - α ethylhexyl) phosphoric acid (abbreviated as HDEHP) as the stationary organic phase , and nitric acid as the mobile aqueous phase . The actinide elution sequence is reversed from that of the cation α - α exchange resin column . The einsteinium separated by this method has the advantage to be free of organic complexing agent , as compared to the separation using a resin column .

== Preparation of the metal ==

Einsteinium is highly reactive and therefore strong reducing agents are required to obtain the pure metal from its compounds . This can be achieved by reduction of einsteinium (III) fluoride with metallic lithium :



However , owing to its low melting point and high rate of self α - α radiation damage , einsteinium has high vapor pressure , which is higher than that of lithium fluoride . This makes this reduction reaction rather inefficient . It was tried in the early preparation attempts and quickly abandoned in favor of reduction of einsteinium (III) oxide with lanthanum metal :



== Chemical compounds ==

== Oxides ==

Einsteinium (III) oxide (Es_2O_3) was obtained by burning einsteinium (III) nitrate . It forms colorless cubic crystals , which were first characterized from microgram samples sized about 30 nanometers . Two other phases , monoclinic and hexagonal , are known for this oxide . The formation of a certain Es_2O_3 phase depends on the preparation technique and sample history , and there is no clear phase diagram . Interconversions between the three phases can occur spontaneously , as a result of self α - α irradiation or self α - α heating . The hexagonal phase is isotypic with lanthanum (III) oxide where the Es^{3+} ion is surrounded by a 6 α - α coordinated group of O_2^- ions .

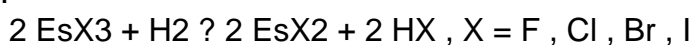
== Halides ==

Einsteinium halides are known for the oxidation states + 2 and + 3 . The most stable state is + 3 for all halides from fluoride to iodide .

Einsteinium (III) fluoride (EsF_3) can be precipitated from einsteinium (III) chloride solutions upon reaction with fluoride ions . An alternative preparation procedure is to exposure einsteinium (III) oxide to chlorine trifluoride (ClF_3) or F_2 gas at a pressure of 1 ? 2 atmospheres and a temperature between 300 and 400 ° C. The EsF_3 crystal structure is hexagonal , as in californium (III) fluoride (CfF_3) where the Es^{3+} ions are 8 @-@ fold coordinated by fluorine ions in a bicapped trigonal prism arrangement .

Einsteinium (III) chloride (EsCl_3) can be prepared by annealing einsteinium (III) oxide in the atmosphere of dry hydrogen chloride vapors at about 500 ° C for some 20 minutes . It crystallizes upon cooling at about 425 ° C into an orange solid with a hexagonal structure of UCl_3 type , where einsteinium atoms are 9 @-@ fold coordinated by chlorine atoms in a tricapped trigonal prism geometry . Einsteinium (III) bromide (EsBr_3) is a pale @-@ yellow solid with a monoclinic structure of AlCl_3 type , where the einsteinium atoms are octahedrally coordinated by bromine (coordination number 6) .

The divalent compounds of einsteinium are obtained by reducing the trivalent halides with hydrogen :



Einsteinium (II) chloride (EsCl_2), einsteinium (II) bromide (EsBr_2), and einsteinium (II) iodide (EsI_2) have been produced and characterized by optical absorption , with no structural information available yet .

Known oxyhalides of einsteinium include EsOCl , EsOBr and EsOI . They are synthesized by treating a trihalide with a vapor mixture of water and the corresponding hydrogen halide : for example , $\text{EsCl}_3 + \text{H}_2\text{O} / \text{HCl}$ to obtain EsOCl .

== Organoeinsteinium compounds ==

The high radioactivity of einsteinium has a potential use in radiation therapy , and organometallic complexes have been synthesized in order to deliver einsteinium atoms to an appropriate organ in the body . Experiments have been performed on injecting einsteinium citrate (as well as fermium compounds) to dogs . Einsteinium (III) was also incorporated into beta @-@ diketone chelate complexes , since analogous complexes with lanthanides previously showed strongest UV @-@ excited luminescence among metallorganic compounds . When preparing einsteinium complexes , the Es^{3+} ions were 1000 times diluted with Gd^{3+} ions . This allowed reducing the radiation damage so that the compounds did not disintegrate during the period of 20 minutes required for the measurements . The resulting luminescence from Es^{3+} was much too weak to be detected . This was explained by the unfavorable relative energies of the individual constituents of the compound that hindered efficient energy transfer from the chelate matrix to Es^{3+} ions . Similar conclusion was drawn for other actinides americium , berkelium and fermium .

Luminescence of Es^{3+} ions was however observed in inorganic hydrochloric acid solutions as well as in organic solution with di (2 @-@ ethylhexyl) orthophosphoric acid . It shows a broad peak at about 1064 nanometers (half @-@ width about 100 nm) which can be resonantly excited by green light (ca . 495 nm wavelength) . The luminescence has a lifetime of several microseconds and the quantum yield below 0 @-@ 1 % . The relatively high , compared to lanthanides , non @-@ radiative decay rates in Es^{3+} were associated with the stronger interaction of f @-@ electrons with the inner Es^{3+} electrons .

== Applications ==

There is almost no use for any isotope of einsteinium outside of basic scientific research aiming at production of higher transuranic elements and transactinides .

In 1955 , mendelevium was synthesized by irradiating a target consisting of about 109 atoms of

^{253}Es in the 60 inch cyclotron at Berkeley Laboratory . The resulting $^{253}\text{Es}(\alpha, n)^{256}\text{Md}$ reaction yielded 17 atoms of the new element with the atomic number of 101 .

The rare isotope einsteinium ^{254}Es is favored for production of ultraheavy elements because of its large mass , relatively long half life of 270 days , and availability in significant amounts of several micrograms . Hence einsteinium ^{254}Es was used as a target in the attempted synthesis of ununennium (element 119) in 1985 by bombarding it with calcium ^{48}Ca ions at the superHILAC linear accelerator at Berkeley , California . No atoms were identified , setting an upper limit for the cross section of this reaction at 300 nanobarns .

<formula>

Einsteinium ^{254}Es was used as the calibration marker in the chemical analysis spectrometer (" alpha scattering surface analyzer ") of the Surveyor 5 lunar probe . The large mass of this isotope reduced the spectral overlap between signals from the marker and the studied lighter elements of the lunar surface .

= = Safety = =

Most of the available einsteinium toxicity data originates from research on animals . Upon ingestion by rats , only about 0 .01 % einsteinium ends in the blood stream . From there , about 65 % goes to the bones , where it remains for about 50 years , 25 % to the lungs (biological half life about 20 years , although this is rendered irrelevant by the short half lives of einsteinium isotopes) , 0 .035 % to the testicles or 0 .01 % to the ovaries ? where einsteinium stays indefinitely . About 10 % of the ingested amount is excreted . The distribution of einsteinium over the bone surfaces is uniform and is similar to that of plutonium .