= Polonium =

Polonium is a chemical element with symbol Po and atomic number 84 . A rare and highly radioactive metal with no stable isotopes , polonium is chemically similar to selenium and tellurium , though it also shows resemblances to its horizontal neighbors thallium , lead , and bismuth due to its metallic character . Due to the short half @-@ life of all its isotopes , its natural occurrence is limited to tiny traces of the fleeting polonium @-@ 210 in uranium ores , as it is the penultimate daughter of natural uranium @-@ 238 : it has a half @-@ life of 138 days . Though slightly longer @-@ lived isotopes exist , they are much more difficult to produce . Today , polonium is more often produced in milligram quantities by the neutron irradiation of bismuth . Due to its intense radioactivity , that results in radiolysis of chemical bonds and immense radioactive self @-@ heating , its chemistry has mostly been investigated on the trace scale only .

Polonium was discovered in 1898 by Marie and Pierre Curie , when it was chemically separated out of uranium ore and identified solely by its strong radioactivity : it was the first element to be so discovered . It was named after Marie Curie 's homeland of Poland . Applications of polonium are sparse and dependent on its radioactivity : they include heaters in space probes , antistatic devices , and sources of neutrons and alpha particles . Its intense radioactivity makes it dangerously toxic to life .

= = Characteristics = =

= = = Isotopes = = =

Polonium has 33 known isotopes , all of which are radioactive . They have atomic masses that range from 188 to 220 u . 210Po (half @-@ life 138 @.@ 376 days) is the most widely available . The longer @-@ lived 209Po (half @-@ life 125 @.@ 2 ± 3 @.@ 3 years , longest @-@ lived of all polonium isotopes) and 208Po (half @-@ life 2 @.@ 9 years) can be made through the alpha , proton , or deuteron bombardment of lead or bismuth in a cyclotron .

210Po is an alpha emitter that has a half @-@ life of 138 @.@ 4 days ; it decays directly to its stable daughter isotope , 206Pb . A milligram (5 curies) of 210Po emits about as many alpha particles per second as 5 grams of 226Ra . A few curies (1 curie equals 37 gigabecquerels , 1 Ci = 37 GBq) of 210Po emit a blue glow which is caused by ionisation of the surrounding air .

About one in 100 @,@ 000 alpha emissions causes an excitation in the nucleus which then results in the emission of a gamma ray with a maximum energy of 803 keV .

= = = Solid state form = = =

Polonium is a radioactive element that exists in two metallic allotropes . The alpha form is the only known example of a simple cubic crystal structure in a single atom basis , with an edge length of 335 @.@ 2 picometers ; the beta form is rhombohedral . The structure of polonium has been characterized by X @-@ ray diffraction and electron diffraction .

210Po (in common with 238Pu) has the ability to become airborne with ease : if a sample is heated in air to 55 ° C (131 ° F) , 50 % of it is vaporized in 45 hours to form diatomic Po2 molecules , even though the melting point of polonium is 254 ° C (489 ° F) and its boiling point is 962 ° C (1 @,@ 764 ° F) . More than one hypothesis exists for how polonium does this ; one suggestion is that small clusters of polonium atoms are spalled off by the alpha decay .

= = = Chemistry = = =

The chemistry of polonium is similar to that of tellurium , although it also shows some similarities to its neighbor bismuth due to its metallic character . Polonium dissolves readily in dilute acids , but is only slightly soluble in alkalis . Polonium solutions are first colored in pink by the Po2 + ions , but

then rapidly become yellow because alpha radiation from polonium ionizes the solvent and converts Po2 + into Po4 + . This process is accompanied by bubbling and emission of heat and light by glassware due to the absorbed alpha particles ; as a result , polonium solutions are volatile and will evaporate within days unless sealed .

= = = = Compounds = = = =

Polonium has no common compounds , and almost all of its compounds are synthetically created ; more than 50 of those are known . The most stable class of polonium compounds are polonides , which are prepared by direct reaction of two elements . Na2Po has the antifluorite structure , the polonides of Ca , Ba , Hg , Pb and lanthanides form a NaCl lattice , BePo and CdPo have the wurtzite and MgPo the nickel arsenide structure . Most polonides decompose upon heating to about 600 ° C , except for HgPo that decomposes at ~ 300 ° C and the lanthanide polonides , which do not decompose but melt at temperatures above 1000 ° C. For example , PrPo melts at 1250 ° C and TmPo at 2200 ° C. PbPo is one of the very few naturally occurring polonium compounds , as polonium alpha decays to form lead .

Polonium hydride (PoH
2) is a volatile liquid at room temperature prone to dissociation ; it is thermally unstable . The two oxides PoO2 and PoO3 are the products of oxidation of polonium .

Halides of the structure PoX2 , PoX4 and PoF6 are known . They are soluble in the corresponding hydrogen halides , i.e. , PoClX in HCl , PoBrX in HBr and PoI4 in HI . Polonium dihalides are formed by direct reaction of the elements or by reduction of PoCl4 with SO2 and with PoBr4 with H2S at room temperature . Tetrahalides can be obtained by reacting polonium dioxide with HCl , HBr or HI .

Other polonium compounds include potassium polonite as a polonite , polonate , acetate , bromate , carbonate , citrate , chromate , cyanide , formate , (II) and (IV) hydroxides , nitrate , selenate , selenite , monosulfide , sulfate , disulfate and sulfite .

= = History = =

Also tentatively called " radium F " , polonium was discovered by Marie and Pierre Curie in 1898 , and was named after Marie Curie 's native land of Poland (Latin : Polonia) . Poland at the time was under Russian , German , and Austro @-@ Hungarian partition , and did not exist as an independent country . It was Curie 's hope that naming the element after her native land would publicize its lack of independence . Polonium may be the first element named to highlight a political controversy .

This element was the first one discovered by the Curies while they were investigating the cause of pitchblende radioactivity . Pitchblende , after removal of the radioactive elements uranium and thorium , was more radioactive than the uranium and thorium combined . This spurred the Curies to search for additional radioactive elements . They first separated out polonium from pitchblende in July 1898 , and five months later , also isolated radium .

In the United States , polonium was produced as part of the Manhattan Project 's Dayton Project during World War II . It was a critical part of the implosion @-@ type nuclear weapon design used in the Fat Man bomb on Nagasaki in 1945 . Polonium and beryllium were the key ingredients of the ' urchin ' detonator at the center of the bomb 's spherical plutonium pit . The urchin ignited the nuclear chain reaction at the moment of prompt @-@ criticality to ensure the bomb did not fizzle .

Much of the basic physics of polonium was classified until after the war . The fact that it was used as an initiator was classified until the 1960s .

The Atomic Energy Commission and the Manhattan Project funded human experiments using polonium on five people at the University of Rochester between 1943 and 1947 . The people were administered between 9 and 22 microcuries (330 and 810 kBq) of polonium to study its excretion .

= = Occurrence and production = =

Polonium is a very rare element in nature because of the short half @-@ life of all its isotopes . 210Po , 214Po , and 218Po appear in the decay chain of 238U ; thus polonium can be found in uranium ores at about 0 @.@ 1 mg per metric ton (1 part in 1010) , which is approximately 0 @.@ 2 % of the abundance of radium . The amounts in the Earth 's crust are not harmful . Polonium has been found in tobacco smoke from tobacco leaves grown with phosphate fertilizers .

Because it is present in such small concentrations , isolation of polonium from natural sources is a very tedious process . The largest batch of the element ever extracted , performed in the first half of the 20th century , contained only 40 Ci (1 @.@ 5 TBq) (9 mg) of polonium @-@ 210 and was obtained by processing 37 tonnes of residues from radium production . Polonium is now obtained by irradiating bismuth with high @-@ energy neutrons or protons .

In 1934 , an experiment showed that when natural 209Bi is bombarded with neutrons , 210Bi is created , which then decays to 210Po via beta @-@ minus decay . The final purification is done pyrochemically followed by liquid @-@ liquid extraction techniques . Polonium may now be made in milligram amounts in this procedure which uses high neutron fluxes found in nuclear reactors . Only about 100 grams are produced each year , practically all of it in Russia , making polonium exceedingly rare .

This process can cause problems in lead @-@ bismuth based liquid metal cooled nuclear reactors such as those used in the Soviet Navy 's K @-@ 27 . Measures must be taken in these reactors to deal with the unwanted possibility of 210Po being released from the coolant .

The longer @-@ lived isotopes of polonium , 208Po and 209Po , can be formed by proton or deuteron bombardment of bismuth using a cyclotron . Other more proton @-@ rich and more unstable isotopes can be formed by the irradiation of platinum with carbon nuclei .

= = Applications = =

Polonium @-@ based sources of alpha particles were produced in the former Soviet Union . Such sources were applied for measuring the thickness of industrial coatings via attenuation of alpha radiation .

Because of intense alpha radiation , a one @-@ gram sample of 210Po will spontaneously heat up to above 500 ° C (932 ° F) generating about 140 watts of power . Therefore , 210Po is used as an atomic heat source to power radioisotope thermoelectric generators via thermoelectric materials . For instance , 210Po heat sources were used in the Lunokhod 1 (1970) and Lunokhod 2 (1973) Moon rovers to keep their internal components warm during the lunar nights , as well as the Kosmos 84 and 90 satellites (1965) .

The alpha particles emitted by polonium can be converted to neutrons using beryllium oxide , at a rate of 93 neutrons per million alpha particles . Thus Po @-@ BeO mixtures or alloys are used as a neutron source , for example in a neutron trigger or initiator for nuclear weapons and for inspections of oil wells . About 1500 sources of this type , with an individual activity of 1 @,@ 850 Ci (68 TBq) , have been used annually in the Soviet Union .

Polonium was also part of brushes or more complex tools that eliminate static charges in photographic plates , textile mills , paper rolls , sheet plastics , and on substrates (such as automotive) prior to the application of coatings . Alpha particles emitted by polonium ionize air molecules that neutralize charges on the nearby surfaces . Some anti @-@ static brushes contain up to 500 microcuries (20 MBq) of 210Po as a source of charged particles for neutralizing static electricity . In USA , the devices with no more than 500 µCi (19 MBq) of (sealed) 210Po per unit can be bought in any amount under a " general license " , which means that a buyer need not be registered by any authorities . Polonium needs to be replaced in these devices nearly every year because of its short half @-@ life ; it is also highly radioactive and therefore has been mostly replaced by less dangerous beta particle sources .

Tiny amounts of 210Po are sometimes used in the laboratory and for teaching purposes ? typically of the order of 4 ? 40 kBq (0 @.@ 11 ? 1 @.@ 08 µCi) , in the form of sealed sources , with the polonium deposited on a substrate or in a resin or polymer matrix ? are often exempt from licensing

by the NRC and similar authorities as they are not considered hazardous . Small amounts of 210Po are manufactured for sale to the public in the United States as ' needle sources ' for laboratory experimentation , and are retailed by scientific supply companies . The polonium is a layer of plating which in turn is plated with a material such as gold , which allows the alpha radiation (used in experiments such as cloud chambers) to pass while preventing the polonium from being released and presenting a toxic hazard . According to United Nuclear , they typically sell between four and eight such sources per year .

= = Biology and toxicity = =

= = = Overview = = =

Polonium is highly dangerous and has no biological role . By mass , polonium @-@ 210 is around 250 @,@ 000 times more toxic than hydrogen cyanide (the LD50 for 210Po is less than 1 microgram for an average adult (see below) compared with about 250 milligrams for hydrogen cyanide) . The main hazard is its intense radioactivity (as an alpha emitter) , which makes it very difficult to handle safely . Even in microgram amounts , handling 210Po is extremely dangerous , requiring specialized equipment (a negative pressure alpha glove box equipped with high performance filters) , adequate monitoring , and strict handling procedures to avoid any contamination . Alpha particles emitted by polonium will damage organic tissue easily if polonium is ingested , inhaled , or absorbed , although they do not penetrate the epidermis and hence are not hazardous as long as the alpha particles remain outside the body . Wearing chemically resistant and intact gloves is a mandatory precaution to avoid transcutaneous diffusion of polonium directly through the skin . Polonium delivered in concentrated nitric acid can easily diffuse through inadequate gloves (e.g. , latex gloves) or the acid may damage the gloves .

It has been reported that some microbes can methylate polonium by the action of methylcobalamin . This is similar to the way in which mercury , selenium and tellurium are methylated in living things to create organometallic compounds . Studies investigating the metabolism of polonium @-@ 210 in rats have shown that only 0 @.@ 002 to 0 @.@ 009 % of polonium @-@ 210 ingested is excreted as volatile polonium @-@ 210 .

= = = Acute effects = = =

The median lethal dose (LD50) for acute radiation exposure is generally about 4 @.@ 5 Sv . The committed effective dose equivalent 210Po is 0 @.@ 51 µSv / Bq if ingested , and 2 @.@ 5 µSv / Bq if inhaled . So a fatal 4 @.@ 5 Sv dose can be caused by ingesting 8 @.@ 8 MBq (240 µCi) , about 50 nanograms (ng) , or inhaling 1 @.@ 8 MBq (49 µCi) , about 10 ng . One gram of 210Po could thus in theory poison 20 million people of whom 10 million would die . The actual toxicity of 210Po is lower than these estimates , because radiation exposure that is spread out over several weeks (the biological half @-@ life of polonium in humans is 30 to 50 days) is somewhat less damaging than an instantaneous dose . It has been estimated that a median lethal dose of 210Po is 15 megabecquerels (0 @.@ 41 mCi) , or 0 @.@ 089 micrograms , still an extremely small amount . For comparison , one grain of table salt is about 0 @.@ 06 mg = 60 ?g . [1]

= = = Long term (chronic) effects = = =

In addition to the acute effects , radiation exposure (both internal and external) carries a long @-@ term risk of death from cancer of 5 ? 10 % per Sv . The general population is exposed to small amounts of polonium as a radon daughter in indoor air ; the isotopes 214Po and 218Po are thought to cause the majority of the estimated 15 @,@ 000 ? 22 @,@ 000 lung cancer deaths in the US every year that have been attributed to indoor radon . Tobacco smoking causes additional exposure to polonium .

= = = Regulatory exposure limits and handling = = =

The maximum allowable body burden for ingested 210Po is only 1 @.@ 1 kBq (30 nCi) , which is equivalent to a particle massing only 6 @.@ 8 picograms . The maximum permissible workplace concentration of airborne 210Po is about 10 Bq / m3 (3 × 10 ? 10 µCi / cm3) . The target organs for polonium in humans are the spleen and liver . As the spleen (150 g) and the liver (1 @.@ 3 to 3 kg) are much smaller than the rest of the body , if the polonium is concentrated in these vital organs , it is a greater threat to life than the dose which would be suffered (on average) by the whole body if it were spread evenly throughout the body , in the same way as caesium or tritium (as T2O) .

210Po is widely used in industry , and readily available with little regulation or restriction . In the US , a tracking system run by the Nuclear Regulatory Commission was implemented in 2007 to register purchases of more than 16 curies (590 GBq) of polonium @-@ 210 (enough to make up 5 @,@ 000 lethal doses) . The IAEA " is said to be considering tighter regulations ... There is talk that it might tighten the polonium reporting requirement by a factor of 10 , to 1 @.@ 6 curies (59 GBq) . " As of 2013 , this is still the only alpha emitting byproduct material available , as a NRC Exempt Quantity , which may be held without a radioactive material license .

Polonium and its compounds must be handled in a glove box , which is further enclosed in another box , maintained at a slightly higher pressure than the glove box to prevent the radioactive materials from leaking out . Gloves made of natural rubber do not provide sufficient protection against the radiation from polonium ; surgical gloves are necessary . Neoprene gloves shield radiation from polonium better than natural rubber .

= = = Well @-@ known poisoning cases = = =

= = = = 20th century = = = =

Polonium was administered to humans for experimental purposes from 1943 to 1947 ; it was injected into four hospitalised patients , and orally given to a fifth . Studies such as this were funded by the Manhattan Project and the AEC , and conducted at the University of Rochester . The objective was to obtain data on human excretion of polonium to correlate with more extensive data from rats . Patients selected as subjects were chosen because experimenters wanted persons who had not been exposed to polonium either through work or accident . All subjects had incurable diseases . Excretion of polonium was followed , and an autopsy was conducted at that time on the deceased patient to determine which organs absorbed the polonium . Patients ' ages ranged from ' early thirties ' to ' early forties . ' The experiments were described in Chapter 3 of Biological Studies with Polonium , Radium , and Plutonium , National Nuclear Energy Series , Volume VI @-@ 3 , McGraw @-@ Hill , New York , 1950 . Not specified is the isotope under study , but at the time polonium @-@ 210 was the most readily available polonium isotope . The DoE factsheet submitted for this experiment reported no follow up on these subjects .

It has also been suggested that Irène Joliot @-@ Curie was the first person to die from the radiation effects of polonium . She was accidentally exposed to polonium in 1946 when a sealed capsule of the element exploded on her laboratory bench . In 1956 , she died from leukemia .

According to the 2008 book The Bomb in the Basement , several deaths in Israel during 1957 ? 1969 were caused by 210Po . A leak was discovered at a Weizmann Institute laboratory in 1957 . Traces of 210Po were found on the hands of professor Dror Sadeh , a physicist who researched radioactive materials . Medical tests indicated no harm , but the tests did not include bone marrow . Sadeh died from cancer . One of his students died of leukemia , and two colleagues died after a few years , both from cancer . The issue was investigated secretly , and there was never any formal admission that a connection between the leak and the deaths had existed .

= = = = 21st century = = = =

The cause of death in the 2006 murder of the Russian KGB agent who defected to the British MI6 intelligence agency , Alexander Litvinenko was determined to be 210Po poisoning . According to Prof. Nick Priest of Middlesex University , an environmental toxicologist and radiation expert , speaking on Sky News on December 3 , 2006 , Litvinenko was probably the first person to die of the acute ? @-@ radiation effects of 210Po .

Abnormally high concentrations of 210Po were detected in July 2012 in clothes and personal belongings of the Palestinian leader Yasser Arafat , a heavy smoker , who died on 11 November 2004 of uncertain causes . The spokesman for the Institut de Radiophysique in Lausanne , Switzerland , where those items were analyzed , stressed that the " clinical symptoms described in Arafat 's medical reports were not consistent with polonium @-@ 210 and that conclusions could not be drawn as to whether the Palestinian leader was poisoned or not " , and that " the only way to confirm the findings would be to exhume Arafat 's body to test it for polonium @-@ 210 . " On 27 November 2012 Arafat 's body was exhumed and samples were taken for separate analysis by experts from France , Switzerland and Russia . On 12 October 2013 , The Lancet published the group 's finding that high levels of the element were found in Arafat 's blood , urine , and in saliva stains on his clothes and toothbrush . The French tests later found some polonium but stated it was from " natural environmental origin . " Following later Russian tests , Vladimir Uiba , the head of the Russian Federal Medical and Biological Agency , stated in December 2013 that Arafat died of natural causes , and they had no plans to conduct further tests .

= = = Treatment = = =

It has been suggested that chelation agents such as British Anti @-@ Lewisite (dimercaprol) can be used to decontaminate humans . In one experiment , rats were given a fatal dose of 1 @.@ 45 MBq / kg (8 @.@ 7 ng / kg) of 210Po ; all untreated rats were dead after 44 days , but 90 % of the rats treated with the chelation agent HOEtTTC remained alive after 5 months .

= = = Detection in biological specimens = = =

Polonium @-@ 210 may be quantified in biological specimens by alpha particle spectrometry to confirm a diagnosis of poisoning in hospitalized patients or to provide evidence in a medicolegal death investigation . The baseline urinary excretion of polonium @-@ 210 in healthy persons due to routine exposure to environmental sources is normally in a range of 5 ? 15 mBq / day . Levels in excess of 30 mBq / day are suggestive of excessive exposure to the radionuclide .

= = = Occurrence in humans and the biosphere = = =

Polonium @-@ 210 is widespread in the biosphere , including in human tissues , because of its position in the uranium @-@ 238 decay chain . Natural uranium @-@ 238 in the Earth 's crust decays through a series of solid radioactive intermediates including radium @-@ 226 to the radioactive gas radon @-@ 222 , some of which , during its 3 @.@ 8 @-@ day half @-@ life , diffuses into the atmosphere . There it decays through several more steps to polonium @-@ 210 , much of which , during its 138 @-@ day half @-@ life , is washed back down to the Earth 's surface , thus entering the biosphere , before finally decaying to stable lead @-@ 206 .

As early as the 1920s Antoine Lacassagne , using polonium provided by his colleague Marie Curie , showed that the element has a very specific pattern of uptake in rabbit tissues , with high concentrations particularly in liver , kidney and testes . More recent evidence suggests that this behavior results from polonium substituting for sulfur in sulfur @-@ containing amino @-@ acids or related molecules and that similar patterns of distribution occur in human tissues . Polonium is indeed an element naturally present in all humans , contributing appreciably to natural background dose , with wide geographical and cultural variations , and particularly high levels in arctic residents , for example .

= = = Tobacco = = =

Polonium @-@ 210 in tobacco contributes to many of the cases of lung cancer worldwide . Most of this polonium is derived from lead @-@ 210 deposited on tobacco leaves from the atmosphere ; the lead @-@ 210 is a product of radon @-@ 222 gas , much of which appears to originate from the decay of radium @-@ 226 from fertilizers applied to the tobacco soils .

The presence of polonium in tobacco smoke has been known since the early 1960s . Some of the world 's biggest tobacco firms researched ways to remove the substance ? to no avail ? over a 40 @-@ year period . The results were never published .

= = = Food = = =

Polonium is also found in the food chain , especially in seafood .