

# Arsenic

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**Arsenic** is the chemical element that has the symbol *As*, atomic number 33 and atomic mass 74.92. Arsenic was first documented by Albertus Magnus in 1250.<sup>[4]</sup> Arsenic is a notoriously poisonous metalloid with many allotropic forms, including a yellow (molecular non-metallic) and several black and grey forms (metalloids). Three metalloidal forms of arsenic, each with a different crystal structure, are found free in nature (the minerals arsenic *sensu stricto* and the much rarer arsenolamprite and pararsenolamprite). However, it is more commonly found as arsenide and in arsenate compounds, several hundred of which are known. Arsenic and its compounds are used as pesticides, herbicides, insecticides and in various alloys.

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germanium ← <b>arsenic</b> → selenium	
P ↑ <b>As</b> ↓ Sb	  <b>33As</b> <span style="float: right;">□</span>
Periodic table	
<b>Appearance</b>	
metallic grey	
	
<b>General properties</b>	
<b>Name, symbol, number</b>	arsenic, As, 33
<b>Pronunciation</b>	<span><span>/<span><span>ˈ</span><span>ɑːr</span><span>s</span><span>ə</span><span>n</span><span>ɪ</span><span>k</span></span>/</span></span> , <i>ARS-ə-nik</i> ; also <span><span>/<span><span>ɑːr</span><span>ˈ</span><span>s</span><span>ɛ</span><span>n</span><span>ɪ</span><span>k</span></span>/</span></span> , <i>ar-SEN-ik</i> when attributive
<b>Element category</b>	metalloid
<b>Group, period, block</b>	15, 4, p
<b>Standard atomic weight</b>	74.92160(2) g·mol <sup>−1</sup>
<b>Electron configuration</b>	[Ar] 4s <sup>2</sup> 3d <sup>10</sup> 4p <sup>3</sup>
<b>Electrons per shell</b>	2, 8, 18, 5 (Image)
<b>Physical properties</b>	
<b>Phase</b>	solid
<b>Density (near r.t.)</b>	5.727 g·cm <sup>−3</sup>
<b>Liquid density at m.p.</b>	5.22 g·cm <sup>−3</sup>
<b>Sublimation point</b>	887 K, 615 °C, 1139 °F
<b>Triple point</b>	1090 K (817°C), 3628 <sup>[1]</sup> kPa
<b>Critical point</b>	1673 K, ? MPa
<b>Heat of fusion</b>	(grey) 24.44 kJ·mol <sup>−1</sup>
<b>Heat of vaporization</b>	? 34.76 kJ·mol <sup>−1</sup>
<b>Specific heat capacity</b>	(25 °C) 24.64 J·mol <sup>−1</sup> ·K <sup>−1</sup>
<b>Vapor pressure</b>	

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## History

The word *arsenic* was borrowed from the Syriac word ܐܪܨܢܝܩܐ 𐤀𐤓𐤕𐤍𐤏𐤍 (*al zarniqa*)<sup>[5]</sup> and the Persian word زرنیخ *Zarnikh*, meaning "yellow orpiment", into Greek as *arsenikon* (Ἀρσενικόν). It is also related to the similar Greek word *arsenikos* (Ἀρσενικός), meaning "masculine" or "potent". The word was adopted in Latin *arsenicum* and Old French *arsenic*, from which the English word *arsenic* is derived.<sup>[5]</sup> Arsenic sulfides (orpiment, realgar) and oxides have been known and used since ancient times.<sup>[6]</sup> Zosimos (circa 300 AD) describes roasting *sandarach* (realgar) to obtain *cloud of arsenic* (arsenious oxide) which he then reduces to metallic arsenic.<sup>[7]</sup> As the symptoms of arsenic poisoning were somewhat ill-defined, it was frequently used for murder until the advent of the Marsh test, a sensitive chemical test for its presence. (Another less sensitive but more general test is the Reinsch test.) Owing to its use by the ruling class to murder one another and its potency and discreetness, arsenic has been called the *Poison of Kings* and the *King of Poisons*.<sup>[8]</sup>

During the Bronze Age, arsenic was often included in bronze, which made the alloy harder (so-called "arsenical bronze"). Albertus Magnus (Albert the Great, 1193–1280) is believed to have been the first to isolate the element in 1250 by heating soap together with arsenic trisulfide.<sup>[4]</sup> In 1649, Johann Schröder published two ways of preparing arsenic.



Alchemical symbol for arsenic

Cadet's fuming liquid (impure cacodyl), the first

organometallic compound, was synthesized in 1760 by Louis Claude Cadet de Gassicourt by the reaction of potassium acetate with arsenic trioxide.<sup>[9]</sup>

In the Victorian era, "arsenic" (colourless, crystalline, soluble "white arsenic" trioxide) was mixed with vinegar and chalk and eaten by women to improve the

<i>P</i> /Pa	1	10	100	1 k	10 k	100 k
at <i>T</i> /K	553	596	646	706	781	874
<b>Atomic properties</b>						
Oxidation states	5, 3, 2, 1, <sup>[2]</sup> −3 (mildly acidic oxide)					
Electronegativity	2.18 (Pauling scale)					
Ionization energies (more)	1st: 947.0 kJ·mol <sup>−1</sup>					
	2nd: 1798 kJ·mol <sup>−1</sup>					
	3rd: 2735 kJ·mol <sup>−1</sup>					
Atomic radius	119 pm					
Covalent radius	119±4 pm					
Van der Waals radius	185 pm					
<b>Miscellanea</b>						
Crystal structure	rhombohedral					
Magnetic ordering	diamagnetic <sup>[3]</sup>					
Electrical resistivity	(20 °C) 333 nΩ·m					
Thermal conductivity	(300 K) 50.2 W·m <sup>−1</sup> ·K <sup>−1</sup>					
Young's modulus	8 GPa					
Bulk modulus	22 GPa					
Mohs hardness	3.5					
Brinell hardness	1440 MPa					
CAS registry number	7440-38-2					
<b>Most stable isotopes</b>						
Main article: Isotopes of arsenic						
iso	NA	half-life	DM	DE (MeV)	DP	
<sup>73</sup> As	syn	80.3 d	ε	-	<sup>73</sup> Ge	
			γ	0.05D, 0.01D, e	-	
<sup>74</sup> As	syn	17.78 d	ε	-	<sup>74</sup> Ge	
			β <sup>+</sup>	0.941	<sup>74</sup> Ge	
			γ	0.595, 0.634	-	
			β <sup>−</sup>	1.35, 0.717	<sup>74</sup> Se	
<sup>75</sup> As	100%	<sup>75</sup> As is stable with 42 neutrons				

complexion of their faces, making their skin paler to show they did not work in the fields. Arsenic was also rubbed into the faces and arms of women to "improve their complexion". The accidental use of arsenic in the adulteration of foodstuffs led to the Bradford sweet poisoning in 1858, which resulted in approximately 20 deaths and 200 people taken ill with arsenic poisoning.<sup>[10]</sup>

## Characteristics

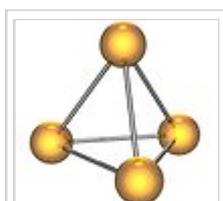
### Isotopes

*Main article: Isotopes of arsenic*

Naturally occurring arsenic is composed of one stable isotope, <sup>75</sup>As.<sup>[11]</sup> As of 2003, at least 33 radioisotopes have also been synthesized, ranging in atomic mass from 60 to 92. The most stable of these is <sup>73</sup>As with a half-life of 80.3 days. Isotopes that are lighter than the stable <sup>75</sup>As tend to decay by β<sup>+</sup> decay, and those that are heavier tend to decay by β<sup>−</sup> decay, with some exceptions.

At least 10 nuclear isomers have been described, ranging in atomic mass from 66 to 84. The most stable of arsenic's isomers is <sup>68m</sup>As with a half-life of 111 seconds.<sup>[11]</sup>

### Allotropes



Structure of yellow arsenic As<sub>4</sub> and white phosphorus P<sub>4</sub>

Like phosphorus, arsenic is an excellent example of an element that exhibits allotropy, as its various allotropes have strikingly different properties. The three most common allotropes are *metallic grey*, *yellow* and *black arsenic*.<sup>[12]</sup>

The most common allotrope of arsenic is *grey arsenic*. It has a similar structure to black phosphorus (β-metallic phosphorus) and has a layered crystal structure somewhat resembling that of graphite. It consists of many six-membered rings which are interlinked. Each atom is bound to three other atoms in the layer and is coordinated by each 3 arsenic atoms in the upper and lower layer. This relatively close packing leads to a high density of 5.73 g/cm<sup>3</sup>.<sup>[13]</sup>

*Yellow arsenic* (As<sub>4</sub>) is soft and waxy, somewhat similar to P<sub>4</sub>. Both have four atoms arranged in a tetrahedral structure in which each atom is bound to each of the other three atoms by a single bond, resulting in very high ring strain and instability. This form of arsenic is the least stable, most reactive, most volatile, least dense, and most toxic of all the allotropes. Yellow arsenic is produced by rapid cooling of arsenic vapour with liquid nitrogen. It is rapidly transformed into the grey arsenic by light. The yellow form has a density of 1.97 g/cm<sup>3</sup>.<sup>[13]</sup>

*Black arsenic* is similar in structure to red phosphorus.<sup>[13]</sup>

### Chemical

The most common oxidation states for arsenic are −3 (arsenides: usually alloy-like intermetallic compounds), +3 (arsenates(III) or arsenites, and most organoarsenic compounds), and +5 (arsenates: the most stable inorganic arsenic oxycompounds). Arsenic also bonds readily to itself, forming square As<sub>4</sub><sup>3−</sup> ions in the arsenide skutterudite. In the +3 oxidation state, the stereochemistry of arsenic

is affected by the presence of a lone pair of electrons.

Arsenic is very similar chemically to its predecessor in the Periodic Table, phosphorus. Like phosphorus, it forms colourless, odourless, crystalline oxides  $\text{As}_2\text{O}_3$  and  $\text{As}_2\text{O}_5$  which are hygroscopic and readily soluble in water to form acidic solutions. Arsenic(V) acid is a weak acid. Like phosphorus, arsenic forms an unstable, gaseous hydride: arsine ( $\text{AsH}_3$ ). The similarity is so great that arsenic will partly substitute for phosphorus in biochemical reactions and is thus poisonous. However, in subtoxic doses, soluble arsenic compounds act as stimulants, and were once popular in small doses as medicine by people in the mid 18th century.<sup>[13]</sup>

When heated in air, arsenic oxidizes to arsenic trioxide; the fumes from this reaction have an odour resembling garlic. This odour can be detected on striking arsenide minerals such as arsenopyrite with a hammer. Arsenic (and some arsenic compounds) sublimes upon heating at atmospheric pressure, converting directly to a gaseous form without an intervening liquid state. The liquid state appears at 20 atmospheres and above, which explains why the melting point is higher than the boiling point.<sup>[13]</sup>

## Compounds

*See also: Category:Arsenic compounds*

Arsenic compounds resemble in many respects those of phosphorus as both arsenic and phosphorus occur in the same group (column) of the periodic table.

The most important compounds of arsenic are arsenic(III) oxide,  $\text{As}_2\text{O}_3$ , ("white arsenic"), the yellow sulfide orpiment ( $\text{As}_2\text{S}_3$ ) and red realgar ( $\text{As}_4\text{S}_4$ ), Paris Green, calcium arsenate, and lead hydrogen arsenate. The latter three have been used as agricultural insecticides and poisons.

Whilst arsenic trioxide forms during oxidation of arsenic, arsenic pentoxide is formed by the dehydration of arsenic acid. Both oxides dissolve in strong alkaline solution, with the formation of arsenite  $\text{AsO}_3^{3-}$  and arsenate  $\text{AsO}_4^{3-}$  respectively. The protonation steps between the arsenate and arsenic acid are similar to those between phosphate and phosphoric acid. However, arsenite and arsenous acid contain arsenic bonded to three oxygen and not hydrogen atoms, in contrast to phosphite and phosphorous acid (more accurately termed 'phosphonic acid'), which contain non-acidic P-H bonds. Arsenous acid is genuinely tribasic, whereas phosphonic acid is not.

A broad variety of sulfur compounds of arsenic are known,  $\text{As}_4\text{S}_3$ ,  $\text{As}_4\text{S}_4$ ,  $\text{As}_2\text{S}_3$  and  $\text{As}_4\text{S}_{10}$ . All arsenic(III) halogen compounds (except with astatine) are known and stable. For the arsenic(V) compounds the situation is different: only the arsenic pentafluoride is stable at room temperature. Arsenic pentachloride is only stable at temperatures below  $-50\text{ }^\circ\text{C}$  and the pentabromide and pentaiodide are unknown.<sup>[13]</sup>

Arsenic is used as group 5 element as part of the III-V semiconducting compounds. Gallium arsenide, indium arsenide and aluminium arsenide are used as semiconductor material when the properties of silicon are not suitable for the application and the higher price of the compounds is acceptable. Other arsenic compounds include cadmium arsenide, gallium arsenide, and lead hydrogen arsenate.

Arsenic also has a formal oxidation state of +2 in  $\text{As}_4\text{S}_4$ , realgar. This is achieved by pairing As

atoms to produce dimeric cations  $[\text{As-As}]^{2+}$ , so the total covalency of As is still in fact three.<sup>[14]</sup>

## Occurrence

*See also: Arsenide minerals and Arsenate minerals*



A large sample of native arsenic.

Arsenopyrite, also unofficially called mispickel,<sup>[15]</sup> ( $\text{FeAsS}$ ) is the most common arsenic-bearing mineral. In the lithosphere, the minerals of the formula  $\text{M(II)AsS}$ , with M(II) being mostly Fe, Ni and Co, are the dominant arsenic minerals.

Orpiment and realgar were formerly used as painting pigments, though they have fallen out of use owing to their toxicity and reactivity.

Although arsenic is sometimes found native in nature, its main economic source is the mineral arsenopyrite mentioned above; it is also found in arsenides of metals such as silver, cobalt (cobaltite:  $\text{CoAsS}$  and skutterudite:  $\text{CoAs}_3$ ) and nickel, as sulfides, and when oxidised as arsenate minerals such as mimetite,  $\text{Pb}_5(\text{AsO}_4)_3\text{Cl}$  and erythrite,  $\text{Co}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$ , and more rarely arsenites ('arsenite' = arsenate(III),  $\text{AsO}_3^{3-}$  as opposed to arsenate (V),  $\text{AsO}_4^{3-}$ ).



Realgar

In addition to the inorganic forms mentioned above, arsenic also occurs in various organic forms in the environment.<sup>[16]</sup>

Other naturally occurring pathways of exposure include volcanic ash, weathering of the arsenic-containing mineral and ores as well as groundwater. It is also found in food, water, soil and air.<sup>[17]</sup>

## Production

In 2005, China was the top producer of white arsenic with almost 50% world share, followed by Chile, Peru and Morocco, reports the British Geological Survey and the United States Geological Survey.<sup>[18]</sup> The arsenic was recovered mostly during mining operations, for example the production from Peru comes mostly from copper mining and the production in China is owing to gold mining. Arsenic is part of the smelter dust from copper, gold, and lead smelters.<sup>[19]</sup>



Arsenic output in 2006<sup>[18]</sup>

On roasting in air of arsenopyrite, arsenic sublimes as arsenic(III) oxide leaving iron oxides,<sup>[16]</sup> while roasting without air results in the production of metallic arsenic. Further purification from sulfur and other chalcogens is achieved by sublimation in vacuum or in a hydrogen atmosphere or by distillation from molten lead-arsenic mixture.<sup>[20]</sup>

## Applications

### Wood preservation

The toxicity of arsenic to insects, bacteria, and fungi led to its use as a wood preservative. In the 1950s a process of treating wood with chromated copper arsenate (also known as CCA or Tanalith) was invented, and for decades this treatment was the most extensive industrial use of arsenic. Due to improved understanding of arsenic's high level of toxicity, most countries banned the use of CCA in consumer products. The European Union and United States led this ban, beginning in 2004.<sup>[21][22]</sup>

As of 2002, US-based industries consumed 19,600 metric tons of arsenic. 90% of this was used for treatment of wood with CCA. In 2007, 50% of the 5,280 metric tons of consumption was still used for this purpose.<sup>[19][23]</sup> In the United States, the use of arsenic in consumer products was discontinued for residential and general consumer construction on December 31, 2003 and alternative chemicals are now used, such as ACQ, borates, copper azole, cyproconazole, and propiconazole.<sup>[24]</sup>

Although discontinued, this application is also one of the most concern to the general public. The vast majority of older pressure-treated wood was treated with CCA. CCA lumber is still in widespread use in many countries, and was heavily used during the latter half of the 20th century as a structural and outdoor building material. Although the use of CCA lumber was banned in many areas after studies showed that arsenic could leach out of the wood into the surrounding soil (from playground equipment, for instance), a risk is also presented by the burning of older CCA timber. The direct or indirect ingestion of wood ash from burnt CCA lumber has caused fatalities in animals and serious poisonings in humans; the lethal human dose is approximately 20 grams of ash. Scrap CCA lumber from construction and demolition sites may be inadvertently used in commercial and domestic fires. Protocols for safe disposal of CCA lumber do not exist evenly throughout the world; there is also concern in some quarters about the widespread landfill disposal of such timber.<sup>[25]</sup>

### Medical

During the 18th, 19th, and 20th centuries, a number of arsenic compounds have been used as medicines, including arsphenamine (by Paul Ehrlich) and arsenic trioxide (by Thomas Fowler). Arsphenamine as well as Neosalvarsan was indicated for syphilis and trypanosomiasis, but has been superseded by modern antibiotics. Arsenic trioxide has been used in a variety of ways over the past 500 years, but most commonly in the treatment of cancer. The US Food and Drug Administration in 2000 approved this compound for the treatment of patients with acute promyelocytic leukemia that is resistant to ATRA.<sup>[26]</sup> It was also used as Fowler's solution in psoriasis.<sup>[27]</sup> Recently new research has been done in locating tumours using arsenic-74 (a positron emitter). The advantages of using this isotope instead of the previously used iodine-124 is that the signal in the PET scan is clearer as the body tends to transport iodine to the thyroid gland producing a lot of noise.<sup>[28]</sup>

### Pigments

Copper acetoarsenite was used as a green pigment known under many different names, including 'Paris Green' and 'Emerald Green'. It caused numerous arsenic poisonings. Scheele's Green, a copper arsenate, was used in the 19th century as a colouring agent in sweets.<sup>[29]</sup>

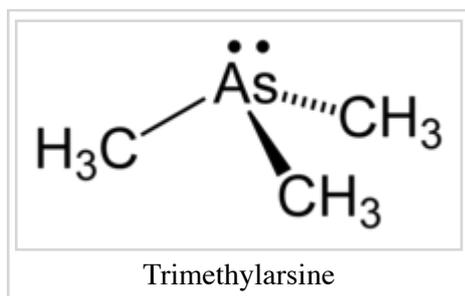
## Military

After World War I the United States built up a stockpile of 20,000 tons of lewisite; a chemical weapon, acting as a vesicant (blister agent) and lung irritant. The stockpile was neutralized with bleach and dumped into the Gulf of Mexico after the 1950s.<sup>[30]</sup> During the Vietnam War the United States used Agent Blue (a mixture of sodium cacodylate) and dimethyl arsenic acid (cacodylic acid) as one of the rainbow herbicides to deprive the Vietnamese of valuable crops.

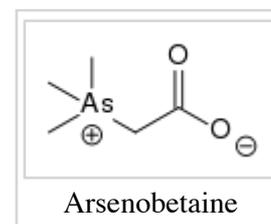
## Other uses

- Various agricultural insecticides, termination and poisons. For example Lead hydrogen arsenate was used well into the 20th century as an insecticide on fruit trees.<sup>[31]</sup> Its use sometimes resulted in brain damage to those working the sprayers. In the last half century, monosodium methyl arsenate (MSMA) and disodium methyl arsenate (DSMA), a less toxic organic form of arsenic, has replaced lead arsenate's role in agriculture.
- Used in animal feed, particularly in the US as a method of disease prevention<sup>[32][33]</sup> and growth stimulation. One example is roxarsone which was used by 69.8 and 73.9% of the broiler starter and growers between 1995 to 2000.<sup>[34]</sup>
- Gallium arsenide is an important semiconductor material, used in integrated circuits. Circuits made using the compound are much faster (but also much more expensive) than those made in silicon. Unlike silicon it is direct bandgap, and so can be used in laser diodes and LEDs to directly convert electricity into light.
- Also used in bronzing and pyrotechnics.
- Up to 2% of arsenic is used in lead alloys for lead shots and bullets.<sup>[35]</sup>
- Arsenic is added in small quantities to brass to make it dezincification resistant. This grade of brass is used to make plumbing fittings.
- Arsenic is also used for taxonomic sample preservation.
- Until recently Arsenic was used in optical glass. Modern glass manufacturers, under pressure from environmentalists, have removed it, along with Lead.<sup>[36]</sup>

## Biological role



Inorganic arsenic and its compounds, upon entering the food chain, are progressively metabolised to less toxic forms of arsenic through a process of methylation. For example, the mold *Scopulariopsis brevicaulis* produce significant amounts of



trimethylarsine if inorganic arsenic is present.<sup>[37]</sup> The organic compound arsenobetaine is found in some marine foods such

as fish and algae, and also in mushrooms in larger concentrations. The average person's intake is about 10–50  $\mu\text{g}/\text{day}$ . Values about 1000  $\mu\text{g}$  are not unusual following consumption of fish or mushrooms. But there is little danger in eating fish because this arsenic compound is nearly non-toxic.<sup>[38]</sup>

Some species of bacteria obtain their energy by oxidizing various fuels while reducing arsenate to

arsenite. The enzymes involved are known as arsenate reductases (Arr).

In 2008, bacteria were discovered that employ a version of photosynthesis in the absence of oxygen with arsenites as electron donors, producing arsenates (just like ordinary photosynthesis uses water as electron donor, producing molecular oxygen). Researchers conjecture that historically these photosynthesizing organisms produced the arsenates that allowed the arsenate-reducing bacteria to thrive. One strain PHS-1 has been isolated and is related to the  $\gamma$ -Proteobacterium *Ectothiorhodospira shaposhnikovii*. The mechanism is unknown, but an encoded Arr enzyme may function in reverse to its known homologues.<sup>[39]</sup>

Arsenic has been linked to epigenetic changes which are heritable changes in gene expression that occur without changes in DNA sequence and include DNA methylation, histone modification and RNA interference. Toxic levels of arsenic cause significant DNA hypermethylation of tumour suppressor genes p16 and p53 thus increasing risk of carcinogenesis. These epigenetic events have been observed in *in vitro* studies with human kidney cells and *in vivo* tests with rat liver cells and peripheral blood leukocytes in humans.<sup>[40]</sup> Inductive coupled plasma mass spectrometry (ICP-MS) is used to detect precise levels of intracellular of arsenic and its other bases involved in epigenetic modification of DNA.<sup>[41]</sup> Studies investigating arsenic as an epigenetic factor will help in developing precise biomarkers of exposure and susceptibility.

## Mapping of industrial releases in the United States

One tool that maps releases of arsenic [1] (<http://toxmap.nlm.nih.gov/toxmap/tri/mapIt.do?chemicalName=arsenic>) to particular locations in the United States<sup>[42]</sup> and also provides additional information about such releases is TOXMAP. TOXMAP is a Geographic Information System (GIS) from the Division of Specialized Information Services of the United States National Library of Medicine (NLM) that uses maps of the United States to help users visually explore data from the United States Environmental Protection Agency's (EPA) Toxics Release Inventory and Superfund Basic Research Programs. TOXMAP is a resource funded by the US Federal Government. TOXMAP's chemical and environmental health information is taken from NLM's Toxicology Data Network (TOXNET)<sup>[43]</sup> and PubMed, and from other authoritative sources.

## Safety

*Main articles: Arsenic poisoning and Arsenic toxicity*



Arsenic and many of its compounds are especially potent poisons. Arsenic disrupts ATP production through several mechanisms. At the level of the citric acid cycle, arsenic inhibits lipoic acid which is a cofactor for pyruvate dehydrogenase; and by competing with phosphate it uncouples oxidative phosphorylation, thus inhibiting energy-linked reduction of NAD<sup>+</sup>, mitochondrial respiration, and ATP synthesis.

Hydrogen peroxide production is also increased, which might form reactive oxygen species and oxidative stress. These metabolic interferences lead to death from multi-system organ failure, probably from necrotic cell death, not apoptosis. A post mortem reveals brick red coloured mucosa, owing to severe haemorrhage. Although arsenic causes toxicity, it can also play a protective role.<sup>[44]</sup>

Elemental arsenic and arsenic compounds are classified as "toxic" and "dangerous for the

environment" in the European Union under directive 67/548/EEC. The International Agency for Research on Cancer (IARC) recognizes arsenic and arsenic compounds as group 1 carcinogens, and the EU lists arsenic trioxide, arsenic pentoxide and arsenate salts as category 1 carcinogens.

Arsenic is known to cause arsenicosis owing to its manifestation in drinking water, "the most common species being arsenate [ $\text{HAsO}_4^{2-}$ ; As(V)] and arsenite [ $\text{H}_3\text{AsO}_3$ ; As(III)]". The ability of arsenic to undergo redox conversion between As(III) and As(V) makes its availability in the environment more abundant. According to Croal, Gralnick, Malasarn, and Newman, "[the] understanding [of] what stimulates As(III) oxidation and/or limits As(V) reduction is relevant for bioremediation of contaminated sites (Croal). The study of chemolithoautotrophic As(III) oxidizers and the heterotrophic As(V) reducers can help the understanding of the oxidation and/or reduction of arsenic."<sup>[45]</sup>

Treatment of chronic arsenic poisoning is easily accomplished. British anti-lewisite (dimercaprol) is prescribed in dosages of 5 mg/kg up to 300 mg each 4 hours for the first day. Then administer the same dosage each 6 hours for the second day. Then prescribe this dosage each 8 hours for eight additional days.<sup>[46]</sup>

## Arsenic in drinking water

*Main article: Arsenic contamination of groundwater*

Arsenic contamination of groundwater has led to a massive epidemic of arsenic poisoning in Bangladesh<sup>[47]</sup> and neighbouring countries. Presently 42 major incidents around the world have been reported on groundwater arsenic contamination. It is estimated that approximately 57 million people are drinking groundwater with arsenic concentrations elevated above the World Health Organization's standard of 10 parts per billion. However, a study of cancer rates in Taiwan<sup>[48]</sup> suggested that significant increases in cancer mortality appear only at levels above 150 parts per billion. The arsenic in the groundwater is of natural origin, and is released from the sediment into the groundwater owing to the anoxic conditions of the subsurface. This groundwater began to be used after local and western NGOs and the Bangladeshi government undertook a massive shallow tube well drinking-water program in the late twentieth century. This program was designed to prevent drinking of bacterially contaminated surface waters, but failed to test for arsenic in the groundwater. Many other countries and districts in South East Asia, such as Vietnam, Cambodia, and China have geological environments conducive to generation of high-arsenic groundwaters. Arsenicosis was reported in Nakhon Si Thammarat, Thailand in 1987, and the dissolved arsenic in the Chao Phraya River is suspected of containing high levels of naturally occurring arsenic, but has not been a public health problem owing to the use of bottled water.<sup>[49]</sup>

In the United States, arsenic is most commonly found in the ground waters of the southwest.<sup>[50]</sup> Parts of New England, Michigan, Wisconsin, Minnesota and the Dakotas are also known to have significant concentrations of arsenic in ground water. Increased levels of skin cancer have been associated with arsenic exposure in Wisconsin, even at levels below the 10 part per billion drinking water standard.<sup>[51]</sup> According to a recent film funded by the US Superfund, millions of private wells have unknown arsenic levels, and in some areas of the US, over 20% of wells may contain levels that exceed established limits.<sup>[52]</sup>

Low-level exposure to arsenic at concentrations found commonly in US drinking water compromises

the initial immune response to H1N1 or swine flu infection according to NIEHS-supported scientists. The study, conducted in laboratory mice, suggests that people exposed to arsenic in their drinking water may be at increased risk for more serious illness or death in response to infection from the virus.<sup>[53]</sup>

Epidemiological evidence from Chile shows a dose dependent connection between chronic arsenic exposure and various forms of cancer, particularly when other risk factors, such as cigarette smoking, are present. These effects have been demonstrated to persist below 50 parts per billion.<sup>[54]</sup>

Analyzing multiple epidemiological studies on inorganic arsenic exposure suggests a small but measurable risk increase for bladder cancer at 10 parts per billion.<sup>[55]</sup> According to Peter Ravenscroft of the Department of Geography at the University of Cambridge,<sup>[56]</sup> roughly 80 million people worldwide consume between 10 and 50 parts per billion arsenic in their drinking water. If they all consumed exactly 10 parts per billion arsenic in their drinking water, the previously cited multiple epidemiological study analysis would predict an additional 2,000 cases of bladder cancer alone. This represents a clear underestimate of the overall impact, since it does not include lung or skin cancer, and explicitly underestimates the exposure. Those exposed to levels of arsenic above the current WHO standard should weigh the costs and benefits of arsenic remediation.

Early (1973) evaluations of the removal of dissolved arsenic by drinking water treatment processes demonstrated that arsenic is very effectively removed by co-precipitation with either iron or aluminum oxides. The use of iron as a coagulant, in particular, was found to remove arsenic with efficiencies exceeding 90%.<sup>[57][58]</sup> Several adsorptive media systems have been approved for point-of-service use in a study funded by the United States Environmental Protection Agency (U.S.EPA) and the National Science Foundation (NSF). A team of European and Indian scientists and engineers have set up six arsenic treatment plants in West Bengal based on in-situ remediation method (SAR Technology). This technology does not use any chemicals and arsenic is left as an insoluble form (+5 state) in the subterranean zone by recharging aerated water into the aquifer and thus developing an oxidation zone to support arsenic oxidizing micro-organisms. This process does not produce any waste stream or sludge and is relatively cheap.<sup>[59]</sup>

Magnetic separations of arsenic at very low magnetic field gradients have been demonstrated in point-of-use water purification with high-surface-area and monodisperse magnetite ( $\text{Fe}_3\text{O}_4$ ) nanocrystals. Using the high specific surface area of  $\text{Fe}_3\text{O}_4$  nanocrystals the mass of waste associated with arsenic removal from water has been dramatically reduced.<sup>[60]</sup>

Epidemiological studies have suggested a correlation between chronic consumption of drinking water contaminated with arsenic and the incidence of type 2 diabetes. However, the literature provides insufficient scientific evidence to show cause and effect between arsenic and the onset of diabetes mellitus type 2.

## Occupational exposures

*Main article: Arsenic poisoning*

Industries that use inorganic arsenic and its compounds include wood preservation, glass production, nonferrous metal alloys, and electronic semiconductor manufacturing. Inorganic arsenic is also found in coke oven emissions associated with the smelter industry.<sup>[61]</sup> Occupational exposure and

poisoning may occur in persons working in these industries.

## See also

- Aqua Tofana
- Arsenic poisoning
- Arsenic trioxide
- Fowler's solution
- Grainger challenge
- White arsenic

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## External links

- CTD's Arsenic page (<http://ctd.mdibl.org/detail.go?type=chem&acc=D001151&queryTerms=arsenic&queryType=contains>) and CTD's Arsenicals page (<http://ctd.mdibl.org/detail.go?type=chem&acc=D001152&queryTerms=arsenicals&queryType=contains>) from the Comparative Toxicogenomics Database

- A Small Dose of Toxicology (<http://www.asmalldoseof.org/>)
- ATSDR - Case Studies in Environmental Medicine: Arsenic Toxicity (<http://www.atsdr.cdc.gov/csem/arsenic/>)
- Contaminant Focus: Arsenic (<http://www.clu-in.org/contaminantfocus/default.focus/sec/arsenic/cat/Overview/>) by the EPA.
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- National Pollutant Inventory - Arsenic (<http://www.npi.gov.au/database/substance-info/profiles/11.html>)
- origen.net – CCA wood and arsenic: toxicological effects of arsenic (<http://www.origen.net/arsenic.html>)
- WebElements.com – Arsenic (<http://www.webelements.com/webelements/elements/text/As/index.html>)

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