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MINERALOGICAL ASPECTS OF ARSENIC – THE ARSENATE MINERALS

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ABSTRACT

Arsenic is an element known since ancient times. It is the 52nd element in order of chemical abundance in the Earth's crust with 1.8 ppm (grams per metric ton). Arsenic combines relatively easy with chlorine sulfur, oxygen and many metals. This article describes some of the uses and properties of arsenic and arsenic compounds and presents a synopsis of the two hundred and seventy eight (278) arsenate minerals known at the present time.

KEY WORDS: Arsenic, Mineralogical Aspects, Arsenates, Uses of Arsenic

RESUMO

O arsênio é um elemento conhecido desde a antiguidade. Está na qüinquagésima segunda (52ª) colocação em ordem de abundância química na crosta terrestre com 1.8 ppm (gramas por tonelada). O arsênio combina facilmente com cloro, enxofre, oxigênio e muitos metais. Este trabalho descreve algumas das propriedades e usos do arsênio e seus compostos e apresenta uma sinopse das duzentos e oitenta (280) espécies mineralógicas de arseniatos conhecidas até a presente data.

PALAVRAS CHAVE: Arsênio , Aspectos mineralógicos, Arseniatos, Usos do Arsênio

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INTRODUCTION

This article represents a continuation of our work dealing with the mineralogy of the elements of the Periodic Table. We have already published a series of papers dealing with mineralogical aspects of silver, copper, gold, lead, platinum, lithium, hydrogen, uranium and the rare earths.[1-8]

Arsenic is an element known since ancient times. It occurs in nature in many minerals, mainly in combination with sulfur and a large number of metals. In general, the arsenic minerals are subdivided into two large groups, those that posses arsenic in a metallic form and the arsenates. In particular, this work describes mainly the arsenate minerals.

The main minerals containing arsenic, other than the arsenates are native arsenic (As), arsenopyrite (iron arsenide sulfide), cobaltite (cobalt iron arsenic sulfide), enargite (copper arsenic sulfide), erythrite (hydrated cobalt arsenate), orpiment (arsenic sulfide), proustite (silver arsenic sulfide), realgar (arsenic sulfide) and tennantite (copper arsenic sulfide).[9-17]

One of the most common minerals is mispickel arsenopyrite, FeSAs, from which upon heating, arsenic sublimes leaving ferrous sulfide. Arsenic is relatively common in volcanic ash and ground waters, due to weathering of mineral ores.

It also occurs in various organic compounds found in nature in bacteria, molds, fish, algae and other plants, the most common ones being trimethyl arsine and arsenobetaine.[18-20]

Arsenic is also present in nature in the elemental state and it occurs in two solid modifications, yellow and grey or metallic with specific gravities of 1.97 and 5.73, respectively. The more common allotropic form is the steel-grey variety that has a bright metallic luster. Under normal pressure it sublimes before melting, but under pressure it melts at 817 °C. It burns with a blue flame at 180 °C forming As_2O_3, arsenic trioxide.

Arsenic combines relatively easy with chlorine, sulfur and certain metals. The most common compound is arsenic trioxide, As_2O_3, sometimes called *white arsenic* or simply arsenic. The valence of arsenic ranges from -3 to +5. Both As_2O_3 and As_2O_5 are hygroscopic, readily soluble in water and form acidic solutions. The corresponding acids H_3AsO_3 , arsenious acid for As (III) and H_3AsO_4, arsenic acid for As(V) are weak acids and the corresponding salts are called arsenites and arsenates, respectively. Some of the more common ones are Paris Green - copper(II) acetoarsenite, calcium arsenate and lead hydrogen arsenate and have been widely used as dyes, agricultural insecticides and poisons.[10-17]

At the present time China is the top producer of arsenic, followed by Chile, Peru and Morocco. Arsenic is mainly recovered as a side product from copper, gold and lead smelters. Most of the operations in Europe and the United States have been discontinued for environmental reasons.[15-17] Some properties of arsenic are given in Table I.

The word arsenic probably derives from the Persian *Zarnik* or *Zarnikh* that means yellow orpiment. Arsenic sulfides, orpiment (As_2S_3); realgar (As_4S_4) and arsenic oxides have been known and used as stimulants, poisons and dyes since ancient times.

Zosimos described about 300AD the roasting of sandarach (realgar) to obtain a cloud of arsenic (arsenious oxide) which was then reduced to metallic arsenic.[9]

Table I. Some Properties of Arsenic

Atomic weight	74.92180 g/mol
Electronic configuration	(Ar) $4s^2$ $3d^{10}$ $4p^3$
Density at room temperature	5.727 g/cm^3
Density of liquid at m.p.	5.22 g/cm^3
Sublimation point	615 ^oK
Critical Point	1673^{o}K, ? MPa
Triple point	817^{o}C, 3628 kPa
Heat of fusion (grey As)	24.44 kJ/mol
Oxidation states	+5,+3,2,+1,-3
Ionization energy	1st 947.0 kJ/mol 2nd 1798 kJ/mol 3rd 2735 kJ/mol
Atomic radius	119 pm
Van de Waals radius	185 pm
Covalent radius	119 pm
Young modulus	8 GPa

The word orpiment comes from the Latin *aurumpigmentum* (*aurum* and *pigmentum* - pigment of gold) and describes the lemon-yellow color the mineral.

The Persian word Zarnik eventually lead to the Greek arsenikon and the Latin arsenicum. *Zerni-zar* is the Persian word for gold.

During the Bronze Age, arsenic was added to the Cu-Sn alloy in order make the bronze harder. It is generally accepted that the first to isolate the metal was Albert the Great (Albertus Magnus, 1193-1280) who obtained it by heating orpiment (As_2S_3) with soap.

The Chinese Encyclopedia on Materia Medica (Pen Ts'ao Kan-Mu or Kang-mu) of about 1600 described properties and uses of arsenic.

In 1760, Louis Claude Cadet de Gassicourt prepared what is sometimes considered the first synthetic organometallic compound (Cadet's fuming liquid, impure cacodyl) by reacting potassium acetate with arsenic trioxide.

In ancient times, arsenic and arsenic compounds in small doses were used as stimulants and in large doses as poisons. The addition of arsenic to bronze (Cu-Sn alloy) in order to make it harder was well known. The use of arsenic compounds as pigments and dyes was also widespread.

As we mentioned earlier, arsenic compounds were used as medicines during the middle ages in Europe and also in the Orient.[9] Their use incosmetics was also common.

A large number of arsenic compounds were synthesized during the 18th and 19th centuries. For Example, *Paris Green*, also known as *Emerald Green*, used in wallpaper, printing ink and also employed widely by Cézanne and Van Gogh in their paintings, was first prepared in 1814 by reacting copper(II) acetate with arsenic trioxide. It was originally used in large scale to kill rats in the Parisian sewers. During the 1950's, Paris Green was used in the United States and Europe as an insecticide in apple orchards and in 1945 it was spread by airplanes in Sardinia and Corsica to control malaria.

At the present time the toxicity of arsenic to insects, bacteria, fungi, plants and higher organisms is well documented. In spite of this, wood is still treated with chromated copper arsenate (CCA or Tanalith) and a large number of agricultural insecticides contain arsenic. Their use is still common in rice and rubber plantations.

Arsphenamine and neosalvarsan were introduced in the beginning of the twentieth century by Paul Ehrlich for the treatment of syphilis and trypanosomiasis and Thomas Fowler used arsenic trioxide for the treatment of psoriasis. As recently as the year 2000, the United States Food and Drug Administration approved As2O3 for the treatment of patients with acute promyelocytic leukemia.

Until very recently, arsenic was added to animal food to prevent disease and stimulate growth. One compound used widely as nutritional supplement for chickens is *Roxarsone*. The use of arsenic as a stimulant by athletes and mountain climbers is still in practice.

One of the main uses of arsenic is for the improvement of nonferrous metal alloys, especially those containing copper and lead. Lead parts in automotive batteries are significantly strengthened by the addition of small quantities of metallic arsenic. Lead alloys used for lead shots and bullets contain up to 2% of arsenic. It is also used in bronzing and pyrotechnics. Small quantities of arsenic are added to alpha-brass to make it resistant to dezincification. This type of brass is used to manufacture plumbing fittings and other parts that are in constant contact with water.

Galium arsenide is a very important semiconductor material employed in integrated circuits. It is prepared by chemical vapor deposition. Circuits made from gallium arsenide (GaAs) are much faster and more expensive than those made from silicon. Unlike silicon, it has a direct band gap and can be used in laser diodes and light emitting diodes (LEDs) to convert directly electricity into light.

Arsenic is also used for taxonomic sample preservation and for the manufacture of optical glass.

Military uses of arsenic include stockpiles of chemical weapons. Trimethyl arsine, $As(CH_3)_3$, was used as a nerve gas in World War I and lewisite, ($ClCH{=}CHAs_2Cl_2$), that is a vesicant (blister agent) and lung irritant was employed in World War II and other recent conflicts.

The high affinity of As (III) for thiols is one of the causes of its high toxicity. The –SH group is part of the amino acid cysteine that is located at the active site of many enzymes.

Several tissue culture studies have shown that As(III) blocks the IKr and IKs channels and activates the IK-ATP channels.

Arsenic also disrupts ATP production by several mechanisms. At the level of the citric acid cycle, arsenic inhibits pyruvate dehydrogenase. By competing with phosphate it uncouples oxidative phosphorylation and inhibits energy linked reduction of NAD+, mitochondrial respiration and ATP synthesis.

Arsenate can replace phosphate in the glycolysis step that produces 1,3-diphosphoglycerate, forming 1-*arseno*-3-phosphoglycerate. This molecule is unstable and hydrolyzes quickly forming 3-phosphopglycerate, the next intermediate in the pathway. Glycolysis proceeds, but the ATP molecule that Would be generated from 1,3-diphosphoglycerate is not formed and is lost. Arsenate thus is an uncoupler of glycolysis and this explains its toxicity.

Various species of bacteria obtain their energy by oxidizing fuel compounds while reducing arsenate too arsenite. Under oxidative environmental conditions, some bacteria can use arsenite and oxidize it to arsenate as a fuel for their metabolism. The enzymes involved in this process are known as *Arsenate Reductases* (Arr). In 2008, R. S. Orelmand and his collaborators discovered a strain of bacteria (PHS-1 related to the gamma-*Proteobacterium echtothiorodospira Shapóshnikovii*) that employs a version of photosynthesis in the absence of oxygen was discovered. For the case of this bacterium, arsenites act as electron donors, producing arsenates, just like ordinary photosynthesis uses water as an electron donor, producing molecular oxygen.

Upon entering the food chain, inorganic arsenic and its compounds are metabolized thorough methylation reactions. The mold Scopulariopsis produces trimethyl arsine. Marine species such as algae, fish, clams, oisters and some species of mushrooms contain large amounts of the organic compound arsenobetaine.

In 2010 a group form the NASA Astrobiology Institute led by Felisa Wolfe Simon in collaboration with Ronald S. Oremland of the U.S. Geological Survey published an article in Science in which they claimed that the microbe strain

GFAJJ-1 of the *Gammaproteobacteria* (*Halomonadaceae*) from arsenic rich Mono Lake in California incorporates arsenic into its DNA backbone and in ATP.[20,21]

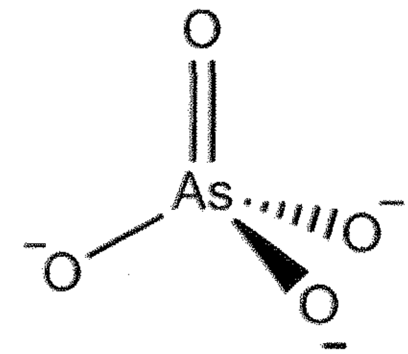
The bacterium was cultured in an environment high in arsenic and low in phosphorus. The group performed a battery of tests including x-ray absorption studies and mass spectrometry and concluded that the organism used arsenic and introduced it in the backbone of the DNA in the place of phosphorus. The arsenate esters supposedly form in the DNA back bone in place of the phosphate esters and As replaces P as one of the six elements of which living things are made (C,N, H, O. S and P). This claim, if true would alter the basic and fundamental understanding of carbon based life and would provide more perspectives to the possibility of extraterrestrial life based on elements different from those on Earth.[20-22]

At the present time there is considerable debate about this claim and many scientists that study the origin of life, arsenic metabolism and synthetic biology echo a chorus of skepticism.

ARSENATE MINERALS

The formula of the arsenate ion is ASO_4^{-3}. Any compound that contains this ion is called an arsenate. The arsenic atom in arsenate has a valence of +5 and is commonly known as pentavalent arsenic As(V).

Arsenate is similar to phosphate in many respects, since As and P occur in the same group in the Periodic Table. The arsenate ion has tetrahedral symmetry and its structural represented in Figure 1. In strongly acidic solutions it exists as arsenic acid, H_3AsO_4; in weakly acidic solutions as the dihydrogen arsenate ion,H_2AsO4^-; in weakly basic solutions as the hydrogen arsenate ion, $HAsO_4^{-2}$ and in strongly basic conditions as the arsenate ion, $AsO_4^{-3.}$



IUPAC name	
arsorate	
Identifiers	
CAS number	12523-21-6
PubChem	27401
Jmol-3D images	Image 1 (http://chemapps.stolaf.edu/jmol/jmol.php?model=%5BO-%5D%5BAs%5D%28%3DO%29%28%5BO-%5D%29%5BO-%5D)
SMILES	
[O-][As](=O)([O-])[O-]	

Figure 1. Structure of Arsenate

By the end of 2008, the International Mineralogical Associataion – IMA, had validated officially 280 (two hundred and eighty) species of arsenate. They are listed in Table II that follows along with their chemical formula and the crystal system.

Table II. The Arsenate Species Validated by the International Mineralogical Association – IMA.

MINERAL	CHEMICAL FORMULA	CRYSTAL SYSTEM
abernathyite	$K[(UO_2)(AsO_4)](H_2O)$	Tetragonal
adamite	$Zn_2(AsO_4)OH$	Orthorhombic
adelite	$CaMg(AsO_4)OH$	Orthorhombic
aerugite	$Ni_{8.5}As_3O_{16}$	Trigonal
agardite-(Ce)	$Ce,Cu_6(AsO_4)_3(OH)_6.3H_2O$	Hexagonal
agardite-(La)	$(La,Ca)Cu_6(AsO_4)_3(OH)_6.3H_2O$	Hexagonal
agardite-(Y)	$(Y,Ca)Cu_6(AsO_4)_3(OH)_6.3H_2O$	Hexagonal
akrochordite	$(Mn,Mg)_5)(AsO_4)_2(OH)_4.4H_2O$	Monoclinic
alarsite	$AlAsO_4$	Trigonal
allactite	$Mn_7(AsO_4)_2(OH)_8$	Monoclinic
alumopharmacosiderite	$KAl_4(AsO_4)_3(OH)_4.6.5H_2O$	Cubic
andyrobertsite	$KCdCu_5(AsO_4)_4[As(OH)_2O_2].2H_2O$	Monoclinic
angelellite	$Fe^{3+}{}_4(AsO_4)_2O_3$	Triclinic
annabergite	$Ni_3(AsO_4)_2.8H_2O$	Monoclinic
arakiite	$(Zn,Mn^{2+})(Mn^{2+},Mg)_{12}(Fe^{3+},Al)_2(As^{3+}O_3)(As^{5+}O_4)_2(OH)_{23}$	Monoclinic
arhbarite	$Cu_2Mg(AsO_4)(OH)_3$	Triclinic
arsenbrackebuschite	$Pb_2Fe^{3+}(AsO_4)_2(OH)$	Monoclinic
arsendescloizite	$PbZn(AsO_4)OH$	Orthorhombic
arseniopleite	$NaCaMn^{2+}(Mn^{2+},Mg)_2(AsO_4)_3$	Monoclinic
arseniosiderite	$Ca_2Fe^{3+}{}_3(AsO_4)_2O_2.3H_2O$	Monoclinic
arsenoclasite	$Mn^{2+}{}_5(AsO_4)_2(OH)_4$	Orthorhombic
arsenocrandallite	$CaAl_3(AsO_4)_2(OH,H_2O)_6$	Trigonal
arsenoflorencite-(Ce)	$CeAl_3(AsO_4)_2(OH,H_2O)_6$	Trigonal
arsenogorceixita	$HBaAl_3(AsO_4)_2(OH,H_2O)_6$	Trigonal
arsenogoyazite	$SrAl_3(AsO_4)_2(OH)_6$	Trigonal

arsenovanmeersscheite	**$U(UO_2)_3(AsO_4)_2(OH)_6.4H_2O$**	**Orthorhombic**
arsentsumebite	**$Pb_2Cu(AsO_4)(SO_4)(OH)$**	**Monoclinic**
arsenuranospathite	**$Al_{1-x}\,\square_x[(UO_2)(AsO_4)]_2(H_2O)_{20+3x}F_{1-3x}$**	**Tetragonal**
arsenuranylite	**$Ca(UO_2)_4(AsO_4)_2(OH)_4.6H_2O$**	**Orthorhombic**
arthurite	**$CuFe^{3+}{}_2(AsO_4)_2(OH)_2.4H_2O$**	**Monoclinic**
asselbornite	**$(Pb,Ba)(UO_2)_6(BiO)_4(AsO_4)_3(OH)_{12}.3H_2O$**	**Cubic**
atelestite	**$Bi_2O(OH)(AsO_4)$**	**Monoclinic**
attikaite	**$Ca_3Cu_2Al_2(AsO_4)_4(OH)_4.2H_2O$**	**Orthorhombic**
auriacusite	**$Fe^{3+}Cu^{2+}(AsO_4)O$**	**Orthorhombic**
austinite	**$CaZn(AsO_4)(OH)$**	**Orthorhombic**
barahonite-(Al)	**$(Ca,Cu,Na,Fe^{3+},Al)_{12}Al)_{12}Al_2(AsO_4)_8(OH,Cl)_x.nH_2O$**	**Monoclinic**
barahonite-(Fe)	**$(Ca,Cu,Na,Fe^{3+},Al)_{12}Fe^{3+}{}_2Al)_{12}(AsO_4)_8(OH,Cl)_x.nH_2O$**	**Monoclinic**
bariopharmacosiderite	**$Ba_{0.5}Fe^{3+}{}_4(AsO_4)_3(OH)_4.6H_2O$**	**Cubic**
bayldonite	**$PbCu_3(AsO_4)_2(OH)_2$**	**Monoclinic**
bearsite	**$Be_2(AsO_4)(OH).4H_2O$**	**Monoclinic**
bergslagite	**$CaBe(AsO_4)(OH)$**	**Monoclinic**
berzeliite	**$(Ca,Na)_3(Mg,Mn^{2+})_2(AsO_4)_3$**	**Cubic**
betpakdalite	**$H_8[K(H_2O)_6]_4[Ca(H_2O)_6]_8[Mo^{6+}{}_{32}Fe^{3+}{}_{12}As^{5+}{}_8O_{148}].8H_2O$**	**Monoclinic**
beudantite	**$PbFe_3[(As,S)O_4]_2(OH,H_2O)_6$**	**Trigonal**
bouazzerite	**$Bi_6(Mg,Co)_{11}Fe_{14}[AsO_4]_{18}O_{12}(OH)_4(H_2O)_{86}$**	**Monoclinic**
bradaczekite	**$NaCu_4(AsO_4)_3$**	**Monoclinic**
braithwaiteite	**$NaCu_5(Ti,Sb)_{202}(AsO_4)[AsO_3(OH)]_2.8H_2O$**	**Triclinic**
brandtite	**$Ca_2(Mn^{2+},Mg)(AsO_4)_2.2H_2O$**	**Monoclinic**
brassite	**$Mg(AsO_3OH).4H_2O$**	**Orthorhombic**
bukovskyite	**$Fe^{3+}{}_2(AsO_4)(SO_4)(OH).7H_2O$**	**Triclinic**
bulachite	**$Al_2(AsO_4)(OH)_3.3H_2O$**	**Orthorhombic**
cabalzarite	**$Ca(Mg,Al,Fe)_2(AsO_4)_2(H_2O,OH)_2$**	**Monoclinic**
cafarsite	**$Ca_8(Ti,Fe^{2+},Fe^{3+},Mn)_{6-7}(As^{3+}O_3)_{12}.4H_2O$**	**Cubic**
cahnite	**$Ca_2B(AsO_4)(OH)_4$**	**Tetragonal**

calcioandyrobertsite	$KCaCu_5(AsO_4)_4[As(OH)_2O_2].2H_2O$	**Orthorhombic/Monoclinic**
camgasite	$CaMg(AsO_4)(OH).5H_2O$	**Monoclinic**
carminite	$PbFe^{3+}{}_2(AsO_4)_2(OH)_2$	**Orthorhombic**
caryinite	$NaCaCa(Mn^{2+},Mg)_2)(AsO_4)_3$	**Monoclinic**
ceruleite	$Cu_2Al_7(AsO_4)_4(OH)_{13}.11.5H_2O$	**Triclinic**
chalcophyllite	$Cu_9Al[(OH)_{12}(SO_4)_{1.5}(AsO_4)_2].18H_2O$	**Trigonal**
chenevexite	$Cu^{2+}{}_2Fe^{3+}{}_2(AsO_4)_2(OH)_4.H_2O$	**Monoclinic**
chernovite-(Y)	$YAsO_4$	**Tetragonal**
chistyakovaite	$Al(UO_2)_2(AsO_4)_2F.6.5H_2O$	**Monoclinic**
chlorophoenicite	$(Mn,Mg)_3Zn_2[AsO_3(OH)](OH)_8$	**Monoclinic**
chudobaite	$(Mg,Zn)_5[AsO_3(OH)]_2(AsO_4)_2.10H_2O$	**Triclinic**
chursinite	$Hg_3(AsO_4)$	**Monoclinic**
clinoclase	$Cu^{2+}{}_3(AsO_4)(OH)_3$	**Monoclinic**
clinomimetite	$Pb_5(AsO_4)_3Cl$	**Monoclinic**
cobaltarthurite	$Co^{2+}Fe^{3+}{}_2(AsO_4)_2(OH)_2.4H_2O$	**Monoclinic**
cobaltaustinite	$CaCoAsO_4(OH)$	**Orthorhombic**
cobaltkoritnigite	$(Co,Zn)(As^{5+}O_3)(OH).H_2O$	**Triclinic**
cobaltlotharmeyerite	$Ca(Co,Fe^{3+},Ni)_2(AsO_4)_2(OH,H_2O)_2$	**Monoclinic**
cobaltneustädtelite	$Bi_2Fe^{3+}Co^{2+}O(OH)_3(AsO_4)_2$	**Triclinic**
cobalttsumcorite	$Pb(Co,Fe^{3+})(AsO_4)_2(H_2O,OH)_2$	**Monoclinic**
conichalcite	$CaCu^{2+}(AsO_4)(OH)$	**Orthorhombic**
coparsite	$Cu_4O_2[(As,V)O_4]Cl$	**Orthorhombic**
cornubite	$Cu^{2+}{}_5(AsO_4)_2(OH)_4$	**Triclinic**
cornwallite	$Cu^{2+}{}_5(AsO_4)_2(OH)_4$	**Monoclinic**
dixenite	$Cu^{1+}Mn^{2+}{}_{14}Fe^{3+}(As^{3+}O_3)_5(SiO_4)_2(As^{5+}O_4)(OH)_6$	**Trigonal**
duftite	$PbCu(AsO_4)(OH)$	**Orthorhombic**
dugganite	$Pb_3Zn_3Te^{6+}O_6)(AsO_4)_2$	**Trigonal**
durangite	$NaAl(AsO_4)F$	**Monoclinic**
dussertite	$BaFe^{3+}{}_3Fe^{3+}(AsO_4)_2(OH,H_2O)_6$	**Trigonal**

erythrite	$Co_3(AsO_4)_2.8H_2O$	Monoclinic
esperanzaite	$NaCa_2Al_2(AsO_4)_2F_4(OH).H_2O$	Monoclinic
euchroite	$Cu^{2+}{}_2(AsO_4)(OH).3H_2O$	Orthorhombic
scorodite	$Fe^{3+}AsO_4.2H_2O$	Orthorhombic
eveite	$Mn^{2+}{}_2(AsO_4)(OH)$	Orthorhombic
feinglosite	$Pb_2Zn(AsO_4)(SO_4)(OH)$	Monoclinic
fermorite	$(Ca,Sr)_5(AsO_4,PO_4)_3(OH)$	Monoclinic
ferrarisite	$Ca_5H_2(AsO_4)_4.9(H_2O)$	Triclinic
ferrilotharmeyerite	$CaZn(Fe^{3+})(AsO_3OH)_2(OH)_3$	Monoclinic
ferrisymplesite	$Fe^{3+}{}_3(AsO_4)_2(OH)_3.5H_2O$	Monoclinic
filatovite	$K(Al,Zn)_2(As,Si)_2O_8$	Monoclinic
flinkite	$Mn^{2+}{}_2Mn^{3+}(AsO_4)(OH)_4$	Orthorhombic
fluckite	$CaMn^{2+}H_2(AsO_4)_2.2H_2O$	Triclinic
gabrielsonite	$PbFe^{2+}AsO_4(OH)$	Orthorhombic
gaitite	$Ca_2Zn(AsO_4)_2.2H_2O$	Triclinic
gallobeudantite	$PbGa_3[(AsO_4),(SO_4)]_2(OH)_6$	Trigonal
gartrellite	$PbCuFe^{3+}(AsO_4)_2[(H_2O)(OH)]$	Triclinic
gasparite-(Ce)	$(Ce,La,Nd)AsO_4$	Monoclinic
geigerite	$Mn^{2+}{}_5(As^{5+}O_4)_2(As^{5+}O_3OH)_2.10H_2O$	Triclinic
gerdtremmelite	$ZnAl_2(AsO_4)(OH)_5$	Triclinic
gilmarite	$Cu_3(AsO_4)(OH)_3$	Triclinic
goudeyite	$(Al,Y)Cu^{2+}{}_6(AsO_4)_3(OH)_6.3H_2O$	Hexagonal
graulichite-(Ce)	$CaFe^{3+}{}_3(AsO_4)_2(OH)_6$	Trigonal
grischunite	$NaCa_2Mn^{2+}{}_4(Mn^{2+}Fe^{3+})(AsO_4)_6.2H_2O$	Orthorhombic
guanacoite	$Cu_2Mg_2(Mg_{0.5}Cu_{0.5})(OH)_4(H_2O)_4(AsO_4)_2$	Monoclinic
guèrinite	$Ca_5H_2(AsO_4)_4.9H_2O$	Monoclinic
haidingerite	$Ca(AsO_3OH).H_2O$	Orthorhombic
hedyphane	$Pb_3Ca_2(AsO_4)_3Cl$	Hexagonal
heinrichite	$Ba(UO_2)(AsO_4)_2.10\text{-}12H_2O$	Tetragonal

helmutwincklerite	$PbZn_2(AsO_4)_2.2H_2O$	Triclinic
hematolite	$(Mn^{2+},Mg,Al)_{15}(AsO_3)(AsO_4)_2(OH)_2$	Trigonal
holdenite	$(Mn^{2+},Mg)_6Zn_3(AsO_4)_2(SiO_4)(OH)_8$	Orthorhombic
hörnesite	$Mg_3(ASO_4)_2.8H_2O$	Monoclinic
hügelite	$Pb_2(UO_2)_3(AsO_4)_2(OH)_4.3H_2O$	Monoclinic
irhtemite	$Ca_4NgH_2(AsO_4)_4.4H_2O$	Monoclinic
jamesite	$Pb_2Zn_2Fe^{3+}{}_5(AsO_4)_5O_4$	Triclinic
jarosewichite	$Mn^{2+}{}_3Mn^{3+}(AsO_4)(OH)_6$	Orthorhombic
johillerite	$Na(Mg,Zn)_3Cu^{2+}(AsO_4)_3$	Monoclinic
johnbaumite	$Ca_5AsO_4)_3(OH)$	Hexagonal
juanitaite	$(Cu,Ca,Fe)_{10}Bi(AsO_4)_4(OH)_{11}.H_2O$	Tetragonal
kaatialaite	$Fe(H_2AsO_4)_3.5H_2O$	Monoclinic
kahlerite	$Fe^{2+}(UO_2)_2(AsO_4)_2.10\text{-}12H_2O$	Tetragonal
kaňkite	$Fe^{3+}(AsO_4).3.5H_2O$	Monoclinic
karibibite	$Fe^{3+}2As^{3+}4(O,OH)_9$	Orthorrhombic
kemmlitzite	$SrAl_3[(As,S)O_4]_2(OH,H_2O)_6$	Trigonal
keyite	$Cu^{2+}{}_3(Zn,Cu^{2+})_4Cd_2(AsO_4)_6(H_2O)_2$	Monoclinic
kolfanite	$Ca_2Fe^{3+}{}_3O_2(AsO_4)_3.2H_2O$	Monoclinic
kolicite	$Mn^{2+}{}_7Zn_4(AsO_4)_3.2H_2O$	Orthorrhombic
koritnigite	$Zn(AsO_3)(OH).H_2O$	Triclinic
köttigite	$Zn_3(AsO_4)_2.8H_2O$	Monoclinic
kraisslite	$Mn_{24}Zn_4(AsO_4)(SiO_4)_8(OH)_{12}$	Hexagonal
krautite	$Mn^{2+}(AsO_3)(OH).H_2O$	Monoclinic
kuznetsovite	$Hg^{1+}2Hg^{2+}Cl(AsO_4)$	Cubic
lammerite	$Cu_3(AsO_4)_2$	Monoclinic
lavendulan	$NaCaCu^{2+}5(AsO_4)_4Cl.5H_2O$	Orthorrhombic
lazarenkoite	$(Ca,Fe^{2+})Fe^{3+}As^{3+}{}_3O_7.3H_2O$	Orthorrhombic
legrandite	$Zn_2(AsO_4)(OH).H_2O$	Monoclinic
leiteite	$ZnAs^{3+}{}_2O_4$	Monoclinic

lemanskiite	$NaCaCu_5(AsO_4)_4Cl.5H_2O$	**Tetragonal**
leogangite	$Cu_{10}(AsO_4)(SO_4)(OH)_6.8H_2O$	**Monoclinic**
lindackerite	$Cu_5(AsO_3OH)_2(AsO_4)_2.10H_2O$	**Monoclinic**
liroconite	$Cu^{2+}{}_2Al(AsO_4)(OH)_4.4H_2O$	**Monoclinic**
liskeardite	$(Al,Fe^{3+})_3(AsO_4)(OH)_6.5H_2O$	**Monoclinic/Orthorrhombic**
lotharmeyerite	$Ca(Zn,Mn^{3+})_2(AsO_4)_2(OH,H_2O)_2$	**Monoclinic**
luetheite	$Cu^{2+}{}_2Al_2(AsO_4)_2(OH)_4.H_2O$	**Monoclinic**
lukhranite	$CaCuFe^{3+}(AsO_4)_2[(H_2O)(OH)]$	**Triclinic**
magnesiochlorophoenicite	$(Mg,Mn)_3Zn_2(AsO_4)(OH,O)_6$	**Monoclinic**
mahnertite	$(Na,Ca)(Cu^{2+}{}_3(AsO_4)_2Cl.5H_2O$	**Tetragonal**
manganberzeliite	$(Ca,Na)_3(Mn^{2+},Mg)_2(AsO4)_3$	**Cubic**
manganohörnesite	$(Mn,Mg)_3(AsO_4)_2.8(H_2O)$	**Monoclinic**
manganolotharmeyerite	$Ca(Mn^{3+},Zn)_2(AsO_4)_2(OH,H_2O)_2$	**Monoclinic**
manganostibite	$(Mn^{2+}, Fe^{2+})_7(SbO_4)(AsO_4,SiO_4O_4)$	**Orthorrhombic**
mansfieldite	$AlAsO_4.2H_2O$	**Orthorrhombic**
mapimite	$Zn_2Fe^{3+}{}_3(AsO_4)_3(OH)_4.10H_2O$	**Monoclinic**
mawbyite	$Pb(Fe^{3+},Zn)_2(AsO_4)_2(OH,H_2O)_2$	**Monoclinic**
maxwellite	$NaFe^{3+}(AsO_4)F$	**Monoclinic**
mcgovernite	$Zn_3(Mn^{2+},Mg)_{42}(As^{3+}O_3)_2(As^{5+}O_4)_4(SiO_4)_8(OH)_{40}$	**Trigonal**
mcnearite	$NaCa_5H_4(AsO_4)_5.4H_2O$	**Triclinic**
medenbachite	$Bi_2Fe^{3+}(Cu,Fe^{2+})(O,OH)_2(OH)_2(ASO_4)_2$	**Triclinic**
metaheinrichite	$Ba(UO_2)_2(AsO_4)_2.8H_2O$	**Tetragonal**
metakhalerite	$Fe^{2+}(UO_2)_2(AsO_4).8H_2O$	**Tetragonal**
metakirchheimerite	$Co(UO_2)_2(AsO_4)_2.8H_2O$	**Tetragonal**
metaköttigite	$(Zn,Fe^{3+})(Zn,Fe^{3+},Fe^{2+})_2(AsO_4)_2.8(H_2O,OH)$	**Triclinic**
metalodèvite	$Zn(UO_2)_2.10H_2O$	**Tetragonal**
metanovácěkite	$Mg(UO_2)_2(AsO_4)_2.4\text{-}8H_2O$	**Tetragonal**
metauranospinite	$Ca(UO_2)_2(AsO_4)_2.8H_2O$	**Tetragonal**
metazeunerite	$Cu^{2+}(UO_2)_2(AsO_4)_2.8H_2O$	**Tetragonal**

mimetite	$Pb_5(AsO_4)_3Cl$	Hexagonal
mixite	$BiCu^{2+}_6(AsO_4)_3(OH)_6.3H_2O$	Hexagonal
natrobetkdalite	$(Na,Ca)_3Fe^{3+}_2(As_2O_4)(MoO_4)_6.15H_2O$	Monoclinic
natropharmacosiderite	$(Na,K)_2Fe^{3+}_4(AsO_4)_3(OH)_5.7H_2O$	Cubic
natrouranospinite	$(Na_2,Ca)(UO_2)_2(AsO_4)_2.5H_2O$	Tetragonal
neustädtelite	$Bi_2Fe^{3+}Fe^{3+}O_2(OH)_2(AsO_4)_2$	Triclinic
nickelaustinite	$CaNiAsO_4(OH)$	Orthorrhombic
nickellotharmeyerite	$Ca(Ni,Fe^{3+})_2(AsO_4)_2(H_2O,OH)_2$	Monoclinic
nickelschneebergite	$BiNi_2(AsO_4)_2[(H_2O)(OH)]$	Monoclinic
nicknichite	$Na_{0,8}Ca_{0,4}Cu_{0,4}(Mg,Fe^{3+})_3(AsO_4)_3$	Monoclinic
novácěkite I	$Mg(UO_2)_2(AsO_4)_2.12H_2O$	Cubic
novácěkite II	$Mg(UO_2)_2(AsO_4)_2.10H_2O$	Monoclinic
nyholmite	$Cd_3Zn_2(AsO_4)_2(HASO_4)_2.4H_2O$	Monoclinic
o'danielite	$Na(Zn,Mg)_3H_2(AsO_4)_3$	Monoclinic
ogdensburgtite	$Ca_2Fe^{3+}_4(Zn,Mn)^{2+}(AsO_4)_4(OH)_6.6H_2O$	Orthorrhombic
ojuelaite	$ZnFe^{3+}_2(AsO_4)_2(OH)_2.4H_2O$	Monoclinic
olivenite	$Cu^{2+}_2(AsO_4)(OH)$	Monoclinic
orthowalpurgite	$(UO_2)Bi_4O_4(AsO_4)_2.2H_2O$	Orthorrhombic
paganoite	$NiBi^{3+}As^{5+}O_5$	Triclinic
parabrandtite	$Ca_2Mn^{2+}(AsO_4)_2.2H_2O$	Triclinic
paradamite	$Zn_2(AsO_4)(OH)$	Triclinic
paranaiite-(Y)	$Ca_2Y(AsO_4)(WO_4)_2$	Tetragonal
parascorodite	$Fe^{3+}AsO_4.2H_2O$	Hexagonal
parasymplesite	Fe 2+3(AsO4)2.8H2O	Monoclinic
parwelite	$(Mn,Mg)_5Sb^{5+}As^{5+}SiO_{12}$	Monoclinic
paulmooreite	$Pb_2As^{3+}_2O_5$	Monoclinic
petewilliamsite	$(Ni,Co)_{30}(As_2O_7)15$	Monoclinic
pharmacolite	$CaHAsO_4.2H_2O$	Monoclinic
phaunoxite	$Ca_3(AsO_4).2H_2O$	Triclinic

philipsbornite	$PbAl_3(AsO_4)_2(OH,H_2O)_6$	**Trigonal**
philipsburgite	$(Cu,Zn)_3(AsO_4)_2(OH)_6.H_2O$	**Monoclinic**
pitticite	(Fe,AsO_4,SO_4,H_2O)	**Amorphous**
plumboagardite	$(Pb,REE,Ca)Cu_6(AsO_4)_3(OH)_6.3H_2O$	**Hexagonal**
pradetite	$CoCu_4(AsO_3OH)_2(AsO_4)_2.9H_2O$	**Triclinic**
preisingerite	$Bi_3O(OH)(AsO_4)_2$	**Triclinic**
prosperite	$CaZn_2H(AsO_4)_2OH$	**Monoclinic**
pushcharovskite	$Cu(AsO_3OH).H_2O$	**Triclinic**
radovanite	$Cu_2Fe^{3+}(AsO_4)(As^{3+}O_2OH)_2.H_2O$	**Orthorrhombic**
rappoldite	$Pb(Co,Ni)_2(AsO_4)_2.2H_2O$	**Triclinic**
rauenthalite	$Ca_3(AsO_4)_2.10H_2O$	**Triclinic**
reinerite	$Zn_3(As^{3+}O_3)_2$	**Orthorrhombic**
retzian-(Ce)	$Mn^{2+}{}_2Ce(AsO_4)(OH)_4$	**Orthorrhombic**
retzian-(La)	$(Mn^{2+},Mg)_2(La,Ce,Nd)(AsO_4)(OH)_4$	**Orthorrhombic**
richelsdorfite	$Ca_2Cu^{2+}{}_3Sb^{5+}(AsO_4)_4Cl(OH)_6.6H_2O$	**Monoclinic**
rollandite	$Cu_3(AsO_4)_2.4H_2O$	**Orthorhombic**
rooseveltite	$BiAsO_4$	**Monoclinic**
roselite	$Ca_2Co(AsO_4)_2.2H_2O$	**Monoclinic**
roselite-beta	$Ca_2(Co^{2+},Mg)(AsO_4)_2.2H_2O$	**Triclinic**
rösslerite	$MgHAsO_4.7H_2O$	**Monoclinic**
rouseite	$Pb_2Mn^{2+}(As^{3+}O_3)_2.2H_2O$	**Triclinic**
Sahlinite	$Pb_{14}(AsO_4)_2O_9Cl_4$	**Monoclinic**
sailaufite	$(Ca,Na,\square)Mn^{3+}{}_3(AsO_4)_2(CO_3)O_2.3H_2O$	**Monoclinic**
sainfeldite	$Ca_5(AsO_4)_2(AsO_3OH)_2.4H_2O$	**Monoclinic**
sarkinite	$Mn^{2+}{}_2(AsO_4)(OH)$	**Monoclinic**
sarmientite	$Fe^{3+}{}_2(AsO_4)(SO_4)(OH).5H_2O$	**Monoclinic**
schlegelite	$Bi_7O_4(MoO_4)_2(AsO_4)$	**Orthorrhombic**
schneebergite	$BiCo_2(AsO_4)_2[(H_2O)(OH)]$	**Monoclinic**
schneiderhönite	$Fe^{2+}Fe^{3+}{}_3As^{3+}{}_5O_{13}$	**Triclinic**

schultenite	$PbHAsO_4$	Monoclinic
seelite	$Mg(UO_2)_2(As^{3+}O_3)_{1.4}(As^{5+}O_4)_{0.6}.7H_2O$	Monoclinic
segnitite	$PbFe^{3+}_3H(AsO_4)_2(OH)$	Trigonal
sewardite	$CaFe^{3+}_2(AsO_4)_2(OH)_2$	Orthorrhombic
shubnikovite	$Ca_2Cu^{2+}_8(AsO_4)_6Cl(OH).7H_2O$	Orthorrhombic (?)
smolyaninovite	$Co_3(Fe^{3+})_2(AsO_4)_4.11H_2O$	Orthorrhombic
sterlinghillite	$Mn^{2+}_3(AsO_4)_2.4H_2O$	Monoclinic
dstranskiite	$Zn_2Cu^{2+}(AsO_4)_2$	Triclinic
dtranshimirite	$Cu^{2+}_8(AsO_4)_4(OH)_4.5H_2O$	Monoclinic
svabite	$Ca_5(AsO_4)_3F$	Hexagonal
svenekite	$CaH_4(AsO_4)_2$	Triclinic
symplesite	$Fe^{2+}_3(AsO_4)_2.8H_2O$	Triclinic
synadelphite	$(Mn^{2+},Mg,Ca,Pb)_9(As^{3+}O_3)(As^{3+}O_4)_2(OH)_9.2H_2O$	Orthorrhombic
talmessite	$Ca_2Mg(AsO_4)_2.2H_2O$	Monoclinic/Triclinic
tetrarooseveltite	$Bi^{3+}AsO_4$	Tetragonal
theisite	$Cu_5Zn_5[(As,Sb)O_4]_2(OH)_{14}$	Trigonal
theoparacelsite	$Cu_3(OH)_2As_2O_7$	Orthorrhombic
thometzekite	$PbCu_2(AsO_4)_2.2H_2O$	Triclinic
tilasite	$CaMg(AsO_4)F$	Monoclinic
trippkeite	$Cu^{2+}As^{3+}_2O_4$	Tetragonal
tröggerite	$(H_3O)[(UO_2)(AsO_4)](H_2O)_3$	Tetragonal
tsumcorite	$Pb(Zn,Fe^{3+})_2(AsO_4)_2(H_2O,OH)_2$	Monoclinic
turneaureite	$Ca_5[(As,P)O_4]_3Cl$	Hexagonal
tyrolite	$CaCu^{2+}_5(AsO_4)_2(CO_3)(OH)_4.6H_2O$	Orthorrhombic
uramarsite	$NH_4(UO_2)AsO_4.3H_2O$	Tetragonal
uranospinite	$Ca(UO_2)_2(AsO_4)_2.10H_2O$	Tetragonal
urusovite	$Cu[AlAsO_5]$	Monoclinic
vajdakite	$(MoO_2)_2(H_2O)_2As^{3+}2O_5.H_2O$	Monoclinic
villyaellenite	$(Mn^{2+},Ca,Zn)_5(AsO_4)_2[AsO_3(OH)]_2.4H_2O$	Monoclinic

vladimirite	**$Ca_5H_2(AsO_4)_4.5H_2O$**	**Monoclinic**
wallkilldellite	**$Ca_4Mn^{2+}{}_6(AsO_4)_4(OH)_8.18H_2O$**	**Hexagonal**
wallkilldellite-Fe	**$(Ca,Cu)_4Fe_6[(As,Si)O_4]_4(OH)_8.18H_2O$**	**Hexagonal**
walpurgite	**(BiO)4(UO2)(AsO4)2.2H2O**	**Triclinic**
warikhanite	**$Zn_3(AsO_4)_2.2H_2O$**	**Triclinic**
weilite	**$Ca(AsO_3OH)$**	**Triclinic**
wendwilsonite	**$Ca_2(Mg,Co)(AsO_4)_2.2H_2O$**	**Monoclinic**
wilhelmkleinite	**$ZnFe^{3+}{}_2(AsO_4)_2(OH)_2$**	**Monoclinic**
xanthiosite	**$Ni_3(AsO_4)_2$**	**Monoclinic**
yanomamite	**$InAsO_4.2H_2O$**	**Orthorrhombic**
yazganite	**$NaMg(Fe^{3+})_2(AsO_4)_3.H_2O$**	**Monoclinic**
yukonite	**$Ca_2Fe^{3+}{}_2(AsO_4)_3(OH)_4.4H_2O$**	**Orthorrhombic**
yvonite	**$Cu(AsO_3OH).2H_2O$**	**Triclinic**
zálesiite	**$CaCu_6[(AsO_4)_2(AsO_3OH)(OH)_6].3H_2O$**	**Hexagonal**
zdněkite	**$NaPbCu_5(AsO_4)_4Cl.5H_2O$**	**Tetragonal**
zeunerite	**$Cu^{2+}(UO_2)_2(AsO_4)_2.10\text{-}16H_2O$**	**Tetragonal**
zincgartrellite	**$Pb(Zn,Fe,Cu)_2(AsO_4)_2(H_2O,OH)_2$**	**Triclinic**
zincolivenite	**CuZnAsO4(OH)**	**Orthorrhombic**
Zincroselite	**$Ca_2Zn(AsO_4)_2.2H_2O$**	**Monoclinic**

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