

Metal

A **metal** (from Greek μέταλλον *métallon*, "mine, quarry, metal"^{[1][2]}) is a material (an element, compound, or alloy) that is typically hard when in solid state, opaque, shiny, and has good electrical and thermal conductivity. Metals are generally malleable—that is, they can be hammered or pressed permanently out of shape without breaking or cracking—as well as fusible (able to be fused or melted) and ductile (able to be drawn out into a thin wire).^[3] Around 90 of the 118 elements in the periodic table are metals; the others are nonmetals or metalloids, though elements near the boundaries of each category have been assigned variably to either (hence the lack of an exact count). Some elements appear in both metallic and non-metallic forms.

Astrophysicists use the term "metal" to refer collectively to all elements in a star that are heavier than the lightest two, hydrogen and helium, and not just traditional metals. A star fuses lighter atoms, mostly hydrogen and helium, to make heavier atoms over its lifetime. Used in that sense, the metallicity of an astronomical object is the proportion of its matter made up of the heavier chemical elements.^[4]

Many elements and compounds that are not normally classified as metals become metallic under high pressures; these are formed as metallic allotropes of non-metals, for example, physicists were able to keep hydrogen in its solid state under more than 3 million times the atmospheric pressure and deduce its metallic properties.^[5]

The strength and resilience of metals has led to their frequent use in high-rise building and bridge construction, as well as most vehicles, many home appliances, tools, pipes, non-illuminated signs and railroad tracks. Precious metals were historically used as coinage.

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In the periodic table

The elements which are considered as metals under ordinary conditions are shown in yellow on the periodic table below. The remaining elements are shown either as nonmetals or as metalloids of intermediate character

Metals–nonmetals in the periodic table																																	
1	2																	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Group →																																	
↓ Period																																	
1	H																										He						
2	Li	Be											B	C	N	O	F	Ne															
3	Na	Mg											Al	Si	P	S	Cl	Ar															
4	K	Ca	Sc						Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr										
5	Rb	Sr	Y						Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe										
6	Cs	Ba	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	
7	Fr	Ra	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og	
Metal		Metalloid		Nonmetal		Unknown properties																											
Background color shows metal–metalloid–nonmetal trend in the periodic table																																	

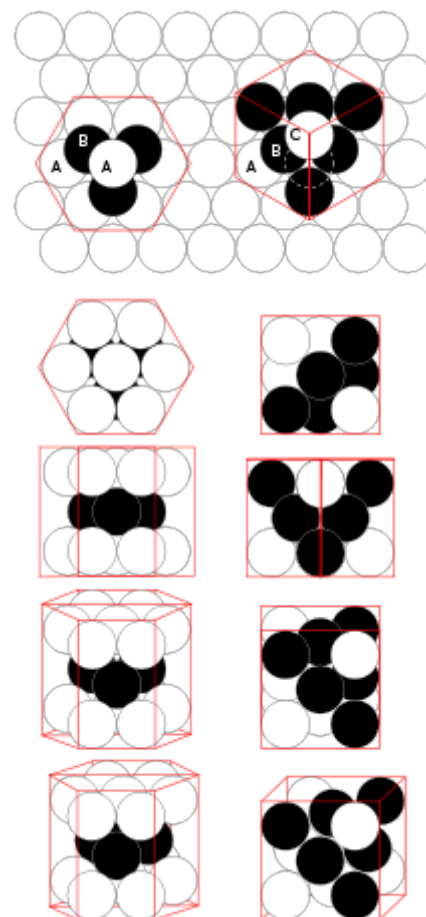
Structure and bonding

The atoms of metallic substances are typically arranged in one of three common crystal structures, namely body-centered cubic (bcc), face-centered cubic (fcc), and hexagonal close-packed (hcp). In bcc, each atom is positioned at the center of a cube of eight others. In fcc and hcp, each atom is surrounded by twelve others, but the stacking of the layers differs. Some metals adopt different structures depending on the temperature.^[6]

Atoms of metals readily lose their outer shell electrons, resulting in a free flowing cloud of electrons within their otherwise solid arrangement. This provides the ability of metallic substances to easily transmit heat and electricity. While this flow of electrons occurs, the solid characteristic of the metal is produced by electrostatic interactions between each atom and the electron cloud. This type of bond is called ametallic bond.^[7]

Crystal structures for some metals are listed in the table below

Metal	Crystal Structure	Atomic Number	Atomic Radius (nm)
Aluminium	FCC	13	0.1431
Cadmium	HCP	48	0.1490
Chromium	BCC	24	0.1249
Cobalt	HCP	27	0.1253
Copper	FCC	29	0.1278
Gold	FCC	79	0.1442
Iron (α)	BCC	26	0.1241
Lead	FCC	82	0.1750
Molybdenum	BCC	42	0.1363
Nickel	FCC	28	0.1246
Platinum	FCC	78	0.1387
Silver	FCC	47	0.1445
Tantalum	BCC	73	0.1430
Titanium (α)	HCP	22	0.1445
Tungsten	BCC	74	0.1371
Zinc	HCP	30	0.1332

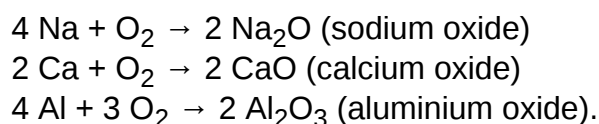


hcp and fcc close-packing of spheres

Properties

Chemical

Metals are usually inclined to form cations through electron loss,^[7] reacting with oxygen in the air to form oxides over various timescales (iron rusts over years, while potassium burns in seconds). Examples:



The transition metals (such as iron, copper, zinc, and nickel) are slower to oxidize because they form a passivating layer of oxide that protects the interior. Others, like palladium, platinum and gold, do not react with the atmosphere at all. Some metals form a barrier layer of oxide on their surface which cannot be penetrated by further oxygen molecules and thus retain their shiny appearance and good conductivity for many decades (like aluminium, magnesium, some steels, and titanium). The oxides of metals are generally basic, as opposed to those of nonmetals, which are acidic. Exceptions are largely oxides with very high oxidation states such as CrO_3 , Mn_2O_7 , and OsO_4 , which have strictly acidic reactions.

Painting, anodizing or plating metals are good ways to prevent their corrosion. However, a more reactive metal in the electrochemical series must be chosen for coating, especially when chipping of the coating is expected. Water and the two metals form an electrochemical cell, and if the coating is less reactive than the coatee, the coating actually promotes corrosion.

Physical

Metals in general have high electrical conductivity, high thermal conductivity, and high density. Typically they are malleable and ductile, deforming under stress without cleaving.^[7] In terms of optical properties, metals are shiny and lustrous. Sheets of metal beyond a few micrometres in thickness appear opaque, but gold leaf transmits green light.

Although most metals have higher densities than most nonmetals,^[7] there is wide variation in their densities, lithium being the least dense solid element and osmium the most dense. The alkali and alkaline earth metals in groups I A and II A are referred to as the light metals because they have low density, low hardness, and low melting points.^[7] The high density of most metals is due to the tightly packed crystal lattice of the metallic structure. The strength of metallic bonds for different metals reaches a maximum around the center of the transition metal series, as those elements have large amounts of delocalized electrons in tight binding type metallic bonds. However, other factors (such as atomic radius, nuclear charge, number of bonds orbitals, overlap of orbital energies and crystal form) are involved as well.^[7]

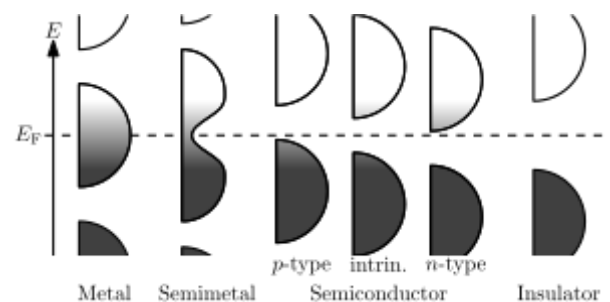


Gallium crystals

Electrical

The electrical and thermal conductivities of metals originate from the fact that their outer electrons are delocalized. This situation can be visualized by seeing the atomic structure of a metal as a collection of atoms embedded in a sea of highly mobile electrons. The electrical conductivity, as well as the electrons' contribution to the heat capacity and heat conductivity of metals can be calculated from the free electron model, which does not take into account the detailed structure of the ion lattice.

When considering the electronic band structure and binding energy of a metal, it is necessary to take into account the positive potential caused by the specific arrangement of the ion cores—which is periodic in crystals. The most important consequence of the periodic potential is the formation of a small band gap at the boundary of the Brillouin zone. Mathematically, the potential of the ion cores can be treated by various models, the simplest being the nearly free electron model.



Filling of the electronic states in various types of materials at equilibrium. Here, height is energy while width is the density of available states for a certain energy in the material listed. The shade follows the Fermi–Dirac distribution (**black** = all states filled, **white** = no state filled). In metals and semimetals the Fermi level E_F lies inside at least one band. In insulators and semiconductors the Fermi level is inside a band gap; however, in semiconductors the bands are near enough to the Fermi level to be thermally populated with electrons or holes.

Mechanical

Mechanical properties of metals include ductility, i.e. their capacity for plastic deformation. Reversible elastic deformation in metals can be described by Hooke's Law for restoring forces, where the stress is linearly proportional to the strain. Forces larger than the elastic limit, or heat, may cause a permanent (irreversible) deformation of the object, known as plastic deformation or plasticity. This irreversible change in atomic arrangement may occur as a result of:

- The action of an applied force (or work). An applied force may be tensile (pulling) force, compressive (pushing) force, shear, bending or torsion (twisting) forces.
- A change in temperature (heat). A temperature change may affect the mobility of the structural defects such as grain boundaries, point vacancies, line and screw dislocations, stacking faults and twins in both crystalline and non-crystalline solids. The movement or displacement of such mobile defects is thermally activated and thus limited by the rate of atomic diffusion.

Viscous flow near grain boundaries, for example, can give rise to internal slip, creep and fatigue in metals. It can also contribute to significant changes in the microstructure like grain growth and localized densification due to the elimination of intergranular porosity. Screw dislocations may slip in the direction of any lattice plane containing the dislocation, while the principal driving force for "dislocation climb" is the movement or diffusion of vacancies through a crystal lattice.

In addition, the nondirectional nature of metallic bonding is also thought to contribute significantly to the ductility of most metallic solids. When the planes of an ionic bond slide past one another, the resultant change in location shifts ions of the same charge into close proximity, resulting in the cleavage of the crystal; such shift is not observed in covalently bonded crystals where fracture and

crystal fragmentation occurs!^[8]

Alloys

An alloy is a mixture of two or more elements in which the main component is a metal. Most pure metals are either too soft, brittle or chemically reactive for practical use. Combining different ratios of metals as alloys modifies the properties of pure metals to produce desirable characteristics. The aim of making alloys is generally to make them less brittle, harder, resistant to corrosion, or have a more desirable color and luster. Of all the metallic alloys in use today, the alloys of iron (steel, stainless steel, cast iron, tool steel, alloy steel) make up the largest proportion both by quantity and commercial value. Iron alloyed with various proportions of carbon gives low, mid and high carbon steels, with increasing carbon levels reducing ductility and toughness. The addition of silicon will produce cast irons, while the addition of chromium, nickel and molybdenum to carbon steels (more than 10%) results in stainless steels.



Hot metal work from a blacksmith.

Other significant metallic alloys are those of aluminium, titanium, copper and magnesium. Copper alloys have been known since prehistory—bronze gave the Bronze Age its name—and have many applications today, most importantly in electrical wiring. The alloys of the other three metals have been developed relatively recently; due to their chemical reactivity they require electrolytic extraction processes. The alloys of aluminium, titanium and magnesium are valued for their high strength-to-weight ratios; magnesium can also provide electromagnetic shielding. These materials are ideal for situations where high strength-to-weight ratio is more important than material cost, such as in aerospace and some automotive applications.

Alloys specially designed for highly demanding applications, such as jet engines, may contain more than ten elements.

Categories

Base metal

In chemistry, the term *base metal* is used informally to refer to a metal that is easily oxidized or corroded, and reacts easily with dilute hydrochloric acid (HCl) to form metal chloride and hydrogen. Examples include iron, nickel, lead and zinc. Copper is considered a base metal as it is oxidized relatively easily, although it does not react with HCl. Base metal is commonly used in opposition to noble metal.

In alchemy, a *base metal* was a common and inexpensive metal, as opposed to precious metals, mainly gold and silver. A longtime goal of the alchemists was the transmutation of base metals into precious metals.

In numismatics, coins in the past derived their value primarily from the precious metal content. Most modern currencies are fiat currency, allowing the coins to be made of base metal.



Zinc, a base metal, reacting with an acid

Ferrous metal

The term "ferrous" is derived from the Latin word meaning "containing iron". This can include pure iron, such as wrought iron, or an alloy such as steel. Ferrous metals are often magnetic, but not exclusively.

Noble metal

Noble metals are metals that are resistant to corrosion or oxidation,^[9] unlike most base metals. They tend to be precious metals, often due to perceived rarity. Examples include gold, platinum, silver, rhodium, iridium and palladium.

Precious metal



A gold nugget

A *precious metal* is a rare metallic chemical element of high economic value.^[10]

Chemically, the precious metals are less reactive than most elements, have high luster and high electrical conductivity. Historically, precious metals were important as currency, but are now regarded mainly as investment and industrial commodities. Gold, silver, platinum and palladium each have an ISO 4217 currency code. The best-known precious metals are gold and silver. While both have industrial uses, they are better known for their uses in art, jewelry, and coinage. Other precious metals include the platinum group metals: ruthenium, rhodium, palladium, osmium, iridium, and platinum, of which platinum is the most widely traded.

The demand for precious metals is driven not only by their practical use, but also by their role as investments and a store of value.^[11] Palladium and platinum are, as of fall 2017, valued at about three quarters the price of gold. Silver is substantially less expensive than these metals, but is often traditionally considered a precious metal for its role in coinage and jewelry

Heavy metal

A heavy metal is any relatively dense metal or metalloid.^[12] More specific definitions have been proposed, but none have obtained widespread acceptance. Some heavy metals have niche uses, or are notably toxic; some are essential in trace amounts.

Extraction

Metals are often extracted from the Earth by means of mining ores that are rich sources of the requisite elements, such as bauxite. Ore is located by prospecting techniques, followed by the exploration and examination of deposits. Mineral sources are generally divided into surface mines, which are mined by excavation using heavy equipment, and subsurface mines

Once the ore is mined, the metals must be extracted, usually by chemical or electrolytic reduction. Pyrometallurgy uses high temperatures to convert ore into raw metals, while hydrometallurgy employs aqueous chemistry for the same purpose. The methods used depend on the metal and their contaminants.

When a metal ore is an ionic compound of that metal and a non-metal, the ore must usually be smelted—heated with a reducing agent—to extract the pure metal. Many common metals, such as iron, are smelted using carbon as a reducing agent. Some metals, such as aluminium and sodium, have no commercially practical reducing agent, and are extracted using electrolysis instead.^{[13][14]}

Sulfide ores are not reduced directly to the metal but are roasted in air to convert them to oxides.

Recycling

Demand for metals is closely linked to economic growth. During the 20th century, the variety of metals uses in society grew rapidly. Today, the development of major nations, such as China and India, and advances in technologies, are fuelling ever more demand. The result is that mining activities are expanding, and more and more of the world's metal stocks are above ground in use, rather than below ground as unused reserves. An example is the in-use stock of copper. Between 1932 and 1999, copper in use in the US rose from 73g to 238g per person.^[15]

Metals are inherently recyclable, so in principle, can be used over and over again, minimizing these negative environmental impacts and saving energy. For example, 95% of the energy used to make aluminium from bauxite ore is saved by using recycled material.^[16] Levels of metals recycling are generally low. In 2010, the International Resource Panel, hosted by the United Nations Environment Programme (UNEP) published reports on metal stocks that exist within society^[17] and their recycling rates.^[15]

The report authors observed that the metal stocks in society can serve as huge mines above ground. They warned that the recycling rates of some rare metals used in applications such as mobile phones, battery packs for hybrid cars and fuel cells are so low that unless future end-of-life recycling rates are dramatically stepped up these critical metals will become unavailable for use in modern technology.

Metallurgy

Metallurgy is a domain of materials science that studies the physical and chemical behavior of metallic elements, their intermetallic compounds, and their mixtures, which are called alloys.

Applications

Some metals and metal alloys possess high structural strength per unit mass, making them useful materials for carrying large loads or resisting impact damage. Metal alloys can be engineered to have high resistance to shear, torque and deformation. However the same metal can also be vulnerable to fatigue damage through repeated use or from sudden stress failure when a load capacity is exceeded. The strength and resilience of metals has led to their frequent use in high-rise building and bridge construction, as well as most vehicles, many appliances, tools, pipes, non-illuminated signs and railroad tracks.

The two most commonly used structural metals, iron and aluminium, are also the most abundant metals in the Earth's crust.^[18]

Metals are good conductors, making them valuable in electrical appliances and for carrying an electric current over a distance with little energy lost. Electrical power grids rely on metal cables to distribute electricity. Home electrical systems, for the most part, are wired with copper wire for its good conducting properties.

The thermal conductivity of metal is useful for containers to heat materials over a flame. Metal is also used for heat sinks to protect sensitive equipment from overheating.

The high reflectivity of some metals is important in the construction of mirrors, including precision astronomical instruments. This last property can also make metallic jewelry aesthetically appealing.

Some metals have specialized uses; radioactive metals such as uranium and plutonium are used in nuclear power plants to produce energy via nuclear fission. Mercury is a liquid at room temperature and is used in switches to complete a circuit when it flows over the switch contacts. Shape memory alloy is used for applications such as pipes, fasteners and vascular stents.

Metals can be doped with foreign molecules—organic, inorganic, biological and polymers. This doping entails the metal with new properties that are induced by the guest molecules. Applications in catalysis, medicine, electrochemical cells, corrosion and more have been developed.^[19]

Trade

The World Bank reports that China was the top importer of ores and metals in 2005 followed by the United States and Japan.^[20]

History

The nature of metals has fascinated humans for many centuries, because these materials provided people with tools of unsurpassed properties both in war and in their preparation and processing. Pure gold and silver have been known to humans since the Stone Age. Lead and silver were fused from their ores as early as the fourth millennium BC.^[21]

Ancient Latin and Greek writers such as Theophrastus, Pliny the Elder in his *Natural History*, or Pedanius Dioscorides did not try to classify metals. The ancient Europeans never attained the concept "metal" as a distinct elementary substance with fixed, characteristic chemical and physical properties. Following Empedocles, all substances within the sublunary sphere were assumed to vary in their constituent classical elements of earth, water, air and fire. Following the Pythagoreans, Plato assumed that these elements could be

further reduced to plane geometrical shapes (triangles and squares) bounding space and relating to the regular polyhedra in the sequence earth:cube, water:icosahedron, air:octahedron, fire:tetrahedron. However, this philosophical extension did not become as popular as the simple four elements, after it was rejected by Aristotle. Aristotle also rejected the atomic theory of Democritus, since he classified the implied existence of a vacuum necessary for motion as a contradiction (a vacuum implies nonexistence, therefore cannot exist). Aristotle did, however, introduce underlying antagonistic qualities (or forces) of dry vs. wet and cold vs. heat into the composition of each of the four elements. The word "metal" originally meant "mines" and only later gained the general meaning of products from materials obtained in mines. In the first centuries A.D. a relation between the planets and the existing metals was assumed as Gold:Sun, Silver:Moon, Electrum:Jupiter, Iron:Mars, Copper:Venus, Tin:Mercury, Lead:Saturn. After electrum was determined to be a combination of silver and gold, the relations Tin:Jupiter and Mercury:Mercury were substituted into the previous sequence.^[22]

Arabic and medieval alchemists believed that all metals, and in fact, all sublunar matter, were composed of the principle of sulfur, carrying the combustible property, and the principle of mercury, the mother of all metals and carrier of the liquidity or fusibility, and the volatility properties. These principles were not necessarily the common substances sulfur and mercury found in most laboratories. This theory reinforced the belief that the all metals were destined to become gold in the bowels of the earth through the proper combinations of heat, digestion, time, and elimination of contaminants, all of which could be developed and hastened through the knowledge and methods of alchemy. Paracelsus added the third principle of salt, carrying the nonvolatile and incombustible properties, in his *tria prima doctrine*. These theories retained the four classical elements as underlying the composition of sulfur, mercury and salt.

The first systematic text on the arts of mining and metallurgy was *De la Pirotechnia* by Vannoccio Biringuccio, which treats the examination, fusion, and working of metals. Sixteen years later, Georgius Agricola published *De Re Metallica* in 1555, a clear and complete account of the profession of mining, metallurgy, and the accessory arts and sciences, as well as qualifying as the greatest treatise on the chemical industry through the sixteenth century. He gave the following description of a metal in his *De Natura Fossilium* (1546).

Metal is a mineral body by nature either liquid or somewhat hard. The latter may be melted by the heat of the fire, but when it has cooled down again and lost all heat, it becomes hard again and resumes its proper form. In this respect it differs from the stone which melts in the fire, for although the latter regain its hardness, yet it loses its pristine form and properties. Traditionally there are six different kinds of metals, namely gold, silver, copper, iron, tin and lead. There are really others, for quicksilver is a metal, although the Alchemists disagree with us on this subject, and bismuth is also. The ancient Greek writers seem to have been ignorant of bismuth, wherefore Ammonius rightly states that there are many species of metals, animals, and plants which are unknown to us. Stibium when smelted in the crucible and refined has as much right to be regarded as a proper metal as is accorded to lead by writers. If when smelted, a certain portion be added to tin, a bookseller's alloy is produced from which the type is made that is used by those who print books on paper. Each metal has its own form which it preserves when separated from those metals which were mixed with it. Therefore neither electrum nor Stannum [not meaning our tin] is of itself a real metal, but rather an alloy of two metals. Electrum is an alloy of gold and silver, Stannum of lead and silver. And yet if silver be parted from the electrum, then gold remains and not electrum; if silver be taken away from Stannum, then lead remains and not Stannum. Whether brass, however, is found as a native metal or not, cannot be ascertained with any surety. We only know of the artificial brass, which consists of copper tinted with the colour of the mineral calamine. And yet if any should be dug up, it would be a proper metal. Black and white copper seem to be different from the red kind. Metal, therefore, is by nature either solid, as I have stated, or fluid, as in the unique case of quicksilver. But enough now concerning the simple kinds.^[23]

See also

- Amorphous metal
- ASM International (society)
- Ductility
- Electric field screening
- Metal theft
- Metalworking
- Properties of metals, metalloids and nonmetals
- Properties and uses of metals

- Solid
- Spin transition
- Steel
- Structural steel
- Transition metal

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