

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijirset.com

Vol. 3, Issue 10, October 2014

Metals in Detail with Properties

Dr. Vishramlal Bairwa

Lecturer, Dept. of Chemistry, Govt. College, Karauli, Rajasthan, India

ABSTRACT: A metal (from Ancient Greek μέταλλον métallon 'mine, quarry, metal') is a material that, when freshly prepared, polished, or fractured, shows a lustrous appearance, and conducts electricity and heat relatively well. Metals are typically ductile (can be drawn into wires) and malleable (they can be hammered into thin sheets). These properties are the result of the metallic bond between the atoms or molecules of the metal. A metal may be a chemical element such as iron; an alloy such as stainless steel; or a molecular compound such as polymeric sulfur nitride.^[1] In physics, a metal is generally regarded as any substance capable of conducting electricity at a temperature of absolute zero.^[2] Many elements and compounds that are not normally classified as metals become metallic under high pressures. For example, the nonmetal iodine gradually becomes a metal at a pressure of between 40 and 170 thousand times atmospheric pressure. Equally, some materials regarded as metals can become nonmetals. Sodium, for example, becomes a nonmetal at pressure of just under two million times atmospheric pressure.

KEYWORDS: metals, properties, malleable, alloy, steel, materials, lustrous, electricity, heat, ductile, hammered

I. INTRODUCTION

In chemistry, two elements that would otherwise qualify (in physics) as brittle metals—arsenic and antimony—are commonly instead recognised as metalloids due to their chemistry (predominantly non-metallic for arsenic, and balanced between metallicity and nonmetallicity for antimony). Around 95 of the 118 elements in the periodic table are metals (or are likely to be such). The number is inexact as the boundaries between metals, nonmetals, and metalloids fluctuate slightly due to a lack of universally accepted definitions of the categories involved.

In astrophysics the term "metal" is cast more widely to refer to all chemical elements in a star that are heavier than helium, and not just traditional metals. In this sense the first four "metals" collecting in stellar cores through nucleosynthesis are carbon, nitrogen, oxygen, and neon, all of which are strictly non-metals in chemistry. A star fuses lighter atoms, mostly hydrogen and helium, into 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.^{[3][4]}

Metals, as chemical elements, comprise 25% of the Earth's crust and are present in many aspects of modern life. The strength and resilience of some metals has led to their frequent use in, for example, high-rise building and bridge construction, as well as most vehicles, many home appliances, tools, pipes, and railroad tracks. Precious metals were historically used as coinage, but in the modern era, coinage metals have extended to at least 23 of the chemical elements.^[5]

The history of refined metals is thought to begin with the use of copper about 11,000 years ago. Gold, silver, iron (as meteoric iron), lead, and brass were likewise in use before the first known appearance of bronze in the fifth millennium BCE. Subsequent developments include the production of early forms of steel; the discovery of sodium—the first light metal—in 1809; the rise of modern alloy steels; and, since the end of World War II, the development of more sophisticated alloys.

Metals are shiny and lustrous, at least when freshly prepared, polished, or fractured. Sheets of metal thicker than a few micrometres appear opaque, but gold leaf transmits green light.

The solid or liquid state of metals largely originates in the capacity of the metal atoms involved to readily lose their outer shell electrons. Broadly, the forces holding an individual atom's outer shell electrons in place are weaker than the attractive forces on the same electrons arising from interactions between the atoms in the solid or liquid metal. The electrons involved become delocalised and the atomic structure of a metal can effectively be visualised as a collection of atoms embedded in a cloud of relatively mobile electrons. This type of interaction is called a metallic bond.^[6] The

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijirset.com

Vol. 3, Issue 10, October 2014

strength of metallic bonds for different elemental metals reaches a maximum around the center of the transition metal series, as these elements have large numbers of delocalized electrons.^[n 1]

Although most elemental metals have higher densities than most nonmetals,^[6] there is a wide variation in their densities, lithium being the least dense (0.534 g/cm^3) and osmium (22.59 g/cm^3) the most dense. (Some of the 6d transition metals are expected to be denser than osmium, but predictions on their densities vary widely in the literature, and in any case their known isotopes are too unstable for bulk production to be possible.) Magnesium, aluminium and titanium are light metals of significant commercial importance. Their respective densities of 1.7, 2.7, and 4.5 g/cm^3 can be compared to those of the older structural metals, like iron at 7.9 and copper at 8.9 g/cm^3 . An iron ball would thus weigh about as much as three aluminum balls of equal volume.

Metals are typically malleable and ductile, deforming under stress without cleaving.^[6] The nondirectional nature of metallic bonding is thought to contribute significantly to the ductility of most metallic solids. In contrast, in an ionic compound like table salt, when the planes of an ionic bond slide past one another, the resultant change in location shifts ions of the same charge closer, resulting in the cleavage of the crystal. Such a shift is not observed in a covalently bonded crystal, such as a diamond, where fracture and crystal fragmentation occurs.^[7] Reversible elastic deformation in metals can be described by Hooke's Law for restoring forces, where the stress is linearly proportional to the strain.

Heat or forces larger than a metal's elastic limit may cause a permanent (irreversible) deformation, known as plastic deformation or plasticity. An applied force may be a tensile (pulling) force, a compressive (pushing) force, or a shear, bending, or torsion (twisting) force. A temperature change may affect the movement or displacement of structural defects in the metal such as grain boundaries, point vacancies, line and screw dislocations, stacking faults and twins in both crystalline and non-crystalline metals. Internal slip, creep, and metal fatigue may ensue.

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.^[8]

The unit cell for each crystal structure is the smallest group of atoms which has the overall symmetry of the crystal, and from which the entire crystalline lattice can be built up by repetition in three dimensions. In the case of the body-centered cubic crystal structure shown above, the unit cell is made up of the central atom plus one-eighth of each of the eight corner atoms. The electronic structure of metals means they are relatively good conductors of electricity. Electrons in matter can only have fixed rather than variable energy levels, and in a metal the energy levels of the electrons in its electron cloud, at least to some degree, correspond to the energy levels at which electrical conduction can occur. In a semiconductor like silicon or a nonmetal like sulfur there is an energy gap between the electrons in the substance and the energy level at which electrical conduction can occur. Consequently, semiconductors and nonmetals are relatively poor conductors.

The elemental metals have electrical conductivity values of from $6.9 \times 10^3 \text{ S/cm}$ for manganese to $6.3 \times 10^5 \text{ S/cm}$ for silver. In contrast, a semiconducting metalloid such as boron has an electrical conductivity $1.5 \times 10^{-6} \text{ S/cm}$. With one exception, metallic elements reduce their electrical conductivity when heated. Plutonium increases its electrical conductivity when heated in the temperature range of around -175 to $+125 \text{ }^\circ\text{C}$.

Metals are relatively good conductors of heat. The electrons in a metal's electron cloud are highly mobile and easily able to pass on heat-induced vibrational energy.

The contribution of a metal's electrons to its heat capacity and thermal conductivity, and the electrical conductivity of the metal itself can be calculated from the free electron model. However, this does not take into account the detailed structure of the metal's ion lattice. Taking into account the positive potential caused by the arrangement of the ion cores enables consideration of the electronic band structure and binding energy of a metal. Various mathematical models are applicable, the simplest being the nearly free electron model.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijirset.com

Vol. 3, Issue 10, October 2014

II.DISCUSSION

Metals are usually inclined to form cations through electron loss.^[6] Most will react with oxygen in the air to form oxides over various timescales (potassium burns in seconds while iron rusts over years). Some others, like palladium, platinum, and gold, do not react with the atmosphere at all. The oxides of metals are generally basic, as opposed to those of nonmetals, which are acidic or neutral. 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 underlying metal, the coating actually promotes corrosion.^[11] The situation can change with pressure: at extremely high pressures, all elements (and indeed all substances) are expected to metallize.^[10] Arsenic (As) has both a stable metallic allotrope and a metastable semiconducting allotrope at standard conditions. Elements near the border between metals and nonmetals often have intermediate chemical behavior. As such, a category of metalloids is often used for such in-between elements, but there is no consensus in the literature as to which elements should qualify.^[12]

An alloy is a substance having metallic properties and which is composed of two or more elements at least one of which is a metal. An alloy may have a variable or fixed composition. For example, gold and silver form an alloy in which the proportions of gold or silver can be freely adjusted; titanium and silicon form an alloy Ti_2Si in which the ratio of the two components is fixed (also known as an intermetallic compound). 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.

Other significant metallic alloys are those of aluminum, 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 need electrolytic extraction processes. The alloys of aluminum, 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.

Metals can be categorised according to their physical or chemical properties. Categories described in the subsections below include ferrous and non-ferrous metals; brittle metals and refractory metals; white metals; heavy and light metals; and base, noble, and precious metals. The Metallic elements^[11] the elemental metals on the basis of their chemical properties into alkali and alkaline earth metals; transition and post-transition metals; and lanthanides and actinides.^[12] Other categories are possible, depending on the criteria for inclusion. For example, the ferromagnetic metals—those metals that are magnetic at room temperature—are iron, cobalt, and nickel. 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. Non-ferrous metals and alloys lack appreciable amounts of iron. While nearly all metals are malleable or ductile, a few—beryllium, chromium, manganese, gallium, and bismuth—are brittle.^[13] Arsenic and antimony, if admitted as metals, are brittle. Low values of the ratio of bulk elastic modulus to shear modulus (Pugh's criterion) are indicative of intrinsic brittleness. In materials science, metallurgy, and engineering, a refractory metal is a metal that is extraordinarily resistant to heat and wear. Which metals belong to this category varies; the most common definition includes niobium, molybdenum, tantalum, tungsten, and rhenium. They all have melting points above 2000 °C, and a high hardness at room temperature. A white metal is any of range of white-coloured metals (or their alloys) with relatively low melting points.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijirset.com

Vol. 3, Issue 10, October 2014

Such metals include zinc, cadmium, tin, antimony (here counted as a metal), lead, and bismuth, some of which are quite toxic. In Britain, the fine art trade uses the term "white metal" in auction catalogues to describe foreign silver items which do not carry British Assay Office marks, but which are nonetheless understood to be silver and are priced accordingly. A heavy metal is any relatively dense metal or metalloid.^[14] 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. All other metals are light metals.

III.RESULTS

In chemistry, the term base metal is used informally to refer to a metal that is easily oxidized or corroded, such as reacting easily with dilute hydrochloric acid (HCl) to form a 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. The term noble metal is commonly used in opposition to base metal. Noble metals are resistant to corrosion or oxidation,^[15] unlike most base metals. They tend to be precious metals, often due to perceived rarity. Examples include gold, platinum, silver, rhodium, iridium, and palladium.

In alchemy and numismatics, the term base metal is contrasted with precious metal, that is, those of high economic value.^[16] A longtime goal of the alchemists was the transmutation of base metals into precious metals including such coinage metals as silver and gold. Most coins today are made of base metals with low intrinsic value; in the past, coins frequently derived their value primarily from their precious metal content.

Chemically, the precious metals (like the noble 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.^[17] Palladium and platinum, as of fall 2011, were 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 in light of its role in coinage and jewelry. Metals up to the vicinity of iron (in the periodic table) are largely made via stellar nucleosynthesis. In this process, lighter elements from hydrogen to silicon undergo successive fusion reactions inside stars, releasing light and heat and forming heavier elements with higher atomic numbers.^[18]

Heavier metals are not usually formed this way since fusion reactions involving such nuclei would consume rather than release energy.^[19] Rather, they are largely synthesised (from elements with a lower atomic number) by neutron capture, with the two main modes of this repetitive capture being the s-process and the r-process. In the s-process ("s" stands for "slow"), singular captures are separated by years or decades, allowing the less stable nuclei to beta decay,^[20] while in the r-process ("rapid"), captures happen faster than nuclei can decay. Therefore, the s-process takes a more-or-less clear path: for example, stable cadmium-110 nuclei are successively bombarded by free neutrons inside a star until they form cadmium-115 nuclei which are unstable and decay to form indium-115 (which is nearly stable, with a half-life 30000 times the age of the universe). These nuclei capture neutrons and form indium-116, which is unstable, and decays to form tin-116, and so on.^{[18][21][n 3]} In contrast, there is no such path in the r-process. The s-process stops at bismuth due to the short half-lives of the next two elements, polonium and astatine, which decay to bismuth or lead. The r-process is so fast it can skip this zone of instability and go on to create heavier elements such as thorium and uranium.^[23] Metals condense in planets as a result of stellar evolution and destruction processes. Stars lose much of their mass when it is ejected late in their lifetimes, and sometimes thereafter as a result of a neutron star merger,^{[24][n 4]} thereby increasing the abundance of elements heavier than helium in the interstellar medium. When gravitational attraction causes this matter to coalesce and collapse new stars and planets are formed.^[26] The Earth's crust is made of approximately 25% of metals by weight, of which 80% are light metals such as sodium, magnesium, and aluminium. Nonmetals (~75%) make up the rest of the crust. Despite the overall scarcity of some heavier metals such as copper, they can become concentrated in economically extractable quantities as a result of mountain building, erosion, or other geological processes.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijirset.com

Vol. 3, Issue 10, October 2014

Metals are primarily found as lithophiles (rock-loving) or chalcophiles (ore-loving). Lithophile metals are mainly the s-block elements, the more reactive of the d-block elements, and the f-block elements. They have a strong affinity for oxygen and mostly exist as relatively low-density silicate minerals. Chalcophile metals are mainly the less reactive d-block elements, and the period 4–6 p-block metals. They are usually found in (insoluble) sulfide minerals. Being denser than the lithophiles, hence sinking lower into the crust at the time of its solidification, the chalcophiles tend to be less abundant than the lithophiles.

On the other hand, gold is a siderophile, or iron-loving element. It does not readily form compounds with either oxygen or sulfur. At the time of the Earth's formation, and as the most noble (inert) of metals, gold sank into the core due to its tendency to form high-density metallic alloys. Consequently, it is a relatively rare metal. Some other (less) noble metals—molybdenum, rhenium, the platinum group metals (ruthenium, rhodium, palladium, osmium, iridium, and platinum), germanium, and tin—can be counted as siderophiles but only in terms of their primary occurrence in the Earth (core, mantle, and crust), rather the crust. These metals otherwise occur in the crust, in small quantities, chiefly as chalcophiles (less so in their native form).^[n 5]

The rotating fluid outer core of the Earth's interior, which is composed mostly of iron, is thought to be the source of Earth's protective magnetic field.^[n 6] The core lies above Earth's solid inner core and below its mantle. If it could be rearranged into a column having a 5 m² (54 sq ft) footprint it would have a height of nearly 700 light years. The magnetic field shields the Earth from the charged particles of the solar wind, and cosmic rays that would otherwise strip away the upper atmosphere (including the ozone layer that limits the transmission of ultraviolet radiation). 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. In some cases, the sale price of the metal(s) involved make it economically feasible to mine lower concentration sources.

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 aluminum and sodium, have no commercially practical reducing agent, and are extracted using electrolysis instead.^{[27][28]}

Sulfide ores are not reduced directly to the metal but are roasted in air to convert them to oxides. Metals are present in nearly all aspects of modern life. Iron, a heavy metal, may be the most common as it accounts for 90% of all refined metals; aluminum, a light metal, is the next most commonly refined metal. Pure iron may be the cheapest metallic element of all at cost of about US\$0.07 per gram. Its ores are widespread; it is easy to refine; and the technology involved has been developed over hundreds of years. Cast iron is even cheaper, at a fraction of US\$0.01 per gram, because there is no need for subsequent purification. Platinum, at a cost of about \$27 per gram, may be the most ubiquitous given its very high melting point, resistance to corrosion, electrical conductivity, and durability. It is said to be found in, or used to produce, 20% of all consumer goods. Polonium is likely to be the most expensive metal that is traded, at a notional cost of about \$100,000,000 per gram, due to its scarcity and micro-scale production.

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, and railroad tracks.

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.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijirset.com

Vol. 3, Issue 10, October 2014

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

The high reflectivity of some metals enables their use in mirrors, including precision astronomical instruments, and adds to the aesthetics of metallic jewelry.

Some metals have specialized uses; mercury is a liquid at room temperature and is used in switches to complete a circuit when it flows over the switch contacts. Radioactive metals such as uranium and plutonium are fuel for nuclear power plants, which produce energy via nuclear fission. Shape-memory alloys are 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.^[29] Demand for metals is closely linked to economic growth given their use in infrastructure, construction, manufacturing, and consumer goods. During the 20th century, the variety of metals used in society grew rapidly. Today, the development of major nations, such as China and India, and technological advances, 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 U.S. rose from 73 g to 238 g per person.^[30]

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 aluminum from bauxite ore is saved by using recycled material.^[31]

Globally, metal recycling is generally low. In 2010, the International Resource Panel, hosted by the United Nations Environment Programme published reports on metal stocks that exist within society^[32] and their recycling rates.^[30] The authors of the report 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.⁴⁰

IV. CONCLUSIONS

The modern era in steelmaking began with the introduction of Henry Bessemer's Bessemer process in 1855, the raw material for which was pig iron. His method let him produce steel in large quantities cheaply, thus mild steel came to be used for most purposes for which wrought iron was formerly used. The Gilchrist-Thomas process (or basic Bessemer process) was an improvement to the Bessemer process, made by lining the converter with a basic material to remove phosphorus.⁴¹

Due to its high tensile strength and low cost, steel came to be a major component used in buildings, infrastructure, tools, ships, automobiles, machines, appliances, and weapons.

In 1872, the Englishmen Clark and Woods patented an alloy that would today be considered a stainless steel. The corrosion resistance of iron-chromium alloys had been recognized in 1821 by French metallurgist Pierre Berthier. He noted their resistance against attack by some acids and suggested their use in cutlery. Metallurgists of the 19th century were unable to produce the combination of low carbon and high chromium found in most modern stainless steels, and the high-chromium alloys they could produce were too brittle to be practical. It was not until 1912 that the industrialisation of stainless steel alloys occurred in England, Germany, and the United States.⁴²

By 1900 three metals with atomic numbers less than lead (#82), the heaviest stable metal, remained to be discovered: elements 71, 72, 75.

Von Welsbach, in 1906, proved that the old ytterbium also contained a new element (#71), which he named cassiopeium. Urbain proved this simultaneously, but his samples were very impure and only contained trace quantities of the new element. Despite this, his chosen name lutetium was adopted.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijirset.com

Vol. 3, Issue 10, October 2014

In 1908, Ogawa found element 75 in thorianite but assigned it as element 43 instead of 75 and named it nipponium. In 1925 Walter Noddack, Ida Eva Tacke, and Otto Berg announced its separation from gadolinite and gave it the present name, rhenium.

Georges Urbain claimed to have found element 72 in rare-earth residues, while Vladimir Vernadsky independently found it in orthite. Neither claim was confirmed due to World War I, and neither could be confirmed later, as the chemistry they reported does not match that now known for hafnium. After the war, in 1922, Coster and Hevesy found it by X-ray spectroscopic analysis in Norwegian zircon. Hafnium was thus the last stable element to be discovered, though rhenium was the last to be correctly recognized.⁴³

REFERENCES

1. Chiang, CK (1977). "Transport and optical properties of polythiazyl bromides: $(\text{SNBr}_{0.4})_x$ ". Solid State Communications. 23 (9): 607–612. Bibcode:1977SSCom..23..607C. doi:10.1016/0038-1098(77)90530-0.; Greenwood, NN; Earnshaw, A (1998). Chemistry of the Elements. Oxford: Butterworth-Heinemann. p. 727. ISBN 978-0-7506-3365-9.; Mutlu, H; Theato, P (2010). "Polymers with sulfur-nitrogen bonds". In Zhang, X; Theato, P (eds.). Sulfur-Containing Polymers: From Synthesis to Functional Materials. Weinheim: Wiley-VCH. pp. 191–234 (191). ISBN 978-3-527-34670-7.
2. ^ Yonezawa, F. (2012). Physics of Metal-Nonmetal Transitions. Amsterdam: IOS Press. p. 257. ISBN 978-1-61499-786-3. Sir Nevill Mott (1905-1996) wrote a letter to a fellow physicist, Prof. Peter P. Edwards, in which he notes... I've thought a lot about 'What is a metal?' and I think one can only answer the question at $T = 0$ (the absolute zero of temperature). There a metal conducts and a nonmetal doesn't.
3. ^ Martin, John C. "What we learn from a star's metal content". John C. Martin's Homepage. Retrieved March 25, 2010.
4. ^ Martin, John C.; Morrison, Heather L. (May 18, 1998) [1998]. "A New Analysis of RR Lyrae Kinematics in the Solar Neighborhood". The Astronomical Journal (published October 1, 1998). 116 (4): 1724–1735. arXiv:astro-ph/9806258. Bibcode:1998AJ....116.1724M. doi:10.1086/300568. S2CID 18530430 – via IOPscience.
5. ^ Roe, J.; Roe, M. (1992). "World's coinage uses 24 chemical elements". World Coinage News. 19 (4, 5): 24–25, 18–19.
6. ^ Mortimer, Charles E. (1975). Chemistry: A Conceptual Approach (3rd ed.). New York: D. Van Nostrand Company.
7. ^ "Ductility – strength (mechanics) of materials".
8. ^ Holleman, A. F.; Wiberg, E. (2001). Inorganic Chemistry. San Diego: Academic Press. ISBN 0-12-352651-8.
9. ^ Greenwood, Norman N.; Earnshaw, Alan (1997). Chemistry of the Elements (2nd ed.). Butterworth-Heinemann. ISBN 978-0-08-037941-8.
10. ^ Siekierski, S.; Burgess, J. (2002). Concise Chemistry of the Elements. Horwood. pp. 60–66. ISBN 978-1-898563-71-6.
11. ^ Mewes, Jan-Michael; Smits, Odile Rosette; Jerabek, Paul; Schwerdtfeger, Peter (25 July 2011). "Oganesson is a Semiconductor: On the Relativistic Band-Gap Narrowing in the Heaviest Noble-Gas Solids". Angewandte Chemie. 58 (40): 14260–14264. doi:10.1002/anie.201108327. PMC 6790653. PMID 31343819.
12. ^ See lists of metalloids.
13. ^ Russell, A. M.; Lee, K. L. (2005). Structure–Property Relations in Nonferrous Metals. Structure-Property Relations in Nonferrous Metals. Hoboken, NJ: John Wiley & Sons. pp. passim. Bibcode:2005srnm.book.....R. ISBN 978-0-471-64952-6.
14. ^ Metal contamination. Editions Quae. 2006. ISBN 978-2-7592-0011-5.
15. ^ Tunay, Olcay; Kabdasli, Isik; Arslan-Alaton, Idil; Olmez-Hanci, Tugba (2010). Chemical Oxidation Applications for Industrial Wastewaters. IWA Publishing. ISBN 978-1-84339-307-8.
16. ^ Walther, John V. (2013). Earth's Natural Resources. Jones & Bartlett Publishers. ISBN 978-1-4496-3234-2.
17. ^ Abdul-Rahman, Yahia (2013). The Art of RF (Riba-Free) Islamic Banking and Finance: Tools and Techniques for Community-Based Banking. John Wiley & Sons. ISBN 978-1-118-77096-2.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijirset.com

Vol. 3, Issue 10, October 2014

18. ^ Cox 1997, pp. 73–89
19. ^ Cox 1997, pp. 32, 63, 85
20. ^ Podosek 2011, p. 482
21. ^ Padmanabhan 2001, p. 234
22. ^ Rehder 2010, pp. 32, 33
23. ^ Hofmann 2002, pp. 23–24
24. ^ Hadhazy 2012
25. ^ Choptuik, Lehner & Pretorius 2013, p. 383
26. ^ Cox 1997, pp. 83, 91, 102–103
27. ^ "Los Alamos National Laboratory – Sodium". Retrieved 2007-06-08.
28. ^ "Los Alamos National Laboratory – Aluminum". Retrieved 2007-06-08.
29. ^ Avnir, David (2013). "Molecularly doped metals". *Acc. Chem. Res.* 47 (2): 579–592. doi:10.1021/ar4001982. PMID 24283194.
30. ^ The Recycling Rates of Metals: A Status Report Archived 2012-01-01 at the Wayback Machine 2010, International Resource Panel, United Nations Environment Programme
31. ^ Tread lightly: Aluminium attack Carolyn Fry, Guardian.co.uk, 22 February 2008.
32. ^ Metal Stocks in Society: Scientific Synthesis Archived 2012-01-01 at the Wayback Machine 2010, International Resource Panel, United Nations Environment Programme
33. ^ "About the Editors". *Metals, Microbes, and Minerals - the Biogeochemical Side of Life*. De Gruyter. 2010. pp. v–vi. doi:10.1515/9783110589771-001. ISBN 9783110589771. S2CID 242357865.
34. ^ Reardon, Arthur C. (2011). *Metallurgy for the non-metallurgist*. Materials Park, Ohio: ASM International. pp. 73–84. ISBN 978-1-61503-845-9. OCLC 780082219.
35. ^ Tylecote, R. F. (1992). *A History of Metallurgy*, Second Edition. London: Maney Publishing, for the Institute of Materials. ISBN 978-1-902653-79-2. Archived from the original on 2013-04-02.
36. ^ Thornton, C.; Lamberg-Karlovsky, C. C.; Liezers, M.; Young, S. M. M. (2002). "On pins and needles: tracing the evolution of copper-based alloying at Tepe Yahya, Iran, via ICP-MS analysis of Common-place items". *Journal of Archaeological Science*. 29 (12): 1451–1460. doi:10.1006/jasc.2002.0809.
37. ^ Kaufman, Brett. "Metallurgy and Archaeological Change in the Ancient Near East". *Backdirt: Annual Review*. 2011: 86.
38. ^ Akanuma, H. (2005). "The significance of the composition of excavated iron fragments taken from Stratum III at the site of Kaman-Kalehöyük, Turkey". *Anatolian Archaeological Studies*. Tokyo: Japanese Institute of Anatolian Archaeology. 14: 147–158.
39. ^ "Ironware piece unearthed from Turkey found to be oldest steel". *The Hindu*. Chennai, India. 2009-03-26. Archived from the original on 2009-03-29. Retrieved 2009-03-27.
40. ^ Knauth, P. (1976). *The Metalsmiths*, revised edition. London: Time-Life International. pp. 133, 137.
41. ^ Published in *The Delineator*, Sept. 1909. Reprinted as the introduction to *Rewards and Fairies* in 1910.
42. ^ Georgius Agricola, *De Re Metallica* (1556) Tr. Herbert Clark Hoover & Lou Henry Hoover (1912); Footnote quoting *De Natura Fossilium* (1546), p. 180
43. ^ Max phase composites *Materials Science and Engineering A*