

Characteristics

Physical properties



Electrolytically refined manganese chips and a 1 cm³ cube

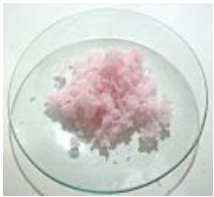
Manganese is a silvery-gray metal that resembles iron. It is hard and very brittle, difficult to fuse, but easy to oxidize.^[4] Manganese metal and its common ions are paramagnetic^[5] Manganese tarnishes slowly in air and oxidizes ("rusts") like iron in water containing dissolved oxygen.

Isotopes

Naturally occurring manganese is composed of one stable isotope, ⁵⁵Mn. Eighteen radioisotopes have been isolated and described, ranging in atomic weight from 46 u (⁴⁶Mn) to 65 u (⁶⁵Mn). The most stable are ⁵³Mn with a half-life of 3.7 million years, ⁵⁴Mn with a half-life of 312.3 days, and ⁵²Mn with a half-life of 5.591 days. All of the remaining radioactive isotopes have half-lives of less than three hours, and the majority of less than one minute. The primary decay mode before the most abundant stable isotope, ⁵⁵Mn, is electron capture and the primary mode after is beta decay.^[6] Manganese also has three meta states.^[6]

Manganese is part of the iron group of elements, which are thought to be synthesized in large stars shortly before the supernova explosion. ⁵³Mn decays to ⁵³Cr with a half-life of 3.7 million years. Because of its relatively short half-life, ⁵³Mn is relatively rare, produced by cosmic rays impact on iron.^[7] Manganese isotopic contents are typically combined with chromium isotopic contents and have found application in isotope geology and radiometric dating. Mn–Cr isotopic ratios reinforce the evidence from ²⁶Al and ¹⁰⁷Pd for the early history of the solar system. Variations in ⁵³Cr/⁵²Cr and Mn/Cr ratios from several meteorites suggest an initial ⁵³Mn/⁵⁵Mn ratio, which indicates that Mn–Cr isotopic composition must result from *in situ* decay of ⁵³Mn in differentiated planetary bodies. Hence, ⁵³Mn provides additional evidence for nucleosynthetic processes immediately before coalescence of the solar system.^[6]

Chemical properties



Manganese(II) chloride crystals – the pale pink color of Mn(II) salts is due to a spin-forbidden 3d transition.^[8]

The most common oxidation states of manganese are +2, +3, +4, +6, and +7, though all oxidation states from −3 to +7 have been observed. Mn²⁺ often competes with Mg²⁺ in biological systems. Manganese compounds where manganese is in oxidation state +7, which are mostly restricted to the unstable oxide Mn₂O₇, compounds of the intensely purple permanganate anion MnO₄[−], and a few oxyhalides (MnO₃F and MnO₃Cl), are powerful oxidizing agents.^[4] Compounds with oxidation states +5 (blue) and +6 (green) are strong oxidizing agents and are vulnerable to disproportionation

The most stable oxidation state for manganese is +2, which has a pale pink color, and many manganese(II) compounds are known, such as manganese(II) sulfate (MnSO₄) and manganese(II) chloride (MnCl₂). This oxidation state is also seen in the mineral rhodochrosite (manganese(II) carbonate). Manganese(II) most commonly exists with a high spin, S = 5/2 ground state because of the high pairing energy for manganese(II). However, there are a few examples of low-spin, S = 1/2 manganese(II).^{[9][9]} There are no spin-allowed d–d transitions in manganese(II), explaining why manganese(II) compounds are typically pale to colorless.^[10]

	acidic, basic or amphoteric; depending on the oxidation state
Electronegativity	Pauling scale: 1.55
Ionization energies	1st: 717.3 kJ/mol 2nd: 1509.0 kJ/mol 3rd: 3248 kJ/mol (more)
Atomic radius	empirical: 127 pm
Covalent radius	Low spin: 139±5 pm High spin: 161±8 pm



Aqueous solution of KMnO_4 illustrating the deep purple of Mn(VII) as it occurs in permanganate

The +3 oxidation state is known in compounds like manganese(III) acetate, but these are quite powerful oxidizing agents and also prone to disproportionation in solution, forming manganese(II) and manganese(IV). Solid compounds of manganese(III) are characterized by its strong purple-red color and a preference for distorted octahedral coordination resulting from the Jahn-Teller effect.

The oxidation state +5 can be produced by dissolving manganese dioxide in molten sodium nitrite.^[12] Manganate (VI) salts can be produced by dissolving Mn compounds, such as manganese dioxide, in molten alkali while exposed to air. Permanganate (+7 oxidation state) compounds are purple, and can give glass a violet color. Potassium permanganate, sodium permanganate, and barium permanganate are all potent oxidizers. Potassium permanganate, also called Condy's crystals, is a commonly used laboratory reagent because of its oxidizing properties; it is used as a topical medicine (for example, in the treatment of fish diseases). Solutions of potassium permanganate were among the first stains and fixatives to be used in the preparation of biological cells and tissues for electron microscopy^[13]

Oxidation states of manganese ^[11]	
0	$\text{Mn}_2(\text{CO})_{10}$
+1	$\text{MnC}_5\text{H}_4\text{CH}_3(\text{CO})_3$
+2	MnCl_2 , MnCO_3 , MnO
+3	MnF_3 , $\text{Mn}(\text{OAc})_3$, Mn_2O_3
+4	MnO_2
+5	K_3MnO_4
+6	K_2MnO_4
+7	KMnO_4 , Mn_2O_7
Common oxidation states are in bold.	

History

The origin of the name manganese is complex. In ancient times, two black minerals from Magnesia (located within modern Greece) were both called *magnes* from their place of origin, but were thought to differ in gender. The male *magnes* attracted iron, and was the iron ore now known as lodestone or magnetite, and which probably gave us the term magnet. The female *magnes* ore did not attract iron, but was used to decolorize glass. This feminine *magnes* was later called *magnesia*, known now in modern times as pyrolusite or manganese dioxide. Neither this mineral nor elemental manganese is magnetic. In the 16th century, manganese dioxide was called *manganesum* (note the two Ns instead of one) by glassmakers, possibly as a corruption and concatenation of two words, since alchemists and glassmakers eventually had to differentiate a *magnesia negra* (the black ore) from *magnesia alba* (a white ore, also from Magnesia, also useful in glassmaking). Michele Mercati called *magnesia negra* *manganesa*, and finally the metal isolated from it became known as *manganese* (German: *Mangan*). The name *magnesia* eventually was then used to refer only to the white *magnesia alba* (magnesium oxide), which provided the name magnesium for the free element when it was isolated much later^[14]



Some of the cave paintings in Lascaux, France, use manganese-based pigments.^[15]

Several colorful oxides of manganese, for example manganese dioxide, are abundant in nature have been used as pigments since the Stone Age. The cave paintings in Gargas that are 30,000 to 24,000 years old contain manganese pigments.^[16]

Manganese compounds were used by Egyptian and Roman glassmakers, either to add to, or remove color from glass.^[17] Use as "glassmakers soap" continued through the Middle Ages until modern times and is evident in 14th-century glass from Venice.^[18]

Because it was used in glassmaking, manganese dioxide was available for experiments by alchemists, the first chemists. Ignatius Gottfried Kaim (1770) and Johann Glauber (17th century) discovered that manganese dioxide could be converted to permanganate, a useful laboratory reagent.^[19] By

the mid-18th century, the Swedish chemist Carl Wilhelm Scheele used manganese dioxide to produce chlorine. First, hydrochloric acid, or a mixture of dilute sulfuric acid and sodium chloride was made to react with manganese dioxide, later hydrochloric acid from the Leblanc process was used and the manganese dioxide was recycled by the Weldon process. The production of chlorine and hypochlorite bleaching agents was a large consumer of manganese ores.

Scheele and other chemists were aware that manganese dioxide contained a new element, but they were not able to isolate it. Johan Gottlieb Gahn was the first to isolate an impure sample of manganese metal in 1774, by reducing the dioxide with carbon.

The manganese content of some iron ores used in Greece led to speculations that steel produced from that ore contains additional manganese, making the Spartan steel exceptionally hard.^[20] Around the beginning of the 19th century, manganese was used in steelmaking and several patents were granted. In 1816, it was documented that iron alloyed with manganese was harder but not more brittle. In 1837, British academic James Couper noted an association between miners' heavy exposure to manganese with a form of Parkinson's disease.^[21] In 1912, United States patents were granted for protecting firearms against rust and corrosion with manganese phosphate electrochemical conversion coatings, and the process has seen widespread use ever since.^[22]

The invention of the Leclanché cell in 1866 and the subsequent improvement of the batteries containing manganese dioxide as cathodic depolarizer increased the demand of manganese dioxide. Until the development batteries with nickel-cadmium and lithium, most batteries contained manganese. The zinc-carbon battery and the alkaline battery normally use industrially produced manganese dioxide because natural occurring manganese dioxide contains impurities. In the



Credit for first isolating manganese is usually given to Johan Gottlieb Gahn.

20th century, manganese dioxide was widely used as the cathodic for commercial disposable dry batteries of both the standard (zinc-carbon) and alkaline types.^[23]

Occurrence and production

Manganese comprises about 1000 ppm (0.1%) of the Earth's crust, the 12th most abundant of the crust's elements.^[24] Soil contains 7–9000 ppm of manganese with an average of 440 ppm.^[24] Seawater has only 10 ppm manganese and the atmosphere contains 0.01 µg/m³.^[24] Manganese occurs principally as pyrolusite (MnO₂), braunite, (Mn²⁺Mn³⁺₆)(SiO₁₂),^[25] psilomelane (Ba,H₂O)₂Mn₅O₁₀, and to a lesser extent asrhodochrosite (MnCO₃).

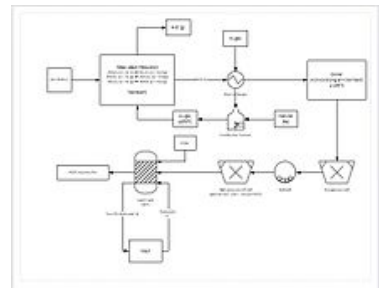
				
Manganese ore	Psilomelane (manganese ore)	Spiegeleisen is an iron alloy with a manganese content of approximately 15%	Manganese oxide dendrites on limestone from Solnhofen, Germany – a kind of pseudofossil Scale is in mm	Mineral rhodochrosite (manganese(II) carbonate)

The most important manganese ore is pyrolusite (MnO₂). Other economically important manganese ores usually show a close spatial relation to the iron ores.^[4] Land-based resources are large but irregularly distributed. About 80% of the known world manganese resources are in South Africa; other important manganese deposits are in Ukraine, Australia, India, China, Gabon and Brazil.^[26] According to 1978 estimate, the ocean floor has 500 billion tons of manganese nodules.^[27] Attempts to find economically viable methods of harvesting manganese nodules were abandoned in the 1970s.^[28]

In South Africa, most identified deposits are located near Hotazel in the Northern Cape Province with a 2011 estimate of 15 billion tons. In 2011 South Africa produced 3.4 million tons, topping all other nations.^[29]

Manganese is mined in South Africa, Australia, China, Brazil, Gabon, Ukraine, India, Fiji, Ghana, Japan^[30] and Kazakhstan. US Import Sources (1998–2001): Manganese ore: Gabon, 70%; South Africa, 10%; Australia, 9%; Mexico, 5%; and other, 6%. Ferromanganese: South Africa, 47%; France, 22%; Mexico, 8%; Australia, 8%; and other, 15%. Manganese contained in all manganese imports: South Africa, 31%; Gabon, 21%; Australia, 13%; Mexico, 8%; and other, 27%.^{[26][31]}

For the production of ferromanganese, the manganese ore is mixed with iron ore and carbon, and then reduced either in a blast furnace or in an electric arc furnace.^[32] The resulting ferromanganese has a manganese content of 30 to 80%.^[4] Pure manganese used for the production of iron-free alloys is produced by leaching manganese ore with sulfuric acid and a subsequent electrowinning process.^[33]



Process flow diagram for a manganese refining circuit.

A more progressive extraction process involves directly reducing manganese ore in a heap leach. This is done by percolating natural gas through the bottom of the heap; the natural gas provides the heat (needs to be at least 850 °C) and the reducing agent (carbon monoxide). This reduces all of the manganese ore to manganese oxide (MnO), which is a leachable form. The ore then travels through a grinding circuit to reduce the particle size of the ore to between 150–250 µm, increasing the surface area to aid leaching. The ore is then added to a leach tank of sulfuric acid and ferrous iron (Fe²⁺) in a 1.6:1 ratio. The iron reacts with the manganese dioxide to form iron hydroxide and elemental manganese. This process yields approximately 92% recovery of the manganese. For further purification, the manganese can then be sent to an electrowinning facility.^[34]

In 1972 the CIA's Project Azorian, through billionaire Howard Hughes, commissioned the ship Hughes Glomar Explorer with the cover story of harvesting manganese nodules from the sea floor. That triggered a rush of activity to collect manganese nodules, which was not actually practical. The real mission of *Hughes Glomar Explorer* was to raise a sunken Soviet submarine, the K-129, with the goal of retrieving Soviet code books.^[35]

Applications

Manganese has no satisfactory substitute in its major applications in metallurgy.^[26] In minor applications, (e.g., manganese phosphating), zinc and sometimes vanadium are viable substitutes.

Steel

Manganese is essential to iron and steel production by virtue of its sulfur-fixing, deoxidizing and alloying properties, as first recognized by the British metallurgist Robert Forester Mushet (1811–1891) who, in 1856, introduced the element, in the form of Spiegeleisen, into steel for the specific purpose of removing excess dissolved oxygen, sulfur, and phosphorus in order to improve its malleability. Steelmaking^[36] including its ironmaking component, has accounted for most manganese demand, presently in the range of 85% to 90% of the total demand.^[33] Manganese is a key component of low-cost stainless steel.^{[31][37]} Often ferromanganese (usually about 80% manganese) is the intermediate in modern processes.

Small amounts of manganese improve the workability of steel at high temperatures by forming a high-melting sulfide and preventing the formation of a liquid iron sulfide at the grain boundaries. If the manganese content reaches 4%, the embrittlement of the steel becomes a dominant feature. The embrittlement decreases at higher manganese concentrations and reaches an acceptable level at 8%. Steel containing 8 to 15% of manganese has a high tensile strength of up to 863 MPa.^{[38][39]} Steel with 12% manganese was discovered in 1882 by Robert Hadfield and is still known as Hadfield steel. It was used for British military steel helmets and later by the U.S. military^[40]



U.S. M1917 combat helmet, a variant of Brodie helmet, made from Hadfield steel manganese alloy

Aluminium alloys

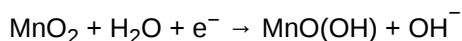
The second largest application for manganese is in aluminum alloys. Aluminium with roughly 1.5% manganese has increased resistance to corrosion through grains that absorb impurities which would lead to galvanic corrosion^[41] The corrosion-resistant aluminium alloys 3004 and 3104 (0.8 to 1.5% manganese) are used for most beverage cans^[42] Before year 2000, more than 1.6 million tonnes of those alloys were used; at 1% manganese, this consumed 16,000 tonnes of manganese.^[42]

Other uses

Methylcyclopentadienylmanganese tricarbonyl is used as an additive in unleaded gasoline to boost octane rating and reduce engine knocking. The manganese in this unusual organometallic compound is in the +1 oxidation state.^[43]

Manganese(IV) oxide (manganese dioxide, MnO₂) is used as a reagent in organic chemistry for the oxidation of benzylic alcohols (where the hydroxyl group is adjacent to an aromatic ring). Manganese dioxide has been used since antiquity to oxidize and neutralize the greenish tinge in glass from trace amounts of iron contamination.^[18] MnO₂ is also used in the manufacture of oxygen and chlorine and in drying black paints. In some preparations, it is a brown pigment for paint and is a constituent of natural lumber.

Manganese(IV) oxide was used in the original type of dry cell battery as an electron acceptor from zinc, and is the blackish material in carbon–zinc type flashlight cells. The manganese dioxide is reduced to the manganese oxide-hydroxide MnO(OH) during discharging, preventing the formation of hydrogen at the anode of the battery^[44]



The same material also functions in newer alkaline batteries (usually battery cells), which use the same basic reaction, but a different electrolyte mixture. In 2002, more than 230,000 tons of manganese dioxide was used for this purpose.^{[23][44]}

The metal is occasionally used in coins; until 2000, the only United States coin to use manganese was the "wartime" nickel from 1942 to 1945.^[45] An alloy of 75% copper and 25% nickel was traditionally used for the production of nickel coins. However, because of shortage of nickel metal during the war it was substituted by more available silver and manganese, thus resulting in an alloy of 56% copper, 35% silver and 9% manganese. Since 2000, dollar coins, for example the Sacagawea dollar and the Presidential \$1 coins are made from a brass containing 7% of manganese with a pure copper core.^[46] In both cases of nickel and dollar, the use of manganese in the coin was to duplicate the electromagnetic properties of a previous identically sized and valued coin in the mechanisms of vending machines. In the case of the later U.S. dollar coins, the manganese alloy was intended to duplicate the properties of the copper/nickel alloy used in the previous Susan B. Anthony dollar.



World-War-II-era 5-cent coin (1942-5 identified by mint mark P, D or S above dome) made from a 56% copper-35% silver-9% manganese alloy

Manganese compounds have been used as pigments and for the coloring of ceramics and glass. The brown color of ceramic is sometimes the result of manganese compounds.^[47] In the glass industry, manganese compounds are used for two effects. Manganese(III) reacts with iron(II) to induce a strong green color in glass by forming less-colored iron(III) and slightly pink manganese(II), compensating for the residual color of the iron(III).^[18] Larger quantities of manganese are used to produce pink colored glass.

Tetravalent manganese is used as an activator in red-emitting phosphors. While many compounds are known which show luminescence^[48] the majority is not used in commercial application due to low efficiency or deep red emission.^{[49][50]} However, several Mn⁴⁺ activated fluorides were reported as potential red emitting phosphors for warm-white LEDs.^{[51][52]} But to this day, only K₂SiF₆:Mn⁴⁺ is commercially available for use in

Biological role

Manganese is an important element for human health, essential for development, metabolism, and the antioxidant system. Nevertheless, excessive exposure or intake may lead to a condition known amanganism, a neurodegenerative disorder that causes dopaminergic neuronal death and symptoms similar to Parkinson's disease.^{[24][54]} The classes of enzymes that have manganese cofactors is large and includes oxidoreductases, transferases, hydrolases, lyases, isomerases, ligases, lectins, and integrins. The reverse transcriptases of many retroviruses (though not lentiviruses such as HIV) contain manganese. The best-known manganese-containing polypeptides may be arginase, the diphtheria toxin, and Mn-containing superoxide dismutase (Mn-SOD).^[55]

Mn-SOD is the type of SOD present in eukaryotic mitochondria, and also in most bacteria (this fact is in keeping with the bacterial-origin theory of mitochondria). The Mn-SOD enzyme is probably one of the most ancient, for nearly all organisms living in the presence of oxygen use it to deal with the toxic effects of superoxide (O_2^-), formed from the 1-electron reduction of dioxygen. The exceptions, which are all bacteria, include Lactobacillus plantarum and related lactobacilli, which use a different nonenzymatic mechanism with manganese (Mn^{2+}) ions complexed with polyphosphate, suggesting a path of evolution for this function in aerobic life.

The human body contains about 12 mg of manganese, mostly in the bones. The soft tissue remainder is concentrated in the liver and kidneys.^[24] In the human brain, the manganese is bound to manganese metalloproteins, most notably glutamine synthetase in astrocytes.^[56]

Manganese is also important in photosynthetic oxygen evolution in chloroplasts in plants. The oxygen-evolving complex (OEC) is a part of photosystem II contained in the thylakoid membranes of chloroplasts; it is responsible for the terminal photooxidation of water during the light reactions of photosynthesis, and has a metalloenzyme core containing four atoms of manganese.^{[57][58]} To fulfill this requirement, most broad-spectrum plant fertilizers contain manganese.

Dietary recommendations

The U.S. Institute of Medicine (IOM) updated Estimated Average Requirements (EARs) and Recommended Dietary Allowances (RDAs) for minerals in 2001. For manganese there was not sufficient information to set EARs and RDAs, so needs are described as estimates for Adequate Intakes (AIs). As for safety, the IOM sets Tolerable upper intake levels (ULs) for vitamins and minerals when evidence is sufficient. In the case of manganese the adult UL is set at 11 mg/day. Collectively the EARs, RDAs, AIs and ULs are referred to as Dietary Reference Intakes (DRIs).^[59] Manganese deficiency is rare.^[60]

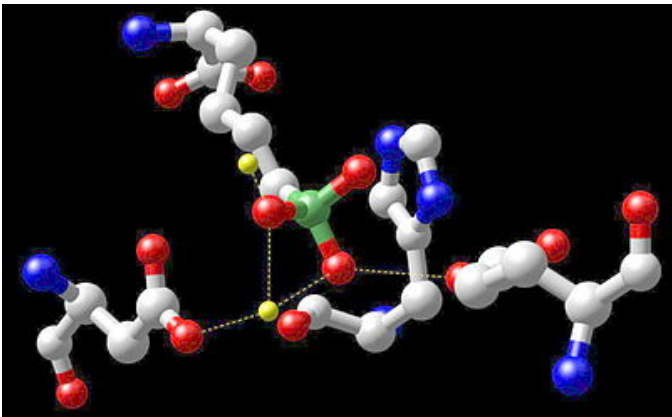
The European Food Safety Authority (EFSA) refers to the collective set of information as Dietary Reference Values, with Population Reference Intake (PRI) instead of RDA, and Average Requirement instead of EAR. AI and UL defined the same as in United States. For people ages 15 and older the AI is set at 3.0 mg/day. AIs for pregnancy and lactation is 3.0 mg/day. For children ages 1–14 years the AIs increase with age from 0.5 to 2.0 mg/day. The adult AIs are higher than the U.S. RDAs.^[61] The EFSA reviewed the same safety question and decided that there was insufficient information to set a UL.^[62]

For U.S. food and dietary supplement labeling purposes the amount in a serving is expressed as a percent of Daily Value (%DV). For manganese labeling purposes 100% of the Daily Value was 2.0 mg, but as of May 27, 2016 it was revised to 2.3 mg to bring it into agreement with the RDA.^[63] A table of the old and new adult Daily Values is provided at Reference Daily Intake. Food and supplement companies have until January 1, 2020 to comply with the change.^[64]

Precautions

Manganese compounds are less toxic than those of other widespread metals, such as nickel and copper.^[65] However, exposure to manganese dusts and fumes should not exceed the ceiling value of 5 mg/m³ even for short periods because of its toxicity level.^[66] Manganese poisoning has been linked to impaired motor skills and cognitive disorders.^[67]

The permanganate exhibits a higher toxicity than the manganese(II) compounds. The fatal dose is about 10 g, and several fatal intoxications have occurred. The strong oxidative effect leads to necrosis of the mucous membrane. For example, the esophagus is affected if the permanganate is swallowed. Only a limited amount is absorbed by the intestines, but this small amount shows severe effects on the kidneys and on the liver.^{[68][69]}



Reactive center of arginase with boronic acid inhibitor – the manganese atoms are shown in yellow

Current AIs of Mn by age group and sex^[59]

Males		Females	
Age	AI (mg/day)	Age	AI (mg/day)
1–3	1.2	1–3	1.2
4–8	1.5	4–8	1.5
9–13	1.9	9–13	1.6
14–18	2.2	14–18	1.6
19+	2.3	19+	1.8
		pregnant:	2
		lactating:	2.6

Manganese exposure in United States is regulated by the Occupational Safety and Health Administration (OSHA).^[70] People can be exposed to manganese in the workplace by breathing it in or swallowing it. OSHA has set the legal limit (permissible exposure limit) for manganese exposure in the workplace as 5 mg/m³ over an 8-hour workday. The National Institute for Occupational Safety and Health (NIOSH) has set a recommended exposure limit (REL) of 1 mg/m³ over an 8-hour workday and a short term limit of 3 mg/m³. At levels of 500 mg/m³, manganese is immediately dangerous to life and health.^[71]

Generally, exposure to ambient Mn air concentrations in excess of 5 µg Mn/m³ can lead to Mn-induced symptoms. Increased ferroportin protein expression in human embryonic kidney (HEK293) cells is associated with decreased intracellular Mn concentration and attenuated cytotoxicity, characterized by the reversal of Mn-reduced glutamate uptake and diminished lactate dehydrogenase leakage.^[72]

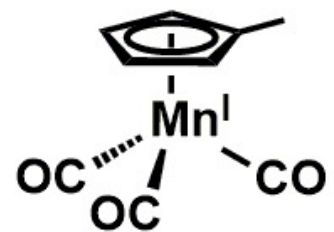
Environmental health concerns

Manganese in drinking water

Waterborne manganese has a greater bioavailability than dietary manganese. According to results from a 2010 study,^[73] higher levels of exposure to manganese in drinking water are associated with increased intellectual impairment and reduced intelligence quotients in school-age children. It is hypothesized that long-term exposure to the naturally occurring manganese in shower water puts up to 8.7 million Americans at risk.^{[74][75]} However, data indicates that the human body can recover from certain adverse effects of overexposure to manganese if the exposure is stopped and the body can clear the excess.^[76]

Manganese in gasoline

Methylcyclopentadienylmanganese tricarbonyl (MMT) is a gasoline additive used to replace lead compounds for unleaded gasolines to improve the octane rating of low octane petroleum distillates. It reduces engine knock agent through the action of the carbonyl groups. Fuels containing manganese tend to form manganese carbides, which damage exhaust valves. The need for lead or manganese additives is merely historic because the modern reformation processes create fuels with increased octane ratings. Such fuels, directly or in mixture with non-reformed distillates, are universal in developed countries (OEU, Japan, etc.). In the USA, the imperative to provide the lowest price per volume on motor fuels and the lowest taxation rate, combined with lax legislation of fuel content before the year 2000, encouraged refineries to use MMT. Compared to 1953, levels of manganese in air have dropped.^[77] Many racing competitions specifically ban manganese compounds in racing fuel for carts and minibikes. MMT contains 24.4–25.2% manganese. Elevated atmospheric manganese concentrations are strongly correlated with automobile traffic density.



Molecular model of methylcyclopentadienylmanganese tricarbonyl (MMT)

Manganese in tobacco smoke

The tobacco plant readily absorbs and accumulates heavy metals such as manganese from the surrounding soil into its leaves. These are subsequently inhaled during tobacco smoking.^[78] While manganese is a constituent of tobacco smoke,^[79] studies have largely concluded that concentrations are not hazardous for human health.^[80]

Role in neurological disorders

Manganism

Manganese overexposure is most frequently associated with manganism, a rare neurological disorder associated with excessive manganese ingestion or inhalation. Historically, persons employed in the production or processing of manganese alloys^{[81][82]} have been at risk for developing manganism; however, current health and safety regulations protect workers in developed nations.^[70] The disorder was first described in 1837 by British academic John Couper, who studied two patients who were manganese grinders.^[21]

Manganism is a biphasic disorder. In its early stages, an intoxicated person may experience depression, mood swings, compulsive behaviors, and psychosis. Early neurological symptoms give way to late-stage manganism, which resembles Parkinson's disease. Symptoms include weakness, monotone and slowed speech, an expressionless face, tremor, forward-leaning gait, inability to walk backwards without falling, rigidity, and general problems with dexterity, gait and balance.^{[21][83]} Unlike Parkinson's disease, manganism is not associated with loss of the sense of smell and patients are typically unresponsive to treatment with L-DOPA.^[84] Symptoms of late-stage manganism become more severe over time even if the source of exposure is removed and brain manganese levels return to normal.^[83]

Animal experiments have given the opportunity to examine the consequences of manganese overexposure under controlled conditions. In (non-aggressive) rats, manganese induces mouse-killing behavior.^[85]

Childhood developmental disorders

Several recent studies attempt to examine the effects of chronic low-dose manganese overexposure on child development. The earliest study was conducted in the Chinese province of Shanxi. Drinking water there had been contaminated through improper sewage irrigation and contained 240–350 µg Mn/L. Although Mn concentrations at or below 300 µg Mn/L were considered safe at the time of the study by the US EPA and 400 µg Mn/L by the World Health Organization, the 92 children sampled (between 11 and 13 years of age) from this province displayed lower performance on tests of manual dexterity and rapidity, short-term memory, and visual identification, compared to children from an uncontaminated area. More recently, a study of 10-year-old children in Bangladesh showed a relationship between Mn concentration in well water and diminished IQ scores. A third study conducted in Quebec examined school children between the ages of 6 and 15 living in homes that received water from a well containing 610 µg Mn/L; controls lived in homes that received water from a 160 µg Mn/L well. Children in the experimental group showed increased hyperactive and oppositional behavior.^[73]

The current maximum safe concentration under **EA** rules is 50 µg Mn/L.^[86]

Neurodegenerative diseases

A protein called DMT1 is the major transporter in manganese absorption from the intestine, and may be the major transporter of manganese across the blood–brain barrier. DMT1 also transports inhaled manganese across the nasal epithelium. The proposed mechanism for manganese toxicity is that dysregulation leads to oxidative stress, mitochondrial dysfunction, glutamate-mediated excitotoxicity and aggregation of proteins.

See also

- List of countries by manganese production
- Parkerizing
- Manganese exporter, membrane transport protein

References

- Meija, J.; et al. (2016). "Atomic weights of the elements 2013 (IUPAC Technical Report)" (<https://www.degruyter.com/downloadpdf/j/pac.2016.88.issue-3/pac-2015-0305/pac-2015-0305.xml>) *Pure and Applied Chemistry* **88** (3): 265–91. doi:10.1515/pac-2015-0305(<https://doi.org/10.1515%2Fpac-2015-0305>)
- Weast, Robert (1984). *CRC, Handbook of Chemistry and Physics* Boca Raton, Florida: Chemical Rubber Company Publishing. pp. E110. ISBN 0-8493-0464-4
- Roth, Jerome; Ponzoni, Silvia; Aschner, Michael (2013). "Chapter 6 Manganese Homeostasis and Transport". In Banci, Lucia. *Metalloomics and the Cell*. Metal Ions in Life Sciences.**12**. Springer. doi:10.1007/978-94-007-5561-1_6(https://doi.org/10.1007%2F978-94-007-5561-1_6) ISBN 978-94-007-5560-4 electronic-book ISBN 978-94-007-5561-1
- Holleman, Arnold F; Wiberg, Egon; Wiberg, Nils (1985). "Mangan". *Lehrbuch der Anorganischen Chemie* (in German) (91–100 ed.). Walter de Gruyter. pp. 1110–1117. ISBN 3-11-007511-3
- Lide, David R. (2004). *Magnetic susceptibility of the elements and inorganic compounds, in Handbook of Chemistry and Physics* (https://web.archive.org/web/20110303222309/http://www-d0.fnal.gov/hardware/cal/lvps_info/engineering/elementmagn.pdf) (PDF). CRC press. ISBN 0-8493-0485-7. Archived from the original (http://www-d0.fnal.gov/hardware/cal/lvps_info/engineering/elementmagn.pdf) (PDF) on 2011-03-03.
- Audi, Georges; Bersillon, O.; Blachot, J.; Wapstra, A. H. (2003). "The NUBASE Evaluation of Nuclear and Decay Properties" (<http://hal.in2p3.fr/in2p3-00014184>) *Nuclear Physics A Atomic Mass Data Center* **729**: 3–128. Bibcode:2003NuPhA.729....3A(<http://adsabs.harvard.edu/abs/2003NuPhA.729....3A>) doi:10.1016/j.nuclphysa.2003.11.001(<https://doi.org/10.1016%2Fj.nuclphysa.2003.11.001>)
- Schaefer, Jeorg; Faestermann, Thomas; Hezog, Gregory F; Knie, Klaus; Korschinek, Gunther; Masarik, Jozef; Meier, Astrid; Poutivsev, Michail; Rugel, Georg; Schlüchter, Christian; Serifiddin, Feride; Winckler, Gisela (2006). "Terrestrial manganese-53 – A new monitor of Earth surface processes". *Earth and Planetary Science Letters* **251** (3–4): 334–345. Bibcode:2006E&PSL.251..334S(<http://adsabs.harvard.edu/abs/2006E&PSL.251..334S>) doi:10.1016/j.epsl.2006.09.016(<https://doi.org/10.1016%2Fj.epsl.2006.09.016>)
- "Ch. 20". *Shriver and Atkins' Inorganic Chemistry* Oxford University Press. 2010. ISBN 978-0-19-923617-6
- Saha, Amrita; Majumdar, Partha; Goswami, Sreebrata (2000). "Low-spin manganese(II) and cobalt(III) complexes of N-aryl-2-pyridylazophenylamines: new tridentate N,N,N-donors derived from cobalt mediated aromatic ring amination of 2-(phenylazo)pyridine. Crystal structure of a manganese(II) complex" *Journal of the Chemical Society Dalton Transactions* (11): 1703–1708. doi:10.1039/a909769d(<http://doi.org/10.1039%2Fa909769d>)
- Rayner-Canham, Geoffrey and Overton, Tina (2003) *Descriptive Inorganic Chemistry* Macmillan, p. 491, ISBN 0-7167-4620-4
- Schmidt, Max (1968). "VII. Nebengruppe" *Anorganische Chemie II* (in German). Wissenschaftsverlag. pp. 100–109.
- Temple, R. B.; Thickett, G. W (1972). "The formation of manganese(v) in molten sodium nitrite" (http://www.publish.csiro.au/?act=view_file&file_id=CH9720655.pdf) (PDF). *Australian Journal of Chemistry* **25** (3): 55. doi:10.1071/CH9720655(<https://doi.org/10.1071%2FCH9720655>)
- Luft, J. H. (1956). "Permanganate – a new fixative for electron microscopy" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2224005>) *Journal of Biophysical and Biochemical Cytology* **2** (6): 799–802. doi:10.1083/jcb.2.6.799(<https://doi.org/10.1083%2Fjcb.2.6.799>) PMC 2224005 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2224005>) PMID 13398447 (<https://www.ncbi.nlm.nih.gov/pubmed/13398447>)
- Calvert, J. B. (24 January 2003). "Chromium and Manganese" (https://web.archive.org/web/20161231161307/http://mysite.du.edu/~jcalvert/p_hys/chromang.htm) Archived from the original on 31 December 2016Retrieved 30 April 2009.
- Chalmin, Emilie; Menu, Michel; Vignaud, Colette (2003). "Analysis of rock art painting and technology of Palaeolithic painters" *Measurement Science and Technology*. **14** (9): 1590–1597. doi:10.1088/0957-0233/14/9/310(<https://doi.org/10.1088%2F0957-0233%2F14%2F9%2F310>)

16. Chalmin, E.; Mgnaud, C.; Salomon, H.; Fargès, F.; Susini, J.; Menu, M. (2006). "Minerals discovered in paleolithic black pigments by transmission electron microscopy and micro-X-ray absorption near-edge structure" *Applied Physics A* **83** (12): 213–218. Bibcode: 2006ApPhA..83..213C(<http://adsabs.harvard.edu/abs/2006ApPhA..83..213C>)doi:10.1007/s00339-006-3510-7(<https://doi.org/10.1007/s00339-006-3510-7>)
17. Sayre, E. V.; Smith, R. W. (1961). "Compositional Categories of Ancient Glass" *Science*. **133** (3467): 1824–1826. Bibcode: 1961Sci...133.1824S(<http://adsabs.harvard.edu/abs/1961Sci...133.1824S>)doi:10.1126/science.133.3467.1824(<https://doi.org/10.1126/science.133.3467.1824>) PMID 17818999 (<https://www.ncbi.nlm.nih.gov/pubmed/17818999>).
18. McCray, W. Patrick (1998). "Glassmaking in renaissance Italy: The innovation of venetiaocrystallo". *Journal of the Minerals, Metals and Materials Society*. **50** (5): 14. Bibcode: 1998JOM....50e..14M(<http://adsabs.harvard.edu/abs/1998JOM....50e..14M>)doi:10.1007/s11837-998-0024-0 (<https://doi.org/10.1007/s11837-998-0024-0>)
19. Rancke-Madsen, E. (1975). "The Discovery of an Element" *Centaurus*. **19** (4): 299–313. Bibcode: 1975Cent...19..299R(<http://adsabs.harvard.edu/abs/1975Cent...19..299R>) doi:10.1111/j.1600-0498.1975.tb00329.x(<https://doi.org/10.1111/j.1600-0498.1975.tb00329.x>)
20. Alessio, L.; Campagna, M.; Lucchini, R. (2007). "From lead to manganese through mercury: mythology, science, and lessons for prevention". *American journal of industrial medicine* **50** (11): 779–787. doi:10.1002/ajim.20524(<https://doi.org/10.1002/ajim.20524>) PMID 17918211 (<https://www.ncbi.nlm.nih.gov/pubmed/17918211>).
21. Couper, John (1837). "On the effects of black oxide of manganese when inhaled into the lungs" *Br. Ann. Med. Pharm. Vital. Stat. Gen. Sci* **1**: 41–42.
22. Olsen, Sverre E.; Tangstad, Merete; Lindstad Tor (2007). "History of manganese" *Production of Manganese Ferroalloys* Tapir Academic Press. pp. 11–12. ISBN 978-82-519-2191-6
23. Preisler, Eberhard (1980). "Moderne Verfahren der Großchemie: Braunstein" *Chemie in unserer Zeit* (in German). **14** (5): 137–148. doi:10.1002/ciuz.19800140502(<https://doi.org/10.1002/ciuz.19800140502>)
24. Emsley, John (2001). "Manganese". *Nature's Building Blocks: An A-Z Guide to the Elements* (<https://books.google.com/?id=j-Xu07p3cKwC>) Oxford, UK: Oxford University Press. pp. 249–253 ISBN 0-19-850340-7.
25. Bhattacharyya, P. K.; Dasgupta, Somnath; Fukuoka, M.; Roy Supriya (1984). "Geochemistry of braunite and associated phases in metamorphosed non-calcareous manganese ores of India" *Contributions to Mineralogy and Petrology* **87** (1): 65–71. Bibcode: 1984CoMP...87...65B (<http://adsabs.harvard.edu/abs/1984CoMP...87...65B>). doi:10.1007/BF00371403(<https://doi.org/10.1007/BF00371403>).
26. Corathers, Lisa A. (2009). "Mineral Commodity Summaries 2009: Manganese" (<http://minerals.usgs.gov/minerals/pubs/commodity/manganese/mcs-2009-manga.pdf>) (PDF). United States Geological Survey Retrieved 2009-04-30.
27. Wang, X; Schröder, HC; Wiens, M; Schlossmacher, U; Müller, WEG (2009). "Manganese/polymetallic nodules: micro-structural characterization of exolithobiontic- and endolithobiontic microbial biofilms by scanning electron microscopy" *Micron*. **40** (3): 350–358. doi:10.1016/j.micron.2008.10.005(<https://doi.org/10.1016/j.micron.2008.10.005>) PMID 19027306 (<https://www.ncbi.nlm.nih.gov/pubmed/19027306>).
28. United Nations Ocean Economics and Technology Office, Technology Branch, United Nations (1978) *Manganese Nodules: Dimensions and Perspectives*. Springer. ISBN 978-90-277-0500-6
29. "Manganese Mining in South Africa – Overview" (<https://web.archive.org/web/20160205194737/http://www.mbendi.com/indy/ming/mang/af/sa/p0005.htm>). MBendi.com. Archived from the original on 5 February 2016 Retrieved 4 January 2014.
30. Inoue, Mitsuo and Kano, Masatoshi (1959). "Manganese Deposit of the Inakuraishi Mine" *Mining Geology*. **9** (38): 360–368. doi:10.11456/shigenchishitsu1951.9.38_36Q(https://doi.org/10.11456/shigenchishitsu1951.9.38_36Q)
31. Corathers, Lisa A. (June 2008). "2006 Minerals Yearbook: Manganese" (<http://minerals.usgs.gov/minerals/pubs/commodity/manganese/myb1-2006-manga.pdf>) (PDF). Washington, D.C.: United States Geological Survey. Retrieved 2009-04-30.
32. Corathers, L. A.; Machamer, J. F. (2006). "Manganese". *Industrial Minerals & Rocks: Commodities, Markets, and Use* (<https://books.google.com/?id=zNidkuulE4C&pg=PA631>) (7th ed.). SME. pp. 631–636. ISBN 978-0-87335-233-8
33. Zhang, Wensheng; Cheng, Chu Yong (2007). "Manganese metallurgy review Part I: Leaching of ores/secondary materials and recovery of electrolytic/chemical manganese dioxide" *Hydrometallurgy*. **89** (3–4): 137–159. doi:10.1016/j.hydromet.2007.08.010(<https://doi.org/10.1016/j.hydromet.2007.08.010>)
34. Chow, Norman; Nacu, Anca; Warkentin, Doug; Aksenov Igor & Teh, Hoe (2010). "The Recovery of Manganese from low grade resources: bench scale metallurgical test program completed" (<https://web.archive.org/web/20120202065633/http://www.americanmanganeseinc.com/wp-content/uploads/2011/08/American-Manganese-Phase-II-August-19-2010-Final-Report-Internet-Version-V2.pdf>) (PDF). Kemetco Research Inc. Archived from the original (<http://www.americanmanganeseinc.com/wp-content/uploads/2011/08/American-Manganese-Phase-II-August-19-2010-Final-Report-Internet-Version-V2.pdf>) (PDF) on 2 February 2012.
35. "Project Azorian: The CIA's Declassified History of the Glomar Explorer" (<http://www2.gwu.edu/~nsarchiv/nukevault/ebb305/index.htm>) National Security Archive at George Washington University. 2010-02-12 Retrieved 2013-09-18.
36. Verhoeven, John D. (2007). *Steel metallurgy for the non-metallurgist* Materials Park, Ohio: ASM International. pp. 56–57 ISBN 978-0-87170-858-8
37. Dastur, Y. N.; Leslie, W. C. (1981). "Mechanism of work hardening in Hadfield manganese steel". *Metallurgical Transactions A*. **12** (5): 749. Bibcode: 1981MTA....12..749D (<http://adsabs.harvard.edu/abs/1981MTA....12..749D>). doi:10.1007/BF02648339(<https://doi.org/10.1007/BF02648339>).
38. Stansbie, John Henry (2007). *Iron and Steel* (<https://books.google.com/?id=FyogLqUxW1cC&pg=PA351>). Read Books. pp. 351–352. ISBN 978-1-4086-2616-0
39. Brady, George S.; Clauser, Henry R.; Vaccari, John A. (2002). *Materials Handbook: an encyclopedia for managers, technical professionals, purchasing and production managers, technicians, and supervisors* (<https://books.google.com/?id=vlhvSQLhhMEC&pg=PA585>). New York, NY: McGraw-Hill. pp. 585–587. ISBN 978-0-07-136076-0

40. Tweedale, Geoffrey (1985). "Sir Robert Abbott Hadfield F.R.S. (1858–1940), and the Discovery of Manganese Steel Geoffrey Tweedale". *Notes and Records of the Royal Society of London* **40** (1): 63–74. doi:10.1098/rsnr.1985.0004 (https://doi.org/10.1098/rsnr.1985.0004) JSTOR 531536 (https://www.jstor.org/stable/531536)
41. "Chemical properties of 2024 aluminum alloy" (http://www.suppliersonline.com/propertypages/2024.asp). Metal Suppliers Online, LLC Retrieved 2009-04-30.
42. Kaufman, John Gilbert (2000). "Applications for Aluminium Alloys and Alloys". *Introduction to aluminum alloys and tempers* (https://books.google.com/?id=idmZIDcwCykC&pg=PA93). ASM International. pp. 93–94. ISBN 978-0-87170-689-8
43. Leigh A. Graham; Alison R. Fout; Karl R. Kuehne; Jennifer L. White; Bhaskar Mookherji; Fred M. Marks; Glenn R. Yap; Lev N. Zakharov; Arnold L. Rheingold & Daniel Rabinovich (2005). "Manganese(I) poly(mercaptoimidazolyl)borate complexes: spectroscopic and structural characterization of MnH–B interactions in solution and in the solid state" *Dalton Transactions* (1): 171–180. doi:10.1039/b412280a (https://doi.org/10.1039/b412280a) PMID 15605161 (https://www.ncbi.nlm.nih.gov/pubmed/15605161)
44. Dell, R. M. (2000). "Batteries fifty years of materials development" *Solid State Ionics* **134**: 139–158. doi:10.1016/S0167-2738(00)00722-0 (https://doi.org/10.1016/S0167-2738(00)00722-0)
45. Kuwahara, Raymond T; Skinner III, Robert B; Skinner Jr., Robert B. (2001). "Nickel coinage in the United States" (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1071501) *Western Journal of Medicine* **175** (2): 112–114. doi:10.1136/ewjm.175.2.112 (https://doi.org/10.1136/ewjm.175.2.112) PMC 1071501 (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1071501) PMID 11483555 (https://www.ncbi.nlm.nih.gov/pubmed/11483555)
46. "Design of the Sacagawea dollar" (http://www.usmint.gov/mint_programs/gold_dollar_coin/index.cfm?action=sacDesign) United States Mint. Retrieved 2009-05-04.
47. Shepard, Anna Osler (1956). "Manganese and Iron—Manganese Paints" *Ceramics for the Archaeologist* Carnegie Institution of Washington. pp. 40–42. ISBN 978-0-87279-620-1
48. Chen, Daquin; Zhou, Yang; Zhong, Jiasong (2016). "A review on Mn⁴⁺ activators in solids for warm white light-emitting diodes" *RSC Advances* **6** (89): 86285–86296. doi:10.1039/C6RA19584A (https://doi.org/10.1039/C6RA19584A)
49. Baur, Florian; Jüstel, Thomas (2016). "Dependence of the optical properties of Mn⁴⁺ activated A₂Ge₄O₉ (A=K,Rb) on temperature and chemical environment". *Journal of Luminescence* **177**: 354–360. Bibcode:2016JLum..177..354B (http://adsabs.harvard.edu/abs/2016JLum..177..354B). doi:10.1016/j.jlumin.2016.04.046 (https://doi.org/10.1016/j.jlumin.2016.04.046)
50. Jansen, T.; Gorobez, J.; Kirm, M.; Brik, M. G.; Vielhauer, S.; Oja, M.; Khaidukov N. M.; Makhov V. N.; Jüstel, T. (2018-01-01). "Narrow Band Deep Red Photoluminescence of Y₂Mg₃Ge₃O₁₂:Mn⁴⁺, Li⁺ Inverse Garnet for High Power Phosphor Converted LEDs" *ECS Journal of Solid State Science and Technology* **7** (1): R3086–R3092. doi:10.1149/2.0121801jss (https://doi.org/10.1149/2.0121801jss)
51. Jansen, Thomas; Baur, Florian; Jüstel, Thomas (2017). "Red emitting K₂NbF₇:Mn⁴⁺ and K₂TaF₇:Mn⁴⁺ for warm-white LED applications". *Journal of Luminescence* **192**: 644–652. Bibcode:2017JLum..192..644J (http://adsabs.harvard.edu/abs/2017JLum..192..644J) doi:10.1016/j.jlumin.2017.07.061 (https://doi.org/10.1016/j.jlumin.2017.07.061)
52. Zhou, Zhi; Zhou, Nan; Xia, Mao; Yokoyama, Meiso; Hintzen, H. T (Bert) (2016-10-06). "Research progress and application prospects of transition metal Mn⁴⁺-activated luminescent materials" *J. Mater. Chem. C* **4** (39): 9143–9161. doi:10.1039/c6tc02496c (https://doi.org/10.1039/c6tc02496c)
53. "TriGain LED phosphor system using red Mn⁴⁺-doped complex fluorides" (https://energy.gov/sites/prod/files/2015/02/f9/setlur_emitters_2015.pdf) (PDF). GE Global Research Retrieved 2017-04-28.
54. Silva Avila, Daiana; Luiz Puntel, Robson; Aschner, Michael (2013). "Chapter 7. Manganese in Health and Disease". In Astrid Sigel; Helmut Sigel; Roland K. O. Sigel. *Interrelations between Essential Metal Ions and Human Diseases* Metal Ions in Life Sciences. **13**. Springer. pp. 199–227. doi:10.1007/978-94-007-7500-8_7 (https://doi.org/10.1007/978-94-007-7500-8_7)
55. Law, N.; Caudle, M.; Pecoraro, V (1998). "Manganese Redox Enzymes and Model Systems: Properties, Structures, and Reactivity". *Advances in Inorganic Chemistry* **46**: 305. doi:10.1016/S0898-8838(08)60152-X (https://doi.org/10.1016/S0898-8838(08)60152-X). ISBN 9780120236466
56. Takeda, A. (2003). "Manganese action in brain function". *Brain Research Reviews* **41** (1): 79–87. doi:10.1016/S0165-0173(02)00234-5 (https://doi.org/10.1016/S0165-0173(02)00234-5) PMID 12505649 (https://www.ncbi.nlm.nih.gov/pubmed/12505649)
57. Umena, Yasufumi; Kawakami, Keisuke; Shen Jian-Ren; Kamiya, Nobuo (May 2011). "Crystal structure of oxygen-evolving photosystem II at a resolution of 1.9 Å". *Nature* **473** (7345): 55–60. Bibcode:2011Natur.473...55U (http://adsabs.harvard.edu/abs/2011Natur.473...55U). doi:10.1038/nature09913 (https://doi.org/10.1038/nature09913) PMID 21499260 (https://www.ncbi.nlm.nih.gov/pubmed/21499260)
58. Dismukes, G. Charles; Willigen, Rogier T van (2006). "Manganese: The Oxygen-Evolving Complex & Models" *Manganese: The Oxygen-Evolving Complex & Models Encyclopedia of Inorganic Chemistry* doi:10.1002/0470862106.ia128 (https://doi.org/10.1002/0470862106.ia128). ISBN 0470860782
59. "Manganese". *Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Chromium Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Chromium* (https://www.nap.edu/read/10026/chapter/12). National Academy Press. 2001. pp. 394–419. ISBN 0-309-07279-4 PMID 25057538 (https://www.ncbi.nlm.nih.gov/pubmed/25057538)
60. See "Manganese" (http://pi.oregonstate.edu/mic/minerals/manganese) *Micronutrient Information Center* Oregon State University Linus Pauling Institute
61. "Overview on Dietary Reference Values for the EU population as derived by the EFSA Panel on Dietetic Products, Nutrition and Allergies" (https://www.efsa.europa.eu/sites/default/files/assets/DRV_Summary_tables_jan_17.pdf) (PDF). 2017.
62. *Tolerable Upper Intake Levels For Vitamins And Minerals* (http://www.efsa.europa.eu/sites/default/files/efsa_rep/blobserver_assets/ndatolera_bleuil.pdf) (PDF), European Food Safety Authority 2006
63. "Federal Register May 27, 2016 Food Labeling: Revision of the Nutrition and Supplement Facts Labels. FR page 33982" (https://www.gpo.gov/vfdspys/pkg/FR-2016-05-27/pdf/2016-11867.pdf) (PDF).

64. "Changes to the Nutrition Facts Panel – Compliance Date"(<https://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/LabelingNutrition/ucm385663.htm#dates>)
65. Hasan, Heather (2008). *Manganese* (<https://books.google.com/?id=nRmpEaudmTYC&pg=PR31>). The Rosen Publishing Group. p. 31. ISBN 978-1-4042-1408-8
66. "Manganese Chemical Background"(<https://web.archive.org/web/20060828211701/http://www.environmentwriter.org/resources/backissues/chemicals/manganese.htm>) Metcalf Institute for Marine and Environmental Reporting University of Rhode Island. April 2006. Archived from the original (<http://www.environmentwriter.org/resources/backissues/chemicals/manganese.htm>) on 28 August 2006 Retrieved 2008-04-30.
67. "Risk Assessment Information System Toxicity Summary for Manganese"(<http://rais.ornl.gov/tox/profiles/mn.html>) Oak Ridge National Laboratory. Retrieved 2008-04-23.
68. Ong, K. L.; Tan, T. H.; Cheung, W. L. (1997). "Potassium permanganate poisoning – a rare cause of fatal self poisoning"(<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1342846>) *Emergency Medicine Journal* **14** (1): 43–45. doi:10.1136/emj.14.1.43(<https://doi.org/10.1136%2Femj.14.1.43>). PMC 1342846 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1342846>) PMID 9023625 (<https://www.ncbi.nlm.nih.gov/pubmed/9023625>).
69. Young, R.; Critchley J. A.; Young, K. K.; Freebairn, R. C.; Reynolds, A. P.; Lolin, Y. I. (1996). "Fatal acute hepatorenal failure following potassium permanganate ingestion" *Human & Experimental Toxicology*. **15** (3): 259–61. doi:10.1177/096032719601500313(<https://doi.org/10.1177%2F096032719601500313>) PMID 8839216 (<https://www.ncbi.nlm.nih.gov/pubmed/8839216>).
70. "Safety and Health Topics: Manganese Compounds (as Mn)" (https://www.osha.gov/dts/chemicalsampling/data/CH_250190.html) U.S. Occupational Safety and Health Administration
71. "NIOSH Pocket Guide to Chemical Hazards – Manganese compounds and fume (as Mn)"(<https://www.cdc.gov/niosh/npg/npgd0379.html>). Centers for Disease Control Retrieved 2015-11-19.
72. Yin, Z.; Jiang, H.; Lee, E. S.; Ni, M.; Erikson K. M.; Milatovic, D.; Bowman, A. B.; Aschner M. (2010). "Ferroportin is a manganese-responsive protein that decreases manganese cytotoxicity and accumulation"(http://libres.uncg.edu/ir/uncg/f/K_Erickson_Ferroportin_2009.pdf) (PDF). *Journal of Neurochemistry* **112** (5): 1190–8. doi:10.1111/j.1471-4159.2009.06534.x(<https://doi.org/10.1111%2Fj.1471-4159.2009.06534.x>) PMC 2819584 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2819584>) PMID 20002294 (<https://www.ncbi.nlm.nih.gov/pubmed/20002294>).
73. Bouchard, M. F.; Sauvé, S.; Barbeau, B.; Legrand, M.; Boufard, T.; Limoges, E.; Bellinger D. C.; Mergler, D. (2011). "Intellectual impairment in school-age children exposed to manganese from drinking water"(https://www.researchgate.net/publication/23245242_Intellectual_Impairment_in_School-Age_Children_Exposed_to_Manganese_from_Drinking_Water). *Environmental Health Perspectives* **119** (1): 138–143. doi:10.1289/ehp.1002321(<https://doi.org/10.1289%2Fehp.1002321>) PMC 3018493 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3018493>) PMID 20855239 (<https://www.ncbi.nlm.nih.gov/pubmed/20855239>). Retrieved 2010-12-11.
74. Elsner, Robert J. F.; Spangler, John G. (2005). "Neurotoxicity of inhaled manganese: Public health danger in the shower?"(https://www.researchgate.net/publication/7827664_Neurotoxicity_of_inhaled_manganese_Public_health_danger_in_the_shower) *Medical Hypotheses* **65** (3): 607–616. doi:10.1016/j.mehy.2005.01.043(<https://doi.org/10.1016%2Fj.mehy.2005.01.043>). PMID 15913899 (<https://www.ncbi.nlm.nih.gov/pubmed/15913899>).
75. Barceloux, Donald; Barceloux, Donald (1999). "Manganese" *Clinical Toxicology*. **37** (2): 293. doi:10.1081/CLT-100102427(<https://doi.org/10.1081%2FCLT-100102427>).
76. Devenyi, A. G.; Barron, T. F.; Mamourian, A. C. (1994). "Dystonia, hyperintense basal ganglia, and high whole blood manganese levels in Alagille's syndrome". *Gastroenterology*. **106** (4): 1068–71. PMID 8143974 (<https://www.ncbi.nlm.nih.gov/pubmed/8143974>).
77. Agency for Toxic Substances and Disease Registry (2012) 6. Potential for human exposure (<http://www.atsdr.cdc.gov/toxprofiles/tp151-c6.pdf>), in *Toxicological Profile for Manganese* (<http://www.atsdr.cdc.gov/ToxProfiles/tp.asp?id=102&tid=23>). Atlanta, GA: U.S. Department of Health and Human Services.
78. Pourkhabbaz, A.; Pourkhabbaz, H. (2012). "Investigation of Toxic Metals in the Tobacco of Different Iranian Cigarette Brands and Related Health Issues" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3586865>). *Iranian Journal of Basic Medical Sciences* **15** (1): 636–644. PMC 3586865 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3586865>).
79. Talhout, Reinskje; Schulz, Thomas; Florek, Eva; Van Benthem, Jan; Wester, Piet; Opperhuizen, Antoon (2011). "Hazardous Compounds in Tobacco Smoke" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3084482>). *International Journal of Environmental Research and Public Health*. **8** (12): 613–628. doi:10.3390/ijerph8020613(<https://doi.org/10.3390%2Fijerph8020613>) PMC 3084482 (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3084482>) PMID 21556207 (<https://www.ncbi.nlm.nih.gov/pubmed/21556207>).
80. Bernhard, David; Rossmann, Andrea; Wick, Georg (2005). "Metals in cigarette smoke" *UBMB Life (International Union of Biochemistry and Molecular Biology: Life)* **57** (12): 805. doi:10.1080/15216540500459667(<https://doi.org/10.1080%2F15216540500459667>).
81. Baselt, R. (2008) *Disposition of Toxic Drugs and Chemicals in Man*, 8th edition, Biomedical Publications, Foster City CA, pp. 883–886, ISBN 0-9626523-7-7.
82. Normandin, Louise; Hazell, A. S. (2002). "Manganese neurotoxicity: an update of pathophysiologic mechanisms" *Metabolic Brain Disease* **17** (4): 375–87. doi:10.1023/A:1021970120965(<https://doi.org/10.1023%2FA%3A1021970120965>). PMID 12602514 (<https://www.ncbi.nlm.nih.gov/pubmed/12602514>).
83. Cersosimo, M. G.; Koller W.C. (2007). "The diagnosis of manganese-induced parkinsonism". *Neurotoxicology*. **27** (3): 340–346. doi:10.1016/j.neuro.2005.10.006(<https://doi.org/10.1016%2Fj.neuro.2005.10.006>) PMID 16325915 (<https://www.ncbi.nlm.nih.gov/pubmed/16325915>).
84. Lu, C. S.; Huang, C.C.; Chu, N.S.; Calne, D.B. (1994). "Levodopa failure in chronic manganese" *Neurology*. **44** (9): 1600–1602. doi:10.1212/WNL.44.9.1600(<https://doi.org/10.1212%2FWNL.44.9.1600>) PMID 7936281 (<https://www.ncbi.nlm.nih.gov/pubmed/7936281>).
85. Lazrshvili, I.; et al. (2016). "Manganese loading induces mouse-killing behaviour in nonaggressive rats". *J. Biol. Phys. Chem* **16** (3): 137–141. doi:10.4024/31LA14L.jbpc.16.03(<https://doi.org/10.4024%2F31LA14L.jbpc.16.03>)
86. "Drinking Water Contaminants" (<http://water.epa.gov/drink/contaminants/index.cfm>). US EPA. Retrieved 2 February 2015.

External links

- [National Pollutant Inventory – Manganese and compounds Fact Sheet](#)
- [International Manganese Institute](#)
- [NIOSH Manganese Topic Page](#)
- [Manganese at *The Periodic Table of Videos*](#) (University of Nottingham)
- [Development of a Standardised Method for Measuring Manganese Exposur](#)by A Sánchez Jiménez and others.Institute of Occupational Medicine Research Report TM/10/04. (This study compares the concentrations of inhalable and respirable manganese collected with three airborne samples: the CIS (Conical Inhalable Sampler), IOM (the Institute of Occupational Medicine) and the Higgins Dewell cyclone.)

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