Transition Metals

Physical Properties

- Most transition metals are ductile, malleable, and good conductors of heat and electric current.
- For transition metals, density and melting point tend to increase across a series or increase to a peak in Group 6B and then decrease.

Sources

- Transition metals come from mineral deposits in Earth’s crust. Minerals that are used for the commercial production of metals are called ores.
- For centuries, people have developed techniques for separating metals from ores. The ore is concentrated and the metal removed by reduction. Then the metal is refined and purified.
Atomic Properties

- Among the transition metals, as atomic number increases, there is an increase in the number of electrons in the second-to-highest occupied energy level.
- In periods 5 and 6, transition metals in the same group have identical or almost identical atomic radii. Consequently, these pairs of elements have very similar chemical properties. They tend to occur together in nature and are difficult to separate.

Chemical Properties

- There is great variation in reactivity among transition metals. Scandium and yttrium are similar to Group 1A and 2A metals. They are easily oxidized on exposure to air and react with water to release hydrogen. Platinum and gold are extremely unreactive and resist oxidation.
- In general, transition metals have multiple oxidation states. Compounds in which the elements are in their highest oxidation states are powerful oxidizing agents.
- Most transition metals form compounds with distinctive colors. The color of a transition metal compound or solution can indicate the oxidation state of the metal.

In these aqueous solutions, vanadium, chromium, and manganese are in their highest oxidation states.
In an internal combustion engine, some hydrocarbon molecules aren’t completely oxidized. They form carbon monoxide instead of carbon dioxide. Some hydrocarbon molecules even pass into the exhaust without reacting. At the high temperature and pressure inside an engine’s cylinders, some nitrogen from the air reacts with oxygen to produce irritating nitrogen oxides.

A catalytic converter keeps these pollutants from being released into the air. Inside the converter is a porous ceramic cylinder with a honeycomb structure. The ceramic absorbs particles of rhodium and platinum. The metals are catalysts for reactions that occur as exhaust gases pass through channels in the converter. Rhodium helps convert nitrogen oxides to nitrogen. Platinum helps convert hydrocarbons and carbon monoxide to carbon dioxide and water.

Copper was one of the first metals to be widely used. It is found uncombined in nature or easily reduced from its ores. The Roman supply of copper came mainly from Cyprus and was known as aes Cyprium (metal of Cyprus). This name evolved to cyprium and then cuprium, which is why copper has the symbol Cu. Pure copper is valued both for its ability to conduct an electric current and its ability to resist corrosion.

Around 3500 BC, people began to add tin to copper to form bronze. This alloy is harder than pure copper and easier to melt for casting. Metalworkers could produce bronze with different properties by varying the amount of tin. Bronze used to make statues might contain as little as 10% tin by mass. Bronze used to make bells would contain 13–25% tin. Most copper coins are bronze with 4% tin and 1% zinc.

Brass is an alloy of copper and zinc. Brass is harder than pure copper and more malleable than bronze. Brass containing at least 65% copper can be worked when it is cold. Brass with 55–65% copper can be worked when it is hot. Before large amounts of gold and silver reached Europe in the 1500s, brass was the metal used for decorative items.

Copper that is exposed to oxygen and water forms a patina of basic copper salts. This thin film protects the underlying metal from further oxidation. The composition of the patina, its color, and the rate at which it forms vary with the climate. The rate is faster near the ocean.

When a bronze bell is struck, the clear, loud tone lasts for several seconds.
Iron and Steel

Carbon is used to extract iron from its ores. At first, people used charcoal from burnt wood. In 1709, Abraham Darby invented a process that used coke instead of charcoal. Coke is almost pure carbon. It is produced when coal is heated and the impurities removed as gases. With coke, the production of iron became less expensive and more efficient.

Iron ore is reduced to metallic iron in a blast furnace. Ore, coke, and limestone are added at the top of the furnace. Molten iron and slag collect at the bottom. The “pig” iron produced contains 3–5% carbon and smaller amounts of other impurities, which make the iron brittle. Pig iron can’t be rolled or welded, but it can be cast. Cast iron is used to make stoves and engine blocks for cars.

Most pig iron is used to make steel. The methods for making steel differ, but they all lower the carbon content to less than 2% and remove other impurities. About 90% of the steel produced is carbon steel, which contains no other metals. Mild steel, which is malleable and ductile, contains less than 0.2% carbon. Medium steel (0.2% to 0.6% carbon) is used for structural components, such as beams and girders. Because high-carbon steel (0.8% to 1.5% carbon) is harder than other carbon steels, it is used to make items such as drill bits and knives.

Transition metals are used to produce alloy steels with a specific set of properties. The most common stainless steel contains about 18% chromium and 8% nickel.

Did You Know...

Swords made with Damascus steel were highly valued. The source of this quality was the 0.02% vanadium in the iron ore that the steel makers used. When they began to use a different source of iron ore, the quality of their steel declined.

Transition Metals
Phytoremediation

Phytoremediation uses plants such as sunflowers, Indian mustard, and dandelions to remove pollutants from contaminated soil and water. The contaminants include organic solvents, pesticides, and toxic metals such as cadmium and chromium.

Plants have a natural ability to absorb nutrients through their roots. Often a plant does not distinguish a toxic metal such as cadmium from a nutrient such as zinc because these metals have similar chemical properties. So cadmium is absorbed and transported to the leaves and stems, where it accumulates. The plants are composted or burned after harvesting. The metal residues are buried in an approved landfill or recovered through smelting.

Permanent Magnets

Refrigerator magnets contain a barium ferrite, BaO•6Fe₂O₃, or strontium ferrite, SrO•6Fe₂O₃, powder, which is embedded in plastic or rubber. Horseshoe magnets usually contain an alloy of aluminum, nickel, and cobalt.

Iron, nickel, and cobalt are strongly attracted to magnetic fields. When these metals are exposed to a magnetic field, their cations line up in an orderly arrangement. When the field is removed, the ions remain lined up, and the material can act as a magnet. This type of magnetism is called ferromagnetism.

A magnet retains its strength unless it is heated past a point called the Curie temperature. For iron, this temperature is 1043 K. For cobalt, it is 1388 K. For nickel, it is 627 K.

Magnets made from a neodymium, boron, and iron alloy are very powerful. If they are allowed to fly together, they will shatter. They are used to check for counterfeit bills because they can detect tiny magnetic particles placed in the ink of genuine bills.

Gold

Gold occurs chiefly as small flecks of free metal in veins of quartz. About 5 g of gold is produced from a metric ton (10⁶ g) of gold-bearing rock.

Gold can be pounded into sheets so thin that they will transmit light. These sheets, called gold leaf, are used for lettering and decoration in general. Gold is used on the outside surfaces of satellites because it resists corrosion. Its high electrical and thermal conductivity make gold a good choice to plate contacts in microcircuits.

Pure gold is alloyed to make it harder and more durable. Gold alloys are safe to use as fillings for teeth because gold is highly unreactive.

Units called karats (k) are used to describe the purity of gold. Pure gold is 24k or 100% gold. Gold in coins is usually 22k or 92% gold. Gold in rings is often 14k (58%).
Micronutrients

Trace amounts of some transition metals are essential for human health.

**Iron** is found mainly in hemoglobin and myoglobin. Hemoglobin is the protein that transports oxygen in blood. Myoglobin is the protein that stores oxygen in muscle tissue. Vitamin C helps the absorption of iron by promoting the reduction of Fe³⁺ ions to Fe²⁺ ions.

**Zinc** is a cofactor in many enzymes. It helps protect the immune system. Hormones that control growth and reproduction do not function properly without zinc. A lack of zinc impairs the sense of taste and reduces the appetite.

**Copper** is a component of enzymes that control the synthesis of melanin, hemoglobin, and phospholipids in the sheath that protects nerves.

**Molybdenum** affects the absorption of copper. It is also needed for the oxidation of lipids and the metabolism of sulfur and nitrogen.

**Chromium** assists in the metabolism of glucose and may help to control adult-onset diabetes. A lack of chromium may affect growth.

**Manganese** is required for the proper function of the nervous system and the thyroid gland. It is needed for glucose metabolism. It helps maintain healthy bones and cartilage.

**Cobalt** is a component of vitamin B12, which is required for the synthesis of red blood cells.

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**Ti Sunscreens**

You need some exposure to sunlight so your skin cells can make vitamin D, which is needed for healthy bones and teeth. Yet the UV radiation in sunlight can damage skin cells and even lead to skin cancer. The best way to protect your skin is to limit your time in the sun. The next best way is to use a sunscreen. All the active ingredients in sunscreens protect against UVB light (280–320 nm), which is the primary cause of sunburn. Some protect against UVA light (320–400 nm), which penetrates deeper and causes long-term damage. A sun protective factor rating (SPF) measures only how effective a sunscreen is against UVB, not UVA.

Titanium dioxide, TiO₂, can reflect and scatter UV light. This stable and nonirritating oxide has one drawback. It looks like white paint on the skin. One manufacturer has addressed this problem by decreasing the size of the TiO₂ particles to a diameter of about 21 nm. At this size, TiO₂ appears transparent because its particles are smaller than wavelengths of visible light and light isn’t reflected by the particles.

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**Transition Metal Micronutrients**

<table>
<thead>
<tr>
<th>Element</th>
<th>RDA or AI</th>
<th>Dietary Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>10 mg RDA (M)</td>
<td>liver, green vegetables, egg yolk, fish, whole wheat, nuts, oatmeal, molasses, and beans</td>
</tr>
<tr>
<td></td>
<td>20 mg RDA (F)</td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>11 mg RDA (M)</td>
<td>liver, eggs, meat, milk, whole grains, and shellfish</td>
</tr>
<tr>
<td></td>
<td>8 mg RDA (F)</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>900 µg RDA</td>
<td>beans, peas, and shellfish</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>45 µg RDA</td>
<td>beans, peas, and whole grains</td>
</tr>
<tr>
<td>Chromium</td>
<td>35 µg AI (M)</td>
<td>meat and whole grains</td>
</tr>
<tr>
<td></td>
<td>25 µg AI (F)</td>
<td></td>
</tr>
<tr>
<td>Manganese</td>
<td>2.3 mg AI (M)</td>
<td>nuts, whole grains, dried fruits, and green leafy vegetables</td>
</tr>
<tr>
<td></td>
<td>1.8 mg AI (F)</td>
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</tbody>
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*Recommended Dietary Allowance or Adequate Intake

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**Did You Know...**

An octopus has blood that is blue, not red, because the compound that transports oxygen in an octopus contains copper, not iron. Snails, oysters, and spiders are also bluebloods.