Cobalt (Co)

Element, chemistry, compounds, and applications

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Element

Introduction

Ancient Egyptian cobalt blue glass beads[4]

ORIGIN OF NAME:

- German term *kobold*, meaning ‘goblin’, or ‘evil spirit’.
- Used by miners that was really difficult to mine and harmful to the miners’ health.[2]

HISTORY OF DISCOVERY:

- Over four thousand years ago, Cobalt has been used for blue dyes in pottery, glass, and glazes.
- First isolated (1735) by Swedish chemist Georg Brandt.
- Brandt finally determined (1742) that the blue colour of those ores was due to the presence of cobalt[3].

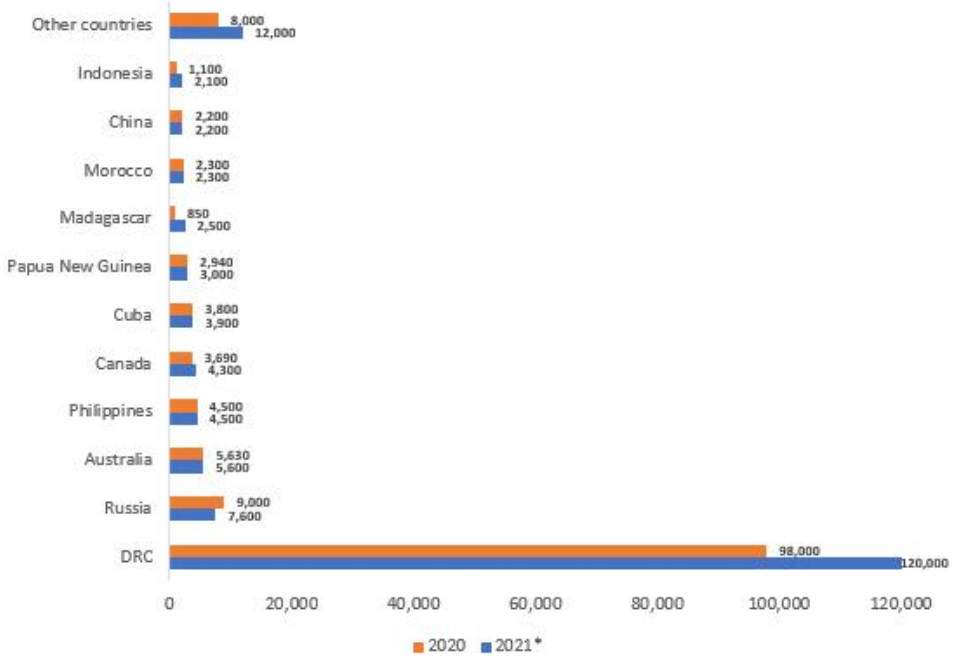
Ancient Roman cobalt blue glass bottle[5]

Early Chinese blue and white porcelain[1]

Occurrence & Production

- The abundance of cobalt in earth's crust is around 25 ppm (only 0.001%) by weight[6].
- The main ores of cobalt are cobaltite (CoAsS), erythrite (hydrated arsenate of cobalt), glaucodot (Co,Fe)AsS, and skutterudite (Co,Ni)As3.
- Generally produced as a by-product of nickel and copper mining[7].
- Congo (Kinshasa) has been a dominant world producer since 1920[8].

Mine cobalt production, tonnes[9].
Source: USGS. Preliminary data for 2021.



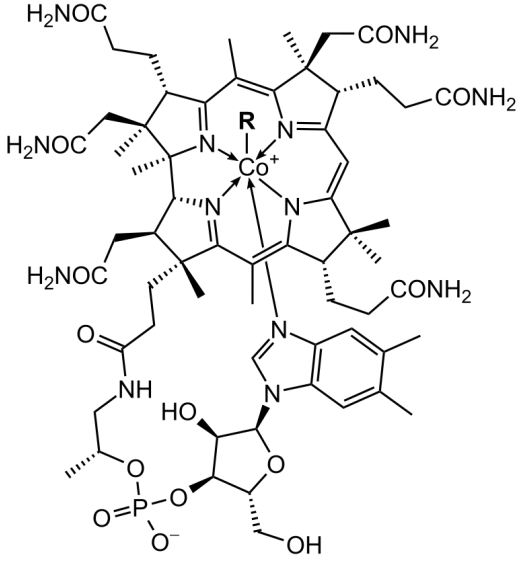
Biological role & Health issues

BIOLOGICAL ROLE:

- Cobalt is a component of cobalamin, also known as vitamin B12, which supports the production of red blood cells[10].
- An essential trace element for humans and animals.
- Cobalt deficiency symptoms resemble anemic disorders[11].

HEALTH ISSUES:

- Cobalt poisoning can occur when you are exposed to large amounts of it.
- Toxic to the heart muscle[12].
- It causes respiratory problems when inhaled and skin problems when touched[1].



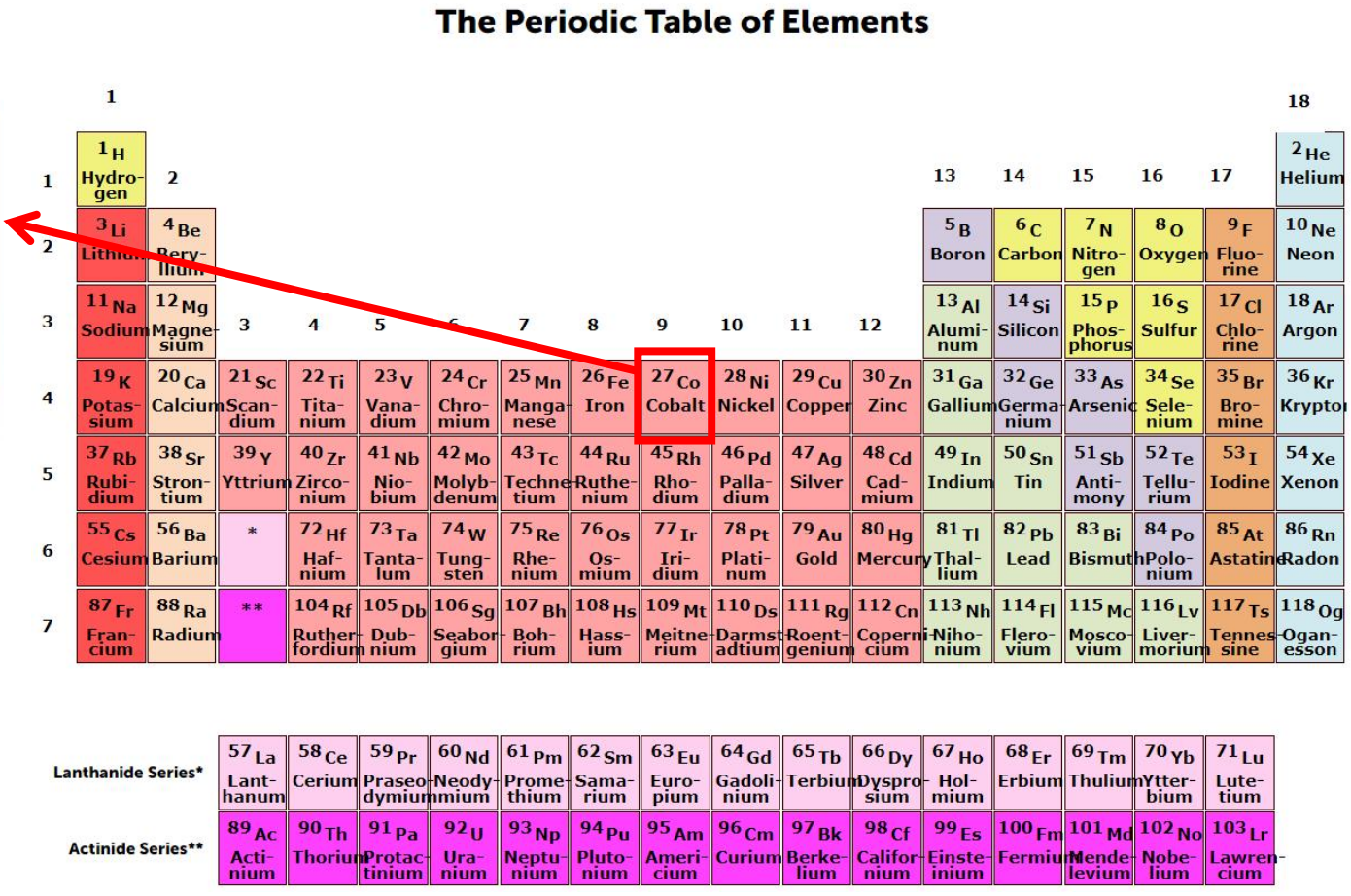
R = 5'-deoxyadenosyl, CH_3, OH, CN

Molecular structure of vitamin B12[11]

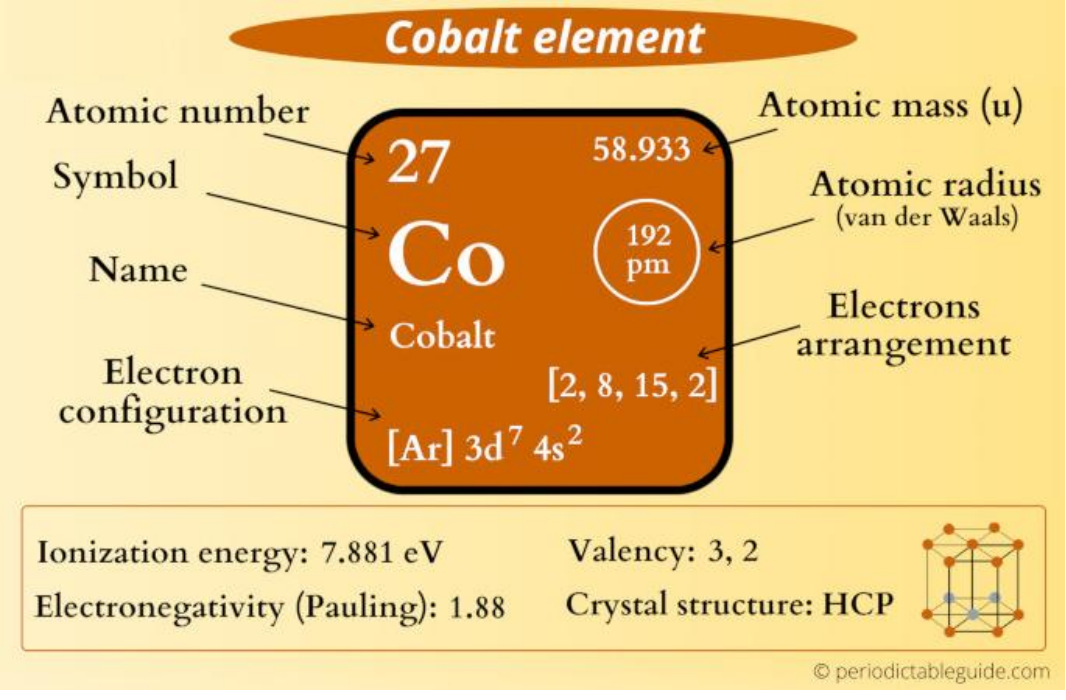
Chemistry

Cobalt in Periodic Table[13]

- Group: 9
- Period: 4
- Block: d



Properties[6, 7]



[15]

- Density(293 K): 8.90g/cm3
- Main isotope: 59Co
- atomic radius: 125 pm
- ionic radius (2+ ion): 83.8 pm
- ionic radius (3+ ion): 71.8 pm[14]

- Bluish-white, lustrous, hard, brittle solid.
- Ferromagnetic: Cobalt stays magnetic to the highest temperature of all the magnetic elements (it has a Curie point of 1121℃).

Reactivity

REACTIONS OF COBALT WITH AIR[16]:

- Cobalt does not react readily with air at room temperature.
- $3\ Co(s) + 4\ O_2(g) \xrightarrow{\Delta} 2\ Co_3O_4(s)$
- $2\ Co(s) + O_2(g) \xrightarrow{900℃} 2\ CoO(s)$
- It does not react with H2 or N2 even when heated[1].

REACTIONS OF COBALT WITH ACIDS:

- $Co(s) + H^+(aq)$ (dilute H_2SO_4、 HCl) $\longrightarrow Co^{2+}(aq) + H_2(g)$
- $3Co(s) + 8HNO_3(aq) \longrightarrow 3Co(NO_3)_2 + 2NO(g) + 4H_2O(l)$[17]
- Concentrated nitric acid reacts quickly with cobalt at room temperature, but passivates the cobalt surface at -10℃[18].
- **Cobalt does not react with water that is at room temperature[19].**

Reactivity

REACTIONS OF COBALT WITH HALOGENS[16, 20]:

- $Co(s) + F_2(g) \xrightarrow{520K} CoF_3(s)$ (brown)
- $Co(s) + Cl_2(g) \xrightarrow{\Delta} CoCl_2(s)$ (blue)
- $Co(s) + Br_2(g) \xrightarrow{\Delta} CoBr_2(s)$ (green)
- $Co(s) + I_2(g) \xrightarrow{\Delta} CoI_2(s)$ (blue-black)

REACTIONS OF COBALT WITH NON-METALS[21]:

- It reacts with boron, carbon, phosphorus, arsenic and sulfur when heated[1].
- $Co(s) + S(s) \longrightarrow CoS(s)$[18]
- $Co(s) + P(s) \longrightarrow Co2P(s)$[22]

Compounds

Cobalt Compounds

In its compounds cobalt nearly always exhibits a +2 or +3 oxidation state, although states of +4, +1, 0, and –1 are known [3].

- The compounds in which cobalt exhibits the +2 oxidation state (Co^{2+}, the ion being stable in water) are called cobaltous [23].
- Compounds in which cobalt exhibits the +3 oxidation state (Co^{3+}) are called cobaltic [23].
- Both Co^{2+} and Co^{3+} form numerous coordination compounds, or complexes [23].

Oxides [24]

- Cobalt oxide: CoO
- Dicobalt trioxide: Co_2O_3
- Tricobalt tetraoxide: Co_3O_4

- Tricobalt tetraoxide Co_3O_4 contains cobalt in both +2 and +3 oxidation states.
- Constitutes up to 40 percent of the commercial cobalt oxide
- Used in the manufacture of **ceramics, glass**, and **enamel** and in the preparation of **catalysts** and **cobalt metal powder**[1]

Complexes [24]

- Tricobalt diphosphate octahydrate: $Co_3(PO4)_2.8H_2O$
- Cobalt nitrate hexahydrate: $Co(NO_3)_2.6H_2O$
- Hexaaquocobalt dichloride: $CoCl_2.6H_2O$
- Tetraquocobalt difluoride: $CoF_2.4H_2O$
- Cobalt dibromide hexahydrate: $CoBr_2.6H_2O$
- Cobalt sulphate heptahydrate: $CoSO_4.7H2O$

- One of the **more important salts** of cobalt is the **sulfate $CoSO_4$**, which is employed in electroplating, in preparing drying agents, and for pasture top-dressing in agriculture[3].
- Cobaltous chloride ($CoCl_2 \cdot 6H_2O$ in commercial form), a pink solid that changes to blue as it dehydrates, is utilized in catalyst preparation and as an indicator of humidity [3].
- Cobaltous phosphate, $Co_3(PO_4)_2 \cdot 8H_2O$, is used in painting porcelain and colouring glass [3].

- **Fluorides**
  - Cobalt difluoride: CoF_2
  - Cobalt trifluoride: CoF_3
  - Cobalt tetrafluoride: CoF_4
- **Chlorides**
  - Cobalt dichloride: $CoCl_2$
  - Cobalt trichloride: CoCl3
  - Cobalt dichloride dihydrate: $CoCl_2.2H_2O$
- **Bromides**
  - Cobalt dibromide: $CoBr_2$
- **Iodides**
  - Cobalt diiodide: $\mathbf{CoI_2}$
- **Carbonyls**
  - Dicobalt octacarbonyl: $Co_2(CO)_8$
  - Tetracobalt dodecacarbonyl: $Co_4(CO)_{12}$
  - Hexacobalt hexadecacarbonyl: $Co_6(CO)_{16}$
- **Sulfides**
  - Cobalt sulphide: CoS
  - Cobalt persulphide: CoS_2
  - Dicobalt trisulphide: $Co2S_3$
- **Selenides**
  - Cobalt selenide: CoSe
- **Tellurides**
  - Cobalt telluride: CoTe

Applications

Cobalt applications

Cobalt has been used in many industrial, commercial, and military applications. Below are some of its common applications

Superalloys[25]

- Cobalt-based superalloys form high-temperature resistant parts for gas turbine aircraft engines, space vehicles, rocket motors, and other aerospace applications.
- Cobalt is used widely as one of the metals needed to create **hard permanent magnets** such as the **aluminium-nickel-cobalt (Al-Ni-Co)** alloy series
- **Alnico magnets** are used in motors, hard disk drives, and sensors. Magnetic resonance imaging is an example of an application for these magnetic alloys.

Electronics[26]

Cobalt oxide, hydroxide, and metals are used in many electrochemical devices that convert chemical energy to electrical energy

Rechargeable batteries

- Portable devices such as mobile phones, laptops, and other consumer electronic devices right up to electric vehicles, all utilise rechargeable batteries.
- Cobalt acts as a raw material in the cathode technology which is essential for recharging batteries
- Lithium cobalt oxide was the first commercially successful cathode for the lithium-ion battery
- Layered $LiCoO_2$ exhibits several features necessary for a good cathode. The Li^+ and Co^{3+} ions order well in alternate layers in $LiCoO_2$ ensuring a **good structural stability**, the **direct Co–Co interaction** in the structure **facilitates high electronic conductivity**, and **the interconnected lithium-ion** sites support **fast lithium-ion conductivity**. These built-in favourable characteristics along with an easy synthesis of $LiCoO_2$ in ambient air made it an appealing cathode[27]

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