



42 95.95

Mo

Molybdenum

[Kr] 4d⁵5s¹

MOLYBDENUM

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CHEM-E4130 - Chemistry of the elements

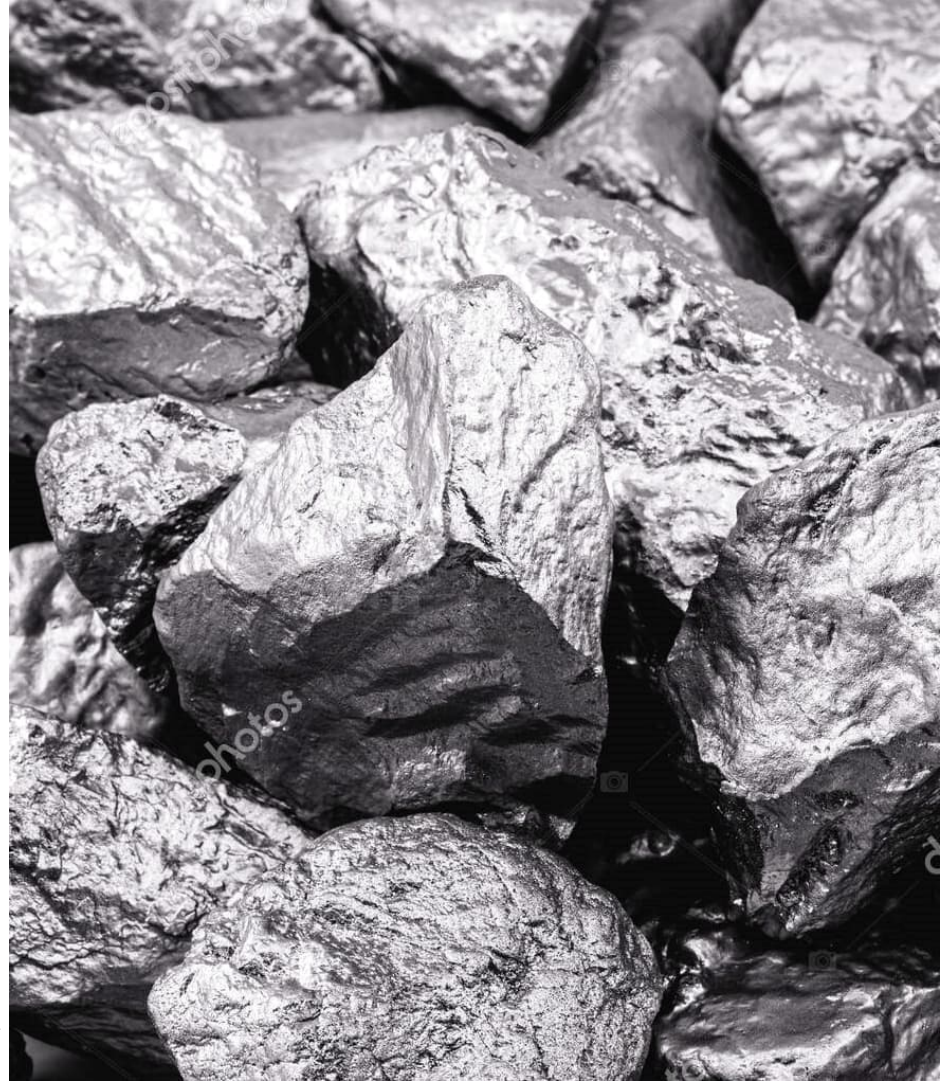
Agenda

- **What is Molybdenum?**
- **Chemistry of the element**
- **Its compounds**
- **Modern applications**

What is Molybdenum?

History

- 1778: C. W. Scheele reported results about the mineral molybdæna (MoS_2).
- 1781: P. J. Hjelm (Stockholm) reduced the MoO_3 to a metal and gave the new element the name molybdenum.
- Μόλυβδος = molybdos, meaning lead.
- Was confused with both graphite and lead.
- Intensively used during WWI – to strengthen steel.



Mo fact sheet

Symbol: **Mo**

Atomic number: **42**

Atomic weight: **95.95 amu**

Ground state electron configuration:

[Kr]4d⁵5s¹

Abundance: **~1.2 ppm**

58th most abundant in the Earth's crust

(W – 56th, Cr – 21st)

Deposits in USA, Chile, China.

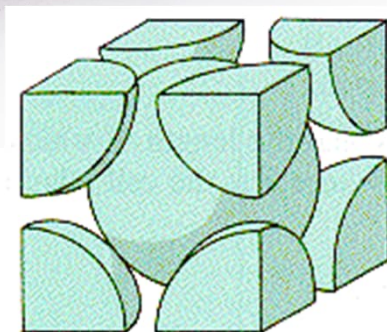
A stylized periodic table element card for Molybdenum (Mo). The card is black with white text and is framed by a white border. At the top left, the atomic weight "95.95" is displayed above the standard atomic weight "684.31". To the right of the atomic weight is the atomic number "42". Below the atomic weight and number, the element symbol "Mo" is written in a large, bold, sans-serif font. Underneath the symbol, the element name "Molybdenum" is written in a smaller, bold, sans-serif font. At the bottom, the ground state electron configuration "[Kr] 5s¹ 4d⁵" and the classification "Transition Metal" are listed. On the right side of the card, a vertical column of oxidation states is shown: +6, +5, +4, +3, +2, +1, -1, -2, and -4.

Chemistry of Mo

PERIODIC TABLE

1 H Hydrogen 1.008																	2 He Helium 4.003															
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180															
11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948															
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.631	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 84.798															
37 Rb Rubidium 84.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.711	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.294															
55 Cs Cesium 132.905	56 Ba Barium 137.328	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018															
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [278]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [280]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [289]	116 Lv Livermorium [293]	117 Ts Tennessee [294]	118 Og Oganesson [294]															
																		57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.243	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.055	71 Lu Lutetium 174.967
																		89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]

Molybdenum



Chemical & Physical Properties

Atomic number	42
Atomic weight	95.95
Group	6
Period	5
Electronic Configuration	[Kr] 4d ⁵ 5s ¹
Block	d
Melting point (°C)	2622°C
Boiling point (°C)	4639°C
Density (g.cm ⁻³)	10.2
Van Der Waals radius (Å)	2.17
Electronegativity	2.16
First ionization energy (kJ.mol ⁻¹)	684.316
Common oxidation states	6 , 5, 4, 3, 2, 0, -1, -2, -4
State at 20°C	Solid
Naturally occurring isotopes	⁹² Mo, ⁹⁴ Mo, ⁹⁵Mo , ⁹⁶Mo , ⁹⁷ Mo, ⁹⁸Mo , ¹⁰⁰ Mo
Crystal Structure	bcc
Lattice Parameter (Å)	3.15

Oxidation states

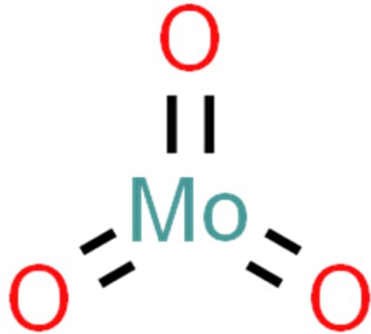
Common oxidation states in compounds: -IV and from -II to +VI

If higher oxidation state: terrestrial and biological compounds

Mid-level oxidation state: metal clusters

Low – organomolybdenum compounds

Chemical Reactions



Chemical Reactions	
Oxygen	Slightly oxidize at 200°C Form MoO_3 at 400°C
Aqueous Vapor	Oxidize over 700°C
Nitrogen	Form Nitride over 1500°C
Hydrogen	No chemical reaction
Carbon dioxide	Oxidize over 1200°C
Dilute Sulfuric Acid(110°C)	2012mm yearly
Concentrated hydrochloric acid(110°C)	0.337mm yearly
10% Sulfuric acid	0.106mm yearly
Concentrated Sulfuric Acid(110°C)	0.287 yearly
Nitric acid + Sulfuric acid	Rapid corrosion
Nitric + Hydrofluoric Acid	Rapid corrosion
Nitric acid + Hydrochloric acid	Rapid corrosion
Hydrofluoric acid (room temperature)	Corrosion
Sulphur (800°C)	Corrosion
Tungsten	Chemical reaction at 2000°C
Thorium	Chemical reaction at 1900°C
Alumina	No chemical reaction at 1900°C

Molybdenum compounds

Compounds: MoS₂ and MoO₃

Molybdenum disulfide:

- Occurs as mineral molybdenite
- unaffected by dilute acids and oxygen
- similar to graphite – dry lubricant
- diamagnetic, indirect bandgap semiconductor similar to silicon,
- Single layer sheets act as a perfect mirror

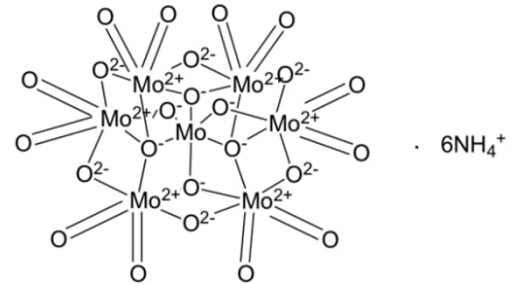
Molybdenum (VI) oxide:

- anhydrous oxide – precursor to metal, alloying agent, industrial catalyst
- It is acidic and dissolve in aqueous alkali to give salts of the Mo₄²⁻ ions
- Reduction of a solution of a molybdate(VI) in water or acid leads to the production of intense molybdenum blues. Oxide/hydroxide species of mixed valence. A sensitive test for the presence of reducing agents.

Compounds: Molybdenum salts



- MoO_3 and a base produce molybdate salts.
- Quite soluble in water.
- These salts serve as the starting materials for the synthesis of:
- fertilizers, corrosion inhibitors, and as an analytical reagent to measure the amounts of phosphates, silicates, arsenates and lead in aqueous solutions.



Compounds: Organomolybdenum

- Mo is bound directly to the carbon atom of carbon monoxide, to organic phosphines, and/or to a variety of unsaturated carbonaceous ligands.
- Molybdenum hexacarbonyl $\text{Mo}(\text{CO})_6$ is the starting material for the synthesis of most organometallic compounds of molybdenum.
- Display organic reactivity
- Have been used as precursors for a variety of homogeneous and heterogeneous catalysts.

Molybdenum in biological molecules

FeMoco – FeMo cofactor and other Molybdenum-bearing enzymes :

- Important enzyme in nitrogen fixation of nitrogen cycle.
- Other Mo-containing biomolecules are essential participants of the reactions in higher eukaryotes (humans too).
- Molybdenum to process proteins and genetic material like DNA or break down drugs and toxic substances.
- (Legumes are a source of Mo)

Modern applications

Alloys

- 86% of Mo produced is used in metallurgy
- Increase hardness, strength, resistance to corrosion
- Moly Steel, Chromoly, Mo-W



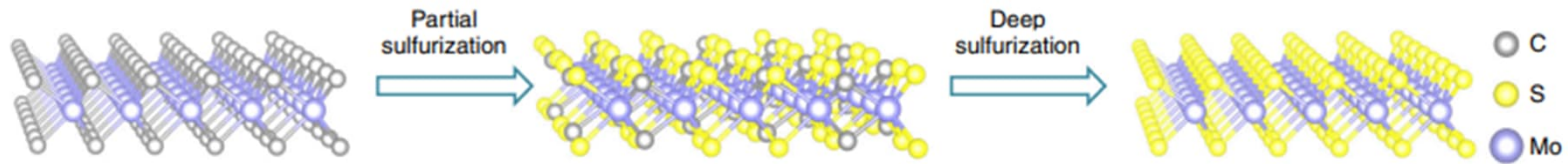
Hydrogen evolution catalysis

Why: MoS₂, a cost-effective material, highly effective for HER. Edged Mo and S atoms with a very small free energy of H adsorption

For hydrogen production from water splitting.

Ammonium molybdate – Mo precursor

Addition of carbon – to distort the electron density. Favorable for efficient HER



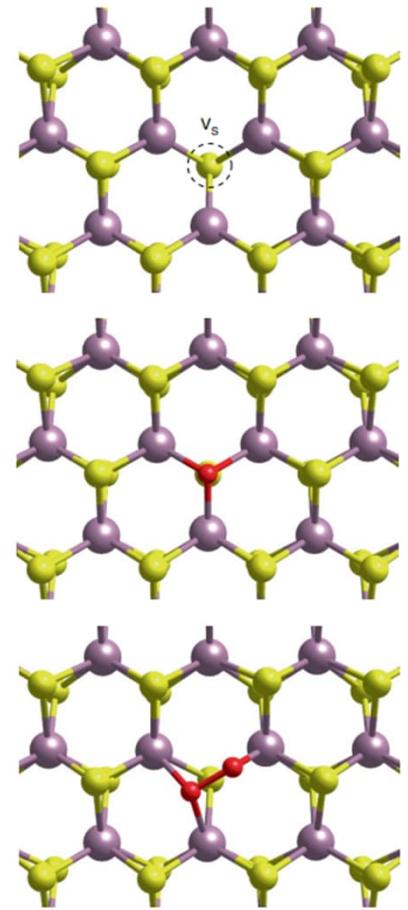
MoS₂ thin films

MoS₂ – a n-type semiconductor for transistors and other advanced electronics.

- bandgap of 1.8–1.9 eV,
- moderate carrier mobility
- atomically thin body (6.5Å)

O₂-CVD (chemical vapor deposition) for production of MoS₂ monolayer with minimal S vacancies by incorporating oxygen.

Exhibit native acceptor-like states.



Thank you for listening!



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References

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