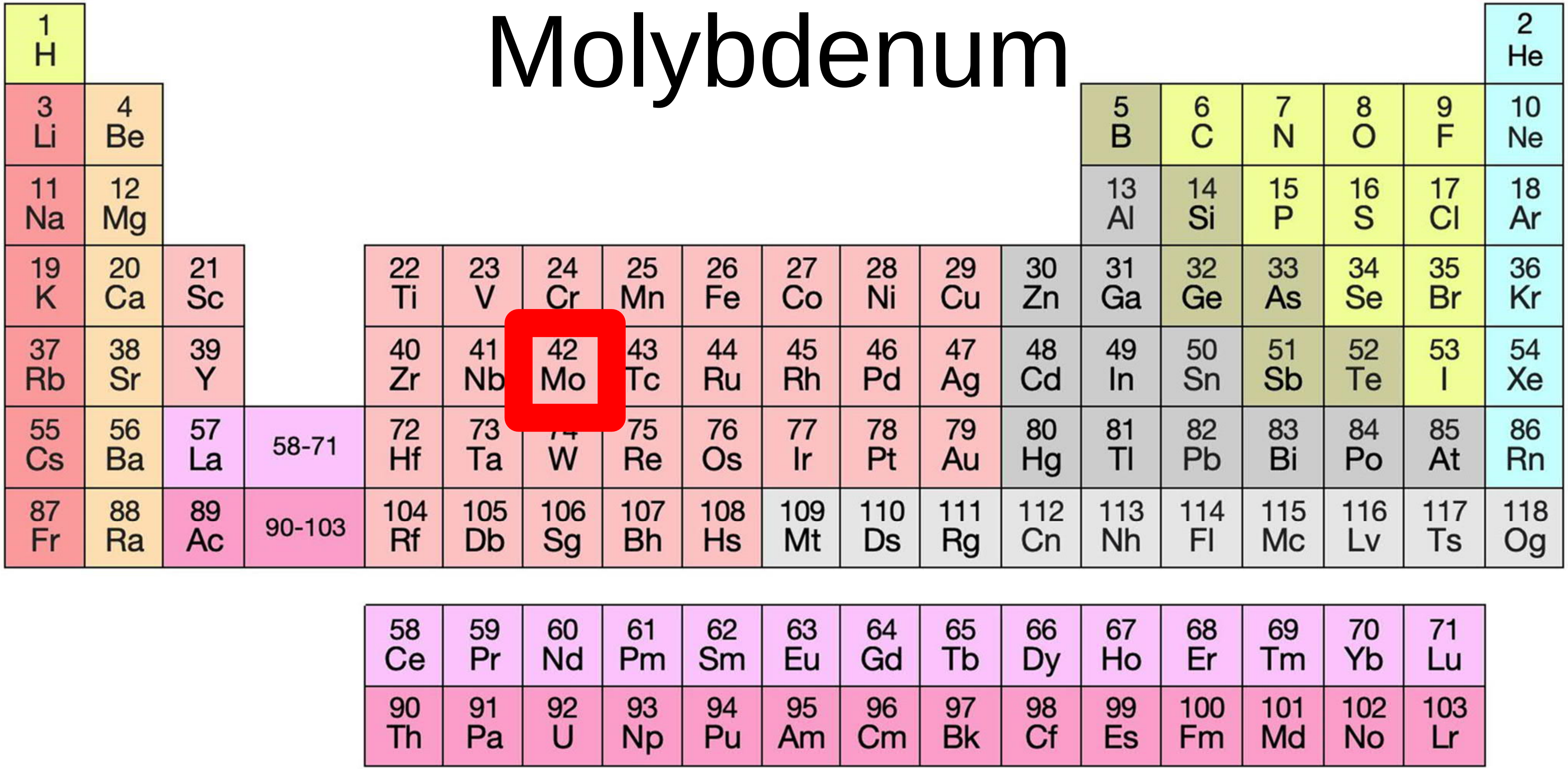
Molybdenum



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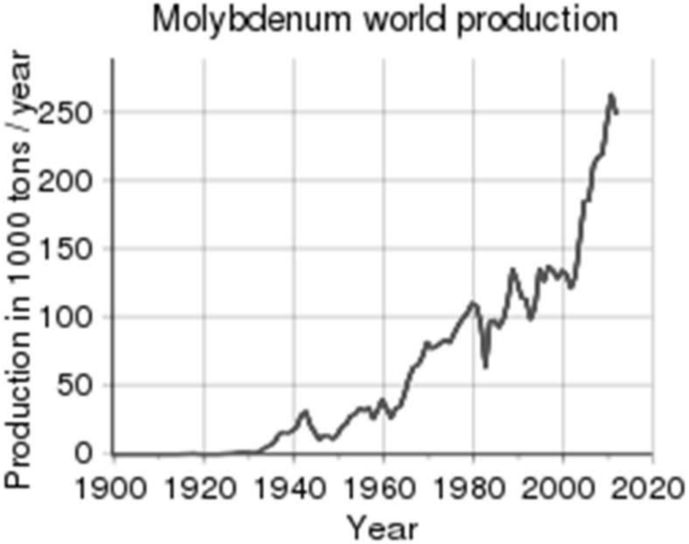
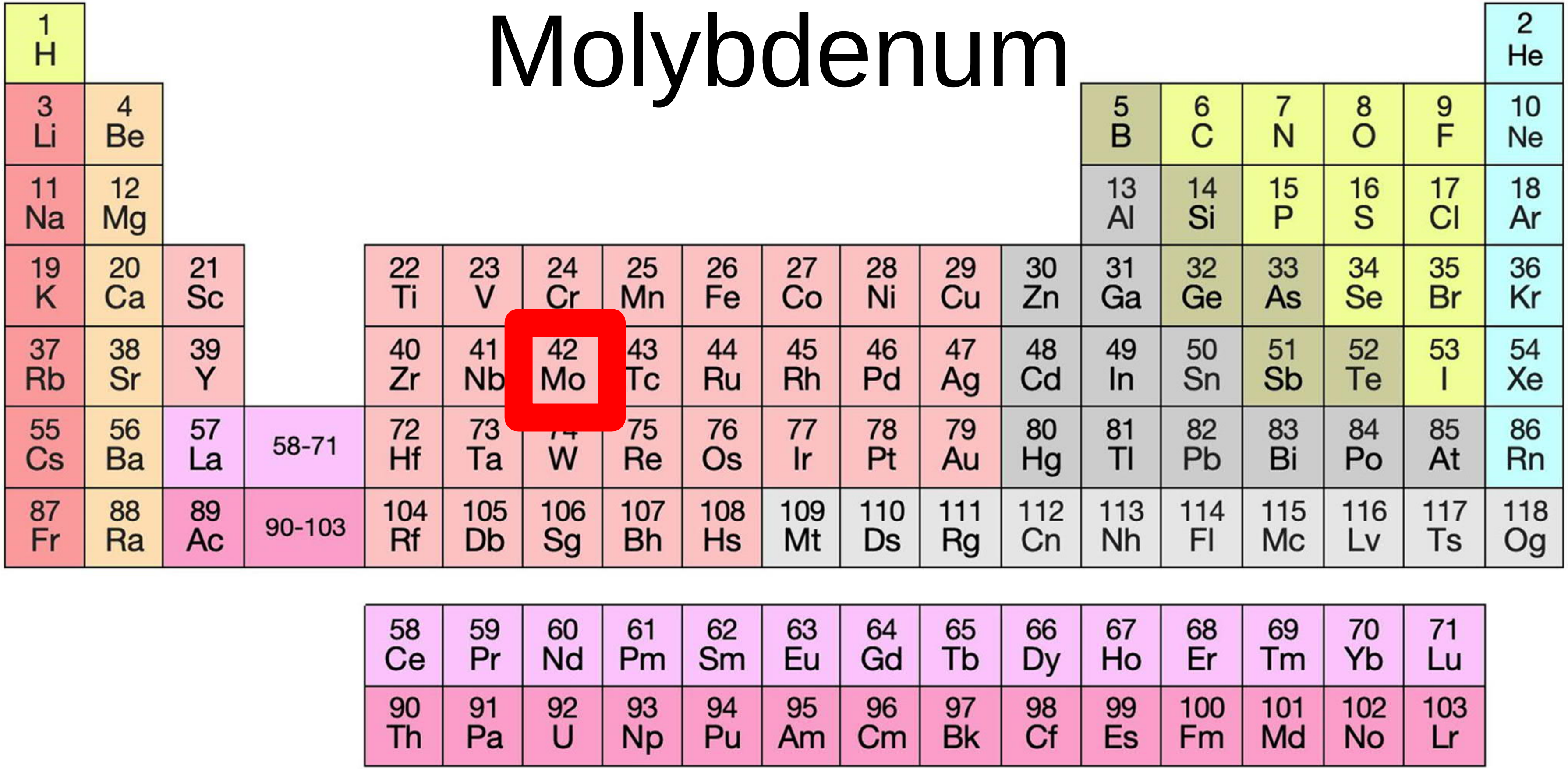
101 Md
102 No
103 Lr

- Discovered in 1778 by Carl Wilhelm Scheele and in 1781 prepared Peter Jacob Hjelm molybdenum in impure form.
- Name come from the Greek molybdos and means lead [1]
- 200,000 tons produced annually [2]
- Largest producers: United States and China [2]



Molybdenum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Chemical properties

- Electron configuration: [Kr]$4d^5 5s^1$
- Reactivity: stable [4]
- Colour: silvery white
- High melting point [5]
- Lowest thermal expansion coefficient of engineering metals [5]
- In soil and natural waters as MoO_4^- [6]

Oxidation state	Example	Effective radius (pm)
0	$Mo(CO)_6$	209
+I	$Na[C_6H_6Mo]$	-
+II	$MoCl_2$	-
+III	$Na_3[Mo(CN)]_6$	69
+IV	MoS_2	65
+V	$MoCl_5$	61
+VI	MoF_5	59

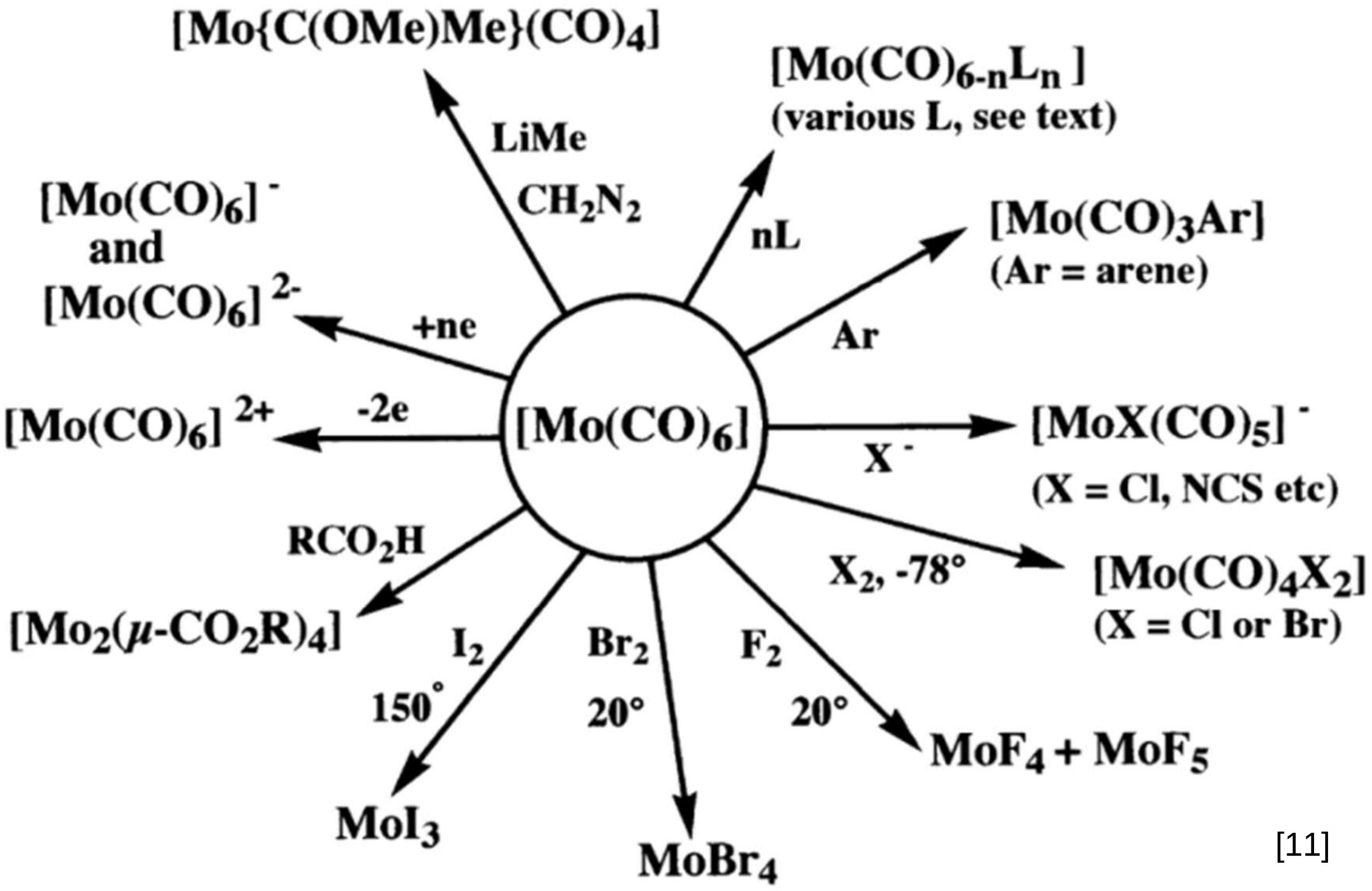
Oxidation states and some examples [7].

Uses for pure molybdenum

- Most Mo used in alloys, moly steel [5]
- Molybdenum alloys used for high-stress applications
- Essential trace metal for living beings[5]
    - Nitrogen-fixing nitrogenase

Used as a fertilizer [11]

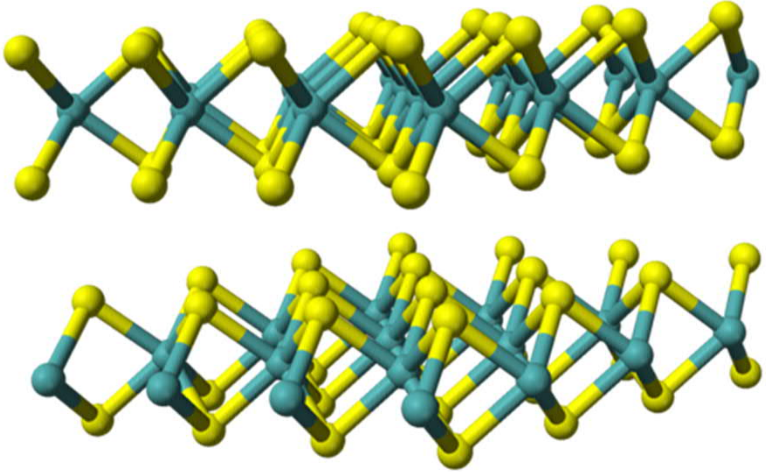
	Chemical formula	Special properties	Applications
Oxides	MoO_3	Properties can depends on thickness [8]	Coating, alloy [9]
	MoO_2	Quite inert [12]	Thin films [10]
Sulfides	MoS_2	Semiconductor, tunable properties, wide range of nanostructures	Catalysts[11], sensors[11] adsorbent[11] solid lubricant [9], Lithium ion battery cathode [9]
Borates	$B_4Mo_3O_{12}$	High melting point [14]	Glasses [13]
Carbides	MoC/Mo_2C	Hard, resistant	Moly steel alloy, HER catalyst[15]



[Mo{C(OMe)Me}(CO)4]
LiMe
CH2N2
[Mo(CO)6-nLn]
(various L, see text)
nL
[Mo(CO)3Ar]
(Ar = arene)
Ar
[Mo(CO)6] -
and
[Mo(CO)6] 2-
+ne
[Mo(CO)6] 2+
-2e
[Mo(CO)6]
[MoX(CO)5] -
X -
(X = Cl, NCS etc)
RCO2H
[Mo2(μ-CO2R)4]
X2, -78°
[Mo(CO)4X2]
(X = Cl or Br)
I2
150°
Br2
20°
F2
20°
MoF4 + MoF5
MoI3
MoBr4

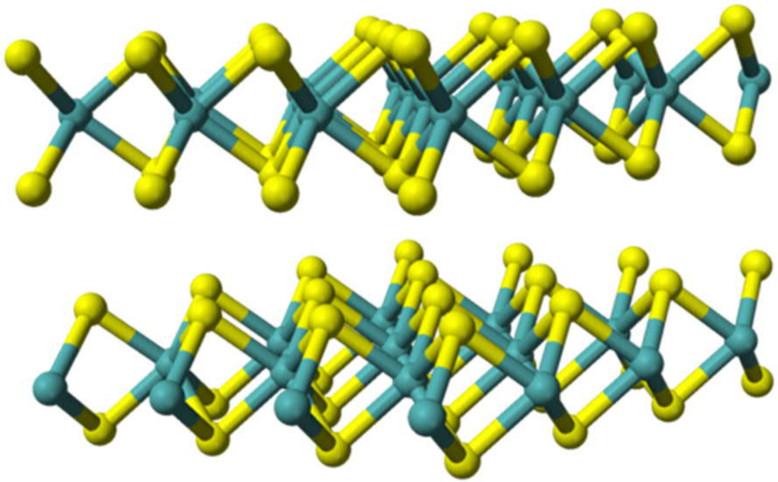
[11]

Molybdenum disulfide



Molybdenum disulfide

- Formula MoS_2, layered structure[12]



- Covalent bonds in layers, van der Waals between[12]

- Semiconductor, band gap 1.23 eV [17]

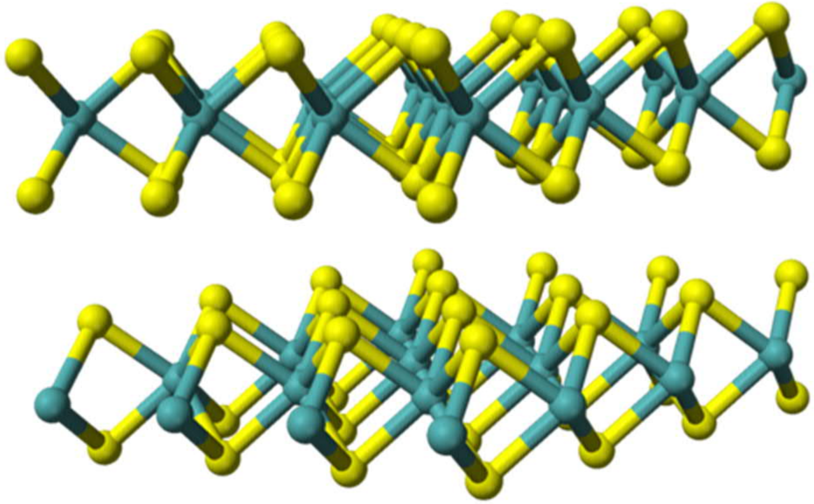
- Single-crystalline and polycrystalline form. [11]

Molybdenum disulfide - Lubricant

- Used as a lubricant [12]

- Weak interlayer interactions allow layers to slide

- Used for hundreds of years mixed with graphite

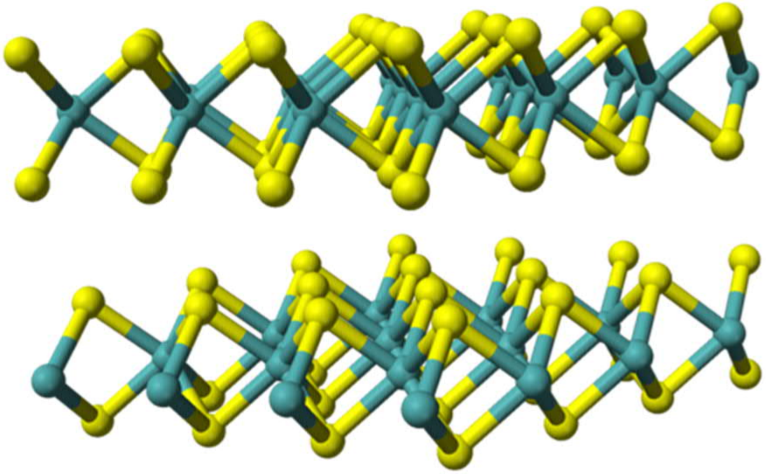


Molybdenum disulfide - Electronics

- Semiconductors
  -> Conductance tunable, i.e. with light[11]

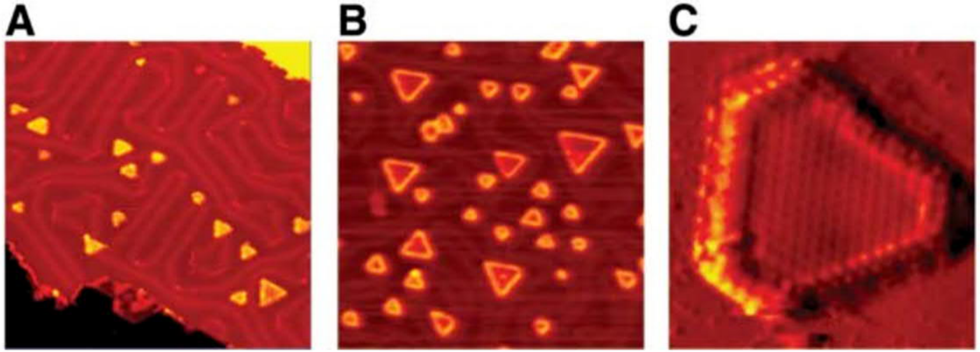
- Highly efficient transistors, due to high band gap[11]

- Chemical and biosensors, optoelectronics, flexible electronics[11][16]



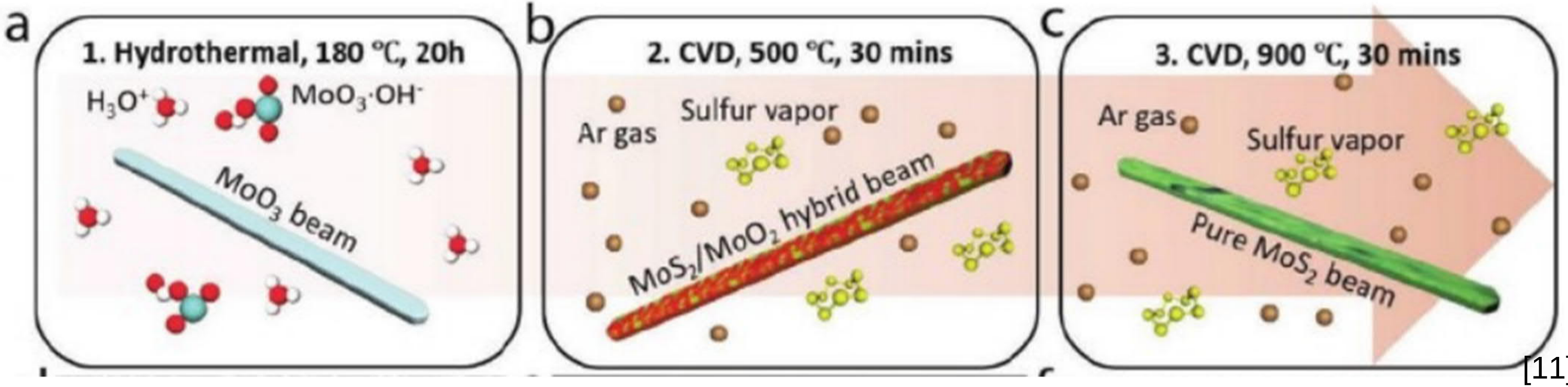
Molybdenum disulfide - Catalyst

- Low Gibbs free energy of adsorption of hydrogen atoms[11]
- Similar to Platinum, but cheap[11]
- Hydrogenation[11], hydrogen evolution reaction[19][20]
- Edges and sulphur anion vacancies active[19][20]



Molybdenum disulfide - Nanostructures

- Polycrystalline form can be used as a nanomaterial [11]
- MoS2 is made from MoO3 in high temperature
- Controlled scalable synthesis has proven difficult. [11]
- Specific nanostructure needed for many applications
- Huang et al. developed a method for growing MoS_2 nanoribbons with tunable morphology[11]



[11]

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