

Niobium (Nb)

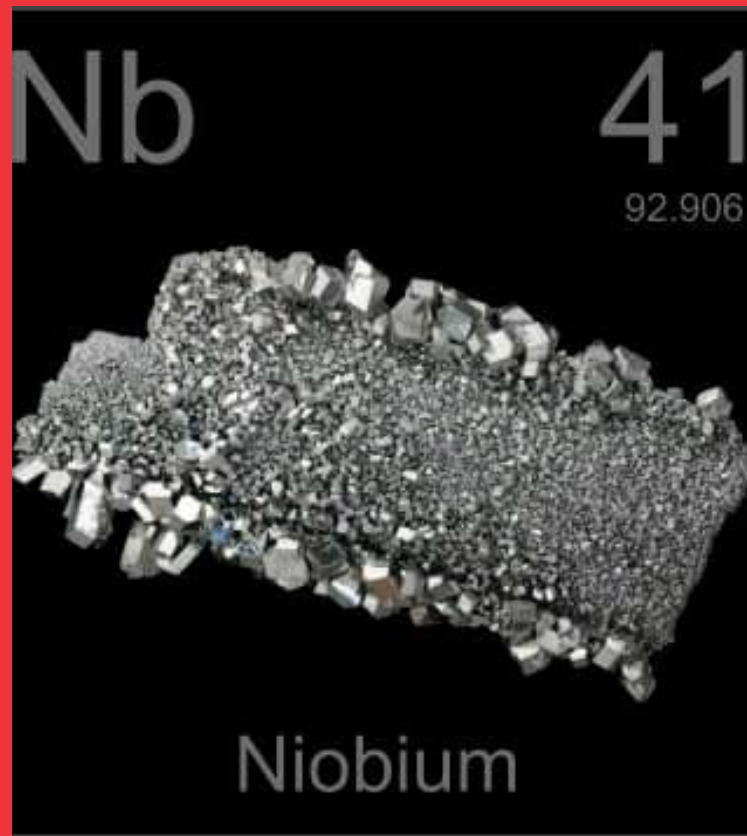
Chemistry, compounds and applications

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Element

Introduction^[1]

- **1801; English chemist Charles Hatchett**
 - Atomic # 41 - ore sample from Connecticut
 - Initially called columbium (Cb)
- **Pegmatite in the form of:**
 - Columbite (FeNb_2O_6)
 - Tantalite (FeTa_2O_6)
 - Pyrochlore
- **Isotope niobium-93.**
- **1844; German Chemist Heinrich Rose noticed tantalum and other element called niobium**
- **1950; IUPAC adopted Niobium as the official name**

[2]



Main Properties^[1]

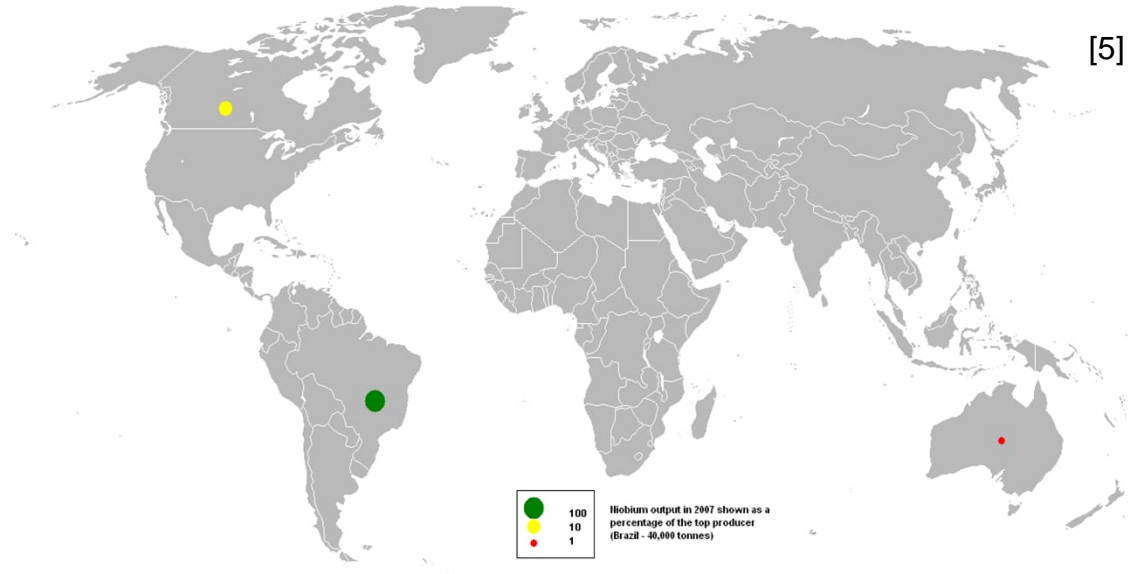
- **Transition Metal (M.P 2,477 C°)**
- **Soft and ductile**
- **Corrosion resistant**
 - susceptible to oxidation above about 400° C
- **Good ductility at room temp.**
- **Gray color**
- **Completely miscible in iron (ferroniobium)**

[3]



Availability & Demand^[1]

- **Brazil (98.53%), Canada (1.01%) and Australia (0.46%) - Nb Reserves**
 - Reservations measures Brazilian niobium (Nb₂O₅) totaled 842.4 million tons, with an average grade of 0.73% Nb₂O₅
- **Brazil stand out with 98.53% of the world Nb mineable reserves, and is the largest producer of the metal, representing approximately 97.2% of the global total.**
- **Niobium is roughly 10 times more abundant in the crust of the Earth than tantalum**
- **Niobium, more plentiful than lead and less abundant than copper in the Earth's crust**



Chemistry of Niobium



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Location of Niobium in the Periodic Table

	1											13	14	15	16	17	18	
1	1 H Hydrogen 1.008																2 He Helium 4.003	
2	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
3	11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminium 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.06	17 Cl Chlorine 35.453	18 Ar Argon 39.948
4	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 83.798
5	37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium 98.906	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.905	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.757	52 Te Tellurium 127.6	53 I Iodine 126.905	54 Xe Xenon 131.29
6	55 Cs Cesium 132.905	56 Ba Barium 137.327	57-71 * Lanthanide Series	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon 222
7	87 Fr Francium (223)	88 Ra Radium 226.025	89-103 ** Actinide Series	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (264)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 Ds Darmstadtium (267)	111 Rg Roentgenium (268)	112 Cn Copernicium (269)	113 Nh Nihonium (270)	114 Fl Flerovium (277)	115 Mc Moscovium (288)	116 Lv Livermorium (293)	117 Ts Tennessine (289)	118 Og Oganesson (294)
Lanthanide Series *			57 La Lanthanum 138.905	58 Ce Cerium 140.12	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.24	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 162.50	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.967	
Actinide Series **			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 251.08	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (260)	

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Niobium (Nb)

- **5d transition metal (four 5d-electrons)**

- **Most favorable oxidation state +V**

- **In RTS, Nb is very inert with hydrogen, air, water or acids (excl. HF and its mixture of HNO₃)**

→ **When T is increased, Nb reacts with most non-metals and generates non-stoichiometric products [1]**

- **Only 1 stable isotope with natural abundance of 100%**

- **Similar chemical properties with tantalum**

Chemical and physical properties of Nb

Atomic number	41
Group	5
Period	5
Block	d
Electronic configuration	[Kr]5s ¹ 4d ⁴
Relative atomic mass	92.906 Da
Isotopes	1 (⁹³ Nb)
Oxidation states	+V, (+III)
Atomic radius (van der Waals)	2.07 Å
Ionic radius (when oxidation state is +V)	0.64 Å
Ionization energy	652.13 kJ mol ⁻¹
Crystal structure	cubic (bcc)
Lattice constant	3.3004 ³ Å
State at 20 °C	solid
Melting point	2477 °C (2750 K)
Boiling point	4741 °C (5014 K)
Density	8.57 g cm ⁻³

[14, 16, 17]

Similarities between niobium and tantalum

- Tantalum ($Z=73$) is at the same group 5 with niobium.
- Both are d-block transition metals (Nb has 4 d-electrons and Ta has 3 d-electrons) and are solid in RTS.
- Their atomic sizes are similar (Nb 2.07 Å, Ta 2.22 Å) and both have a body-centred cubic crystal structure ($a=b=c$, $\alpha=\beta=\gamma=90^\circ$).
- Tantalum also has an oxidation state of +V (bond-forming with two 6s- and three 5d-electrons).
- Although similar with many chemical properties, tantalum is much denser (16.4 g cm^{-3}) with an atomic mass of 180.948 Da.
- Bigger size of Ta also increases the m.p. and b.p. of the element.

Nb compounds and properties



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Compounds and their properties

Nb compounds can be divided: Niobium Oxides, Niobium Phosphates
Molecular Sieves Containing Niobium (e.g., Zeolites NbNaY) [16]

Group 5 metal exhibits compounds in oxidation states +2 to +5 [7]

Examples

- NbP: dark grey crystal and insoluble in water, exhibit extremely large magnetoresistance which can be used in electric components [5]
- NbB₂: grey powder with melting point at 3050C -> ultra high temperature ceramic [6]

Metal Cluster Halides

- These highly symmetric clusters consist of a central octahedron constituted by 6 heavy metal atoms, stabilised by 12 bridging halogen atoms [8].
- 6 different cationic cores $\{\text{Nb}_6\text{F}_{12}\}^n$ $\{\text{Nb}_6\text{Cl}_{12}\}^n$ $\{\text{Nb}_6\text{Br}_{12}\}^n$ $\{\text{Nb}_6\text{I}_{12}\}$ clusters remain yet to be synthesised. [8]
- The cluster is **remarkably stable** and can undergo oxidative addition to form $[\text{M}_6\text{X}_{18}]^{2-}$ clusters, in which one halogen atom has attached terminally to each metal atom [7]
- Require significant development with possible applications in catalysis and bio–medicine [8].

CHAPTER 21 • Properties of the 4d and 5d Transition Metals

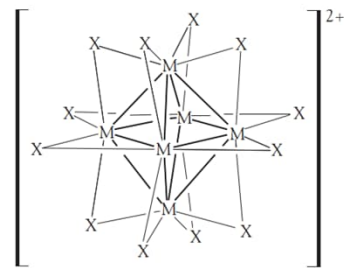


FIGURE 21.8 Structure of the $[\text{M}_6\text{X}_{12}]^{2+}$ ion, where $\text{M} = \text{Nb}$ or Ta and $\text{X} = \text{halide}$.

$\text{M} = \text{Nb, Ta}$
 $\text{X} = \text{halide}$

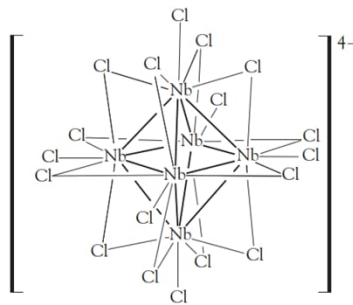
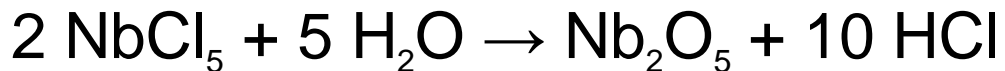


FIGURE 21.9 Structure of the $[\text{M}_6\text{X}_{18}]^{2-}$ ion, where $\text{M} = \text{Nb}$ or Ta and $\text{X} = \text{a halogen}$.

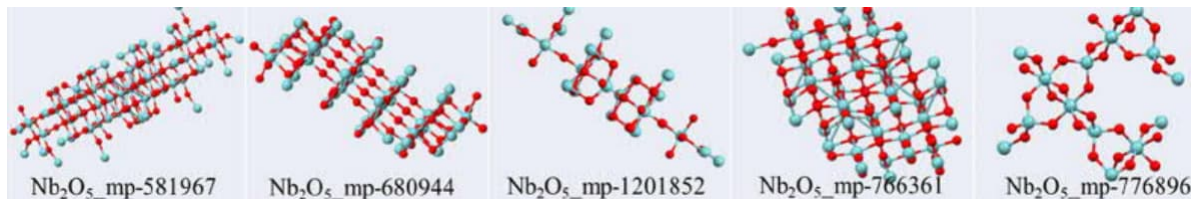
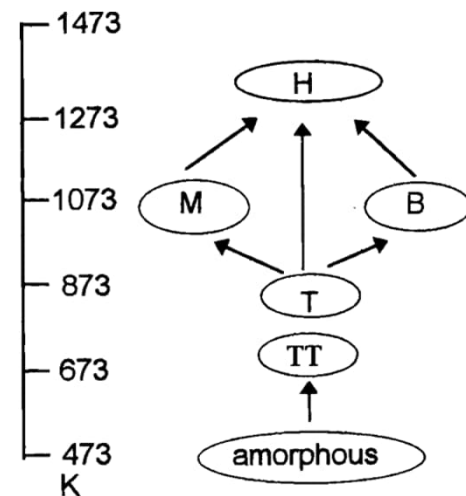
Nb₂O₅

- Niobium pentoxide is a white, air-stable, water-insoluble solid.[8]

- **Production**



- **Nb₂O₅** possesses a quite complex crystalline morphology and about 20 different structures have been identified



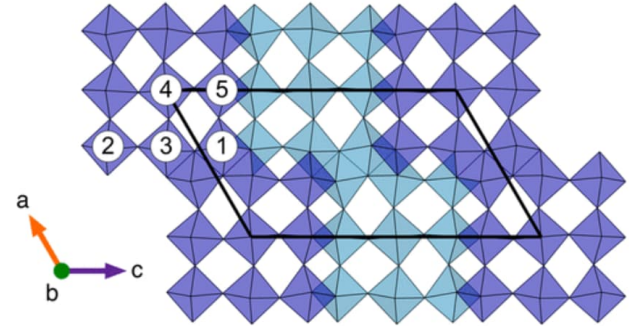
Applications ^[1]

Table 3. Some types of products Nb and applications¹²⁻²⁰.

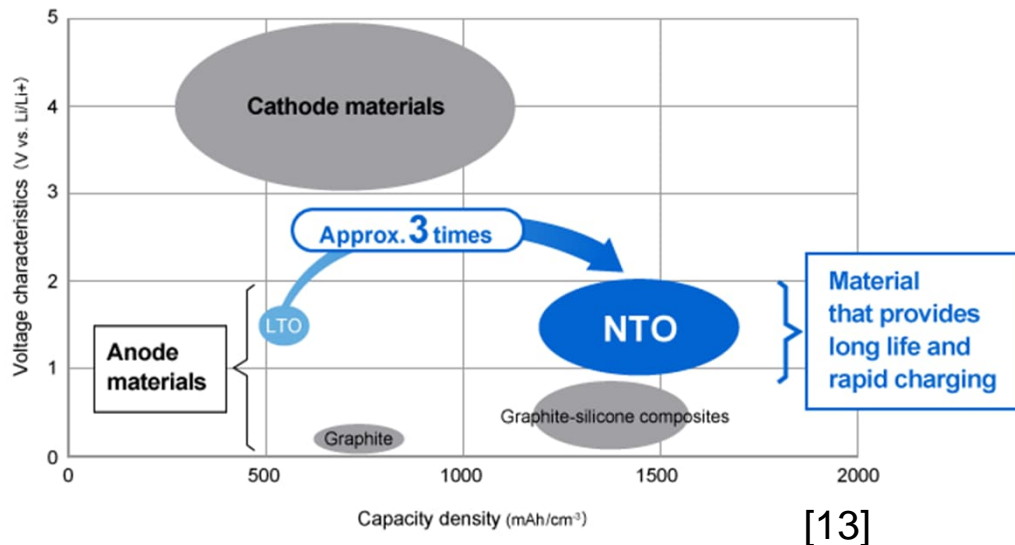
Niobium Species	Principal Properties	Applications
Nb oxide	High index of refraction High dielectric constant Increase light transmittance	Camera lenses Coating on glass for computer screens Ceramic capacitors Manufacture of lithium niobate for surface acoustic wave filters
Nb carbide	High temperature deformation and controls grain growth	Cutting tool compositions
Nb powder	High dielectric constant, stability of oxide dielectric	Nb capacitors for electronic circuits
Nb metal	Corrosion resistance	Chemical processing Equipment
FeNb	Weight reduction, increased strength and toughness due to grain refining	Nb additive to high strength low alloy steel and stainless steel
Nb titanium and Nb tin alloys	Very low electrical resistance of alloywire at low temperatures	Superconducting magnetic coils in magnetic resonance imagery

Titanium Niobium Oxide – Fast charging battery [22]

- TiNb_2O_7 is being developed as a high-energy-density alternative anode material to $\text{Li}_4\text{Ti}_5\text{O}_{12}$ for specific market sectors
- The reaction of TiNb_2O_7 with lithium is not as well-defined
- The reduction to $\text{Li}_3\text{Ti}^{\text{III}}\text{Nb}^{\text{IV}}_2\text{O}_7$ (one lithium per transition metal) occurs at ~ 1.4 V vs Li^+/Li , providing a theoretical capacity of **232.6** mAh g^{-1} .
- The reaction proceeds further as the voltage is decreased and can proceed to $\text{Li}_5\text{Ti}^{\text{III}}\text{Nb}^{\text{III}}_2\text{O}_7$ with a theoretical capacity of **387.7** mAh g^{-1} .



Titanium Niobium Oxide – Fast charging battery



TOSHIBA

Application Of Niobium In Alloy Steel^[11]

- **Increase strength, mechanical, welding properties and corrosive resistance**
- **Low-alloy high-strength steel (80% Nb)**
 - small amount of niobium to form stable carbides and carbonitrides
 - precipitation of niobium carbide can improve the strength and creep resistance of the steel.
- **High-alloy steels**
 - additives metal niobium bars or ferroniobium (50-70% Nb)
 - stainless steel, heat-resistant steel, and corrosion-resistant steel

Application Of Niobium In Alloy Steel^[11]

- **Niobium has showed improvements in the production process**
 - melt shop, Niobium result in less oxidation, where the efficiency of FeNb is about 95%,
 - FeTi ranges from 80 to 85%.
- **Niobium also avoid clogging during casting**
- **Considerable effect on the pitting corrosion**
 - increase of Nb content in the matrix which causes “beneficial disorders” increasing corrosion resistance by the formation of Niobium Oxides
 - higher protection than Chromium oxides

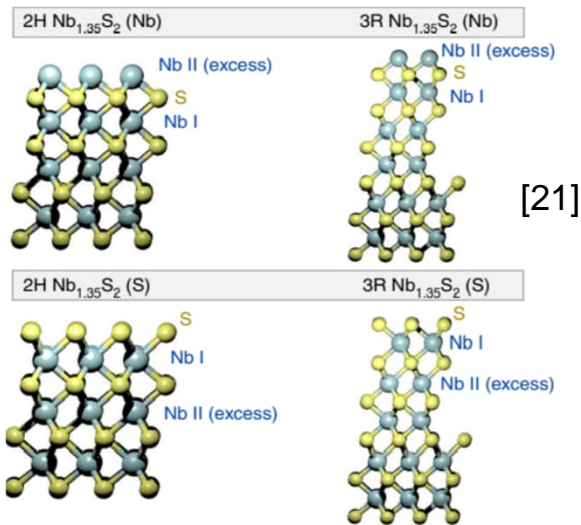


[12]

**Niobium disulfide
NbS₂ could be a
viable catalyst for
the hydrogen
evolution reaction
(HER)**

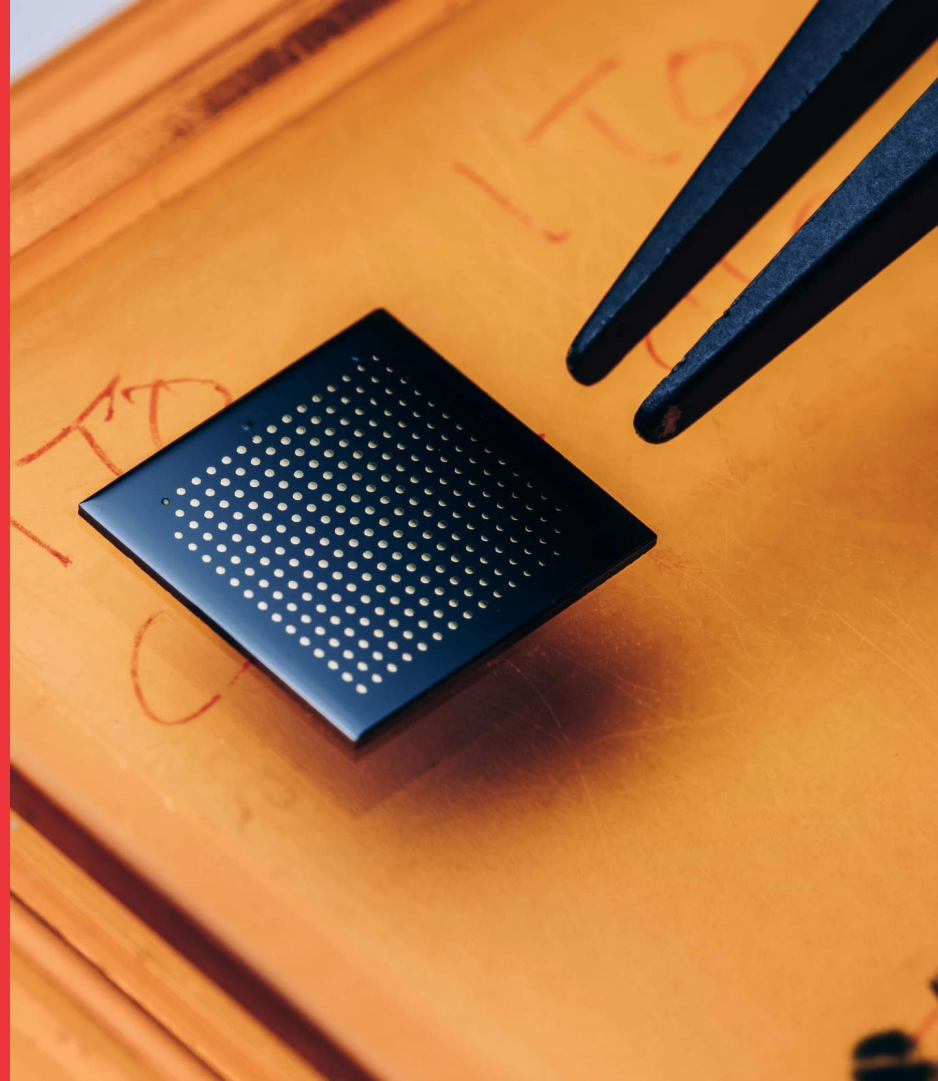
- **Transition metal dichalcogenides (TMDs) are good catalysts for the hydrogen evolution reaction**
- **However, noble metals like Pt have a current density of >1000 mA/cm², while TMDs such as semi-conductive MoS₂ have a current density of ~10-100 mA/cm²**
- **Lower current density for many TMDs is caused by proton-adsorption on their surface in the first step of HER, decreasing the conductivity of 2D nanosheets**

An electrolyser based
2H Nb_{1+x}S₂ cathode can
generate current
densities of >1000
mA/cm²



- Layered 2H (hexagonal) NbS₂ is predicted to be one of the most efficient TMD electrocatalysts for the hydrogen evolution reaction
- Metallic 2H Nb_{1+x}S₂ (where x ~ 0.35) with additive niobium does not have the van der Waals gaps between its layers, so the conductivity improves → reaching up to same current densities than with Pt or Ir

Questions?



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