

Unit 1 – Deck 1

ELECTROCHEMISTRY



Introduction – Electricity in Chemistry

Topics

- ① Introduction to electrochemistry
- ② Reduction & oxidation
- ③ **Assigning oxidation states**

- ④ Electrochemical cell
- ⑤ Cathodes and anodes
- ⑥ Cells and half cells

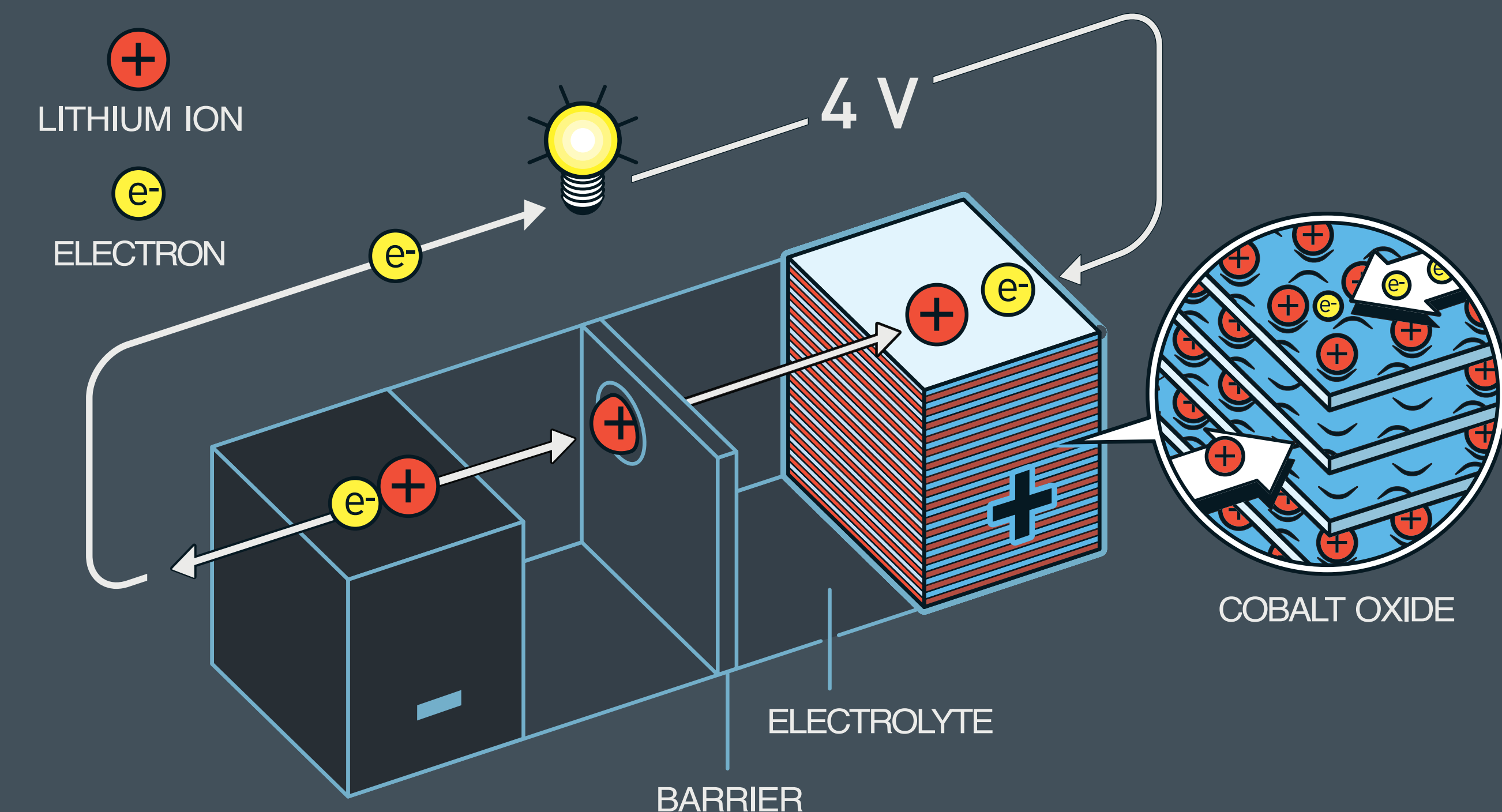
What is Electrochemistry?

Electrochemistry:

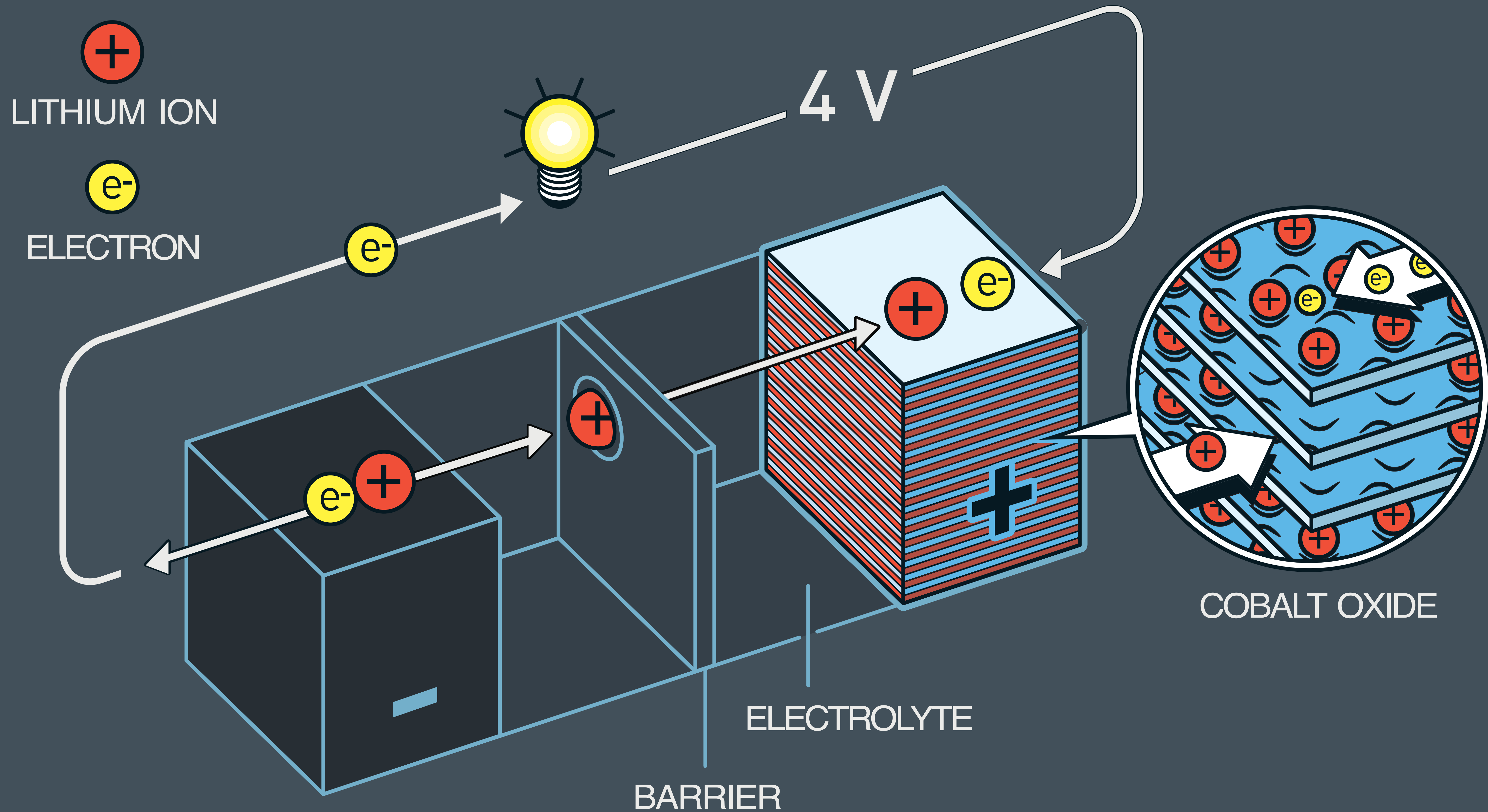
- The study of chemical reactions that generate electricity or can be carried out by running electricity through them.
- *Chemistry that involves the net transfer of charge between discrete components (atoms, ions, molecules, materials...) of a chemical system.*

Common Examples:

- **Batteries** 
- Nerve impulses in our bodies 



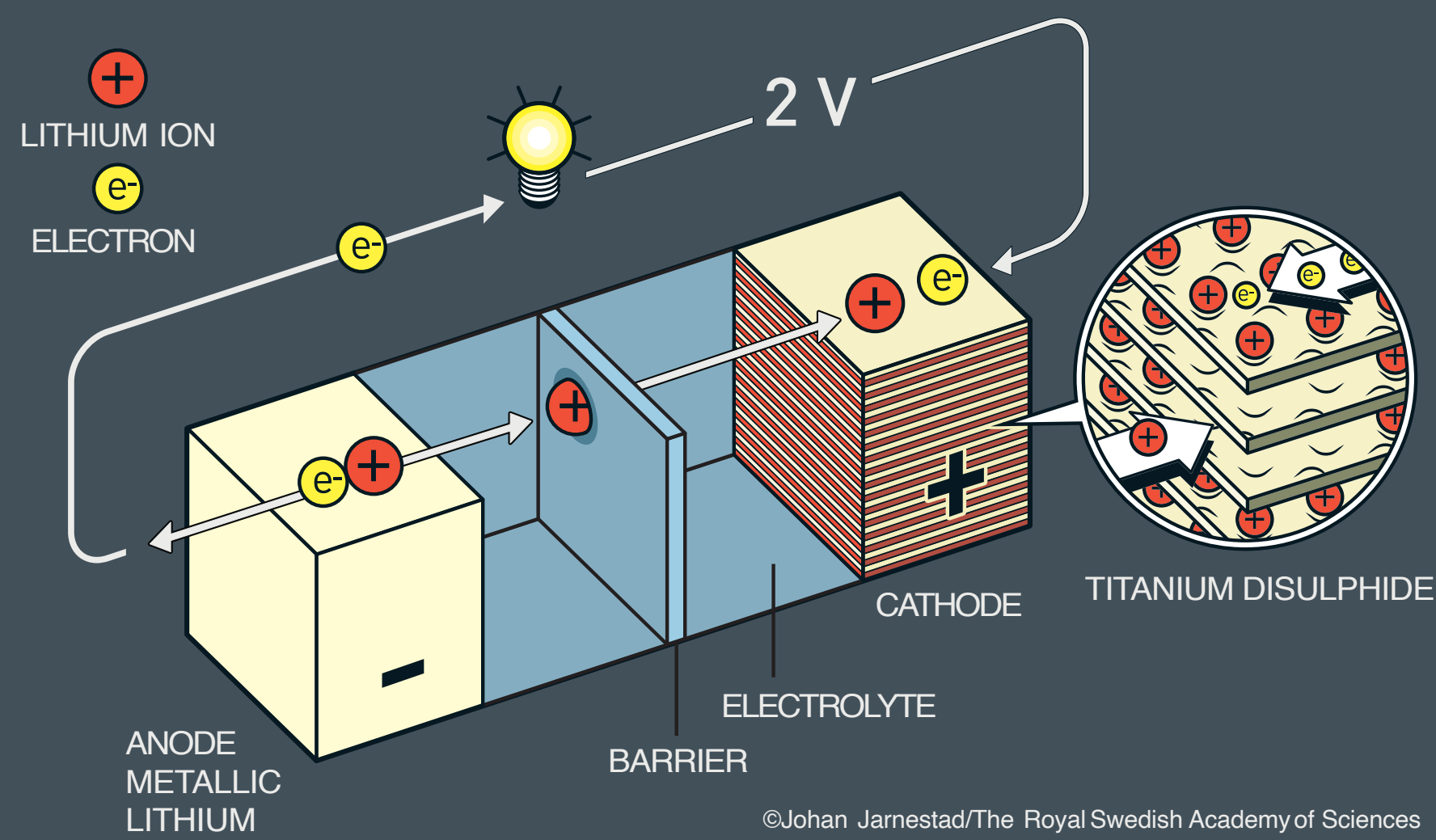
What is a battery?



Nobel Prize in Chemistry - 2019



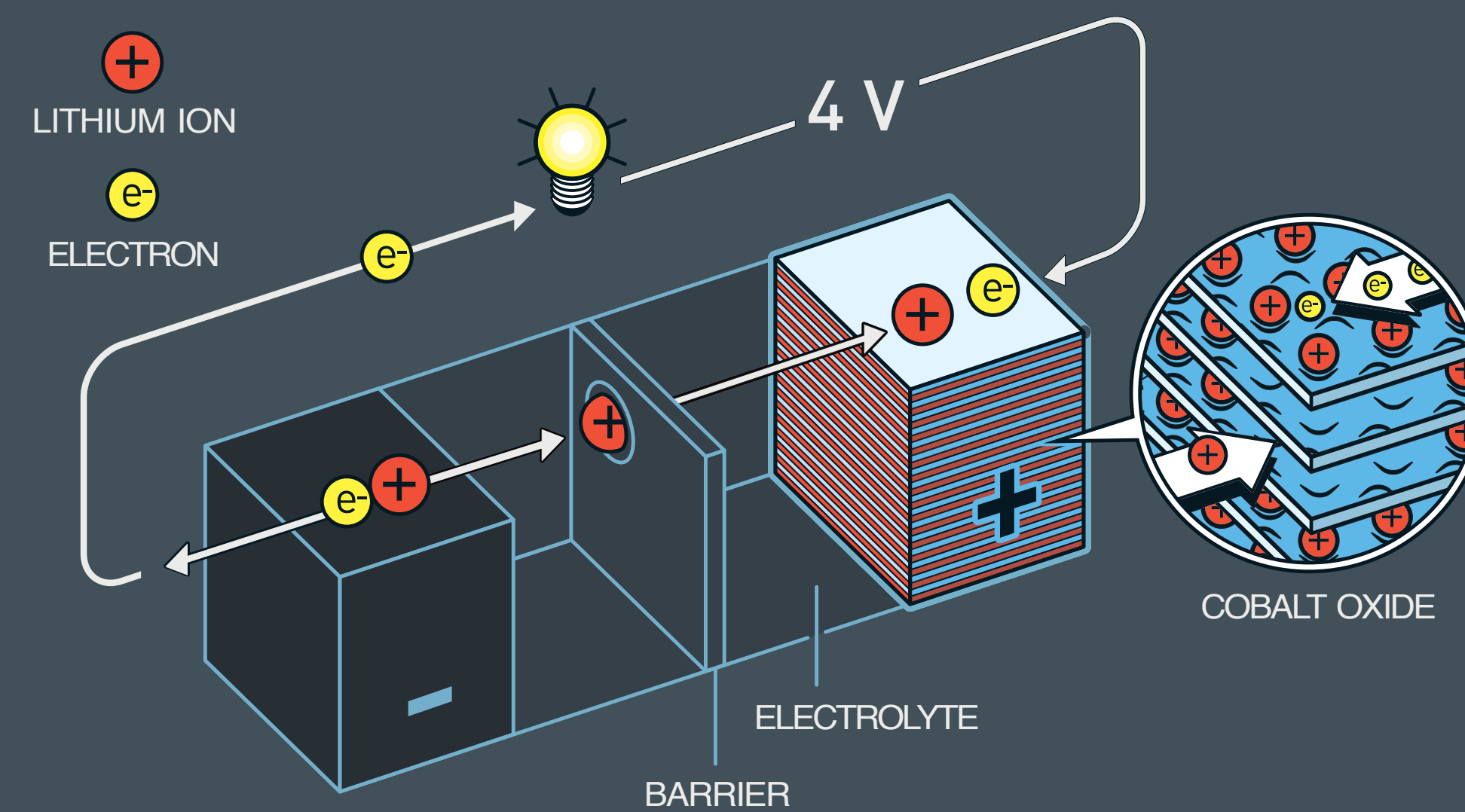
M. Stanley Whittingham
1970



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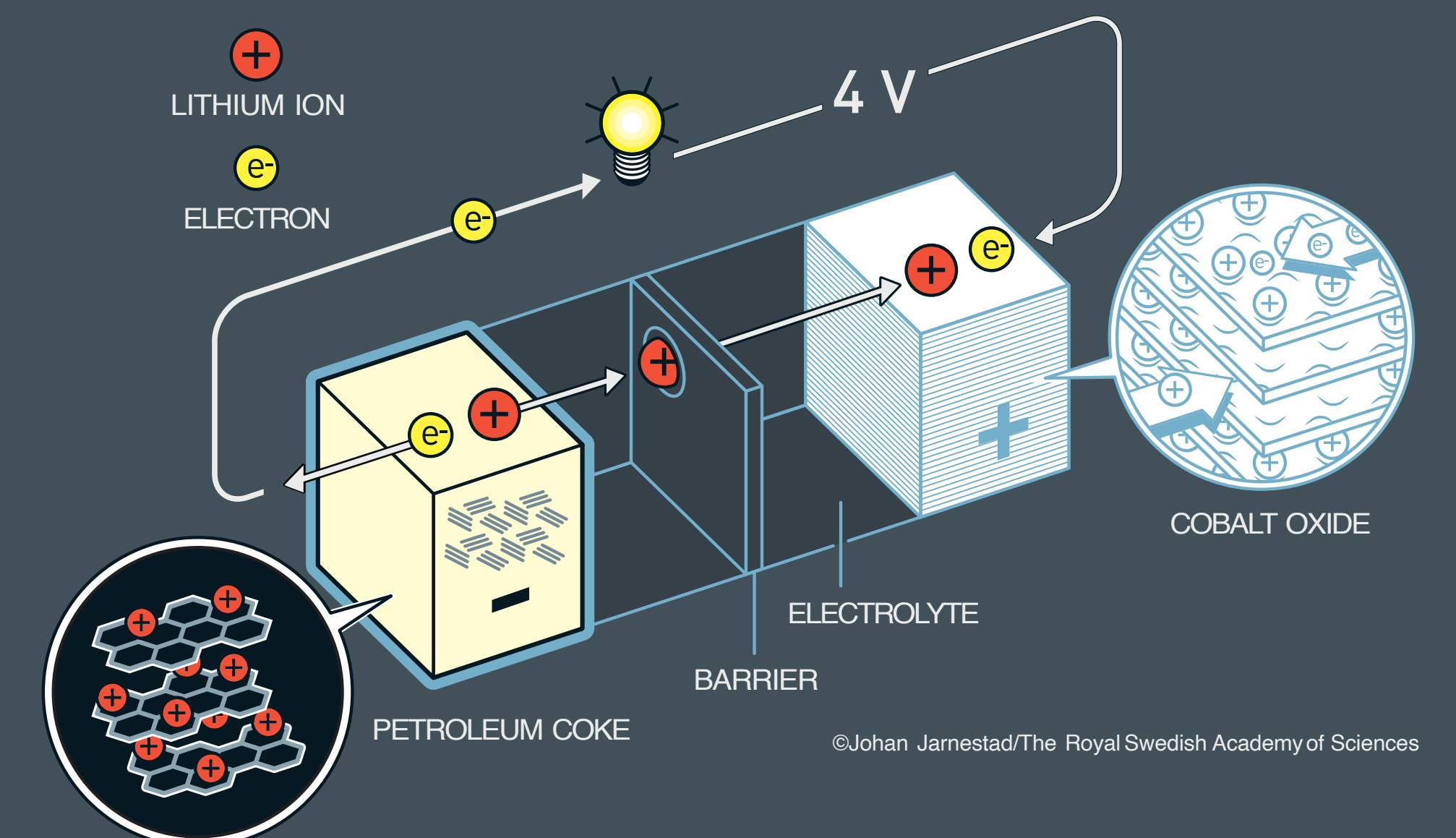
John B. Goodenough
1980



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Akira Yoshino
1985



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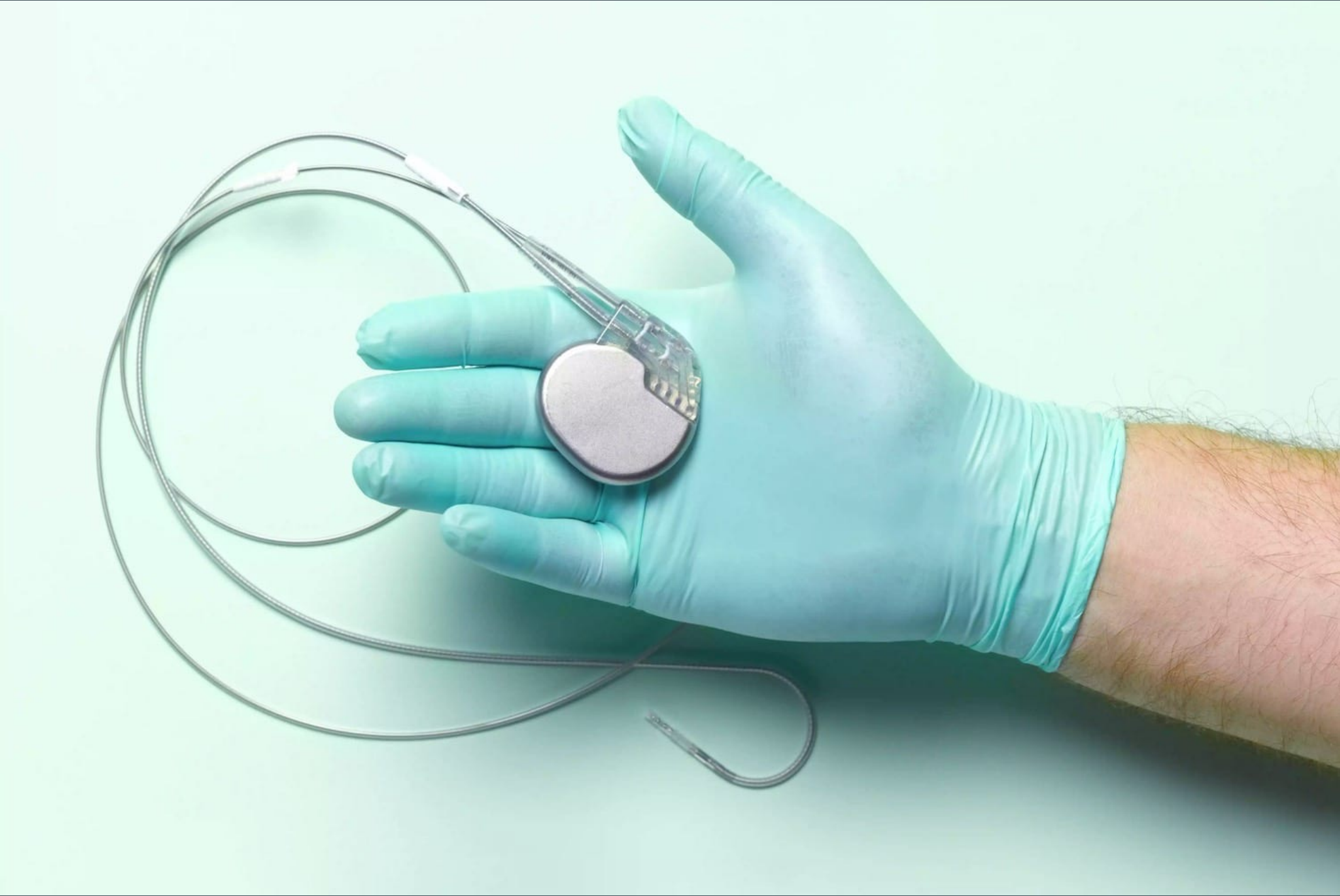
Applications



Electric vehicles



Grid Storage for wind, solar, and load balancing



Medical devices

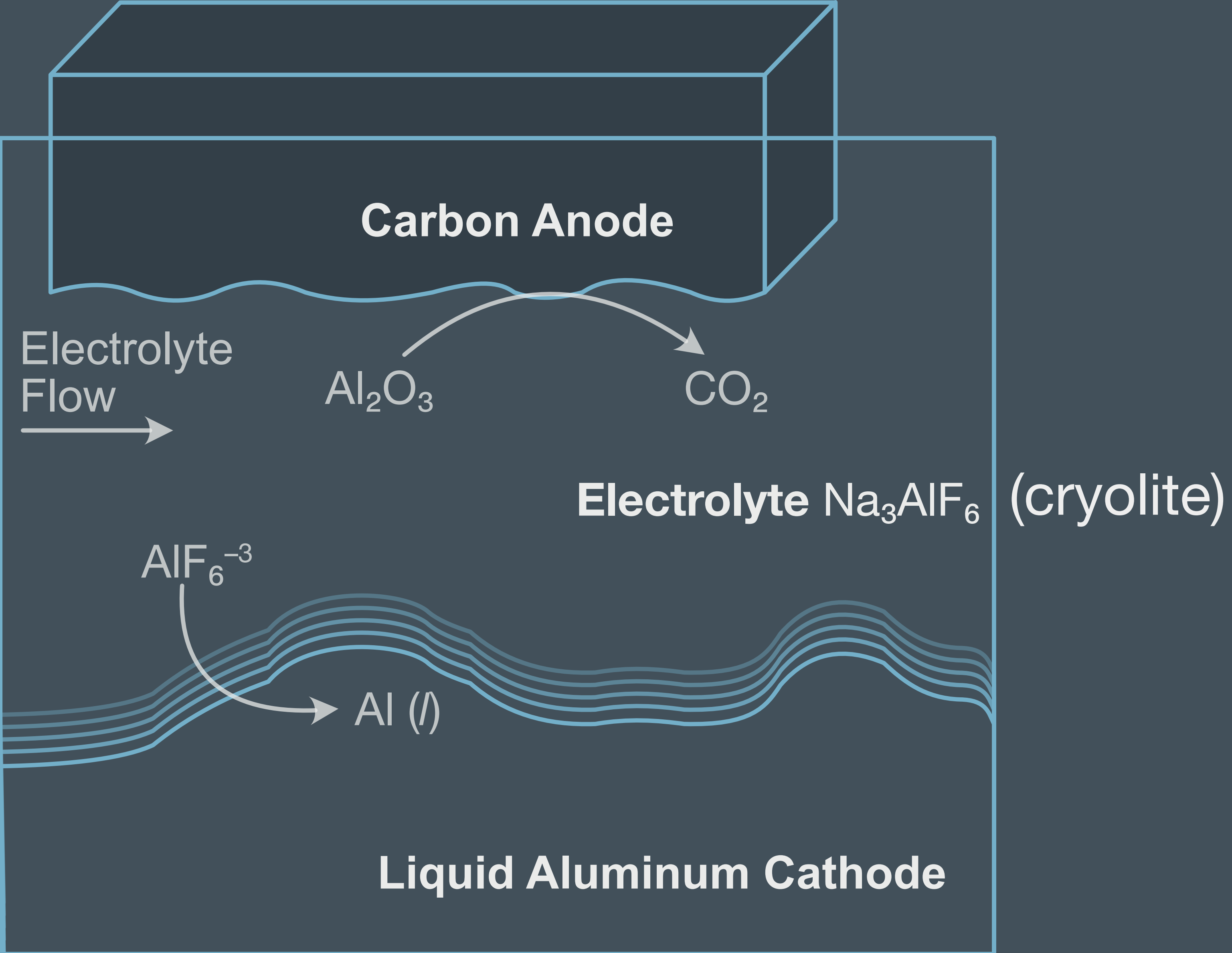




Electrochemistry in synthesis – the electrolytic cell

Hall-Héroult process

Smelting | reduction in molten state



0.5 PWh per year



Oxidation of one Al can will power your laptop for ~3 hours



Aerospace Superalloys



Structural materials



Powerlines from oil fields

1.5 km potline

~3000 kg/day per pot





Reduction-Oxidation Chemistry

Reduction-Oxidation (**redox**) chemistry is the study of the movement of electrons from one atom to another in chemical reactions.

- Sometimes strong bonds are broken/formed:

- Sometimes only weaker bonding interactions involved:

Definitions

Oxidation Reactions

- Gaining oxygen (O_2)
- Losing hydrogen (H_2)
- Losing electrons

Reduction Reactions

- Losing oxygen (O_2)
- Gaining hydrogen (H_2)
- Gaining electrons

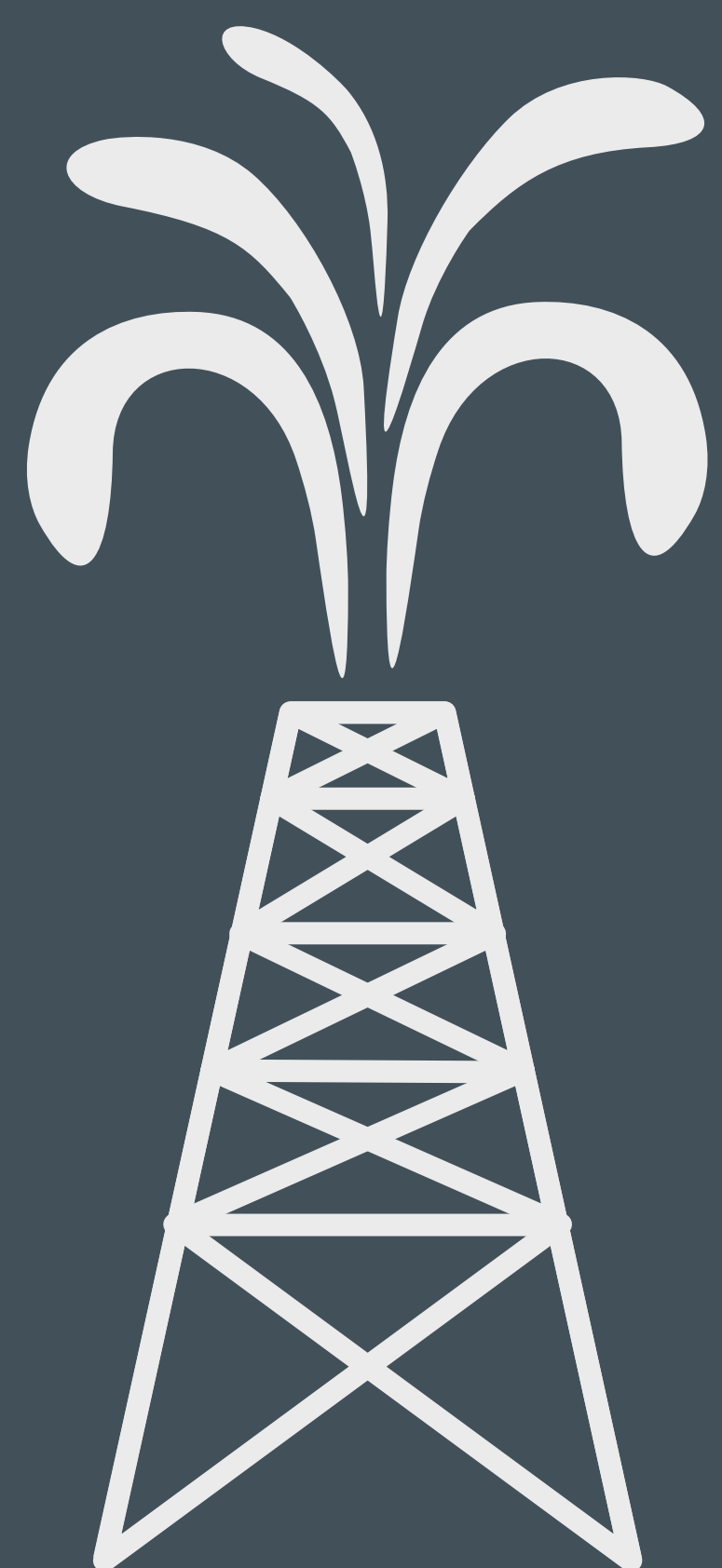
Electronegativity

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H Hydrogen 2.20	Atomic Symbol Name Weight																2 He Helium
2	3 Li Lithium 0.98	4 Be Beryllium 1.57											5 B Boron 2.04	6 C Carbon 2.55	7 N Nitrogen 3.04	8 O Oxygen 3.44	9 F Fluorine 3.98	10 Ne Neon
3	11 Na Sodium 0.93	12 Mg Magnesium 1.31											13 Al Aluminium 1.61	14 Si Silicon 1.90	15 P Phosphorus 2.19	16 S Sulfur 2.58	17 Cl Chlorine 3.16	18 Ar Argon
4	19 K Potassium 0.82	20 Ca Calcium 1.0	21 Sc Scandium 1.36	22 Ti Titanium 1.54	23 V Vanadium 1.63	24 Cr Chromium 1.66	25 Mn Manganese 1.55	26 Fe Iron 1.83	27 Co Cobalt 1.88	28 Ni Nickel 1.91	29 Cu Copper 1.90	30 Zn Zinc 1.65	31 Ga Gallium 1.81	32 Ge Germanium 2.01	33 As Arsenic 2.18	34 Se Selenium 2.55	35 Br Bromine 2.96	36 Kr Krypton 3.0
5	37 Rb Rubidium 0.82	38 Sr Strontium 0.95	39 Y Yttrium 1.22	40 Zr Zirconium 1.33	41 Nb Niobium 1.6	42 Mo Molybdenum 2.16	43 Tc Technetium 1.9	44 Ru Ruthenium 2.2	45 Rh Rhodium 2.28	46 Pd Palladium 2.20	47 Ag Silver 1.93	48 Cd Cadmium 1.69	49 In Indium 1.78	50 Sn Tin 1.96	51 Sb Antimony 2.05	52 Te Tellurium 2.1	53 I Iodine 2.66	54 Xe Xenon 2.6
6	55 Cs Caesium 0.79	56 Ba Barium 0.89	57–71	72 Hf Hafnium 1.3	73 Ta Tantalum 1.5	74 W Tungsten 2.36	75 Re Rhenium 1.9	76 Os Osmium 2.2	77 Ir Iridium 2.20	78 Pt Platinum 2.28	79 Au Gold 2.54	80 Hg Mercury 2.0	81 Tl Thallium 1.62	82 Pb Lead 2.33	83 Bi Bismuth 2.02	84 Po Polonium 2.0	85 At Astatine 2.2	86 Rn Radon
7	87 Fr Francium 0.7	88 Ra Radium 0.9	89–103	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson

Electronegativity measures the tendency of an atom to attract a shared pair of electrons towards itself.

6	57 La Lanthanum 1.10	58 Ce Cerium 1.12	59 Pr Praseodymium 1.13	60 Nd Neodymium 1.14	61 Pm Promethium	62 Sm Samarium 1.17	63 Eu Europium	64 Gd Gadolinium 1.20	65 Tb Terbium	66 Dy Dysprosium 1.22	67 Ho Holmium 1.23	68 Er Erbium 1.24	69 Tm Thulium 1.25	70 Yb Ytterbium	71 Lu Lutetium 1.27
7	89 Ac Actinium 1.1	90 Th Thorium 1.3	91 Pa Protactinium 1.5	92 U Uranium 1.38	93 Np Neptunium 1.36	94 Pu Plutonium 1.28	95 Am Americium 1.3	96 Cm Curium 1.3	97 Bk Berkelium 1.3	98 Cf Californium 1.3	99 Es Einsteinium 1.3	100 Fm Fermium 1.3	101 Md Mendelevium 1.3	102 No Nobelium 1.3	103 Lr Lawrencium

Redox Mnemonics



OIL RIG

Oxidation **I**s **L**oss of electrons

Reduction **I**s **G**ain of electrons

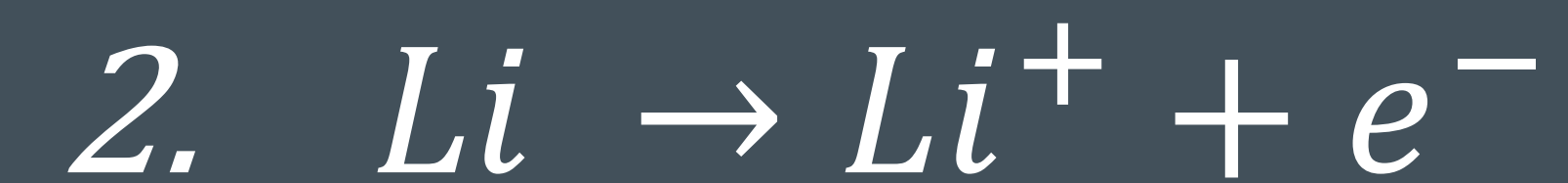
LEO says **GER!**
Lose **E**lectrons **O**xidation
Gain **E**lectrons **R**eduction





Example – Reduction and Oxidation

Which of the following is an oxidation reaction?



Who is the oxidizing agent?
Who is the reducing agent?
Who is the oxidant?
Who is the reductant?

Oxidation vs reduction how to tell

Reduction

Gain of electrons

Decrease in oxidation number

Increase in number of hydrogens

Decrease in number of oxygens

Oxidation

Loss of electrons

Increase in oxidation number

Decrease in number of hydrogens

Increase in number of oxygens

Careful here!
There are
plenty of
exceptions.



Oxidation States

Each atom in a compound has its own oxidation state.

- Oxidation states are *not* real ionic charges.
- Oxidation states typically range from -4 to $+7$.
- Oxidation states can be 0 and can even be fractions (unusual).

Assigning Oxidation States

Step #1:

Start with elements that have the below conditions

- Free, uncombined element = zero
- Monatomic ion = charge on ion
- Group IA in compounds = +1
- Group IIA in compounds = +2
- F = -1 in compounds

Step #2:

Assign oxidation states for H and O

- H = +1 (in metal hydrides H = -1)
- O = -2 (in peroxides O = -1; H-O-O-H)

Consideration of ΔEN can help in cases like peroxide

For now, we will assign oxidation states only to individual atoms.

Assigning Oxidation States

Step #3:

Work on “The Others”

- Sum of oxidation numbers in compound = 0
- Sum of oxidation numbers in polyatomic ion = charge on ion

Step #4:

Work on “The Unknowns” by choosing the “best guess” to start assigning oxidation numbers

- More electronegative element assigned negative
- Less electronegative element assigned positive

For now, we will assign oxidation states only to individual atoms.



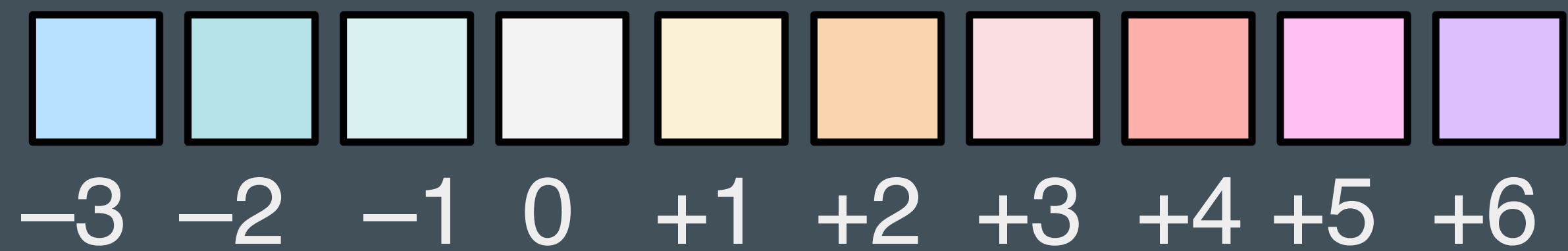
Example

Identify the oxidation state for each element in the below chemical equations.



Most Common Oxidation States

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra																
		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	
		Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	

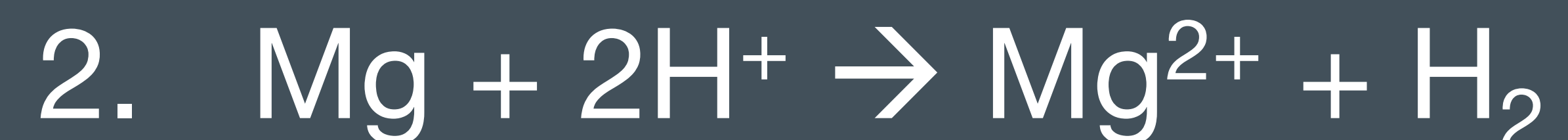


WARNING: this list is not at all, in any way, comprehensive.



Example – Reduction and Oxidation

Identify which species is oxidized and which species is reduced in the below chemical equations.



Who is the oxidizing agent?
Who is the reducing agent?
Who is the oxidant?
Who is the reductant?

Advanced: Oxidation states for whole molecules

In charge delocalized compounds (and those with multiple resonance structures) assigning an integer *formal oxidation state* (FOS) to single atoms is not very useful. But we can assign partial charges to atoms and a FOS for the whole molecular fragment instead.



Preview: electrochemical series

- More **electropositive** elements and compounds are stronger **reductants**
- More **electronegative** elements and compounds are stronger **oxidants**

H																	He
Li	Be										B	C	N	O	F	Ne	
Na	Mg										Al	Si	P	S	Cl	Ar	
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra																

*Generally, we must also consider electron counts and relative stabilities of whole compounds, but generally **electron poor compounds are more oxidizing***

La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr



Poll: what is the stronger oxidant?

Which do you expect to be the stronger oxidizing agent?

1. Cl_2 or Cl^-

2. N_2O_5 or N_2O

3. K_2FeO_4 or Fe_2O_3