Chem 1B Objective 13:
Apply oxidation-reduction reaction principles to batteries.

Key Ideas: Many important reactions are oxidation-reduction reactions: combustion, photosynthesis, biological reactions. Common oxidizing agents: bleach, hydrogen peroxide.

Oxidation – loss of electrons; reduction – gain of electrons

A battery (galvanic cell) converts chemical energy to electrical energy.

A battery involves a spontaneous chemical reaction ($\Delta G < 0$).

Two substances with different activity are connected together. Electrons move from the more active metal (anode - oxidation) to the less active metal (cathode - reduction).

OILRIG

http://www.businessinsider.com/baker-hughes-rig-count-may-29-2015-5

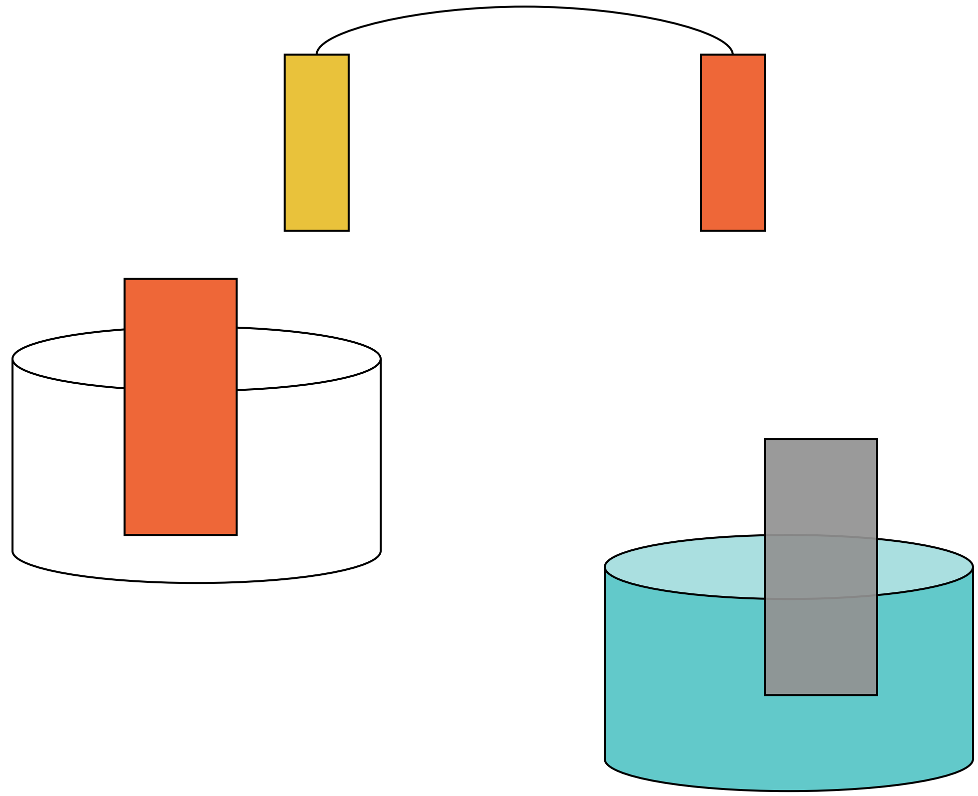
Oxidation Is Losing ….. Reduction Is Gaining
electrons electrons

Metals Tend to Lose Electrons
Different Metals Have a Different Ability (see Activity Series) to Lose Electrons

1. Connect one metal to another metal with a wire. What happens?

2. A piece of Cu metal is placed into Zn^{2+} (aq). What happens? Why?

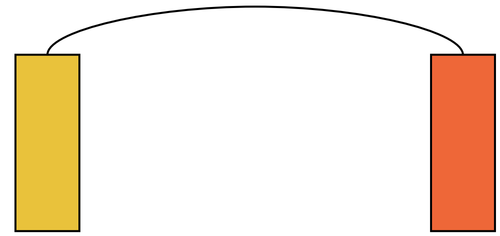
3. A piece of Zn metal is placed into Cu^{2+} (aq). What happens? Why?



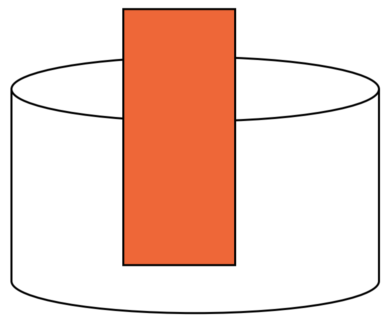
Write molecular equation and net ionic equation.
ID oxidizing and reducing agents.
Which reaction is spontaneous? Why?

Metals Tend to Lose Electrons
Different Metals Have a Different Ability (see Activity Series) to Lose Electrons

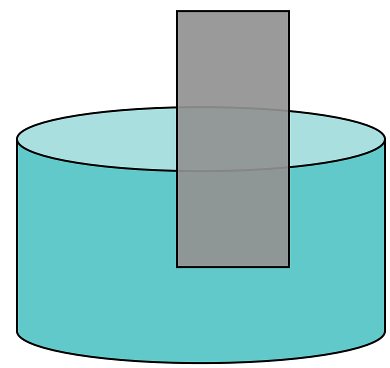
1. Connect one metal to another metal. e^- flows from more active to less active metal.



2. A piece of Cu metal is placed into Zn^{2+} (aq). No Reaction



3. A piece of Zn metal is placed into Cu^{2+} (aq). Cu metals is plated onto the Zn.



Zn (s) +	$CuSO_4$ (aq)	----> Cu (s)	+ $ZnSO_4$ (aq)	molecular eq.
Zn (s) +	Cu^{2+} (aq)	----> Cu (s)	+ Zn^{2+} (aq)	net ionic eq.
Oxidized	reduced			
Reducing agent	oxidizing agent			

An **<u>Active</u>** **<u>Metal</u>** is a Metal that ***Easily*** Gives Up (Loses) its e^-.

Using The *<u>Activity Series of Metals</u>* (Chang, Fig. 4.14, p. 114):

- Reducing agent has a partner Oxidizing agent
- Reducing agents are listed from strongest to weakest; Oxidizing agents are listed from weakest to strongest.
- A Reducing agent reacts with any Oxidizing agent below it or an Oxidizing agent reacts with any Reducing agent ______ it.
- Predict the products of an oxidation-reduction reaction.

	<u>Metal</u> (Reducing Agent)	--->	<u>Metal Ion</u> (Oxidizing Agent)	
Strongest	Li	--->	Li^+	Weakest
(Best giver)	Zn	--->	Zn^{2+}	
	Fe	--->	Fe^{2+}	
	H_2	--->	H^+	
	Cu	--->	Cu^{2+}	
	Ag	--->	Ag^+	
Weakest	Au	--->	Au^+	Strongest (Best taker)

Activity Series with Numbers ($\Delta G = -nFE$)

Standard Reduction Potentials

Increased ability to be reduced

Element	Reduction Reaction	Standard Reduction Potential E^{o}_{red} (in volts)
Potassium	$K^+(aq) + e^- \rightarrow K(s)$	-2.93
Calcium	$Ca^{2+}(aq) + 2e^- \rightarrow Ca(s)$	-2.87
Sodium	$Na^+(aq) + e^- \rightarrow Na(s)$	-2.71
Magnesium	$Mg^{2+}(aq) + 2e^- \rightarrow Mg(s)$	-2.37
Aluminum	$Al^{3+}(aq) + 3e^- \rightarrow Al(s)$	-1.66
Zinc	$Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$	-0.76
Iron	$Fe^{2+}(aq) + 2e^- \rightarrow Fe(s)$	-0.44
Lead	$Pb^{2+}(aq) + 2e^- \rightarrow Pb(s)$	-0.13
*Hydrogen	$2H^+(aq) + 2e^- \rightarrow H_2(g)$	0.00
Copper	$Cu^{2+}(aq) + e^- \rightarrow Cu^+(aq)$	0.15
Silver	$Ag^+(aq) + e^- \rightarrow Ag(s)$	0.80
Gold	$Au^{3+}(aq) + 3e^- \rightarrow Au(s)$	1.50

*Hydrogen is the standard reference electrode

http://www.expertsmind.com/questions/define-standard-reduction-potential-30159762.aspx

Gold would rather be an ion. True False

K^+ (aq) wants to gain an electron. True False

If the reducing agent is strong, its partner oxidizing agent is _____. Relate to thermo.

Oxidation-Reduction Reactions Involve the Transfer of Electrons

a. Name 2 common oxidizing agents.

Oxygen, ozone, bleach, hydrogen peroxide, KMnO4, ..

b. Name 2 common reducing agents.

Metal elements, $NaBH_4$, Vitamin C, $C_2O_4^{2-}$, ..

Oxidizing Agents and Reducing Agents Have a Different Ability to Gain or Lose Electrons (See Table 19.1 Standard Reduction Potentials)

Rank the following common oxidizing agents in order of strength. Give reasons for your ranking.

http://livingwithchemicals.homestead.com/HydrogenPeroxideAndItsManyUses.html

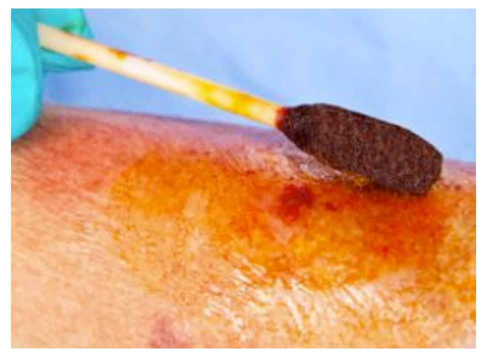
hydrogen peroxide (H_2O_2)

http://www.gonebythehour.com/category/home-brewing/

bleach (NaClO)

http://www.gerimedix.com/category/masks/

oxygen (O_2)



http://www.globalhealingcenter.com/natural-health/uses-for-iodine/

iodine (I_2)

Oxidizing Agents and Reducing Agents Have a Different Ability to Gain or Lose Electrons (See Table 19.1 Standard Reduction Potentials)

Rank the following common oxidizing agents in order of strength. Give reasons for your ranking.

Half Reaction	E^o, V
H_2O_2 (aq) + 2 H^+ (aq) + 2 e^- ---> 2 H_2O	+1.77
HClO (aq) + H^+ (aq) + 2 e^- ---> Cl^- (aq) + H_2O	+1.49
O_2 (g) + 4 H^+ (aq) + 4 e^- ---> 2 H_2O	+1.23
I_2 (s) + 2 e^- ---> 2 I^- (aq)	+0.53

Oxidizing Agents and Reducing Agents Have a Different Ability to Gain or Lose Electrons (See Table 19.1 Standard Reduction Potentials)

Due to its unreactiveness and other properties, gold (Au) is considered a noble metal.

http://www.clipart.dk.co.uk/136/az/Crystal__Gems/Gold_nugget

Which of the four oxidizing agents will oxidize Au?

Bleach, H_2O_2, O_2, I_2.

Write a balanced chemical equation to show your answer. (If more than one oxidizing agent oxidizes Au, choose one oxidizing agent and write one balanced chemical equation to show your answer.)

Oxidizing Agents and Reducing Agents Have a Different Ability to Gain or Lose Electrons (See Table 19.1 Standard Reduction Potentials)

Rank the following common oxidizing agents in order of strength. Give reasons for your ranking.

Half Reaction	E^o, V
H_2O_2 (aq) + 2 H^+ (aq) + 2 e^- ---> 2 H_2O	+1.77
Au^{3+} (aq) + 3 e^- ---> Au (s)	+1.50
HClO (aq) + H^+ (aq) + 2 e^- ---> Cl^- (aq) + H_2O	+1.49
O_2 (g) + 4 H^+ (aq) + 4 e^- ---> 2 H_2O	+1.23
I_2 (s) + 2 e^- ---> 2 I^- (aq)	+0.53

<u>Gold</u> (and other nobel metals) are very **<u>unreactive</u>**. Is there a substance that dissolves gold?

Aqua Regia ("royal water") = 1 part concentrated HNO_3 to 3 parts concentrated HCl

CEN, 4/4/11, p. 11 Organic ***aqua regia*** <u>*selectively*</u> dissolves noble metals:
1:20 $SOCl_2$ - dimethylformamide dissolves Au but not Pd and Pt
3:1 $SOCl_2$ - pyridine dissolves Au and Pd but not Pt

Gold mining uses ***cynanide*** (http://en.wikipedia.org/wiki/Gold_cyanidation)
$4\ Au + 8\ NaCN + O_2 + 2\ H_2O \dashrightarrow 4\ Na[Au(CN)_2] + 4\ NaOH$
Cyanide also used in Cu, Zn, and Ag mining.

How can you get the gold back?

Balancing Redox Reactions

E.g., H_2O_2 oxidizes Au

Half Reactions Method

Acid solution: add H_2O and H^+

Base solution: add H_2O and OH^-

see Chang, p. 676, 19.2c and a

Trick to balancing redox reactions: Use reduction potentials table

H_2O_2 (aq) + 2 H^+ (aq) + 2 e^- ---> 2 H_2O E = 1.77V

Au^{3+} (aq) + 3 e^- ---> Au (s) *REVERSE* this equation E = 1.50V

Au (s) ---> Au^{3+} (aq) + 3 e^- E = -1.50V

of e^- lost = # of e^- gained so multiply 1st eq. by 3 and 2nd by 2

3 H_2O_2 (aq) + 6 H^+ (aq) + 6 e^- ---> 6 H_2O E = 1.77V

2 Au (s) ---> 2 Au^{3+} (aq) + 6 e^- E = -1.50V

3 H_2O_2 (aq) + 6 H^+ (aq) + 2 Au (s) ---> 2 Au^{3+} (aq) + 6 H_2O

E = 1.77V + (-1.50V) = 0.27 V

$\Delta G = -nFE < 0$ spontaneous

<u>Electrochemistry involves chemical energy and electrical energy</u>

A **<u>Voltaic Cell</u>** Uses Chemical Energy to Make Electrical Energy
An **<u>Electrolytic Cell</u>** Uses Electrical Energy to Make a Chemical Reaction Occur

Cell voltage (E_{cell}) is related to ΔG: $\Delta G = -n F E_{cell}$
where n = moles of e- transferred, F = Faraday's constant = 96,500 C/mole

a. Which cell type produces energy?
b. Which type involves a spontaneous reaction?
c. Which type requires energy?
d. Which type has a positive E_{cell}?
e. Which type requires a salt bridge to separate the anode from cathode?

Current is like the size of a water pipe (broadband vs. dial-up)

Voltage is like ______

Electricity Terms:

Charge of an electron = 1.6×10^{-19} Coulombs

Energy = charge x voltage $E = Q \times V$

Units: Joule = Coulombs x volts

Current = charge / time $I = Q / t$

Units: Amperes = Coulombs/ sec

Voltage = current x resistance $V = I \times R$

Units: Volts = Amperes x Ohms

Power = Energy / time $P = E / t$

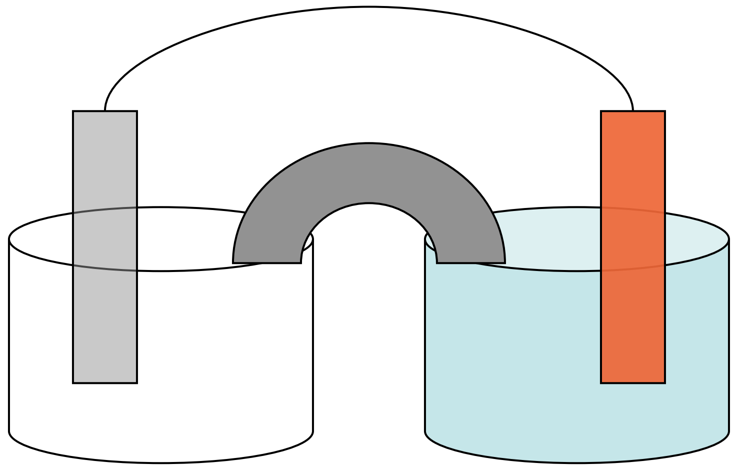
= current x voltage $P = I \times V$

Units: Watts = J / sec = Amperes x volts

Objective: How to make a battery?

"Connect one metal to another metal with a wire."

How to use this to make a battery? (Daniell cell)



Label the following: Zn, Zn^{2+} (aq), Cu, Cu^{2+} (aq), anode, cathode, (+) electrode, (-) electrode

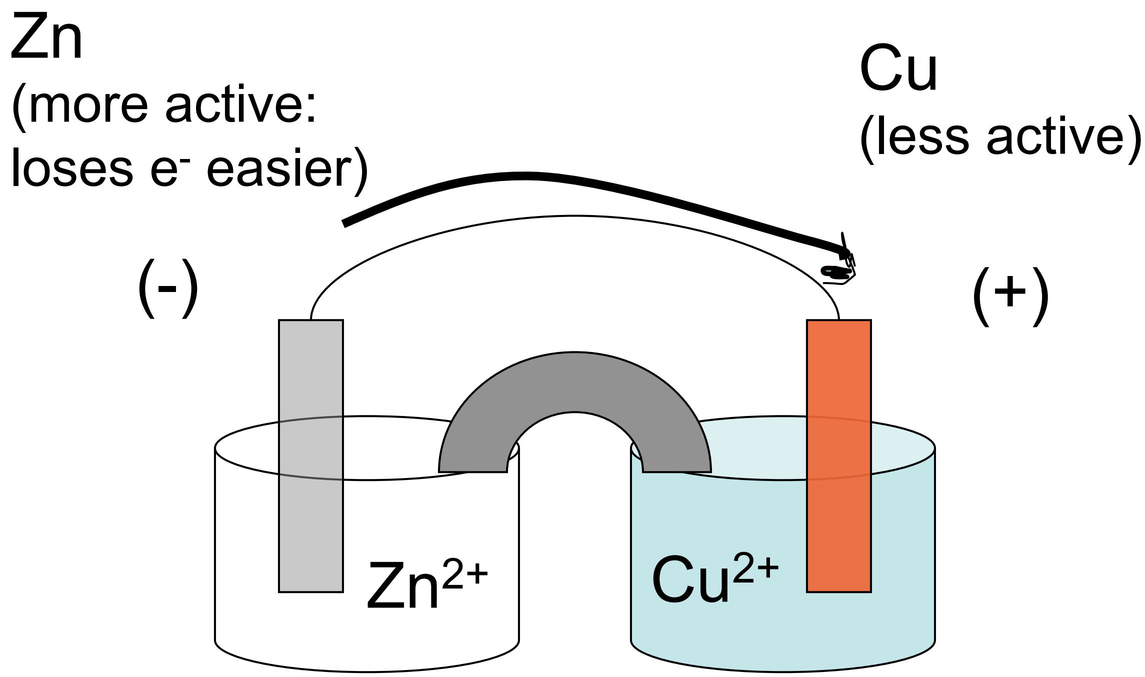
Show: direction electron current flows, the half-reaction at each electrode, overall cell reaction

Cu/Zn cell animation:

http://www.mhhe.com/physsci/chemistry/animations/chang_2e/galvanic_cell.swf

Salt bridge: http://itech.pjc.edu/eurbansky/saltbridge.pdf

Zn/Cu Battery



<u>Oxidation:</u>
$Zn \dashrightarrow Zn^{2+} + 2\,e^-$

<u>Reduction</u>:
$Cu^{2+} + 2\,e^- \dashrightarrow Cu$

Overall cell reaction: $Zn + Cu^{2+} \dashrightarrow Zn^{2+} + Cu$

Objective: How much *voltage does the Zn/Cu battery* (Daniell cell) produce?

Look up the Standard ***Reduction*** **Potentials** (Table 19.1).
Note: ***reverse*** the oxidation reaction to make a reduction.

$Cu^{2+} + 2\ e^- \text{--->} Cu\ (s)$ $\qquad E^o = +\ 0.34\ V$

$Zn^{2+} + 2\ e^- \text{--->} Zn\ (s)$ $\qquad E^o = -\ 0.76\ V$

Method 1: $E_{cell} = E_{cathode} - E_{anode}$ (cathode = reduction)

$E_{cell} = +\ 0.34\ V - (-0.76\ V)$ (anode = oxidation)

$= +\ 1.10\ V$

Zn/Cu battery produces 1.10V of electrical energy

<u>Objective</u>: How much *<u>voltage does the Zn/Cu battery</u>* (Daniell cell) produce?

<u>Method 2</u>: reverse reaction --> change sign of E^o

oxidation half rxn: $Zn\ (s) \longrightarrow Zn^{2+} + 2\ e^-$ $\quad E^o = + 0.76\ V$

$$E_{cell} = E_{reduction} + E_{oxidation}$$

$$E_{cell} = + 0.34\ V + 0.76\ V$$

$$= + 1.10\ V$$

Electrochem is an application of Thermo:

$$\Delta G = - n F E$$

where n = moles of e- transferred, F = Faraday's constant = 96,500 C/mole

Battery reaction is **<u>spontaneous</u>** and **<u>produces energy</u>**

so $\Delta G < 0$

For a battery, E_{cell} is

(i) positive (ii) negative (iii) depends

A battery ____ energy.

a. supplies b. Produces c. Gives

For a battery, ΔG is _____.

a. > 0 b. < 0 c. $= 0$

As A Battery Discharges, The Voltage Drops

A Cu/Zn voltaic cell produces 1.10 V as long as [Cu^{2+}] and [Zn^{2+}] are 1 M and T = 25^{o}C (*standard state* conditions)

As the battery discharges,
what happens to the Zn and Cu electrodes?
(i) Zn gets bigger and Cu gets smaller
(ii) Zn gets smaller and Cu gets bigger
(iii) No change

What happens to [Cu^{2+}] and [Zn^{2+}]?
(i) [Zn^{2+}] increases and [Cu^{2+}] decreases
(ii) [Zn^{2+}] decreases and [Cu^{2+}] increases
(iii) No change

Draw a picture of a discharging battery.
What is a "dead" battery"?

Objective: use the Nernst equation to calculate voltage Under non-standard state conditions, Use the **Nernst Equation** to calculate E_{cell} (for discharging battery).

$$E_{cell} = E^o_{cell} - \frac{RT}{nF} \ln \frac{[\text{products}]}{[\text{reactants}]}$$

a. Calculate the cell voltage when 10% of the reactants have been consumed.

	$Zn\ (s)\ +\ Cu^{2+}\ (aq)$	$\longrightarrow Zn^{2+}\ (aq)\ +\ Cu\ (s)$
Initial	1 M	1 M
Reacts	0.1 M	0.1 M produced
Left over	0.9 M	1.1 M

b. Calculate the cell voltage when 50% of the reactants have been consumed.

c. Calculate the cell voltage when 90% of the reactants have been consumed.

d. Calculate the concentration of reactants when a Cu/Zn battery disharges to 1.0 V.

Alkaline Batteries

https://en.wikipedia.org/wiki/Alkaline_battery

Can't be recharged (primary battery)

Parts: (http://www.energizer.com/learning-center/Pages/how-batteries-work.aspx)

Container:	steel can
Electrodes:	Zn and MnO_2
Separator:	non-woven, fibrous fabric
Electrolyte:	KOH (aq)
Collector:	brass pin in middle of cell that conducts electricity to outside circuit

$$Zn(s) + 2OH^-(aq) \rightarrow ZnO(s) + H_2O(l) + 2e^- \qquad E° = 1.28\ V$$
$$2MnO_2(s) + H_2O(l) + 2e^- \rightarrow Mn_2O_3(s) + 2OH^-(aq) \quad E° = +0.15\ V$$

Overall reaction: $Zn(s) + 2MnO_2(s) \rightarrow ZnO(s) + Mn_2O_3(s)$

What is the cathode? What is being oxidized?
How much voltage does this battery produce?

Primary battery = not rechargeable
Secondary battery = rechargeable

The **Lead Acid Battery** In Cars **is Rechargeable**

Electrodes: Pb and PbO_2

Electrolyte: 18 M H_2SO_4

a. Why is a car battery 12 V?
b. Calculate the cell voltage for a Pb/PbO_2 cell under standard state conditions.
c. For a car battery, [H_2SO_4] = 18 M. Calculate the cell voltage under these conditions.
d. Which metal, Pb or PbO_2, is the anode? Why?
e. A car battery is rechargeable. Why? If a car battery is rechargeable, why doesn't it last forever?

The **Lead Acid Battery** In Cars **is Rechargeable**
Electrodes: Pb and PbO_2
Electrolyte: 18 M H_2SO_4

$PbO_2 + 4\ H^+ + SO_4^{2-} + 2\ e^- \text{--->} PbSO_4 + 2\ H_2O$ E = 1.69 V

$PbSO_4 + 2\ e^- \text{--->} Pb + SO_4^{2-}$ E = -0.35 V

$Pb + PbO_2 + 2\ H_2SO_4 \rightarrow 2\ PbSO_4 + 2\ H_2O$ E_{cell} = ?

$$E_{cell} = E^o_{cell} - \frac{RT}{nF} \ln \frac{[\text{products}]}{[\text{reactants}]}$$

H_2SO_4 = 18 M, so E_{cell} = ??

Electric Cars Run On Pb Acid Batteries

In 1996, GM produced the first electric car.
Range = 90 miles.
Battery rating = 200 amp hr.
a. Calculate the mass of Pb, PbO_2, and H_2SO_4 to make a 200 amp hr battery.
b. Calculate battery range.

<u>Solution</u>: 1 amp hr = 3600 C; 200 amp hr = $7.2\text{x}10^5$ C
n = $Q/\mathcal{F}$ = $7.2\text{x}10^5$ C/96,500 C/mole = 7.46 moles of electrons
7.46 moles electrons x 1 mole Pb/2 moles electrons =
  3.73 moles Pb x 207.2 g/mole = 773 g Pb
7.46 moles electrons x 1 mole PbO_2/2 moles electrons =
  3.73 moles PbO_2 x 239.2 g/mole = 892 g PbO_2
7.46 moles electrons x 1 mole H_2SO_4/1 moles electrons =
  7.46 moles H_2SO_4 x 98 g/mole = 731 g H_2SO_4

$$ To Be Made In Batteries For Electric Cars:

2023: 230,000 electric vehicles sold (predicted) = **$3.2 billion**
2014: 90,000 electric vehicles sold (CEN, 7/14/14, p. 12)

Nissan Leaf
$29,000
Battery range: 84 miles

Tesla Model S
$71,000
Battery weight: 670 kg
Range: 250 miles
Accounts for about ½ cost of car
http://evobsession.com/electric-cars-2014-list/

New Battery Technology Uses Low Atomic Weight Substances

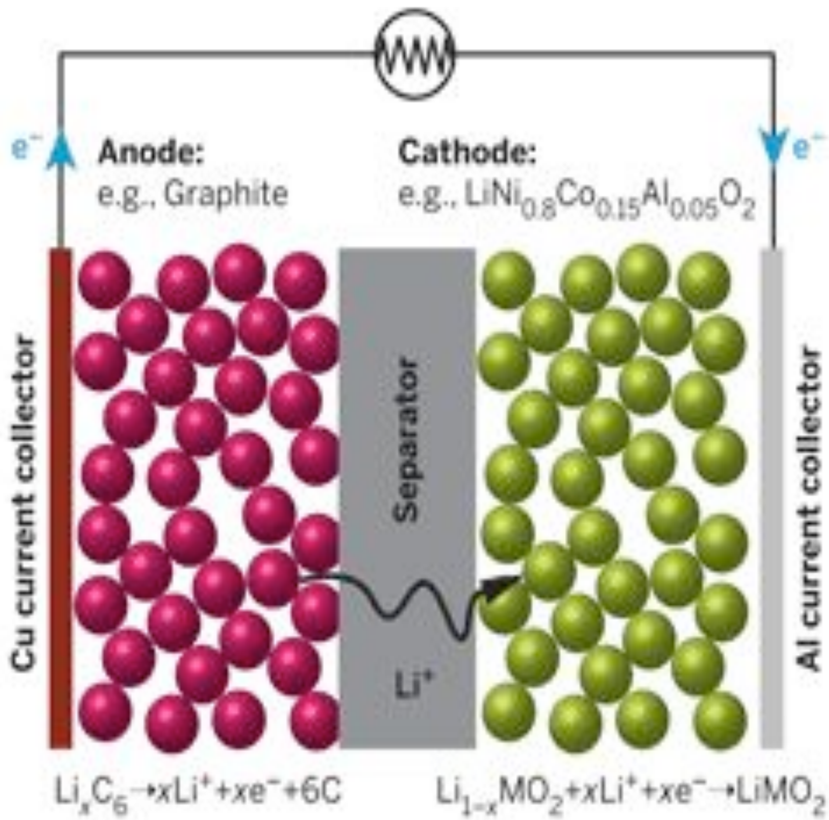
Battery range ≈ Σ(atomic weight of reacting elements)/number of electrons produced in reaction.
Lowest At.Wt./electron gives greatest range.

Battery	Anode	Cath-ode	Reaction	Battery Range, amu/electron
Lead Acid	Pb	PbO_2	$Pb + PbO_2 + 2\ H_2SO_4 \rightarrow 2\ PbSO_4 + 2\ H_2O$	(207+239+196) /2 = 321
Sodium-Sulfur	Na	S	$2\ Na + 3\ S \rightarrow Na_2S_3$	(46+96)/2 = 71
Lithium Polymer	V_6O_{13}	Li	$18\ Li + 5\ V_6O_{13} \rightarrow V_{30}O_{65}Li_{18}$	(126+2570)/18 = 150

What is the advantage of using low atomic weight substances in batteries?

IN THE FLOW

In a rechargeable lithium-ion battery, lithium ions move from the anode and cathode when providing power to a device. During charging, the ions move from the cathode to the anode. Anode, cathode, and separator materials can be changed to alter battery performance.



Rechargeable Li^+ Batteries are used in computers, cell phones, electric cars (CEN, 7/27/09, p. 24; 10/3/11, p. 18; 2/6/12, p. 18)

Anode: graphite

Li_xC_6 --> x Li^+ + x e^- + 6 C

Cathode: $LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$

$Li_{1-x}MO_2$ + x Li^+ + x e^- --> $LiMO_2$

e.g., M = Co

http://en.wikipedia.org/wiki/Lithium-ion_battery

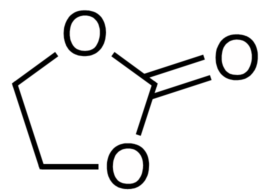
Electrolytes: blends of lithium salts ($LiPF_6$), solvents (cyclic and linear carbonates - **flammable**!), and proprietary additives.

CEN, 9/20/10, p. 6. Paper Li ion batteries: metal-containing Li compound on top of C nanotubes deposited on both sides of sheet of paper.

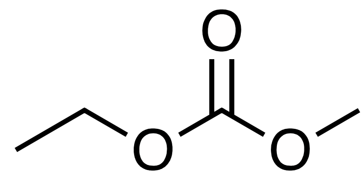
http://cen.acs.org/articles/91/i15/Preventing-Battery-Fires.html

Preventing Battery Fires: Novel electrolytes could solve flammability problems that grounded Boeing Dreamliners

Currently, Li-ion batteries use **flammable** organic solvents, such as ethylene carbonate and ethyl methyl carbonate, for the electrolyte solutions.

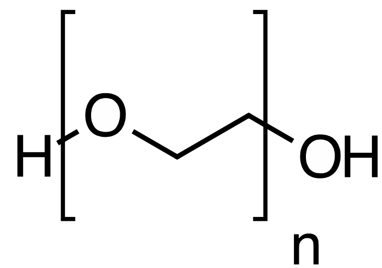


Li^+



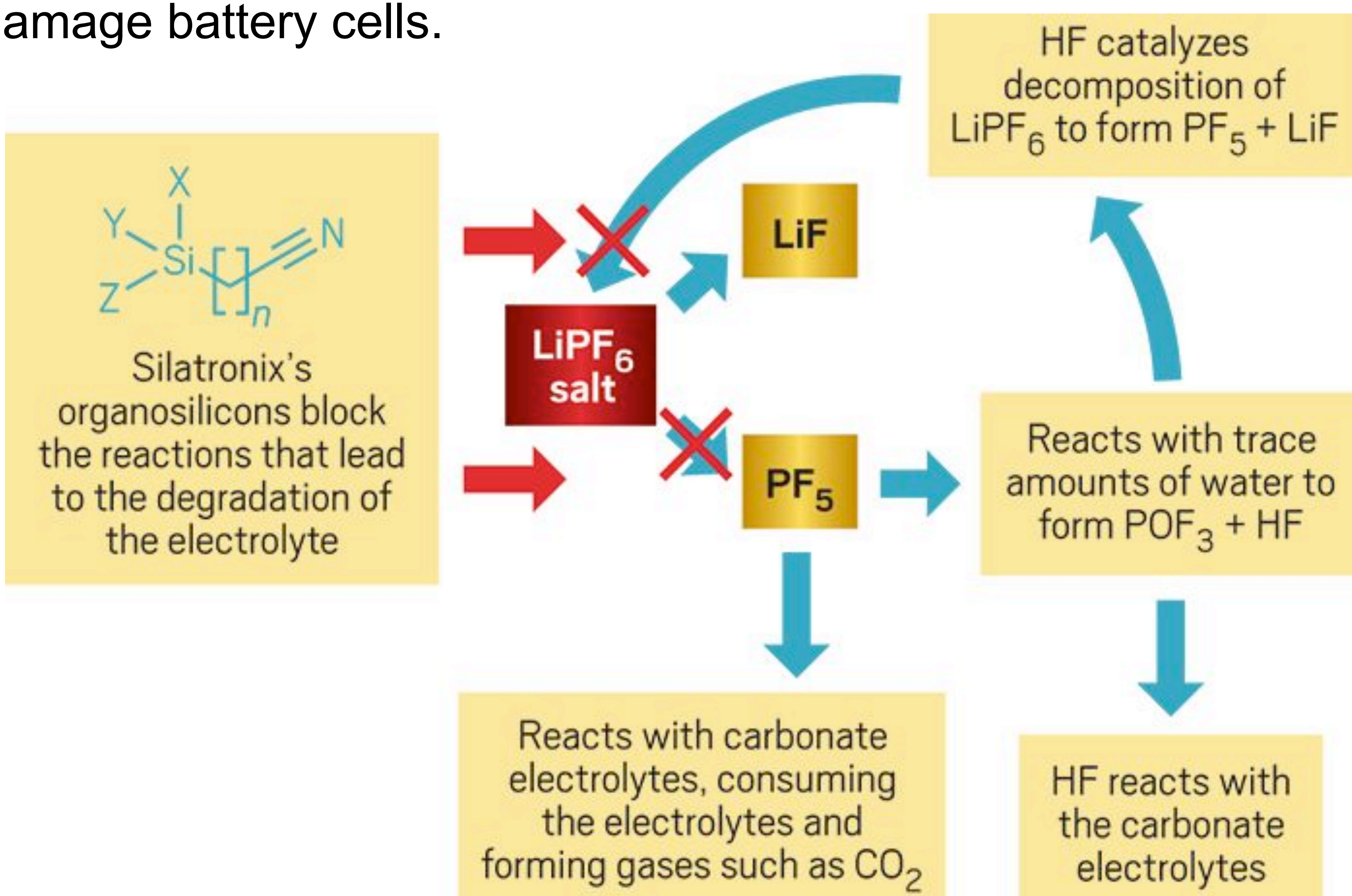
New electrolyte system is based on a mixture of **nonflammable** perfluoropolyethers and either poly(ethylene oxide) or polyethylene glycol.

$F\text{-}(CF(CF_3)\text{-}CF_2\text{-}O)_n\text{-}CF_2CF_3$



Silatronix makes Li ion batteries safer and more reliable
http://cen.acs.org/articles/94/i43/Silatronix.html

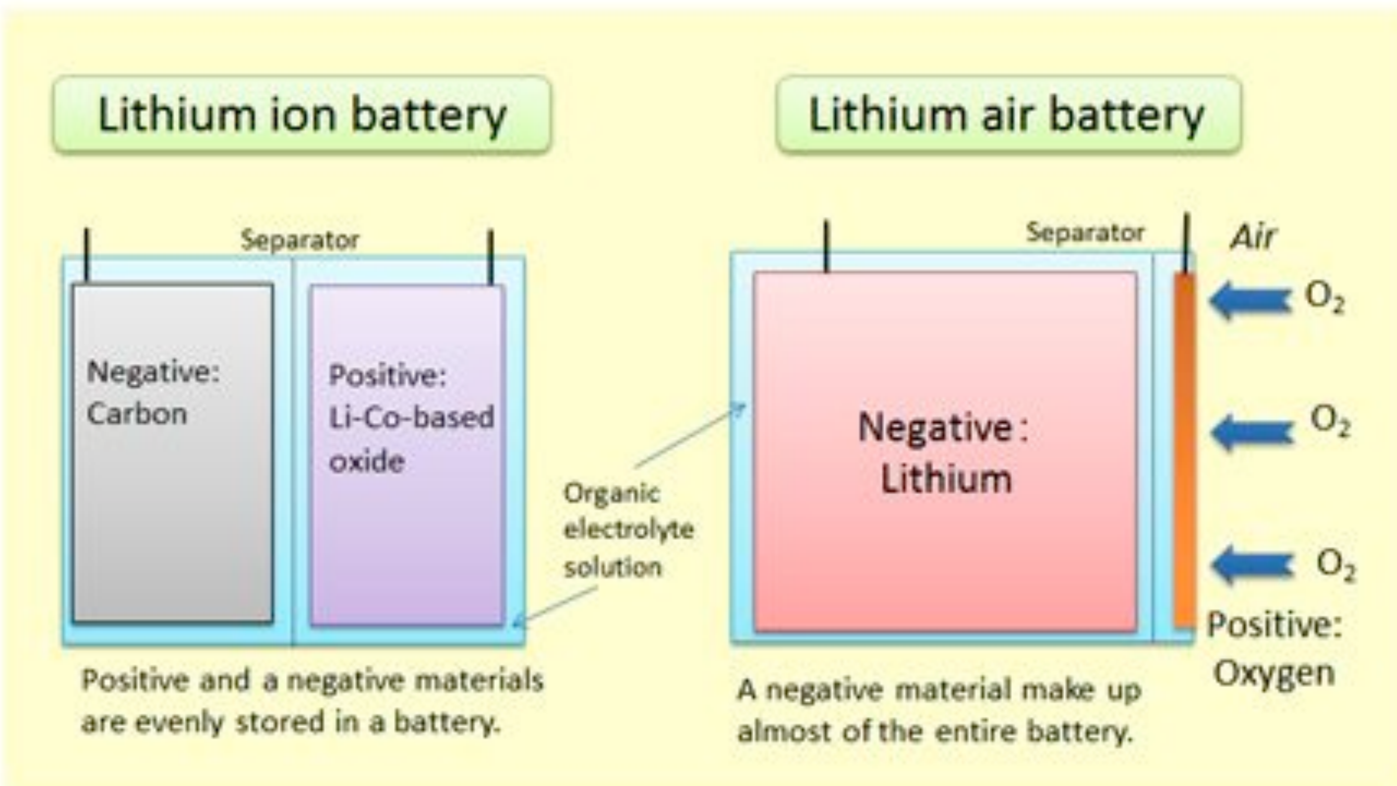
Organosilicon compound inhibits unwanted reactions that damage battery cells.



http://spectrum.ieee.org/nanoclast/green-tech/advanced-cars/nanoscale-peak-at-lithiumair-batteries-promise-better-electric-vehicles

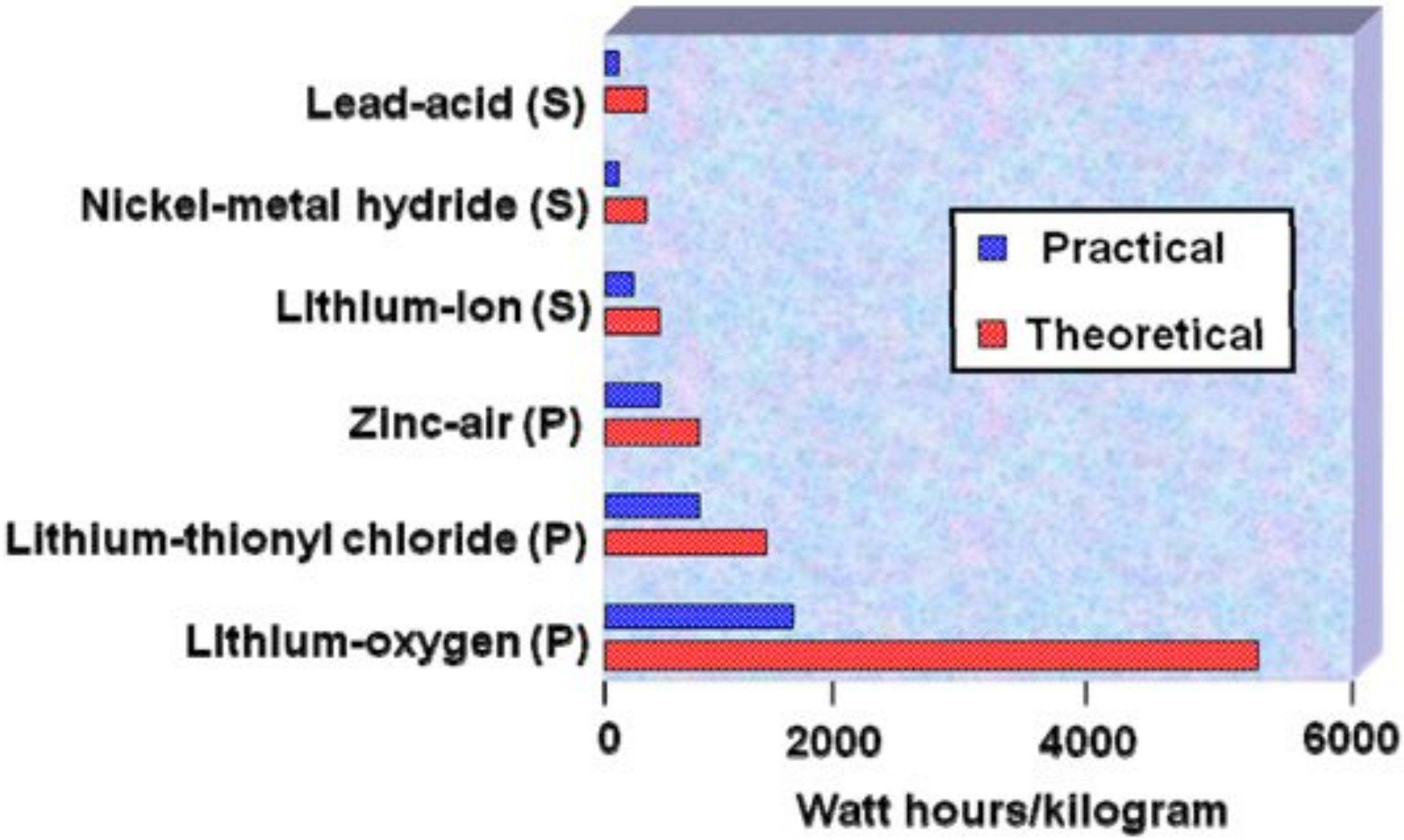
Lithium-air battery has 5 to 10x the energy density of a Li ion battery

But various technical challenges: short lifetimes, low # of charging cycles.



http://www.ntt.co.jp/inlab/kankyo/eng/research/1_lithium-air/index.html

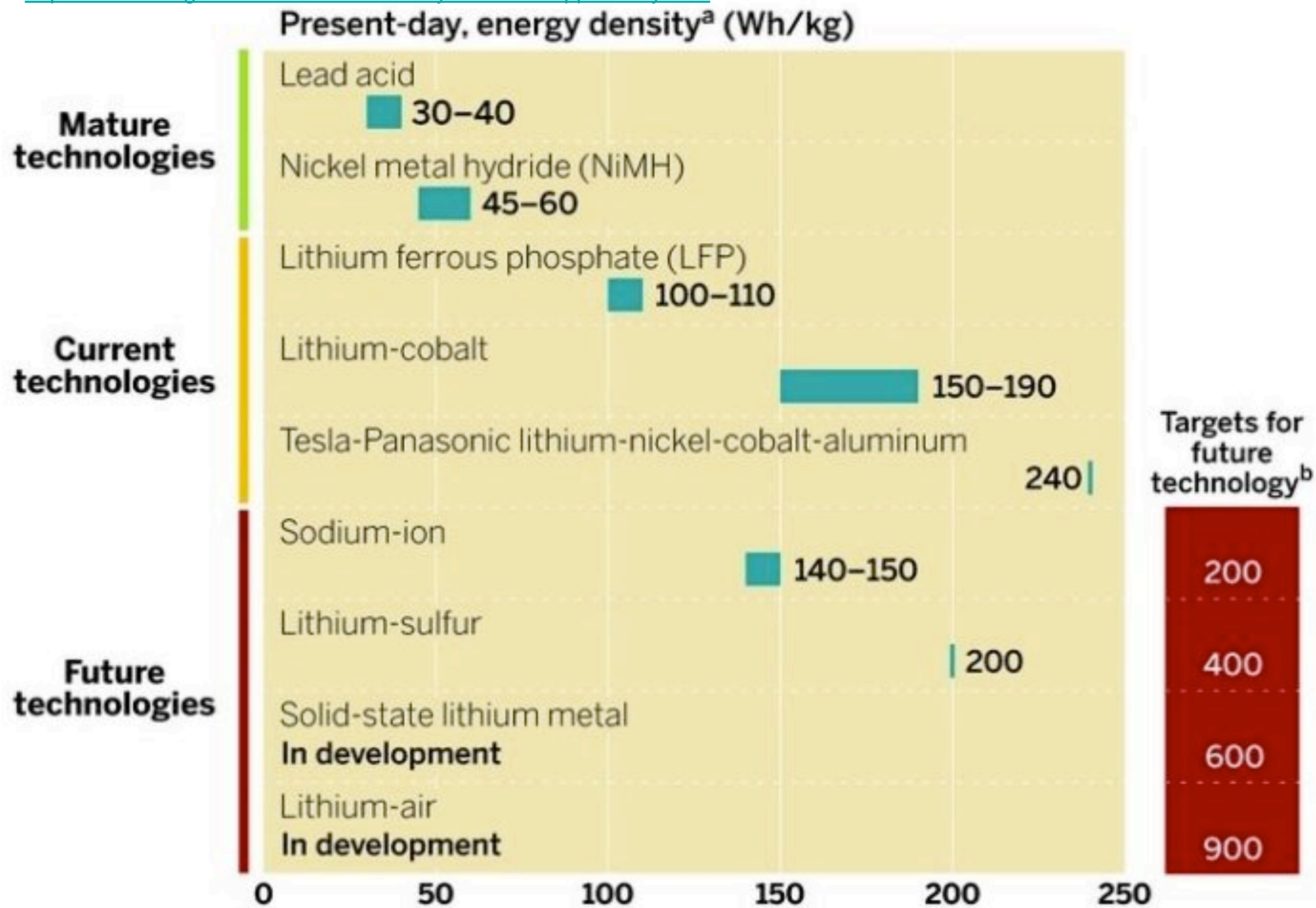
Comparison of Amount of energy stored per kg of battery



http://www.mmi.org/memlabattery.html

Another Comparison of Amount of energy stored per kg of battery

http://cen.acs.org/articles/92/i28/Chemistrys-Electric-Opportunity.html



http://cen.acs.org/articles/91/i49/Researchers-Design-Lithium-Sulfur-Batteries.html

Lithium-Sulfur Batteries theoretically could store ***FOUR TIMES*** as much energy as conventional lithium-ion batteries.

Anode: Li

Cathode: S (substitute graphene oxide coated with sulfur)

Electrolyte: conventional organic solvent mixed with ionic liquid, which prevents S from leaching from the cathode

A test battery made with these materials could be charged and discharged 1,500 times with little degradation in performance.

Its initial energy-storage capacity was 500 watt-hours per kilogram of battery material.

After 1,000 cycles, the storage capacity dropped to 300 Wh/kg.

Conventional lithium-ion batteries store about 200 Wh/kg, and the U.S. Department of Energy's target for electric vehicle batteries is 400 Wh/kg.

Pb Acid Battery Stores the Least Energy per kg Because Pb is Heavy!

http://electronics.howstuffworks.com/battery4.htm
http://www.allaboutbatteries.com/Battery-Energy.html

Fuel Source	Amount of energy stored/kg of battery:
Pb acid	35 W hr/kg (1 W hr = 3600 J)
Ni-Cd	55
Na-S	85
Li polymer	160
gasoline-air	12,192

Which fuel source stores the most energy per kg?
Which fuel source is the best for your $?

Battery Types

Battery	anode	cathode	electrolyte
Lead acid	Sponge metallic lead	Lead dioxide (PbO_2)	H_2SO_4 (aq)
	$Pb + SO_4^{2-} \text{-->} PbSO_4 + 2\ e^-$	$PbO_2 + SO_4^{2-} + 4\ H^+ + 2$ e- $\text{-->} PbSO_4 + 2\ H_2O$	
Alkaline cell	Zinc powder	Manganese dioxide (MnO_2) powder	KOH
	$Zn + OH^- \text{-->} ZnO + 2\ H_2O + 2\ e^-$	$2\ MnO_2 + 2\ H_2O + 2\ e^- \text{--->} Mn_2O_3 + 2\ OH^-$	
Nickel/cadmium	cadmium	Nickel oxyhydroxide (NiOOH)	KOH
	$Cd + 2\ OH^- \text{-->} Cd(OH)_2 + 2\ e^-$	$2\ NiOOH + 2\ H_2O + 2\ e^- \text{--->} 2\ Ni(OH)_2 + 2\ OH^-$	
Nickel/metal hydride (NIMH)	Rare earth or nickel alloys with many metals	Nickel oxyhydroxide	KOH
	$MH + OH^- \text{-->} M + H_2O + e^-$	$NiOOH + H_2O + e^- \text{--->} Ni(OH)_2 + OH^-$	
Zinc/air	Amalgamated zinc powder and electrolyte	Oxygen (O_2)	
	$Zn + 4\ OH^- \text{-->} Zn(OH)_4^{2-} + 2\ e^-$	$\frac{1}{2}\ O_2 + H_2O + 2\ e^- \text{--->} 2\ OH^-$	
Solid cathode lithium	Lithium	Heat treated MnO_2	Propylene carbonate and 1,2-dimethoxyethane
	$Li \text{--->} Li^+ + e^-$	$MnO_2 + Li^+ + e^- \text{--->} Mn(III)O_2(Li^+)$	
Lithium ion	Carbon compound	Lithium oxide	$LiPF_6$
	Based on “intercalation”	Intercalation – the reversible insertion of guest atoms like lithium into host solids like the battery electrode materials.	

CA plans to get one-third of its electricity from wind and solar energy by 2020
(http://www.npr.org/2013/12/11/250043599/big-batteries-needed-to-make-fickle-wind-and-solar-power-work)

PG&E uses Sodium-Sulfur batteries to store electricity from solar and wind
batteries are NOT very efficient (waste about 25 percent of the energy in the process of being charged and discharged)
need to be heated to 600 degrees Fahrenheit to work
Expensive: $10 million

CA plans to get one-third of its electricity from wind and solar energy by 2020

12/23/13 "Could Big Batteries Be Big Business In California?" (http://www.npr.org/2013/12/23/250031679/could-big-batteries-be-big-business-in-california)
California Public Utilities Commission has called on utilities and private companies to install about $5 billion worth of batteries and other forms of energy storage to help the state power grid cope with the erratic power supplied by wind and solar energy.

Stem (Millbrae, CA). makes storage batteries that helps reduce electricity bills for businesses.

CA plans to get one-third of its electricity from wind and solar energy by 2020

5/1/15 Tesla Home Battery: Powerall (http://www.teslamotors.com/powerwall)

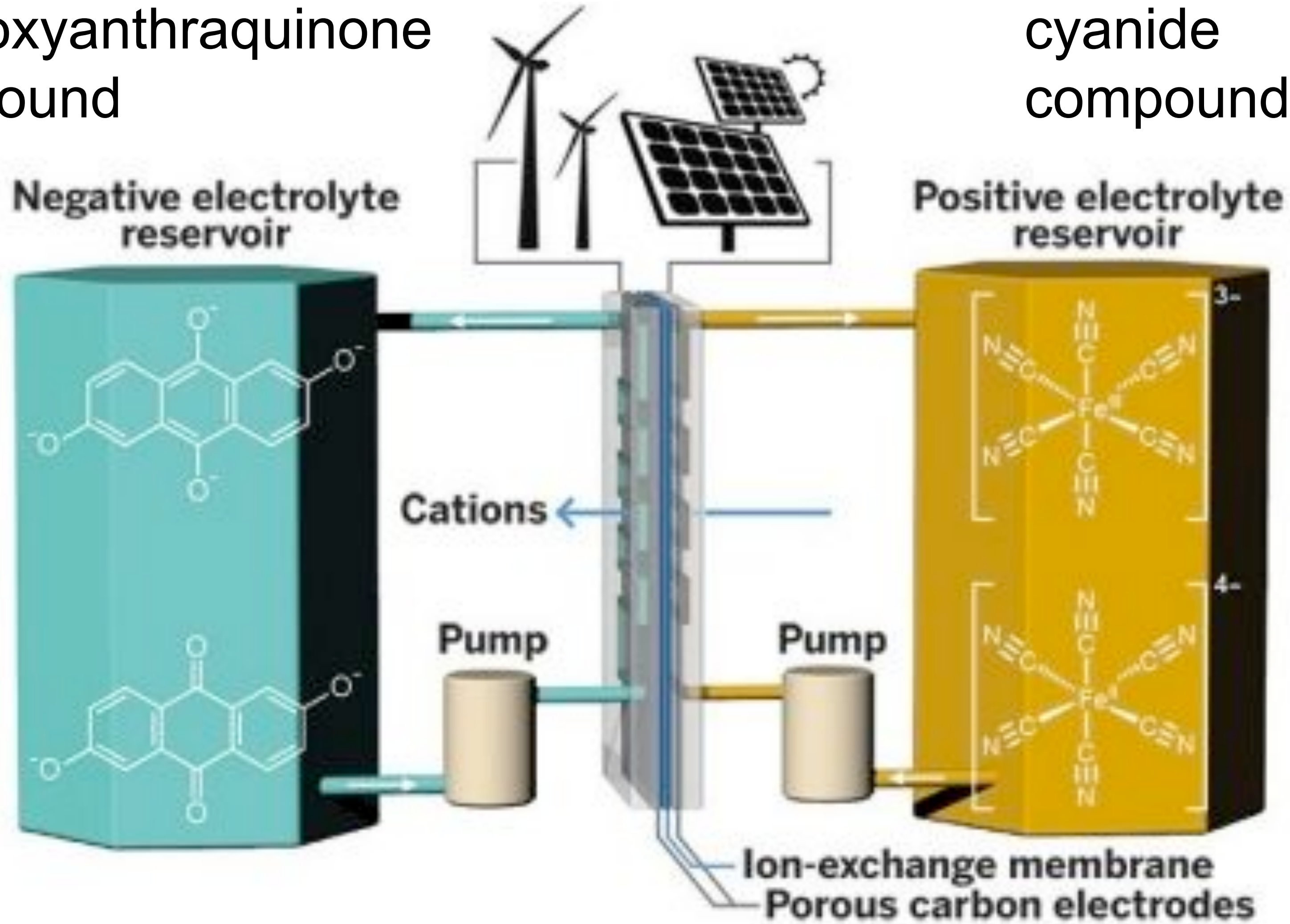
"Powerwall is a home battery that charges using electricity generated from solar panels, or when utility rates are low, and powers your home in the evening. It also fortifies your home against power outages by providing a backup electricity supply. Automated, compact and simple to install, Powerwall offers independence from the utility grid and the security of an emergency backup."

Redox flow battery could store energy from wind and solar

http://cen.acs.org/articles/94/i6/Redox-Flow-Batteries-Stabilize-Electric.html

Reduce dihyroxyanthraquinone compound

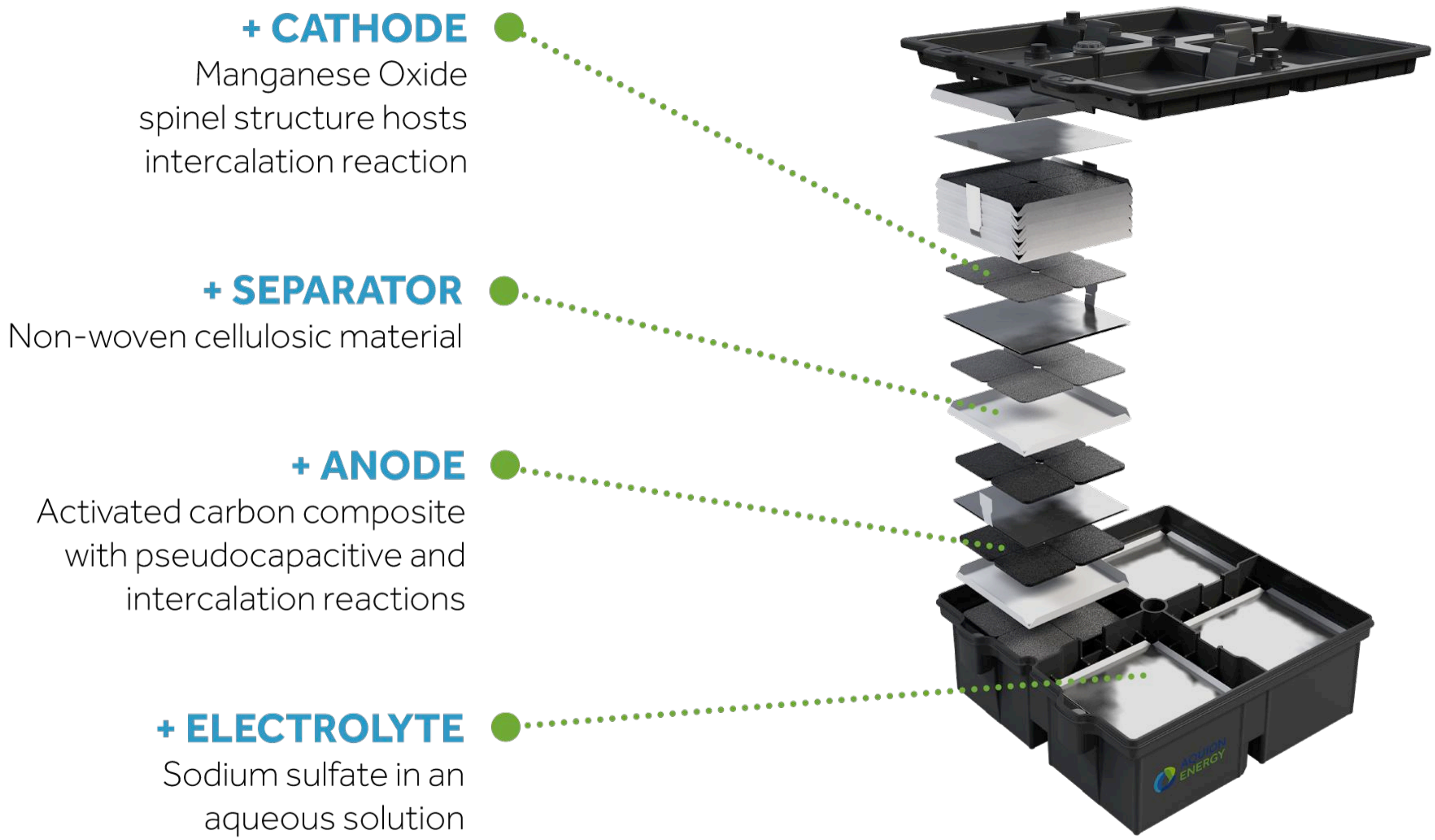
Oxidize iron cyanide compound



Aquion Energy makes an Aqueous Hybrid Ion (Salt water) battery

http://www.aquionenergy.com/energy-storage-technology

For off-grid and microgrid energy storage



http://www.theguardian.com/sustainable-business/technology-environment-batteries-aquion-katerva-landfills-recycling