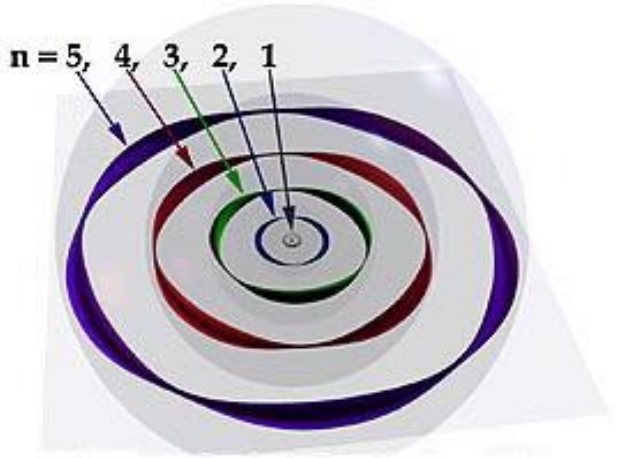
Chapter 19: Oxidation-Reduction Reactions

Honors Chemistry
Mrs. Agostine

Let's Review…

- In chapter 4, you learned how atoms rearrange to form nev



- Now, you will look at how electrons rearrange in chemical processes
- The Key to understanding the Redox Reactions are to look at the electrons!

Section 19.1

What is an Oxidation-Reduction Reaction?

Oxidation Numbers

- So far, we have used electron counts and ionic charges to determine how electrons are lost and gained
- **Oxidation Number**:
  - A charge assigned to the atoms in any compound
  - Accounting tool to determine oxidizing and reducing agents

Oxidation Numbers

$$C\ (s) + O_2\ (g) \rightarrow CO_2\ (g)$$

- The transfer of electrons is not as obvious
- **Basic Rules for Assigning Oxidation #'s:**
  - Ionic compounds: simply the charges on the ions in the compound
  - Covalent compound or polyatomic ion: use a bookkeeping procedure in which we treat the atoms in the compound as if they were ions with charges that are established by a set of rules

Assigning Oxidation Numbers

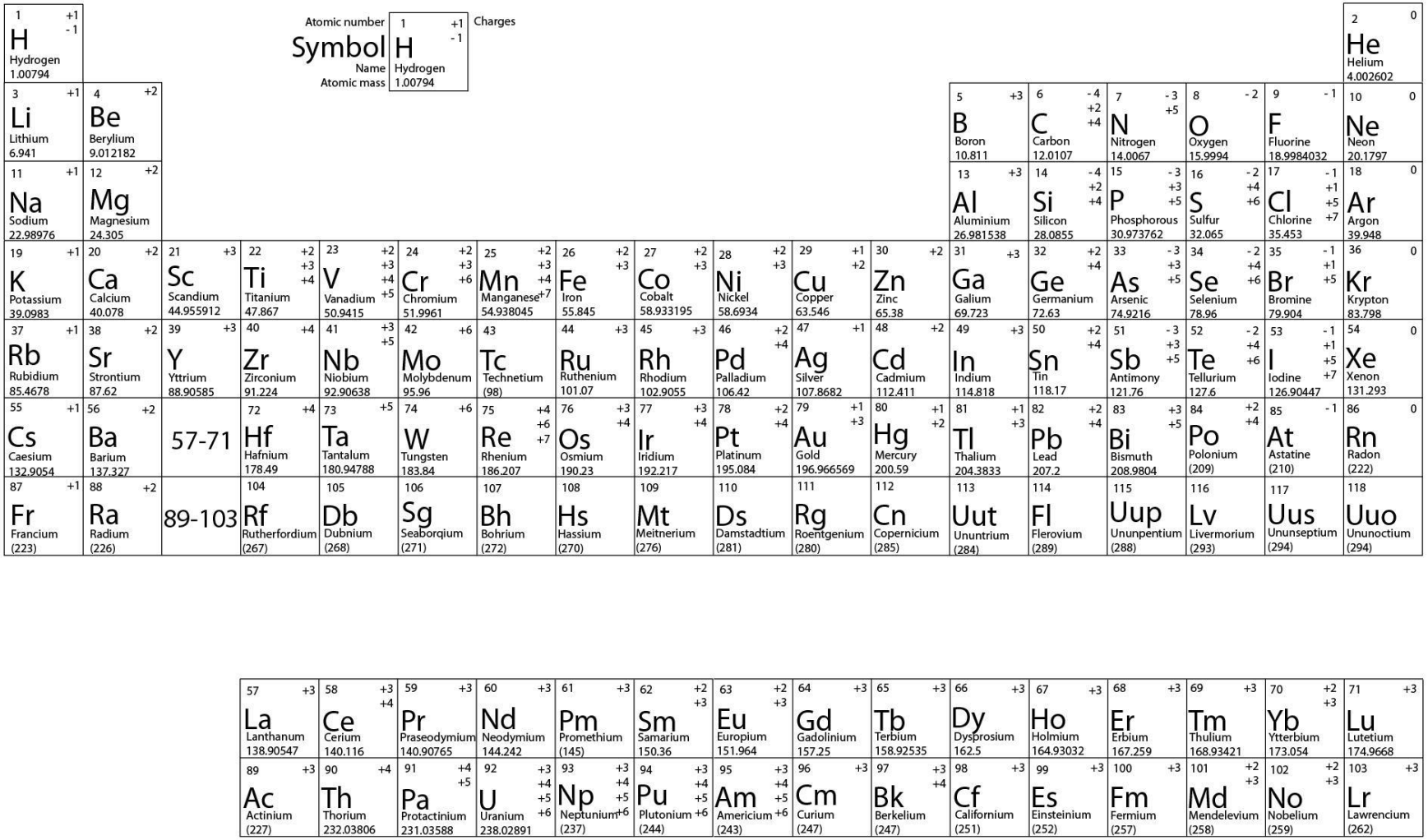
1. The oxidation number of any pure element is 0. (The oxidation number of Na(s) = 0
2. The oxidation number of a monatomic ion equals the charge on the ion. (The oxidation number of Cl^- = -1)
3. The more electronegative element in a binary compound is assigned the number equal to the charge it would have if it were an ion. (The oxidation number of O in NO = -2)

Assigning Oxidation Numbers

4. The oxidation number of fluorine in a compound is always -1.
5. Oxygen has an oxidation number of-2 unless it is combined with fluorine, in which it is +1 or +2, or it is in an peroxide, in which it is -1.
6. Hydrogen's oxidation state in most of its compounds is +1 unless it is combined with a metal, in which case it is -1.

Assigning Oxidation Numbers

7. In compounds, Group 1 and 2 elements and aluminum have oxidation numbers of +1, +2, +3, respectively.
8. The sum of the oxidation numbers of all atoms in a neutral compound is 0.
9. The sum of the oxidation numbers of all the atoms in a polyatomic ion equals the charge of the ion.


Atomic number
Symbol
Name
Atomic mass
1 +1 -1 H Hydrogen 1.00794
Charges
1 +1 -1 H Hydrogen 1.00794
1 +1 -1 H Hydrogen 1.00794
2 0 He Helium 4.002602
3 +1 Li Lithium 6.941
4 +2 Be Beryllium 9.012182
5 +3 B Boron 10.811
6 -4 +2 +4 C Carbon 12.0107
7 -3 +5 N Nitrogen 14.0067
8 -2 O Oxygen 15.9994
9 -1 F Fluorine 18.9984032
10 0 Ne Neon 20.1797
11 +1 Na Sodium 22.98976
12 +2 Mg Magnesium 24.305
13 +3 Al Aluminium 26.981538
14 -4 +2 +4 Si Silicon 28.0855
15 -3 +3 +5 P Phosphorous 30.973762
16 -2 +4 +6 S Sulfur 32.065
17 -1 +1 +5 +7 Cl Chlorine 35.453
18 0 Ar Argon 39.948
19 +1 K Potassium 39.0983
20 +2 Ca Calcium 40.078
21 +3 Sc Scandium 44.955912
22 +2 +3 +4 Ti Titanium 47.867
23 +2 +3 +4 +5 V Vanadium 50.9415
24 +2 +3 +6 Cr Chromium 51.9961
25 +2 +3 +4 +7 Mn Manganese 54.938045
26 +2 +3 Fe Iron 55.845
27 +2 +3 Co Cobalt 58.933195
28 +2 +3 Ni Nickel 58.6934
29 +1 +2 Cu Copper 63.546
30 +2 Zn Zinc 65.38
31 +3 Ga Galium 69.723
32 +2 +4 Ge Germanium 72.63
33 -3 +3 +5 As Arsenic 74.9216
34 -2 +4 +6 Se Selenium 78.96
35 -1 +1 +5 Br Bromine 79.904
36 0 Kr Krypton 83.798
37 +1 Rb Rubidium 85.4678
38 +2 Sr Strontium 87.62
39 +3 Y Yttrium 88.90585
40 +4 Zr Zirconium 91.224
41 +3 +5 Nb Niobium 92.90638
42 +6 Mo Molybdenum 95.96
43 Tc Technetium (98)
44 +3 Ru Ruthenium 101.07
45 +3 Rh Rhodium 102.9055
46 +2 +4 Pd Palladium 106.42
47 +1 Ag Silver 107.8682
48 +2 Cd Cadmium 112.411
49 +3 In Indium 114.818
50 +2 +4 Sn Tin 118.17
51 -3 +3 +5 Sb Antimony 121.76
52 -2 +4 +6 Te Tellurium 127.6
53 -1 +1 +5 +7 I Iodine 126.90447
54 0 Xe Xenon 131.293
55 +1 Cs Caesium 132.9054
56 +2 Ba Barium 137.327
57-71
72 +4 Hf Hafnium 178.49
73 +5 Ta Tantalum 180.94788
74 +6 W Tungsten 183.84
75 +4 +6 +7 Re Rhenium 186.207
76 +3 +4 Os Osmium 190.23
77 +3 +4 Ir Iridium 192.217
78 +2 +4 Pt Platinum 195.084
79 +1 +3 Au Gold 196.966569
80 +1 +2 Hg Mercury 200.59
81 +1 +3 Tl Thalium 204.3833
82 +2 +4 Pb Lead 207.2
83 +3 +5 Bi Bismuth 208.9804
84 +2 +4 Po Polonium (209)
85 -1 At Astatine (210)
86 0 Rn Radon (222)
87 +1 Fr Francium (223)
88 +2 Ra Radium (226)
89-103
104 Rf Rutherfordium (267)
105 Db Dubnium (268)
106 Sg Seaborgium (271)
107 Bh Bohrium (272)
108 Hs Hassium (270)
109 Mt Meitnerium (276)
110 Ds Damstadtium (281)
111 Rg Roentgenium (280)
112 Cn Copernicium (285)
113 Uut Ununtrium (284)
114 Fl Flerovium (289)
115 Uup Ununpentium (288)
116 Lv Livermorium (293)
117 Uus Ununseptium (294)
118 Uuo Ununoctium (294)
57 +3 La Lanthanum 138.90547
58 +3 +4 Ce Cerium 140.116
59 +3 Pr Praseodymium 140.90765
60 +3 Nd Neodymium 144.242
61 +3 Pm Promethium (145)
62 +2 +3 Sm Samarium 150.36
63 +2 +3 Eu Europium 151.964
64 +3 Gd Gadolinium 157.25
65 +3 Tb Terbium 158.92535
66 +3 Dy Dysprosium 162.5
67 +3 Ho Holmium 164.93032
68 +3 Er Erbium 167.259
69 +3 Tm Thulium 168.93421
70 +2 +3 Yb Ytterbium 173.054
71 +3 Lu Lutetium 174.9668
89 +3 Ac Actinium (227)
90 +4 Th Thorium 232.03806
91 +4 +5 Pa Protactinium 231.03588
92 +3 +4 +5 +6 U Uranium 238.02891
93 +3 +4 +5 +6 Np Neptunium (237)
94 +3 +4 +5 +6 Pu Plutonium (244)
95 +3 +4 +5 +6 Am Americium (243)
96 +3 Cm Curium (247)
97 +3 +4 Bk Berkelium (247)
98 +3 Cf Californium (251)
99 +3 Es Einsteinium (252)
100 +3 Fm Fermium (257)
101 +2 +3 Md Mendelevium (258)
102 +2 +3 No Nobelium (259)
103 +3 Lr Lawrencium (262)

Single-Replacement Reactions

$Zn\ (s) + CuCl_2\ (aq) \rightarrow ZnCl_2\ (aq) + Cu\ (s)$

Zn metal replaces the Cu^{2+} (aq) to displace it to make Cu metal

Take a look at the rxn from the point of view of the electrons… (complete ionic equation)

$Zn\ (s) + Cu^{2+}\ (aq) + 2\ Cl^-\ (aq) \rightarrow Zn^{2+}\ (aq) + 2\ Cl^-\ (aq) + Cu\ (s)$

Single-Replacement Reactions

Chloride Ions are the spectator ions

$$Zn\ (s) + Cu^{2+}\ (aq) \rightarrow Zn^{2+}\ (aq) + Cu\ (s)$$

Zn metal forms an aqueous cation

- Zn must lose 2 electrons to do so

An aqueous copper cation forms Cu metal

- Cu^{2+} must gain 2 electrons to do so

Oxidation-Reduction Reaction (Redox):

- A reaction in which electrons are transferred

Redox Reactions

Redox reactions are named for the 2 separate processes that occur together

- **Oxidation**:
  - The process of losing one or more electrons
- **Reduction**:
  - The process of gaining one or more electrons

Oxidation cannot occur without reduction!

- **Reactions do not need to involve oxygen!**

Redox Reactions

Try a mnemonic!

LEO the Lion says **GER**!

LEO:

- **L**oses **E**lectrons-**O**xidation

GER:

- **G**ains **E**lectrons-**R**eduction

Redox Reactions

Try another mnemonic…

- **OEL REG**!

  (pronounced **OIL RIG**)

  OEL:

  - **O**xidation: **E**lectrons **L**ost

  REG:

  - **R**eduction: **E**lectrons **G**ained

Redox Reactions

- One more trick to help remember:
  - The substance whose oxidation number decreased was reduced (because it gained electrons and electrons are negative!)
  - The substance whose oxidation number increased was oxidized (it lost electrons and electrons are negative so – (-2) is + 2

Redox Reactions

- Consider the charges for the equation:

$$\overset{0}{Zn}\ (s) + \overset{2+\ 1-}{CuCl_2}\ (aq) \rightarrow \overset{2+\ 1-}{ZnCl_2}\ (aq) + \overset{0}{Cu}\ (s)$$

- Zinc changes from a charge of 0 to 2+
  - Involves a loss of electrons; **oxidation**
- Copper changes from a charge of 2+ to 0
  - Involves a gain of electrons; **reduction**

Redox Reactions

Oxidation of Zinc

- $Zn\ (s) \rightarrow Zn^{2+}\ (aq)$
- Is this balanced? No
  - You must balance the atoms and the charges!
- $Zn\ (s) \rightarrow Zn^{2+}\ (aq) + 2\ e^-$
  - Neutral charges on each side!

Reduction of Copper

- $Cu^{2+}\ (aq) \rightarrow Cu\ (s)$ should instead be:
- $Cu^{2+}\ (aq) + 2\ e^- \rightarrow Cu\ (s)$

Redox Reactions

Chemists commonly describe reactants as agents of oxidation or reduction

- **Reducing Agent:**
  - A reactant that gives up electrons that is being oxidized
    - The reactant that is oxidized is the reducing agent because it **provides the electrons to the reactant that gets reduced**

Redox Reactions

Oxidizing Agent:

- A reactant that gains electrons that is being reduced
  - The reactant that is reduced is the oxidizing agent because it **accepts the electrons that are lost by the reactant that is oxidized**

oxidized reduced

$$Zn\ (s) + CuCl_2\ (aq) \rightarrow ZnCl_2\ (aq) + Cu\ (s)$$

reducing agent oxidizing agent

Identifying Redox Reactions

How can we use oxidation numbers to identify the oxidation and reduction in an equation?

$$\overset{0}{C}\ (s) + \overset{0}{O_2}\ (g) \rightarrow \overset{4+\ 2-}{CO_2}\ (g)$$

- **<u>An oxidation-reduction reaction occurs if one or more elements changes in oxidation number!</u>**

Identifying Redox Reactions

$$\overset{0}{C}\ (s) + \overset{0}{O_2}\ (g) \rightarrow \overset{4+\ 2-}{CO_2}\ (g)$$

Carbon changed from 0 to 4+

- Oxidation number increases: oxidation
- Loss of electrons: therefore carbon is being oxidized

- Oxygen changed from 0 to 2-
  - Oxidation number decreases: reduction
  - Gain of electrons: therefore oxygen is being reduced

Identifying Redox Reactions

$$\overset{0}{C}\,(s) + \overset{0}{O_2}\,(g) \rightarrow \overset{4+\ 2-}{CO_2}\,(g)$$

- Reducing Agent: carbon (s)
  - Giving up electrons so that oxygen can be reduced
- Oxidizing Agent: oxygen gas
  - Taking the electrons from C (s)

Section 19.2

Balancing Redox Equations

Half-Reaction Method

1. Write the formula, then write the ionic equation:
2. Assign oxidation numbers, then delete elements that do not change oxidation state.
3. Write the half-reaction for oxidation
   - Balance the atoms
   - Balance the charge

Half-Reaction Method

4. Write the half-reaction for reduction
   - Balance the atoms
   - Balance the charge
5. Balance the equation such that the number of electrons lost in oxidation equals the number gained in reduction.
6. Combine the half-reactions, and cancel out anything common to both sides of the equation.

Half-Reaction Method

7. Combine ions to form the compounds shown in the original formula equation. Check to ensure that all other ions balance.

Half-Reaction Method

1. $H_2S + HNO_3 \rightarrow H_2SO_4 + NO_2 + H_2O$

   $H_2S + H^+ + NO_3^- \rightarrow 2\ H^+ + SO_4^- + NO_2 + H_2O$
2. Sulfur changes from -2 to +6 and nitrogen changes from +5 to +4. The other substances are deleted.
3. $H_2S \rightarrow SO_4^{2-}$ (water must be added to balance oxygen)

   $H_2S + 4\ H_2O \rightarrow SO_4^{2-} + 10\ H^+ + 8\ e^-$

   net charge = 0 → net charge = +8

Half-Reaction method

4. NO_3^- + 2 H+ → NO_2 + H_2O

   NO_3^- + 2 H+ + e^- → NO_2 + H_2O

5. 8 e^- lost in oxidation, 1 e^- gained in reduction

   1 • (H_2S + 4 H_2O → SO_4^{2-} + 10 H^+ + 8 e^-)

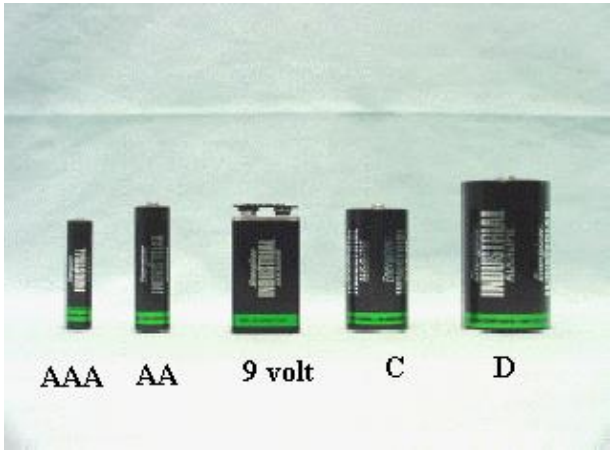
   8 • (NO_3^- + 2 H+ + e^- → NO_2 + H_2O)

6. Combine and cancel (add 2H^+ to each side)

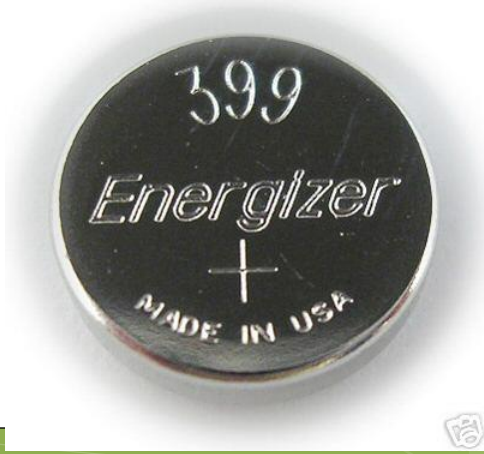
   $8NO_3^-$ + H_2S + 8 H^+ → $8NO_2$ + $4H_2O$ + SO_4^{2-} + $2H^+$

7. $8HNO_3$ + H_2S → $8NO_2$ + $4H_2O$ + H_2SO_4

Section 19.3



Batteries

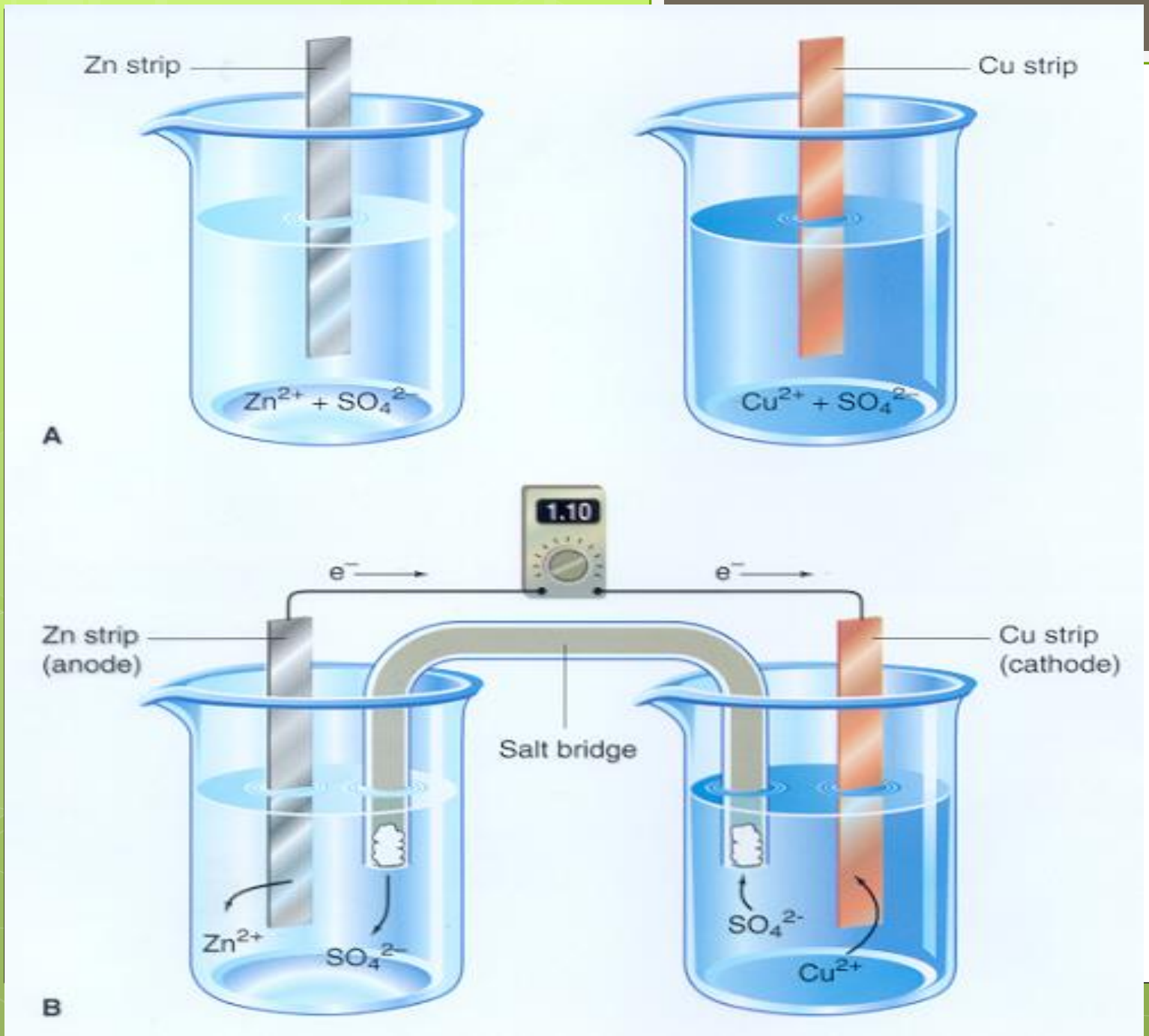


Batteries

- Electricity: a flow of electrons
  - Redox reactions: reaction where electrons are transferred
- All redox reactions that occur without outside intervention release energy
- Ex) combustion of methane
  - Provides heat and is useful to heat homes, but not much help when we want to run electronic devices

Batteries

- **Voltaic (or galvanic) Cell**:
  - A device that sets up spontaneous chemical reaction to produce electricity
  - The operational parts of the battery
- **Voltage:**
  - Tendency for electrons to flow in a cell
  - Chemical reactions vary in their potentials to cause electrons to flow
  - Measured in volts (greater in cells containing the strongest reducing and oxidizing agents)


Zn strip
Cu strip
$Zn^{2+} + SO_4^{2-}$
$Cu^{2+} + SO_4^{2-}$
A
1.10
e⁻
e⁻
Zn strip
(anode)
Cu strip
(cathode)
Salt bridge
Zn^{2+}
SO_4^{2-}
SO_4^{2-}
Cu^{2+}
B

Voltaic Cells

$$\overset{0}{Zn}\ (s) + \overset{2+}{Cu^{2+}}\ (aq) \rightarrow \overset{2+}{Zn^{2+}}\ (aq) + \overset{0}{Cu}\ (s)$$

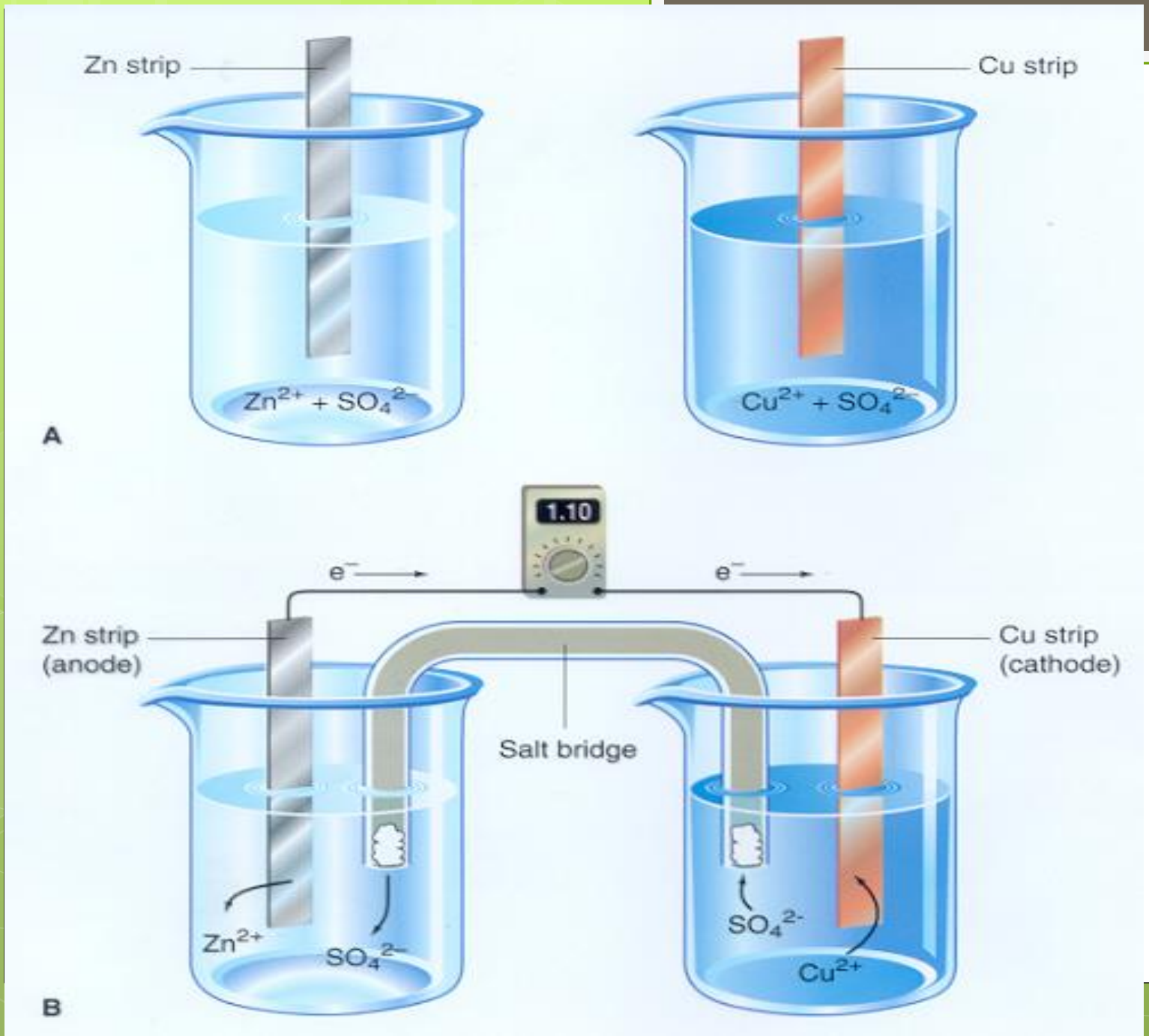
- Oxidation: $Zn\ (s) \rightarrow Zn^{2+}(aq) + 2\ e^-$
- Reduction: $Cu^{2+}\ (aq) + 2\ e^- \rightarrow Cu\ (s)$
- **Half reaction**:
  - Represents either the oxidation or the reduction that occurs in the separate compartments of a voltaic cell
- **Half-Cell**:
  - Each compartment of a voltaic cell

Voltaic Cell Parts

- **Electrode**:
  - A solid material that conducts electricity to provide a site for each half-reaction
  - Commonly a metal immersed in an electrolyte solution containing a salt of the same metal
- **Anode**: electrode at which oxidation occurs
- **Cathode**: electrode at which reduction occurs

Voltaic Cell Parts

- Electricity will not flow unless there is a complete circuit between the anode and the cathode
- **Salt Bridge**:
  - Allows ions to flow so charge balance is maintained
  - Typically a glass tube in the shape of an inverted U containing an ionic compound such as Na_2SO_4 in a gel


Zn strip
Cu strip
$Zn^{2+} + SO_4^{2-}$
$Cu^{2+} + SO_4^{2-}$
A
1.10
e⁻
e⁻
Zn strip
(anode)
Cu strip
(cathode)
Salt bridge
Zn^{2+}
SO_4^{2-}
SO_4^{2-}
Cu^{2+}
B

How Does Electricity Flow?

- Anode: oxidation occurs
  - Loses electrons
- Cathode: reduction occurs
  - Gains electrons
- **Electrons flow from an area where they are lost to where they are gained!**
  - **Electrons flow from anode to cathode, A to C**
  - **ALPHABETICALLY!**

Identifying Components of a Voltaic Cell

- Example: Magnesium reactions with copper (II) sulfate according to the following equation:
- $Mg\ (s) + CuSO_4\ (aq) \rightarrow MgSO_4\ (aq) + Cu\ (s)$
- Write equations to represent the oxidation and reduction half reactions
- Determine the oxidizing and reducing agents
- Identify the parts of a voltaic cell

Identifying Components of a Voltaic Cell

Answer:

- Sulfate ion is a spectator ion

  0 2+ 2+ 0

- $Mg\ (s) + Cu^{2+}\ (aq) \rightarrow Mg^{2+}\ (aq) + Cu\ (s)$
- Oxidation: $Mg\ (s) \rightarrow Mg^{2+}\ (aq) + 2\ e^-$
  - Reducing agent
- Reduction: $Cu^{2+}\ (aq) + 2\ e^-\ (aq) \rightarrow Cu\ (s)$
  - Oxidizing agent

Identifying Components of a Voltaic Cell

Answer:

- A: anode of Mg (s)
- B: electrolyte of Magnesium such as $Mg(NO_3)_2$
- C: Salt bridge ofNa_2SO_4
- D: cathode of Cu (s)
- E: electrolyte of copper such as $Cu(NO_3)_2$