WELCOME TO PERIOD 15: MASS AND ENERGY

Homework #14 is due today.
• What is the relationship between mass and energy?
• What is binding energy?
• What is the difference between stable and unstable isotopes of atoms?
<table>
<thead>
<tr>
<th>Energy Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinetic</td>
<td>The energy exhibited by objects in motion.</td>
</tr>
<tr>
<td>Thermal</td>
<td>The unorganized energy of motion of vibrating atoms and molecules.</td>
</tr>
<tr>
<td>Sound</td>
<td>The organized energy of motion of vibrating atoms and molecules.</td>
</tr>
<tr>
<td>Electrical</td>
<td>The energy resulting from forces between charged particles.</td>
</tr>
<tr>
<td>Magnetic</td>
<td>The energy resulting from the forces between magnets.</td>
</tr>
<tr>
<td>Radiant</td>
<td>The energy resulting from vibrations of charges, such as radio waves, microwaves, or visible light.</td>
</tr>
<tr>
<td>Gravitational</td>
<td>The energy stored in raised objects that could fall.</td>
</tr>
<tr>
<td>Strain</td>
<td>The energy stored in a stretched or compressed spring.</td>
</tr>
<tr>
<td>Chemical</td>
<td>The energy available in the chemical bonds binding atoms together.</td>
</tr>
<tr>
<td>Electrical</td>
<td>The energy stored by static electric charges.</td>
</tr>
<tr>
<td>Nuclear</td>
<td>Energy available in the nuclei of radioactive atoms that are radioactive and undergo nuclear changes.</td>
</tr>
</tbody>
</table>
Mass and energy

- $E = M c^2$ relates mass and energy

- The amount of energy contained in matter equals the mass times $c^2$ where $c =$ the speed of light

$$E = M c^2$$

$E$ = energy (joules)
$M$ = mass (kilograms)
$c$ = the speed of light = $3 \times 10^8$ m/s
Physical change: no change in chemical composition

- No change to the compounds or substances.
- Energy may be absorbed or released.
- Example: a phase change between solid and liquid phases or between liquid and gas phases.

Chemical change: new compounds are formed

- One or more substances are partially used up.
- One or more new substances are formed.
- Energy may be absorbed or released.
- Some compounds are partially used up and new compounds are formed.
Composition of atoms

✓ The nucleus of an atom contains nucleons – positively charged protons and neutral neutrons.

✓ The strong nuclear force holds the nucleons together in the nucleus.

✓ The nucleus is surrounded by a cloud of negative electrons. The electromagnetic force binds the electrons to the nucleus.

✓ The number of protons (Z) determines which element an atom is. Example: an atom with 6 protons is the element carbon.
Isotopes

Isotopes are species of atoms of a given element that have different numbers of neutrons. Example: two isotopes of carbon

$^{12}\text{C}$ Carbon-12 has 6 protons and 6 neutrons.

$^{14}\text{C}$ Carbon-14 has 6 protons and 8 neutrons.

Since the number of protons is the same in both isotopes (6), the identity of the atom remains carbon.
Isotope notation

\[ ^A_Z X \]

- \( Z \) = the number of protons (identifies the element \( X \))
- \( A \) = the total number of nucleons (protons + neutrons)
- \( A - Z \) = the number of neutrons (identifies the isotope of the element)

Cobalt-60: \( ^{60}_{27} \text{Co} \)
Changes to nuclei

- Protons can be added to or removed from atomic nuclei.
- A neutron in the nucleus can be changed into a proton, or a proton can be changed into a neutron.
- Since the number of protons (Z) determines which element an atom is, adding or removing protons changes the identity of the element.

Nuclear reactions involve changes to the nuclei of atoms that result in the formation of atoms of new elements.

Chemical changes involve making and breaking chemical bonds to create new molecules.

Physical changes involve no changes to the identity of atoms or molecules.
Mass converted into energy

The mass of unbound protons and neutrons is greater than their total mass when these protons and neutrons are bound into a nucleus.

This difference in mass is the energy released when nuclei form.

This is the mass $M$ in $E = Mc^2$
Calculating $E = Mc^2$

a) Multiply the mass of one proton by the number of protons.

b) Multiply the mass of one neutron by the number of neutrons.

c) Add these to find the total mass of the unbound protons + neutrons.

The actual mass of the nucleus is less than the total mass of the unbound protons + neutrons.

d) Subtract the mass of the bound nucleus from the total mass of the unbound nucleons.

The answer is the mass $M$ in $E = Mc^2$

e) Solve $E = Mc^2$ for $E$

$$C = 3 \times 10^8 \text{ m/s} \quad C^2 = 9 \times 10^{16} \text{ m}^2/\text{s}^2.$$
Energy Calculation: $E = M c^2$

Energy released when nuclei form = $[(\text{mass of unbound protons + neutrons}) - (\text{mass of nucleus})] c^2$

Energy = $[Z M_p + (A - Z) M_n - M_{nuc}] c^2$

- $M_p$ = mass of a free proton = $1.6726 \times 10^{-27}$ kg
- $M_n$ = mass of a free neutron = $1.6749 \times 10^{-27}$ kg
- $M_{nuc}$ = mass of the assembled nucleus in kg
- $Z$ = number of protons in the nucleus
- $A-Z$ = number of neutrons in the nucleus
- $c^2$ = $(\text{speed of light})^2 = (3 \times 10^8 \text{ m/s})^2$
Binding energy

The binding energy of a nucleus is the energy....

- released when free protons and neutrons bind into a nucleus
- required to break a nucleus into free protons and neutrons.

Binding energy per nucleon = $\frac{\text{binding energy}}{\text{number of nucleons}}$

To convert units between mega electron volts (MeV) and joules, use:

1 Mev = $10^6$ eV = $1.6 \times 10^{-13}$ joules or
1 joule = $6.25 \times 10^{12}$ MeV
Nuclei with the greatest binding energy per nucleon are the most stable.
Nucleus stability

Stable nuclei have:

- 83 or fewer protons.
- The same number of protons and neutrons for light elements with 20 or fewer protons.
- More neutrons than protons for elements with more than 20 protons.
BEFORE THE NEXT CLASS…

- Read textbook chapter 16.
- Complete Homework Exercise 15.
- Print out Activity Sheet 16.