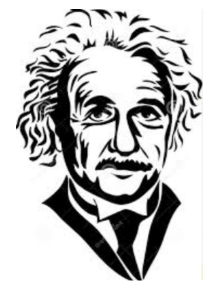
PHYSICS 3204

WORKSHEET #6 MASS - ENERGY EQUIVALENCE EQUATION

One of the most famous equations is Einstein's Mass - Energy Equivalence Equation. Einstein discovered that matter could be converted to energy (and vice-versa). The equation that expresses this mass-energy equivalency is:



$$E = mc^2 \quad (c = 3.00\text{x}10^8 \text{ m/s})$$

or

$$E = \Delta mc^2$$

In other words:

E = energy (measured in joules, J)
m = mass (measured in kilograms, kg)
c = the speed of light (measured in metres per second, ms-1)

A huge amount of energy from a small amount of mass. Every process that releases energy is accompanied by an equivalent loss of mass. Every process that absorbs energy results in a gain of mass. The mass changes accompanying chemical reactions are too small to measure but mass changes due to nuclear reactions can be measured using a mass spectrometer. The following process releases energy (how do you know?):

protons + neutrons ➜ nucleus

Thus, the mass of a nucleus is less than the sum of the masses of the protons and neutrons from which it is composed! The difference in mass is called the **mass defect (m):**

The mass-energy equivalency formula can be used to calculate:

1) Binding Energy

The binding energy represents the amount of energy that must be supplied to break the nucleus into its individual protons and neutrons. (Conversely, it is the energy released when the nucleus is formed from individual protons and neutrons.) For a single nucleus, the magnitude of the binding energy is typically between 10^{-10} to 10^{-1}2 J. (For convenience, nuclear binding energies are sometimes expressed in mega electron volts (MeV), where 1 MeV = 10^6 eV = 1.60×10^{-13} J)

A more useful quantity for comparing the stability of nuclides is the binding energy per nucleon:

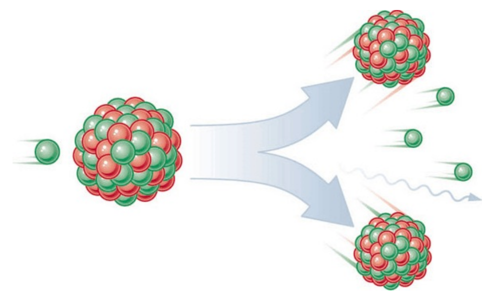
Binding Energy per nucleon = ΔE/A

where A = the mass number of the isotope (number of nucleons). The greater the binding energy per nucleon, the more stable the nucleus.

2) Fission

Fission = the splitting of a heavy nucleus into two nuclei with smaller mass numbers. This process is induced by absorption of a neutron by the reactant nucleus, and results in the release of energy and an additional 2 or 3 neutrons as products. For example 3 of the many possible outcomes of uranium-235 fission are:

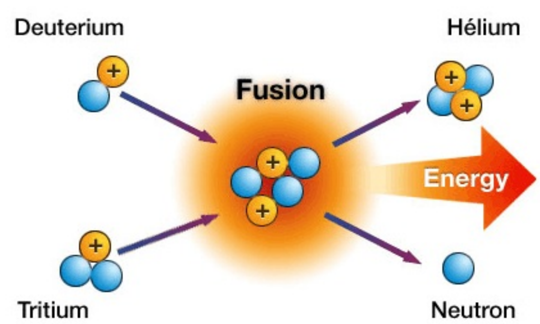
$${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{90}_{38}Sr + {}^{143}_{54}Xe + 3\,{}^{1}_{0}n$$
$${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{137}_{52}Te + {}^{97}_{40}Zr + 2\,{}^{1}_{0}n$$
$${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{142}_{56}Ba + {}^{91}_{36}Kr + 3\,{}^{1}_{0}n$$



3) Fusion

Fusion the combining of two light nuclei to form a heavier, more stable nucleus. For example, the following reactions (among others) take place in the sun:

$${}^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + {}^{0}_{1}e$$
$${}^{1}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He$$
$${}^{3}_{2}He + {}^{1}_{1}H \rightarrow {}^{4}_{2}He + {}^{0}_{1}e$$
$${}^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + 2\,{}^{1}_{1}H$$



Because of the large binding energies involved in a nucleus, both fission and fusion involve energy changes of more than a million times larger than those energy changes associated with chemical reactions.

1. What is the mass defect of a fission reaction that releases 2.9×10^{-11} J of energy?

   (A) 3.2×10^{-28} kg
   (B) 9.7×10^{-20} kg
   (C) 9.7×10^{20} kg
   (D) 3.1×10^{27} kg

2. What is the mass difference in a nuclear reaction if the energy released is $2.98 \times 10\text{-}^{11}$ J?

   (A) 3.31×10^{-28} kg
   (B) 9.93×10^{-20} kg
   (C) 2.78×10^{-8} kg
   (D) 8.94×10^{-3} kg

3. How much energy is released in a nuclear reaction if 4.37×10^{-25} kg of mass is converted to energy?

   (A) 4.86×10^{-42} J
   (B) 1.46×10^{-33} J
   (C) 1.31×10^{-16} J
   (D) 3.93×10^{-8} J

4. Which process involves making one helium atom from four hydrogen atoms?

(A) fission
(B) fusion
(C) gamma radiation
(D) radioactive dating

5. Which best describes nuclear fusion?

(A) It requires very high temperatures which are difficult to contain.
(B) It requires very high temperatures which are easy to contain.
(C) It requires very low temperatures which are difficult to contain.
(D) It requires very low temperatures which are easy to contain.

6. Given the information below, how much energy is emitted in the reaction?

$${}^{23}_{10}\text{Ne} \rightarrow {}^{23}_{11}\text{Na} + {}^{0}_{-1}e + {}^{0}_{0}\overline{\nu}$$

mass of ${}^{23}_{10}\text{Ne}$	22.9945
mass of ${}^{23}_{11}\text{Na}$	22.9898 u
mass of ${}^{0}_{-1}\text{e}$	0.00055 u

(A) 3.87 MeV
(B) 4.15 MeV
(C) 4.38 MeV
(D) 4.89 MeV

7. If the mass of the products in a fission reaction is 3.2×10^{-28} kg less than the reactants, how much energy is released in the reaction?

(A) 3.6×10^{-45} J
(B) 1.1×10^{-38} J
(C) 9.6×10^{-20} J
(D) 2.9×10^{-11} J

8. What is the mass defect of a fission reaction that releases 2.9×10^{-11} J of energy?

(A) 3.2×10^{-28} kg
(B) 9.7×10^{-20} kg
(C) 9.7×10^{20} kg
(D) 3.1×10^{27} kg

9. If the mass of the products in a fission reaction is 3.2×10^{-28} kg less than the reactants, how much energy is released in the reaction?

(A) 3.6×10^{-45} J
(B) 1.1×10^{-38} J
(C) 9.6×10^{-20} J
(D) 2.9×10^{-11} J

10. In the Sun, a series of nuclear reactions have the net effect of making one helium atom form four hydrogen atoms. Which process does this describe?

(A) chain reaction
(B) fission
(C) fusion
(D) nuclear reactor

1. Calculate the energy, in Joules, released in the reaction shown below. AUGUST 2009

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + ^{1}_{0}n$$

Particle	Mass (u)
$^{2}_{1}H$	**2.014102**
$^{1}_{0}n$	**1.008665**
$^{3}_{2}He$	**3.01603**

2. Calculate the energy produced in the reaction below. August 2008

$$^{2}_{1}H + ^{14}_{7}N \rightarrow ^{12}_{6}C + ^{4}_{2}He$$

Particle	Mass (kg)
$^{2}_{1}H$	**3.343 x 10^{-27}**
$^{14}_{7}N$	**2.325 x 10^{-26}**
$^{12}_{6}C$	**1.992 x 10^{-26}**
$^{4}_{2}He$	**6.644 x 10^{-27}**

3. Calculate the energy released in the reaction shown below. June 2008

$$^{6}_{3}Li + ^{1}_{0}n \rightarrow ^{4}_{2}He + ^{3}_{1}H$$

Particle	Mass (u)
$^{6}_{3}Li$	**6.01513**
$^{1}_{0}n$	**1.00867**
$^{4}_{2}He$	**4.0026**
$^{3}_{1}H$	**3.01604**

4. Radium-226 undergoes the following radioactive decay. Calculate the energy released in the reaction below. AUGUST 2007

$$^{226}_{88}\text{Ra} \rightarrow \, ^{222}_{86}\text{Rn} + \, ^{4}_{2}\text{He}$$

Particle	Mass (kg)
$^{226}_{88}\text{Ra}$	**3.752 x 10^{-25}**
$^{222}_{86}\text{Rn}$	**3.685 x 10^{-25}**
$^{4}_{2}\text{He}$	**3.644 x 10^{-27}**

5. Calculate the energy produced in the reaction below. JUNE 2007

$$^{2}_{1}\text{H} + \, ^{3}_{1}\text{H} \rightarrow \, ^{4}_{2}\text{He} + \, ^{1}_{0}\text{n} + \text{energy}$$

Particle	**Mass (Kg)**
$^{2}_{1}H$	**3.3444 x 10^{-27}**
$^{3}_{1}H$	**5.0082 x 10^{-27}**
$^{4}_{2}He$	**6.6463 x 10^{-27}**
$^{1}_{0}n$	**1.6749 x 10^{-27}**

6. How much energy is released by the alpha decay given the masses below?

Particle	**Mass (u)**
radium isotope	**226.0244**
radon isotope	**222.0164**
alpha	**4.0026**

7. Calculate the energy released in the reaction below.

$$^{3}_{1}\text{H} + \, ^{3}_{1}\text{H} \rightarrow \, ^{4}_{2}\text{He} + 2\,^{1}_{0}n$$

$^{3}_{1}\text{H} = 5.007 \times 10^{-27}$ kg ; $^{4}_{2}\text{He} = 6.644 \times 10^{-27}$ kg ; $\text{n} = 1.6749 \times 10^{-27}$ kg

Using the equation from (c) above, calculate the amount of energy released in the production of 1.00×10^{-6} kg of ? $^{4}_{2}\text{He}$

8. If the mass of a carbon-14 ($^{14}_{6}C$) nucleus is 2.3252 × 10^{-26} kg, what is the binding energy of the carbon nucleus? JUNE 2005

9. How much energy is released during the fusion of one atom $^{2}_{1}H$ and one ator $^{3}_{1}H$ AUGUST 2004

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$$

Particle	Mass (Kg)
$^{2}_{1}H$	**3.3444 x 10^{-27}**
$^{3}_{1}H$	**5.0082 x 10^{-27}**
$^{4}_{2}He$	**6.6463 x 10^{-27}**
$^{1}_{0}n$	**1.6749 x 10^{-27}**

10. Radium-226 undergoes the following radioactive decay: How much energy is released given the masses below

$$^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + ^{4}_{2}He$$

Particle	Mass (u)
$^{226}_{88}Ra$	**226.0244**
$^{222}_{86}Rn$	**222.0164**
$^{4}_{2}He$	**4.0026**

8. Calculate the energy produced in the reaction below.

$$^{2}_{1}H + ^{14}_{7}N \rightarrow ^{12}_{6}C + ^{4}_{2}He$$

Particle	Mass (kg)
$^{2}_{1}H$	3.343×10^{-27}
$^{14}_{7}N$	2.325×10^{-26}
$^{12}_{6}C$	1.992×10^{-26}
$^{4}_{2}He$	6.644×10^{-27}

9. Calculate the energy released in the reaction shown below.

$$^{6}_{3}Li + ^{1}_{0}n \rightarrow ^{4}_{2}He + ^{3}_{1}H$$

Particle	Mass (u)
$^{6}_{3}Li$	6.01513
$^{1}_{0}n$	1.00867
$^{4}_{2}He$	4.0026
$^{3}_{1}H$	3.01604

10. Calculate the energy, in Joules, released in the reaction shown below.

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He + ^{1}_{0}n$$

Particle	**Mass (u)**
$^{2}_{1}H$	**2.014102**
$^{1}_{0}n$	**1.008665**
$^{3}_{2}He$	**3.01603**