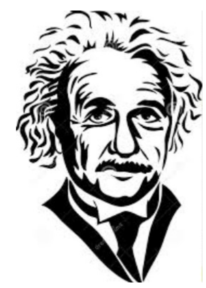
Physics 2204

Unit 3: Work, Power and Energy

Worksheet 14: Mass -Energy Equivalence Equation

Student Name:__________________________________

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:



$$E = mc^2 \quad (c = 3.00\times10^{8}\ \text{m/s})$$

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:

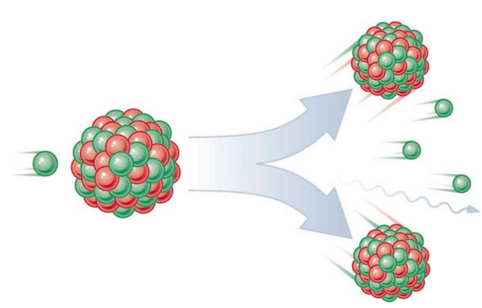
1) Fission

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:

$${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{90}_{38}Sr + {}^{143}_{54}Xe + 3\,{}^{1}_{0}n$$

$${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{137}_{52}Te + {}^{97}_{40}Zr + 2\,{}^{1}_{0}n$$

$${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{142}_{56}Ba + {}^{91}_{36}Kr + 3\,{}^{1}_{0}n$$



Example 1:

For the reactions shown below:

Particle	Mass
neutron	1.67493×10^{-27} kg
235U	3.902999×10^{-25} kg
141Ba	2.3398×10^{-25} kg
92Kr	1.5264×10^{-25} kg

Calculate:

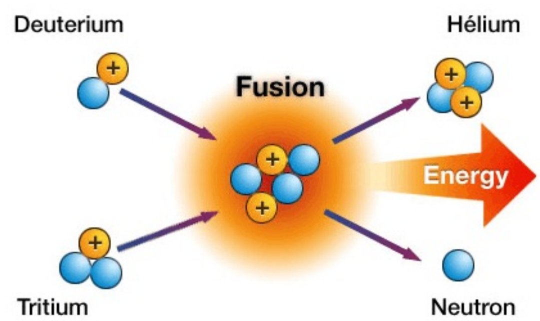
(A) Mass difference

(B) Energy released in the reaction

2) 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:

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



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.

Example 2:

Calculate the energy produced in the reaction below.

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

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

PART A: MULTIPLE CHOICE

Instructions: Shade the letter of the correct answer on the computer scorable answer sheet provided

1. What scientist came up with the formula $E = mc^2$?

(A) Albert Einstein
(B) Aristotle
(C) Isaac Newton
(D) Thomas Edison

2. What does the famous equation $E = mc^2$ state?

(A) Energy and mass are equivalent
(B) Energy and the speed of light are equivalent
(C) Mass is always greater than energy
(D) Mass and the speed of light are equivalent

3. Which of the following can be true for a nuclear reaction?

I Mass is conserved
II The mass of the products is greater than the mass of the reactants
III The mass of the reactants is greater than the mass of the products
IV Mass is changed to energy

(A) I and II
(B) I and IV
(C) II and IV
(D) III and IV

4. 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

5. 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

6. What is the mass difference in a nuclear reaction if the energy released is 2.98×10^{-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

7. 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

8. What happens when the energy from splitting an atom is released all at once?

(A) A small electric charge is generated
(B) Nuclear explosion
(C) The mass of the atom is lost
(D) The energy released can be used to power a nuclear plant

9. Which of the following describes what occurs in the fission process?

(A) A heavy nucleus is fragmented into lighter ones.
(B) A neutron is split into a neutron and proton.
(C) Two light nuclei are combined into a heavier one.
(D) A proton is split into three quarks.

10. The name of the following reaction $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n$?

(A) Fission
(B) Fusion
(C) α - decay
(D) γ - decay

11. What is nuclear fusion?

(A) The process of an electron moving from one atom to another
(B) The process when two or more atoms are joined together to make a larger atom
(C) The process of releasing the neutrons from atoms
(D) The process of splitting a large atom into two smaller atoms

12. Where does nuclear fusion take place?

(A) Inside stars
(B) In nuclear power plants
(C) In submarines
(D) None of the Above

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

(A) Fission
(B) Fusion
(C) Gamma radiation
(D) Radioactive dating

14. 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.

15. 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

16. The name of the following reaction $^{2}_{1}H+^{3}_{1}H \rightarrow ^{4}_{2}He+^{1}_{0}n$?

(A) Fission
(B) Fusion
(C) α - decay
(D) γ - decay

PART B: WRITTEN RESPONSE

1. Radium-226 undergoes the following radioactive decay.

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

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}**

(A) What type of reaction is this?
(B) What is the mass difference?
(C) How much energy is released in this reaction?

2. Use the information below to answer the following questions:

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

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}**

(A) What type of reaction is this?
(B) What is the mass difference?
(C) How much energy is released in this reaction?

3. Write the equation for á decay of radium-226 and calculate the energy released in the reaction using the following information

Particle	Mass (kg)
$^{226}_{88}Ra$	3.752 x 10^{-25}
$^{222}_{86}Rn$	3.685 x 10^{-25}
$^{4}_{2}He$	6.644 x 10^{-27}

4. In a nuclear reaction, the mass of the reactants is 2.38 x 10^{-18} kg and the mass of the products is 2.35 x 10^{-18} kg. Determine the energy released from this reaction.

5. Calculate the mass defect in a nuclear process that releases 5.1 x 10^{-13} J.