Period 8 Activity Solutions: Mass and Energy

8.1 What is the Relationship between Energy and Mass?
Your instructor will discuss Einstein’s equation, \( E = mc^2 \), which is probably the most important equation of the 20th century.

1) Einstein's Equation applied to physical changes: stored potential energy
Should adding energy to a spring by winding it change the mass of the spring?

a) Find the weight of the free play radio. _____________

b) Calculate the mass of the radio \( \text{Use } M = F / g \text{ to find mass in kg} \)

c) While the radio is still hanging, carefully turn the crank one turn to wind up the radio’s spring. Did the weight of the radio change? No Did the mass of the radio change? No

d) Using the small newton scale, find the force needed to turn the radio’s handle at a constant speed. ___13 N__

e) Find the distance in meters that the end of the handle travels in when it is turned one revolution.

The handle radius = 0.1 meter. The distance the end of the handle travels is the circumference of the circle = \( 2\pi \times \) radius

f) Calculate the amount of work done to turn the handle one revolution.

use \( W = F \times D \)

g) The work done to turn the radio handle equals the energy added to the radio’s spring. Use your result from part f) and Einstein’s equation to find the additional mass of the radio as a result of winding its spring.

\( \text{use } M = E / c^2 - E \text{ is the work you found in part g)} \)

h) Group Discussion Question: Why did the scale register no change in weight when the spring was wound?

The energy added by winding the spring was very small.

2) Einstein's Equation applied to physical changes: phase changes

a) Fill a beaker with 100 ml of water. What is the mass of this water? __100 grams_

b) Measure the temperature of the water in Celsius degrees. _______________

c) Suppose that the water was placed in the refrigerator and cooled to 0 °C without any of the water freezing. Calculate how much energy the water has lost once it has cooled to 0 °C. (The specific heat of water is 4.186 J/gram °C)

If 100 grams of water temperature cooled from 25 °C to 0 °C, the energy removed is

\[ Q = \text{s}_{heat} \times M \times \Delta T = (4.186 \text{ J/gram } °C) \times 100 \text{ grams} \times 25 °C = 10,465 \text{ J} \]

d) How much mass has the water lost as a result of this cooling?

\[ M = E / c^2 = 10,465 \text{ J} / (3 \times 10^8 \text{ m/s})^2 = 1.16 \times 10^{-13} \text{ kg} \]
e) What if the water at 0 °C is changed into ice at 0 °C? How much energy has the water lost during the phase change from liquid to solid? (The latent heat of freezing water is 335 J/gram.)

\[ Q = L_{\text{heat}} \quad M = 335 \text{ J/gram} \times 100 \text{ grams} = 33,500 \text{ J} \]

f) How much mass has the water lost as a result of this phase change?

\[ M = \frac{E}{c^2} = \frac{33,500 \text{ J}}{(3 \times 10^8 \text{ m/s})^2} = 3.72 \times 10^{-13} \text{ kg} \]

g) How much total mass has the water lost after the cooling and freezing processes described above?

Total mass lost = mass lost due to cooling + mass lost due to freezing

h) What percent is this mass loss of the total mass of the water at room temperature?

\[
\text{mass found in part g} \\
0.10 \text{ kg}
\]

3) Einstein's Equation applied to chemical changes

a) Measure the mass of a light stick _approx 22 grams_

b) Break the light stick's vial. What type of energy is given off? __visible light__ Do you detect any infrared radiation? _No_

c) Examine a night light. What type of energy is given off? __visible light__ Do you detect any infrared radiation? _No_

d) Since the light stick and the night light give off similar radiation, we compare the brightness of the light stick to the brightness of two night lights. If the light stick's brightness is 10 times greater than the two night lights, what is the wattage of the light stick? (Hint: the wattage of the night lights is given on their back cover.) _0.6 watts_

e) If the light stick radiates energy at the rate of 0.6 watts for one hour, how many joules of energy have been emitted?

\[ 0.6 \text{ J/s} \times 3,600 \text{ s} = 2,160 \text{ J} \]

f) Calculate the mass loss due to this emitted energy.

\[
\text{use } M = \frac{E}{c^2} \quad \text{answer: } 2.4 \times 10^{-14} \text{ kg}
\]

g) What is the percent change in the mass of the light stick after it has been radiating for one hour?

\[
\frac{\text{mass loss}}{\text{mass of light stick}}
\]

h) Measure the mass of the radiating light stick. ____________ Is there a noticeable change in mass? _no_ Note: we will measure the mass of the light stick again at the end of this period after it has radiated for a longer time.
4) The limits of mass measurement

Watch the video clip of the mass of a pencil dot.

a) What was the mass of the paper before the “i” was dotted? _97.239 mg_

b) What was the mass of the added dot? _0.162 mg or 1.62 x 10⁻⁷ kg_

c) What was the percent change in the mass of the paper after the dot was added?

\[
\frac{0.162 \text{ mg}}{97.239 \text{ mg}} = 0.00167 = 0.167 \%
\]

d) What was the change in mass in units of energy?

use \( E = Mc^2 \)  answer: \( 1.5 \times 10^{10} \) J

e) Group Discussion Question: If the scale used in the video could measure one part in one million, would such a scale be helpful in measuring any change in mass of your light stick? Why or why not?

No, this scale would not help since the mass loss calculated in part 3.f was \( 2.4 \times 10^{-11} \) grams. The ratio of mass loss per 22 gram light stick is approximately \( 1 \times 10^{-10} : 1 \), which is much smaller than the scale sensitivity of \( 1 \times 10^{-6} : 1 \).

8.2 What are Nuclear Processes?

5) Difference between atomic and nuclear processes

a) What determines which element an atom is?

The number of protons in the atom’s nucleus determines the identity of the atom.

b) How can an atom of one element change into an atom of a different element?

Protons can be added to or removed from atomic nuclei. As we will see in Period 9, a neutron in the nucleus can be changed into a proton, or a proton can be changed into a neutron. Changing the number of protons within a nucleus changes the properties of the atom and it becomes an atom of a different element.

c) Is this process a physical, chemical, or nuclear change?

Changing the number of protons is a nuclear change. Changes in the atomic nucleus involve nuclear reactions.

d) What is the difference between a physical change, a chemical reaction, and a nuclear reaction?

In a physical change, molecules may change phase or rearrange, but no molecules are created or destroyed. In a chemical reaction molecules may be created or destroyed, but atoms are not created or destroyed. In a nuclear reaction, atoms may be created or destroyed, but nucleons (protons or neutrons) are not created or destroyed.
6) **Photon Emission**  Watch the flash bulb/glow-in-the-dark stickers demonstration

a) Are glow-in-the dark stickers radioactive? **No**

b) What makes them glow?

The phosphorescent stickers are NOT radioactive. High energy (ultraviolet) photons are absorbed by the stickers knocking electrons in the atoms to higher energy levels. As those electrons fall back down to normal ground state energy levels, they emit lower energy photons (visible light) and this is what we see as glowing.

c) How are glow-in-the-dark stickers different from radium glow-in-the-dark clocks manufactured years ago?

Glow-in-the-dark clocks manufactured years ago had a radium based paint. The radioactive decay of radium provided the energy to knock the electrons to higher energy levels.

8.3 **What Holds Nuclei Together?**

7) **The force binding nuclei**

a) What holds electrons in orbit around the nucleus of an atom?

Electrons are negatively charged, protons are positively charged, and neutrons are electrically neutral. The electrostatic force of attraction between the protons and electrons holds the electrons in orbit.

b) What is a nucleon?

A positively charged proton or a neutral neutron

c) What is a nucleus?

The nucleus is the part of the atom made up of protons and neutrons. The nucleus, which is at the center of the atom, comprises 99.9% of the atom’s mass, while it only takes up roughly one ten-thousandth of the volume of a typical atom.

d) What holds nucleons together within the nucleus of an atom?

The strong nuclear force holds together the nucleons (even though the protons are electrically repulsed by each other.)

e) The tennis ball model simulates the forces between two protons. What force do the springy wires represent? **electromagnetic force**  What force do the magnets represent? **strong nuclear force**

f) How would the model have to be modified to make it represent a neutron and a proton?

The spring wires representing the electromagnetic force would have to be removed from the model.
g) How would the model have to be modified to make it represent two neutrons?

*Again, the spring wires representing the electromagnetic force would have to be removed from the model.*

8.4 Which Nuclei are Stable?

8) Isotopes

a) What is an isotope?

*Isotopes are species of atoms of a given chemical element that have different numbers of neutrons (but the same number of protons). For instance, the most common isotope of carbon, carbon-12, has 6 protons and 6 neutrons, while a rarer isotope, carbon-14, has 6 protons and 8 neutrons.*

b) How many protons are contained in one atom of Cobalt-60 (\(^{60}\text{Co}\))? 

*One atom has 27 protons. The lower left number indicates the number of protons.*

c) How many neutrons are contained in one atom of \(^{60}\text{Co}\)?

*One atom has 60 - 27 = 33 neutrons. The upper left number indicates the total number of nucleons.*

9) Nuclei stability

**OVERHEAD 8.7: STABLE NUCLEI**

a) What determines whether an element with 20 or fewer protons is stable?

*Small nuclei with equal numbers of protons and neutrons tend to be stable.*

b) What determines whether an element with many more than 20 protons is stable?

*Large nuclei with more neutrons than protons tend to be stable.*

c) What can happen to nuclei with more than 82 protons?

*Nuclei with more than 82 protons break into small nuclei. These nuclei are called radioactive. As they decay into small nuclei, they may give off radioactive particles, which will be discussed in the next period.*

d) What can happen to a nuclei with \(Z < 82\) protons that has too many neutrons?

*The weak nuclear force can change a neutron into a proton.*

e) What can happen to a nuclei with \(Z < 82\) protons that has too few neutrons?

*The weak nuclear force can change a proton into a neutron.*
f) Why do the stability of small nuclei and the stability of large nuclei follow different rules?

If a nucleus contains too many neutrons or protons, the weak nuclear force changes one type of nucleon into the other. The strong nuclear force binding the nucleus together operates over very short distances. Adding more neutral neutrons to large nuclei separates the positive protons, reducing the repulsive electromagnetic force among them. The weak nuclear force adjusts the relative numbers of neutrons and protons to produce stable nuclei.
10) Graph of Stable Nuclei

The graph below shows the number of neutrons versus the number of protons for stable elements.

a) Find the slope of the straight line. 
\[ \text{slope} = 1 \]

b) What does the straight line represent?

Nuclei with equal numbers of protons and neutrons.

c) What does the curved line show?

It shows nuclei with more neutrons than protons. These are the isotopes that are stable.

Graph of neutron number N vs proton number Z for stable nuclei
11) Enlarged graph of Stable Nuclei

The grid on the next page represents an enlargement of a portion of the graph shown in part 9).

a) The stable isotopes of calcium are Calcium-40 (\(^{40}_{20}\text{Ca}\)), Calcium-42 (\(^{42}_{20}\text{Ca}\)), Calcium-43 (\(^{43}_{20}\text{Ca}\)), Calcium-44 (\(^{44}_{20}\text{Ca}\)), Calcium-46 (\(^{46}_{20}\text{Ca}\)), and Calcium-48 (\(^{48}_{20}\text{Ca}\)). Darken the squares on the grid that represent these stable isotopes.

b) Mark an X in the square that represents the nucleus of Silicon-40 (\(^{40}_{14}\text{Si}\))

c) Silicon-40 nuclei last only a few seconds. Why is this nucleus unstable?

It has too many neutrons for the number of protons.

d) How would this nucleus change as it becomes more stable?

Neutrons would change into protons.

e) How many neutrons must change into protons for this nucleus to become the stable nucleus Calcium-40 (\(^{40}_{20}\text{Ca}\))? Six neutrons must become protons.

f) Draw a dotted line showing how the box representing Silicon-40 would move as the nucleus turns into a stable nucleus.

12) Mass of the Light Stick

Now that the light stick used in part 3) has been radiating energy for approximately an hour, measure the mass of the stick again. Is it possible to measure a change in the mass of the stick with this scale? _No_