Name ____________________________ Section ____________________

Activity 9: Mass and Energy

9.1 Einstein's Equation Applied to Physical and Chemical Changes

Your instructor will discuss Einstein's equation, $E = Mc^2$, which is probably the most important equation of the 20th century.

1) Mass and Energy

What is the relationship between mass and energy?

2) 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) What is the mass of the free play radio in kilograms? ______________

b) Your instructor will turn the crank to wind the radio's spring. Does the mass of the radio appear to change after the spring is wound? ______________

c) How much force is needed to turn the radio's handle at a constant speed? _______

d) Find the distance in **meters** that the end of the handle travels in when it is turned one revolution by measuring the radius of the extended crank handle.

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

f) 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.

g) How would the following physical changes affect the energy and mass of a substance?

	Energy Change	Mass Change
1) A book is raised to a shelf.	__________________	______________
2) A spring is stretched.	__________________	______________
3) A car accelerates	__________________	______________
4) Liquid nitrogen boils.	__________________	______________
5) Water is frozen into ice.	__________________	______________

h) Group Discussion Question: Would these changes in mass register on a scale? Why or why not?

3) Einstein's Equation applied to chemical changes

a) What is the mass of a light stick in kilograms? ________________________

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

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

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.) _____________

e) If the light stick radiates energy at this same rate for one hour, how many joules of energy have been emitted? (Hint: one watt = one joule/second)

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

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

h) Measure the mass of the radiating light stick. ___________________________

Is there a noticeable change in mass? __________ 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? ____________

b) What was the mass of the added dot? __________________________

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

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

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?

9.2 Nuclear Processes

5) Atoms and isotopes

a) What determines which element an atom is?

b) What is an isotope?

c) How many protons are contained in one atom of Cobalt-60 ($^{60}_{27}Co$)? __________

d) How many neutrons are contained in one atoms of $^{60}_{27}Co$? __________________

6) Nuclear Processes

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

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

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

9.3 Einstein's Equation Applied to Nuclear Processes

From Einstein's equation, $E = Mc^2$, we know that changing the energy of a substance changes its mass. We have found this mass change too small to measure for physical changes and chemical reactions. Next, we consider a situation where mass changes can be measured – changes to an atomic nucleus.

7) Energy released when nuclei form

The mass of a $^{238}_{92}U$ nucleus is 395.2138 x 10^{-27} kg. Follow the steps below to find the energy that binds together the nucleons of $^{238}_{92}U$ into a nucleus.

a) How many protons does the $^{238}_{92}U$ nucleus have? ______________________
Find the mass of these protons. (The mass of one proton = 1.6726 x 10^{-27} kg)

b) How many neutrons does the $^{238}_{92}U$ nucleus have? ______________________
Find the mass of these neutrons. (The mass of one neutron = 1.6749 x 10^{-27} kg.)

c) Find the total mass of these nucleons.

d) What is the difference in mass between the total mass you found in part c) and the mass of the U-238 nucleus, which is 395.2138 x 10^{-27} kg?

e) Calculate the energy in joules that was given off when the U-238 nucleus was formed.

9.4 The Binding Energy of Nuclei

8) Binding energy

The energy given off when the uranium nucleus was formed is called the binding energy of the $^{238}_{92}U$ nucleus.

a) Find the binding energy ***per nucleon*** of a $^{238}_{92}U$ nucleus.

b) Convert the binding per nucleon from joules into units of megaelectron volts (MeV). (1 joule = 6.25 x 10^{12} MeV)

c) When two protons come together, one proton can change into a neutron. The proton and neutron can then bind together to form one deuterium nucleus. For each deuterium nucleus formed, 3.52 x 10^{-13} joules of energy are given off. What is this energy called? ____________________

d) What is the process of nucleons binding called? ________________

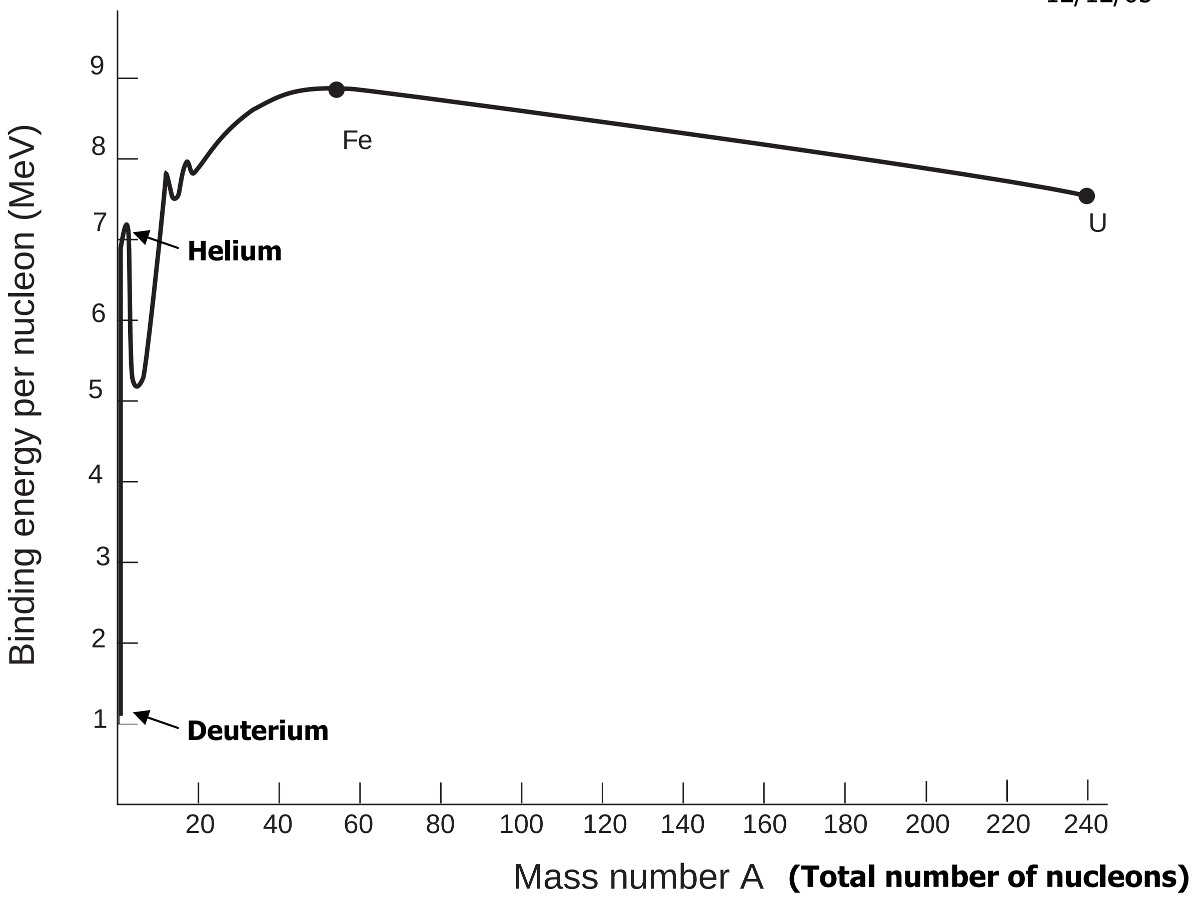
e) Calculate the number of electrons volts (eV) in 3.52 x 10^{-13} joules. (Hint: 1 eV = 1.6 x 10^{-19} J).

f) How many megaelectron volts (MeV) is this? ________________________

g) How many MeV is this per nucleon? _____________________________

9) Graph of the binding energy of nuclei

The figure on the next page graphs the binding energy per nucleon of the most stable nucleus of a given mass number (that is, the isotope of each element with the largest binding energy) versus the mass number of that nucleus. The mass number is the total number of nucleons in a nucleus.



a) The leftmost point of the graph is deuterium (^2_1H). What is the binding energy per nucleon of deuterium? ________________

b) The point marked to the right of deuterium is helium (^4_2He). What is the binding energy per nucleon of helium? ________________

c) How much energy is given off *per nucleon* if two deuterium nuclei fuse to form one helium nucleus?

d) How much energy is given off *per helium nucleus* formed? ________________

9.5 Stable and Unstable Nuclei

10) Nuclei stability and the binding energy graph

a) According to the binding energy graph, the nucleus of which element has the most binding energy? ________________

b) Why is this nucleus also the most stable?

c) Which is the least stable heavy element on this graph? Why is it the least stable?

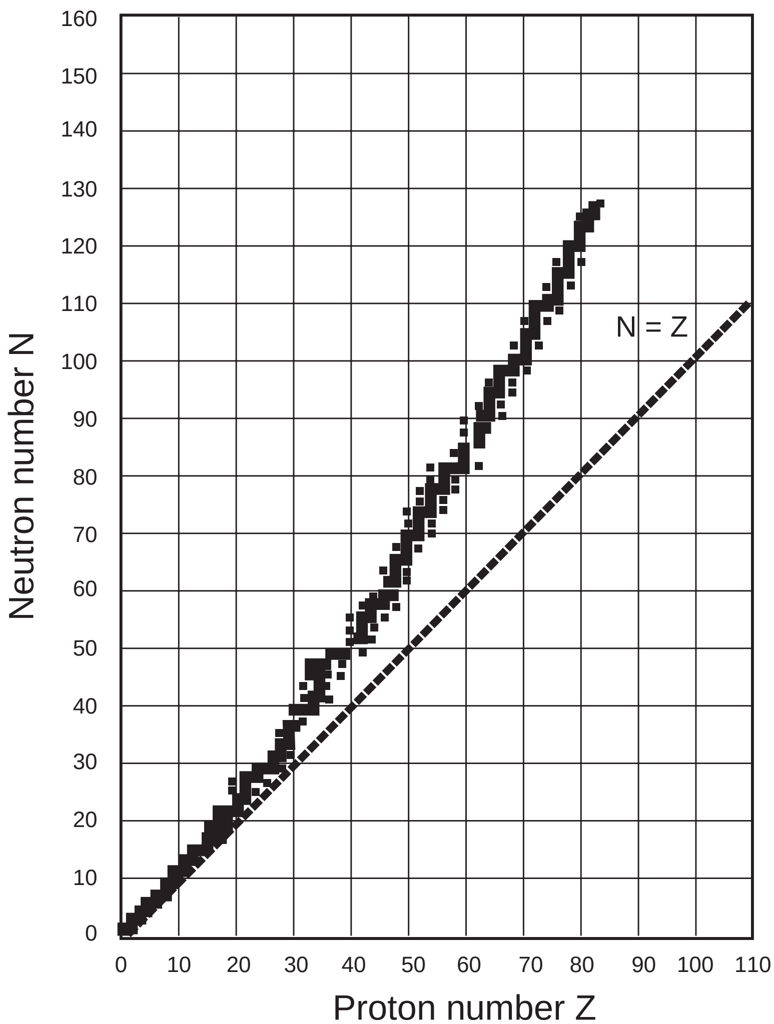
11) *Graph of Stable Nuclei* The graph below shows the number of neutrons versus the number of protons for stable elements.

a) Find the slope of the straight line.

b) What does the straight line represent?

c) What does the group of points that form a curved line show?

Graph of neutron number N versus proton number Z for stable nuclei



12) Determining the stability of nuclei

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

i) Is the isotope $^{14}_{7}\mathbf{N}$ (nitrogen-14) stable? Why or why not?

ii) Is the isotope $^{14}_{6}\mathbf{C}$ (carbon-14) stable? Why or why not?

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

c) What will happen to a nucleus with more than 83 protons?

13) The role of the weak nuclear force

a) A deuterium nucleus can form from two protons. Why would you expect the process of forming a deuterium nucleus to require a large activation energy?

b) A deuteron nucleus consists of a neutron and a proton, but the formation process started with two protons. What must have happened to one of the protons? ____

What force was involved in this process? ______________________

c) What can happen to a nucleus with 83 or fewer protons that has too few neutrons?

d) What can happen to a nucleus with 83 or fewer protons that has too many neutrons?

e) How do the strong and the weak force combine to produce the stable isotopes?

14) Enlarged graph of Stable Nuclei

The grid below represents an enlargement of a portion of the graph shown in part 12).

a) Darken the squares on the grid that represent the following stable isotopes of calcium: Calcium-40 ($^{40}_{20}Ca$), Calcium-42 ($^{42}_{20}Ca$), Calcium-43 ($^{43}_{20}Ca$), Calcium-44 ($^{44}_{20}Ca$), Calcium-46 ($^{46}_{20}Ca$), and Calcium-48 ($^{48}_{20}Ca$).

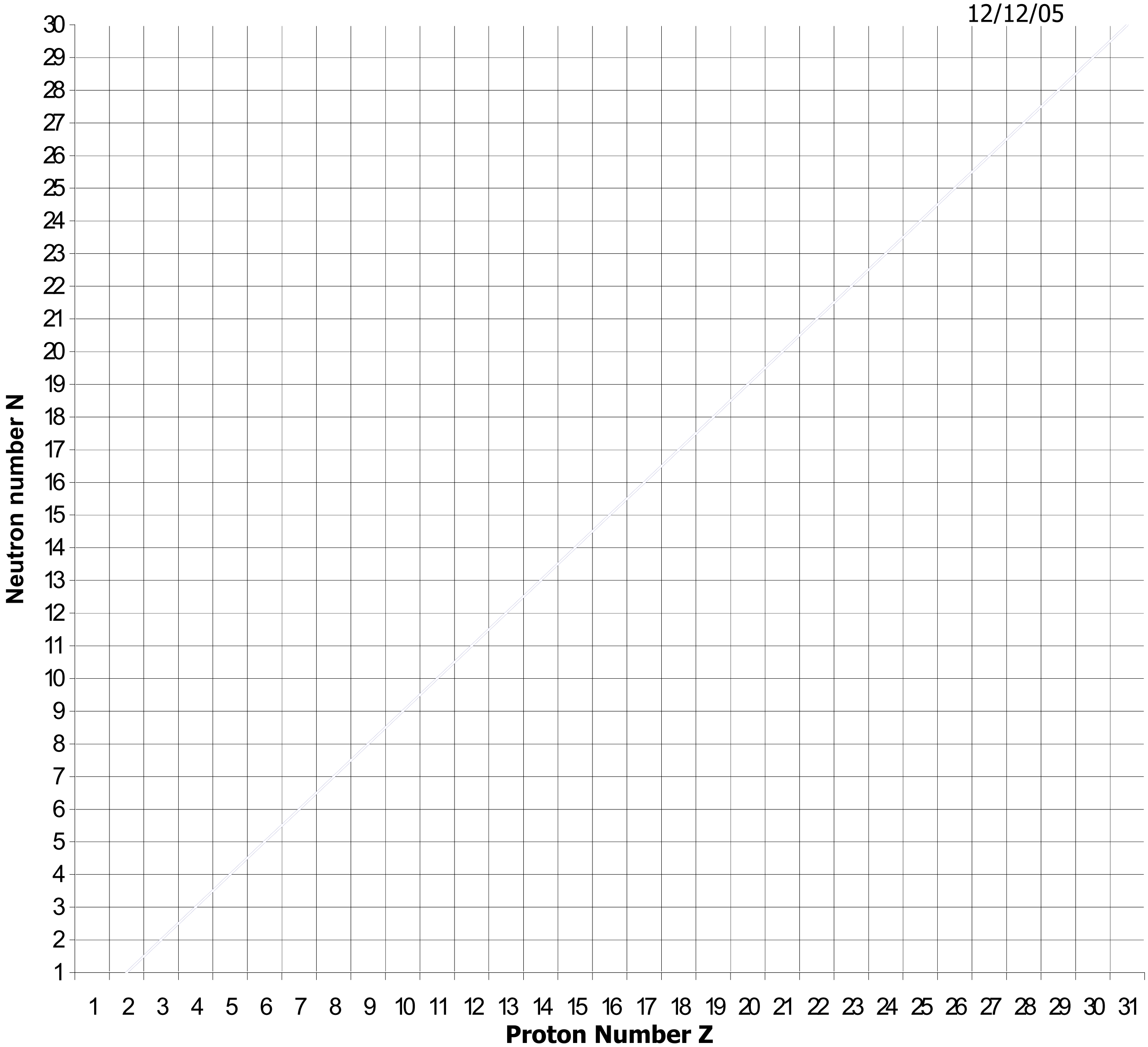
b) Mark an X in the square that represents the nucleus of Silicon-40 ($^{40}_{14}Si$)

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

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

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

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



15) Mass of the Light Stick

a) 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? _______________ Why or why not?

b) Group Discussion Question: When hydrogen and oxygen atoms combine in a fuel cell to form a water molecule, the chemical binding energy given off is approximately 2.5 eV per molecule. When a proton and a neutron combine to form a nucleus of deuterium, the nuclear binding energy given off is 2.2×10^6 eV per nucleus.

Why is it that we cannot measure a change in mass in chemical reactions but we can measure a change in mass in nuclear processes? (Hint: approximately how many times greater is the binding energy of a deuterium nucleus than that of a water molecule?)