15. <u>Specific Heat Capacity, *c*</u>

A. Q = *m c* ΔT

The specific heat capacity of a substance, *c*, is the amount of energy needed to raise the temperature of 1 g of a substance by 1 ^oC.

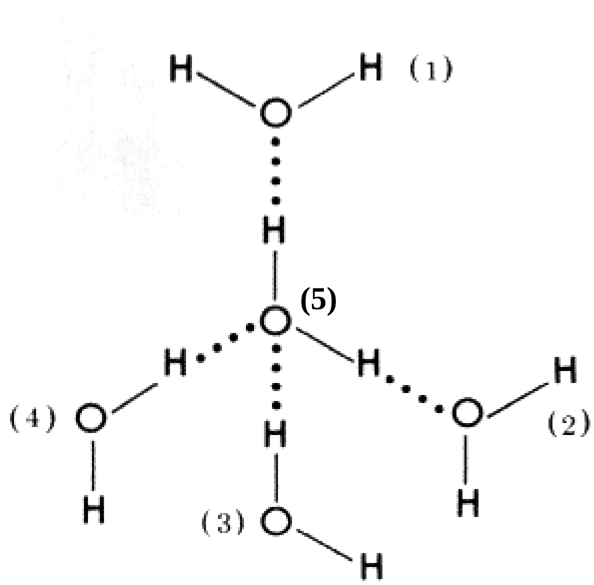
Specific heat capacity is a physical characteristic property. Different substances have different specific heats. Water has a very high specific heat: it takes 4.19 J to raise the temperature of 1 g or 1 ml of water by 1 ^oC. Most metals, on the other hand, have much lower specific heats. Cu's *c* value is only 0.39 J/(g C).

<u>Example</u> Give an example of another everyday substance that has a low specific heat.

When I get hard boiled eggs ready for my kids in the morning, I sometimes place water in a pot but forget the egg. If I remember within 30 seconds or so, it is still safe to place my hand in the water, but it would be a bad idea to touch the pot itself. Metals warm up faster than water does---so that's what a high specific heat implies: the higher the *c* value, the more difficult it is to warm up that substance. By the same token, high specific heat substances also lose their heat slowly, while metals cool off quickly.

The high specific heat capacity of water helps temper the rate at which air changes temperature, which is why temperature changes between seasons is gradual, especially near large lakes or the ocean. Water is the reason why Toronto is milder than Montreal.

If water's specific heat was lower than it actually is, life would not be possible. The rate of evaporation would be too high, and it would be too difficult for the evolutionary precursors of cells to maintain homeostasis.



Why is water special? The reason it is difficult to raise water's temperature is that *hydrogen bonds* exist between molecules of water. The hydrogens of one molecule are attracted to the oxygen atom of another molecule.
(see the dots = ···· in the adjacent diagram. Each set represents a hydrogen bond. Five molecules are shown in all)) To overcome this attraction, energy is needed. The bonds between the water molecules are like the links between the wagons of a train. Just like it is difficult to get a big train to reach a high speed, it takes a lot of energy to warm up water. Once the train is moving, it is difficult to stop. Similarly it is difficult to cool water.
A very useful formula allows us to calculate the amount of heat either absorbed or lost by a substance during a physical change.

$Q = m\,c\,\Delta T$

Q = quantity of heat in joules (J)
m = mass of the substance acting as the environment in grams (g)
c = specific heat capacity (4.19 for H_2O) in J/(g ^oC)
ΔT = change in temperature = $T_{final} - T_{initial}$ in ^oC

Example 1 How much energy is needed to warm up 300.0 kg of water from 10.0 ^oC to a comfortable 37.0 ^{o} C?

Example 2 a) What final temperature will be attained by a 250.0 ml cup of 10.0 ^oC water if it absorbs 1.00X 10^3 J of heat?
Note, because water's density = 1g/mL

b) What final temperature will be attained by a 250.0 g sample of Cu at 10.0 ^oC if it absorbs 1000.0 J of heat? Cu 's *c* = 0.39 J/(g C)

c. What do you notice by comparing your answer (b) to that of (a)?

Mixing Problems The amount of heat lost a hot object can be assumed to be absorbed by a colder object, assuming that the system is well insulated. Mathematically, however, these quantities can only become equal if an extra negative sign is inserted.

- heat lost by hot object = heat gained by cold object

(Use $Q = mc\Delta T$ to obtain the heat for each respective object)

Example 1 What final temperature will be attained if 300.0 grams of 30.0^o C water are mixed with an equal mass of 66.0 ^{o} C alcohol? The specific heat of the alcohol is 2.3 J/(g ^{o} C). Comment on why the final temperature of the mixture is NOT simply the average of the two liquids' temperature.

Exercises

1. 800.0 g of water are warmed from 10.0 ^{o}C to 80.0 ^{o}C. How much energy in J were absorbed?

2. 700.0 g of water are allowed to cool from its boiling point to 20.0 ^{o}C. How much energy in kJ were released into the room?

3. How many kJ of energy must a heater supply in order for 200 kg of bathwater to warm up from 10 ^{o}C to our body temperature of 37.0 ^{o}C?

4. If 9000.0 J of heat are absorbed by 800.0 g of water at 5.0 ^{o}C, what will be its final temperature?

5. 800.0 kJ were absorbed by a pond, sending its temperature rising from 20.0 ^{o}C to 25.0 ^{o}C. How much water was in the pond?

6. Find the specific heat of a material that lost 41 900 J of energy when 200.0 g of the material went down 50.0 ^{o}C in temperature. What was the material?

Flashback Problems

7. How much energy in kJ does a 120 V appliance drawing 2.5 A current use in 6.0 hours?

8. If eight 10.0 Ω resistors are connected in parallel to a 120.0 V source, how much current will be drawn by each resistor? Draw out this situation before you tackle the problem.

9. What two families of the periodic table form compounds involving the +1 and +2 ions, respectively?

10. Specific heat is a characteristic physical property.

    a. Give another physical characteristic property for water
    b. Give a characteristic *chemical* property of water.

More Specific Heat

Basic Problems

1. In the summertime, you find that tap water at 18.0 °C is too warm to drink. You put 500.0 mL of this water in the refrigerator. After a period of time, the temperature of the water is 4.0 °C. While it was cooling, the water lost a certain quantity of heat energy.

   What quantity of heat energy was lost?

2. A calorimeter contained 250.0 g of water at 24.0 °C. An electric current was passed through a heater placed in the water. The heater transferred 14 700 J of energy to the water.

   What is the final temperature of the water?

3. A water tank contains 200.0 kg of water. The water is heated by a 4500-W heating element.
   How much energy is required to raise the temperature of the water from 15.0 °C to 60.0 °C?

Mixing Problems

4. What mass of copper, originally at 50.0 ºC, must be added to 1.0 kg of 10.0 C water to raise its temperature to 20.0 ºC? [sp heat for Cu = 0.39 J/(g ºC)]

5. A 450 mL sample of water is originally at 25.0 C. How cold will it get if we add 300.0 mL of 0.5 ºC water to that sample?

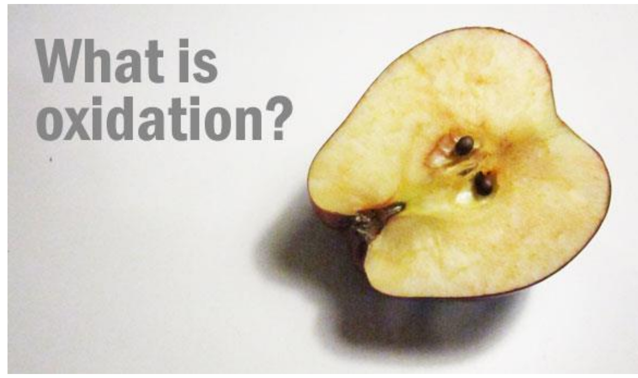
6. Zinc(Zn), platinum(Pt) and titanium(Ti) follow the M*c* = 25 formula for metals, where M is the molar mass in g/mole and *c* = specific heat in J/(gºC). Estimate the specific heat for these three elements.

7. Based on the relationship M*c* = 25 J/(mole ºC), what elemental metal has the highest specific heat? M = molar mass in g/mole

Challenger

8. Starting with the same formula used in #4, prove that for *equal* masses of the *same* material, the final temperature obtained by mixing two samples will simply be the average of the two initial temperatures.

16. **Types of Chemical Change**



Oxidation: this is a reaction where oxygen or another substance takes electrons from a reactant.

Examples with oxygen:

Examples without oxygen:

a) Which reactant is playing the role of oxygen?

b) Show that one of the reactants is oxidizing (in other words, it`s taking electrons.)

Exothermic Reactions

Most oxidations release heat because they create more tightly bonded products with lower potential energy. An exothermic reaction, in general, is one that releases heat.

Examples:

$CH_{4(g)} + 2\ O_{2(g)} \rightarrow CO_{2(g)} + 2\ H_2O_{(g)} + 890\ kJ$

Other exothermic reactions, but which are not oxidations.

Examples: (neutralizations; dissolution of sodium hydroxide)

Endothermic Reactions: An endothermic reaction is one that removes heat from the environment in order to create products.

Examples:

Stochiometry With Endothermic and Exothermic Reactions.

Example 1: **Given:** $C_2H_5OH_{(l)} + 3\ O_{2(g)} \rightarrow 2\ CO_{2(g)} + 3\ H_2O_{(l)} + 1367\ kJ$

How many kJ of heat will be released if we burn 3.0 g of alcohol?

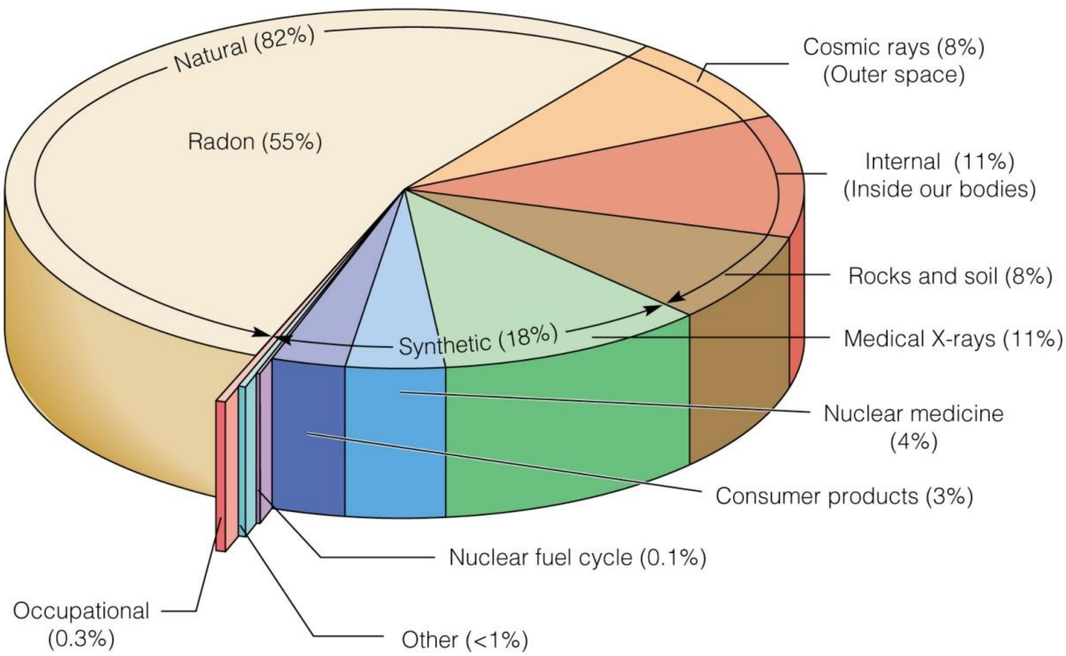
Example 2: $2\ NaOH_{(aq)} + H_2SO_{4(aq)} \rightarrow Na_2SO_{4(aq)} + 2\ H_2O_{(l)} + 54\ kJ$

a) If 0.20 L of 0.10 M $NaOH_{(aq)}$ are neutralized, how much heat will be released?

b) If the above reaction released 2.45 kJ, and 200.0 ml of base were used, what was the concentration of the base?

17. RADIOACTIVITY

Radioactivity is the process by which the nucleus of an atom either breaks up or changes. This leads to important differences between chemical and nuclear reactions:

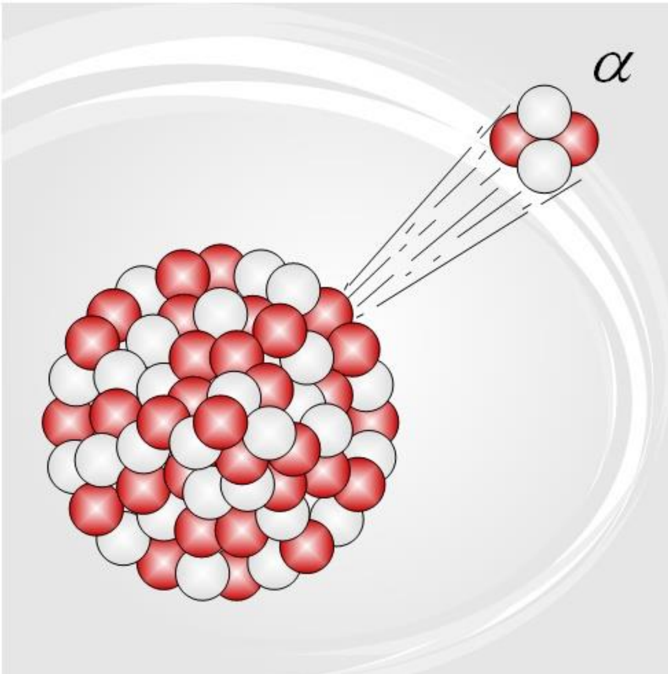


	Nuclear	Chemical
Do protons and neutrons change?		
Are particles released from the nucleus?		
Is mass conserved?		
Are electrons energy levels involved?(shells)		
How does the energy released compare?		

Although radioactivity can be man-made, some of it is of natural origin. Potassium-40 and carbon-14 are both radioactive isotopes in our body, and uranium-238 is found in the earth's crust.

Here are examples of the different types of radiation that can be released:

Alpha Decay:



If a particle consisting of two neutrons and two protons is released from a radioactive nucleus, we call that particle an **alpha particle**(a helium nucleus) :

Example 1:

$$ {}^{238}_{92}U \rightarrow {}^{4}_{2}He + {}^{234}_{90}Th $$

Example 2: Notice how atomic number and mass number are conserved. (Sum of subscripts on left side equals sum on the right side. The same is true for the subscripts.) Based on this, fill in the blank.

$$ {}^{210}_{84}Po \rightarrow \qquad + {}^{4}_{2}He $$

Beta Decay:

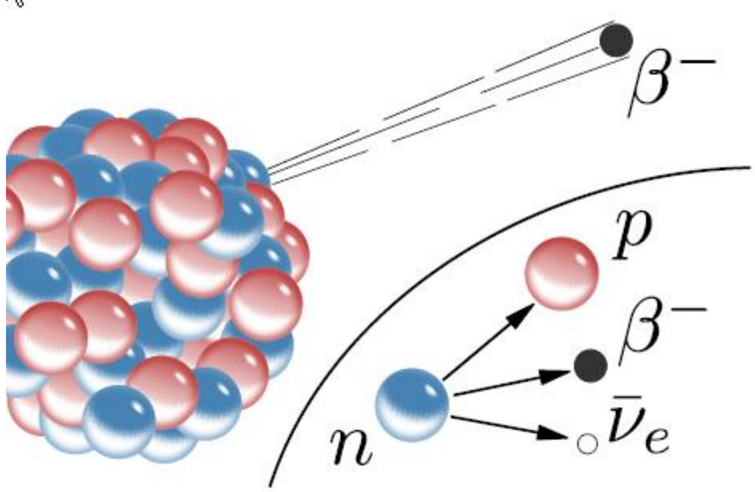
If a neutron is converted into a proton, a **beta particle** (electron) is also produced:

Example 1:

$$ {}^{40}_{19}K \rightarrow {}^{40}_{20}Ca + {}^{0}_{-1}e $$

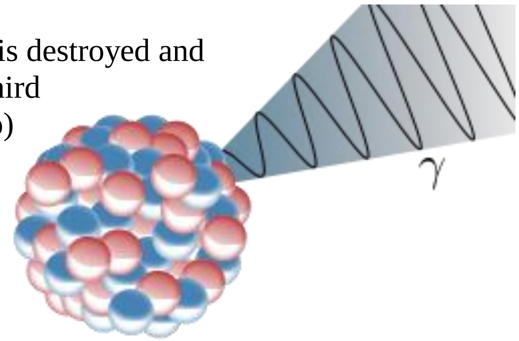
Example 2: Fill in the blank:

$$ {}^{131}_{53}I \rightarrow \qquad + {}^{0}_{-1}e $$



Gamma Decay:

In many nuclear reactions, a small amount of mass is destroyed and converted to energy in the form of gamma rays, a third form of radiation (alpha and beta being the first two)



Example 1:

$$^{238}_{92}U \rightarrow {}^{4}_{2}He + {}^{234}_{90}Th + {}^{0}_{0}\gamma$$

Example 2: Fill in the blank with the correct form of radiation:

$$^{12}_{6}C + {}^{1}_{1}H \rightarrow {}^{13}_{7}N + \_\_\_\_\_$$

Positrons: These are examples of antimatter. They have very little mass like electrons, but they have a positive charge.. The symbol is ${}^{0}_{1}e$

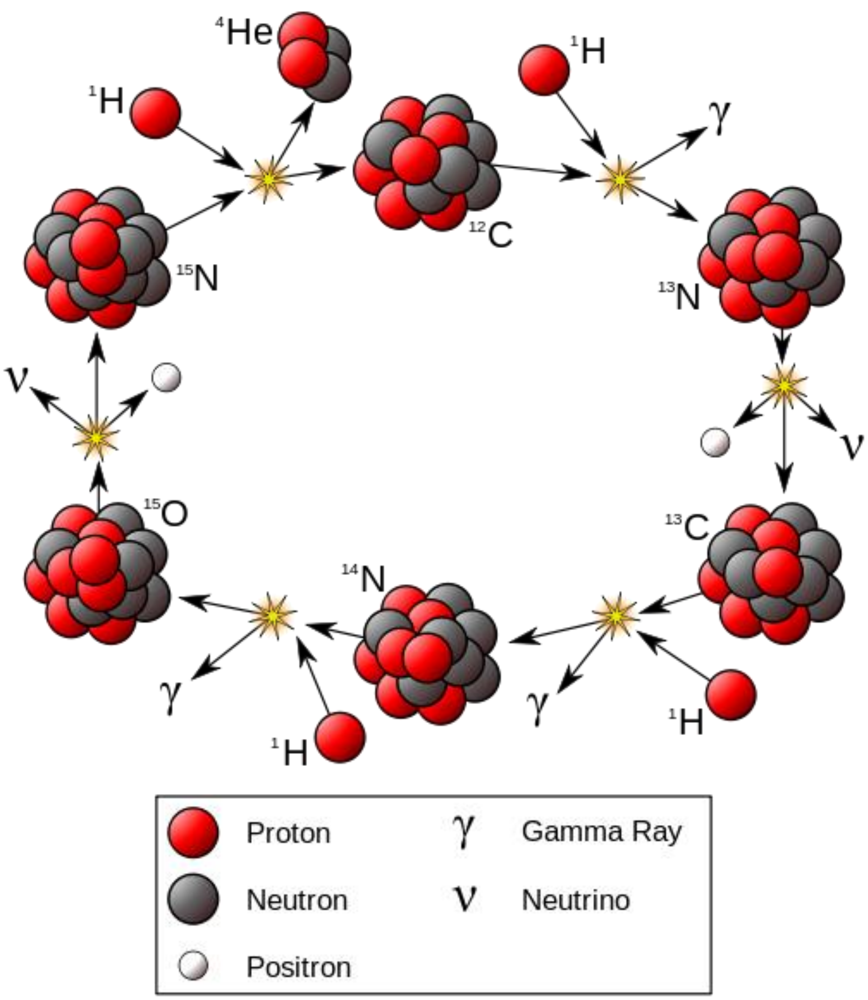
Example 1:

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

Example 2: Fill in the blank with the correct form of radiation:

$$^{12}_{6}C + {}^{1}_{1}H \rightarrow {}^{13}_{6}C + \_\_\_\_\_$$

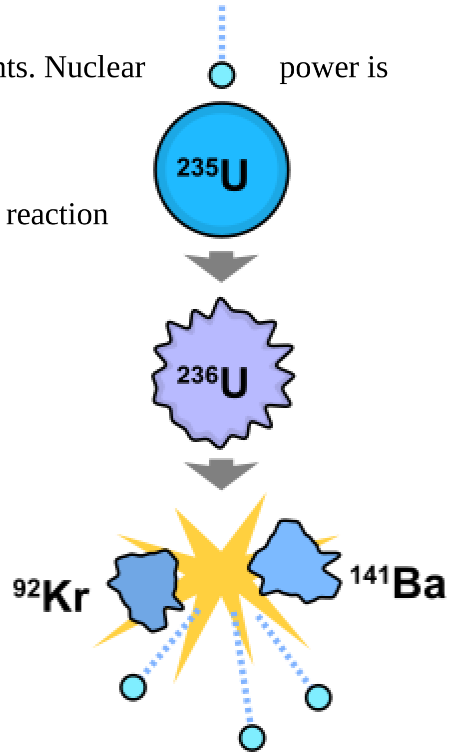
Example 3 Use the diagram below to write two nuclear equations involving positrons.



<u>Fission and Fusion</u>

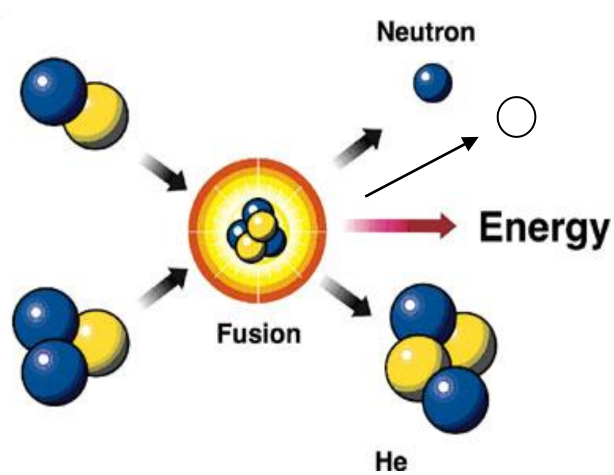
Fission is the process by which a heavy nucleus splits into fragments. Nuclear power is derived from fission reactions.

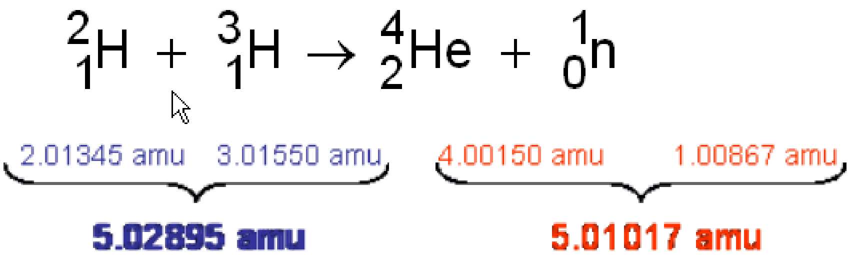
<u>Example 1</u> Write an equation to represent the following fission reaction



Fusion involves joining smaller nuclei into larger ones. Strangely both result in the release of large amounts of energy, as mass is destroyed:
$\Delta E = \Delta mc^2$. But fusion releases far more energy than fission.

<u>Example 1</u> Write an equation to represent the fusion reaction shown below:





<u>Example 2</u> Find the change in mass (note the unit is an ***amu*** = atomic mass unit)

Δm = ______________________ amu (That's for just one atom of ^{2}H that fuses with ^{3}H.

Example 3 a) If 1 mole of ^{2}H fused with a mole of ^{3}H, then 1.13 X10^{22} *amu* would be lost. Show how they arrived at that answer.

b) If you look up the mass of one ***amu***, it equals 1.6605 X 10^{-27} kg. Calculate the energy released when 1 mole of ^{2}H fuses with a mole ^{3}H, using $\Delta E = \Delta mc^2$.
c = speed of light = 2.98 X10^{8} m/s

c) How does that compare to burning 1 mole of hydrogen in oxygen, which releases 142 000 J?

Stars (including our sun) shine because of fusion reactions, which release more energy than fission reactions.

Exercises

1. Classify as beta, alpha or positron decay.

a) $^{238}{}_{92}\,U \rightarrow {}^{234}{}_{90}\,Th + {}^{4}{}_{2}\,He$

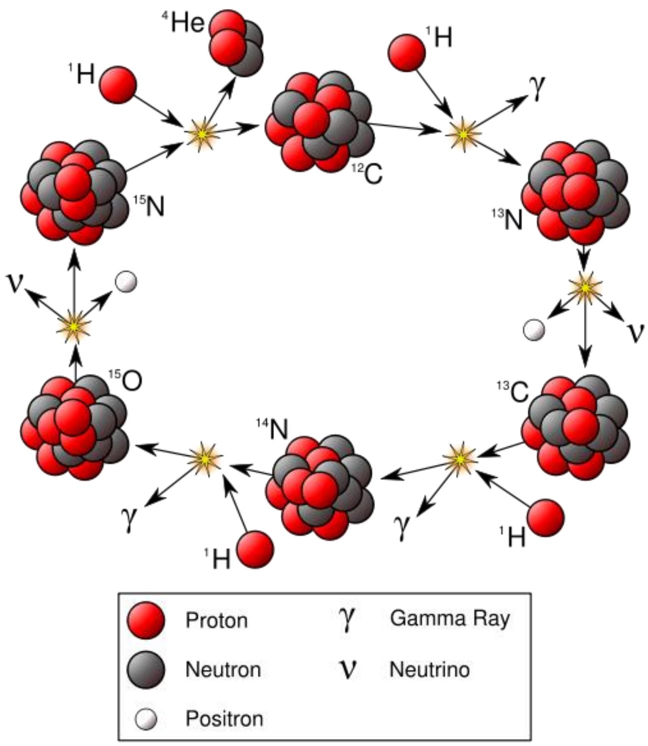
b) $^{12}{}_{7}\,N \rightarrow {}^{12}{}_{6}\,C + {}^{0}{}_{1}\,e + \nu$

2. Fill in the blank:

a) $? + {}^{0}{}_{-1}e \rightarrow {}^{244}{}_{94}Pu$

b) $^{1}{}_{1}H + {}^{4}{}_{2}He \rightarrow ?$

3. a) Use the diagram below to write a nuclear equation involving alpha particles.
   b) Write two equations involving the release of gamma rays.



4. Classify as fusion or fission

a) $^{1}_{0}n + ^{235}_{92}U \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n$

b) $^{1}_{1}H + ^{1}_{1}H \rightarrow ^{2}_{1}H + ^{0}_{1}e + \nu$

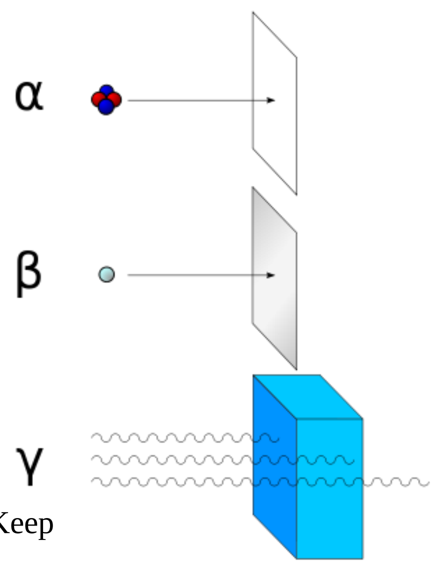
5. Here are some of the reactions that occur in the sun. Fill in the blanks.

a) $^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ???$

b) $^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{1}H + ???$

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

d) $^{2}_{1}H + ^{3}_{2}He \rightarrow ??? + ^{1}_{1}H$



5. Alpha can penetrate thin sheets of metal, but it has a hard time penetrating paper. Beta can be stopped by an aluminum plate. It takes a thick block of lead to shield gamma rays.

Based on this, which particle has the weakest penetrating power?

6. List the differences between chemical and nuclear reactions.

7. Calculate the amount of energy released when 28 g of ^{2}H fuses. Keep in mind that each mole of fused ^{2}H releases 1.67×10^{12} J.

8. Find the change in mass and corresponding change in energy for the reaction shown. 1 ***amu*** equals 1.6605×10^{-27} kg. (it's not exactly the same calculation we did in class; we did it for a mole of fusing atoms)