Workshop module 13 - Physics 123, Spring 2013

1. Jimmy thinks Lois Lane is one wonderful lady. He'd love nothing better than to have her over for dinner. However, the scuttlebutt in the newsroom is that Lois is Superman's main squeeze and Jimmy has no desire to face a jealous Superman! But Jimmy is a pretty bright guy. He takes nuclear physics courses in night school. The other day he stole a pocketful of kryptonite from the laboratory. Everyone knows that the radioactive decay of kryptonite makes Superman powerless when he is nearby. So Jimmy figures he can keep keep the kryptonite in his pocket and hit on Lois at will, provided she thinks it's a good idea.

   Kryptonite is an unusual element. It decays with a half life of two years ($6x10^7$ s) by emitting an alpha particle. The mechanism of kryptonite's effect on Superman is not understood. However, it is known that any kryptonite sample with an activity (also known as decay rate) of 10,000 decays/s or greater causes Superman to lose his powers instantaneously if he is within 10-20 meters.

   Jimmy stole a sample of kryptonite oxide containing $2x10^{12}$ kryptonite nuclei. How long after the theft can Jimmy court Lois before Superman squashes him with his superpowers?

   Given the location of the sample (in his pocket), is the Kryptonite more or less damaging to Jimmy's body than a gamma source of comparable activity? Why?

   As it turns out, Jimmy's plan goes awry because Superman also studied physics. Jimmy gets no further than lighting the candles at dinner when Superman zips in through one open window and out another at a very high velocity. He grabs Lois as he flies by and takes her away to have dinner at his place.

   How fast must Superman fly as he passes through Jimmy's apartment in order to be able to nab Lois without losing his powers? Assume the dinner occurred such a short time after Jimmy's theft that Jimmy measured the activity of the sample to be virtually unchanged.

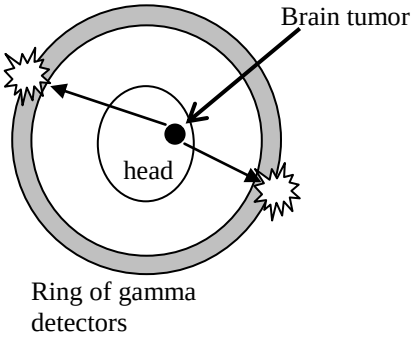
2. The rubidium isotope ^{87}Rb (Z=37) has a half-life of $4.9x10^{10}$ years. It decays into ^{87}Sr (Z=38).

   (a) 4 pts - What type of radiation is emitted by ^{87}Rb when it decays?

   (b) 6 pts - Rubidium is often used to determine the age of rocks and fossils. Rocks containing the fossils of early animals contain a ratio of ^{87}Sr to ^{87}Rb of 0.0100. Assuming that there was no ^{87}Sr present when the rocks were formed, calculate the age of these fossils.

3. The medical imaging technique of positron emission tomography (PET) begins by injecting β^+-emitting radiopharmaceuticals into a patient. The β^+ particle is a positively charged electron called the positron. It is the electron's anti-particle. It will travel in the body until it approaches an electron, at which point the positron and the electron will annihilate each other and turn into two 0.511 MeV gamma rays emitted back-to-back. Generally, the positron travels a very short distance before it annihilates with an electron. So the gamma rays are emitted in roughly the location of the initial nuclear decay leading to the positron. PET works by setting up gamma ray detectors in a circle around the body. By detecting the difference in time of detection of the two back-to-back gamma rays, one can determine the position of the annihilation along the flight path of the two gammas. Integrated over many decays in many directions, a three-dimensional image can be formed of the region where the β-decays are taking place. The medical utility of this imaging technique comes about when the nucleus undergoing β-decay is part of an atom that is incorporated into a molecule that tends to concentrate in inflamed regions of the body. The molecule concentrates around the tumor. Thus the decays happen around the tumor and a PET scan images the tumor.

Gamma to right hits before gamma to the left, telling the observer that the distance to the right is shorter than the distance to the left. The difference in time is used to calculate the "exact" position of the positron emission (the tumor).

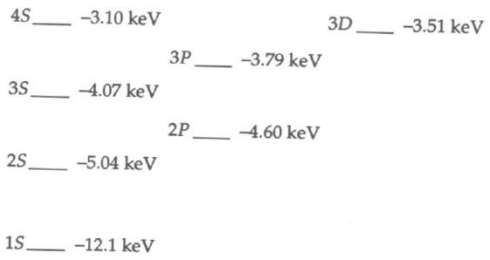


a) Suppose the isotope $^{13}_{7}N$ is used as the decaying nucleus for a PET scan. What is the electron shell configuration for atomic $^{13}_{7}N$?

b) Write the relevant nuclear decay equation for the β-decay that takes place.

c) ^{13}N has a half-life of 10 minutes. At noon today, the PET detectors register 1000 counts/minute above background due to the ^{13}N injected into a patient. How many counts/minute will the PET detectors register in one hour for the same patient? (For this calculation, please ignore any biological activity that might change the counts over the period of an hour.)

4. Joe radiologist operates (or, more likely, asks an X-ray technician to operate) an X-ray machine with a nickel target. (The machine consists of a beam of electrons accelerated to some energy incident on a nickel target, where the X-rays are created.) The X-ray machine is being operated at a potential of 50 keV. The energy level diagram for nickel is shown here. From this information, determine the wavelength of the K-alpha X-rays emitted by this machine. *(h=4.1x10^{-18} keV-sec)*



5. How much energy is released in the fusion reaction below?

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

   In what form(s) might this energy appear when the reaction happens?

   Potentially useful information:
   atomic mass of $^{2}_{1}H$ in MeV/c^2 is 1875.328
   atomic mass of $^{3}_{1}H$ in MeV/c^2 is 2808.239
   atomic mass of $^{4}_{2}He$ in MeV/c^2 is 3726.818
   mass of proton in MeV/c^2 is 937.873
   mass of neutron in MeV/c^2 is 939.565
   mass of electron in MeV/c^2 is 0.511

6. Suppose we find a rock and geologists tell us that when that rock was formed in a volcano it would have contained an equal amount of Iridium-192 (Z=77, symbol = Ir) and Bismuth-209 (Z=83, symbol = Bi). Suppose that Iridium-192 and Bismuth-209 are both naturally radioactive. Also, suppose that Iridium-192 decays with a half-life of 500,000 years and Bismuth-209 decays with a half-life of 1 million years. If the rock is two million years old and you measure the amount of Iridium-192 and Bismuth-209 in the rock, what ratio for the amount of Iridium-192 to Bismuth-209 would you expect to measure?

7. Because of your amazing physics expertise you become a consultant on nuclear terrorism to the U.S. Department of Missiles and Urban Development (MUD) after graduation. One day the Grand Pubah Ubersecretary of MUD, Samuel Thudpucker III, calls you to his office to ask for your advice on a national security matter. Samuel sits you down and says, "We have just apprehended a nasty, scumbag terrrorist type and interrogated him. He didn't give up much information at first, but after we threatened to make him watch CNN's Nancy Grace endlessly, he broke. The scumbag told us that he and his nasty friends recently acquired a special nuclear bomb that uses iron as the active bomb material. Is this credible? Should we be worried?"
   Please give here a brief and appropriate response to Ubersecretary Thudpucker's questions using what you have learned in this course.

8. Please explain briefly why the Tel Aviv Organization of Realtors should be concerned that the Iranian government has accquired high strength steel that can be used to build centrifuges.