Workshop Tutorials for Introductory Physics
QI5: **Radioactivity**

A. Review of Basic Ideas:

Use the following words to fill in the blanks:
photon, nuclides, radionuclides, decay, medicine, strongly, random, radiation, electron, charged, helium, 4, β^-, positively, large, half-life, nuclei

Radiation
Most species of nuclei, or ________, are stable, but some are not. Those that are unstable can become stable by emitting _______. This process is called radioactive decay. The unstable nuclei are called radioactive nuclides, or ________.

There are three types of radiation which can be emitted when a radionuclide decays. It can emit an α particle, which is the same as a ________ nucleus. This is the heaviest and most highly ________ of the nuclear radiations, it has a mass number of ________ and a positive charge of $2e$. These particles interact ________ with matter.

The next heaviest are the β particles. There are two types of β particle, a β^+ and a _____. The β^- is the same as an ________, it has a negative charge, and a small mass. A β^+ particle is a _____ charged electron, also known as a positron. These particles don't interact as strongly with matter as the α particles.

The third type of radiation is γ radiation. A γ particle is a _____. It has no mass and no charge, but may have a lot of energy. A γ particle is emitted from an excited nucleus. They are also often emitted along with a β or α particle during radioactive ________.

Radioactivity has some very useful applications. The emitted particles can be used to track where the radioactive material is, such as in nuclear imaging in ________. Another application is radioactive dating. Although radioactive decay is a ________ process, so that it's impossible to predict when a given nucleus will decay, it does obey statistics. The behaviour of a ________ number of nuclei is, on average, predictable. For example, we can say that half of the nuclei, on average, will decay in a given period of time. This time is called the ________. If we know the half-life of a material, and how many ________ there were to start with, then we can calculate how old the material is.

Discussion questions

1. A particular ^{238}U nucleus was created during a massive stellar explosion, perhaps 10^{10} years ago. It suddenly decays by α emission while you are observing it. After all those years, why did it decide to decay while you were watching?

2. Complete the following equations:

$^{218}_{84}Po \rightarrow \_\_\_\_ + \alpha$ $\qquad$ $^{11}_{6}C \rightarrow ^{11}_{5}B + \_\_\_\_$

$^{12}_{6}C^* \rightarrow \_\_\_\_ + \gamma$ $\qquad$ $\_\_\_\_ \rightarrow ^{101}_{47}Ag + \beta^+ + \nu$

B. Activity Questions:

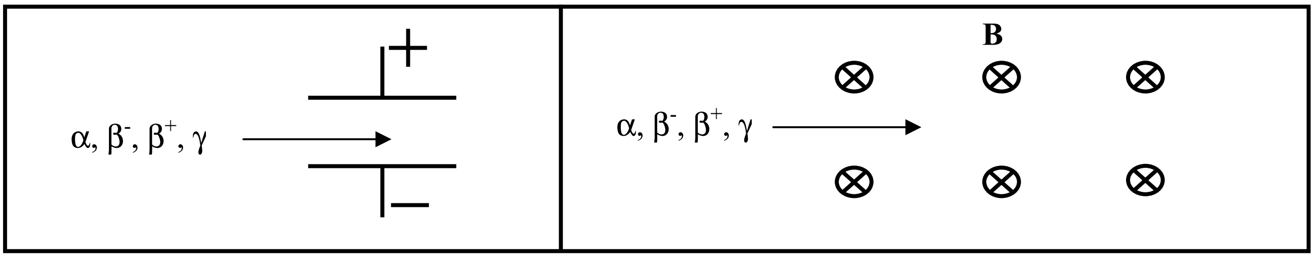
1. Colleen's Cubes
Shake the bag containing the nuclei (cubes) and pour them into the tray. Write down the number of cubes with dots showing on top, remove those cubes and replace the rest in the bag. How many cubes are left of the original 100?
Repeat 10 times. Sketch the number of cubes removed (the activity) as a function of number of throws. Sketch the number of cubes remaining in the bag as a function of number of throws.

2. Smoke detector

Examine the smoke detector. It contains a radioactive source, ^{241}Americium, an α emitter. The α particles ionise air molecules between two charged plates. The positive ions go to the negative plate, the negative ions to the positive plate, which gives a current.
Use the circuit diagram to locate the main components of the detector.
How does smoke disrupt the current?

C. Qualitative Questions:

1. Beams of α, β^- and γ radiation of approximately the same energy pass through electric and magnetic fields as shown below.



a. Show the path taken by each particle in the two fields. Why do they follow these paths?
b. How are β^-, β^+ and electrons different?
c. How are x-rays, γ rays and photons different?

2. Carbon dating has been used to date many archeological finds, including the Dead Sea scrolls.
The scrolls are mostly made of animal skins or papyrus, but one is made of copper. Carbon-14 dating of samples from the scrolls has dated the scrolls at 1950 years old.
a. Describe how the decay of ^{14}C can be used to tell how old things are.
b. Why is it not possible to date the copper scroll in this way?
c. Carbon-14 has a half-life of 5,730 years. Why is carbon dating not used to date things over around 50,000 years old?

D. Quantitative Question:

Many processes and systems follow exponential decay over time. For example; the rate of cooling of a cup of coffee, the improvement in your time at completing a puzzle, the number of members of a population under environmental stress, the charge in a discharging capacitor and the number of radioactive atoms in a sample. The following example illustrates an exponential decay process.
Consider a street with 200 houses. In 1980 every household had one car, which ran on super (leaded) petrol. Every year, one tenth of households, on average, replace their car with one that runs on unleaded fuel.
a. How many cars from this street ran on unleaded fuel in 1982?
b. Draw a graph of number of cars using leaded petrol in this street as a function of time.
c. Draw a graph of number of cars replaced each year as a function of time.
d. What is the "half life" of a leaded-petrol car in this street?
Radioactive decay works in exactly the same way. The number of remaining nuclei, N, at time t is given by $N(t) = N(0)\, e^{-kt}$ where $k = \ln 2$ / half-life.
e. Write an equation of this form which gives the number of leaded-petrol cars as a function of time.
f. What is the number of remaining cars analogous to in radioactive decay? What is the number of cars replaced each year analogous to?