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

A. Review of Basic Ideas:

Radiation

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

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 **helium** nucleus. This is the heaviest and most highly **charged** of the nuclear radiations, it has a mass number of **4** and a positive charge of 2e. These particles interact **strongly** with matter.
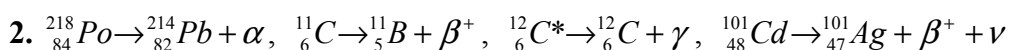
The next heaviest are the β particles. There are two types of β particle, a β^+ and a β^-. The β^- is the same as an **electron**, it has a negative charge, and a small mass. A β^+ particle is a **positively** charged electron, also known as a positron. These particles don't interact as strongly with matter as the α particles.

The third type of radiation is γ radiation. A γ particle is a **photon**. 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 **decay**.

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 **medicine**. Another application is radioactive dating. Although radioactive decay is a **random** process, so that it's impossible to predict when a given nucleus will decay, it does obey statistics. The behaviour of a **large** 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 **half-life**. If we know the half-life of a material, and how many **nuclei** there were to start with, then we can calculate how old the material is.

Discussion questions

1. Large numbers of nuclei behave in statistically predictable ways, but individual nuclei do not. Nuclear decay is unpredictable, and a single nucleus may decay at any time.

2. $^{218}_{84}Po \rightarrow {}^{214}_{82}Pb + \alpha$, ${}^{11}_{6}C \rightarrow {}^{11}_{5}B + \beta^+$, ${}^{12}_{6}C^* \rightarrow {}^{12}_{6}C + \gamma$, ${}^{101}_{48}Cd \rightarrow {}^{101}_{47}Ag + \beta^+ + \nu$

B. Activity Questions:

1. Colleens Cubes
You should have come up with an exponentially decreasing curve for both the number of cubes remaining, and the number of cubes removed at each throw. Many physical processes follow this pattern.

2. Smoke detector
When smoke enters the space between the plates the ions attach themselves to the heavy smoke particles and the flow of current is disrupted, setting off the alarm.

C. Qualitative Questions:

1.

a. The charged particles are deflected and follow a curved path in an electric or magnetic field. The γ particles are uncharged and hence are not affected. The α's are charged, but are very heavy and are less deflected than the βs.
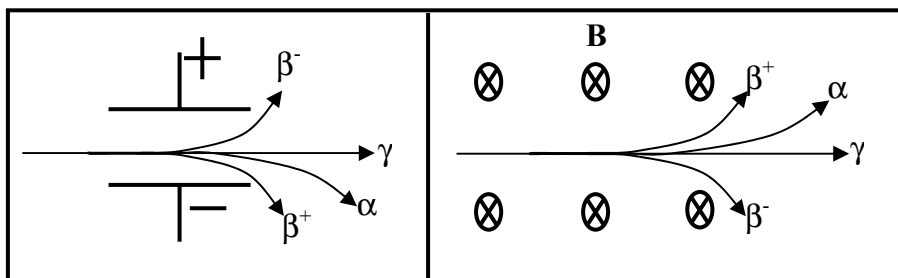
b. β⁻s and electrons are exactly the same, they were named βs before it was known that they were electrons. β⁺s are positrons, or positively charged electrons. They have the same mass as an electron, and the same magnitude of charge, but are positive.

c. x-rays and γ rays are both photons, they have no charge and no mass. γ rays have higher energy (and higher frequency) than x-rays, and both are higher energy than photons of visible light.

2.

a. There is a constant exchange of Carbon between the body and the environment for all living things. In this way the proportion of ^{14}C is kept approximatley the same in the body as in the atmosphere. When an organism dies this exchange stops, and the proportion of ^{14}C gradually decreases due to decay without being replenished. We know the proportion of ^{14}C in the atmosphere, and how long it takes to decay, hence we can measure how much is left in a sample and work out from this when it stopped exchanging C with the environment, and hence how old it is.

b. Copper is not organic, hence it was never exchanging C with the atmosphere. However the ink used was organic and hence the scroll could be dated that way.

c. Carbon-14 has a half-life of 5,730 years After 50,000 years there is not enough ^{14}C left in the sample to date it accurately.

D. Quantitative Question:

Every year one tenth of 200 households replace their car with one that runs on unleaded fuel.

a. In 1981 10% of the cars = 20 cars were replaced, leaving 180 cars. In 1982 10% of this 180, = 18 cars, were replaced, giving a total of 38 cars on unleaded fuel.

b.

c.
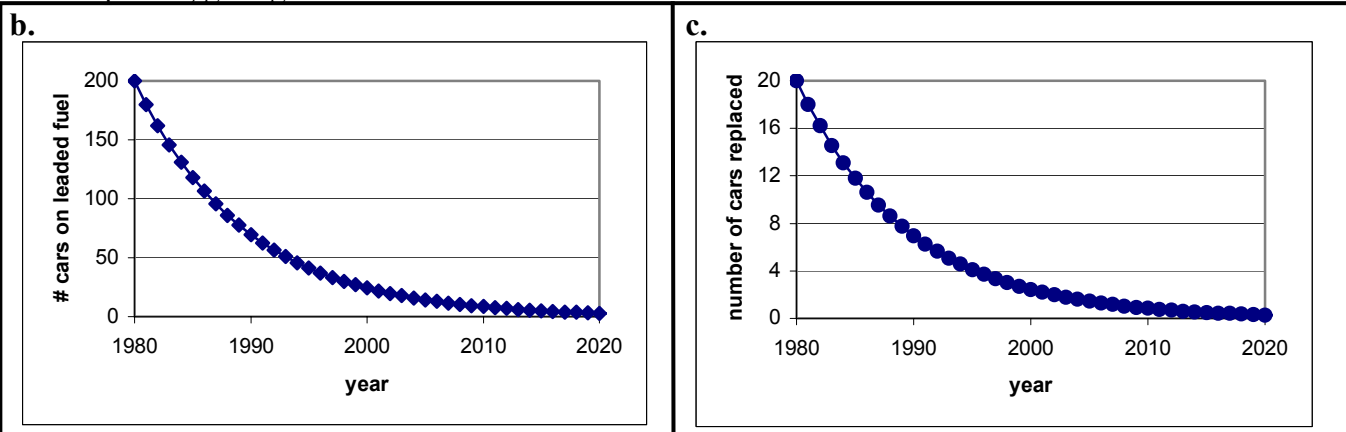
d. The "half life" of a leaded-petrol car in this street is the time taken for the number of cars on leaded fuel to reduce to 100 cars, from the graph this is approximately 6 years. We can check this using

$N_{cars}(t) = N_{cars}(0) \times 0.9^{\,t}$ where t is the number of years since 1980.

Putting in $t = 7$ gives $N_{cars} = 200 \times 0.9^7 = 96$ cars.

Or we can find the half life more precisely:

$N_{cars}(t) = N_{cars}(0) \times 0.9^{\,t}$ and putting in the values for N:

$100 = 200 \times 0.9^t$ so $0.5 = 0.9^t$ and taking ln of both sides:

$\ln 0.5 = \ln 0.9^t = t \ln 0.9$ from which we get $t = \ln 0.5 / \ln 0.9 = 6.58$ years.

e. Using the analogy with radioactive decay, we could write an exponential equation:

$N_{cars}(t) = N_{cars}(0)\, e^{-kt}$ where the decay constant $k = \ln2/\text{halflife}$.

f. In radioactive decay the number of cars remaining is analogous to the number of nuclei not yet decayed. The number of cars replaced in a year is analogous to the number of decays per time period.