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OCR

A Level

# A Level Physics

## Radioactive decay (Answers)

Name:

MME

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Total Marks: /30

1. Radioactive decay is something that has only come to be understood in the twentieth century, after having been discovered by accident in 1896. It is now widely exploited for its medical, military and industrial uses.

Total for Question 1: 10

(a) What are the two defining characteristics of radioactive decay? [2]

**Solution:** It is **random** and **spontaneous**.

(b) What is meant by ionising radiation? [1]

**Solution:** Radiation that is capable of stripping an atom of electrons, leaving behind a positively charged ion.

(c) Compare and contrast the nature and range of $\alpha, \beta$ and $\gamma$ radiation. [4]

**Solution:**
Alpha: positively charged (2e) helium nuclei; very short range (a few cm) because of their large mass and consequent high rate of ionisation.
Beta: fast-moving electrons (-e) or positrons (e) with small mass; much longer range (about 1m) because they are less massive and hence less ionising .
Gamma: high-energy photons travelling at the speed of light (no charge); much less ionising that either because they do not have charge so they travel larger distances.

(d) Outline an experiment you could perform to investigate the absorption properties of different materials. Be precise about the apparatus you would use, any measurements you would take and any analysis you would perform. [3]

**Solution:** The sample is placed between a GM tube and a source of ionising radiation. Three measurements are required:
- Before the radiation is released, a background count rate must be recorded in the presence of no radiation other than that naturally present.
- The count rate is then recorded with the radiation and the absorber. The difference between these is the absorbed and corrected count rate.
- The count rate is then measured without the absorber. The difference between this and the background rate is the raw radiation count rate.

These quantities can be manipulated to calculate, for example, the proportion of the raw radiation that is being absorbed by the sample. The sample's thickness can also be changed.

2. Zircons are minerals typically found in old igneous rocks. Uranium and lead are usually found in small quantities within zircons. $^{238}$U decays radioactively, eventually forming $^{206}$Pb.

Total for Question 2: 13

(a) Rewrite the following equation for $\alpha$ decay, replacing each instance of $x$ with the correct substitution: [2]

$$^{\mathrm{A}}_{x}\mathrm{P} \longrightarrow {}^{x}_{\mathrm{Z}-2}\mathrm{Q} + {}^{4}_{x}\mathrm{x}$$

**Solution:** $^{\mathrm{A}}_{\mathrm{Z}}\mathrm{P} \longrightarrow {}^{\mathrm{A}-4}_{\mathrm{Z}-2}\mathrm{Q} + {}^{4}_{2}\mathrm{He}$

(b) How many $\alpha$-decay events are involved in the decay chain from $^{238}$U to $^{206}$Pb? [1]

**Solution:** 8

(c) Outline an experiment that could be performed to determine the half-life of a $^{238}$U atom. [3]

**Solution:** Measure the background count rate. Now measure the sample + background count rate. Subtract one from the other to get the sample count rate.
Plot a graph of the natural logarithm of the corrected count rate against time. The gradient will be $-\lambda$.
Then, $t_{1/2} = \ln(2)/\lambda$

(d) Given that the half-life of $^{238}$U is $1.41 \times 10^{17}$ s, calculate its decay constant. [2]

**Solution:** $4.92 \times 10^{-18}\ \mathrm{s}^{-1}$

(e) Write an equation for the number of $^{206}$Pb atoms present at a time $t$ in terms of the initial number of $^{206}$Pb atoms, the number of $^{238}$U present, the decay constant of $^{238}$U and $t$. [3]

**Solution:** $^{206}\mathrm{Pb_t} = {}^{206}\mathrm{Pb_0} + {}^{238}\mathrm{U_t}(\exp(\lambda t) - 1)$

In reality, this technique cannot often be used as it is here: it is unfortunately almost impossible to calculate the initial amount of $^{206}$Pb. However, this is why zircons are chosen: their crystal structures are not welcoming to Pb atoms and so the initial Pb is thought to be very low.

(f) Ignoring any $^{206}$Pb that was initially present, calculate the crystallisation age, in years, of a rock which now has a lead-uranium of $\frac{^{206}\mathrm{Pb}}{^{238}\mathrm{U}} = 0.798$ [2]

**Solution:** 3.80 billion yrs

3. A complex physical argument suggests that the initial isotopic ratio for two uranium isotopes was $\frac{^{235}\text{U}}{^{238}\text{U}} = 1$. The half-lives of $^{235}$U and $^{238}$U are 704 Myr and $1.41 \times 10^{17}$ s, respectively.

Total for Question 3: 7

(a) Write an equation that expresses the ratio $^{235}\text{U}/^{238}\text{U}$ in terms of the original abundances, time and the decay constants of each isotope. [2]

**Solution:** $\frac{^{235}\text{U}}{^{238}\text{U}} = \frac{^{235}\text{U}_0(\exp(-t\lambda_{235}))}{^{238}\text{U}_0(\exp(-t\lambda_{238}))}$

(b) Given the present isotopic ratio is $\frac{^{235}\text{U}}{^{238}\text{U}} = \frac{1}{138}$, calculate an estimate for the age of Earth. [4]

**Solution:** 5.97 billion yrs

(c) This is an upper bound. Why? [1]

**Solution:** It is the time of formation of the uranium, not when the Earth formed. However, Earth clearly cannot have formed before the elements that make it up were around.