# AQA Examination-style questions

## Unit 5: Nuclear physics, thermal physics plus an optional topic

**1** The equation

$$p \longrightarrow n + \beta^+ + \nu_e$$

represents the emission of a positron from a proton.

(a) Energy and momentum are conserved in this emission.
What other quantities are conserved in this emission? *(3 marks)*

(b) Draw the Feynman diagram that corresponds to the positron emission represented in the equation. *(4 marks)*

(c) Copy and complete the following table using ticks ✓ and crosses ✗.

| particle | meson | baryon | lepton |
|---|---|---|---|
| p | | | |
| n | | | |
| $\beta^+$ | | | |
| $\nu_e$ | | | |

*(4 marks)*
AQA, 2005

**2** (a) (i) Alpha and beta emissions are known as *ionising radiations*. State and explain why such radiations can be described as *ionising*.

(ii) Explain why beta particles have a greater range in air than alpha particles. *(4 marks)*

(b) **Figure 1** shows the variation with time of the number of radon ($^{220}$Ra) atoms in a radioactive sample.

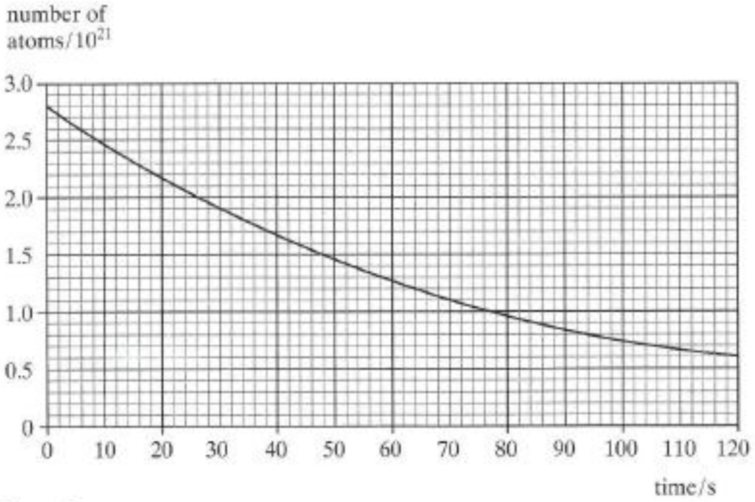

**Figure 1**

(i) Use the graph to show that the half-life of the decay is approximately 53 s. Show your reasoning clearly.

(ii) The decay constant of $^{220}$Ra is $1.3 \times 10^{-2}\,s^{-1}$. Use data from the graph to find the activity of the sample at a time $t = 72$ s. *(6 marks)*

(c) (i) State **two** origins of background radiation.

(ii) Suggest why it should be unnecessary to allow for background radiation when measuring the activity of the sample described in part (b)(ii). *(3 marks)*

AQA, 2005

3 A nucleus of plutonium ($^{240}_{94}Po$) decays to form uranium (U) and an alpha particle (α).

(a) Copy and complete the equation that describes this decay:

$$^{240}_{94}Po \longrightarrow$$

*(2 marks)*

(b) (i) Show that about 1 pJ of energy is released when one nucleus decays.

mass of plutonium nucleus = $3.98626 \times 10^{-25}$ kg

mass of uranium nucleus = $3.91970 \times 10^{-25}$ kg

mass of alpha particle = $6.64251 \times 10^{-25}$ kg *(3 marks)*

(ii) The plutonium isotope has a half-life of $2.1 \times 10^{-11}$ s. Show that the decay constant of the plutonium is about $3 \times 10^{-12}\,s^{-1}$.

(iii) A radioactive source in a school laboratory contains $3.2 \times 10^{21}$ atoms of plutonium. Calculate the energy that will be released in one second by the decay of the plutonium described in part (b)(i).

(iv) Comment on whether the energy release due to the plutonium decay is likely to change by more than 5% during 100 years. Support your answer with a calculation. *(12 marks)*

AQA, 2004

4 The table shows data for some nuclei.

| **element** | $Z$ | $A$ | **nuclear radius $r/10^{-15}$ m** | **binding energy per nucleon/MeV** | **emission (half-life)** |
|---|---|---|---|---|---|
| beryllium | 4 | 9 | 2.5 | 6.46 | stable |
| sodium | 11 | 23 | 3.4 | 8.11 | stable |
| manganese | 25 | 56 | 4.6 | 8.74 | $\beta^-$ (2.6 h) |

(a) (i) Show that these data support the rule that

$$r = r_0 A^{1/3}$$

where $r_0$ is a constant.

(ii) The mass of a nucleon is about $1.7 \times 10^{-27}$ kg. Calculate the density of nuclear matter. *(6 marks)*

(b) (i) Explain what is meant by the binding energy of a nucleus.

(ii) Show that the total binding energy of a sodium-23 nucleus is about $3 \times 10^{-11}$ J.

(iii) Calculate the mass-equivalent of this binding energy. *(5 marks)*

(c) Nuclear structure can be explored by bombarding the nuclei with alpha particles. The de Broglie wavelength of the alpha particle must be similar to the nuclear diameter. Calculate the energy of an alpha particle that could be used to explore the structure of manganese-56.

mass of an alpha particle = $6.8 \times 10^{-27}$ kg *(4 marks)*

(d) (i) State the proton number and nucleon number of the nucleus formed by the decay of manganese-56.

(ii) The activity of a sample of manganese-56 varies with time according to the equation

$$A = A_0 e^{-\lambda t}$$

What value should be used for $\lambda$ in calculations involving manganese-56 when $t$ is in seconds? *(4 marks)*

AQA, 2007

5 (a) When an $\alpha$ particle is emitted from a nucleus of the isotope ${}^{212}_{83}\text{Bi}$, a nucleus of thallium, Tl, is formed. Copy and complete the equation below.

$$ {}^{212}_{83}\text{Bi} \longrightarrow \alpha + \text{Tl} $$

*(2 marks)*

(b) The $\alpha$ particle in part (a) is emitted with 6.1 MeV of kinetic energy.

(i) The mass of the $\alpha$ particle is 4.0 u. Show that the speed of the $\alpha$ particle immediately after it has been emitted is $1.7 \times 10^7\,\text{m}\,\text{s}^{-1}$. Ignore relativistic effects.

(ii) Calculate the speed of recoil of the daughter nucleus immediately after the $\alpha$ particle has been emitted. Assume the parent nucleus is initially at rest. *(6 marks)*

AQA, 2002

6 (a) A solar panel of area $3.8\,\text{m}^2$ is fitted to a satellite in orbit above the Earth. The panel produces a current of 2.8 A at a pd of 25 V when solar radiation is incident normally on it.

(i) Calculate the electrical power output of the panel.

(ii) Solar radiation on the panel has an intensity of $1.4\,\text{kW}\,\text{m}^{-2}$. Calculate the efficiency of the panel. *(4 marks)*

(b) The back-up power system of the satellite is provided by a radioactive isotope enclosed in a sealed container which absorbs the radiation from the isotope. Energy from the radiation is converted to electrical energy by means of a thermoelectric module.

(i) The isotope produces $\alpha$ particles of energy 4.1 MeV and the container absorbs energy from the $\alpha$ particles at a rate of $85\,\text{J}\,\text{s}^{-1}$. Show that the isotope has an activity of $1.3 \times 10^{14}$ Bq.

(ii) The half-life of the isotope is 200 years. Calculate the decay constant, $\lambda$, of this isotope.
1 year = $3.15 \times 10^7$ s.

(iii) The nucleon number of the isotope is 209. Calculate the mass of isotope needed for an activity of $1.3 \times 10^{14}$ Bq. *(7 marks)*

AQA, 2006

7 The radioactive isotope ${}^{40}_{19}\text{K}$ decays by $\beta^-$ emission to form a stable isotope of calcium (Ca) or by electron capture to form a stable isotope of argon (Ar).

(a) (i) Copy and complete the following equation which represents the $B^-$ decay of ${}^{40}_{19}\text{K}$.

$$ {}^{40}_{19}\text{K} \longrightarrow \beta^- + \text{Ca} + \bar{\nu}_e $$

(ii) Sketch the Feynman diagram for this process. *(4 marks)*

(b) (i) Copy and complete the following equation which represents electron capture by ${}^{40}_{19}\text{K}$.

$$ {}^{40}_{19}\text{K} + e^- \longrightarrow \text{Ar} + \nu_e $$

(ii) Sketch the Feynman diagram for this process. *(3 marks)*

(c) The isotope of argon formed as a result of electron capture by ${}^{40}_{19}\text{K}$ is found as a trapped gas in ancient rocks. The age of an ancient rock can be determined by measuring the proportion of this isotope of argon to ${}^{40}_{19}\text{K}$.

An ancient rock is found to contain 1 argon atom for every 4 atoms of ${}^{40}_{19}\text{K}$.

(i) The decay of ${}^{40}_{19}\text{K}$ by $\beta^-$ emission is 8 times more likely than electron capture. Show that for every argon atom in this rock, there must have originally been 13 atoms of ${}^{40}_{19}\text{K}$.

(ii) ${}^{40}_{19}\text{K}$ has a half-life of 1250 million years. Calculate the age of this rock. *(6 marks)*

AQA, 2004

**8** (a) (i) Explain why, despite the electrostatic repulsion between protons, the nuclei of most atoms of low nucleon number are stable.

(ii) Suggest why stable nuclei of higher nucleon number have greater numbers of neutrons than protons.

(iii) All nuclei have approximately the same density. State and explain what this suggests about the nature of the strong nuclear force. *(6 marks)*

(b) (i) Compare the electrostatic repulsion and the gravitational attraction between a pair of protons the centres of which are separated by $1.2 \times 10^{-15}$ m.

(ii) Comment on the relative roles of gravitational attraction and electrostatic repulsion in nuclear structure. *(5 marks)*

AQA, 2006

**9** A beaker contains $1.3 \times 10^{-4}\,\text{m}^3$ of water at a temperature of 18 °C. The beaker is placed in a freezer. The water cools to 0 °C and freezes in a total time of 1700 s.

(a) (i) Calculate the mass of water in the beaker.

density of water = $1000\,\text{kg}\,\text{m}^{-3}$

(ii) Calculate the average energy per second transferred from the water. Assume the beaker has negligible heat capacity.

specific heat capacity of water = $4200\,\text{J}\,\text{kg}^{-1}\,\text{K}^{-1}$

specific latent heat of fusion of ice = $3.3 \times 10^5\,\text{J}\,\text{kg}^{-1}$ *(4 marks)*

(b) The freezer uses electrical energy from the mains at a rate of $25\,\text{J}\,\text{s}^{-1}$. Calculate the total energy transferred to the surroundings from the time the beaker of water is placed in the freezer to when it freezes completely. *(2 marks)*

AQA, 2005

**10** A long vertical tube contains several small particles of lead, which rest on its base. When the tube is inverted the particles of lead fall freely through a vertical height equal to the length of the tube, which is 1.2 m.

(a) Describe the energy changes that take place in the lead particles during one inversion of the tube. *(3 marks)*

(b) The tube is made from an insulating material and is used in an experiment to determine the specific heat capacity of lead. The following results are obtained.

| | |
|---|---|
| mass of lead: 0.025 kg | number of inversions: 50 |
| length of tube: 1.2 m | change in temperature of the lead: 4.5 K |

Calculate:

(i) the change in potential energy of the lead as it falls after one inversion down the tube,

(ii) the total change in potential energy after 50 inversions,

(iii) the specific heat capacity of the lead. *(4 marks)*

AQA, 2005

**11** An electric shower heats the water flowing through it from 10 °C to 42 °C when the volume flow rate is $5.2 \times 10^{-5}\,\text{m}^3\,\text{s}^{-1}$.

(a) (i) Calculate the mass of water flowing through the shower each second.

density of water = $1000\,\text{kg}\,\text{m}^{-3}$

(ii) Calculate the power supplied to the shower, assuming all the electrical energy supplied to it is gained by the water as thermal energy.

specific heat capacity of water = $4200\,\text{J}\,\text{kg}^{-1}\,\text{K}^{-1}$. *(4 marks)*

(b) A jet of water emerges horizontally at a speed of $2.5\,\text{m}\,\text{s}^{-1}$ from a hole in the shower head. The hole is 2.0 m above the floor of the shower. Calculate the horizontal distance travelled by this jet. Assume air resistance is negligible. *(3 marks)*

AQA, 2004

**12** (a) **Figure 4** shows an arrangement used to investigate the energy stored by a capacitor.

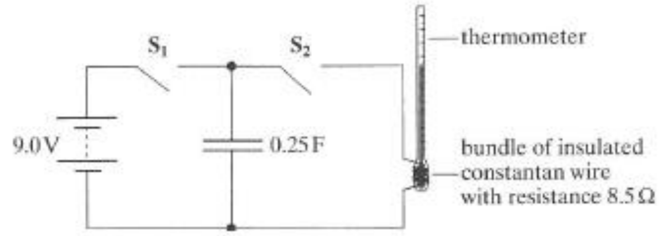

**Figure 4**

The bundle of constantan wire has a resistance of 8.5 Ω. The capacitor is initially charged to a potential difference of 9.0 V by closing $\mathbf{S}_1$.

- (i) Calculate the charge stored by the 0.25 F capacitor.
- (ii) Calculate the energy stored by the capacitor.
- (iii) Switch $\mathbf{S}_1$ is now opened and $\mathbf{S}_2$ is closed so that the capacitor discharges through the constantan wire.
  Calculate the time taken for the potential difference across the capacitor to fall to 0.10 V. *(7 marks)*

AQA, 2006

(b) The volume of constantan wire in the bundle in **Figure 4** is $2.2 \times 10^{-7}\,\text{m}^3$.

density of constantan = $8900\,\text{kg}\,\text{m}^{-3}$

specific heat capacity of constantan = $420\,\text{J}\,\text{kg}^{-1}\,\text{K}^{-1}$

- (i) Assume that all the energy stored by the capacitor is used to raise the temperature of the wire. Use your answer to part (a)(ii) to calculate the expected temperature rise when the capacitor is discharged through the constantan wire.
- (ii) Give **two** reasons why, in practice, the final temperature will be lower than that calculated in part (b)(i). *(5 marks)*

AQA, 2006

**13** (a) A 3.0 kW electric kettle heats 2.4 kg of water from 16 °C to 100 °C in 320 s.

- (i) Calculate the electrical energy supplied to the kettle.
- (ii) Calculate the heat energy supplied to the water.
  specific heat capacity of water = $4200\,\text{J}\,\text{kg}^{-1}\,\text{K}^{-1}$
- (iii) Give **one** reason why not all the electrical energy supplied to the kettle is transferred to the water. *(4 marks)*

(b) The potential difference supplied to the kettle in part (a) is 230 V.

- (i) Calculate the resistance of the heating element of the kettle.
- (ii) The heating element consists of an insulated conductor of length 0.25 m and diameter 0.65 mm. Calculate the resistivity of the conductor. *(5 marks)*

AQA, 2004

**14** (a) The air in a room of volume $27.0\,\text{m}^3$ is at a temperature of 22 °C and a pressure of 105 kPa.
Calculate:

- (i) the temperature, in K, of the air,
- (ii) the number of moles of air in the room,
- (iii) the number of gas molecules in the room. *(5 marks)*

(b) The temperature of an ideal gas in a sealed container falls. State, with a reason, what happens to the

- (i) mean square speed of the gas molecules,
- (ii) pressure of the gas. *(4 marks)*

AQA, 2004

**15** The table gives the average kinetic energy of gas molecules at certain temperatures.

| $E_k$/J × $10^{-21}$ | 6.21 | 6.62 | 7.04 | 7.45 | 7.87 | 8.28 |
|---|---|---|---|---|---|---|
| $T$/K | 300 | 320 | 340 | 360 | 380 | 400 |

(a) (i) Plot a graph of $E_k$ against $T$.

(ii) Determine the gradient of your graph and hence calculate a value for the Boltzmann constant. Show all your working. *(8 marks)*

(b) One of the assumptions of the kinetic theory is that collisions of gas molecules are elastic.

(i) State what is meant by an elastic collision.

(ii) State another assumption of the kinetic theory.

(iii) Explain how the data in the table leads to the concept of absolute zero. *(4 marks)*

AQA, 2002

**16** (a) (i) State **three** assumptions concerning the motion of the molecules in an ideal gas.

(ii) For an ideal gas at a temperature of 300 K, show that the mean kinetic energy of a molecule is $6.2 \times 10^{-21}$ J. *(5 marks)*

(b) (i) When no current passes along a metal wire, conduction electrons move about in the wire like molecules in an ideal gas.

Calculate the speed of an electron which has $6.2 \times 10^{-21}$ J of kinetic energy.

(ii) Describe the motion of conduction electrons in a wire when a pd is applied across the ends of the wire. *(6 marks)*

AQA, 2007

**17** A sample of air has a density of 1.24 kg m$^{-3}$ at a pressure of $1.01 \times 10^5$ Pa and a temperature of 300 K.

(a) Calculate the mean kinetic energy of an air molecule under these conditions. *(2 marks)*

(b) Calculate the mean square speed for the air molecules. *(3 marks)*

(c) Explain why, when the temperature of the air is increased to 320 K, some of the molecules will have speeds much less than that suggested by the value you calculated in part (b). *(2 marks)*

AQA, 2007

**18** (a) (i) At the surface of a spherical planet of radius $R$, show that the gravitational potential, $V_s$, is related to the gravitational field of strength, $g_s$, by

$$V_s = -g_s R.$$

(ii) The gravitational field strength of the Moon at its surface is 1.6 N kg$^{-1}$. Show that the gravitational potential energy of an oxygen molecule at the surface is $-1.4 \times 10^{-19}$ J.

radius of the Moon = 1700 km    molar mass of oxygen = 0.032 kg mol$^{-1}$ *(5 marks)*

(b) Oxygen gas at 400 K is released on the surface of the Moon.

(i) Calculate the mean kinetic energy of an oxygen gas molecule at this temperature.

(ii) The maximum temperature of the surface of the Moon is about 400 K. Use the data from part (a)(ii) and the results of your calculations to explain why some of the oxygen gas released at the Moon's surface would escape into space. *(4 marks)*

AQA, 2005