Selected Questions – Set 4

1.

The space probe, Curiosity, roaming on the surface of Mars, is powered by a radioisotope thermoelectric generator (RTG). The generator transforms thermal energy into electrical energy. The thermal energy comes from the radioactive decay of plutonium-238.
Fig. 5.1 shows an image of Curiosity.

Fig. 5.1

(a) The plutonium-238 ($^{238}_{94}Pu$) isotope can be artificially produced by bombarding uranium-238 ($^{238}_{92}U$) with deuterium ($^{2}_{1}H$). This produces an intermediate isotope of neptunium-238 ($^{238}_{93}Np$) and neutrons. The isotope of $^{238}_{93}Np$ then decays by beta-minus emission to form plutonium-238.

(i) Complete the following reaction.

$$^{238}_{92}U + {}^{2}_{1}H \rightarrow {}^{238}_{93}Np + \text{.............}$$ **[1]**

(ii) Complete the following decay equation for $^{238}_{93}Np$.

$$^{238}_{93}Np \rightarrow {}^{238}_{94}Pu + \text{.............} + \text{.............}$$ **[2]**

(b) Plutonium-238 is an alpha-emitter with a half-life of 88 years. The kinetic energy produced during each decay is 9.0×10^{-13} J. The RTG on Curiosity produces 120 W of electrical power from 2000 W of thermal power.

(i) Calculate the mass of plutonium-238 on board Curiosity.

molar mass of plutonium-238 = $0.238\,\text{kg}\,\text{mol}^{-1}$

mass = ... kg **[4]**

(ii) Calculate the output electrical energy in kW h from the RTG in a day.

energy = ... kW h **[2]**

2.

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

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.... **[1]**

(b) The fusion of protons occurs in a star when the temperature within the core is greater than about 10^7 K. It takes the fusion of 4 protons to form a helium-4 (^4_2He) nucleus. In this process, known as the proton–proton cycle, energy is released.

The net energy released in producing a single helium-4 nucleus is 4.53×10^{-12} J.
Calculate the binding energy per nucleon of the helium-4 nucleus.

binding energy per nucleon = ... J **[1]**

(c) The fusion of helium nuclei to make heavier elements occurs in red giants at temperatures above 10^8 K.

Explain why fusion of helium requires higher temperatures than the fusion of hydrogen (protons).

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.... **[2]**

(d) Estimate the mean speed of helium nuclei at a temperature of 10^8 K.

mass of helium nucleus = 6.6×10^{-27} kg

speed = ... $m s^{-1}$ **[2]**

3.

Some fruits, such as bananas, are naturally radioactive because they contain the unstable isotope of potassium-40 ($^{40}_{19}K$).

(i) The isotope of potassium-40 is a beta-minus emitter.

Complete the following decay equation for $^{40}_{19}K$.

$$^{40}_{19}K \rightarrow \, ^{\cdots\cdots}_{\cdots\cdots}Ca \quad + \quad \cdots\cdots\cdots \quad + \quad \cdots\cdots\cdots$$ **[2]**

(ii) Explain why energy is released when a single nucleus of potassium-40 decays.

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.... **[2]**

(iii) A banana contains 4.5×10^{-4} kg of potassium. About 0.012% of the mass of potassium in the banana has the unstable isotope of potassium-40. This isotope of potassium-40 has a half-life of 4.2×10^{16} s. The molar mass of potassium-40 is 0.040 kg mol^{-1}.

Calculate the activity from this banana.

activity = ... Bq **[3]**

4.

This question is about capacitors.

(a) Fig. 4.1 shows two capacitors **A** and **B** connected in series to a battery.

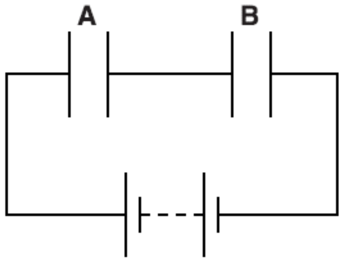

Fig. 4.1

The capacitance of **B** is twice the capacitance of **A**.
Explain why the potential difference across capacitor **A** is twice the potential difference across capacitor **B**.

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.... **[2]**

(b) Fig. 4.2 shows a circuit with an arrangement of capacitors and resistors.

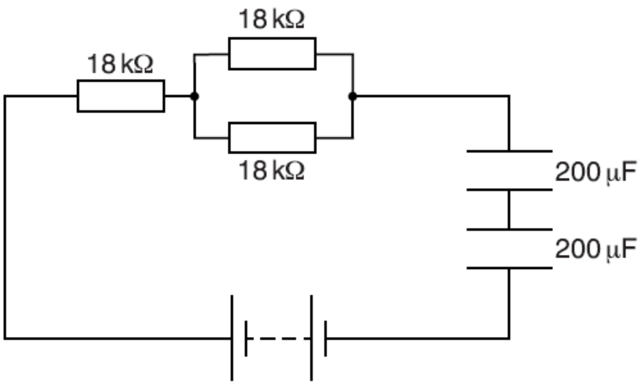

Fig. 4.2

Calculate the time constant of the circuit.

time constant = ... s **[3]**

(c) A charged capacitor of capacitance 1200 μF is connected across the terminals of a resistor of resistance 40 kΩ.
Fig. 4.3 shows the variation of the current I in the resistor against time t.

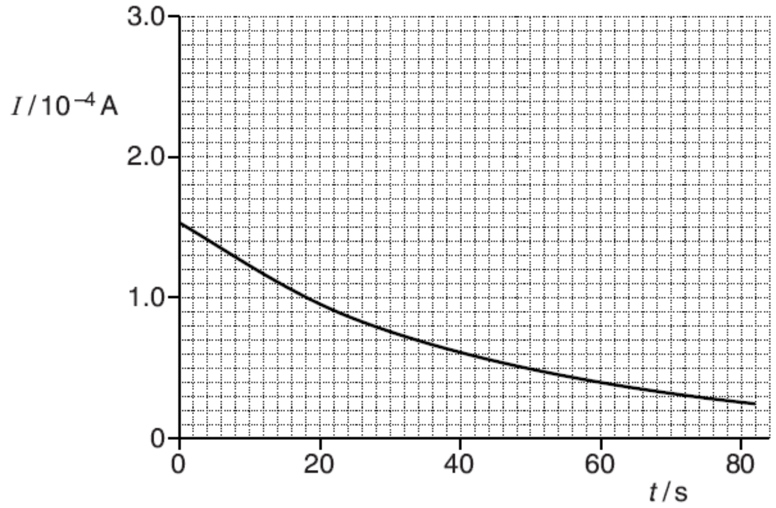

Fig. 4.3

(i) Use Fig. 4.3 to calculate the initial charge stored by the capacitor.

charge = ... C **[2]**

(ii) The capacitor is charged again to the same initial potential difference. It is now discharged across two 40 kΩ resistors connected in **parallel**.
On Fig. 4.3 draw carefully a graph to show the variation of the current I in the combination of resistors with time t. **[2]**

5.

(a) A charged capacitor is connected across the ends of a negative temperature coefficient (NTC) thermistor kept at a fixed temperature. The capacitor discharges through the thermistor. The potential difference V across the capacitor is maximum at time $t = 0$.

(i) On the axes of Fig. 4.1, carefully sketch a graph to show how the potential difference V across the capacitor varies with time t. Label this graph **L**.

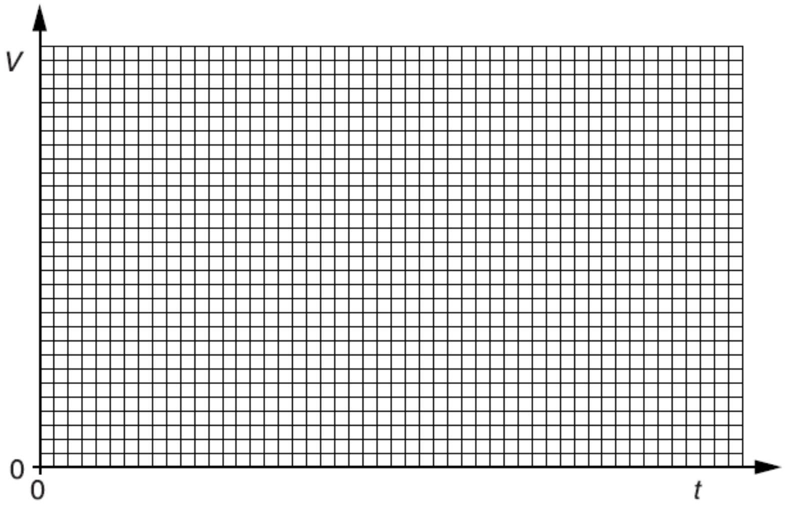

Fig. 4.1 **[1]**

(ii) The temperature of the thermistor is increased to a higher fixed value. On Fig. 4.1, sketch another graph to show the variation of V with t when the same charged capacitor is discharged across the ends of the hotter thermistor. Label this graph **H**. **[1]**

(iii) Explain how you can show that the graph sketched in **(i)** has a constant-ratio property (exponential decay).

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.... **[1]**

(b) Fig. 4.2 shows an electrical circuit.

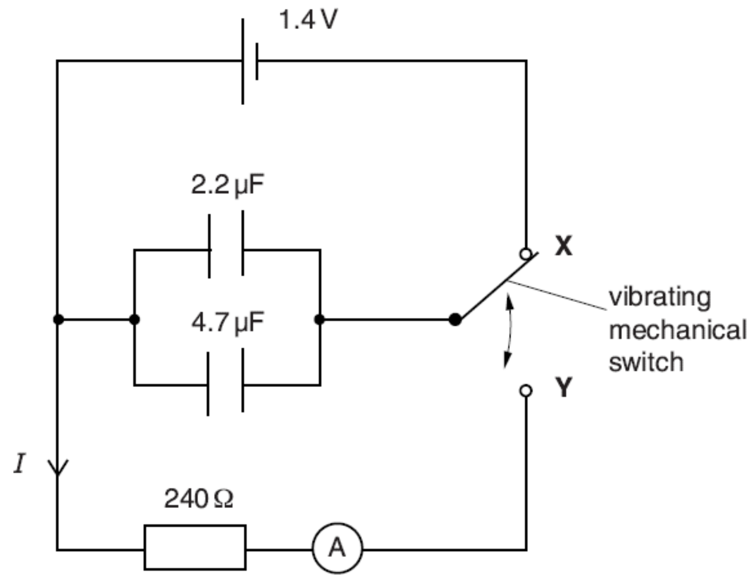

Fig. 4.2

The cell has e.m.f. 1.4 V and negligible internal resistance. The values of the capacitors and the resistor are shown in Fig. 4.2. A mechanical switch vibrates between contacts **X** and **Y** at a frequency of 120 Hz.

(i) Calculate the time constant of the circuit.

time constant = ... s **[1]**

(ii) Calculate the value of the average current I in the resistor. Assume that the capacitors are fully discharged between each throw of the switch.

I = ... A **[3]**

(iii) The frequency of vibration of the mechanical switch is doubled. Explain why the average current in the circuit is not doubled.

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.... **[2]**