# Selected Questions – Set 2

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.

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

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

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

**(b)** Plutonium-238 is an alpha-emitter with a half-life of 88 years. The kinetic energy produced during each decay is $9.0 \times 10^{-13}$ 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 kg 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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**(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 $4.53 \times 10^{-12}$ 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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**(d)** Estimate the mean speed of helium nuclei at a temperature of $10^8$ K.

mass of helium nucleus = $6.6 \times 10^{-27}$ 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 $^{40}_{19}K$.

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

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

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**(iii)** A banana contains $4.5 \times 10^{-4}$ 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 $4.2 \times 10^{16}$ 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.

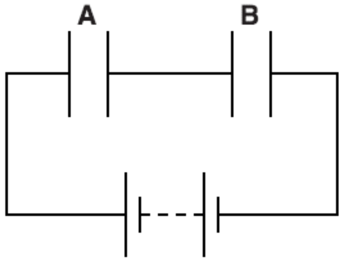


**Fig. 4.1**

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

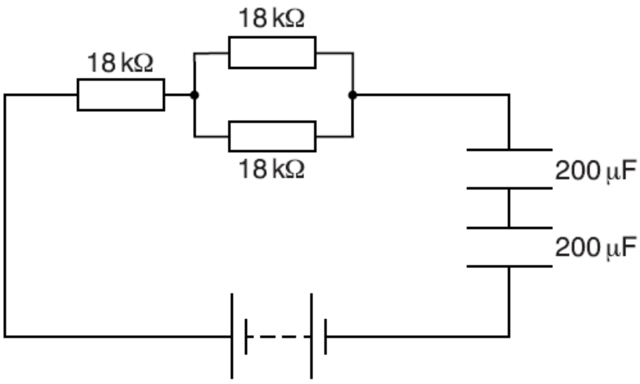


**Fig. 4.2**

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 $t$.

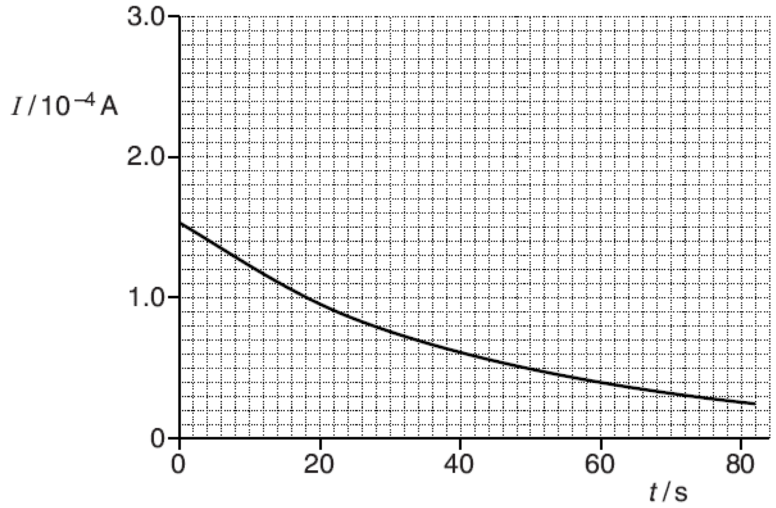


**Fig. 4.3**

**(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**.

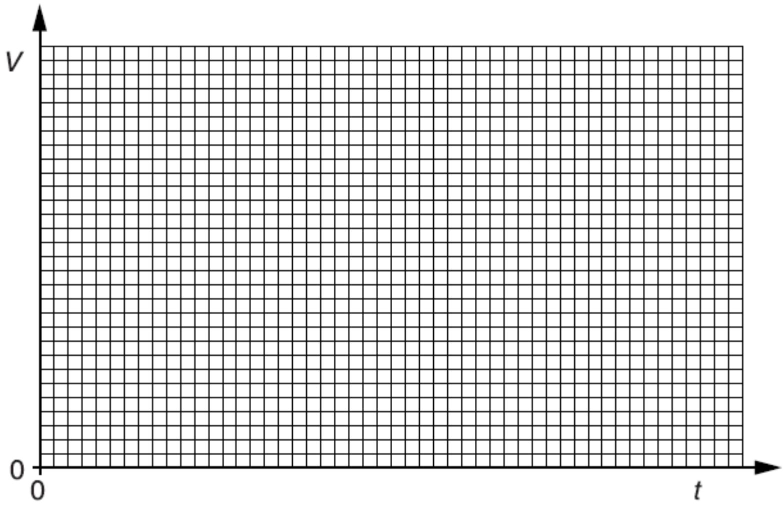


**Fig. 4.1** **[1]**

**(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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**(b)** Fig. 4.2 shows an electrical circuit.

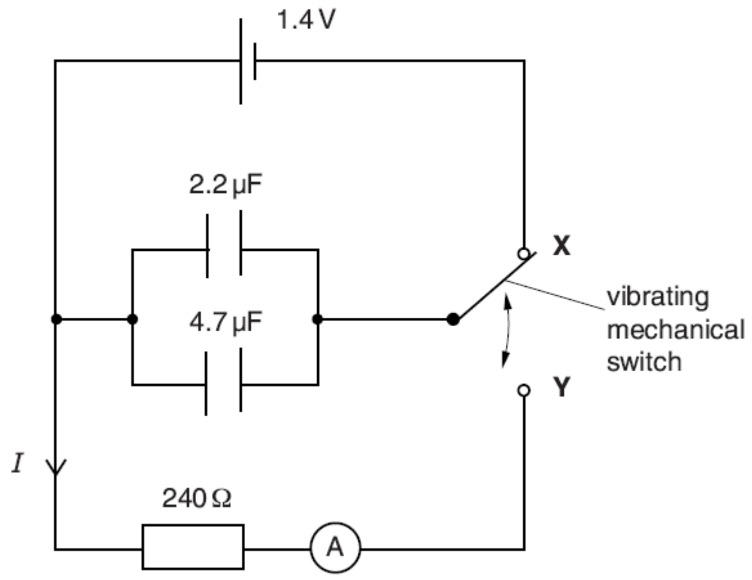


**Fig. 4.2**

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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