Selected Questions – Set 6

1.

This question is about the radioisotope americium-241 used in smoke detectors. Fig. 6.1 shows a cross-section through a simplified smoke detector mounted on the ceiling.

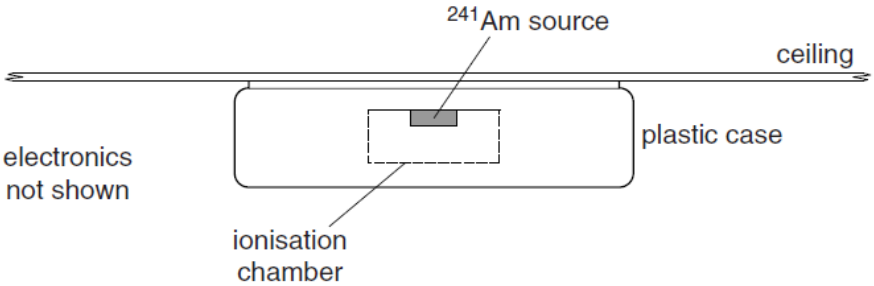

Fig. 6.1

The alpha particles emitted by the americium ionise the air inside the ionisation chamber maintaining a small current in a circuit including the ionisation chamber in series. When smoke enters the chamber the ions are absorbed and the current falls, causing the alarm to sound.

(a) Americium-241 occurs naturally from the decay of plutonium-241 by beta minus emission, or is made artificially by the bombardment of plutonium-240 inside a nuclear reactor. The nuclear equations for each of these processes are shown below with letters substituted for some of the symbols.

$$^{241}_{Z}\text{Pu} \rightarrow \, ^{241}_{95}\text{Am} + \beta^-$$

$$^{240}_{Z}\text{Pu} + \text{X} \rightarrow \, ^{241}_{95}\text{Am} + \beta^-$$

Write down

(i) the numerical value of the letter Z .... **[1]**

(ii) what Z represents .... **[1]**

(iii) the correct name of particle X. .... **[1]**

(b) A typical smoke detector contains 2.5×10^{-10} kg of americium-241.

(i) Show that the source contains about 6×10^{14} nuclei of americium-241.

[2]

(ii) The half-life of americium-241 is 480 years. Show that its decay constant is about $4.6 \times 10^{-11}\,s^{-1}$.

1 year = 3.15×10^{7} s

[1]

(iii) Calculate the activity of the americium-241 in the smoke detector. Give a suitable unit with your answer.

activity = ... unit .... **[3]**

(iv) Estimate the time it takes for the activity to fall by one percent.

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

(c) Nuclei of americium-241 decay by alpha particle emission. Suggest

(i) why the americium is not a hazard when it is inside the detector

....

.... **[1]**

(ii) how a small speck of the source could be hazardous if it came out of the plastic case.

....

....

.... **[2]**

2. (OCR/June 2012)

The radioactive nucleus of plutonium ($^{238}_{94}Pu$) decays by emitting an alpha particle ($^{4}_{2}He$) of kinetic energy 5.6MeV with a half-life of 88 years. The plutonium nucleus decays into an isotope of uranium.

(a) State the number of neutrons in the **uranium** isotope.

.... **[1]**

(b) The mass of an alpha particle is 6.65×10^{-27} kg.

(i) Show that the kinetic energy of the alpha particle is about 9×10^{-13} J.

[1]

(ii) Calculate the speed of the alpha particle.

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

(c) In a space probe, a source containing plutonium-238 nuclei is used to generate 62W for the onboard electronics.

(i) Use your answer to **(b)(i)** to show that the initial activity of the sample of plutonium-238 is about 7×10^{13} Bq.

[1]

(ii) Calculate the decay constant of the plutonium-238 nucleus.

1 year = 3.16×10^{7} s

decay constant = ... s^{-1} **[2]**

(iii) The molar mass of plutonium-238 is 0.24 kg. Calculate

1 the number of plutonium-238 nuclei in the source

number of nuclei = ... **[2]**

2 the mass of plutonium in the source.

mass = ... kg **[1]**

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3. (OCR/June 2012)

The nuclear reaction represented by the equation

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{94}_{39}\text{Y} + ^{139}_{53}\text{I} + 3\,^{1}_{0}\text{n}$$

takes place in the core of a nuclear reactor at a power station.

(a) Describe how this reaction can lead to a chain reaction.

....

....

.... **[1]**

(b) Explain the role of fuel rods, control rods and a moderator in a nuclear reactor.

In your answer you should make clear how chain reactions are controlled in the reactor.

.... **[5]**

(c) In the nuclear reactor of a power station, each fission reaction of uranium produces 3.2×10^{-11} J of energy. The electrical power output of the power station is 3.0 GW. The efficiency of the system that transforms nuclear energy into electrical energy is 22%. Calculate

(i) the total power output of the reactor core

power output = ... W **[1]**

(ii) the total energy output of the reactor core in one day

1 day = 8.64×10^4 s

energy output = ... J **[1]**

(iii) the mass of uranium-235 converted in one day. The mass of a uranium-235 nucleus is 3.9×10^{-25} kg.

mass = ... kg **[2]**

(d) Discuss the physical properties of nuclear waste that makes it dangerous.

....

....

....

.... **[2]**

4.

A spark plug is the device in a petrol engine which ignites the fuel-air mixture, causing an explosion in the cylinder.

(a) A potential difference of 40 kV is needed across a gap of 0.60 mm to produce the spark which ignites the fuel vapour. Calculate the magnitude of the electric field strength in the spark gap just before the spark.

electric field strength = ... unit .... [3]

(b) The electrical supply in a motor car is 12 V. To achieve 40 kV, two coils are wound on the same iron core, shown schematically in Fig. 5.1. The secondary coil is in series with the spark gap. The primary coil is in series with the battery and a switch.

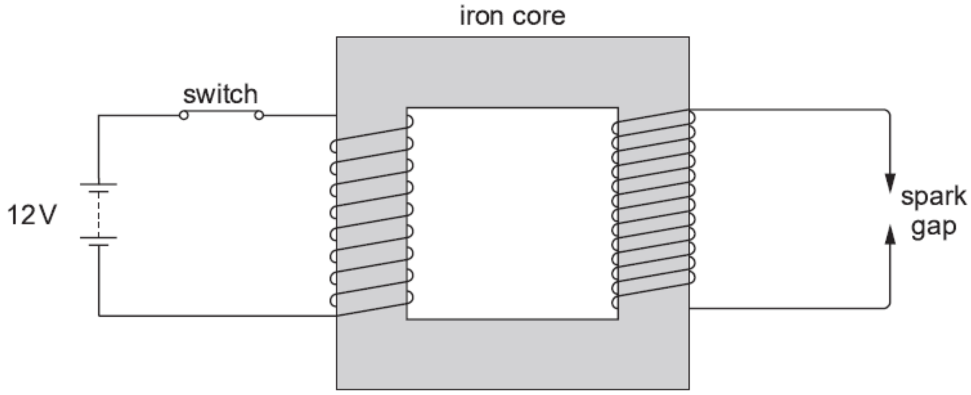

Fig. 5.1

(i) Draw on Fig. 5.1 the complete paths of **two** lines of magnetic flux linked with the current in the primary coil. [2]

(ii) The magnetic flux through both coils is the same but the magnetic flux linkage is not. Explain why.

....

....

....

....[2]

(iii) Explain why a potential difference is produced across the spark gap as the switch is opened.

....

....[1]

(iv) Explain how each of the following factors influences the size of the potential difference across the spark gap:

1 the rate of collapse of the magnetic flux

....

....

....

....

....[2]

2 the ratio of the number of turns between the primary and secondary coils.

....

....

....

....

....[2]

5. (OCR/June 2012)

Fig. 2.1 shows the circular track of an electron moving in a uniform magnetic field.

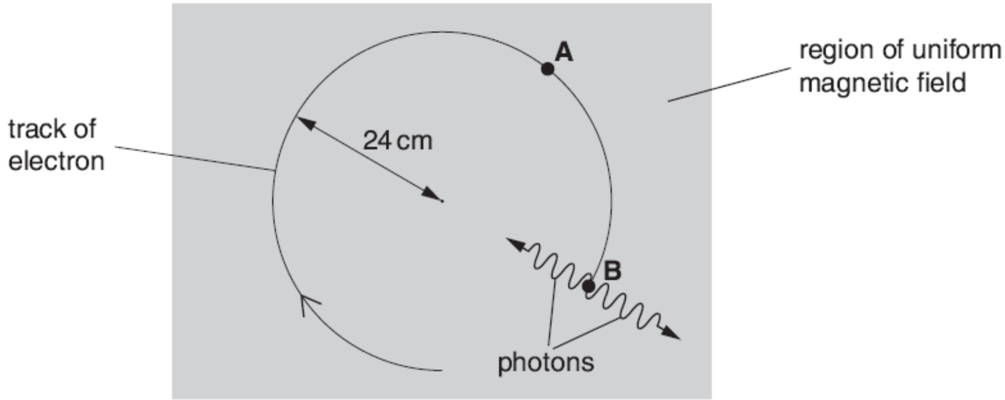

Fig. 2.1

The magnetic field is perpendicular to the plane of Fig. 2.1. The speed of the electron is $6.0 \times 10^7\,\text{m s}^{-1}$ and the radius of the track is 24 cm. At point **B** the electron interacts with a stationary positron.

(a) **(i)** On Fig. 2.1, draw an arrow to show the force acting on the electron when at point **A**. Label this arrow **F**. **[1]**

(ii) Explain why this force does not change the speed of the electron.

....

....

.... **[1]**

(b) Calculate the magnitude of the force F acting on the electron due to the magnetic field when it is at **A**.

F = ... N **[2]**

(c) Calculate the magnetic flux density of the magnetic field.

magnetic flux density = ... T **[2]**

(d) At point **B**, the electron and the positron annihilate each other. A positron has a positive charge and the same mass as the electron. The particles create two gamma ray photons. Calculate the wavelength of the gamma rays assuming the kinetic energy of the electron is negligible.

In your answer, you should make your reasoning clear.

wavelength = ... m **[3]**

6. OCR/June 2012)

Fig. 3.1 shows the variation of the magnetic flux **linkage** with time *t* for a small generator.

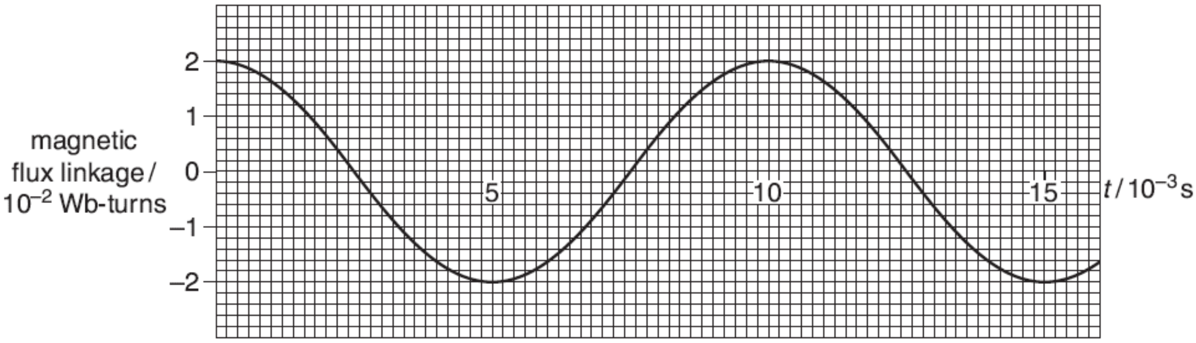

Fig. 3.1

The generator has a flat coil of negligible resistance that is rotated at a steady frequency in a uniform magnetic field. The coil has 400 turns and cross-sectional area $1.6 \times 10^{-3}\,m^2$. The output from the generator is connected to a resistor of resistance 150 Ω.

(a) Use Fig. 3.1 to

(i) calculate the frequency of rotation of the coil

frequency = ... Hz **[1]**

(ii) calculate the magnetic flux density *B* of the magnetic field

B = ... T **[3]**

(iii) show that the **maximum** electromotive force (e.m.f.) induced in the coil is about 12V.

[3]

(b) Hence calculate the **maximum** power dissipated in the resistor.

power = ... W **[2]**

7. (OCR/June 2011/Q1)

(a) Define *electromotive force*.

....

.... **[1]**

(b) Define *magnetic flux*.

....

....

.... **[1]**

(c) Fig. 1.1 shows a simple transformer.

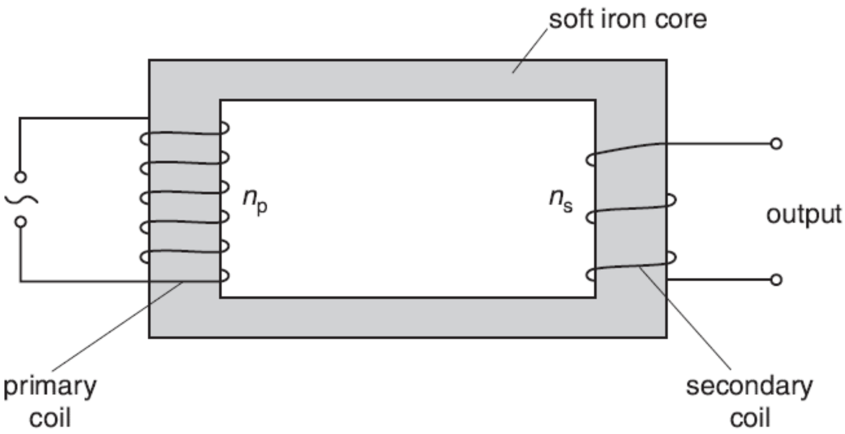

Fig. 1.1

(i) The primary coil is connected to an alternating voltage supply. Explain how an e.m.f. is induced in the secondary coil.

....

....

....

....

....

....

.... **[3]**

(ii) State how you could change the transformer to increase the maximum e.m.f. induced in the secondary coil.

....

....

.... **[1]**

(d) A transformer with 4200 turns in the primary coil is connected to a 230V mains supply. The e.m.f. across the output is 12V. Assume the transformer is 100% efficient.

(i) Calculate the number of turns in the secondary coil.

number of turns = ... **[2]**

(ii) The transformer output terminals are connected to a lamp using leads that have a total resistance of 0.35Ω. The p.d. across the lamp is 11.8V. Calculate

1 the current in the leads connected to the lamp

current = ... A **[2]**

2 the power dissipated in the leads.

power = ... W **[2]**