Mixed Exam Questions – Set 10

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.

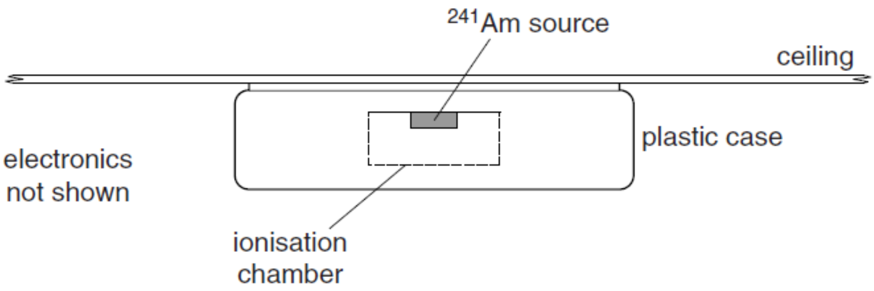

Fig. 6.1

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.

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.

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

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

$$^{238}_{93}Np \quad \longrightarrow \quad ^{238}_{94}Pu \quad + \quad .... \quad + \quad ....$$ **[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]**

3.

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

....

.... **[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).

....

....

.... **[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]**

4.

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 $^{40}_{19}K$.

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

5.

Figure 8 shows a side view of an act performed by two acrobats. **Figure 9** shows the view from above.

Figure 8

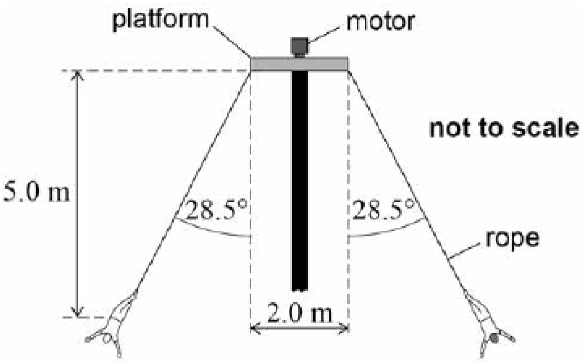
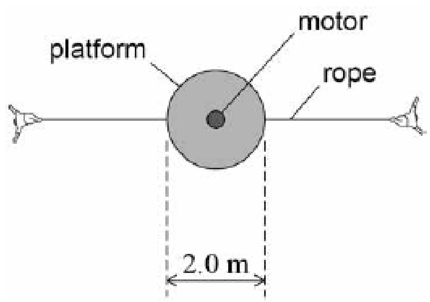


Figure 9



The acrobats, each of mass 85 kg, are suspended from ropes attached to opposite edges of a circular platform that is at the top of a vertical pole. The platform has a diameter of 2.0 m

A motor rotates the platform so that the acrobats move at a constant speed in a horizontal circle, on opposite sides of the pole.

When the period of rotation of the platform is 5.2 s, the centre of mass of each acrobat is 5.0 m below the platform and the ropes are at an angle of 28.5° to the vertical as shown in **Figure 8**.

(a)

Show that the linear speed of the acrobats is about 4.5 m s^{-1}

[2 marks]

(b)

Determine the tension in each rope that supports the acrobats.

[3 marks]

tension = ______________________ N

(c)

Discuss the consequences for the forces acting on the pole when one acrobat has a much greater mass than the other.

[3 marks]

Question 6 is on the next page.

6.

A mass hanging from a vertical spring is pulled down.
It is then released from rest at time $t = 0$.
The mass oscillates vertically in a **vacuum** with simple harmonic motion about the equilibrium position. The spring is in tension at all times.

Fig. 18.1 shows the position of the mass at $t = 0$.

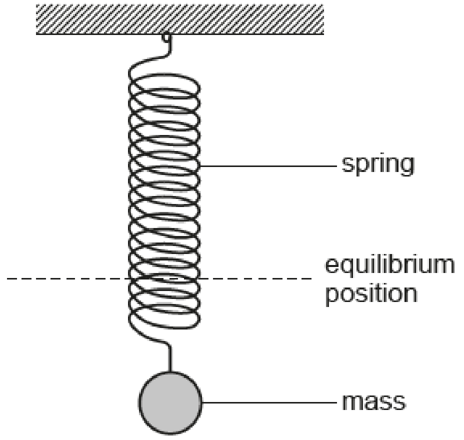


Fig. 18.1

At time $t = 6.5\,s$ the magnitude of the acceleration a of the mass is $3.6\,m\,s^{-2}$ and its displacement x is $4.6 \times 10^{-2}\,m$.

(a) **(i)** Use the defining equation for simple harmonic motion to show that the natural frequency f_0 of the mass-spring system is about 1.4 Hz.

[3]

(ii) Calculate the amplitude *A* of the oscillations.

A = ... m **[2]**

(b) The mass-spring system shown in Fig. 18.1 is now made to oscillate in **air**.

Different types of energy are involved in the oscillations of this mass-spring system.

Describe the energy changes that will take place as the mass moves from the lowest point in its motion through the equilibrium position to the highest point in its motion.

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.... **[4]**

(c) Fig. 18.2 shows the mass and spring now attached to a mechanical vibrator, which can oscillate with variable frequency.

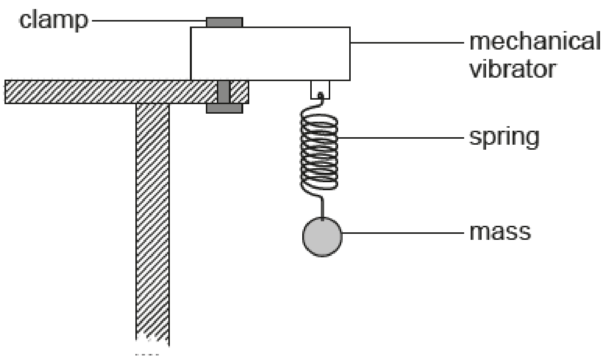

Fig. 18.2

The mass oscillates in air.

(i) The vibrator frequency is varied from 0 Hz to 2.5 Hz.
On Fig. 18.3, sketch a graph to show the variation with vibrator frequency of the amplitude of the mass. Label your graph **K**.

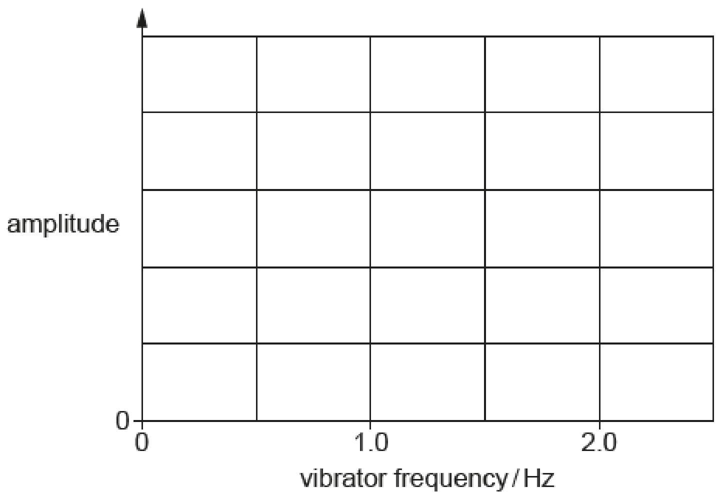

Fig. 18.3

[2]

(ii) A light disc is now attached to the mass to increase the damping.
The vibrator frequency is again varied from 0 Hz to 2.5 Hz.
Sketch a second graph on Fig. 18.3 to show the new variation of the amplitude.
Label this graph **D**. **[1]**

(iii) Explain why the phenomenon demonstrated in this experiment can cause problems for engineers when designing suspended footbridges.

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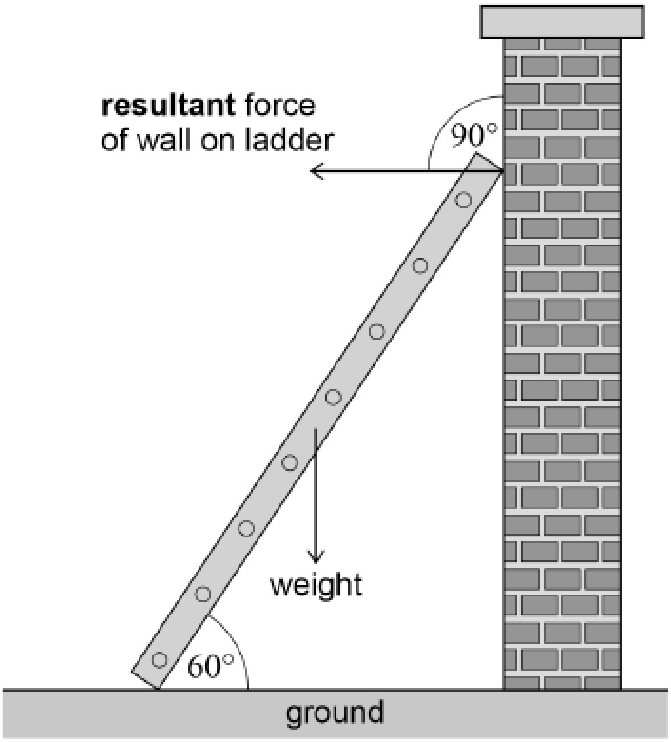
.... **[2]**

7.

Figure 7 shows two of the forces acting on a uniform ladder resting against a vertical wall. The ladder is at an angle of 60° to the ground.

Figure 7



(a)

Explain how **Figure 7** shows that the friction between the ladder and the wall is negligible.

[1 mark]

(b)

The forces acting on the ladder are in equilibrium.

Draw an arrow on **Figure 7** to show the direction of the resultant force from the ground acting on the ladder. Label your arrow **G**.

[2 marks]

(c)

The ladder is 8.0 m long and weighs 390 N.

Calculate the magnitude of the resultant force from the wall on the ladder.

[2 marks]

resultant force = ______________________________ N

(d)

Suggest the changes to the forces acting on the ladder that occur when someone climbs the ladder.

[3 marks]

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