AQA
Realising potential

2021 ASSESSMENT MATERIALS

A-level
PHYSICS

7408 – Particles and radiation / Nuclear physics

Total number of marks: 40

0 1 . 1 Two isotopes of iodine are $^{125}_{53}I$ and $^{131}_{53}I$.

Determine, for these two isotopes, the difference between the constituents of the nuclei.

- Different No. of neutrons, $^{131}_{53}I$ has 6 more neutrons. **[1 mark]**

0 1 . 2 A $^{131}_{53}I$ nuclide undergoes beta (β^-) decay to form a xenon nuclide.

State the nucleon number of the xenon nuclide.

[1 mark]

$^{131}_{53}I \rightarrow ^{131}_{54}Xe + ^{0}_{-1}e$ (131)

0 1 . 3 A $^{125}_{53}I$ nuclide decays by electron capture to form a tellurium nuclide.

State **two** differences between the constituents of the iodine nucleus and the tellurium nucleus it decays into.

[2 marks]

- Tellurium has an extra neutron
- Tellurium has one less electron / proton.

0 6 A thermal nuclear reactor uses enriched uranium as its fuel.
This is fuel in which the ratio of U-235 to U-238 has been artificially increased from that found in naturally-occurring ore.

0 6 . 1 Describe what happens when neutrons interact with U-235 and U-238 nuclei in a thermal nuclear reactor. - Neutrons are absorbed by the Uranium nucleus.
- Uranium nucleus splits, releasing a lot of energy and more neutrons. **[3 marks]**
- Those fast-moving neutrons go on to split more nuclei, releasing more energy.

0 6 . 2 The amounts of U-235 and U-238 in the ore decrease due to radioactive decay at different rates.

A sample of uranium ore today contains 993 g of U-238
The mass of U-238 in this sample was greater 2.00×10^9 years ago.

Show that the mass of U-238 in this sample at that time was about 1.4 kg.

decay constant of U-238 = 1.54×10^{-10} year^{-1}

[2 marks]

$M = M_0 e^{-\lambda t}$

$0.993 = M_0 e^{-1.54\times10^{-10} \times 2\times10^9}$

$M_0 = 1.35 \approx 1.4\,kg$

0 6 . 3 A thermal nuclear reactor requires a minimum of 3.0% of its uranium mass to be U-235

The ratio of U-235 to U-238 in the ore has changed over time.
2.00×10^9 years ago, the sample in Question **06.2** contained 52 g of U-235

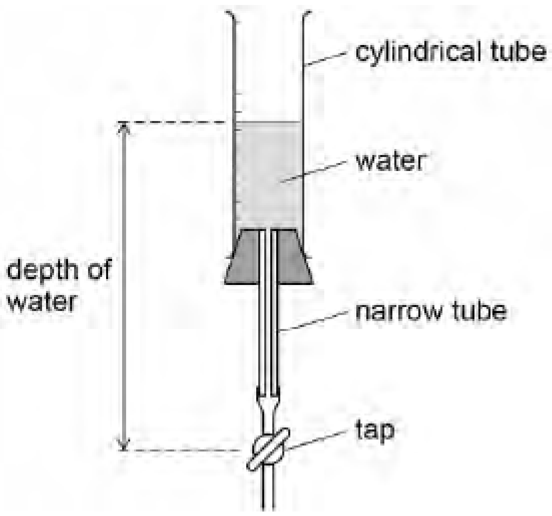
Deduce whether the sample had a high enough U-235 content to be used in a reactor 2.00×10^9 years ago.

$\frac{0.052}{1.4} \times 100 = 3.7\% > 3\%$

[1 mark]

0 6 **Figure 11** shows how radioactive decay of one nuclide can be modelled by draining water through a tap from a cylindrical tube.

Figure 11

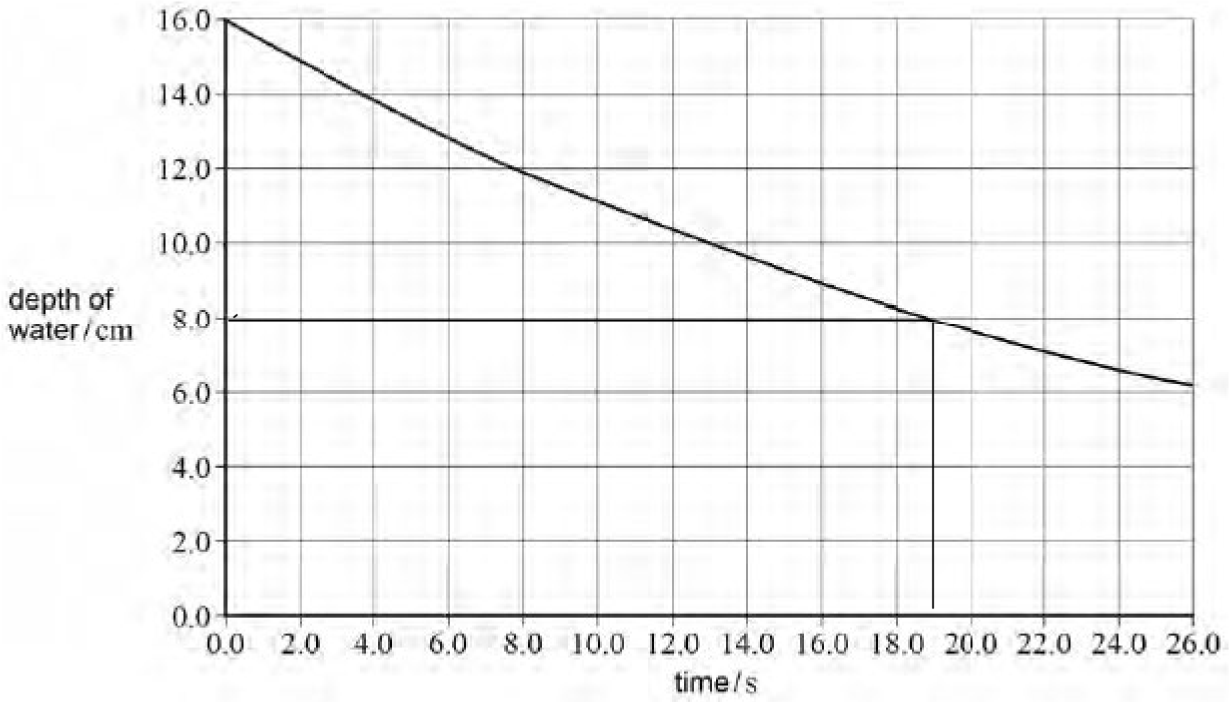


The water flow-rate is proportional to the pressure of the water. The pressure of the water is proportional to the depth of the water. Therefore the rate at which the depth decreases is proportional to the depth of the water.

Before the tap is opened the depth is 16.0 cm

The tap is opened and the depth is measured at regular intervals. These data are plotted on the graph in **Figure 12**.

Figure 12



0 6 . 1 Determine the predicted depth of water when the time is 57 s

[1 mark]

$t_{1/2} = 19s$ 16 → 8 → 4 → 2

$\frac{57}{19} = 3$ half lives

depth = 2 cm

0 6 . 2 Suggest how the apparatus in **Figure 11** may be changed to represent a radioactive sample of the same nuclide with a greater number of nuclei.

[1 mark]

Increase the depth of water.

0 6 . 3 Suggest how the apparatus in **Figure 11** may be changed to represent a radioactive sample of a nuclide with a smaller decay constant.

[1 mark]

Partially close the tap.

0 6 . 4 The age of the Moon has been estimated from rock samples containing rubidium (Rb) and strontium (Sr), brought back from Moon landings.
$^{87}_{37}Rb$ decays to $^{87}_{38}Sr$ with a radioactive decay constant of 1.42×10^{-11} year^{-1}

Calculate, in years, the half-life of $^{87}_{37}Rb$.

[1 mark]

$\ln 2 = \lambda t_{1/2}$

$\frac{\ln 2}{\lambda} = t_{1/2} = \frac{\ln 2}{1.42 \times 10^{-11}} = 4.88 \times 10^{10}$

half-life = 4.88×10^{10} years

0 6 . 5 A sample of Moon rock contains 1.23 mg of $^{87}_{37}Rb$.

Calculate the mass, in g, of $^{87}_{37}Rb$ that the rock sample contained when it was formed 4.47×10^{9} years ago.

Give your answer to an appropriate number of significant figures.

[3 marks]

$1.23 \times 10^{-3} = M_0 e^{-1.42 \times 10^{-11} \times 4.47 \times 10^{9}}$

$M_0 = 1.31 \times 10^{-3} = 1.31$ mg

mass = 1.31×10^{-3} g

0 6 . 6 Calculate the activity of a sample of $^{87}_{37}Rb$ of mass 1.23 mg

Give an appropriate unit for your answer.

[3 marks]

$87 \times 1.661 \times 10^{-27} = 1.44507 \times 10^{-25}$ Kg

$\frac{1.23 \times 10^{-6}}{1.44507 \times 10^{-25}} = 8.512 \times 10^{18}$ nuclei

$A = \lambda N$

$\lambda = \frac{1.42 \times 10^{-11}}{365 \times 24 \times 60^2} = 4.503 \times 10^{-19}$

$A = \lambda N$

$A = 3.83$

activity = 3.83 unit Bq

0 2 **Table 1** shows results of an experiment to investigate how the de Broglie wavelength λ of an electron varies with its velocity v.

Table 1

v / 10^7 m s^{-1}	λ / 10^{-11} m
1.5	4.9
2.5	2.9
3.5	2.1

0 2 . 1 Show that the data in **Table 1** are consistent with the relationship $\lambda \propto \frac{1}{v}$

[2 marks]

$\lambda = \frac{k}{v}$ → ① $4.9 \times 10^{-11} = \frac{k}{1.5 \times 10^7}$

$k = 7.35 \times 10^{-4}$

② $2.9 \times 10^{-11} = \frac{k}{2.5 \times 10^7}$

$k = 7.25 \times 10^{-4}$

③ $2.1 \times 10^{-11} = \frac{k}{3.5 \times 10^7}$

$k = 7.35 \times 10^{-4}$

K, constant of proportionality stays pretty much constant.

0 2 . 2 Calculate a value for the Planck constant suggested by the data in **Table 1**.

[2 marks]

$E = hF$

$v = F\lambda$

$\frac{v}{\lambda} = F$

$\frac{E}{F} = h$

$\frac{\frac{1}{2}mv^2}{F} = h$

$\frac{1}{2}mv\lambda = h$

$h = \frac{1}{2} \times 9.11 \times 10^{-31} \times 1.5 \times 10^{7} \times 4.9 \times 10^{-11}$

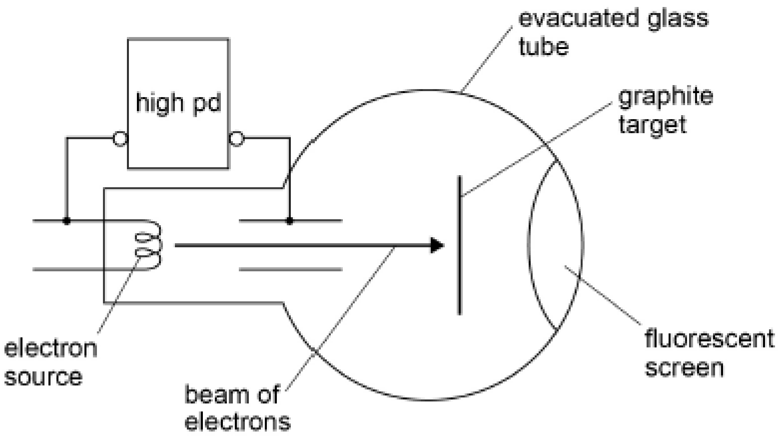
$= 3.35 \times 10^{-34}$

Planck constant = 3.35×10^{-34} J s

0 2 . 3 **Figure 2** shows the side view of an electron diffraction tube used to demonstrate the wave properties of an electron.

Figure 2

Side view

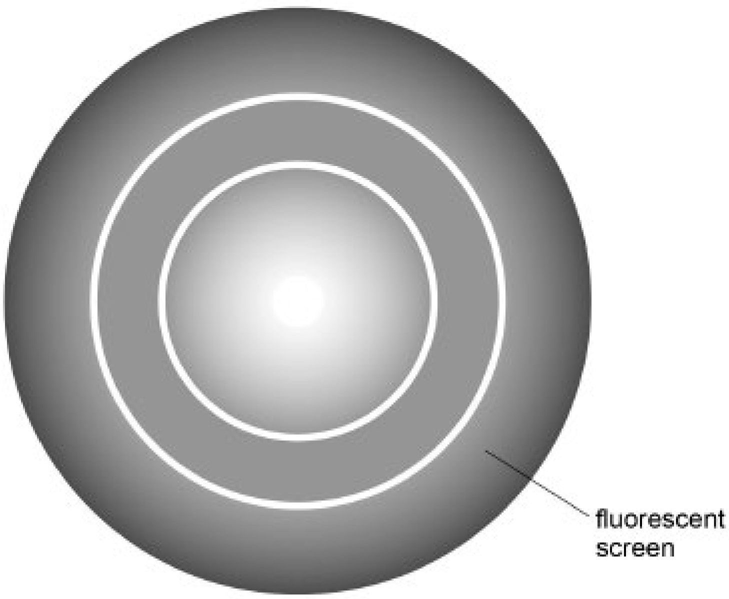


An electron beam is incident on a thin graphite target that behaves like the slits in a diffraction grating experiment. After passing through the graphite target the electrons strike a fluorescent screen.

Figure 3 shows the appearance of the fluorescent screen when the electrons are incident on it.

Figure 3

Front view



Explain how the pattern produced on the screen supports the idea that the electron beam is behaving as a wave rather than as a stream of particles.

[3 marks]

- The light rings are areas of constructive interference.
- Graphite causes electrons to spread out (Diffraction).
- The rings (Orders) get further apart and dimmer the further out of the target you look.
- These behaviours are defining wave behaviours.

0 2 . 4 Explain how the emission of light from the fluorescent screen shows that the electrons incident on it are behaving as particles.

[3 marks]

- Electrons provide energy in discrete amounts.

0 6 . 4 One fission process which can occur in a thermal nuclear reactor is represented by the equation

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} = ^{142}_{54}\text{Xe} + ^{90}_{38}\text{Sr} + 4^{1}_{0}\text{n}$$

Calculate in MeV the energy released in this fission process.

mass of $^{235}_{92}\text{U}$ = 235.044 u

mass of $^{142}_{54}\text{Xe}$ = 141.930 u

mass of $^{90}_{38}\text{Sr}$ = 89.908 u

mass of $^{1}_{0}\text{n}$ = 1.0087 u

[3 marks]

235.044 U + 1.0087 u = 141.93 u + 89.908 u + 4.0348 u + destroyed mass

236.0527 u = 235.8728 + destroyed mass

destroyed mass (Δm) = 0.1799

$E = \Delta m c^2$

$E = 0.1799 (3\times10^8)^2$

$E = 1.6\times10^{16}$ eV

$= 1.6\times10^{10}$ MeV

energy released = 1.6×10^{10} MeV

2 9 The number of parent nuclei in a sample of a radioactive element is N at time t.
The radioactive element has a half-life $t_{\frac{1}{2}}$

The rate of decay is proportional to

[1 mark]

A N ☑

B t ☐

C $\frac{1}{t}$ ☐

D $t_{\frac{1}{2}}$ ☐

0 9 A deuterium nucleus and a tritium nucleus fuse together to produce a helium nucleus and particle **X**.

$$^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + \mathbf{X}$$

What is **X**?

[1 mark]

A an electron ☐

B a neutron ☑

C a positron ☐

D a proton ☐

1 0 The radioactive nuclide $^{232}_{90}\mathrm{Th}$ decays by one α emission followed by two β^- emissions.

Which nuclide is formed as a result of these decays?

[1 mark]

A $^{238}_{92}\mathrm{U}$ ☐

B $^{230}_{90}\mathrm{Th}$ ☐

C $^{228}_{90}\mathrm{Th}$ ☑

D $^{228}_{88}\mathrm{Rn}$ ☐

$$^{232}_{90} \rightarrow {}^{228}_{88} + {}^{4}_{2}\mathrm{He}$$

$$^{228}_{88} = {}^{228}_{90}\mathrm{X} + {}^{0}_{-1}e + {}^{0}_{-1}e$$

0 9 An electron collides with an isolated atom and raises an orbiting electron to a higher energy level.

Which statement is correct?

[1 mark]

A The colliding electron is captured by the nucleus of the atom. ☐

B A photon is emitted when the electron rises to the higher energy level. ☐

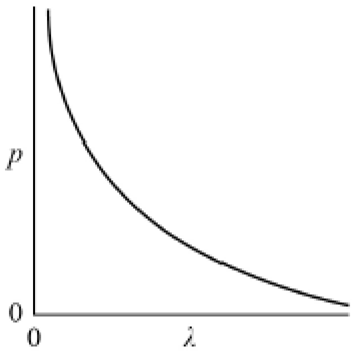
C An electron is emitted when the excited electron returns to the ground state. ☐

D Energy is transferred from the colliding electron to the orbiting electron. ☑

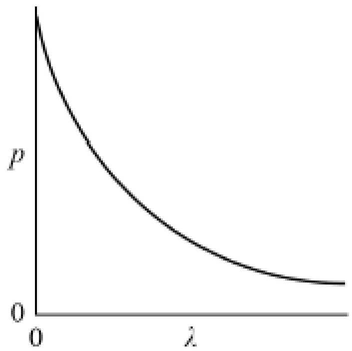
1 3 Which graph shows the variation of momentum p with wavelength λ of a photon?

[1 mark]

A

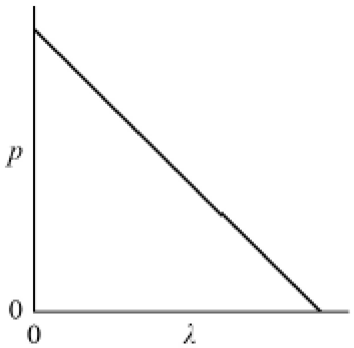


B

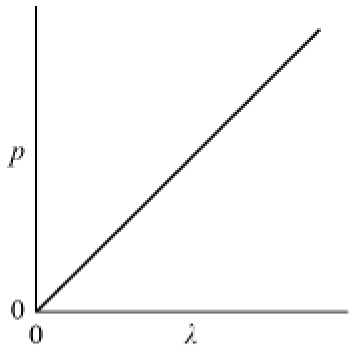


$p = \frac{h}{\lambda}$

C



D



- **A** ☑
- **B** ☐
- **C** ☐
- **D** ☐

3 0 The table shows the masses of three particles.

Particle	Mass / u
proton	1.00728
neutron	1.00867
nucleus of lithium $^{7}_{3}Li$	7.01436

What is the mass difference of a $^{7}_{3}Li$ nucleus?

[1 mark]

A 4.99841 u ⬭

B 0.04216 u ⬭ ✓

C 0.04147 u ⬭

D 0.04077 u ⬭

$4 \times 1.00867 = 4.03468$
$3 \times 1.00728 = 3.02184$ +
7.05652

$7.05652 - 7.01436$
$= 0.04216$

3 1 During a single fission event of uranium-235 in a nuclear reactor the total mass lost is 0.23 u. The reactor is 25% efficient.

How many events per second are required to generate 900 MW of power?

[1 mark]

A 1.1×10^{14} ⬭

B 6.6×10^{18} ⬭

C 1.1×10^{20} ⬭ ✓

D 4.4×10^{20} ⬭

events : mass
1 : 0.23u
1 : 3.8203×10^{-28} kg
1.047×10^{20} 6 1.04×10^{20} : 4×10^{-8} kg

$900 \times 10^{6} = E/t$ $t = 1$
$E = 900 \times 10^{6}$
$\frac{900 \times 10^{6}}{0.25} = 3600 \times 10^{6}$
$3600 \times 10^{6} = mc^{2}$
$m = 4 \times 10^{-8}$