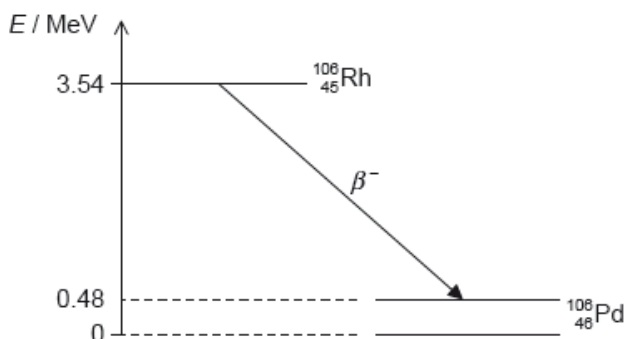# HL Paper 2

Rhodium-106 ($^{106}_{45}\mathrm{Rh}$) decays into palladium-106 ($^{106}_{46}\mathrm{Pd}$) by beta minus (β^-) decay. The diagram shows some of the nuclear energy levels of rhodium-106 and palladium-106. The arrow represents the β^- decay.

b. Bohr modified the Rutherford model by introducing the condition $mvr = n\frac{h}{2\pi}$. Outline the reason for this modification. [3]

c.i. Show that the speed v of an electron in the hydrogen atom is related to the radius r of the orbit by the expression [1]

$$v = \sqrt{\frac{ke^2}{m_e r}}$$

where k is the Coulomb constant.

c.ii. Using the answer in (b) and (c)(i), deduce that the radius r of the electron's orbit in the ground state of hydrogen is given by the following [2]

expression.

$$r = \frac{h^2}{4\pi^2 k m_e e^2}$$

c.iii Calculate the electron's orbital radius in (c)(ii). [1]

d.i. Explain what may be deduced about the energy of the electron in the β^- decay. [3]

d.ii. Suggest why the β^- decay is followed by the emission of a gamma ray photon. [1]

d.iii Calculate the wavelength of the gamma ray photon in (d)(ii). [2]

This question is in **two** parts. **Part 1** is about the oscillation of a mass. **Part 2** is about the photoelectric effect.

Part 2 Photoelectric effect

A student carries out a photoelectric experiment in which radiation is incident on a metal surface in a vacuum.

A graph of the results of the experiment show how the maximum kinetic energy E_{max} of the emitted photoelectrons varies with the frequency f of the incident radiation.

E_{max} / eV
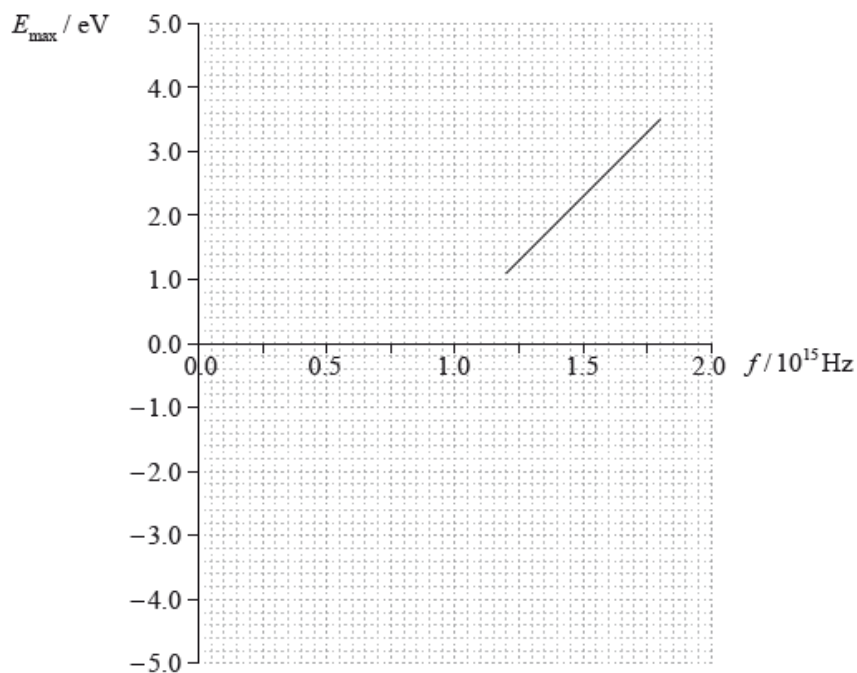
Use the graph to

d. Explain why photoelectrons are not emitted from the metal surface unless the frequency of incident light exceeds a minimum value.   [2]

e.i. identify the minimum value of the frequency f_0 for photoelectrons to be emitted.   [1]

e.ii. determine the Planck constant.   [3]

e.iii calculate the work function, in eV, for the metal surface.   [2]

f. The student repeats the experiment with a different metal surface that has a smaller value   [2]

for the work function. On the graph in (e), draw a line to show how E_{max} varies with f.

This question is in **two** parts. **Part 1** is about the simple pendulum. **Part 2** is about the de Broglie hypothesis.

Part 2 de Broglie hypothesis

Part 2 b. A beam of electrons is accelerated from rest through a potential difference of 85 V.   [3]

Show that the de Broglie wavelength associated with the electrons in the beam is 0.13 nm.

Part 2 c. Electrons with the same kinetic energy as those in (b) are incident on a circular aperture of diameter 1.1 nm.   [4]
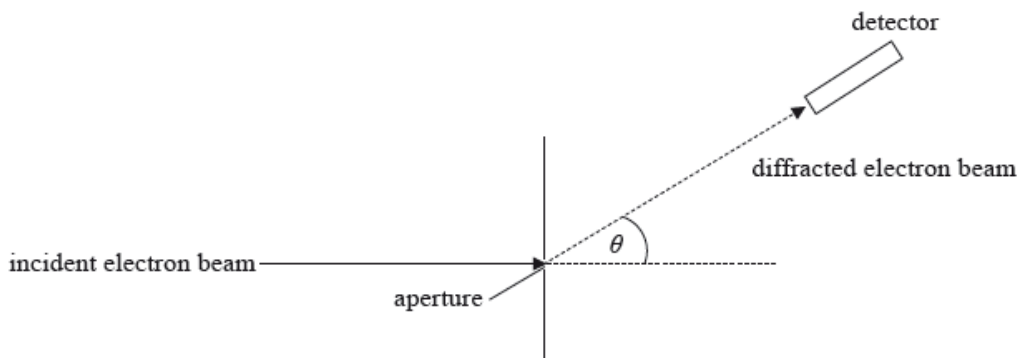
The electrons are detected beyond the aperture.

The graph shows the variation with angle θ of the number n of electrons detected per second after diffraction by the aperture.
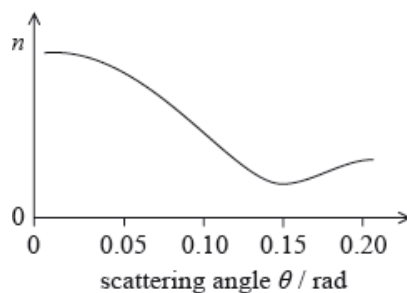
Use your answer to (b) opposite to explain how data from the graph support the de Broglie hypothesis.

a. An alpha particle with initial kinetic energy 32 MeV is directed head-on at a nucleus of gold-197 $\left(^{197}_{79}\text{Au}\right)$. [5]

(i) Show that the distance of closest approach of the alpha particle from the centre of the nucleus is about 7×10^{-15}m.

(ii) Estimate the density of a nucleus of $^{197}_{79}\text{Au}$ using the answer to (a)(i) as an estimate of the nuclear radius.

b. The nucleus of $^{197}_{79}\text{Au}$ is replaced by a nucleus of the isotope $^{195}_{79}\text{Au}$. Suggest the change, if any, to your answers to (a)(i) and (a)(ii). [2]

Distance of closest approach:

Estimate of nuclear density:

c. An alpha particle is confined within a nucleus of gold. Using the uncertainty principle, estimate the kinetic energy, in MeV, of the alpha particle. [3]

This question is in **two** parts. **Part 1** is about electric cells. **Part 2** is about atoms.

Part 1 Electric cells

Cells used to power small electrical devices contain both conductors and insulators.

Cells also have the property of internal resistance.

Part 2 Atoms

Photoelectric emission occurs when ultraviolet radiation is incident on the surface of mercury but not when visible light is incident on the metal.

Photoelectric emission occurs when visible light of all wavelengths is incident on caesium.

a. (i) Distinguish between an insulator and a conductor. [4]

(ii) Outline what is meant by the internal resistance of a cell.

c. State what is meant by the photoelectric effect. [1]

d. (i) Suggest why the work function for caesium is smaller than that of mercury. [4]

(ii) Ultraviolet radiation of wavelength 210 nm is incident on the surface of mercury. The work function for mercury is 4.5 eV. Determine the maximum kinetic energy of the photoelectrons emitted.

f. An exact determination of the location of the electron in a hydrogen atom is not possible. Outline how this statement is consistent with the [3]

Schrödinger model of the hydrogen atom.

The first scientists to identify alpha particles by a direct method were Rutherford and Royds. They knew that radium-226 ($^{226}_{86}$Ra) decays by alpha

emission to form a nuclide known as radon (Rn).

At the start of the experiment, Rutherford and Royds put 6.2 x 10^{-4} mol of pure radium-226 in a small closed cylinder A. Cylinder A is fixed in the

centre of a larger closed cylinder B.

cylinder A
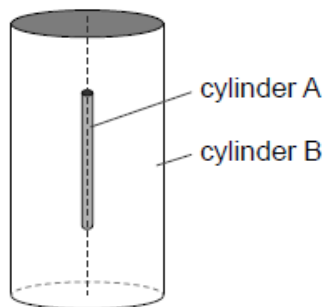
cylinder B

The experiment lasted for 6 days. The decay constant of radium-226 is 1.4 x 10^{-11} s^{-1}.

At the start of the experiment, all the air was removed from cylinder B. The alpha particles combined with electrons as they moved through the wall of

cylinder A to form helium gas in cylinder B.

a. Write down the nuclear equation for this decay. [2]

b.i. Deduce that the activity of the radium-226 is almost constant during the experiment. [2]

b.ii. Show that about 3 x 10^{15} alpha particles are emitted by the radium-226 in 6 days. [3]

c.i. The wall of cylinder A is made from glass. Outline why this glass wall had to be very thin. [1]

c.ii.The experiment was carried out at a temperature of 18 °C. The volume of cylinder B was 1.3 x 10^{-5} m^3 and the volume of cylinder A was [3]

negligible. Calculate the pressure of the helium gas that was collected in cylinder B over the 6 day period. Helium is a monatomic gas.

Part 3 Atomic energy levels

b. Outline how atomic emission spectra provide evidence for the quantization of energy in atoms. [2]

c. Consider an electron confined in a one-dimensional "box" of length L. The de Broglie waves associated with the electron are standing waves [3]

with wavelengths given by $\frac{2L}{n}$, where n=1, 2, 3, …

Show that the energy E_n of the electron is given by

$$E_n = \frac{n^2 h^2}{8 m_e L^2}$$

where h is Planck's constant and m_e is the mass of the electron.

d. An electron is confined in a "box" of length L=1.0×10^{-10}m in the n=1 energy level. Its position as measured from one end of the box is [4]

(0.5±0.5)×10^{-10}m. Determine

(i) the momentum of the electron.

(ii) the uncertainty in the momentum.

Part 2 Electrons

a. Monochromatic light is incident on a metal surface and electrons are emitted instantaneously from the surface. [4]

Explain why

(i) the emission of the electrons is instantaneous.

(ii) the energy of the emitted electrons does not depend on the intensity of the incident light.

b. The wavelength of the incident light in (a) is 420 nm and the work function of the metal is 3.4×10^{-19}J. [6]

(i) Determine, in joules, the maximum kinetic energy of an emitted electron.

(ii) The metal surface has dimensions of 1.5 mm×2.0 mm. The intensity of the light incident on the surface is 4.5×10^{-6} W m^{-2}. On average, one electron is emitted for every 300 photons that are incident on the surface. Determine the initial electric current leaving the metal surface.

This question is about nuclear processes.

a. Describe what is meant by [4]

(i) radioactive decay.

(ii) nuclear fusion.

b. Tritium is a radioactive nuclide with a half-life of 4500 days. It decays to an isotope of helium.   [3]

Determine the time taken for 90% of a sample of tritium to decay.

c. A nuclide of deuterium $\left(^2_1\mathrm{H}\right)$ and a nuclide of tritium $\left(^3_1\mathrm{H}\right)$ undergo nuclear fusion. The reaction equation for this process is   [1]

$$^2_1\mathrm{H} + ^3_1\mathrm{H} \rightarrow\ ^4_2\mathrm{He} + \mathrm{X}$$
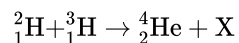
Identify X.

This question is about the photoelectric effect.

Monochromatic light of wavelength 420 nm is incident on a clean metal surface. The work function of the metal is 2.6×10^{-19} J.

a. Outline why the wave model of light cannot account for the photoelectric effect.   [3]

b.i.Calculate, in eV, the maximum kinetic energy of the photoelectrons emitted.   [3]

b.ii.The intensity of the light is $5.1\ \mu\mathrm{W\,m^{-2}}$. Determine the number of photoelectrons emitted per second for each $\mathrm{mm^2}$ of the metal surface. Each   [3]
photon has a 1 in 800 chance of ejecting an electron.

Yellow light of photon energy 3.5 x 10^{-19} J is incident on the surface of a particular photocell.
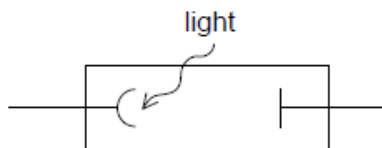
The photocell is connected to a cell as shown. The photoelectric current is at its maximum value (the saturation current).
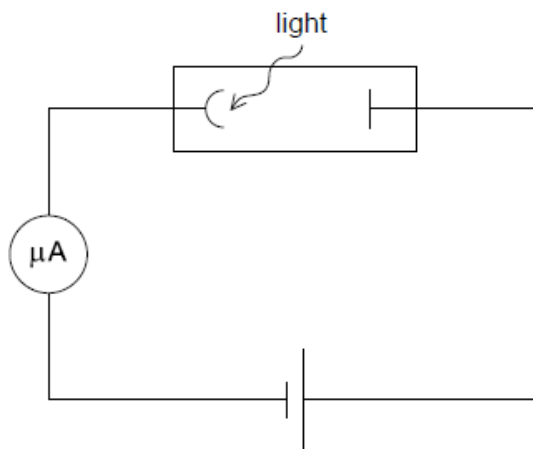
Radiation with a greater photon energy than that in (b) is now incident on the photocell. The intensity of this radiation is the same as that in (b).

a.i. Calculate the wavelength of the light. [1]

a.ii. Electrons emitted from the surface of the photocell have almost no kinetic energy. Explain why this does not contradict the law of conservation [2]

of energy.

b. Radiation of photon energy 5.2 x 10^{-19} J is now incident on the photocell. Calculate the maximum velocity of the emitted electrons. [2]

c.i. Describe the change in the number of photons per second incident on the surface of the photocell. [1]

c.ii. State and explain the effect on the maximum photoelectric current as a result of increasing the photon energy in this way. [3]

This question is in **two** parts. **Part 1** is about electric fields and radioactive decay. **Part 2** is about waves.

Part 1 Electric fields and radioactive decay

An ionization chamber is a device which can be used to detect charged particles.
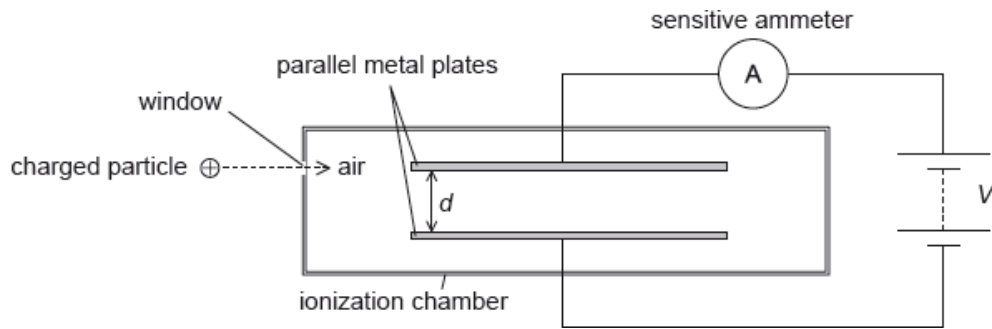
The charged particles enter the chamber through a thin window. They then ionize the air between the parallel metal plates. A high potential difference across the plates creates an electric field that causes the ions to move towards the plates. Charge now flows around the circuit and a current is detected by the sensitive ammeter.

The separation of the plates d is 12 mm and the potential difference V between the plates is 5.2 kV. An ionized air molecule M with charge $+2e$ is produced when a charged particle collides with an air molecule.

Radium-226 $\left(^{226}_{88}\mathrm{Ra}\right)$ decays into an isotope of radon (Rn) by the emission of an alpha particle and a gamma-ray photon. The alpha particle may be detected using the ionization chamber but the gamma-ray photon is unlikely to be detected.

a. On the diagram, draw the shape of the electric field between the plates. [2]

b.i. Calculate the electric field strength between the plates. [1]

b.ii. Calculate the force on M. [2]

b.iii. Determine the change in the electric potential energy of M as it moves from the positive to the negative plate. [3]

c.ii. Construct the nuclear equation for the decay of radium-226. [2]

$$^{226}_{88}\mathrm{Ra} \rightarrow \text{\_\_\_}\,\mathrm{Rn} + \text{\_\_\_}\,\mathrm{He} + ^{0}_{0}\gamma$$
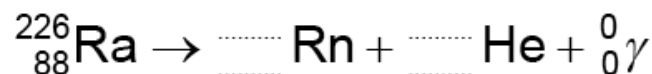
c.iii Radium-226 has a half-life of 1600 years. Determine the time, in years, it takes for the activity of radium-226 to fall to 5% of its original activity. [3]
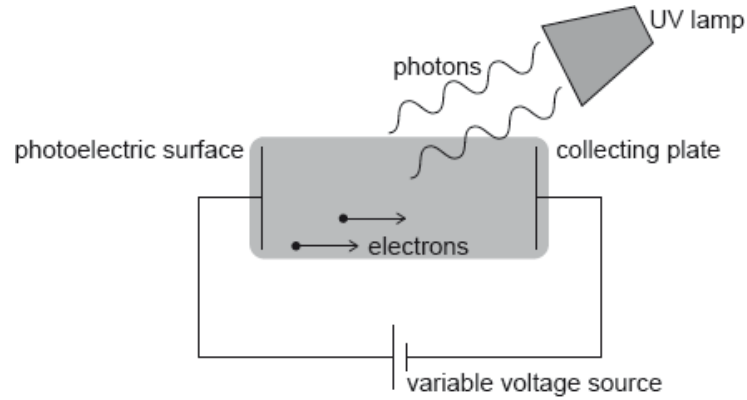

Hydrogen atoms in an ultraviolet (UV) lamp make transitions from the first excited state to the ground state. Photons are emitted and are incident on a photoelectric surface as shown.

The photons cause the emission of electrons from the photoelectric surface. The work function of the photoelectric surface is 5.1 eV.

The electric potential of the photoelectric surface is 0 V. The variable voltage is adjusted so that the collecting plate is at −1.2 V.
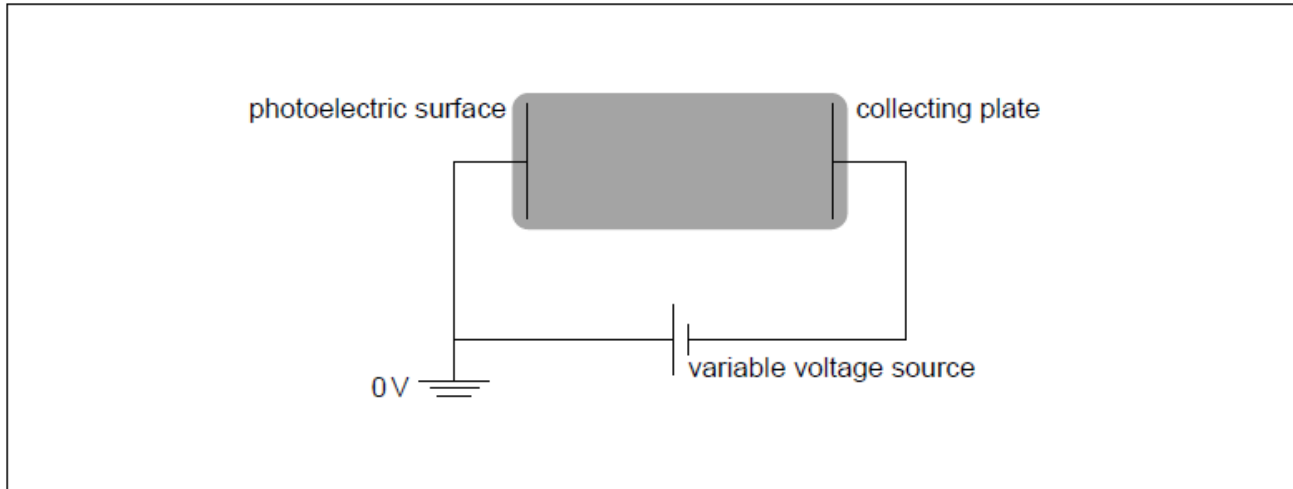
a. Show that the energy of photons from the UV lamp is about 10 eV. [2]

b.i. Calculate, in J, the maximum kinetic energy of the emitted electrons. [2]

b.ii Suggest, with reference to conservation of energy, how the variable voltage source can be used to stop all emitted electrons from reaching the collecting plate. [2]

b.iii The variable voltage can be adjusted so that no electrons reach the collecting plate. Write down the minimum value of the voltage for which no electrons reach the collecting plate. [1]

c.i. On the diagram, draw and label the equipotential lines at −0.4 V and −0.8 V. [2]

c.ii. An electron is emitted from the photoelectric surface with kinetic energy 2.1 eV. Calculate the speed of the electron at the collecting plate.   [2]

---

a. A particular K meson has a quark structure ūs. State the charge, strangeness and baryon number for this meson.   [2]

Charge:	. . . .
Strangeness:	. . . .
Baryon number:	. . . .

b. The Feynman diagram shows the changes that occur during beta minus (β^-) decay.   [3]
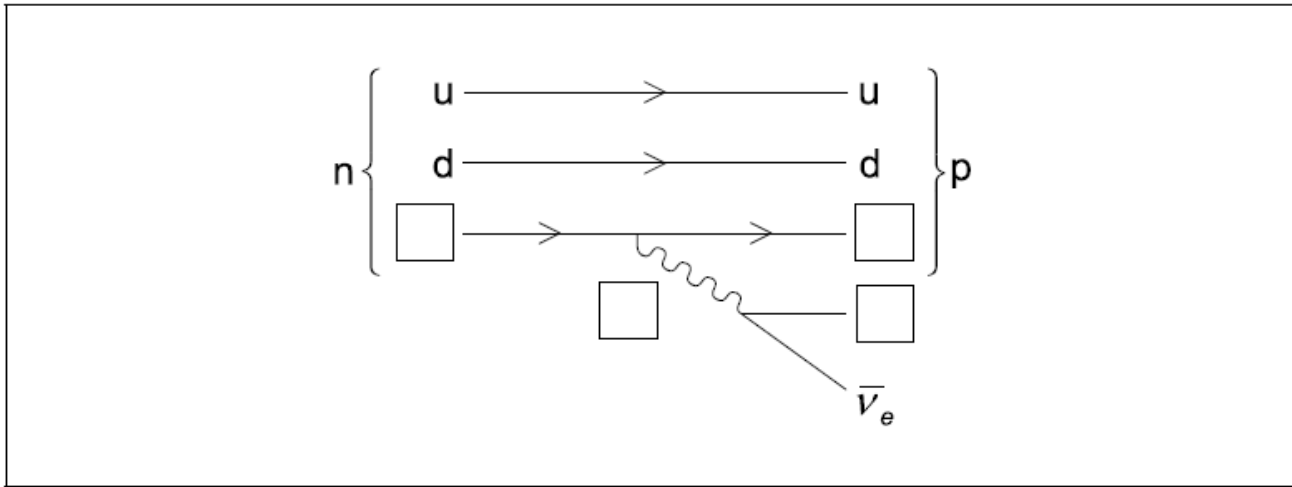

Label the diagram by inserting the **four** missing particle symbols **and** the direction of the arrows for the decay particles.

d. C-14 decay is used to estimate the age of an old dead tree. The activity of C-14 in the dead tree is determined to have **fallen to** 21% of its original value. C-14 has a half-life of 5700 years.   [4]

(i) Explain why the activity of C-14 in the dead tree decreases with time.

(ii) Calculate, in years, the age of the dead tree. Give your answer to an appropriate number of significant figures.

An apparatus is used to investigate the photoelectric effect. A caesium cathode C is illuminated by a variable light source. A variable power supply is connected between C and the collecting anode A. The photoelectric current I is measured using an ammeter.

$\lambda = 400\,nm$
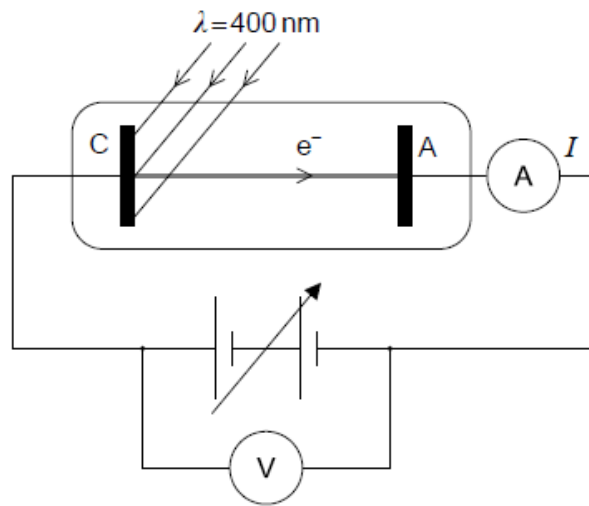
a. A current is observed on the ammeter when violet light illuminates C. With V held constant the current becomes zero when the violet light is replaced by red light of the same intensity. Explain this observation. [3]

b. The graph shows the variation of photoelectric current *I* with potential difference *V* between C and A when violet light of a particular intensity is used. [6]
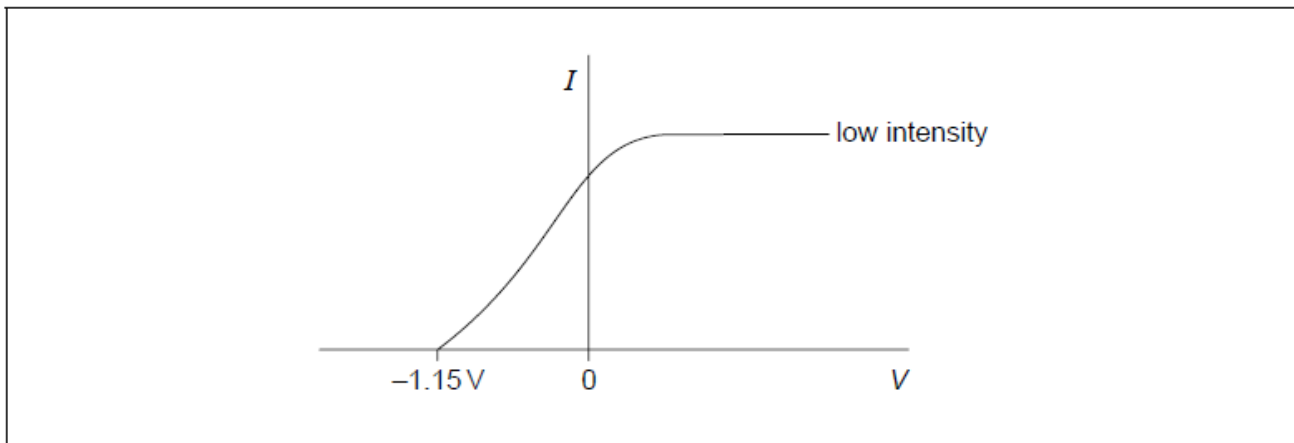
The intensity of the light source is increased without changing its wavelength.

(i) Draw, on the axes, a graph to show the variation of *I* with *V* for the increased intensity.

(ii) The wavelength of the violet light is 400 nm. Determine, in eV, the work function of caesium.

(iii) *V* is adjusted to +2.50V. Calculate the maximum kinetic energy of the photoelectrons just before they reach A.

This question is about electrical generation using nuclear power.

Exposure to radiation is a safety risk both to miners of uranium ore and to workers in nuclear power plants.

b. Outline why uranium ore needs to be enriched before it can be used successfully in a nuclear reactor. [3]

c. (i) One possible waste product of a nuclear reactor is the nuclide caesium-137 $\left(^{137}_{55}Cs\right)$ which decays by the emission of a beta-minus (β−) particle to form a nuclide of barium (Ba). [6]

State the nuclear reaction for this decay.

$$^{137}_{55}\text{Cs} \rightarrow \ ^{....}_{....}\text{Ba} + \ ^{....}_{....}\beta^- + \ ....$$
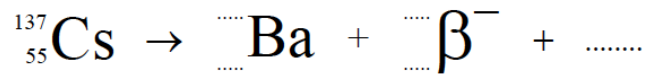
(ii) The half-life of caesium-137 is 30 years. Determine the fraction of caesium-137 remaining in the waste after 100 years.

d. Some waste products in nuclear reactors are good absorbers of neutrons. Suggest why the formation of such waste products requires the [2] removal of the uranium fuel rods well before the uranium is completely used up.

This question is in **two** parts. **Part 1** is about simple harmonic motion (SHM) and waves. **Part 2** is about atomic and nuclear energy levels.

Part 1 Simple harmonic motion (SHM) and waves

Part 2 Atomic and nuclear energy levels

a. A particle P moves with simple harmonic motion. [3]

(i) State, with reference to the motion of P, what is meant by simple harmonic motion.

(ii) State the phase difference between the displacement and the velocity of P.

d. The diagram shows four spectral lines in the visible line emission spectrum of atomic hydrogen. [6]

410   434   485   656

wavelength λ / nm ⟶   (not to scale)
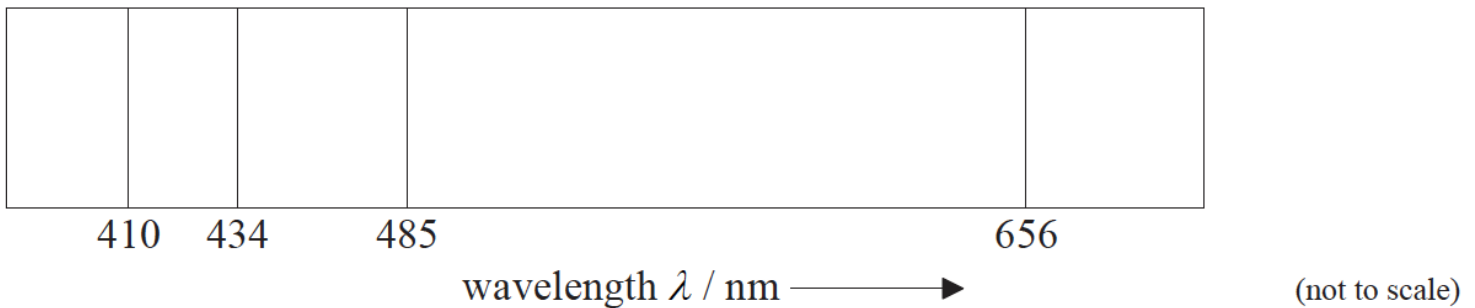
(i) Outline how such a spectrum may be obtained in the laboratory.

(ii) Explain how such spectra give evidence for the existence of discrete atomic energy levels.

e. The energies of the principal energy levels in atomic hydrogen measured in eV are given by the expression [4]

$E_n = -\frac{13.6}{n^2}$ where n=1, 2, 3 ....

The visible lines in the spectrum correspond to electron transitions that end at n=2.

(i) Calculate the energy of the level corresponding to n=2.

(ii) Show that the spectral line of wavelength λ=485nm is the result of an electron transition from n=4.

f. The alpha particles and gamma rays produced in radioactive decay have discrete energy spectra. This suggests that nuclei also possess [2] discrete energy levels. However, beta particles produced in radioactive decay have continuous energy spectra. Describe how the existence of the antineutrino accounts for the continuous nature of beta spectra.

The Feynman diagram shows electron capture.
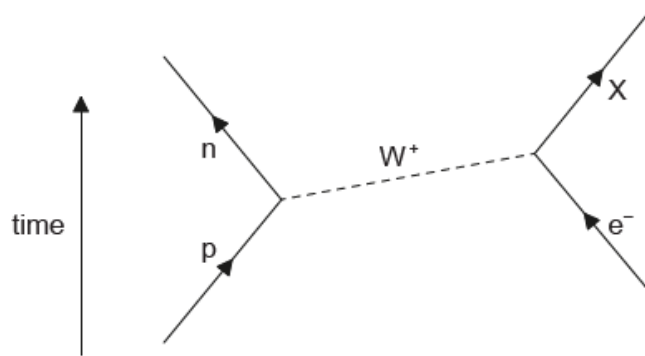
Particles can be used in scattering experiments to estimate nuclear sizes.

Electron diffraction experiments indicate that the nuclear radius of carbon-12 is 2.7 x 10⁻¹⁵ m. The graph shows the variation of nuclear radius with nucleon number. The nuclear radius of the carbon-12 is shown on the graph.
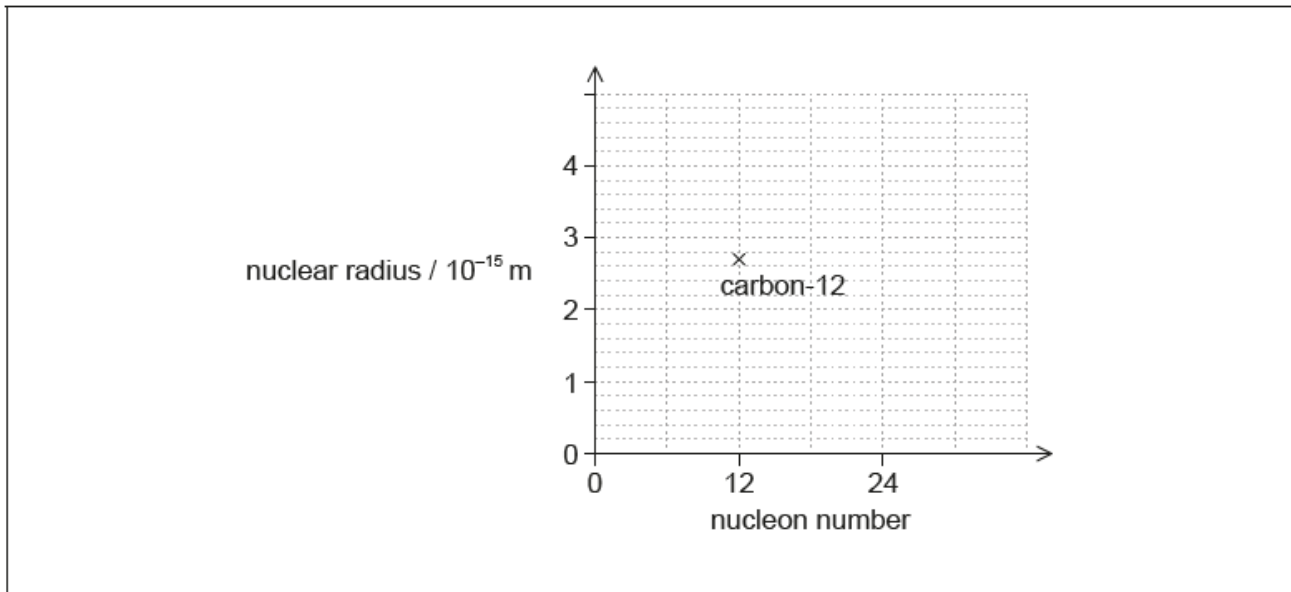
a.i. State and explain the nature of the particle labelled X.   [3]

b.i. Outline how these experiments are carried out.   [2]

b.ii.Outline why the particles must be accelerated to high energies in scattering experiments.   [3]

c. State and explain **one** example of a scientific analogy.   [2]

d.i. Determine the radius of the magnesium-24 nucleus.   [2]

d.ii.Plot the position of magnesium-24 on the graph.   [1]

d.iiiDraw a line on the graph, to show the variation of nuclear radius with nucleon number.   [2]

Part 3 The photoelectric effect and the Heisenberg uncertainty principle

f. Light is incident on a metal surface A. A potential difference is applied between A and an electrode B. Photoelectrons arrive at B and the   [6]

resulting current is measured by a sensitive ammeter. (Note: the complete electrical circuit is not shown.)
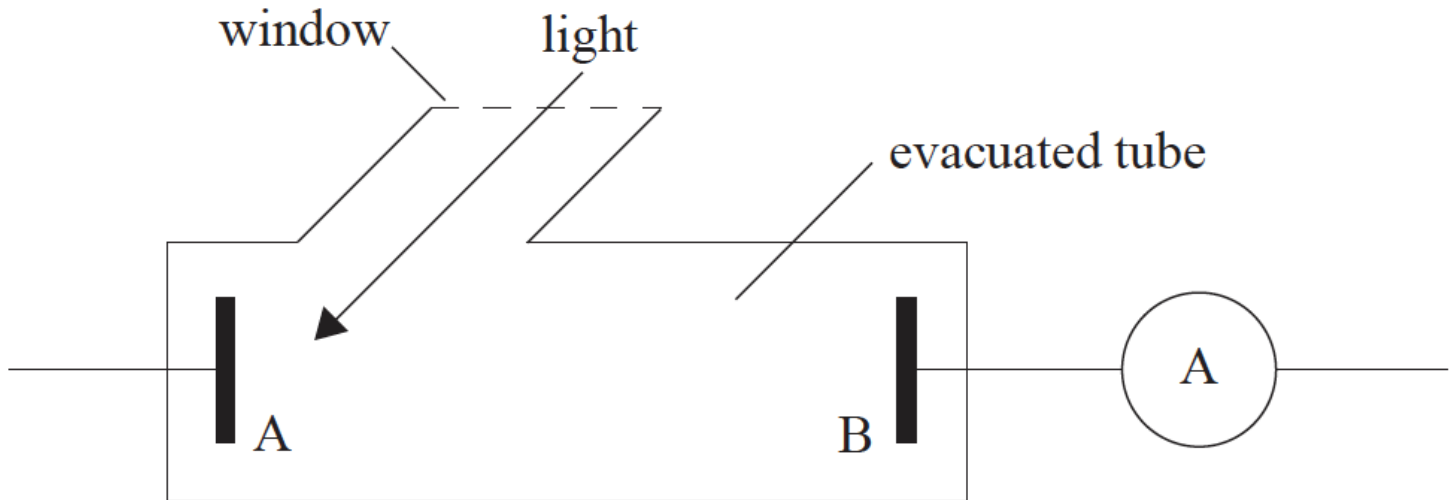
(i) The frequency of the light is reduced until the current measured by the ammeter falls to zero. Explain how Einstein's photoelectric theory accounts for this observation.

(ii) A different metal surface is used so that a current is again measured. Outline the effect on the photoelectric current when the intensity of the light is doubled and the frequency remains constant.

g. A photon of energy 6.6×10^{-19}J is incident upon a clean sodium surface. The work function of sodium is 3.7×10^{-19}J. The photon causes an   [5]

electron to be emitted from the surface with the maximum possible kinetic energy. The position of this electron is measured with an uncertainty

of 5.0×10^{-9}m.

Calculate the

(i) momentum of the electron.

(ii) uncertainty in the momentum of the electron.

This question is in **two** parts. **Part 1** is about quantum aspects of the electron. **Part 2** is about electric circuits.

Part 1 Quantum aspects of the electron

The wavefunction ψ for an electron confined to move within a "box" of linear size $L =1.0\times10^{-10}$m, is a standing wave as shown.
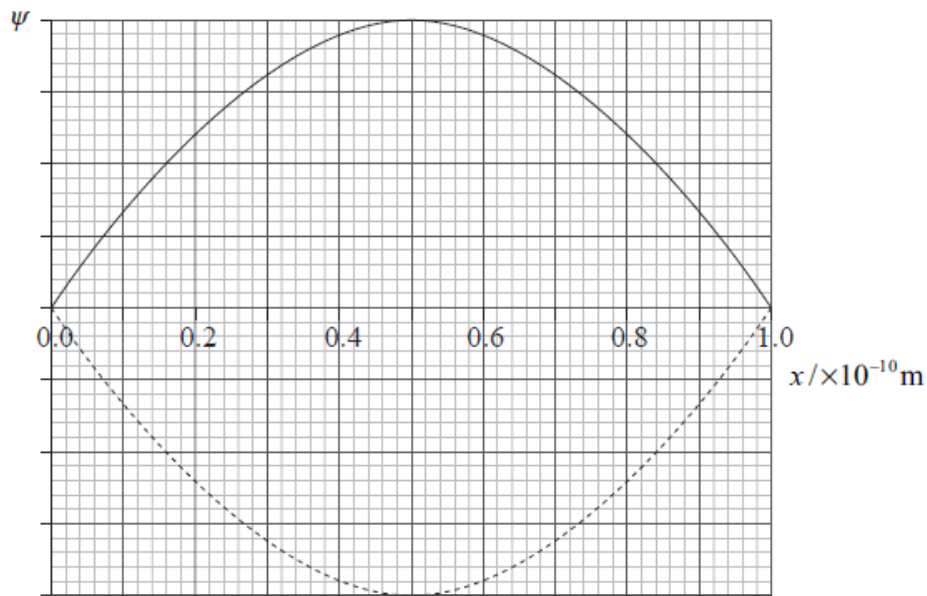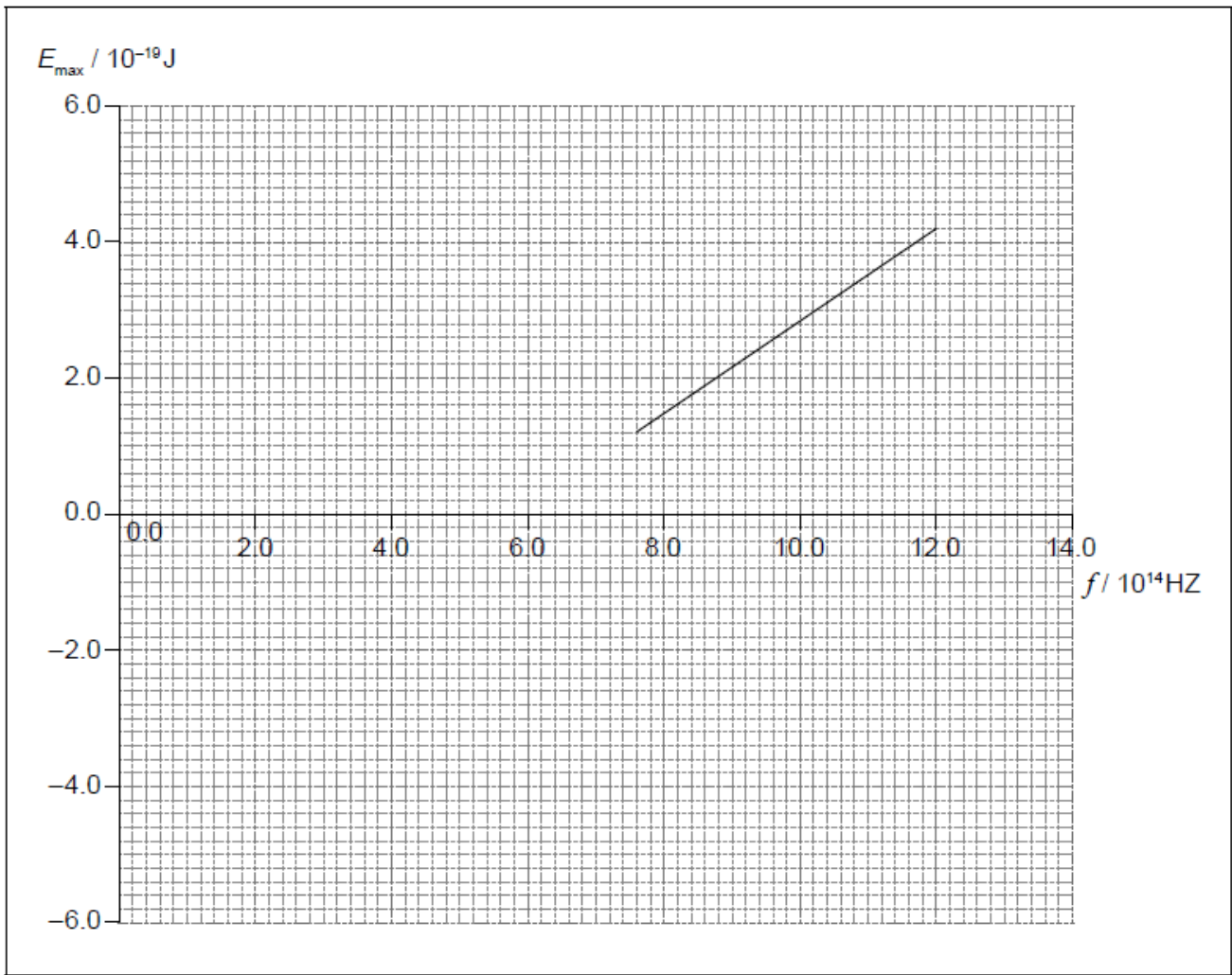
a. State what is meant by a wavefunction. [1]

b. State the position near which this electron is most likely to be found. [1]

c. Calculate the momentum of the electron. [2]

d. The energy, in joules, of the electron in a hydrogen atom, is given by $E = \frac{2.18 \times 10^{-18}}{n^2}$ where n is a positive integer. Calculate the wavelength of [3]

the photon emitted in a transition from the first excited state of hydrogen to the ground state.

e. The electron stays in the first excited state of hydrogen for a time of approximately $\Delta t = 1.0 \times 10^{-10}$s. [4]

(i) Determine the uncertainty in the energy of the electron in the first excited state.

(ii) Suggest, with reference to your answer to (e)(i), why the photons emitted in transitions from the first excited state of hydrogen to the ground state will, in fact, have a small range of wavelengths.

Two observations about the photoelectric effect are

Observation 1: For light below the threshold frequency no electrons are emitted from the metal surface.

Observation 2: For light above the threshold frequency, the emission of electrons is almost instantaneous.

The graph shows how the maximum kinetic energy E_{max} of electrons emitted from a surface of barium metal varies with the frequency f of the incident

radiation.

E_{max} / 10^{-19} J

f / 10^{14} HZ

a. Explain how each observation provides support for the particle theory but not the wave theory of light. [4]

Observation 1: . . . .

. . . .

. . . .

. . . .

Observation 2: . . . .

. . . .

. . . .

. . . .

b.i. Determine a value for Planck's constant. [2]

b.ii. State what is meant by the work function of a metal. [1]

b.iii. Calculate the work function of barium in eV. [2]

c. The experiment is repeated with a metal surface of cadmium, which has a greater work function. Draw a second line on the graph to represent [2] the results of this experiment.

Part 2 Nuclear energy and radioactivity

The graph shows the variation of binding energy per nucleon with nucleon number. The position for uranium-235 (U-235) is shown.
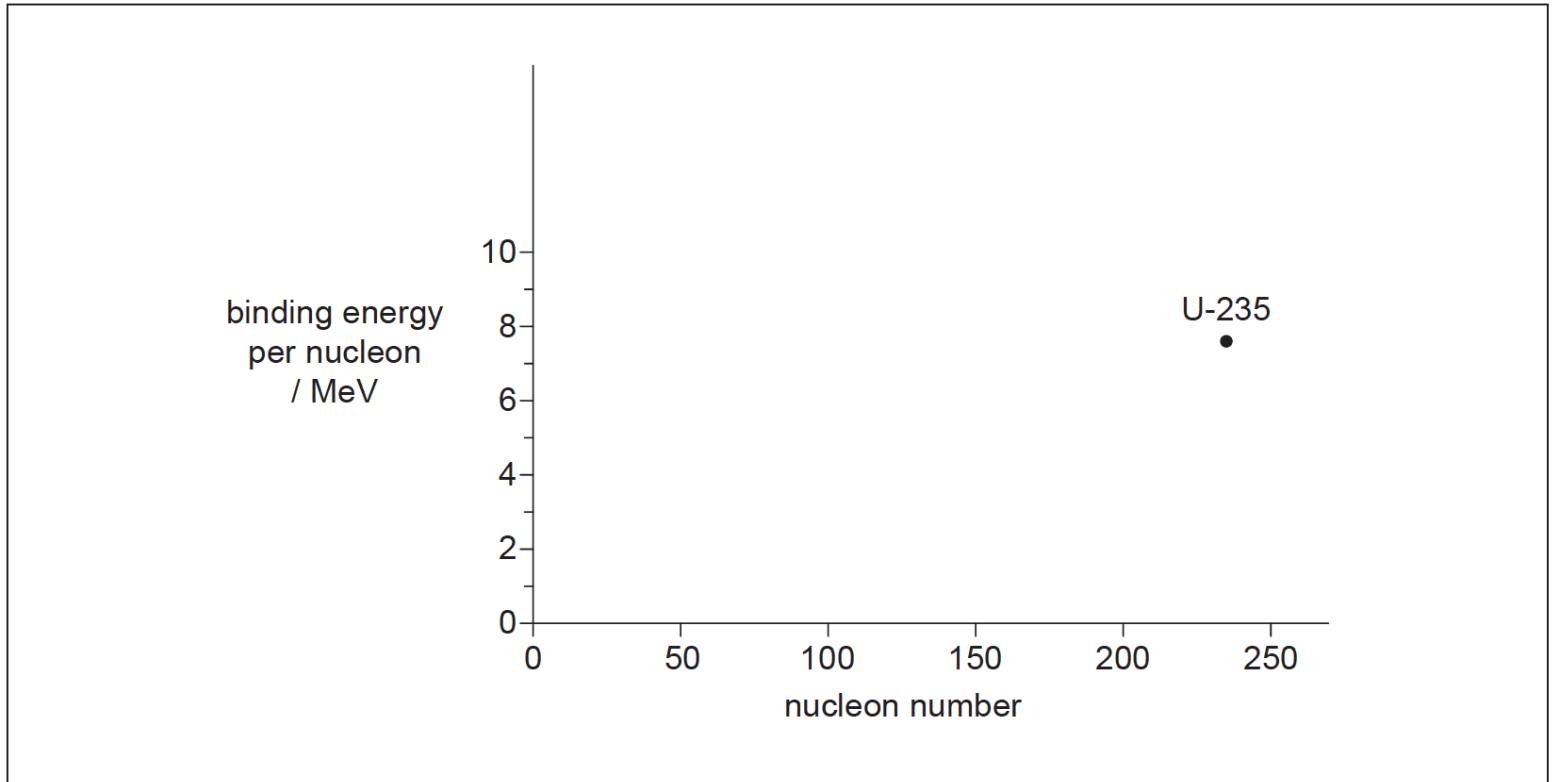
U-235 $\left(^{235}_{92}\text{U}\right)$ can undergo alpha decay to form an isotope of thorium (Th).

(i) State the nuclear equation for this decay.

(ii) A sample of rock contains a mass of 5.6 mg of U-235 at the present day. The half-life of U-235 is 7.0×10^8 years. Determine the initial mass of the U-235 if the rock sample was formed 3.9×10^9 years ago.

The radioactive nuclide beryllium-10 (Be-10) undergoes beta minus (β–) decay to form a stable boron (B) nuclide.

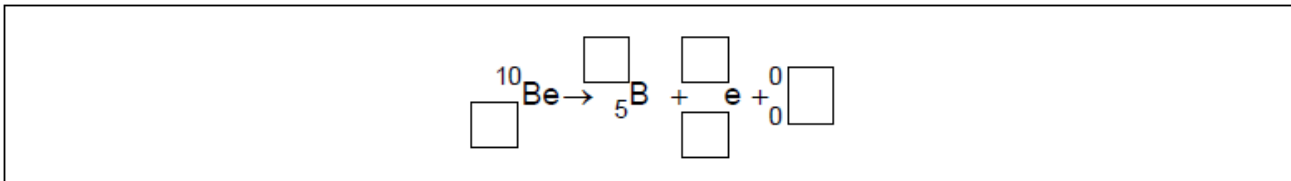The initial number of nuclei in a pure sample of beryllium-10 is N_0. The graph shows how the number of remaining **beryllium** nuclei in the sample varies with time.
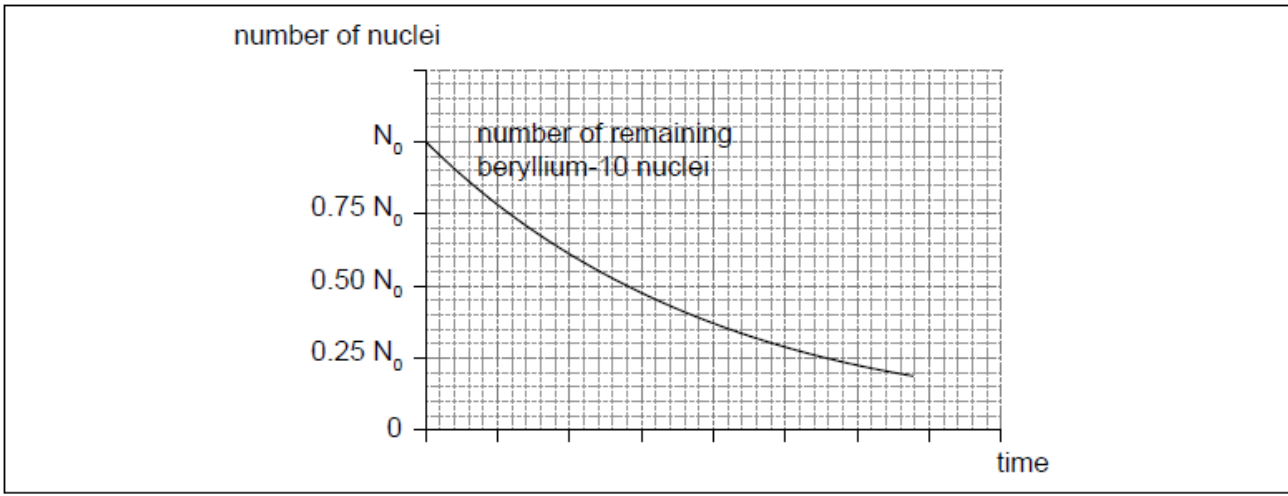
An ice sample is moved to a laboratory for analysis. The temperature of the sample is –20 °C.

a. Identify the missing information for this decay.   [2]

$$^{10}_{\square}\text{Be} \rightarrow\ ^{\square}_{5}\text{B}\ +\ ^{\square}_{\square}\text{e} +\ ^{0}_{0}\square$$

b.iiiBeryllium-10 is used to investigate ice samples from Antarctica. A sample of ice initially contains 7.6×10^{11} atoms of beryllium-10. The present   [3]

activity of the sample is 8.0×10^{-3} Bq.

Determine, in years, the age of the sample.

c.ivThe temperature in the laboratory is higher than the temperature of the ice sample. Describe **one** other energy transfer that occurs between the   [2]

ice sample and the laboratory.

Photoelectric effect and de Broglie wavelength

The diagram is a representation of apparatus used to study the photoelectric effect.
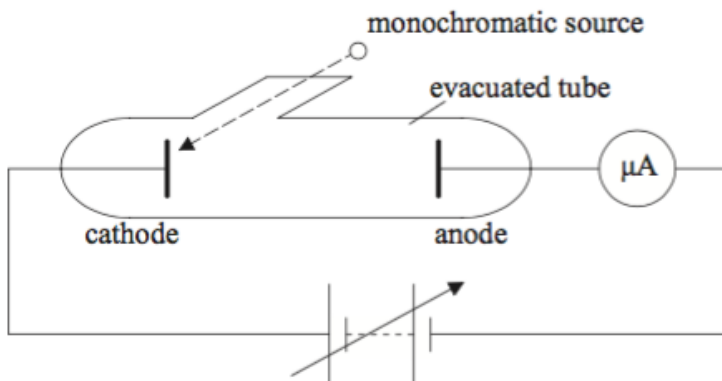
Light from the monochromatic source is incident on a cathode placed in an evacuated tube. A variable voltage supply is connected between anode and cathode and the photoelectric current is registered by the microammeter. The sketch graph shows how the photoelectric current *I* varies with the potential difference *V* between anode and cathode for two sources of light, A and B, of different frequencies and intensities.
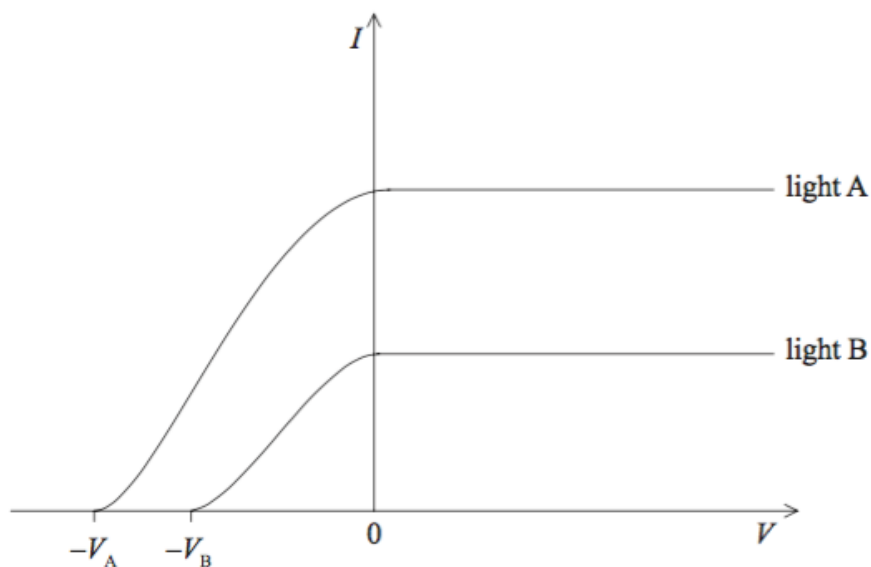

a. Explain with reference to the Einstein model, which graph, A or B, corresponds to the light with the greater frequency. [4]

b. The frequency of the light that produces graph A is 8.8×10^{14}Hz. The magnitude of V_A is 1.6V. [3]

(i) State the value of the maximum energy, in eV, of the electrons emitted from the cathode.

(ii) Determine the work function, in eV, of the surface of the cathode.

c. The frequency of the incident light is increased but the intensity remains constant. Explain why this increase in frequency results in a change to the maximum photoelectric current (saturation current). [3]

d. The electrons emitted from the photo-cathode have an associated de Broglie wavelength. Describe what is meant by the de Broglie wavelength. [2]

This question is in two parts. **Part 1** is about thermal properties of matter. **Part 2** is about quantum physics.

Part 1 Thermal properties of matter

Part 2 Quantum physics

The diagram shows the end of an electron diffraction tube.

thin graphite screen

electron gun

diffraction pattern

central bright spot
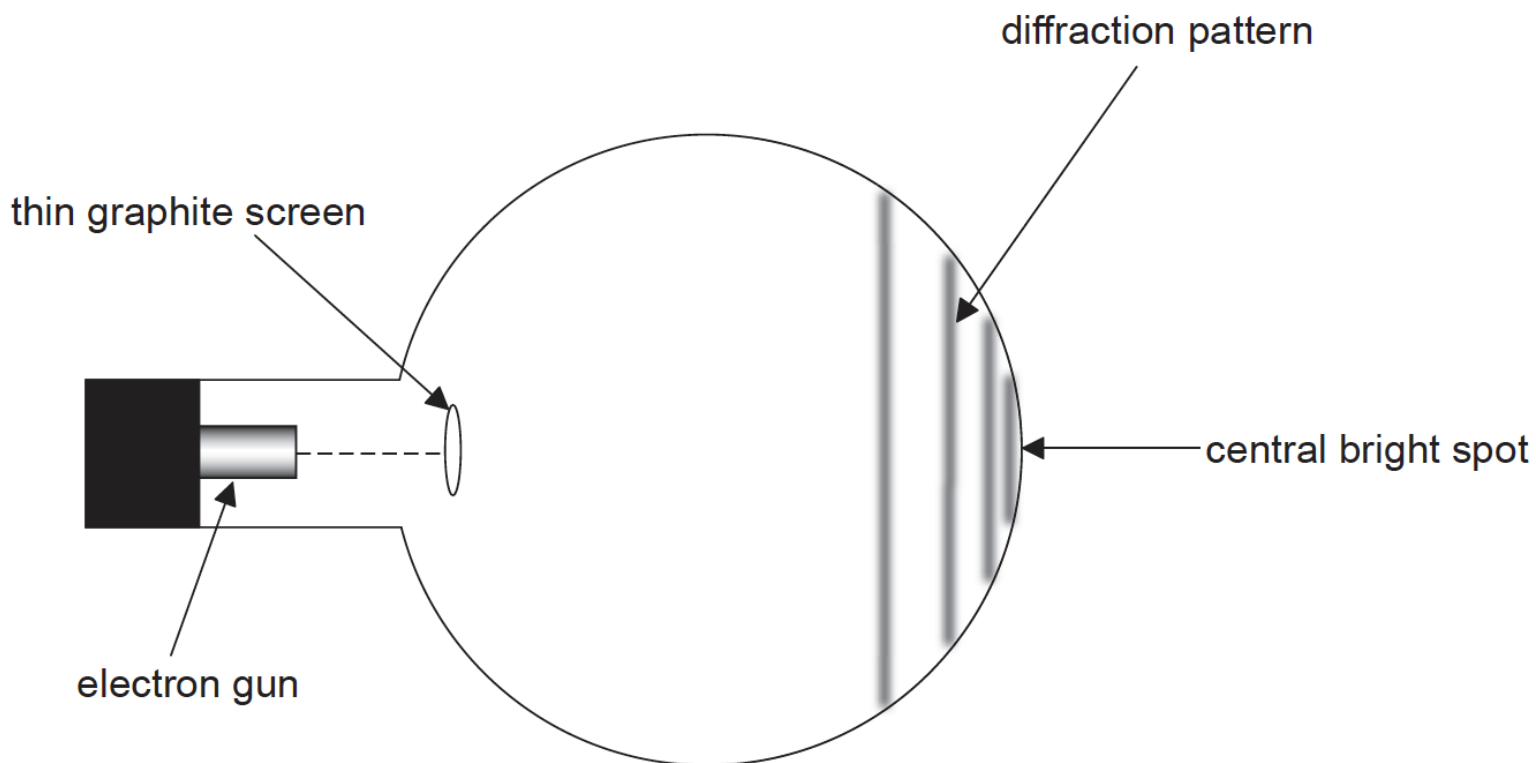
A pattern forms when diffracted electrons are incident on a fluorescent layer at the end of the tube.

b. Three ice cubes at a temperature of 0°C are dropped into a container of water at a temperature of 22°C. The mass of each ice cube is 25 g and [8] the mass of the water is 330 g. The ice melts, so that the temperature of the water decreases. The thermal capacity of the container is negligible.

(i) The following data are available.

Specific latent heat of fusion of ice = 3.3×10^5 J kg^{-1}
Specific heat capacity of water = 4.2×10^3 J kg^{-1} K^{-1}

Calculate the final temperature of the water when all of the ice has melted. Assume that no thermal energy is exchanged between the water and the surroundings.

(ii) Explain how the first law of thermodynamics applies to the water when the ice cubes are dropped into it.

c. Explain how the pattern demonstrates that electrons have wave properties. [3]

d. Electrons are accelerated to a speed of 3.6×10^7 ms^{-1} by the electric field. [5]

(i) Calculate the de Broglie wavelength of the electrons.

(ii) The cathode and anode are 22 mm apart and the field is uniform.
The potential difference between the cathode and the anode is 3.7 kV.
Show that the acceleration of the electrons is approximately 3×10^{16} ms^{-2}.

e. State what can be deduced about an electron from the amplitude of its associated wavefunction. [2]

f. An electron reaching the central bright spot on the fluorescent screen has a small uncertainty in its position. Outline what the Heisenberg [2] uncertainty principle is able to predict about another property of this electron.

This question is in **two** parts. **Part 1** is about photoelectricity. **Part 2** is about electrical and magnetic force fields.

Part 1 Photoelectricity

a. State what is meant by work function.   [1]

b. The diagram shows part of an experimental arrangement used to investigate the photoelectric effect.   [4]
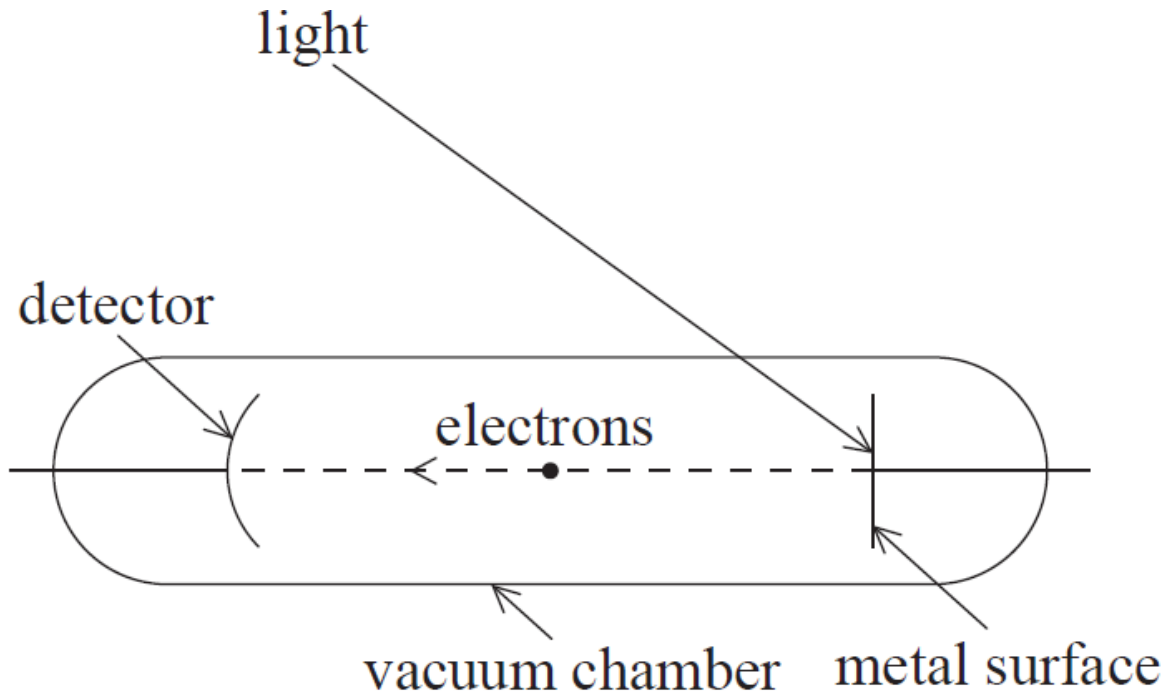
(i) Explain how the maximum kinetic energy of the emitted electrons is determined experimentally.

(ii) On the diagram, draw the power supply and other necessary components needed in order to carry out the experiment in (b)(i).

c. Using results obtained with the apparatus in (b), the following graph was drawn. The graph shows how the maximum kinetic energy of the   [3]

photoelectrons varies with the frequency of the incident radiation.
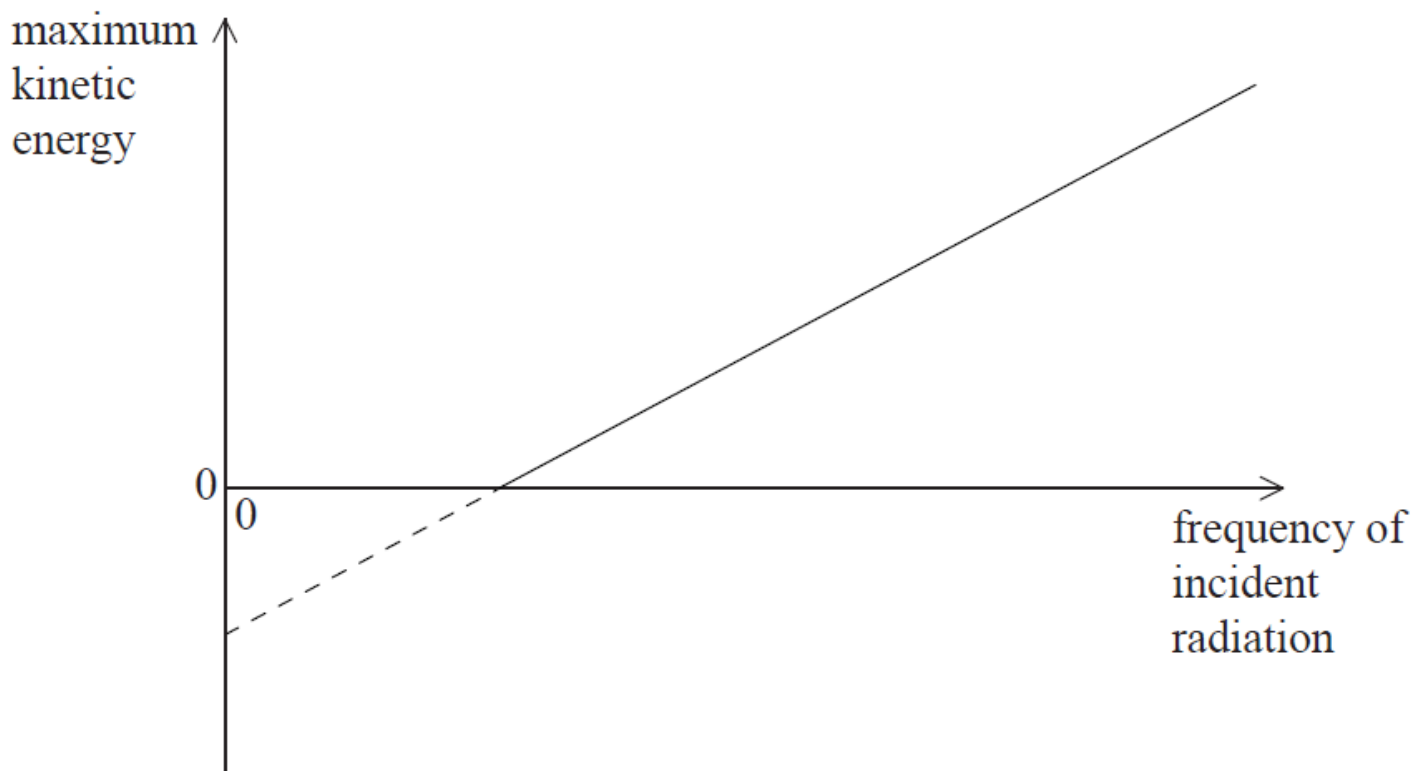
State how the graph can be used to determine

(i) a value for the Planck constant.

(ii) the work function of the material.

(iii) the threshold wavelength of the material.

d. In an experiment, light at a particular frequency is incident on a surface and electrons are emitted. Explain what happens to the number of [2]

electrons emitted per second when the intensity of this light is increased.

Part 2 Radioactivity

Radium-224 $\left(^{224}_{88}\mathrm{RA}\right)$ is a radioactive nuclide that decays to form radon-220. Radon-220 is itself radioactive and undergoes a further decay. The table shows the series of radioactive nuclides that are formed as the decays proceed. The series ends with a stable isotope of lead.

Parent nuclide	Emitter	Half-life	Daughter nuclide(s)
radium-224	alpha	3.64 days	radon-220 (Rn)
radon-220	alpha	55 seconds	polonium-216 (Po)
polonium-216	alpha	0.15 seconds	lead-212 (Pb)
lead-212	beta	10.6 hours	bismuth-212 (Bi)
bismuth-212	beta alpha	60.6 minutes	polonium-212 thallium (Tl)
polonium-212	alpha	3.0×10^{-7} seconds	lead-208 (stable)
thallium	beta	3.1 minutes	lead-208 (stable)

f. For the final thallium nuclide, identify the   [2]

(i) nucleon number.

(ii) proton number.

g. Radon-220 is a radioactive gas. It is released by rocks such as granite. In some parts of the world, houses are built from materials containing   [2]

granite. Explain why it is unlikely that radon-220 will build up in sufficient quantity to be harmful in these houses.

h. (i) Calculate, in hour^{-1}, the decay constant of lead-212.   [6]

(ii) In a pure sample of lead-212 at one instant, 8.0 × 10^{-3} kg of the lead-212 is present. Calculate the mass of lead-212 that remains after a period of 35 hours.

(iii) A sample of pure radium begins to decay by the series shown in the table. At one instant, a mass of 8.0 × 10^{-3} kg of lead-212 is present in the sample. Suggest why, after 35 hours, there will be a greater mass of lead-212 present in the sample than the value you calculated in (h)(ii).


This question is in two parts. **Part 1** is about current electricity. **Part 2** is about atoms.

Part 1 Current electricity

Part 2 Atoms

a. A 24Ω resistor is made from a conducting wire.   [8]

(i) The diameter of the wire is 0.30 mm and the wire has a resistivity of 1.7 × 10^{-8} Ω m. Calculate the length of the wire.

(ii) A potential difference of 12V is applied between the ends of the wire. Calculate the acceleration of a free electron in the wire.

(iii) Suggest why the average speed of the free electron does not keep increasing even though it is being accelerated.

b. An electric circuit consists of a supply connected to a 24Ω resistor in parallel with a variable resistor of resistance R. The supply has an emf of [7] 12V and an internal resistance of 11Ω.


12V, 11Ω
V
24Ω
R
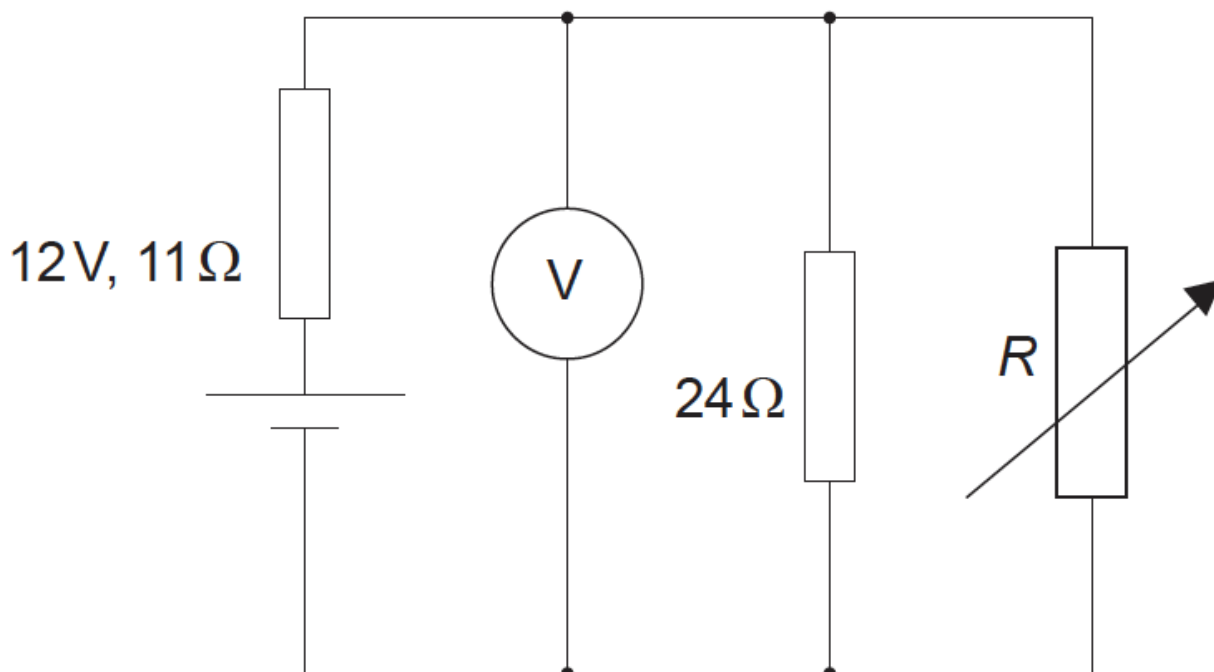
Power supplies deliver maximum power to an external circuit when the resistance of the external circuit equals the internal resistance of the power supply.

(i) Determine the value of R for this circuit at which maximum power is delivered to the external circuit.

(ii) Calculate the reading on the voltmeter for the value of R you determined in (b)(i).

(iii) Calculate the power dissipated in the 24Ω resistor when the maximum power is being delivered to the external circuit.

c. State what is meant by the wavefunction of an electron. [1]

d. An electron is confined in a length of 2.0×10^{-10} m. [9]

(i) Determine the uncertainty in the momentum of the electron.

(ii) The electron has a momentum of 2.0×10^{-23}Ns. Determine the de Broglie wavelength of the electron.

(iii) On the axes, sketch the variation of the wavefunction Ψ of the electron in (d)(ii) with distance x. You may assume that $\Psi = 0$ when $x = 0$.

Ψ

0

0   2 x / 10^{-10} m
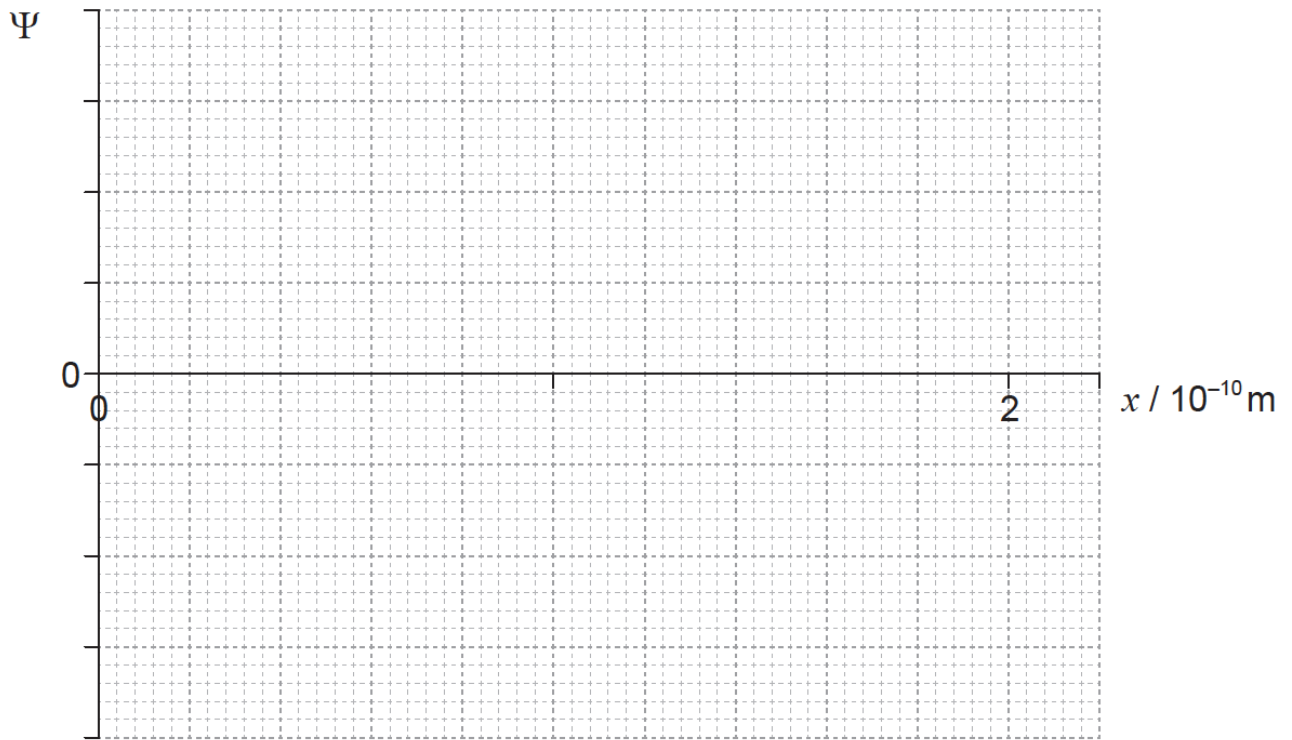
(iv) Identify the feature of your graph in (d)(iii) that gives the probability of finding the electron at a particular position and at a particular time.