T12-1 *[228 marks]*

1. Photoelectrons are emitted at a certain rate when monochromatic light is incident on a metal surface. Light of the same intensity but of higher frequency is now used. After this change, the rate of emission of electrons from the surface is *[1 mark]*

A. zero.

B. lower.

C. the same.

D. higher.

2. Which phenomenon provides evidence for the wave nature of an electron? *[1 mark]*

A. Line spectra of atoms

B. Photoelectric effect

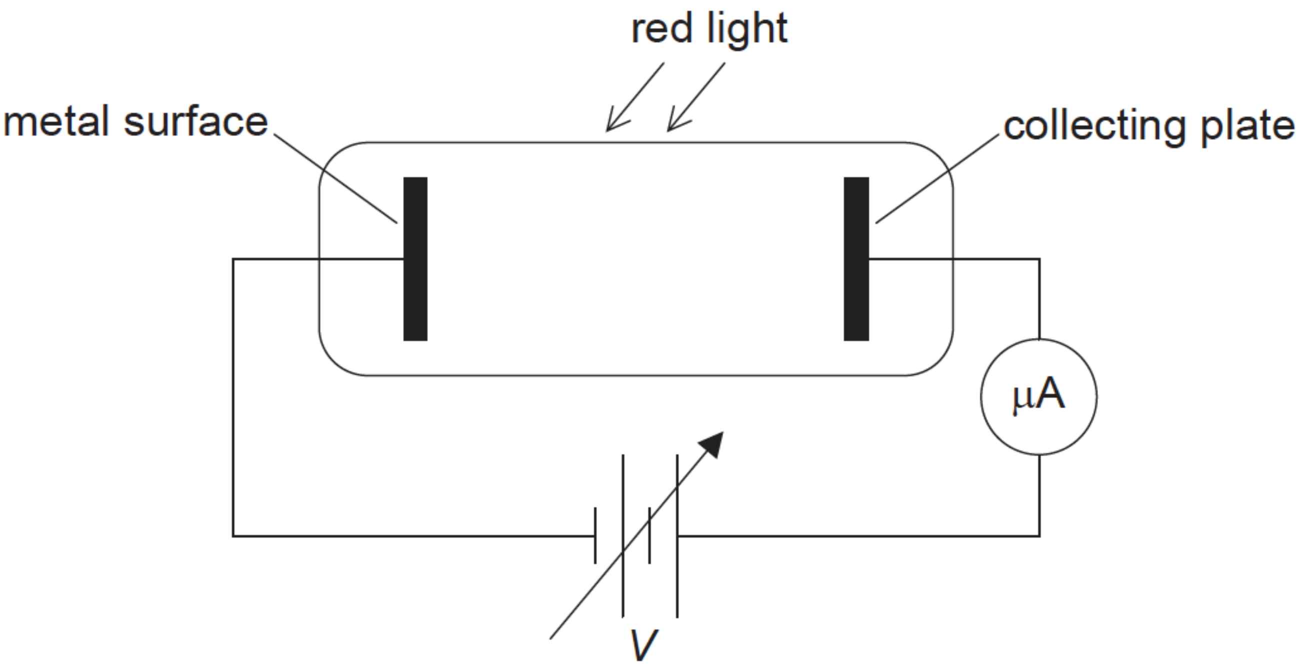
C. Beta decay of nuclei

D. Scattering of electrons by a crystal

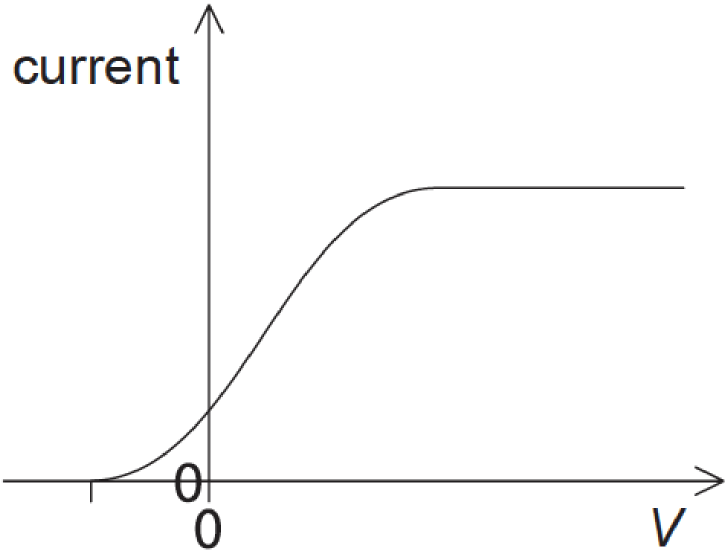
3. A particular radioactive substance decays and emits both β^+ particles and neutrinos. Which describes the nature of the energy spectrum of the β^+ particles and the nature of the energy spectrum of the neutrinos? *[1 mark]*

	Energy spectrum of β^+ particles	Energy spectrum of neutrinos
A.	discrete	discrete
B.	discrete	continuous
C.	continuous	discrete
D.	continuous	continuous

4. Red light incident on a metal surface produces photoelectrons. *[1 mark]*



The potential *V* of the supply is varied and the current is measured. The results are shown on the graph.



The light source is changed to blue. This blue source emits the same number of photons per second as the red source. Which graph shows the variation with potential of current for blue light? The results for the red light are shown as a dashed line.

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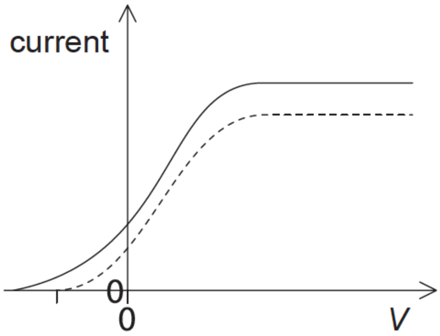

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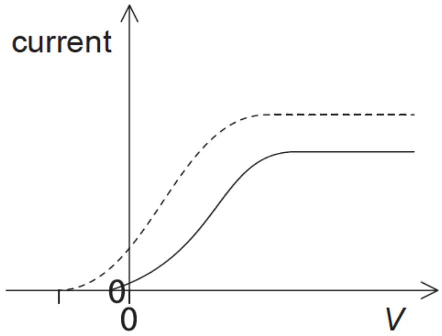

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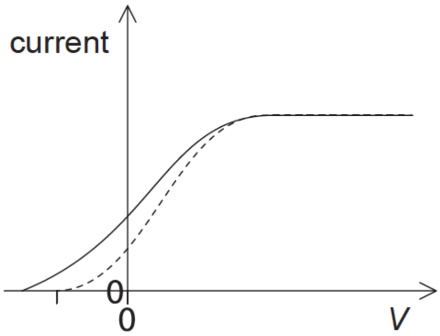
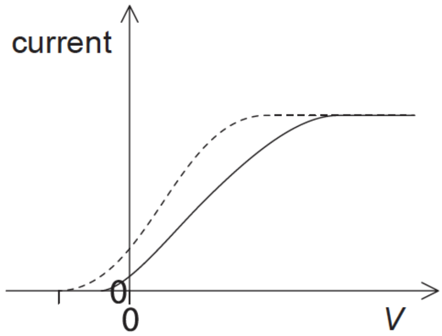


D.



5. The following observations are made during nuclear decays. *[1 mark]*

I. Discrete energy of alpha particles

II. Continuous energy of beta particles

III. Discrete energy of gamma rays

Which of the observations provide evidence of the existence of nuclear energy levels?

A. I only

B. II only

C. I and III only

D. I, II and III

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

6a. Three ice cubes at a temperature of 0ºC are dropped into a container of water at a temperature of 22ºC. The mass of each ice cube is 25 g and 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. *[8 marks]*

(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.

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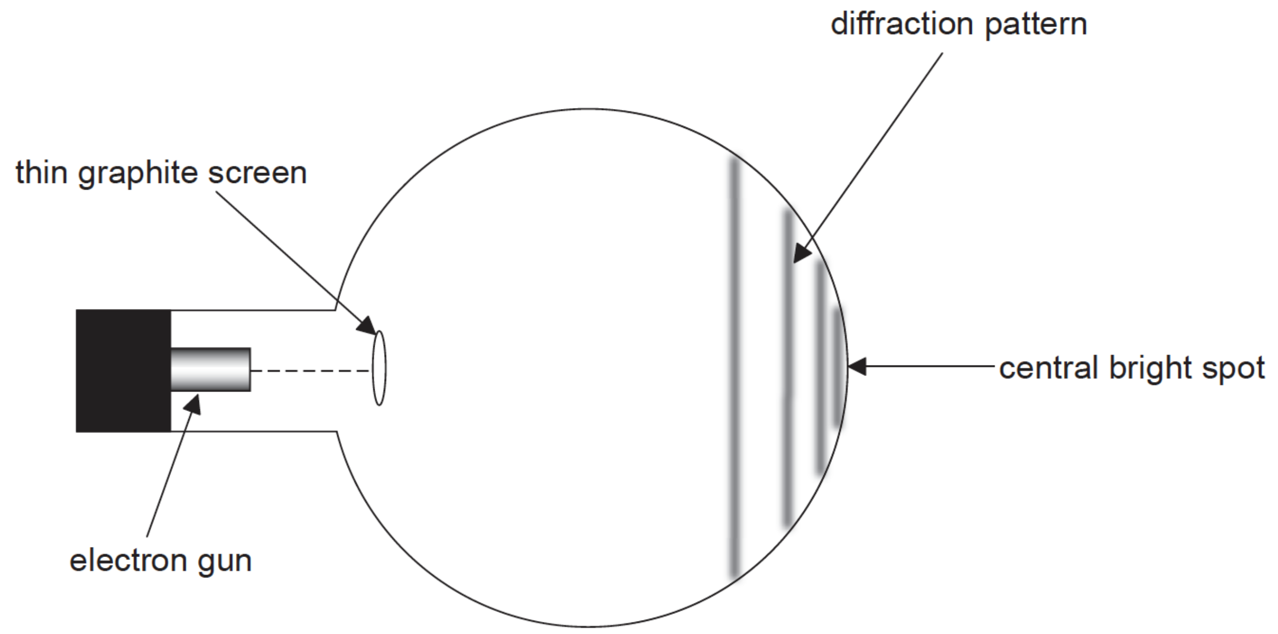
Part 2 Quantum physics

The diagram shows the end of an electron diffraction tube.



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

6b. Explain how the pattern demonstrates that electrons have wave properties. *[3 marks]*

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6c. Electrons are accelerated to a speed of 3.6×10^{7} ms^{-1} by the electric field. *[5 marks]*

(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 $3\times10^{16}ms^{-2}$.

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6d. State what can be deduced about an electron from the amplitude of its associated wavefunction. *[2 marks]*

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6e. An electron reaching the central bright spot on the fluorescent screen has a small uncertainty in its position. *[2 marks]*
Outline what the Heisenberg uncertainty principle is able to predict about another property of this electron.

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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)

7a. For the final thallium nuclide, identify the *[2 marks]*

(i) nucleon number.

(ii) proton number.

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7b. 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 granite. Explain why it is unlikely that radon-220 will build up in sufficient quantity to be harmful in these houses. *[2 marks]*

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7c. (i) Calculate, in hour^{-1}, the decay constant of lead-212. *[6 marks]*

(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).

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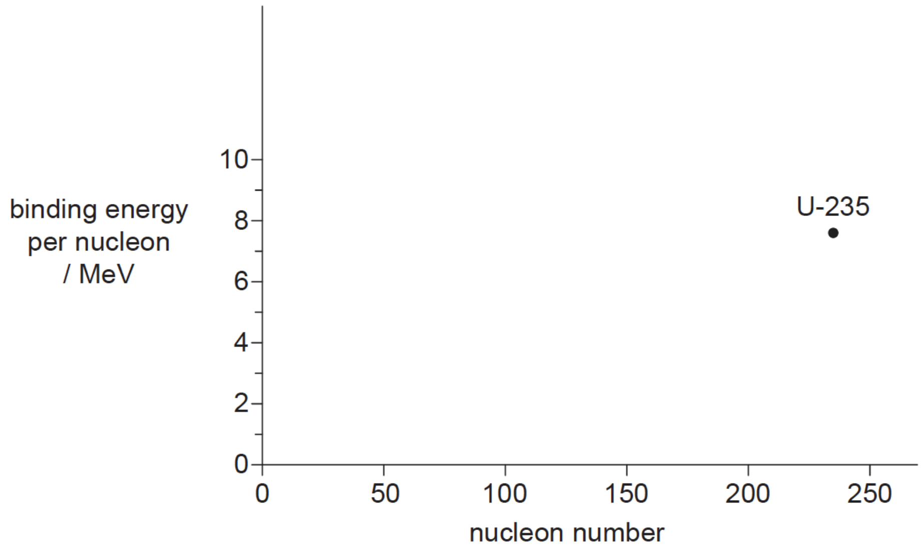
Part 2 Nuclear energy and radioactivity

The graph shows the variation of binding energy per nucleon with nucleon number. The position for uranium-235 (U-235) is shown.



8. U-235 $\left({}^{235}_{92}\mathrm{U}\right)$ can undergo alpha decay to form an isotope of thorium (Th). *[4 marks]*

(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.

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

Part 1 Current electricity

9a. A 24Ω resistor is made from a conducting wire. *[8 marks]*

(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.

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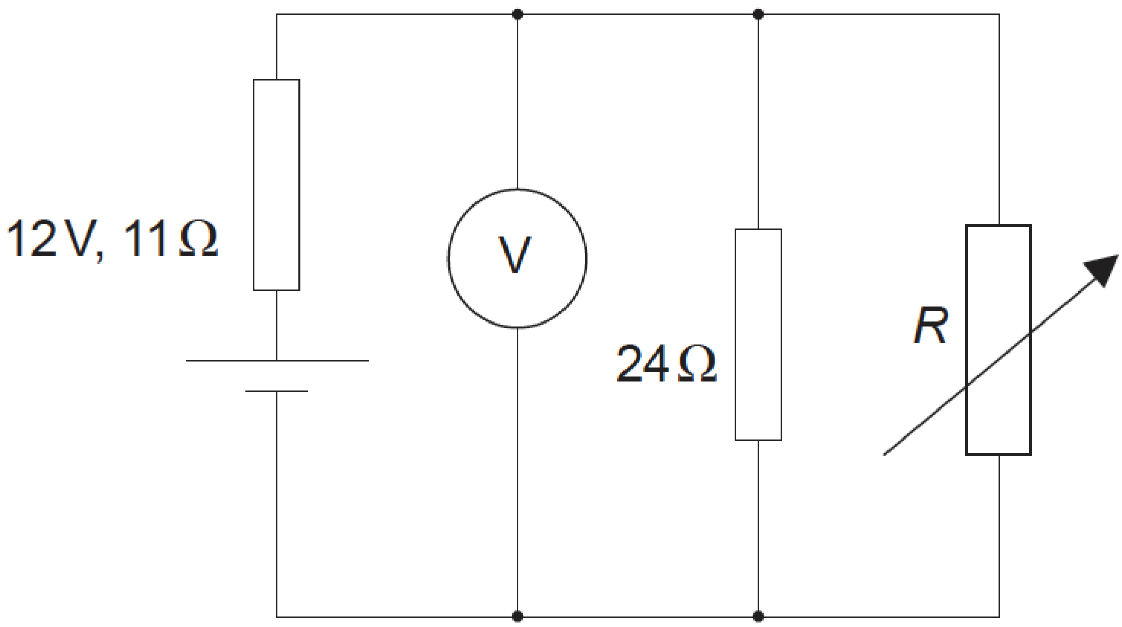
9b. An electric circuit consists of a supply connected to a 24Ω resistor in parallel with a variable resistor of resistance *R*. The supply has an emf of 12V and an internal resistance of 11Ω. *[7 marks]*



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.

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Part 2 Atoms

9c. State what is meant by the wavefunction of an electron. *[1 mark]*

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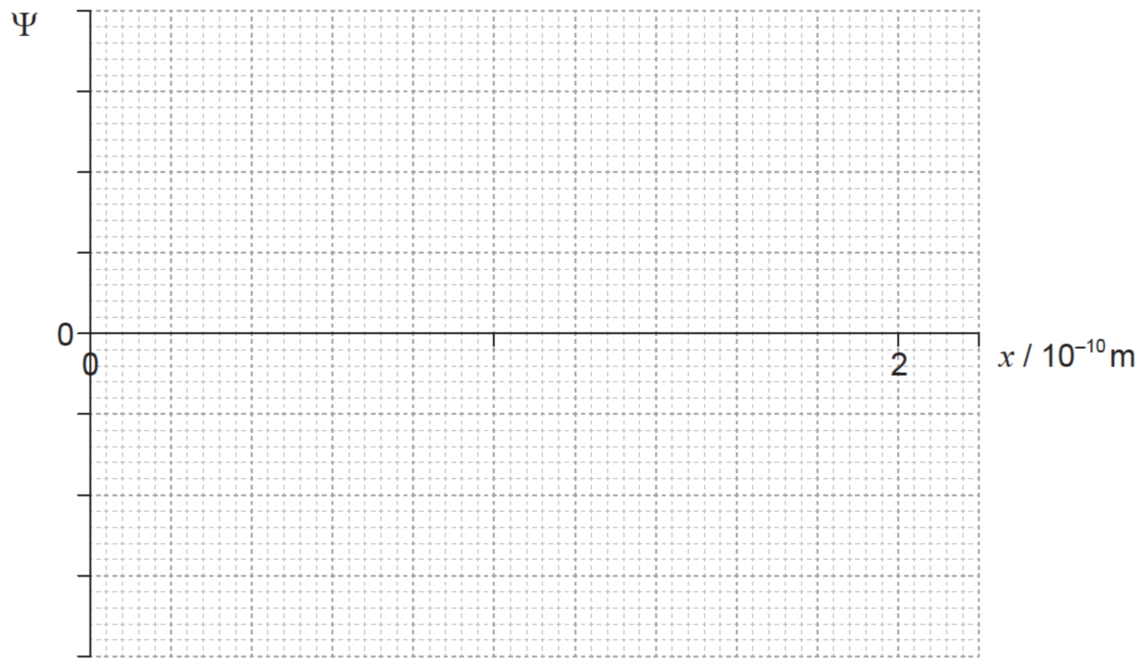
9d. An electron is confined in a length of 2.0×10^{-10} m. *[9 marks]*

(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 $x = 0$.



(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.

This question is about the photoelectric effect and the de Broglie hypothesis.

When photons are incident on a lithium surface photoelectrons are emitted. The work function φ of lithium is 2.9 eV.

10a. Define *work function.* *[1 mark]*

10b. Determine the maximum wavelength of the photons that can cause photoemission. *[2 marks]*

10c. Calculate the momentum of an electron that has the same de Broglie wavelength as the wavelength of the photons in (b). *[2 marks]*

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This question is about radioactive decay.

A nucleus of magnesium-23 decays forming a nucleus of sodium-23 with the emission of an electron neutrino and a β^+ particle.

11a. Outline why the existence of neutrinos was hypothesized to account for the energy spectrum of beta decay. *[3 marks]*

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11b. The decay constant for magnesium-23 is 0.061 s^{-1}. Calculate the time taken for the number of magnesium-23 nuclei to fall to 12.5% of its initial value. *[2 marks]*

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This question is about the photoelectric effect.

In a photoelectric experiment, light of wavelength 450 nm is incident on a sodium surface. The work function for sodium is 2.4 eV.

12a. (i) Calculate, in eV, the maximum kinetic energy of the emitted electrons. *[5 marks]*

(ii) The number of electrons leaving the sodium surface per second is 2×10^{15}. Calculate the current leaving the sodium surface.

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12b. The wavelength of the light incident on the sodium surface is decreased without changing its intensity. Explain why the number of electrons emitted from the sodium will decrease. *[4 marks]*

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This question is about radioactive decay.

Nuclide X has a half-life that is estimated to be in the thousands of years.

13a. Outline how the half-life of X can be determined experimentally. *[4 marks]*

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13b. A pure sample of X has a mass of 1.8 kg. The half-life of X is 9000 years. Determine the mass of X remaining after 25000 years. *[3 marks]*

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14. In the “electron in a box” model, an electron is confined to move along a line of length *L*. What is the smallest possible value of the momentum of the electron? *[1 mark]*

A. 0

B. $\frac{h}{2L}$

C. $\frac{h}{L}$

D. $\frac{3h}{2L}$

15. Light that is shone onto a metal surface may result in the emission of electrons from the surface. Three statements regarding the emission of the electrons are the *[1 mark]*

I. number of electrons emitted per unit time depends on the intensity of the incident light
II. energy of the electrons depends on the frequency of the incident light
III. emission of the electrons takes place instantaneously.

Which of the above statements can **only** be explained by assuming light consists of photons?

A. II only

B. III only

C. II and III only

D. I, II and III

16. An electron X is accelerated from rest through a potential difference V. Another electron Y is accelerated from rest through a potential difference $2V$. After acceleration, the de Broglie wavelength of X is λ_X and that of Y is λ_Y. The speeds reached by the electrons are well below that of the speed of light. *[1 mark]*

What is the ratio $\frac{\lambda_X}{\lambda_Y}$?

A. 2

B. $\sqrt{2}$

C. $\frac{1}{2}$

D. $\frac{1}{\sqrt{2}}$

17. If there is no uncertainty in the value of the de Broglie wavelength of a particle then this means that *[1 mark]*

A. both the momentum and position of the particle are known precisely.

B. the position of the particle is known precisely but all knowledge of its momentum is lost.

C. both the energy and the position of the particle are known precisely.

D. only the momentum of the particle is known precisely but all knowledge of its position is lost.

18. Three types of radiation emitted from radioactive materials are given below. *[1 mark]*

I. Alpha
II. Beta
III. Gamma

Which type(s) of radiation has/have a discrete energy when emitted from radioactive materials?

A. I only
B. I and III only
C. I and II only
D. I, II and III

19. Which of the following is correct for the de Broglie wavelength λ of a particle when the kinetic energy of the particle is E_K? *[1 mark]*

A. $\lambda \propto \frac{1}{E_K}$

B. $\lambda \propto \frac{1}{\sqrt{E_K}}$

C. $\lambda \propto E_K$

D. $\lambda \propto {E_K}^2$

20. According to the Heisenberg uncertainty principle, conjugate quantities are pairs of quantities that cannot be known precisely for the same object at the same time. What is the unit when two conjugate quantities are multiplied together? *[1 mark]*

A. kg $m^2 s^{-1}$

B. $kg^2 m\ s^{-1}$

C. kg $m^2 s$

D. kg $m^2 s^{-2}$

21. Three phenomena associated with nuclear and quantum physics are *[1 mark]*

I. Einstein photoelectric effect
II. de Broglie hypothesis
III. Rutherford alpha particle scattering.

Which of the phenomena can be verified by firing electrons at a metal surface?

A. I only
B. II only
C. I and III only
D. II and III only

22. A radioactive nuclide decays to a stable daughter nuclide. Initially the sample consists entirely of atoms of the radioactive nuclide. What fraction of the sample consists of the daughter nuclide after four half-lives? *[1 mark]*

A. $\frac{15}{16}$

B. $\frac{1}{16}$

C. $\frac{1}{8}$

D. $\frac{7}{8}$

This question is in **two** parts. **Part 1** is about nuclear reactions. **Part 2** is about thermal energy transfer.

Part 1 Nuclear reactions

23a. (i) Define the term *unified atomic mass unit.* *[2 marks]*

(ii) The mass of a nucleus of einsteinium-255 is 255.09 u. Calculate the mass in $MeVc^{-2}$.

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23b. When particle X collides with a stationary nucleus of calcium-40 (Ca-40), a nucleus of potassium (K-40) and a proton are produced. *[6 marks]*

$$^{40}_{20}\text{Ca} + \text{X} \rightarrow {}^{40}_{19}\text{K} + {}^{1}_{1}\text{p}$$

The following data are available for the reaction.

Particle	Rest mass / MeV c^{-2}
calcium-40	37 214.694
X	939.565
potassium-40	37 216.560
proton	938.272

(i) Identify particle X.

(ii) Suggest why this reaction can only occur if the initial kinetic energy of particle X is greater than a minimum value.

(iii) Before the reaction occurs, particle X has kinetic energy 8.326 MeV. Determine the total combined kinetic energy of the potassium nucleus and the proton.

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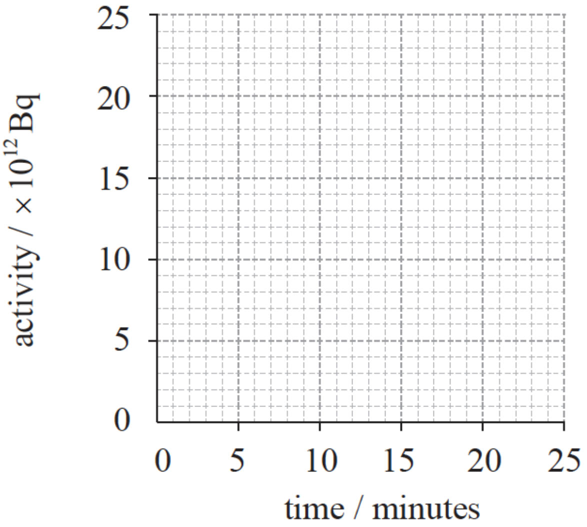
23c. Potassium-38 decays with a half-life of eight minutes. *[5 marks]*

(i) Define the term *radioactive half-life*.

(ii) A sample of potassium-38 has an initial activity of 24×10^{12}Bq. On the axes below, draw a graph to show the variation with time of the activity of the sample.



(iii) Determine the activity of the sample after 2 hours.

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Part 2 Thermal energy transfer

23d. (i) Define the *specific latent heat* of fusion of a substance. *[5 marks]*

(ii) Explain, in terms of the molecular model of matter, the relative magnitudes of the specific latent heat of vaporization of water and the specific latent heat of fusion of water.

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23e. A piece of ice is placed into a beaker of water and melts completely. *[5 marks]*

The following data are available.

Initial mass of ice = 0.020 kg
Initial mass of water = 0.25 kg
Initial temperature of ice = 0°C
Initial temperature of water = 80°C
Specific latent heat of fusion of ice = 3.3×10^{5} J kg^{-1}
Specific heat capacity of water = 4200 J $kg^{-1}K^{-1}$

(i) Determine the final temperature of the water.

(ii) State **two** assumptions that you made in your answer to part (f)(i).

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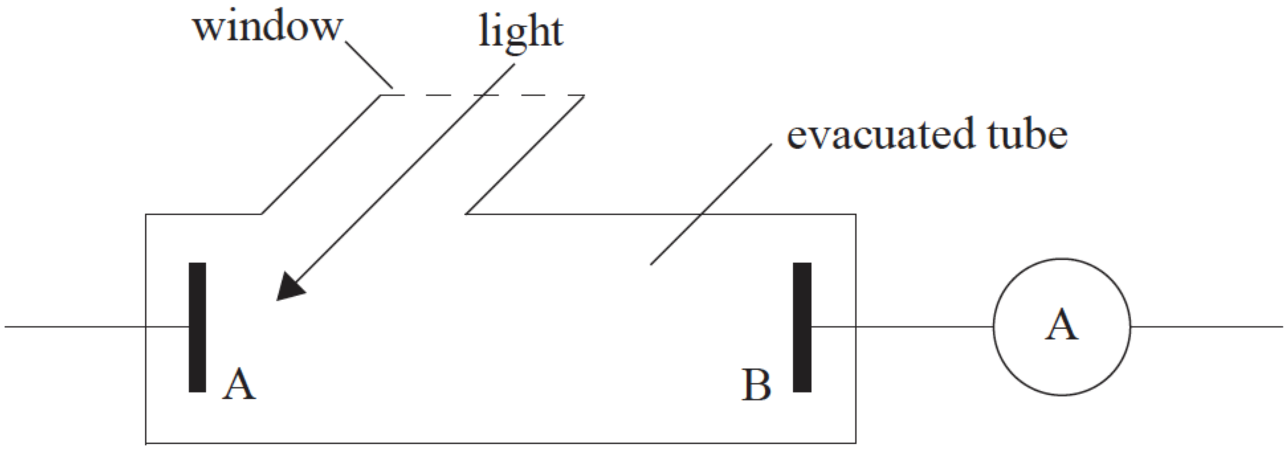
Part 3 The photoelectric effect and the Heisenberg uncertainty principle

24a. Light is incident on a metal surface A. A potential difference is applied between A and an electrode B. *[6 marks]*
Photoelectrons arrive at B and the 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.

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24b. 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 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. *[5 marks]*

Calculate the

(i) momentum of the electron.

(ii) uncertainty in the momentum of the electron.

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This question is about quantum physics.

25a. Describe the de Broglie hypothesis. *[2 marks]*

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25b. The momentum of the electron is known precisely. Deduce that all the information on its position is lost. *[2 marks]*

25c. With reference to Schrödinger's model, state the meaning of the amplitude of the wavefunction for the electron. *[1 mark]*

This question is about nuclear physics and radioactive decay.

26a. Define *decay constant.* *[1 mark]*

26b. A sample of 1.6 mol of the radioactive nuclide radon-210 $\left({}^{210}_{86}\mathrm{Rn}\right)$ decays into polonium-206 $\left({}^{206}_{84}\mathrm{Po}\right)$ with the production of one other particle. *[5 marks]*

$$^{210}_{86}\mathrm{Rn} \rightarrow {}^{206}_{84}\mathrm{Po} + \mathrm{X}$$

(i) Identify particle X.
(ii) The radioactive decay constant of radon-210 is $8.0\times10^{-5}\,\mathrm{s}^{-1}$. Determine the time required to produce 1.1 mol of polonium-206.

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26c. Particle X has an initial kinetic energy of 6.2MeV after the decay in (b). In a scattering experiment, particle X is aimed head-on at a stationary gold-197 $\left({}^{197}_{76}\mathrm{Au}\right)$ nucleus. *[3 marks]*

Determine the distance of closest approach of particle X to the Au nucleus.

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27. According to the Heisenberg uncertainty principle the quantity paired with momentum is *[1 mark]*

A. time.
B. energy.
C. position.
D. mass.

28. Photons are incident on a metal surface. Electrons are emitted from the surface. What single change may result in **no** electrons being emitted from the surface? *[1 mark]*

A. Doubling the wavelength of the photons
B. Halving the wavelength of the photons
C. Doubling the number of photons incident on the surface per second
D. Halving the number of photons incident on the surface per second

29. Evidence for nuclear energy levels comes from discrete energies of *[1 mark]*

I. alpha particles
II. beta particles
III. gamma ray photons.

Which of the above statements is/are **true**?

A. I and II only
B. I and III only
C. II only
D. III only

30. Which particles are emitted in β+ decay? *[1 mark]*

A. Positron and neutrino
B. Positron and antineutrino
C. Electron and neutrino
D. Electron and antineutrino

31. When the cathode of a photoelectric cell is illuminated with red light, a photoelectric current is produced in the cell. The illumination is changed to blue light but the rate at which photons arrive at the cathode remains the same. Which of the following statements is/are correct under these conditions? *[1 mark]*

I. The number of electrons released is unchanged
II. The current falls to zero
III. The kinetic energy of the electron increases

A. I only
B. III only
C. I and II only
D. I and III only

32. In the Heisenberg uncertainty principle, conjugate quantities are pairs of quantities that cannot both be known precisely at the same instant. What unit is used for the product of the conjugate quantities? *[1 mark]*

A. kg m^2s^{-3}
B. kg m^2s^{-2}
C. kg m^2s^{-1}
D. kg m^2s

33. The decay constant is the probability of the *[1 mark]*

A. number of radioactive decays per unit time.
B. decay of a nucleus per unit time.
C. decay of a nucleus.
D. number of nuclei decaying in any given time.

34. An electron accelerated from rest through a potential difference *V* has de Broglie wavelength λ. What is the wavelength of an electron accelerated from rest through a potential difference of 2*V*? *[1 mark]*

A. 2λ

B. $\frac{\lambda}{2}$

C. $\sqrt{2\lambda}$

D. $\frac{\lambda}{\sqrt{2}}$

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35. A radioactive sample of initial activity 12.0Bq has a half-life of 3.0 days. Which of the following is the activity after 4.0 days? *[1 mark]*

A. 3.0 Bq
B. 3.8 Bq
C. 4.0 Bq
D. 4.8 Bq

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

Part 1 Photoelectricity

36a. State what is meant by work function. *[1 mark]*

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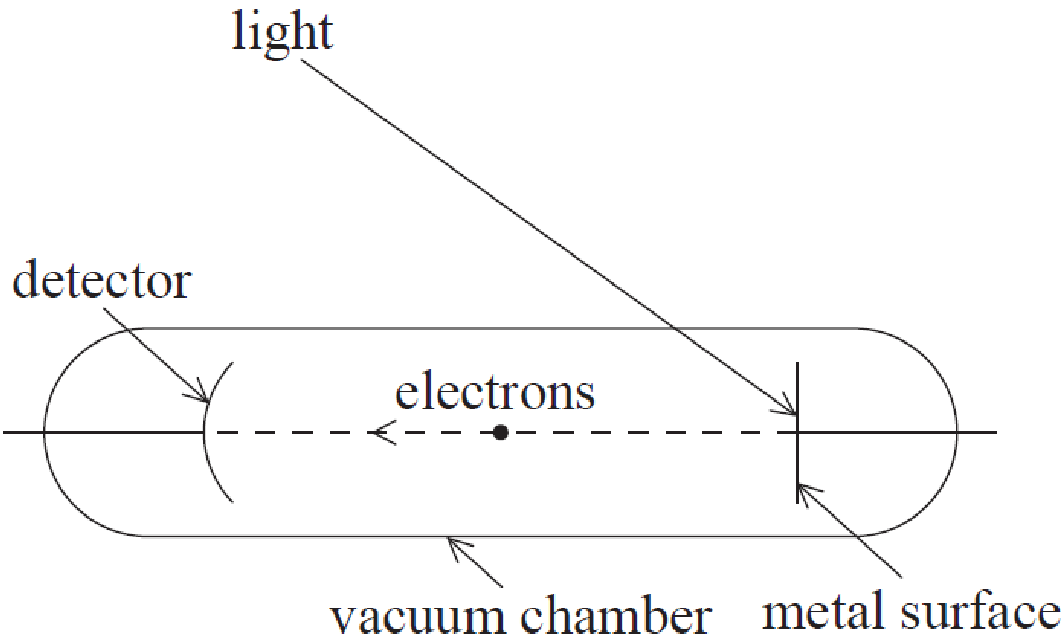
36b. The diagram shows part of an experimental arrangement used to investigate the photoelectric effect. *[4 marks]*



(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).

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36c. In an experiment, light at a particular frequency is incident on a surface and electrons are emitted. Explain what happens to the number of electrons emitted per second when the intensity of this light is increased. *[2 marks]*

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This question is about atomic energy levels.

37a. Explain how atomic spectra provide evidence for the quantization of energy in atoms. *[3 marks]*

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37b. Outline how the de Broglie hypothesis explains the existence of a **discrete** set of wavefunctions for electrons confined in a box of length L. *[3 marks]*

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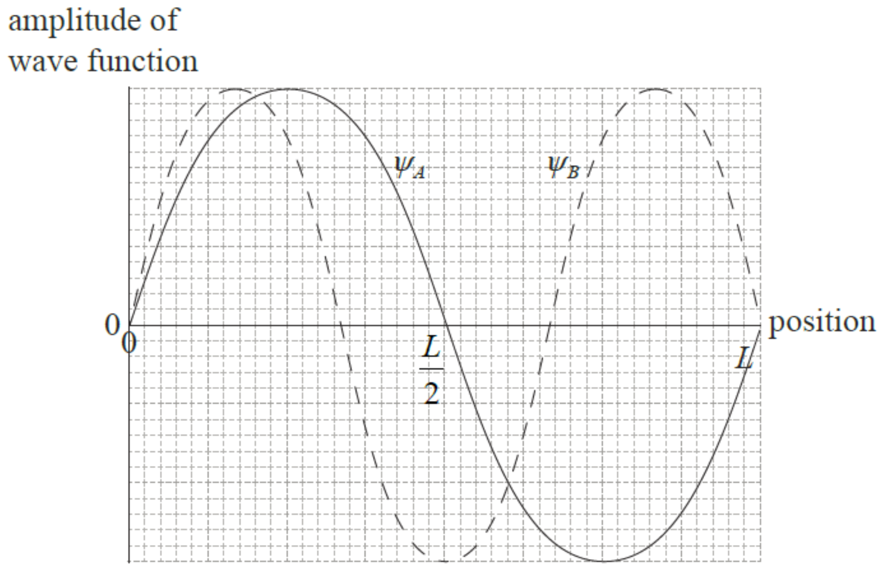
37c. The diagram below shows the shape of two allowed wavefunctions ψ_A and ψ_B for an electron confined in a one-dimensional box of length L. *[6 marks]*



(i) With reference to the de Broglie hypothesis, suggest which wavefunction corresponds to the larger electron energy.

(ii) Predict and explain which wavefunction indicates a larger probability of finding the electron near the position $\frac{L}{2}$ in the box.

(iii) On the graph in (c) on page 7, sketch a possible wavefunction for the **lowest** energy state of the electron.

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This question is about radioactive decay.

Sodium-22 undergoes β^+ decay.

38a. Identify the missing entries in the following nuclear reaction. *[3 marks]*

$$^{22}_{11}\mathrm{Na} \rightarrow {}^{22}_{\ldots}\mathrm{Ne} + {}^{0}_{\ldots}e + {}^{0}_{0}\ldots$$

38b. Define *half-life*. *[1 mark]*

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38c. Sodium-22 has a decay constant of 0.27 yr^{-1}. *[4 marks]*

(i) Calculate, in years, the half-life of sodium-22.

(ii) A sample of sodium-22 has initially 5.0×10^{23} atoms. Calculate the number of sodium-22 atoms remaining in the sample after 5.0 years.

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39. The decay constant of a radioactive isotope with half-life T is defined as *[1 mark]*

A. $\frac{T}{\ln 2}$.

B. the rate of decay of one nucleus of the isotope per second.

C. $T\ln 2$.

D. the probability of decay of one nucleus of the isotope per unit of time.

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

40a. A particle P moves with simple harmonic motion. *[3 marks]*

(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.

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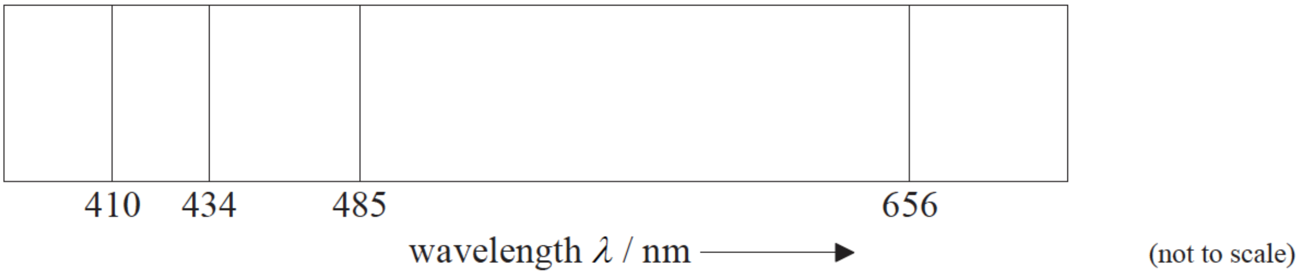
40b. The diagram shows four spectral lines in the visible line emission spectrum of atomic hydrogen. *[6 marks]*



(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.

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40c. The energies of the principal energy levels in atomic hydrogen measured in eV are given by the expression *[4 marks]*

$E_n = -\frac{13.6}{n^2}$ 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.

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40d. The alpha particles and gamma rays produced in radioactive decay have discrete energy spectra. This suggests that nuclei also possess 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. *[2 marks]*

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This question is about the photoelectric effect.

41a. Monochromatic light of different frequencies is incident on a metal surface placed in a vacuum. As the frequency is increased a value is reached at which electrons are emitted from the surface. Below this frequency, no matter how intense the light, no electrons are emitted. Outline how the *[6 marks]*

(i) wave theory of light is unable to account for these observations.

(ii) Einstein model of the photoelectric effect is able to account for these observations.

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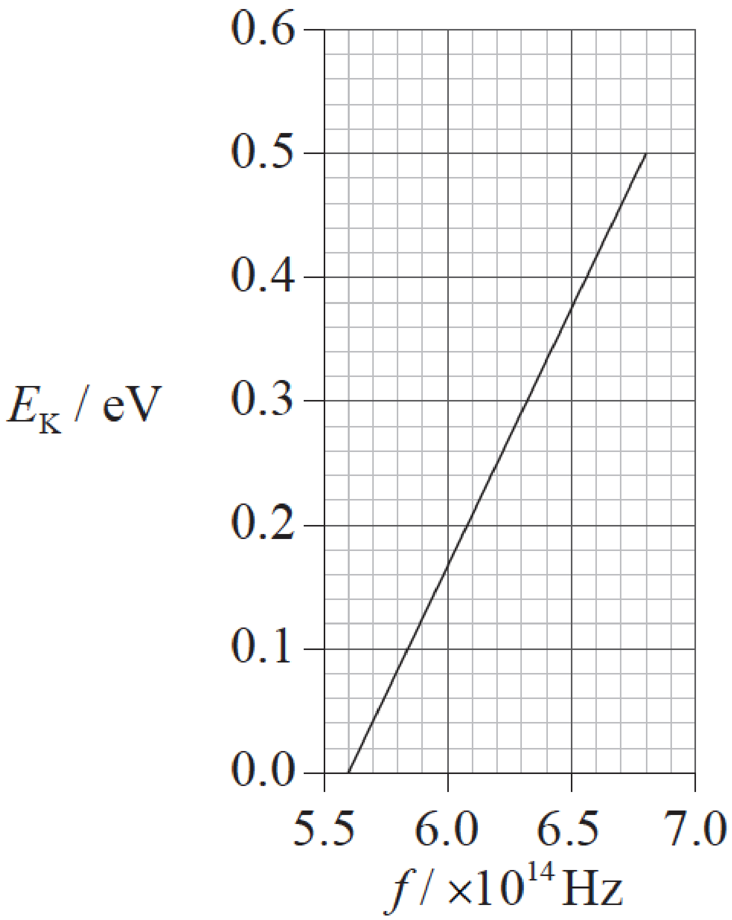
41b. The graph shows how the maximum kinetic energy E_K of the ejected electrons in (a) varies with the frequency f of the incident light. *[5 marks]*



Use the graph to determine the

(i) Planck constant.

(ii) work function of the metal.

41c. Show that electrons of energy 0.50 eV have a de Broglie wavelength of about 1.7×10^{-9}m. *[3 marks]*

This question is about radioactive decay.

42a. Potassium-40 (K-40) is a radioactive isotope that occurs naturally in many different types of rock. A very small percentage of the isotope undergoes β^{+} decay to form an isotope of argon (Ar). Construct and complete the nuclear reaction equation for this decay. *[2 marks]*

42b. Overall about 10% of a sample of K-40 will decay to argon. In a particular rock sample it is found that there are 1.6×10^{22} atoms of K-40 and 8.4×10^{21} atoms of argon. The half-life of K-40 is 1.2×10^{9} yr. Estimate the time elapsed since the rock sample was formed. *[4 marks]*

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This question is about radioactive decay.

Nitrogen-13 $\left({}^{13}_{7}\mathrm{N}\right)$ is an isotope that is used in medical diagnosis. The decay constant of nitrogen-13 is $1.2\times10^{-3}\,\mathrm{s}^{-1}$.

43a. (i) Define *decay constant*. *[3 marks]*

(ii) A sample of nitrogen-13 has an initial activity of 800 Bq. The sample cannot be used for diagnostic purposes if its activity becomes less than 150 Bq. Determine the time it takes for the activity of the sample to fall to 150 Bq.

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43b. (i) Calculate the half-life of nitrogen-13. *[4 marks]*

(ii) Outline how the half-life of a sample of nitrogen-13 can be measured in a laboratory.

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43c. Nitrogen-13 undergoes β+ decay. Outline the experimental evidence that suggests another particle, the neutrino, is also emitted in the decay. *[2 marks]*

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