Power Physics Pro 2021

Quantum Physics

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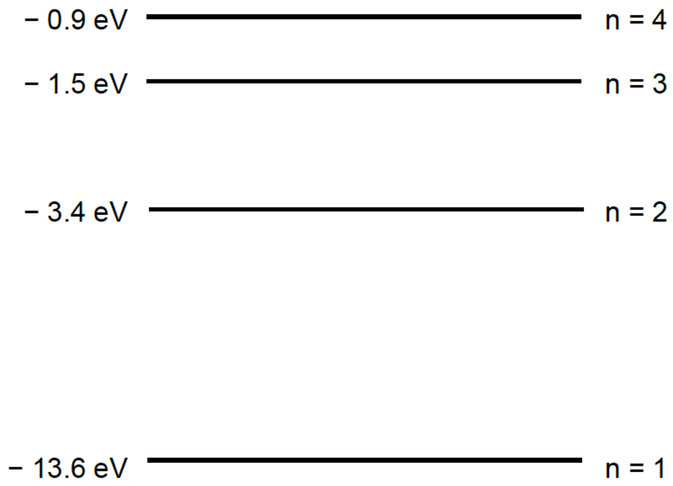
2020 Prelim RI

The diagram shows the first four energy levels of a hydrogen atom.



Which statement is correct?

A An electron transition from n = 4 to n = 2 produces visible light.

B An electron of energy 12.0 eV will not be able to excite a hydrogen atom in the ground state.

C A hydrogen atom in the −1.5 eV state can emit a photon of energy 0.6 eV in order to arrive at the −0.9 eV state.

D An electron transition from n = 4 to n = 1 produces a photon of a longer wavelength than a transition from n = 4 to n = 2.

2020 Prelim RI

A virus of mass $(7.0 \pm 0.7) \times 10^{-18}$ kg is moving with a speed of (2.5 ± 0.1) μm s^{-1}.

What is the minimum uncertainty in the measurement of the position of the virus?

A 10×10^{-9} m **B** 3×10^{-10} m **C** 7×10^{-27} m **D** 5×10^{-33} m

2020 Prelim RI

When the properties of a biological molecule like DNA are being studied, it is usually first attached to a microscopic glass bead. The bead is then immersed in a medium with a refractive index that is smaller than the refractive index of the glass bead. Following which, the bead is trapped and manipulated by optical tweezers in order to study the molecule's properties.

The restoring forces experienced by the trapped glass bead can be explained using the refraction of light through the glass bead. Fig. 7.6 shows a light ray from the laser beam being refracted as it passes through the glass bead.

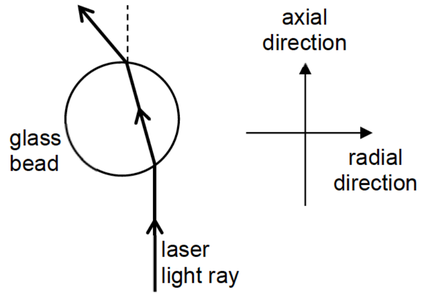


Fig. 7.6

(i) By considering the momentum of photons, explain how the refraction of the light ray exerts a force radially to the right on the glass bead.

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..... [3]

(ii) A photon of wavelength 960 nm enters the glass bead and undergoes refraction, as shown in Fig. 7.7. It leaves the glass bead with the same wavelength but at an angle of 32° to its original direction.

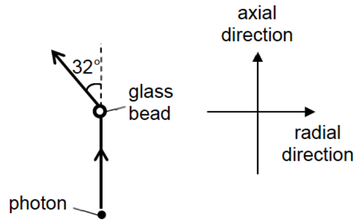

Fig. 7.7

Calculate

1. the momentum of the incident photon,

momentum = ... kg m s^{-1} [2]

2. the magnitude of the impulse of the photon in the radial direction,

impulse = ... kg m s^{-1} [2]

3. the magnitude of the impulse of the photon in the axial direction.

impulse = ... kg m s^{-1} [2]

2020 Prelim RI

(a) To produce X-rays, a metal target inside an X-ray tube is bombarded with high speed electrons that have been accelerated over a large potential difference.

Fig. 6.1 shows the variation with wavelength of the emitted radiation from the tube of the X-ray intensity. It consists of a continuous spectrum with two sharp peaks, labelled K_α and K_β. The X-ray spectrum cuts off at a minimum wavelength of λ_0.

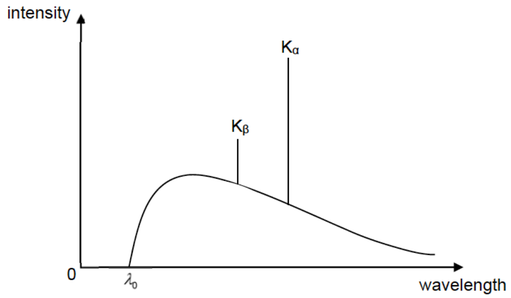

Fig. 6.1

(i) Explain the formation of the continuous spectrum.

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.....

..... [3]

(ii) Determine λ_0 if the electrons are accelerated over a potential difference of 50 kV.

λ_0 = ... m [2]

(iii) Besides the K_α and K_β peaks, two other peaks L_α and L_β can also be observed on the X-ray spectrum in Fig 6.1.

The L_α and L_β peaks are due to photons produced from electronic transitions within the metal atoms from energy levels n = 3 to n = 2, and n = 4 to n = 2 respectively.

Sketch the L_α and L_β peaks on Fig. 6.1. Label the two peaks clearly. [2]

(b) In a photoelectric experiment, a metal target in a vacuum tube is bombarded with electromagnetic radiation.

Fig. 6.2 shows the variation with the frequency f of the incident radiation of the stopping potential V_S.

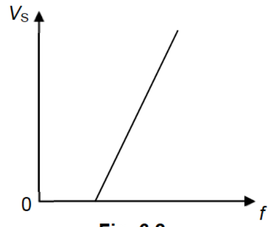

Fig. 6.2

(i) Determine, with clear explanations, the gradient of the graph.

gradient = ... [2]

(ii) When potassium was used as the metal target, it was found that no photocurrent was generated when the frequency of the incident electromagnetic radiation was below 5.55×10^{14} Hz.

Determine the work function energy of potassium.

work function energy = ... eV [2]

(iii) On Fig. 6.2, sketch a graph to represent the variation with f of V_S if tungsten was used as the metal target instead. The work function energy of tungsten is 4.50 eV. [1]

2020 Prelim ACJC

The minimum intensity of light that the human eye can detect is 2.0×10^{-11} W m^{-2}.

Given that the pupil of the eye has a diameter of 4 mm, how many photons per second of wavelength 550 nm must enter the eye for a distant star to be visible?

A 695 **B** 2780 **C** 1.26×10^{9} **D** 5.10×10^{9}

2020 Prelim ACJC

A very slow moving electron has a kinetic energy E and de Broglie wavelength λ.

If the electron's kinetic energy is $4E$, what is its corresponding de Broglie wavelength?

A $\frac{\lambda}{4}$ **B** $\frac{\lambda}{2}$ **C** 2λ **D** 4λ

2020 Prelim ACJC

A beam of electrons with a speed 10^{6} m s^{-1} is directed towards an aperture of diameter of 10^{-10} m. Due to the Heisenberg uncertainty principle, the transmitted electrons are observed to diffract within 1 m diameter on the screen.

What is the order of magnitude of the distance between the aperture and the screen?

A 10^{-2} m **B** 10^{-1} m **C** 10^{0} m **D** 10^{1} m

2020 Prelim ACJC

(a) Photoelectric emission experiments are carried out in a dark room.

(i) The circuit in Fig. 7.1a shows electrodes X and Y which are made of zinc.

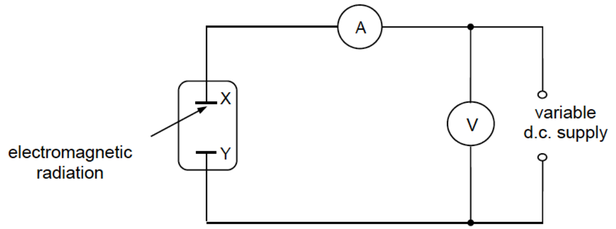

Fig. 7.1a

Current-voltage (*I-V*) characteristics in Fig. 7.1b is obtained when **only** electrode X is illuminated with light of wavelength 250 nm.

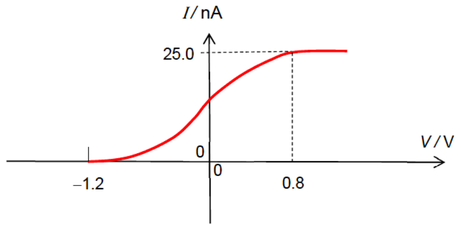

Fig. 7.1b

1. Show that the work function of zinc is 3.8 eV.

[2]

2. Explain why the stopping potential remains the same even when the intensity of the light is changed.

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..... [3]

(ii) The circuit in Fig. 7.2a shows electrodes X and Z. Electrode X is made of zinc, and electrode Z is made of nickel.

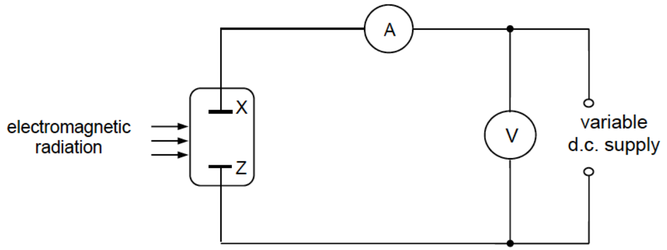

Fig. 7.2a

Current-voltage (*I-V*) characteristics is obtained when **both** electrodes are illuminated with a monochromatic light.

1. When the light has a wavelength of 250 nm, the *I-V* characteristics is as shown in Fig. 7.2b.

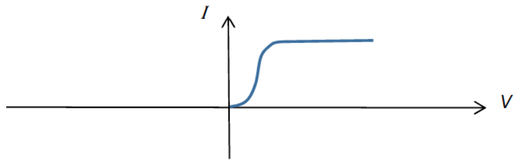

Fig. 7.2b

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Explain why the photocurrent has positive values only.

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..... [2]

2. When the light has a wavelength of 100 nm, the *I-V* characteristics is as shown in Fig. 7.2c.

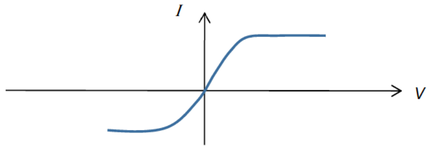

Fig. 7.2c

Explain why the photocurrent has both positive and negative values.

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..... [2]

(b) The X-ray spectrum consists of a broad continuous spectrum and a series of sharp lines known as the characteristic peaks.

Fig. 7.3 shows two X-ray spectra lines produced during X-ray emissions.

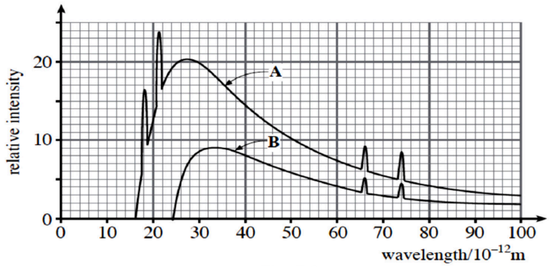

Fig. 7.3

(i) State and explain

1. one **similarity** between graphs A and B.

.....

..... [1]

2. one **difference** between graphs A and B.

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..... [1]

(ii) Determine the potential difference to accelerate the bombarding electrons in graph A.

potential difference = ... V [3]

Fig. 7.4 shows three sets of X-ray spectra produced by different accelerating potentials 100 kV, 80 kV and 50 kV with the same target.

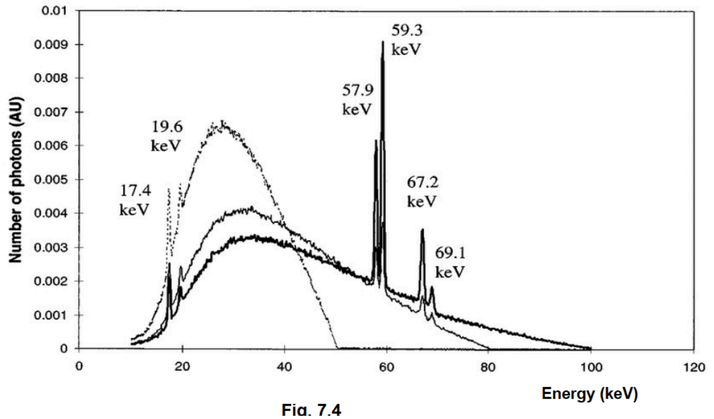

Fig. 7.4

2020 Prelim ACJC

A simplified set of energies of levels K, L, M, and N of tungsten and molybdenum are provided in Fig. 7.5. For a more detailed analysis, Level L is split into 2 levels L_I and L_{II}.

level	energy of level of tungsten / eV	energy of level of molybdenum / eV
N	- 594.1	- 63.2
M	- 2820	- 506.3
L_{II}	- 10207	- 2520
L_I	- 12100	- 2625
K	- 69525	- 20000

Fig. 7.5

(iii) Use the table in Fig. 7.5 to determine the **<u>two</u>** least energetic photons (K_α lines) produced when electrons transit to level K

1. in tungsten, and

energies of photons = …….. keV, …….. keV

2. in molybdenum.

energies of photons = …….. keV, …….. keV [2]

(iv) Comment on the element(s) used to make the target based on your calculations in **(iii)** and Fig. 7.4.

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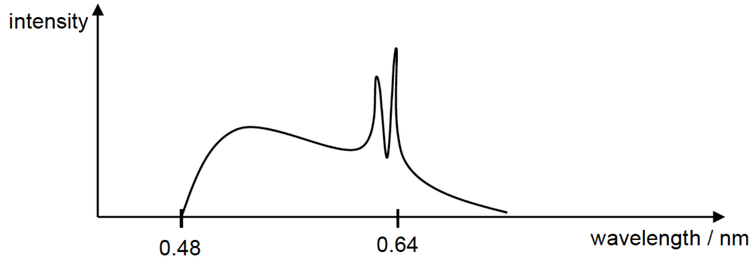
…… [4]

2020 Prelim ASRJC

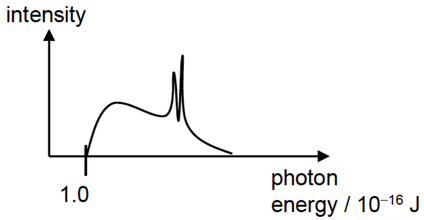
X-rays were produced via high speed electrons bombarding a target metal.

The variation with wavelength of the intensity of X-rays emitted is as shown below.

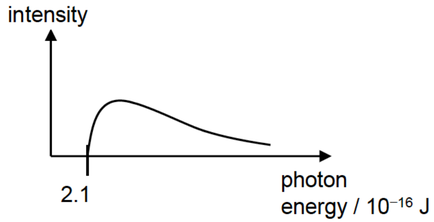


Which of the following diagrams shows the variation with photon energy of the intensity when the speed of the electrons is halved?

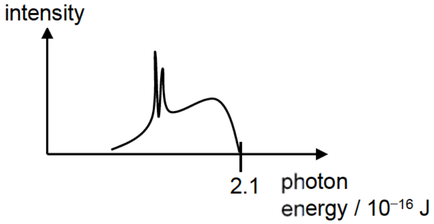
A



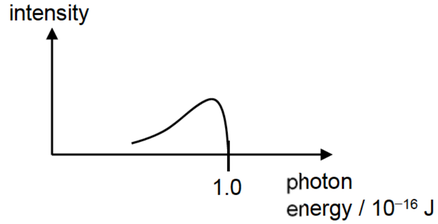
B



C



D



2020 Prelim ASRJC

The uncertainty in position of a particle in space is 2.00×10^{-20} m and the uncertainty in its momentum is 4.00×10^{-14} N s.

What is the minimum percentage change in uncertainty of its momentum when the uncertainty in position is halved?

A −100 % **B** −66 % **C** 66 % **D** 100 %

2020 Prelim ASRJC

(a) With reference to energy levels, explain briefly how an electric discharge lamp filled with hydrogen gas produces light.

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.....[2]

(b) Describe the appearance of a visible emission line spectrum.

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.....[1]

(c) Some electron energy levels of an isolated hydrogen atom are illustrated in Fig. 6.1.

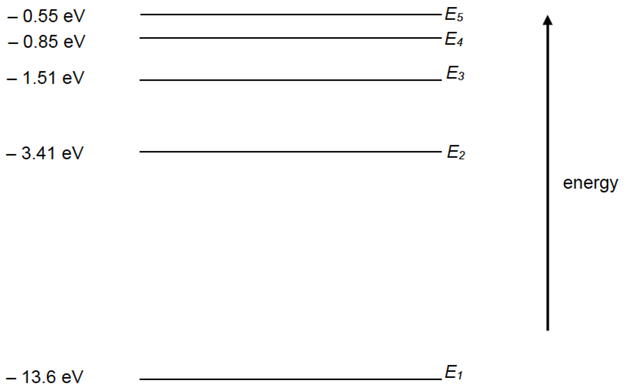

Fig. 6.1 (not to scale)

(i) On Fig 6.1, draw an arrow to show a transition that results in the emission of electromagnetic wave of the shortest wavelength. [1]

(ii) A line spectrum is produced from the electron energy levels shown in Fig. 6.1.

1. Determine the shortest wavelength of photon in this spectrum,

wavelength = ... m [2]

2. state the number of lines that lie in this spectrum,

number = ... [1]

3. sketch the line spectrum formed by the three shortest wavelength in Fig. 6.2.

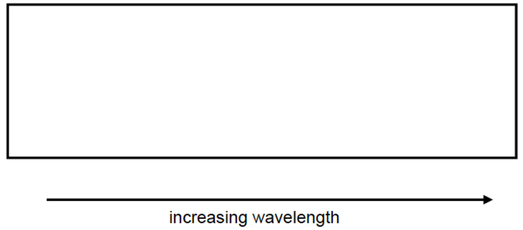

Fig. 6.2

[1]

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(d) The radiation emitted from transitions between levels shown in Fig. 6.1 is incident on the surface of a sheet of metal A as shown in Fig. 6.3.

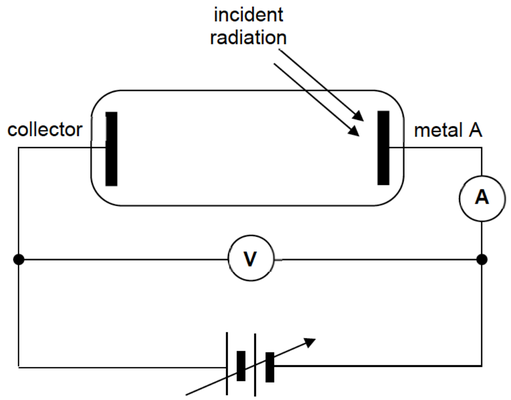

Fig. 6.3

The e.m.f. is varied and the corresponding readings on ammeter and voltmeter are plotted as shown in Fig. 6.4.

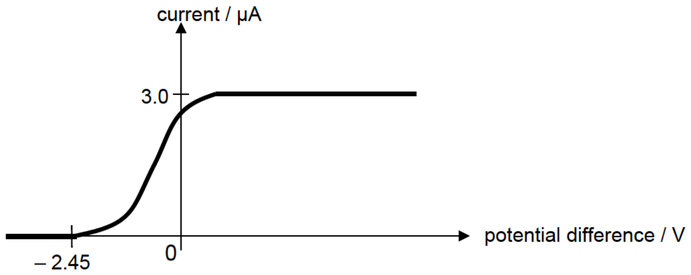

Fig. 6.4

(i) Determine the work function energy of metal A.

work function energy = ... J [3]

(ii) **1.** This irradiation of metal A has a quantum yield of 9.2×10^{-7}. Quantum yield is defined as the ratio

$$\frac{\text{number of photoelectrons emitted per second}}{\text{number of photons incident per second}}.$$

Determine the number of photons incident per second on metal A.

number of photons incident per second = ... s^{-1} [2]

2. State a possible reason why the quantum yield is so much smaller than 1.

.....

.....

.....[1]

2020 Prelim ASRJC

(iii) Describe and explain the change on the graph in Fig. 6.4 when the following changes are made independently.

1. The unpolarised radiation was polarised before it is incident on metal A.

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.....[2]

2. Metal A was replaced with another metal with a lower work function energy.

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.....[2]

(iv) By reference to the de Broglie equation, suggest whether light incident on the metal surface exerts a pressure on the surface.

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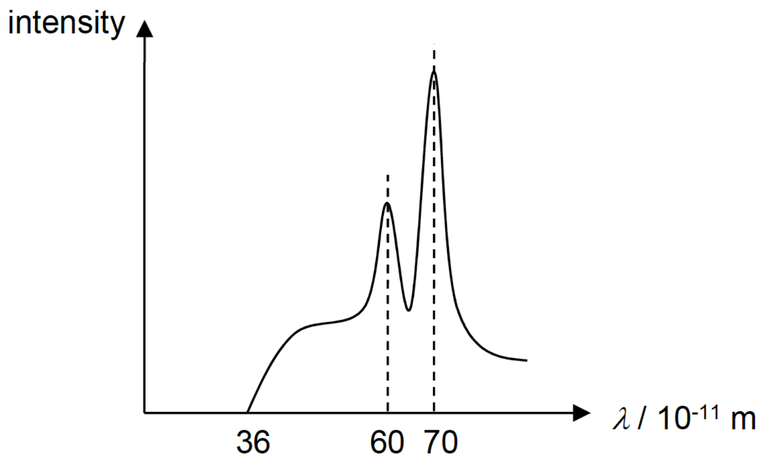
.....[2]

[Total: 20]

2020 Prelim CJC

The x-ray spectrum of a metal target is shown in the figure below.



Which of the following statements is correct?

A The smallest wavelength detected, 36 x 10^{-11} m, is dependent on the target material.

B The graph shows that electrons with a range of kinetic energies are used to bombard the target.

C The locations of the peaks can be used to identify the element that the target material is made of.

D The position of the peaks allow us to calculate the energy of the electrons used to bombard the target.

2020 Prelim CJC

A photon of wavelength 555.00 nm, measured to an accuracy of 0.01 nm.

What is the minimum uncertainty in the location of the photon?

A 6.6×10^{-23} m **B** 1.0×10^{-11} m **C** 3.1×10^{-2} m **D** 3.0×10^{-1} m

2020 Prelim CJC

A photocell is connected in a series circuit with a variable d.c. power supply and a sensitive ammeter as shown in Fig. 6.1.

The photocell is illuminated with electromagnetic radiation of wavelength 264 nm and power 3.8 mW and photoelectrons are emitted. The potential difference V between the collector C and emitter E in the photocell is adjusted and the photocurrent I is measured. Fig. 6.2 below shows the graph of I against V.

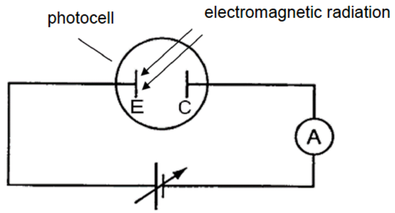


Fig. 6.1

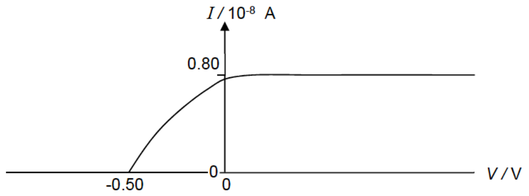


Fig. 6.2

(a) Explain why the photocurrent does not continue to increase for positive values of V.

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.....

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..... [1]

(b) **(i)** Determine the energy of a photon of the incident electromagnetic radiation.

energy = ... J [1]

(ii) Calculate the rate at which the photons are incident on the emitter.

rate of photon incidence = ... s^{-1} [2]

(iii) Show that the maximum rate of photoelectron emission is 5.0×10^{10} s^{-1}.

[1]

(iv) Suggest a reason for the difference between **(b)(ii)** and your answer in **(b)(iii)**.

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..... [1]

(c) **(i)** Calculate the work function energy of the emitter.

work function energy = ... J [1]

(ii) The emitter is replaced with another emitter of **half** the work function energy. On Fig. 6.2, sketch a graph to show the new variation with V of I. [2]

2020 Prelim CJC

Fig. 7.1 shows some of the energy levels of an helium atom.

Fig. 7.1

An electron with kinetic energy of 50.0 eV collides with a helium atom in its ground state and the helium atom is excited.

(a) **(i)** In Fig. 7.1, use arrows to show the possible energy transitions when the excited helium atom de-excites. [2]

(ii) Calculate the shortest wavelength of the radiation that is emitted from the transitions in **(a)(i).**

shortest wavelength = ... m [2]

(b) When a beam of white light is passed through a cold helium gas, an absorption spectrum of coloured background with dark lines is observed.

Use Fig. 7.1 to explain quantitatively why one of the dark lines correspond to a wavelength of 471 nm.

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..... [3]

2020 Prelim DHS

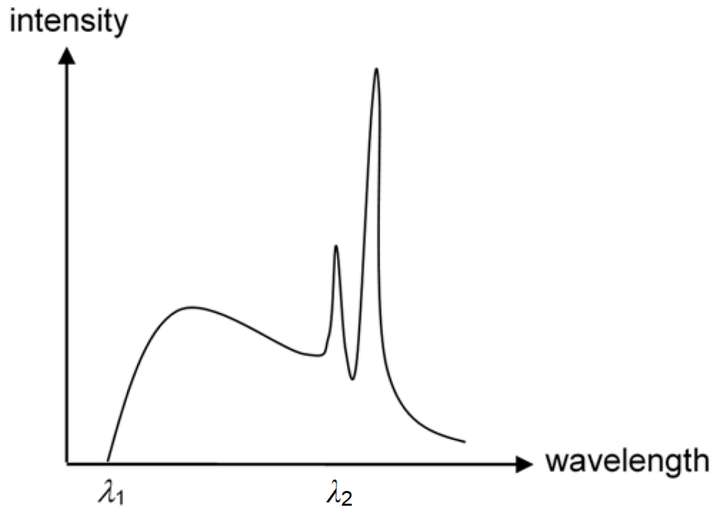
When monochromatic light of wavelength 440 nm is incident on a metal surface, electrons are emitted. No electrons are emitted from the surface when the wavelength of the incident light is greater than 550 nm.

What is the minimum de Broglie wavelength of an emitted electron?

A 3.6×10^{-10} m **B** 7.2×10^{-10} m **C** 8.1×10^{-10} m **D** 1.6×10^{-9} m

2020 Prelim DHS

The graph below shows the variation of X-ray intensity with wavelength emitted from an X-ray tube.



What are the factors that will affect λ_1 and λ_2?

	λ_1	λ_2
A	target metal	target metal
B	target metal	accelerating voltage
C	accelerating voltage	target metal
D	accelerating voltage	accelerating voltage

2020 Prelim DHS

(a) Explain what is meant by a *photon*.

.....

.....[2]

(b) An X-ray photon of wavelength 6.50 × 10^{-12} m is incident on an isolated stationary electron, as illustrated in Fig. 9.1.

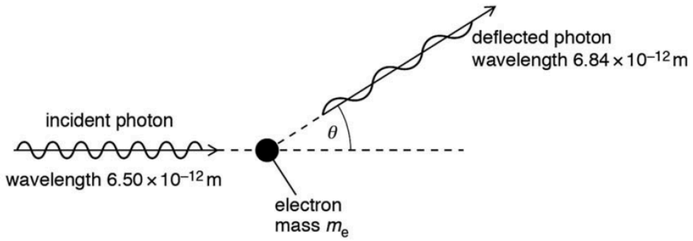


Fig. 9.1

The photon is deflected elastically by the electron of mass m_e. The wavelength of the deflected photon is 6.84 × 10^{-12} m.

(i) On Fig. 9.1, draw an arrow to indicate a possible initial direction of motion of the electron after the photon has been deflected. [1]

(ii) Calculate

1. the change in energy of the deflected photon.

change in photon energy = ... J [2]

2. the speed of the electron after the photon has been deflected.

speed = ... m s^{-1} [2]

(iii) The electron is deflected at an angle of 70° to the horizontal.

Calculate the angle θ through which the photon is deflected.

θ = ... ° [3]

(c) The deflected photon in Fig. 9.1 falls on a metal surface of work function 180 keV. Photoelectrons are emitted.

(i) Calculate the maximum kinetic energy of the photoelectrons.

maximum kinetic energy = ... J [2]

2020 Prelim DHS

(ii) Calculate the stopping potential of the photoelectrons

stopping potential = ... kV [2]

(iii) Explain why the kinetic energy of the photoelectrons is described as maximum.

.....

.....[1]

(d) The electron in **(b)(ii)2** collided with an atom with the 5 lowest energy levels shown in Fig. 9.2.

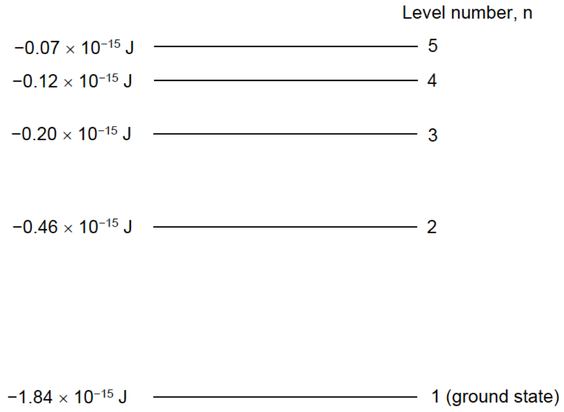


Fig. 9.2

The atom is initially at ground state. As a result of the collision, the atom transits to an excited state.

(i) Calculate the remaining energy of the recoiling electron after the collision.

energy = ... J [3]

(ii) State and explain whether the atom will transit to higher energy level if a photon of identical energy is incident on the atom.

.....

.....[2]

2020 Prelim EJC

When light of frequency f_1 is incident on a metal surface, the maximum energy of the emitted electrons emitted is E_1. When the same surface is illuminated with light of frequency f_2, the maximum energy of the emitted electrons emitted is E_2.

What is the Planck constant given by?

A $\dfrac{f_2E_1 + f_1E_2}{f_1f_2}$

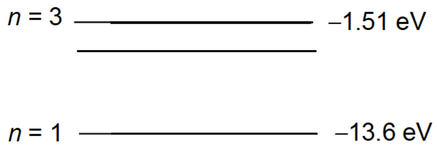
B $\dfrac{f_2E_1 - f_1E_2}{f_1f_2}$

C $\dfrac{E_1 + E_2}{f_1 + f_2}$

D $\dfrac{E_1 - E_2}{f_1 - f_2}$

2020 Prelim EJC

The diagram below shows three energy levels of a hydrogen atom, with the values of the first and third levels given.



A hydrogen atom absorbs a photon of wavelength λ such that the electron in the ground state is brought to an excited level of $n = 3$.

What is the maximum wavelength of a photon that can cause ionisation of a hydrogen atom in the ground state?

A $\frac{2}{3}\lambda$

B $\frac{8}{9}\lambda$

C $\frac{9}{8}\lambda$

D $\frac{3}{2}\lambda$

2020 Prelim EJC

The momentum of an electron is measured to be 6.42×10^{-23} kg m s^{-1} with a percentage uncertainty of 1.00 %.

What is the minimum uncertainty in its position?

A 8.07×10^{-24} m
B 1.03×10^{-9} m
C 2.06×10^{-9} m
D 6.50×10^{-9} m

2020 Prelim EJC

A particular X-ray tube uses molybdenum (Mo) as the target element and another X-ray tube uses tungsten (W). An accelerating potential of 25 kV is applied to both tubes, giving rise to continuous spectrums being formed. The atomic number Z of molybdenum is 42 while that of tungsten is 74.

(a) Explain, with reference to the mechanisms of X-ray production,

(i) how the continuous spectrum is formed

.....

.....

.....

..... [2]

(ii) why the minimum wavelength produced is the same for both target elements.

.....

.....

.....

..... [3]

(b) Explain why the characteristic peaks K_α and K_β occur for molybdenum, but not for tungsten at an accelerating potential of 25 kV.

.....

.....

.....

..... [1]

(c) Calculate the wavelength of the electrons being accelerated in the X-ray tubes.

wavelength = ... m [3]

(d) Sketch a well labelled diagram of the X-ray spectrum for molybdenum in Fig. 4.1.

Fig. 4.1

[3]

[Total: 12]

2020 Prelim EJC

A monochromatic light source has a power output P of 0.50 W and a wavelength λ of 350 nm. The light is incident on a metal surface that has a work function Φ of 3.8 eV .

(a) (i) Explain whether photoelectrons are emitted from the metal surface.

.....

..... [2]

(ii) The power of the light is increased at the same wavelength.

Explain how this will affect your answer to **(a)(i)**.

.....

.....

..... [2]

(b) Calculate the rate of emission of photons from the light source.

rate = ... s^{-1} [1]

(c) (i) The radiation is incident normally on an area A of 4.0×10^{-7} m^2 of the metal surface. All of the radiation is absorbed.

Determine the radiation pressure exerted on the metal surface.

Explain your working clearly.

radiation pressure = ... Pa [3]

(ii) Explain how your answer to **(c)(i)** will change if some of the incident radiation is reflected off the metal surface instead.

.....

.....

..... [1]

[Total: 9]

2020 Prelim JPJC

The atomic spacing in a thin metal film is of the order of magnitude 10^{-10} m.

For the diffraction of an electron beam, what order of magnitude of velocity is required?

A 10^{4} m s^{-1}

B 10^{5} m s^{-1}

C 10^{6} m s^{-1}

D 10^{7} m s^{-1}

2020 Prelim JPJC

The transitions of electrons between three consecutive energy levels in an atom give rise to three spectral lines. The shortest and longest wavelengths of the spectral lines are λ_1 and λ_2 respectively.

Which of the following gives the wavelength of the other spectral line, in terms of λ_1 and λ_2?

A $\left(\frac{1}{\lambda_1}-\frac{1}{\lambda_2}\right)^{-1}$

B $\frac{\lambda_1\lambda_2}{\lambda_1+\lambda_2}$

C $\frac{\lambda_1+\lambda_2}{2}$

D $\lambda_1-\lambda_2$

2020 Prelim JPJC

(a) By reference to the photoelectric effect, state what is meant by the *work function energy* of a surface.

.....

.....

..... [1]

(b) Fig. 9.1 shows two parallel metal plates A and B enclosed in an evacuated glass tube. Plate A is at an electric potential of 3.7 V.

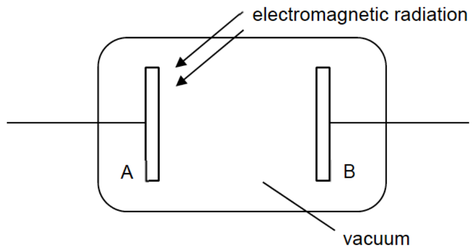


Fig. 9.1

(i) Plate A is illuminated with electromagnetic radiation.

The variation with electric potential of plate B of the photoelectric current is shown in Fig. 9.2.

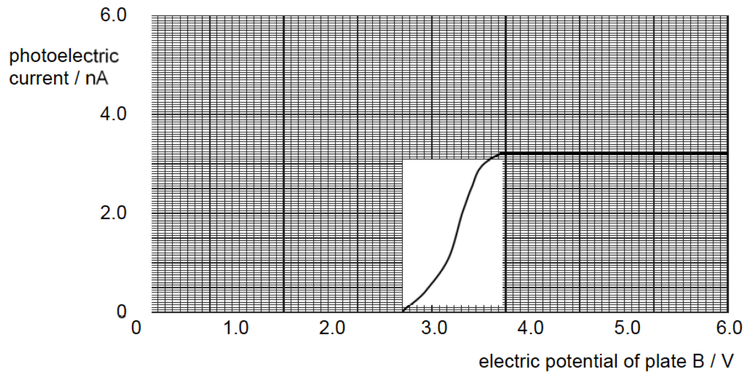


Fig. 9.2

1. With reference to photoelectrons, explain the significance of the sloping section of the graph in Fig. 9.2.

.....

.....

.....

..... [2]

2. Calculate the maximum speed of the photoelectrons emitted from plate A.

maximum speed = ... m s^{-1} [3]

3. Calculate the number of electrons collected per second by plate B.

number of electrons per second = ... s^{-1} [2]

4. Calculate the number of photons incident per second on plate A, if one electron is emitted for every 1.0×10^5 incident photons.

number of photons per second = ... s^{-1} [1]

5. The frequency of the electromagnetic radiation is kept constant as its intensity is halved. On Fig. 9.2 sketch a graph to show the variation with electric potential of plate B of the photoelectric current for this decreased intensity. [2]

2020 Prelim JPJC

(ii) Electromagnetic radiation of wavelength λ illuminates plate A. Electrons are emitted from plate A with maximum speed v_{max}.

The variation with $\frac{1}{\lambda}$ of ${v_{max}}^2$ is shown in Fig. 9.3.

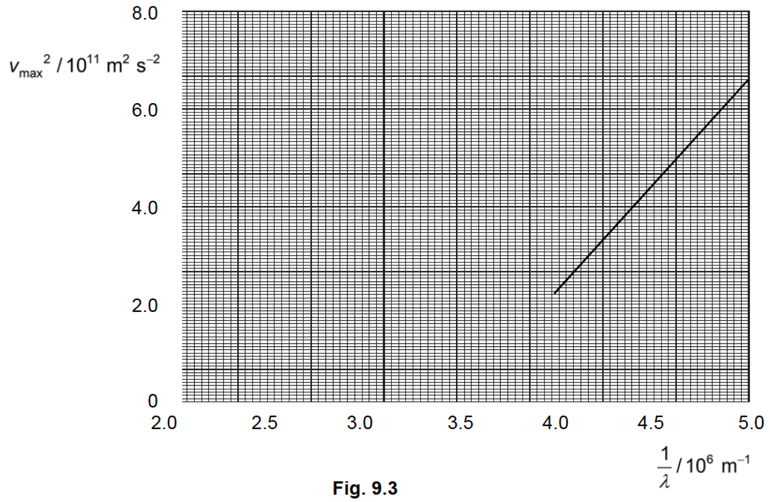


Fig. 9.3

1. Use Fig. 9.3 to determine the Planck constant.

Planck constant = ... J s [3]

2. Use Fig. 9.3 and your answer in **1.** to determine the work function energy of plate A.

work function energy = ... eV [2]

3. On Fig. 9.3, draw a line to show the variation with $\frac{1}{\lambda}$ of ${v_{max}}^2$ for a metal with a lower work function energy. [1]

(c) Electromagnetic radiation of wavelength 200 nm is emitted from a source rated at 0.76 mW. The photons are incident normally on a metal surface and are all absorbed by the surface.

(i) Show that the number of photons incident per second on the metal surface is 7.6×10^{14} s^{-1}.

[1]

(ii) Calculate the magnitude of the force exerted on the metal surface by the incident photons.

force = ... N [2]

2020 Prelim MI

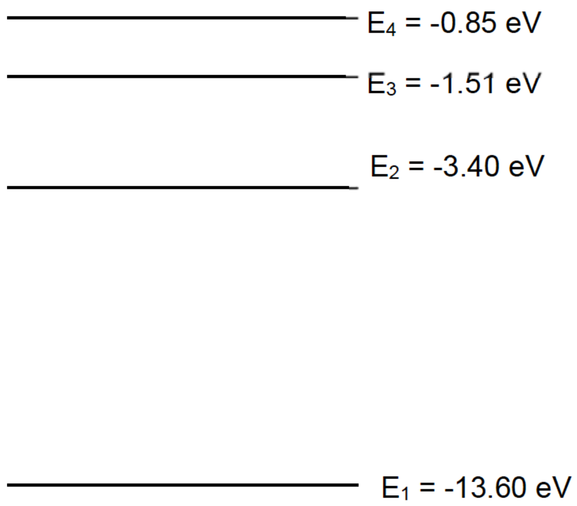
In a photoelectric effect experiment, ultraviolet light of wavelength 150 nm shines on a clean metal surface. The stopping potential is determined to be 2.1 V.

What is the work function of the metal used?

A 2.1 eV **B** 6.2 eV **C** 8.3.eV **D** 10.4 eV

2020 Prelim MI

The diagram shows some of the energy levels (not drawn to scale) of hydrogen atom. Four photons of wavelength 7.5 nm, 8.0 nm, 11.4 nm and 74.6 nm, strike a sample containing these hydrogen atoms in their ground state.



What is the maximum speed of the ejected electron?

A 1.04×10^6 m s^{-1}

B 2.36×10^6 m s^{-1}

C 7.31×10^6 m s^{-1}

D 7.61×10^6 m s^{-1}

2020 Prelim MI

Fig 6.1 below shows how x-rays are produced inside an x-ray tube. The electrons emitted at the cathode are accelerated from rest using an accelerating voltage to hit a target made of a metal at the anode and produce x-rays as a result.

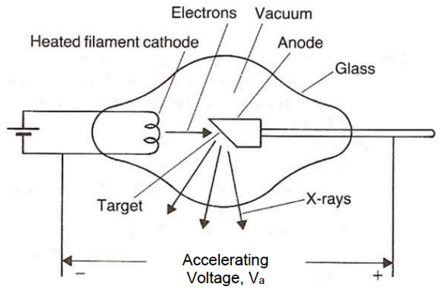


Fig. 6.1

A graph of relative intensity against wavelength of the emitted radiation shows an emission line spectrum superimposed on a continuous spectrum as shown in Fig. 6.2.

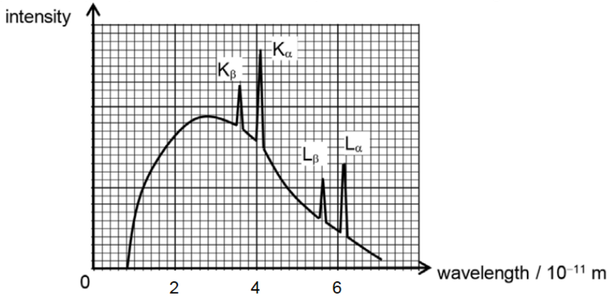


Fig. 6.2

(a) Explain how the characteristic X-ray lines and continuous spectrum are produced in Fig. 6.2.

.....

.....

.....

.....

.....

.....

..... [3]

(b) **(i)** Determine the maximum energy of the x-ray photons emitted.

maximum energy= ..... J [2]

(ii) Show that the accelerating voltage V_a used is 155 kV.

[1]

(iii) Calculate the speed at which the electrons hit the target when the accelerating voltage is 155 kV.

velocity of electron = ... m s^{-1} [2]

(c) By using your answer in **(b)(iii)**, make a suitable calculation to suggest why the *wave properties* of electrons are not observable in this experiment.

.....

.....

..... [2]

[Total: 10]

2020 Prelim MI

In a photoelectric emission experiment setup shown in Fig. 5.1, ultraviolet radiation of wavelength 265 nm and intensity 150 W m^{-2} is incident on a rhodium surface S in an evacuated tube, so that an area of 14 mm^2 is illuminated. Electrons are ejected from the rhodium surface S and collected by a collector cup C.

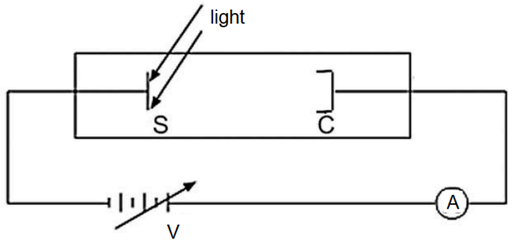


Fig. 5.1

When a potential difference V is set up between rhodium surface S and collector cup C, the graph A in Fig. 5.2 illustrates how photocurrent i changes with the potential difference V.

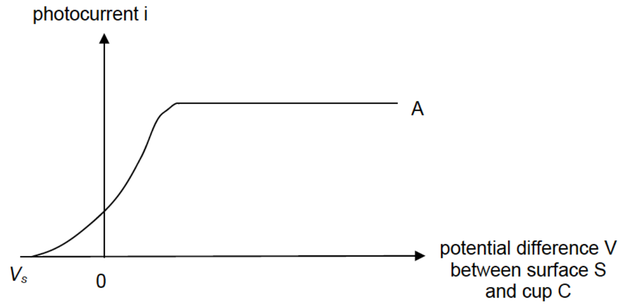


Fig. 5.2

(a) Explain what is meant by a *photon*.

.....

.....

..... [2]

(b) Calculate the energy of an incident photon.

energy of incident photon = ... eV [2]

(c) **(i)** State and explain the term *work function*.

.....

..... [1]

(ii) Explain using conservation of energy how the minimum potential difference V_s will change when light of higher wavelength is used to illuminate the rhodium surface S.

.....

.....

.....

.....

.....

..... [3]

(d) Explain why the photoelectric current in graph A reaches a maximum value no matter how large V is.

.....

.....

.....

..... [2]

(e) Using the original ultraviolet radiation of wavelength of 265 nm, the intensity of illumination is then increased and the experiment repeated. In Fig. 5.2, draw the new graph that would be obtained and label it as B. [2]

[Total: 12]