Quantum Physics

1. Electromagnetic radiation is incident on a metal of work function 2.3 eV.
The maximum kinetic energy (KE) of the photoelectrons is 1.7 eV.

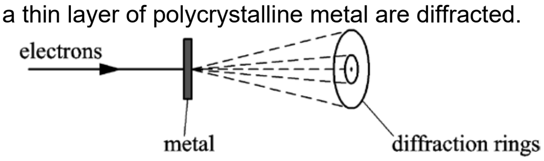
The frequency of this incident electromagnetic radiation is kept the same but its intensity is doubled.

What is the maximum KE of the photoelectrons now?

A 1.7 eV
B 2.9 eV
C 3.4 eV
D 4.0 eV

Your answer [1]

2. Electrons travelling through a thin layer of polycrystalline metal are diffracted.



Which statement is correct about these electrons?

A. The electrons travel as photons through the metal.
B. The electrons have a wavelength of about 10^{-10} m.
C. The electrons are diffracted by holes in the metal.
D. The electrons repel each other to produce the diffraction.

Your answer

[1]

3. An electron, a proton, a neutron and an alpha-particle are travelling in a vacuum at the same speed.

Which of these particles has the **shortest** de Broglie wavelength?

A electron
B proton
C neutron
D alpha-particle

Your answer

[1]

4. The de Broglie wavelength of a proton is 160 pm.

The kinetic energy of this proton is doubled.

What is the de Broglie wavelength of the proton now?

A 80 pm
B 110 pm
C 230 pm
D 320 pm

Your answer ☐ **[1]**

5. The energy of a photon is 2.5 eV.

What is the principal radiation for this photon?

A infrared
B radio waves
C visible light
D x-rays

Your answer ☐ **[1]**

6. An electron moves in a circle of radius 2.0 cm in a uniform magnetic field of flux density 170 mT.

What is the momentum of this electron?

A 3.4×10^{-3} kg m s^{-1}
B 5.4×10^{-17} kg m s^{-1}
C 1.4×10^{-18} kg m s^{-1}
D 5.4×10^{-22} kg m s^{-1}

Your answer ☐ **[1]**

7. The total energy released in a single fusion reaction is 4.0 MeV.

What is the change in mass in this fusion reaction?

A 7.1×10^{-36} kg
B 7.1×10^{-30} kg
C 2.1×10^{-21} kg
D 4.4×10^{-17} kg

Your answer ☐ **[1]**

8. Which of the following statements is / are true about photons?

1. All photons travel at the same speed in a vacuum.
2. Photons have no charge.
3. The energy of a photon depends only on its frequency.

A. 1, 2 and 3
B. Only 2 and 3
C. Only 1 and 2
D. Only 2

Your answer

[1]

9. What can be deduced from the diffraction of electrons by graphite atoms?

A Electrons are electromagnetic waves.
B Electrons can also become photons.
C Electrons interact with photons on a one-to-one basis.
D Electrons show wave-like behaviour.

Your answer **[1]**

10. Electrons travelling through a thin film of carbon are diffracted.
Which statement is correct?

The electrons behave like ....

A photons and are deflected by the carbon atoms.
B photons and change direction as their speed changes.
C waves and are refracted by the holes in the carbon film.
D waves of wavelength similar to the spacing between carbon atoms.

Your answer

[1]

11. A sodium lamp is rated at 40 W. About 12% of the power is emitted as yellow light of wavelength 5.9×10^{-7} m.

How many photons of yellow light are emitted per second from this lamp?

A. $1.4 \times 10^{19}\ s^{-1}$
B. $1.2 \times 10^{20}\ s^{-1}$
C. $3.6 \times 10^{27}\ s^{-1}$
D. $1.0 \times 10^{40}\ s^{-1}$

Your answer

[1]

12. Photons of energy 4.8 × 10^{-19} J are incident on the surface of a clean metal plate of work function 3.2 × 10^{-19} J.

What is the maximum speed of emitted electrons?

A 5.9 × 10^{5} m s^{-1}
B 8.4 × 10^{5} m s^{-1}
C 1.0 × 10^{6} m s^{-1}
D 1.3 × 10^{6} m s^{-1}

Your answer

[1]

13. What can be deduced from the diffraction of electrons by a thin film of graphite?

A Electrons are leptons.
B Electrons are negatively charged.
C Electrons interact with atoms on a one-to-one basis.
D Electrons travel as waves.

Your answer **[1]**

14. State what is meant by the *photoelectric effect*.

[1]

15. State **one** piece of evidence for the wave-like behaviour of electrons.

[1]

16. A researcher is investigating the work function of metals using the photoelectric effect.
The table below shows the threshold frequency f_0 and the work function φ for various metals.

metal	**A**	**B**	**C**	**D**	**E**
f_0 / 10^{14} Hz	4.5	5.6	6.5	8.0	9.7
φ / eV	1.9	2.3	2.7	3.4	4.1

Explain what is meant by *threshold frequency*.

[1]

17. An electron has a de Broglie wavelength equal to the wavelength of X-rays.

What is the **best** estimate of the momentum of this electron?

A 10^{-30} kg m s^{-1}
B 10^{-27} kg m s^{-1}
C 10^{-23} kg m s^{-1}
D 10^{-18} kg m s^{-1}

Your answer ☐ **[1]**

18. Which is **not** a unit of energy?

A kW h
B eV
C J
D W

Your answer ☐ **[1]**

19. A student is explaining the photoelectric effect to his friend.

Which statement is correct?

A An electron is emitted when the photon energy is greater than the threshold frequency.
B Increasing the intensity increases the maximum kinetic energy of the emitted electrons.
C Photons are emitted from the metal during the photoelectric effect.
D The energy of a photon is proportional to the frequency of the electromagnetic radiation.

Your answer ☐ **[1]**

20. Which of the following statements is / are true about photons?

1. The speed of a photon changes at the boundary between air and glass.
2. Photons are electrically neutral.
3. The energy of a photon depends only on its wavelength.

A. 1, 2 and 3 are correct
B. Only 1 and 2 are correct
C. Only 2 and 3 are correct
D. Only 1 is correct

Your answer ☐

[1]

21. The total energy gained by 20 electrons travelling through a potential difference *V* is 30 ke*V*. What is the potential difference *V*?

A 1.5 V
B 3.0 V
C 1500 V
D 3000 V

Your answer [1]

22. Electromagnetic radiation is incident on a metal. The radiation has constant wavelength with each photon having an energy of 5.0 eV. The work function of the metal is 3.0 eV.

Which of the following **cannot** be the kinetic energy of an emitted photoelectron?

A 0 eV
B 1.0 eV
C 2.0 eV
D 3.0 eV

Your answer [1]

23. An electron with initial kinetic energy of 100 eV and initial speed of 5.9×10^6 m s^{-1} is **accelerated** through a potential difference of 250 V.

What is the final speed of this electron?

A 5.9×10^6 m s^{-1}
B 7.3×10^6 m s^{-1}
C 9.4×10^6 m s^{-1}
D 1.1×10^7 m s^{-1}

Your answer [1]

24. Violet light is incident on the surface of a metal. Photoelectrons are emitted from the surface of the metal. The frequency of the radiation incident on this metal is increased but the intensity of the radiation is kept constant.

Which statement is correct?

A The value of the Planck constant increases.
B The work function of the metal increases.
C The number of photoelectrons emitted per second increases.
D The maximum kinetic energy of photoelectrons increases.

Your answer

[1]

25. A proton has kinetic energy 8.00×10^{-17} J.

Which is the correct expression for the de Broglie wavelength λ of the proton?

A $\lambda = \dfrac{6.63 \times 10^{-34}}{2 \times 1.67 \times 10^{-27} \times 8.00 \times 10^{-17}}$

B $\lambda = \dfrac{6.63 \times 10^{-34}}{2 \times 9.11 \times 10^{-31} \times 8.00 \times 10^{-17}}$

C $\lambda = \dfrac{6.63 \times 10^{-34}}{\sqrt{2 \times 1.67 \times 10^{-27} \times 8.00 \times 10^{-17}}}$

D $\lambda = \dfrac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.11 \times 10^{-31} \times 8.00 \times 10^{-17}}}$

Your answer ☐ **[1]**

26. The de Broglie wavelength of an electron after being accelerated through a potential difference (p.d.) *V* is λ_0. The accelerating p.d. is now doubled.

What is the new de Broglie wavelength of the electron in terms of λ_0?

A $\dfrac{\lambda_0}{2}$

B $\dfrac{\lambda_0}{\sqrt{2}}$

C $\sqrt{2}\lambda_0$

D $2\lambda_0$

Your answer ☐ **[1]**

27. What is the de Broglie wavelength in nm of a proton travelling at 1.5×10^4 m s^{-1}?

A 2.6×10^{-2} nm

B 2.6 nm

C 49 nm

D 4.9×10^4 nm

Your answer ☐

[1]

28. Define the **work function** of a metal.

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[1]

29. A sodium lamp is rated at 40 W.
12% of the power is emitted as yellow light of wavelength 5.9 x 10^{-7} m.

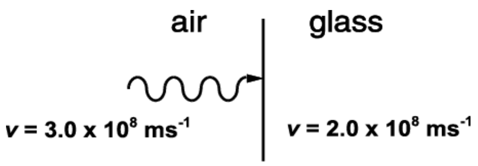
How many photons of yellow light are emitted per second from this lamp?

A. 1.4×10^{19}
B. 1.2×10^{20}
C. 3.6×10^{27}
D. 1.0×10^{40}

Your answer

[1]

30. A beam of monochromatic light passes from air into glass. The speed of the photons in air is 3.0 x 10^8 m s^{-1} and in glass is 2.0 x 10^8 m s^{-1}.



Which of the following statements is correct?

A. The energy of a photon in glass is 1.5 times the energy of the photon in air.
B. The energy of a photon in glass is the same as the energy of the photon in air.
C. The energy of a photon in glass is $\frac{2}{3}$ of the energy of the photon in air.
D. When the intensity of the monochromatic light beam is halved the energy of each photon of the beam in air is halved.

Your answer

[1]

31. The minimum potential difference across a light-emitting diode (LED) before it conducts is 2.1 V. The wavelength of the light emitted by the LED is λ.

e = elementary charge
c = speed of light in a vacuum

What is the correct expression for determining the Planck constant h?

A $h = 2.1ec\lambda$

B $h = \frac{2.1e}{\lambda}$

C $h = \frac{c}{2.1e\lambda}$

D $h = \frac{2.1e\lambda}{c}$

Your answer

[1]

32 (a). Moving electrons have wave-like properties.
Calculate the de Broglie wavelength λ for electrons travelling at 5.5×10^5 m s^{-1}.

λ = ________________________________ m **[2]**

(b). Einstein derived the following equation to explain the photoelectric effect:

$$hf = \phi + KE_{max}$$

Define the following terms from the equation

i. *hf*

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[1]

ii. ϕ

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[1]

33. Fig. 19 shows a photocell.

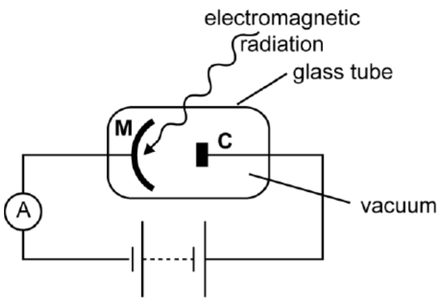

Fig. 19

The wavelength of the incident radiation is kept constant but the intensity of the radiation is doubled.

State and explain the effect, if any, on the current in the photocell.

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[2]

34. The Planck constant *h* is an important fundamental constant in quantum physics.

Determine the S.I. base units for *h*.

base units = ... **[2]**

35(a). Electron diffraction provides evidence for the wave-like behaviour of particles. Electrons are diffracted by a thin slice of graphite.

In one experiment, electrons are accelerated from rest through a potential difference of 300 V.

Show that the final speed *v* of the electrons is 1.0×10^{7} m s^{-1}.

[3]

(b). Determine the de Broglie wavelength λ of the electrons.

λ = ... m **[2]**

(c). After the electrons are diffracted by the graphite they hit a fluorescent screen.
The electrons are diffracted because of the spacing between the carbon atoms is comparable with the de Broglie wavelength of the electrons. Fig. 8 shows the diffraction pattern (bright rings) seen on the fluorescent screen when the electrons are accelerated through a potential difference of 300 V.

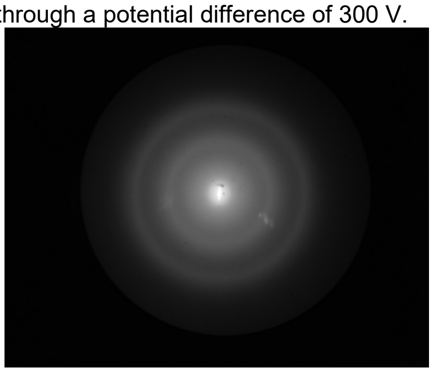

Fig. 8

The potential difference is now increased. Explain how the diffraction pattern will change.

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[2]

36 (a). This question is about a photoelectric cell, which is an electronic device that detects photons.
Fig. 6 shows a cross-section through a simple photocell.

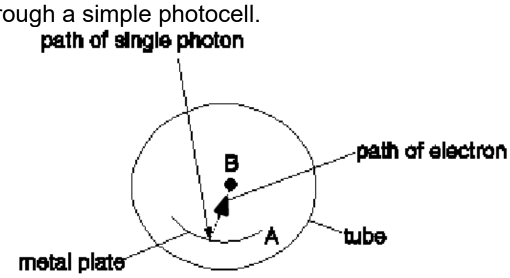

Fig. 6

A metal plate **A** is coated with potassium in an evacuated transparent tube. A photon of high enough energy, incident on the plate, can cause an electron to be released from the surface towards the collector rod **B**.

The photocell is connected to a 12 V supply and a sensitive ammeter which can detect a current of 1.0×10^{-9} A. Only 5.0% of the photons of average energy 4.0×10^{-19} J incident on the plate **A** cause electrons to be released.

Calculate the minimum light energy that plate **A** must absorb per second for the photocell circuit to detect a current.

[3]

(b). Potassium has a work function of 3.5×10^{-19} J. Show that the longest wavelength of light that the photocell can detect is about 570 nm.

[3]

37. An exploding star in a distant galaxy emitted a burst of electromagnetic radiation. X-rays and ultraviolet radiation from this burst were detected simultaneously at the Earth.
The wavelength of the X-rays was 2.5×10^{-11}m.

Special detectors at the Earth were used to detect the individual X-ray photons.
In one type of detector, the interaction of a single X-ray photon with the material of the detector produced many photons of visible light with wavelength of about 500nm.

Estimate the number of visible light photons emitted in each interaction.

number of visible light photons = ... **[3]**

38. Fig. 22.1 shows the circular track of a positron moving in a uniform magnetic field.

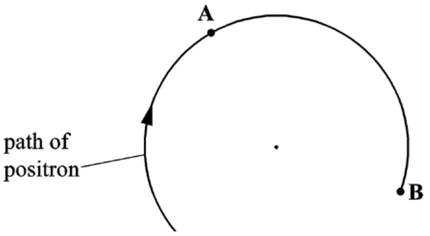

Fig. 22.1

The magnetic field is perpendicular to the plane of **Fig. 22.1**.
The speed of the positron is 5.0×10^{7} m s^{-1} and the radius of the track is 0.018 m.

At point **B** the positron interacts with a stationary electron and they annihilate each other. The annihilation process produces two identical gamma photons travelling in opposite directions.

Calculate the wavelength of the gamma photons. Assume the kinetic energy of the positron is negligible.

wavelength = ... m **[3]**

39. Fig. 19 shows a photocell.

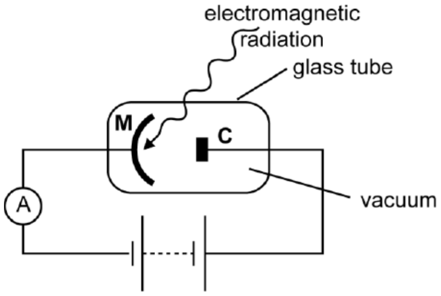

Fig. 19

When the metal **M** is exposed to electromagnetic radiation, photoelectrons are ejected from the surface of the metal. These photoelectrons are collected at the electrode **C** and the sensitive ammeter indicates the presence of a tiny current.
The work function of the metal **M** is 2.3 eV.
The incident electromagnetic radiation has wavelength 5.1×10^{-7} m.
The ammeter reading is 0.24 μA.

Calculate the maximum kinetic energy of the ejected photoelectrons.

maximum kinetic energy = ... J **[3]**

40. Filament lamps are being replaced by LED lamps in many large organisations. LEDs are low-powered devices.

i. Apart from cost, state one major advantage this can have on the environment.

---

[1]

ii. A light-emitting diode emits photons of a specific wavelength. The intensity of the light emitted from the LED is doubled.
Explain the effect this has on the energy of a photon.

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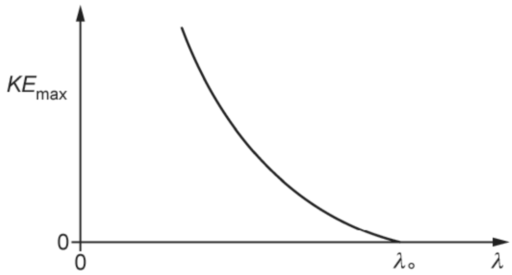
[2]

41. Electromagnetic radiation, with a range of wavelengths, is incident on a metal.
Electrons are removed from the metal due to the photoelectric effect.

The maximum kinetic energy KE_{max} of the emitted electrons against wavelength λ graph is shown below.



Explain the shape of the graph in terms of quantum physics.

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[3]

42. Calculate the maximum wavelength of the X-rays for the pair production process.

maximum wavelength = ... m **[3]**

43. electromagnetic radiation of frequency 9.60×10^{14}Hz falls on a negatively-charged metal surface with a work function of 3.2 eV.

Calculate the maximum kinetic energy $E_{k\,(max)}$ in joules of the particles emitted from the surface of the metal.

$E_{k\,(max)}$ = ... J **[3]**

44 (a). Electromagnetic radiation is incident on a negatively charged zinc plate. Electrons are emitted from the surface of the plate when a weak intensity ultraviolet source is used. Electrons are not emitted at all when an intense visible light from a lamp is used.

Explain these observations.

---

[4]

(b). The **maximum** wavelength of the electromagnetic radiation incident on the surface of a metal which causes electrons to be emitted is 2.9×10^{-7} m.

Calculate the maximum kinetic energy of electrons emitted from the surface of the metal when each incident photon has energy of 5.1 eV.

maximum kinetic energy = ... J **[3]**

(c). Electromagnetic radiation of constant wavelength is incident on a metal plate. Photoelectrons are emitted from the metal plate. Fig. 19.1 shows an arrangement used to determine the maximum kinetic energy of electrons emitted from a metal plate.

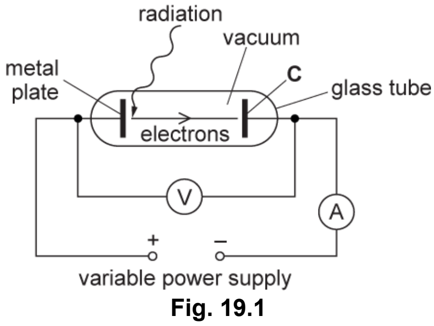

Fig. 19.1

The metal plate and the electrode **C** are both in a vacuum. The electrode **C** is connected to the negative terminal of the variable power supply.

Fig. 19.2 shows the variation of current I in the circuit as the potential difference V between the metal plate and **C** is increased from 0 V to 3.0 V.

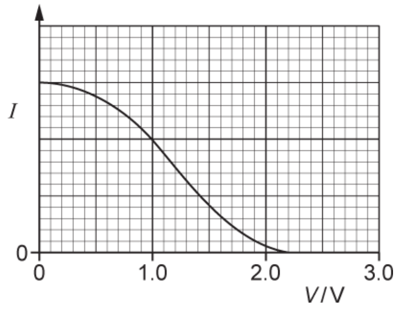

Fig. 19.2

Explain why the current decreases as V increases and describe how you can determine the maximum kinetic energy of the emitted electrons.

-- **[3]**

45. A high energy gamma photon passing through a scintillator crystal converts some of its energy into visible light photons of mean wavelength 450 nm.

Show that the energy of a single photon of wavelength 450 nm is less than 3 eV.

[3]

46. The wavelength of light from an LED is 480 nm. The radiant power emitted from the LED is 1.2 mW. Calculate the number of photons *N* emitted from the LED per second.

N = ... s^{-1} **[3]**

47. A light-emitting diode (LED) emits red light when it is positively biased and has a potential difference (p.d.) greater than about 1.8 V.

The energy of a photon of red light is about 1.8 eV.

Calculate the wavelength λ of this red light.

λ = ... m **[3]**

48 (a). The photoelectric effect cannot be explained in terms of the wave-model of electromagnetic waves. Discuss how the new knowledge of the particulate nature of radiation was used by physicists to validate the photon model.

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[3]

(b). A metal plate is placed in an evacuated chamber. Electromagnetic radiation of wavelength 380 nm is incident on the plate. The work function of the metal is 1.1 eV.

i. Calculate the maximum speed of the photoelectrons emitted from the plate.

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

ii. State the change, if any, to the maximum speed of the emitted photoelectrons when the intensity of the incident electromagnetic radiation on the metal plate is doubled.

---

[1]

49 (a). A stationary uranium-238 nucleus $\left({}^{238}_{92}\text{U}\right)$ decays into a nucleus of thorium-234 by emitting an alpha-particle.

The chemical symbol for thorium is Th. Write a nuclear equation for this decay.

[2]

(b). The mass of the uranium nucleus is 4.0×10^{-25} kg. After the decay the thorium nucleus has a speed of 2.4×10^{5} m s^{-1}.

Calculate the kinetic energy, in MeV, of the alpha-particle.

kinetic energy = ... MeV **[4]**

(c). The uranium-238 $\left({}^{238}_{92}\text{U}\right)$ nucleus starts the decay chain which ends with a nucleus of lead-206 $\left({}^{206}_{82}\text{Pb}\right)$. Show that 14 particles are emitted during this decay chain. Explain your reasoning.

[3]

50 (a). Electrons can behave as a wave.

Describe the behaviour of electrons which demonstrates that they have wave properties.

[4]

(b). In an experiment to demonstrate the photoelectric effect, electromagnetic waves are incident on a silver surface.
Fig. 6 shows the variation with frequency *f* of the maximum kinetic energy KE_{max} of the photoelectrons.

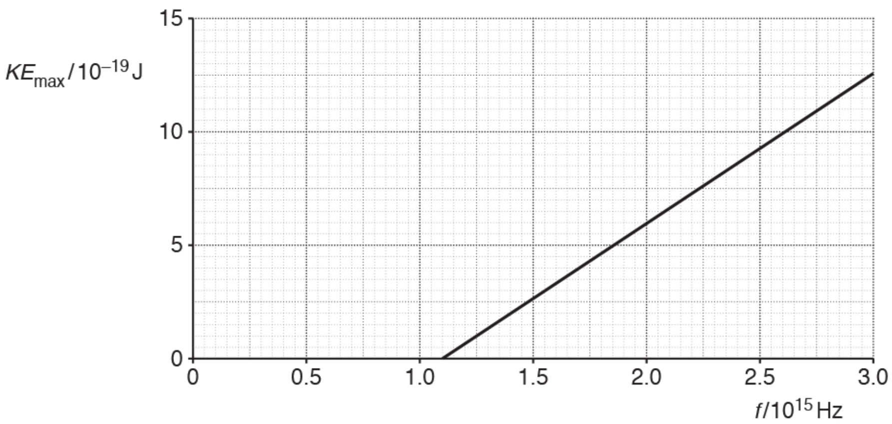

Fig. 6

i. Define the term **threshold frequency**.

[1]

ii. Use Fig. 6 to state the threshold frequency f_0 for silver.

f_0 .... Hz **[1]**

iii. Use your answer in **(ii)** to calculate the work function φ of silver.

Give your answer in electron volt (eV).

φ = ... eV **[2]**

51. Some lasers are used in eye surgery.
One such laser emits a beam of light of wavelength 490 nm and power 230 mW.

Calculate

i. the energy of each photon of light from the laser.

energy = ... J **[2]**

ii. the number of photons of light emitted in each second.

number of photons = ... **[2]**

52. Electromagnetic waves interact with matter as photons.

Explain the photoelectric effect using ideas of **photons, conservation of energy** and **work function**.

----
[4]

53. Fig. 6.1 shows a single photomultiplier tube and its internal components. The tube can detect gamma photons in high-energy physics experiments.
A single gamma photon incident on the scintillator crystal generates many photons of blue light. These visible light photons travel to the photocathode where they are converted into photoelectrons. The number of electrons is then multiplied in the photomultiplier tube with the help of electrodes called dynodes. A short pulse of electric current is produced at the output end of the photomultiplier tube.

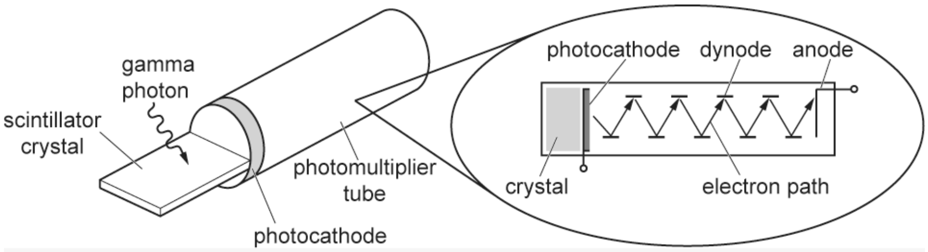

Fig. 6.1

The photocathode is coated with potassium which has a work function of 2.3 eV. Each emitted photoelectron is accelerated by a potential difference of 100 V between the photocathode and a metal plate, called the first dynode.

i. Show that the maximum kinetic energy of an emitted electron at the photocathode is very small compared to its kinetic energy of 100 eV at the first dynode.

[1]

ii. 2000 photoelectrons are released from the photocathode. Each photoelectron has enough energy to release four electrons from the first dynode at the collision. These four electrons are then accelerated to the next dynode where the process is repeated. There are 9 dynodes in the photomultiplier tube. The total number of electrons collected at the anode for each photoelectron is 4^9.

The pulse of electrons at the anode lasts for a time of 2.5×10^{-9} s.

Calculate the average current due to this pulse.

average current = ____________________ A **[3]**

54 (a). This question is about a laser pen.

Green light from the laser pen passes through a pair of narrow slits S_1 and S_2 as shown in Fig. 5.1.

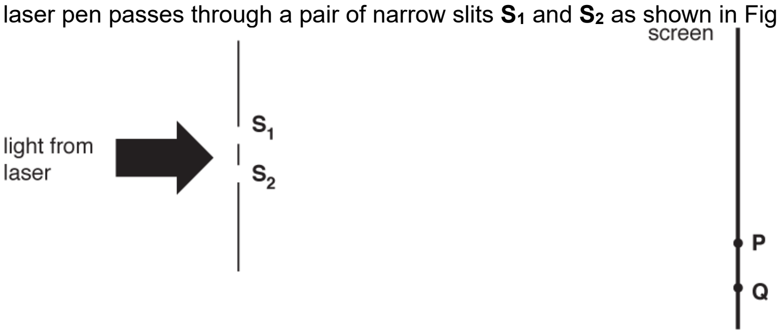

Fig. 5.1

A pattern is produced on a screen consisting of regularly spaced bright and dark lines as shown in Fig. 5.2.

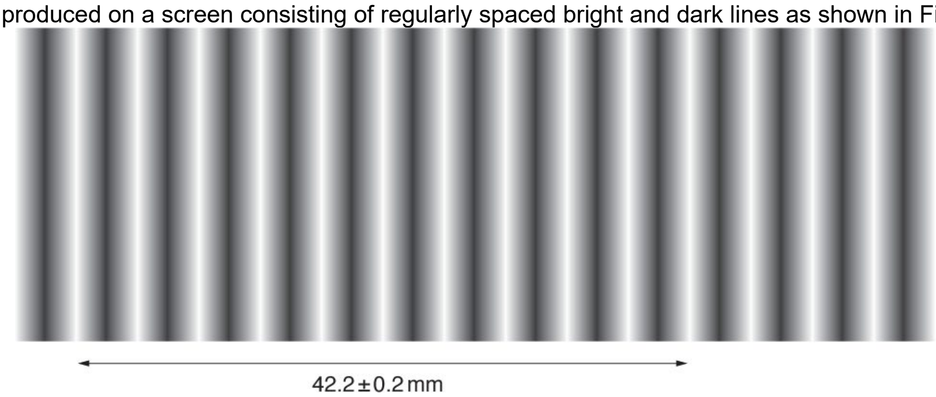

Fig. 5.2

i. Fig. 5.1 shows two points, **P** and **Q**, on the screen. Explain in terms of path difference why point **P** is a bright line and point **Q** is a dark line.

---

[2]

ii. The screen is at a distance of 4.50 ± 0.02 m from the slits and the slit separation is 0.56 ± 0.02 mm.

1. Use Fig. 5.2 to determine the wavelength λ of the light.

λ = ... m **[3]**

2. Determine the percentage uncertainty in λ.

percentage uncertainty = ... % **[2]**

(b). The power of the green light from the laser pen is 50.0 mW. It is now used in a demonstration of the photoelectric effect.

i. Calculate the number of photons *n* that the laser emits per second.

n = ... **[2]**

ii. The green light falls on a negatively charged metal plate with a work function of 2.6 eV. Explain whether photoelectrons will be emitted.

---

[2]

55. A proton with kinetic energy 0.52 MeV is travelling directly towards a stationary nucleus of cobalt-59 $({}^{59}_{27}\text{Co})$ in a head-on collision.

i. Explain what happens to the electric potential energy of the proton-nucleus system.

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[1]

ii. Calculate the **minimum** distance *R* between the proton and cobalt nucleus.

R = ---------------------------- m **[3]**

56. Fig. 20.2 shows a gold-leaf electroscope with a clean zinc plate.

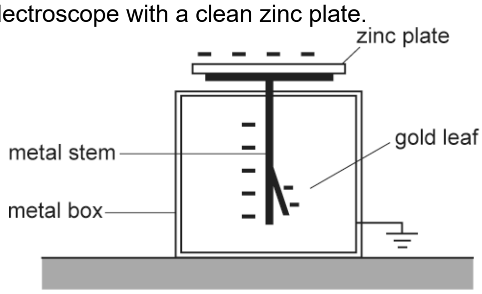

Fig. 20.2

The zinc plate, metal stem and the gold-leaf are given a negative charge by briefly connecting the zinc plate to the negative electrode of a high-voltage supply.

The gold leaf is fully diverged.

The position of the leaf is not affected by intense white light from a table lamp incident on the zinc plate. The gold leaf collapses very quickly when low-intensity ultraviolet radiation from a mercury lamp is incident on the zinc plate.

Explain these observations in terms of photons.

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[4]

57. Electromagnetic radiation of wavelength 300 nm is incident on the surface of two metals **X** and **Y**. Metal **X** has work function 2.0 eV and metal **Y** has work function 5.0 eV.

With the help of calculations, explain any difference between the emission of photoelectrons from the surfaces of the metals **X** and **Y**.

[4]

58. The fusion of two $^{3}_{1}H$ nuclei produces a stable nucleus of $^{4}_{2}He$ and some fast-moving neutrons.

i. Explain why the fusion of the $^{3}_{1}H$ nuclei must produce two neutrons.

[2]

ii. The total energy released in this fusion reaction is 11 MeV. The binding energy per nucleon of the $^{4}_{2}He$ nucleus is 7.1 MeV.

Calculate in J the binding energy per nucleon of the $^{3}_{1}H$ nucleus.

binding energy per nucleon = ... J **[3]**

59. Fig. 21.1 shows some of the energy levels of electrons in hydrogen gas atoms.
The energy levels are labelled **A**, **B**, **C** and **D**.

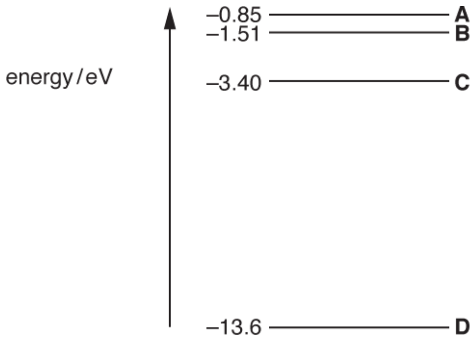


Fig. 21.1 (not to scale)

i. Explain why the energy levels are negative.

---

[1]

ii. An electron makes a transition (jump) from level **C** to level **A**.

1. Calculate the energy gained by this electron.

energy = ... eV **[1]**

iii.

1. Calculate the wavelength in nm of the photon absorbed by this electron.

wavelength = ... nm **[3]**

60. Uranium-235 is used in many fission reactors as fuel and fusion reactors are still at an experimental stage.

i. State one major disadvantage of having fission reactors.

---

[1]

ii. The fission of a uranium-235 nucleus releases about 200 MeV of energy, whereas the fusion of four hydrogen-1 nuclei releases about 28 MeV.
At first sight it would appear that fusion would produce less energy than fission. However the energy released in the fission of one kilogramme of uranium-235 is about eight times less than the energy released in the fusion of one kilogramme of hydrogen-1.

Explain this by considering the initial number of particles in one kilogramme of each.

---

[4]

61. In an electron-gun, each electron is accelerated to a maximum kinetic energy of 210 eV.

i. Show that the final speed of each electron is about 9×10^{6} ms^{-1}.

[3]

ii. Calculate the de Broglie wavelength λ of each electron.

λ = ... m **[2]**

62. Procyon is a star of radius 1.4×10^9 m. The total output power of the electromagnetic radiation from its surface is 2.7×10^{27} W. The average wavelength of the electromagnetic waves from Procyon is 5.0×10^{-7} m.

i. Show that the surface intensity of the radiation from Procyon is 1.1×10^8 W m^{-2}.

[2]

ii. Calculate the energy of a photon of wavelength 5.0×10^{-7} m.

energy = ____________________ J **[2]**

iii. Estimate the total number of photons emitted per second from the surface of Procyon.

number per second = ____________________ s^{-1} **[1]**

63. An LED emits blue light of wavelength 4.7×10^{-7} m.

i. Estimate the number of blue light photons emitted from the LED per second.

number of photons per second = ... s^{-1} **[3]**

ii. The light from the LED is incident on a metal of work function 2.3 eV.

Explain, with the help of a calculation, whether or not photoelectrons will be emitted from the surface of the metal.

[2]

64. Fig. 21.1 shows two oppositely charged ions to the left of a point **X**.

Fig. 21.1

The separation between the centres of the ions is 3.0×10^{-10} m. Each ion has charge of magnitude 1.6×10^{-19} C.

i. Explain why the direction of the **resultant** electric field strength at point **X** is to the left.

[2]

ii. Calculate the minimum energy in eV required to completely separate the ions.

energy = ... eV **[3]**

65. In an experiment, photoelectrons are emitted from the surface of an aluminium plate when electromagnetic radiation of wavelength 98nm falls on the plate.

The work function of aluminium is 4.1 eV.

i. Calculate the maximum kinetic energy KE_{max} in joules (J) of the photoelectrons emitted from the surface of the aluminium.

KE_{max} = ... J **[3]**

ii. The intensity of the electromagnetic radiation falling on the aluminium plate is now decreased without changing its wavelength.

State and explain the change, if any, to the maximum kinetic energy of the photoelectrons.

---

[2]

66. This question is about a photoelectric cell, which is an electronic device that detects photons.
Fig. 6 shows a cross-section through a simple photocell.

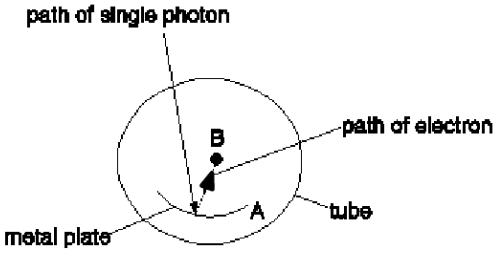


Fig. 6

A metal plate **A** is coated with potassium in an evacuated transparent tube. A photon of high enough energy, incident on the plate, can cause an electron to be released from the surface towards the collector rod **B**.

There is a potential difference of 12 V between plate **A** and rod **B** so that released electrons are accelerated towards and collected by rod **B**. **B** is 5.0 mm from **A.**
Light of wavelength 570 nm is incident on plate **A**.

i. Calculate the speed v of electrons arriving at rod **B**.

v = ... ms^{-1} **[4]**

ii. Estimate the response time of the photocell, that is the time it takes for electrons to travel from **A** to **B**.

response time = ... s **[2]**

67. A researcher is investigating the work function of metals using the photoelectric effect.
The table below shows the threshold frequency f_0 and the work function φ for various metals.

metal	**A**	**B**	**C**	**D**	**E**
f_0 / 10^{14} Hz	4.5	5.6	6.5	8.0	9.7
φ / eV	1.9	2.3	2.7	3.4	4.1

Fig. 27 shows the data points for the metals **A**, **B**, **D** and **E** plotted on a φ against f_0 grid.

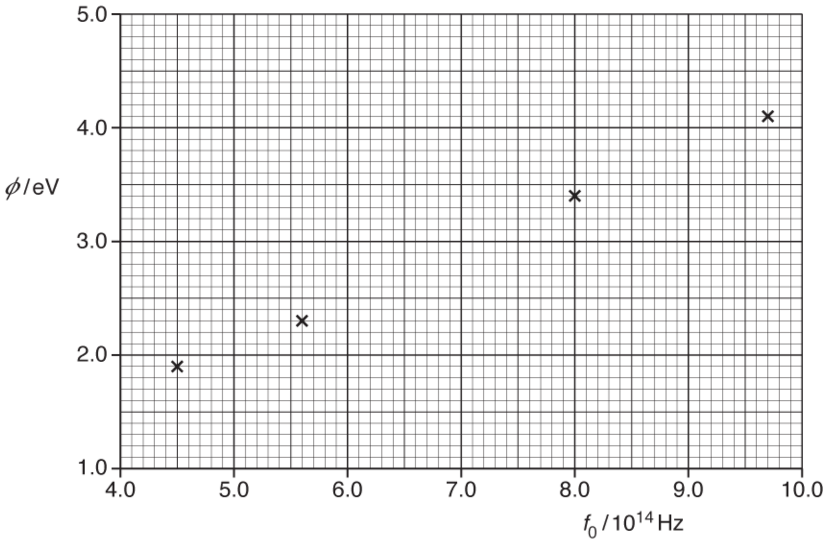


Fig. 27

i. Use Einstein's photoelectric equation to show

$$\varphi = hf_0$$

where h is the Planck constant.

[1]

ii. Plot the data point for C on Fig. 27 and draw the straight line of best fit.

[1]

iii. Use Fig. 27 to determine the experimental value for h.

h = ... J s **[2]**

iv. Explain, without doing any calculations, how you could use Fig. 27 to determine the percentage uncertainty in h.

---

[2]

68. This question is about the brightest wavelength (590 nm) of light from a sodium lamp.

Analysis of the light from the sodium lamp using a diffraction grating shows that there are photons of two different energies at wavelengths 589.0 nm and 589.6 nm.

i. Calculate the energy difference ΔE between these two photons.

ΔE = ... J **[3]**

ii. The light at these wavelengths can be seen as two separate lines when viewed through a diffraction grating. In order to be distinguishable from each other, the angular separation between the lines must be at least 0.02°.

Show that the lines will appear separated in the **second order** spectrum when the sodium lamp is viewed through a grating with 300 lines per millimetre.

[3]

69. Einstein derived the following equation to explain the photoelectric effect:

$$hf = \phi + KE_{max}$$

Electromagnetic radiation of frequency 1.2×10^{15} Hz is incident on the surface of a negatively charged aluminium plate. The work function of aluminium is 4.1 eV.

i. Show that the maximum speed of the electrons emitted from the surface of the aluminium is 5.5×10^5 m s^{-1}.

[4]

ii. State and explain what change, if any, occurs to the maximum speed of the emitted electrons when the intensity of the electromagnetic radiation is increased.

---

[2]

70. Fig. 26.1 shows part of the apparatus for an experiment in which electrons pass through a thin slice of graphite (carbon atoms) and emerge to produce concentric rings on a fluorescent screen.

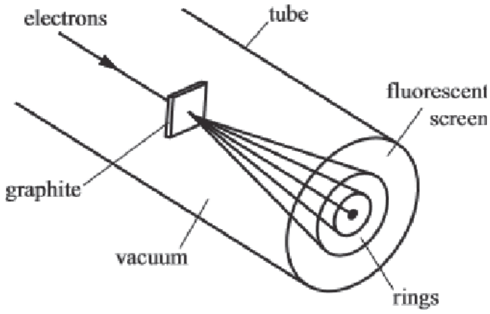


Fig. 26.1

i. Explain how this experiment demonstrates the wave-nature of electrons.

---

[3]

ii. The beam of electrons in the apparatus shown in **Fig. 26.1** is produced by accelerating electrons through a potential difference of 1200 V.

Show that the de Broglie wavelength of the electrons is 3.5×10^{-11} m.

[2]

iii. When de Broglie first put forward his idea it was new to the scientific community. Describe one way in which they could validate his ideas.

---

[1]

71. * The Planck constant h can be measured in an experiment using light-emitting diodes (LEDs).

Each LED used in the experiment emits monochromatic light. The wavelength λ of the emitted photons is determined during the manufacturing process and is provided by the manufacturer.

When the p.d. across the LED reaches a specific minimum value V_{min} the LED suddenly switches on emitting photons of light of wavelength λ.

V_{min} and λ are related by the energy equation $eV_{min} = hc / \lambda$.

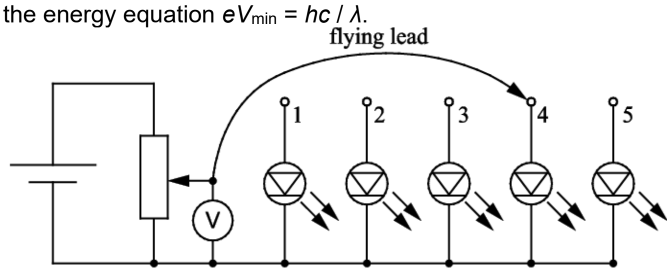


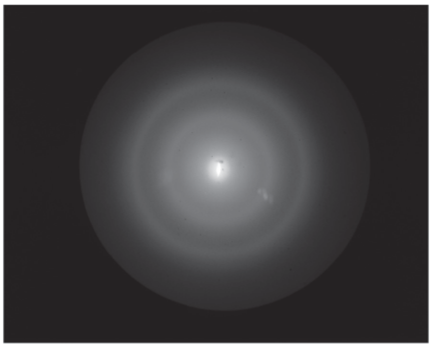
Fig. 7.1

LED	λ / nm	V_{min} / V
1 red	627	1.98
2 yellow	590	2.10
3 green	546	2.27
4 blue	468	2.66
5 violet	411	3.02

Discuss how you could use the circuit of **Fig. 7.1** to determine accurate values for V_{min} and how data from the table can be used graphically to determine a value for the Planck constant.

[6]

72. * A student is investigating electron diffraction. A beam of electrons is directed towards a thin slice of graphite in an evacuated tube.
The electrons are accelerated by a potential difference of 2000 V. The diagram below shows the pattern formed on the fluorescent screen of the evacuated tube.



Describe and explain how the pattern changes as the potential difference is increased. Include how the de Broglie wavelength λ of the electron is related to the potential difference V.

[6]

73. * A gold leaf electroscope is used to demonstrate the photoelectric effect. A zinc plate is placed on top of the electroscope. The zinc plate is negatively charged as shown in Fig. 7.

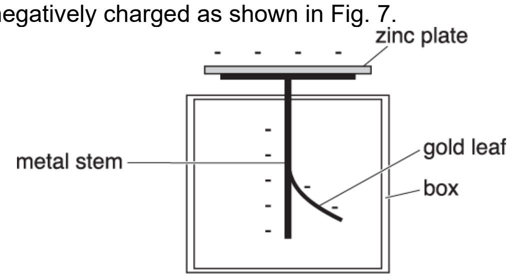


Fig. 7

White light from a table lamp is allowed to fall on to the electroscope from a distance of 10.0 cm. The experiment is then repeated with light from a distance of 4.0 cm. Both experiments are then repeated with ultraviolet radiation. The electroscope is fully charged before each experiment.

The observations are recorded in Table 7.

Incident radiation	Observations
Light at a distance of 10.0 cm	Gold leaf takes a very long time to fall
Light at a distance of 4.0 cm	Gold leaf takes a very long time to fall
Ultraviolet radiation at a distance of 10.0 cm	Gold leaf falls quickly
Ultraviolet radiation at a distance of 4.0 cm	Gold leaf falls very quickly

Table 7

Explain how these observations demonstrate the photoelectric effect and provide evidence for the particulate nature of electromagnetic radiation.

[6]

74. *Two groups of researchers, **A** and **B**, conduct photoelectric effect experiments on a new material. The maximum kinetic energy KE_{max} of the photoelectrons emitted from the material is determined for different frequencies *f* of the electromagnetic radiation incident on the material.

Fig. 19 shows incomplete graphs of KE_{max} against *f* from the groups **A** and **B**.

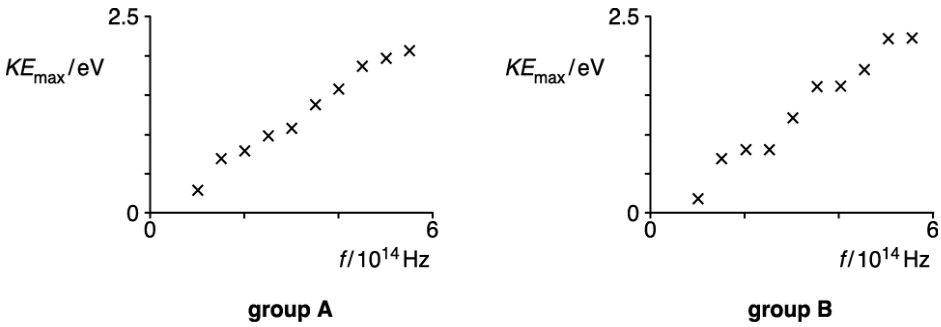


Fig. 19

The value of the Planck constant *h* is determined from the completed KE_{max} against *f* graphs.
The result from each group is shown below.

group A: $h = (6.3 \pm 0.3) \times 10^{-34}$ J s
group B: $h = (6.6 \pm 0.6) \times 10^{-34}$ J s

Explain how a graph of KE_{max} against f can be used to determine h. Discuss the accuracy and precision of the results from each group.

[6]

75. Some nuclear fission reactors use uranium-235 as fuel. In the future, there is possibility of using hydrogen-2 as fuel in fusion reactors.

Here is some information and data on fission and fusion reactions.

	Fission reactor	**Fusion reactor**
Typical reaction	${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{144}_{56}Ba + {}^{89}_{36}Kr + 3{}^{1}_{0}n$	${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{1}H + {}^{1}_{1}H$
Approximate energy produced in each reaction	200 MeV	4 MeV
Molar mass of fuel material	uranium-235: 0.235 kg mol^{-1}	hydrogen-2: 0.002 kg mol^{-1}

- Describe the similarities and the differences between fission and fusion reactions.
- Explain with the help of calculations, which fuel produces more energy per kilogram.

[6]

76. The nuclear reaction below shows how the isotope of fluorine-18 ($^{18}_{9}F$) is made from the isotope of oxygen-18 ($^{18}_{8}O$).

$$^{18}_{8}O + ^{1}_{1}p \rightarrow ^{18}_{9}F + ^{1}_{0}n + \gamma$$

The oxygen-18 nucleus is **stationary** and the proton has kinetic energy of 0.25×10^{-11} J.
The binding energy of the $^{18}_{8}O$ nucleus is 2.24×10^{-11} J and the binding energy of the $^{18}_{9}F$ nucleus is 2.20×10^{-11} J.
The proton and the neutron have zero binding energy.

i. Explain why a high-speed proton is necessary to trigger the nuclear reaction shown above.

---

[2]

ii. Estimate the minimum wavelength λ of the gamma ray photon (γ).

λ = ________________ m **[3]**

iii. Fluorine-18 is a positron emitter.
Name a medical imaging technique that uses fluorine-18 and state one benefit of the technique.

---

[2]

77. A beam of ultraviolet light is incident on a clean metal surface. The graph of **Fig. 7.2** shows how the maximum kinetic energy KE_{max} of the electrons ejected from the surface varies with the frequency f of the incident light.

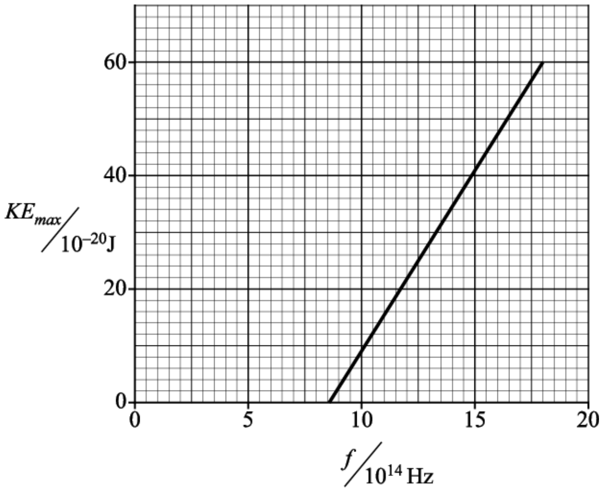


Fig.7.2

i. Explain how the graph shown in **Fig 7.2** cannot be explained in terms of the wave-model for electromagnetic waves.

----

[2]

ii. Use data from **Fig.7.2** to find a value of

1. the Planck constant

Planck constant = ... J s **[2]**

2. the threshold frequency of the metal

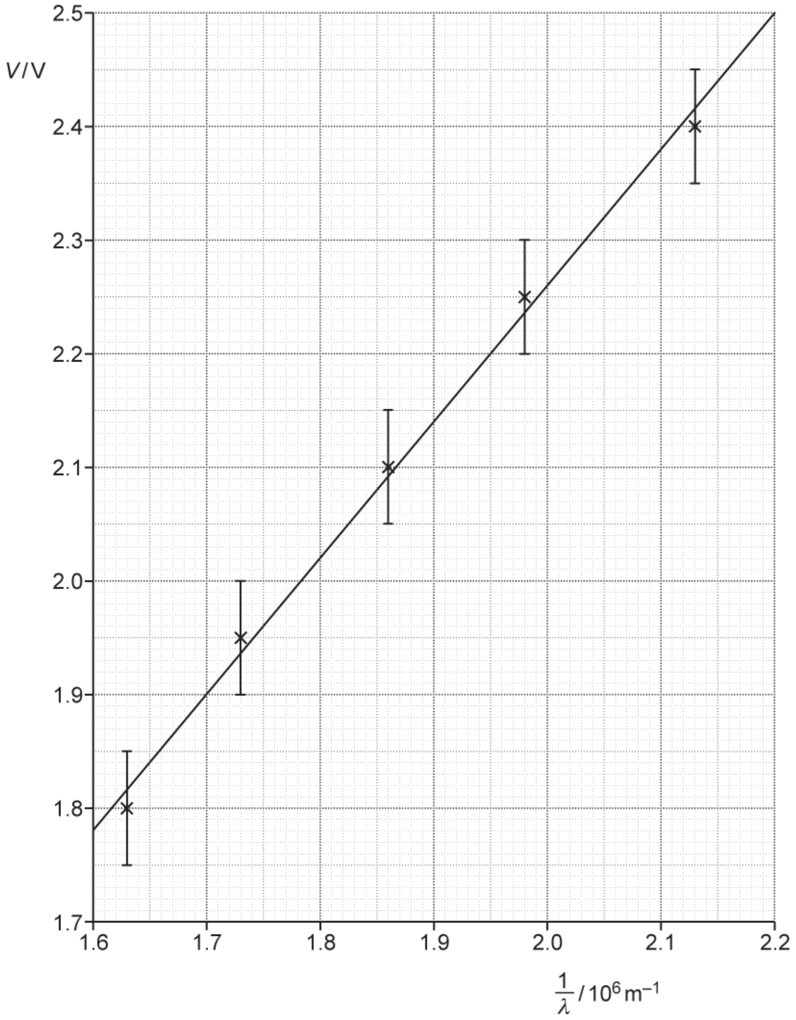
threshold frequency = ... Hz **[1]**

3. the work function of the metal.

work function = ... J **[2]**

78. A student investigates the potential difference across a light emitting diode (LED).
The student records the wavelength λ of the light emitted from the LED from a datasheet.
The student measures the minimum potential difference *V* across the LED when the LED first starts to emit light.
The student then repeats the experiment for LEDs with different values of λ. For each value of λ, the student measures *V* and determines the absolute uncertainty in *V*.

The student plots a graph of potential difference *V* (*y*-axis) against 1/λ (*x*-axis) including the error bars in *V* and a straight line of best fit.



It is suggested that the relationship between *V* and λ is

$$V = \frac{hc}{e}\frac{1}{\lambda} + D$$

where *h* is the Planck constant, *c* is the speed of light in a vacuum, *e* is the elementary charge and *D* is a constant.

i. Show that the gradient of the straight line of best fit is about 1.2×10^{-6} V m.

[2]

ii. Use the gradient from **(i)** to determine a value for *h*.
Write your answer to **2** significant figures.

h = ... Js **[2]**

iii. Draw a worst acceptable straight line.

[1]

iv. Use your worst acceptable straight line to determine the percentage uncertainty in your value for *h*.

v.

percentage uncertainty = ... % **[3]**

79. The work function of potassium is 2.3 eV.

i. Potassium emits electrons from its surface when blue light is incident on it. Extremely intense red light produces no electrons.

Explain these observations in terms of photons and their energy.

---

[4]

ii. Light from a laser is incident on some potassium in a vacuum. Electrons are emitted. The wavelength of the light is 320 nm.

Calculate the shortest de Broglie wavelength of the emitted electrons.

de Broglie wavelength = ... m **[4]**

END OF QUESTION PAPER