Q1.

7 (a) State the de Broglie relation, explaining any symbols you use.

....

....

.... [2]

(b) An electron of mass m has kinetic energy E. Show that the de Broglie wavelength λ of this electron is given by

$$\lambda = \frac{h}{\sqrt{2mE}}.$$

[2]

(c) Calculate the potential difference through which an electron, initially at rest, must be accelerated so that its de Broglie wavelength is equal to 0.40 nm (the diameter of an atom).

potential difference = ... V [3]

Q2.

Us

7 A parallel beam of electrons, all travelling at the same speed, is incident normally on a carbon film. The scattering of the electrons by the film is observed on a fluorescent screen, as illustrated in Fig. 7.1.

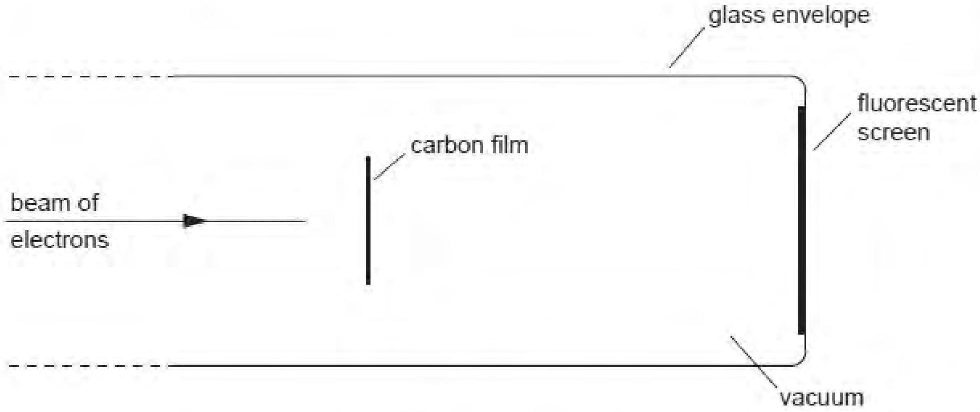

Fig. 7.1

(a) Assuming that the electrons behave as **particles**, predict what would be seen on the screen.

....

.... [1]

(b) In this experiment, the electrons do **not** behave as particles.

Describe briefly the pattern that is actually observed on the screen. You may draw a sketch if you wish.

....

.... [1]

(c) The speed of the electrons is gradually increased.

State and explain what change, if any, is observed in the pattern on the screen.

....

....

....

.... [3]

Q3.

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

....

.... [1]

(ii) Show that the photon energy of light of wavelength 350 nm is 5.68×10^{-19} J. [1]

(iii) State the value of the ratio

$$\frac{\text{energy of photon of light of wavelength 700 nm}}{\text{energy of photon of light of wavelength 350 nm}}.$$

ratio = ... [1]

(b) Two beams of monochromatic light have similar intensities. The light in one beam has wavelength 350 nm and the light in the other beam has wavelength 700 nm.

The two beams are incident separately on three different metal surfaces. The work function of each of these surfaces is shown in Fig. 5.1.

metal	work function / eV
tungsten	4.49
magnesium	3.68
potassium	2.26

Fig. 5.1

(i) Explain what is meant by the *work function* of the surface.

....

....

.... [2]

use

(ii) State which combination, if any, of monochromatic light and metal surface could give rise to photo-electric emission. Give a quantitative explanation of your answer.

....

....

....

....

....

.... [3]

Q4.

7 The Millikan oil-drop experiment enabled the charge on the electron to be determined.

(a) State a fundamental property of charge that was suggested by this experiment.

....

.... [1]

(b) Two parallel metal plates P and Q are situated in a vacuum. The plates are horizontal and separated by a distance of 5.4 mm, as illustrated in Fig. 7.1.

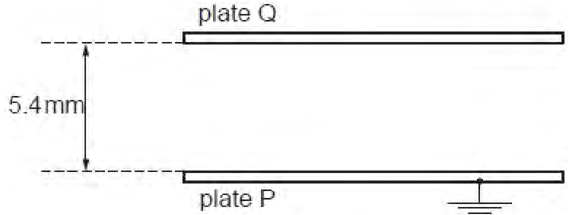

Fig. 7.1

The lower plate P is earthed. The potential difference between the plates can be varied. An oil droplet of mass 7.7×10^{-15} kg is observed to remain stationary between the plates when plate Q is at a potential of +850 V.

(i) Suggest why plates P and Q must be parallel and horizontal.

....

....

.... [2]

(ii) Calculate the charge, with its sign, on the oil droplet.

charge = ... C [3]

(c) The procedure in **(b)** was repeated for three further oil droplets. The magnitude of the charge on each of the droplets was found to be 3.2×10^{-19} C, 6.4×10^{-19} C and 3.2×10^{-19} C.
Explain what value these data and your answer in **(b)(ii)** would suggest for the charge on the electron.

....

....

.... [1]

Q5.

8 **(a)** Explain why, for the photoelectric effect, the existence of a threshold frequency and a very short emission time provide evidence for the particulate nature of electromagnetic radiation, as opposed to a wave theory.

....

....

....

....

....

.... [4]

(b) State and explain two relations in which the Planck constant h is the constant of proportionality.

1. ....

....

....

....

2. ....

....

....

....

[6]

Q6.

7 Experiments are conducted to investigate the photoelectric effect.

(a) It is found that, on exposure of a metal surface to light, either electrons are emitted immediately or they are not emitted at all.

Suggest why this observation does not support a wave theory of light.

....

....

....

.... [3]

(b) Data for the wavelength λ of the radiation incident on the metal surface and the maximum kinetic energy E_K of the emitted electrons are shown in Fig. 7.1.

λ / nm	E_K / 10^{-19} J
650 240	– 4.44

Fig. 7.1

(i) Without any calculation, suggest why no value is given for E_K for radiation of wavelength 650 nm.

....

.... [1]

(ii) Use data from Fig. 7.1 to determine the work function energy of the surface.

work function energy = ... J [3]

(c) Radiation of wavelength 240 nm gives rise to a maximum photoelectric current I.
The intensity of the incident radiation is maintained constant and the wavelength is now reduced.

State and explain the effect of this change on

(i) the maximum kinetic energy of the photoelectrons,

....

....

.... [2]

(ii) the maximum photoelectric current I.

....

....

.... [2]

Q7.

7 (a) State what is meant by the *de Broglie wavelength*.

....

....

.... [2]

(b) An electron is accelerated in a vacuum from rest through a potential difference of 850 V.

(i) Show that the final momentum of the electron is 1.6×10^{-23} N s.

[2]

(ii) Calculate the de Broglie wavelength of this electron.

wavelength = ... m [2]

(c) Describe an experiment to demonstrate the wave nature of electrons.
You may draw a diagram if you wish.

....

....

....

....

....

.... [5]

Q8.

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

....

....

....

.... [3]

(b) An emission spectrum is seen as a series of differently coloured lines on a black background.

Suggest how this observation provides evidence for discrete electron energy levels in atoms.

....

....

....

.... [2]

Q9.

6 **(a)** Describe the main principles of the determination of the charge on an oil drop by Millikan's experiment. You may draw a diagram if you wish.

....

....

....

....

....

....

....

....

....

....

....[7]

(b) In an experiment to determine the fundamental charge, values of charge on oil drops were found by a student to be as shown below.

3.2×10^{-19} C; 6.4×10^{-19} C; 16×10^{-19} C; 9.7×10^{-19} C;

12.8×10^{-19} C; 3.1×10^{-19} C; 6.3×10^{-19} C.

State the value, to two significant figures, of the fundamental charge that is suggested by these values of charge on oil drops.

fundamental charge = ... C [1]

Q10.

7 The photoelectric effect may be represented by the equation

photon energy = work function energy + maximum kinetic energy of electron.

(a) State what is meant by *work function energy*.

....

....[1]

F
Exan
U

(b) The variation with frequency *f* of the maximum kinetic energy E_K of photoelectrons emitted from the surface of sodium metal is shown in Fig. 7.1.

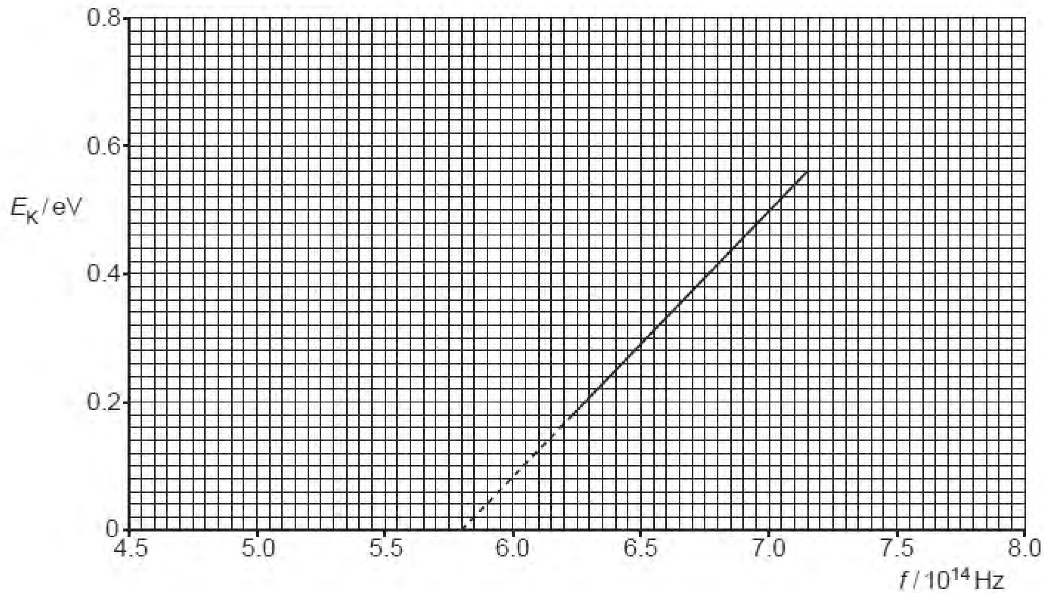

Fig. 7.1

Use the gradient of the graph of Fig. 7.1 to determine a value for the Planck constant *h*. Show your working.

h = ... J s [2]

(c) The sodium metal in **(b)** has a work function energy of 2.4 eV. The sodium is replaced by calcium which has a work function energy of 2.9 eV.

On Fig. 7.1, draw a line to show the variation with frequency *f* of the maximum kinetic energy E_K of photoelectrons emitted from the surface of calcium. [3]

Q11.

7 Some data for the work function energy Φ and the threshold frequency f_0 of some metal surfaces are given in Fig. 7.1.

metal	Φ / 10^{-19} J	f_0 / 10^{14} Hz
sodium	3.8	5.8
zinc	5.8	8.8
platinum	9.0	

Fig. 7.1

(a) **(i)** State what is meant by the *threshold frequency*.

....

....

.... [2]

(ii) Calculate the threshold frequency for platinum.

threshold frequency = ... Hz [2]

(b) Electromagnetic radiation having a continuous spectrum of wavelengths between 300 nm and 600 nm is incident, in turn, on each of the metals listed in Fig. 7.1.
Determine which metals, if any, will give rise to the emission of electrons.

....

....

....

.... [2]

(c) When light of a particular intensity and frequency is incident on a metal surface, electrons are emitted.
State and explain the effect, if any, on the rate of emission of electrons from this surface for light of the same intensity and higher frequency.

....

....

....

.... [3]

Q12.

7 **(a)** The emission spectrum of atomic hydrogen consists of a number of discrete wavelengths.
Explain how this observation leads to an understanding that there are discrete electron energy levels in atoms.

For Examiner's Use

....

....

....

.... [2]

(b) Some electron energy levels in atomic hydrogen are illustrated in Fig. 7.1.

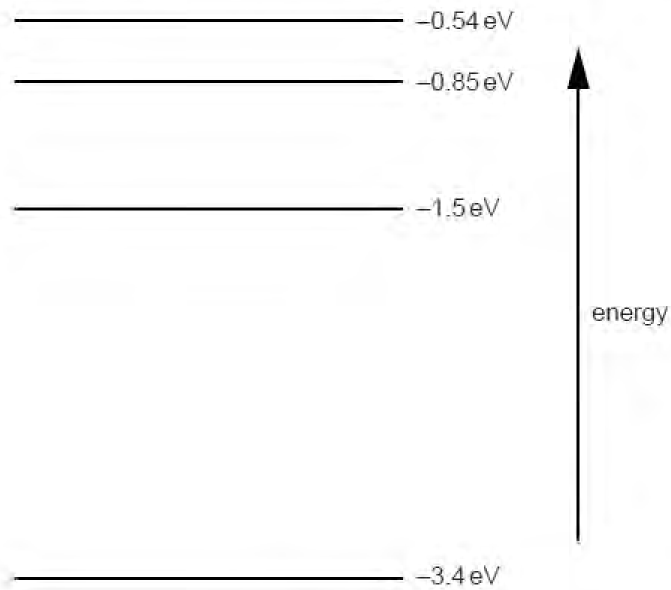

Fig. 7.1

The longest wavelength produced as a result of electron transitions between two of the energy levels shown in Fig. 7.1 is 4.0×10^{-6} m.

For Examiner Use

(i) On Fig. 7.1,

1. draw, and mark with the letter L, the transition giving rise to the wavelength of 4.0×10^{-6} m, [1]

2. draw, and mark with the letter S, the transition giving rise to the shortest wavelength. [1]

(ii) Calculate the wavelength for the transition you have shown in **(i) part 2**.

wavelength = ... m [3]

(c) Photon energies in the visible spectrum vary between approximately 3.66 eV and 1.83 eV.

Determine the energies, in eV, of photons in the visible spectrum that are produced by transitions between the energy levels shown in Fig. 7.1.

photon energies .... eV [2]

Q13.

2 Fig. 2.1 gives information on three lines observed in the emission spectrum of hydrogen atoms.

Use

wavelength / nm	photon energy / 10^{-19} J
656	3.03
486	....
1880	1.06

Fig. 2.1

(a) Complete Fig. 2.1 by calculating the photon energy for the wavelength of 486 nm.

[2]

(b) Fig. 2.2 is a partially completed diagram to show energy levels of a hydrogen atom.

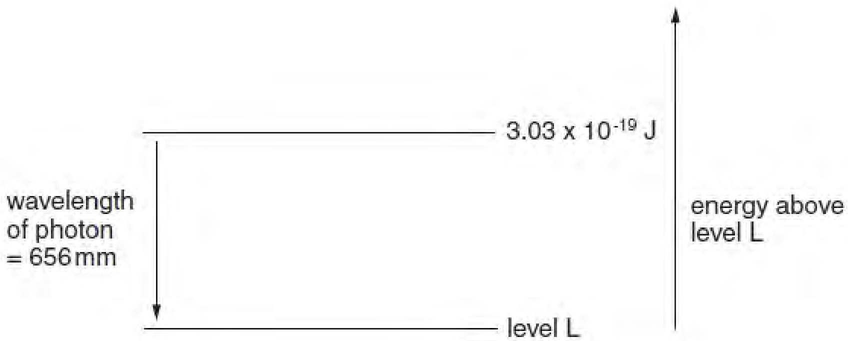

Fig. 2.2

On Fig. 2.2 draw one further labelled energy level, and complete the diagram with arrows to show the energy changes for the other two wavelengths. [3]

Q14.

6 **(a)** Explain what is meant by a *photon* of electromagnetic radiation.

....

....

.... [2]

(b) The photoelectric effect provides evidence for the particulate nature of electromagnetic radiation. State three experimental observations that support this conclusion.

1. ....

....

2. ....

....

3. ....

.... [3]

(c) Electromagnetic radiation of wavelength λ and intensity I, when incident on a metal surface, causes n electrons to be ejected per unit time. The maximum kinetic energy of the electrons is E_{max}.

State and explain the effect, if any, on n and E_{max} when

(i) the intensity is reduced to $\frac{1}{2}I$ but the wavelength λ is unchanged,

....

....

....

(ii) the wavelength λ is reduced but the intensity I is not changed.

....

....

....

[4]

Q15.

7 The photoelectric effect may be summarised in terms of the word equation

photon energy = work function energy + maximum kinetic energy of emitted electrons.

(a) Explain

(i) what is meant by a *photon*,

....

....

.... [2]

(ii) why most electrons are emitted with kinetic energy less than the maximum.

....

....

.... [2]

(b) Light of constant intensity is incident on a metal surface, causing electrons to be emitted.

State and explain why the rate of emission of electrons changes as the frequency of the incident light is increased.

....

....

.... [2]

Q16.

7 **(a)** State three pieces of evidence provided by the photoelectric effect for a particulate nature of electromagnetic radiation.

For Examiner's Use

1. ....

....

2. ....

....

3. ....

....
[3]

(b) **(i)** Briefly describe the concept of a photon.

....

....

....[2]

(ii) Explain how lines in the emission spectrum of gases at low pressure provide evidence for discrete electron energy levels in atoms.

....

....

....[2]

(c) Three electron energy levels in atomic hydrogen are represented in Fig. 7.1.

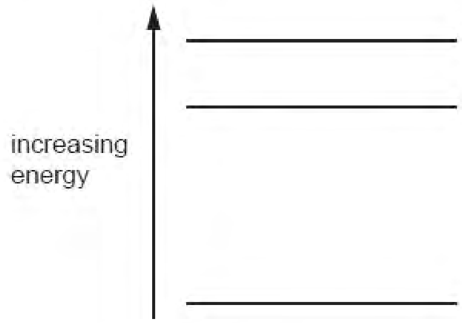

Fig. 7.1

The wavelengths of the spectral lines produced by electron transitions between these three energy levels are 486 nm, 656 nm and 1880 nm.

(i) On Fig. 7.1, draw arrows to show the electron transitions between the energy levels that would give rise to these wavelengths.
Label each arrow with the wavelength of the emitted photon. [3]

(ii) Calculate the maximum change in energy of an electron when making transitions between these levels.

energy = ... J [3]

Q17.

7 **(a)** Explain how a line emission spectrum leads to an understanding of the existence of discrete electron energy levels in atoms.

....

....

....

.... [3]

(b) Some of the lines of the emission spectrum of atomic hydrogen are shown in Fig. 7.1.

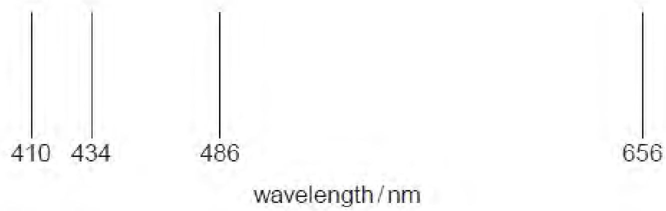

Fig. 7.1

The photon energies associated with some of these lines are shown in Fig. 7.2.

wavelength / nm	photon energy / 10^{-19} J
410	4.85
434	4.58
486	....
656	3.03

Fig. 7.2

(i) Complete Fig. 7.2 by calculating the photon energy for a wavelength of 486 nm.

[2]

(ii) Energy levels of a single electron in a hydrogen atom are shown in Fig. 7.3.

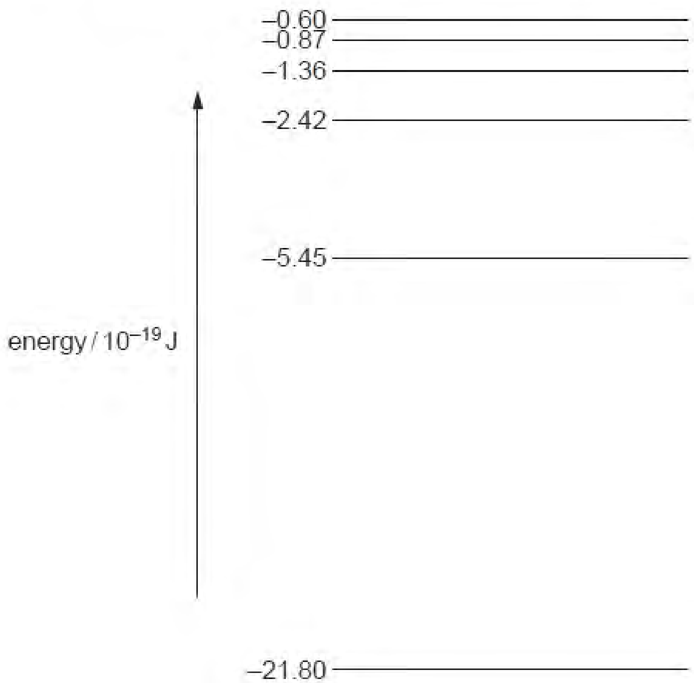

Fig. 7.3 (not to scale)

Use data from **(i)** to show, on Fig. 7.3, the transitions associated with each of the four spectral lines shown in Fig. 7.1. Show each transition with an arrow. [2]

Q18.

7 **(a)** State an effect, one in each case, that provides evidence for

For Examiner Use

(i) the wave nature of a particle,

.... [1]

(ii) the particulate nature of electromagnetic radiation.

.... [1]

(b) Four electron energy levels in an atom are shown in Fig. 7.1.

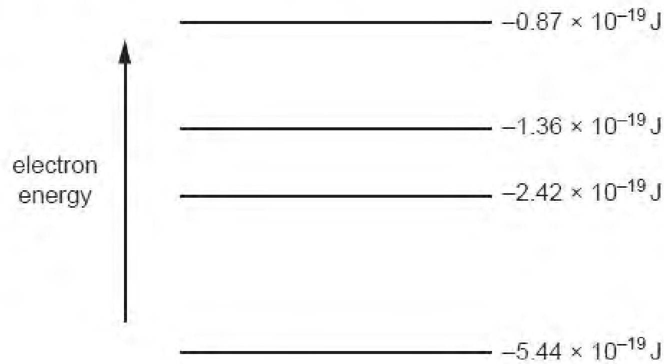

Fig. 7.1 (not to scale)

An emission spectrum is associated with the electron transitions between these energy levels.
For this spectrum,

(i) state the number of lines,

.... [1]

(ii) calculate the minimum wavelength.

wavelength = ... m [2]

Q19.

8 **(a)** By reference to the photoelectric effect, state what is meant by the *threshold frequency*.

....

....

.... [2]

(b) The surface of a zinc plate has a work function of 5.8×10^{-19} J.
In a particular laboratory experiment, ultraviolet light of wavelength 120 nm is incident on the zinc plate. A photoelectric current I is detected.
In order to view the apparatus more clearly, a second lamp emitting light of wavelength 450 nm is switched on. No change is made to the ultraviolet lamp.

Using appropriate calculations, state and explain the effect on the photoelectric current of switching on this second lamp.

....

.... [4]

Q20.

7 **(a)** Explain how the line spectrum of hydrogen provides evidence for the existence of discrete electron energy levels in atoms.

....

....

....

....

.... [3]

(b) Some electron energy levels in atomic hydrogen are illustrated in Fig. 7.1.

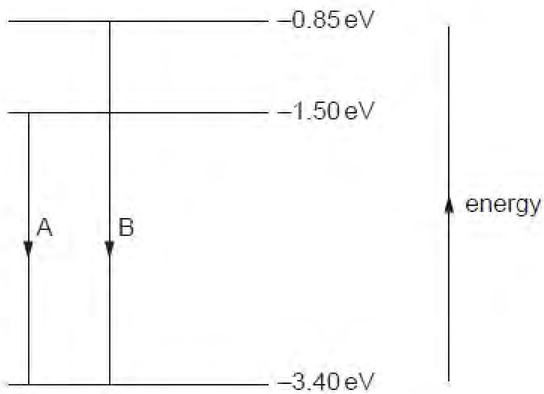

Fig. 7.1

Two possible electron transitions A and B giving rise to an emission spectrum are shown.
These electron transitions cause light of wavelengths 654 nm and 488 nm to be emitted.

(i) On Fig. 7.1, draw an arrow to show a third possible transition. [1]

(ii) Calculate the wavelength of the emitted light for the transition in **(i)**.

wavelength = ... m [3]

(c) The light in a beam has a continuous spectrum of wavelengths from 400 nm to 700 nm. The light is incident on some cool hydrogen gas, as illustrated in Fig. 7.2.

Fig. 7.2

Using the values of wavelength in **(b)**, state and explain the appearance of the spectrum of the emergent light.

....

....

....

....

....

.... [4]

Q21.

7 An explanation of the photoelectric effect includes the terms photon energy and work function energy.

(a) Explain what is meant by

(i) a *photon*,

....

....

.... [2]

(ii) *work function energy*.

....

.... [1]

(b) In an experiment to investigate the photoelectric effect, a student measures the wavelength λ of the light incident on a metal surface and the maximum kinetic energy E_{max} of the emitted electrons. The variation with E_{max} of $\frac{1}{\lambda}$ is shown in Fig. 7.1.

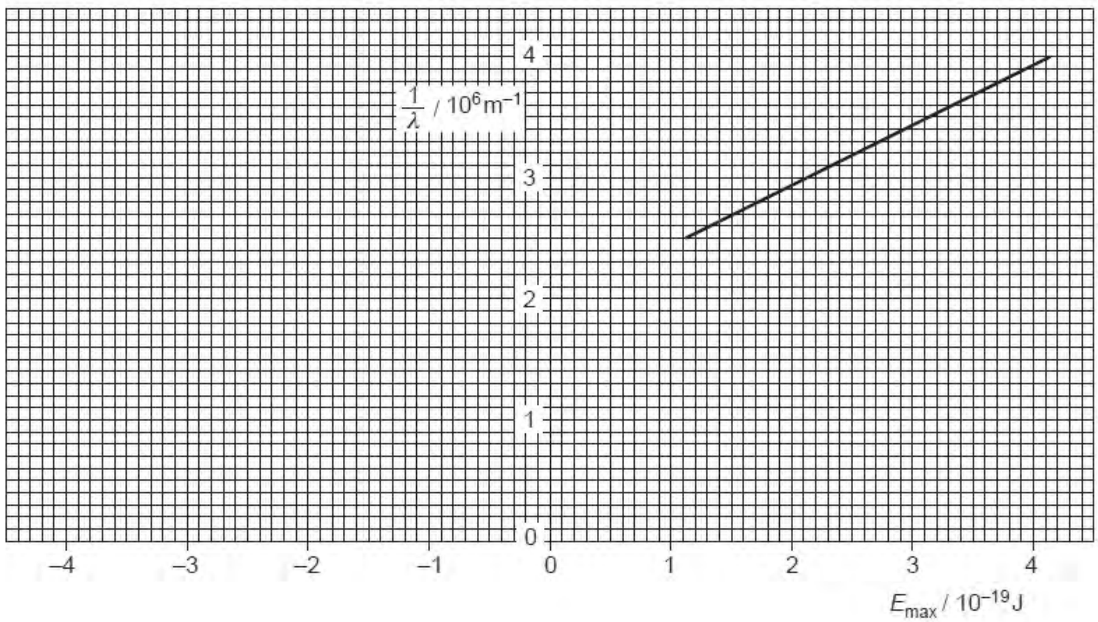

Fig. 7.1

(i) The work function energy of the metal surface is Φ.
State an equation, in terms of λ, Φ and E_{max}, to represent conservation of energy for the photoelectric effect. Explain any other symbols you use.

....

....

.... [2]

(ii) Use your answer in **(i)** and Fig. 7.1 to determine

1. the work function energy Φ of the metal surface,

Φ = ... J [2]

2. a value for the Planck constant.

Planck constant = ... J s [3]

Q22.

8 **(a)** State what is meant by a *photon*.

....

....

.... [2]

(b) It has been observed that, where photoelectric emission of electrons takes place, there is negligible time delay between illumination of the surface and emission of an electron.

State three other pieces of evidence provided by the photoelectric effect for the particulate nature of electromagnetic radiation.

1. ....

....

2. ....

....

3. ....

....

[3]

(c) The work function of a metal surface is 3.5 eV. Light of wavelength 450 nm is incident on the surface.
Determine whether electrons will be emitted, by the photoelectric effect, from the surface.

[3]

Q23.

7 **(a)** State what is meant by the *de Broglie wavelength*.

For Examiner's Use

....

....

....[2]

(b) An electron is accelerated from rest in a vacuum through a potential difference of 4.7 kV.

(i) Calculate the de Broglie wavelength of the accelerated electron.

wavelength = ... m [5]

(ii) By reference to your answer in **(i)**, suggest why such electrons may assist with an understanding of crystal structure.

....

....

....

....[2]

Q24.

7 Electrons, travelling at speed v in a vacuum, are incident on a very thin carbon film, as illustrated in Fig. 7.1.

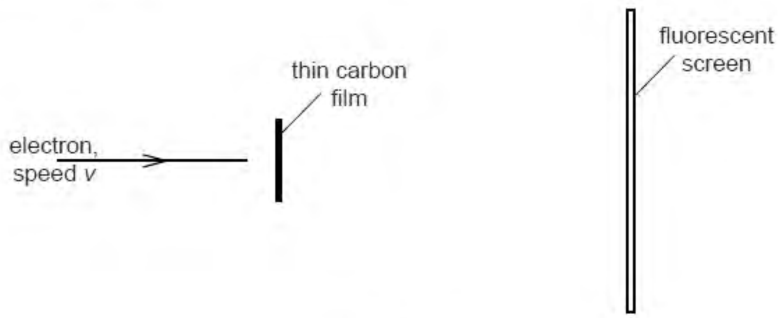

Fig. 7.1

The emergent electrons are incident on a fluorescent screen.
A series of concentric rings is observed on the screen.

(a) Suggest why the observed rings provide evidence for the wave nature of particles.

....

....

....

.... [2]

(b) The initial speed of the electrons is increased. State and explain the effect, if any, on the radii of the rings observed on the screen.

....

....

....

.... [3]

(c) A proton and an electron are each accelerated from rest through the same potential difference.
Determine the ratio

$$\frac{\text{de Broglie wavelength of the proton}}{\text{de Broglie wavelength of the electron}}.$$

ratio = ... [4]

For Examiner's Use

Q25.

7 (a) By reference to the photoelectric effect, explain

(i) what is meant by *work function energy*,

....

....

.... [2]

(ii) why, even when the incident light is monochromatic, the emitted electrons have a range of kinetic energy up to a maximum value.

....

....

.... [2]

For Examiner's Use

(b) Electromagnetic radiation of frequency f is incident on a metal surface. The variation with frequency f of the maximum kinetic energy E_{MAX} of electrons emitted from the surface is shown in Fig. 7.1.

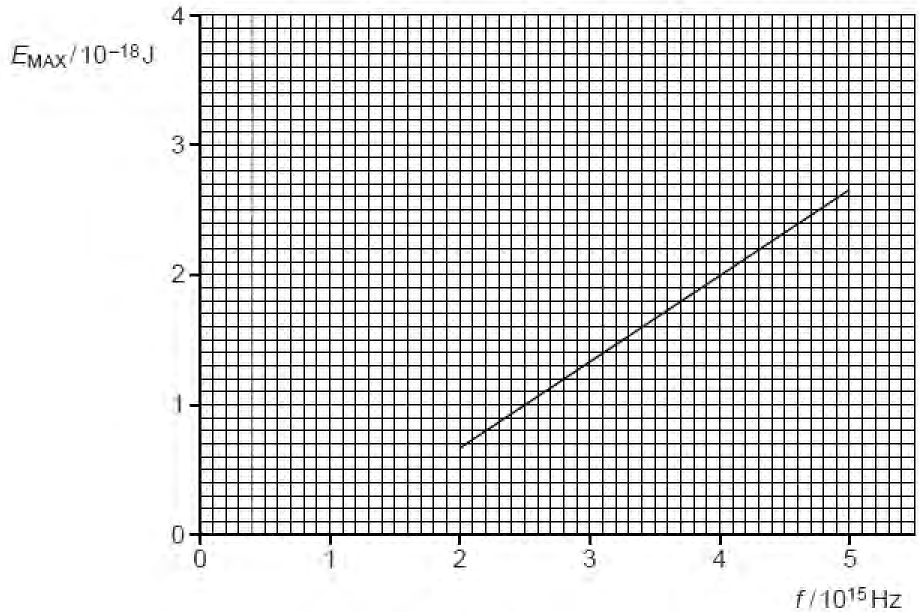

Fig. 7.1

(i) Use Fig. 7.1 to determine the work function energy of the metal surface.

For Examiner's Use

work function energy = ... J [3]

(ii) A second metal has a greater work function energy than that in **(i)**.
On Fig. 7.1, draw a line to show the variation with f of E_{MAX} for this metal. [2]

(iii) Explain why the graphs in **(i)** and **(ii)** do not depend on the intensity of the incident radiation.

....

....

.... [2]

Q26.

8 **(a)** State what is meant by *quantisation* of charge.

....

.... [1]

(b) A student carries out an experiment to determine the elementary charge.
A charged oil drop is positioned between two horizontal metal plates, as shown in Fig. 8.1.

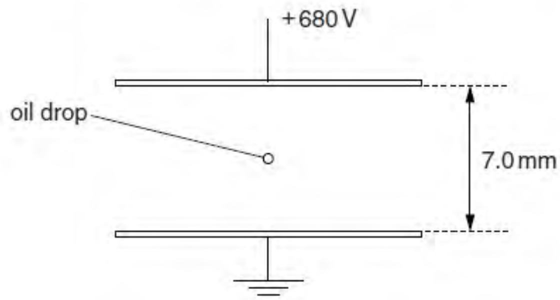

Fig. 8.1

The plates are separated by a distance of 7.0 mm. The lower plate is earthed.
The potential of the upper plate is gradually increased until the drop is held stationary. The potential for the drop to be stationary is 680 V.
The weight of the oil drop, allowing for the upthrust of the air, is 4.8×10^{-14} N.
Calculate the value for the charge on the oil drop.

charge = ... C [2]

(c) The student repeats the experiment and determines the following values for the charge on oil drops.

3.3×10^{-19} C 4.9×10^{-19} C 9.7×10^{-19} C 3.4×10^{-19} C

Use these values to suggest a value for the elementary charge. Explain your working.

elementary charge = ... C [2]

Q27.

9 For a particular metal surface, it is observed that there is a minimum frequency of light below which photoelectric emission does not occur. This observation provides evidence for a particulate nature of electromagnetic radiation.

(a) State three further observations from photoelectric emission that provide evidence for a particulate nature of electromagnetic radiation.

1. ....

....

2. ....

....

3. ....

.... [3]

(b) Some data for the variation with frequency *f* of the maximum kinetic energy E_{MAX} of electrons emitted from a metal surface are shown in Fig. 9.1.

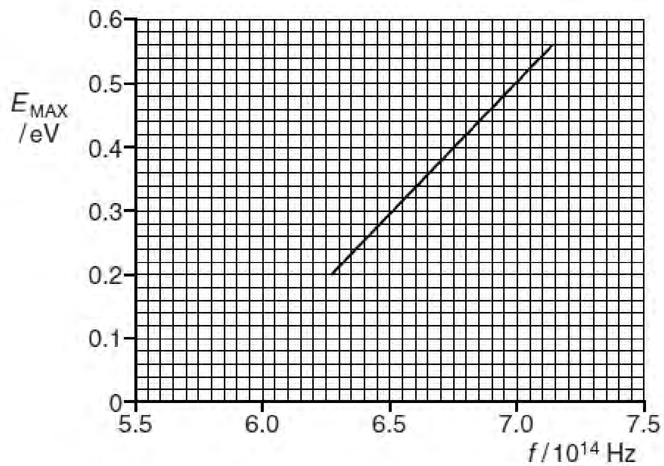

Fig. 9.1

(i) Explain why emitted electrons may have kinetic energy less than the maximum at any particular frequency.

....

....

.... [2]

(ii) Use Fig. 9.1 to determine

1. the threshold frequency,

threshold frequency = ... Hz [1]

2. the work function energy, in eV, of the metal surface.

work function energy = ... eV [3]

Q28.

8 Light of wavelength 590nm is incident normally on a surface, as illustrated in Fig. 8.1.

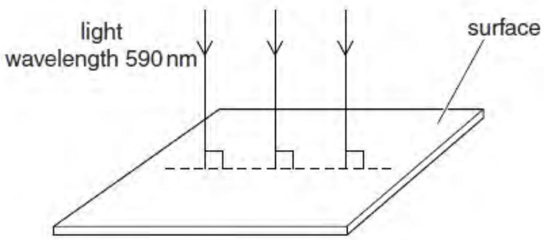

Fig. 8.1

The power of the light is 3.2mW. The light is completely absorbed by the surface.

(a) Calculate the number of photons incident on the surface in 1.0s.

number = ... [3]

(b) Use your answer in **(a)** to determine

(i) the total momentum of the photons arriving at the surface in 1.0s,

momentum = ... $kg\,m\,s^{-1}$ [3]

(ii) the force exerted on the surface by the light.

force = ... N [1]

Q29.

8 White light is incident on a cloud of cool hydrogen gas, as illustrated in Fig. 8.1.

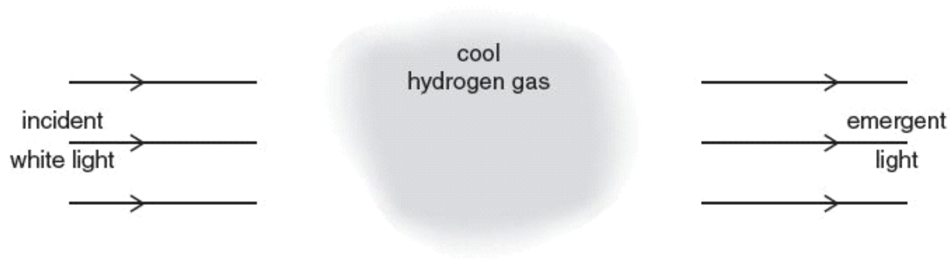

Fig. 8.1

The spectrum of the light emerging from the gas cloud is found to contain a number of dark lines.

(a) Explain why these dark lines occur.

....

....

....

....

.... [3]

(b) Some electron energy levels in a hydrogen atom are illustrated in Fig. 8.2.

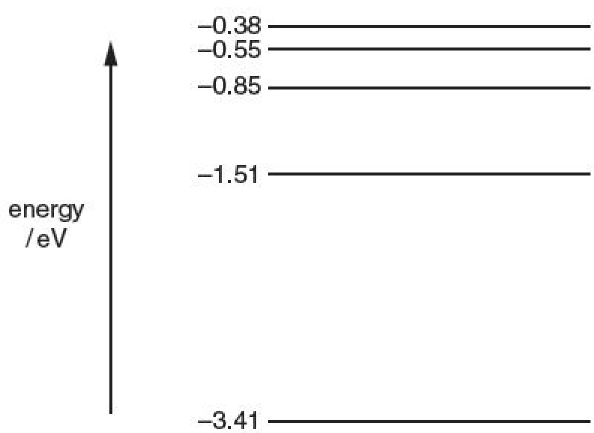

Fig. 8.2

One dark line is observed at a wavelength of 435 nm.

(i) Calculate the energy, in eV, of a photon of light of wavelength 435 nm.

energy = ... eV [4]

(ii) On Fig. 8.2, draw an arrow to indicate the energy change that gives rise to this dark line. [1]

Q30.

7 (a) State what is meant by *quantisation* of charge.

....

.... [1]

(b) Charged parallel plates, as shown in Fig. 7.1, produce a uniform electric field between the plates.

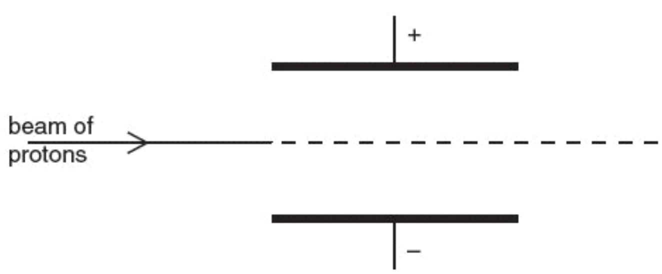

Fig. 7.1

The electric field outside the region between the plates is zero.
A uniform magnetic field is applied in the region between the plates so that a beam of protons passes undeviated between the plates.

(i) State and explain the direction of the magnetic field between the plates.

....

....

.... [2]

(ii) The magnetic flux density between the plates is now increased.

On Fig. 7.1, sketch the path of the protons between the plates. [2]

Q31.

8 (a) State what is meant by a *photon*.

....

....

.... [2]

(b) A beam of light is incident normally on a metal surface, as illustrated in Fig. 8.1.

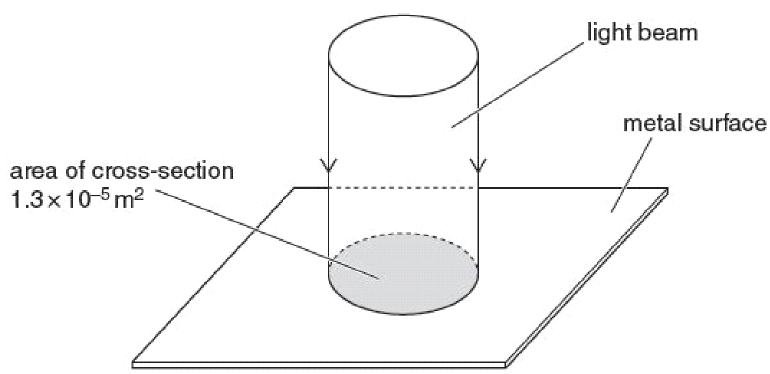

Fig. 8.1

The beam of light has cross-sectional area $1.3 \times 10^{-5}\,m^2$ and power $2.7 \times 10^{-3}\,W$.
The light has wavelength 570 nm.

The light energy is absorbed by the metal and no light is reflected.

(i) Show that a photon of this light has an energy of 3.5×10^{-19} J.

[1]

(ii) Calculate, for a time of 1.0 s,

1. the number of photons incident on the surface,

number = ... [2]

2. the change in momentum of the photons.

change in momentum = ... $kg\,m\,s^{-1}$ [3]

(c) Use your answer in **(b)(ii)** to calculate the pressure that the light exerts on the metal surface.

pressure = ... Pa [2]

Q32.

1 **(a)** State the significance of the Millikan experiment.

....

.... [1]

(b) In the Millikan experiment, oil droplets were found to have the following charges.

1.56×10^{-19} C
4.88×10^{-19} C
1.64×10^{-19} C
3.14×10^{-19} C
4.76×10^{-19} C

Use these data to determine a value for the elementary charge. Explain your working.

....

....

elementary charge = ... C [2]