 For Examiner's Use

1 Electrons are emitted from a metal surface when it is illuminated with suitable electromagnetic radiation.

(a) Name the effect described above.

....[1]

(b) The variation with frequency *f* of the maximum kinetic energy E_k of the emitted electrons is shown in Fig. 7.1.

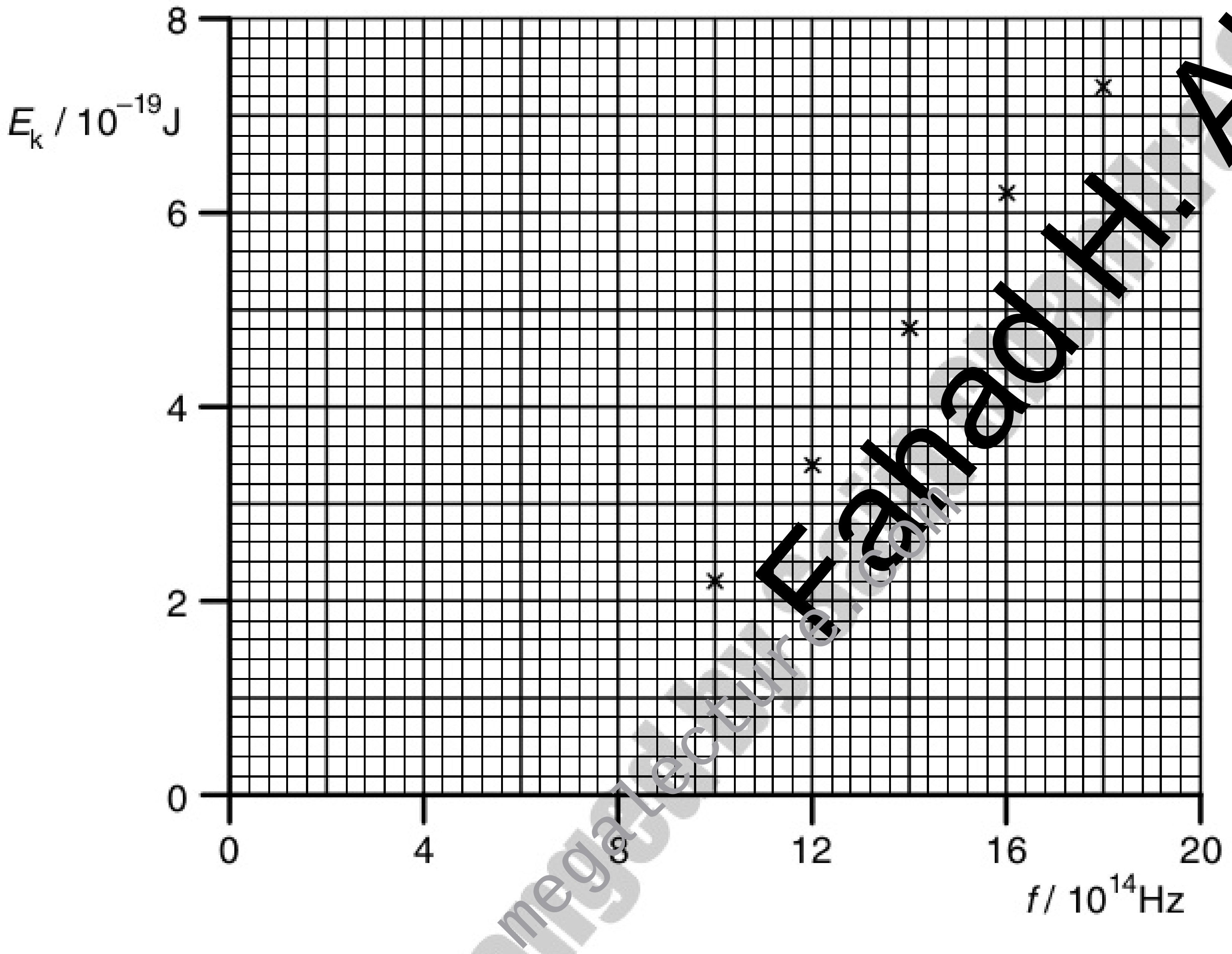

Fig. 7.1

Use Fig. 7.1 to determine

(i) the threshold frequency of the radiation,

threshold frequency = ... Hz

(ii) a value for the Planck constant.

Planck constant = ... J s
[4]

(c) On Fig. 7.1, draw a line to show the variation with frequency *f* of the maximum kinetic energy E_k of the emitted electrons for a second metal which has a lower work function than that in **(b)**. [2]

(d) The kinetic energy of the electrons is described as the maximum. Suggest why emitted electrons are likely to have a range of values of kinetic energy for any one frequency of the electromagnetic radiation.

....

....

....[2]

2 **(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]

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

....

.... [1]

(ii) Show that the photon energy of light of wavelength 350nm 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 350nm and the light in the other beam has wavelength 700nm.

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]

For Examiner's 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]

For Examiner's Use

4 **(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]

5 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]

For Examiner's Use

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

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.

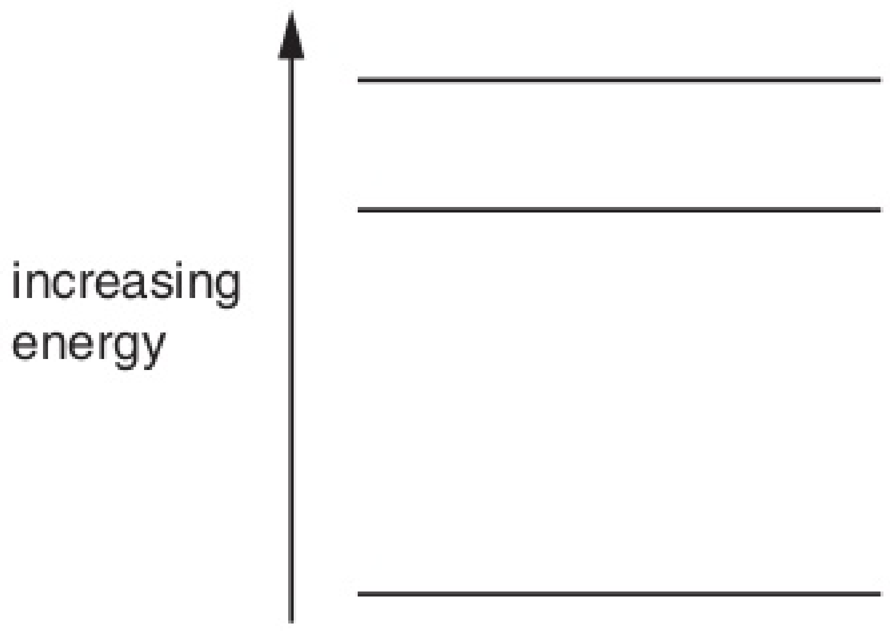

Fig. 7.1

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]

For Examiner's Use

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.

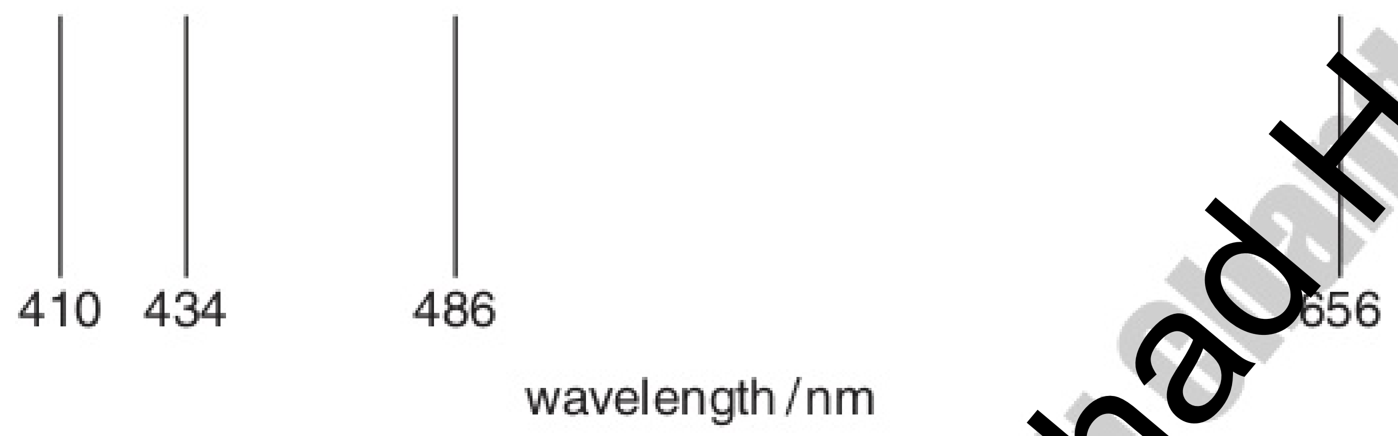

Fig. 7.1

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]

For Examiner's Use

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

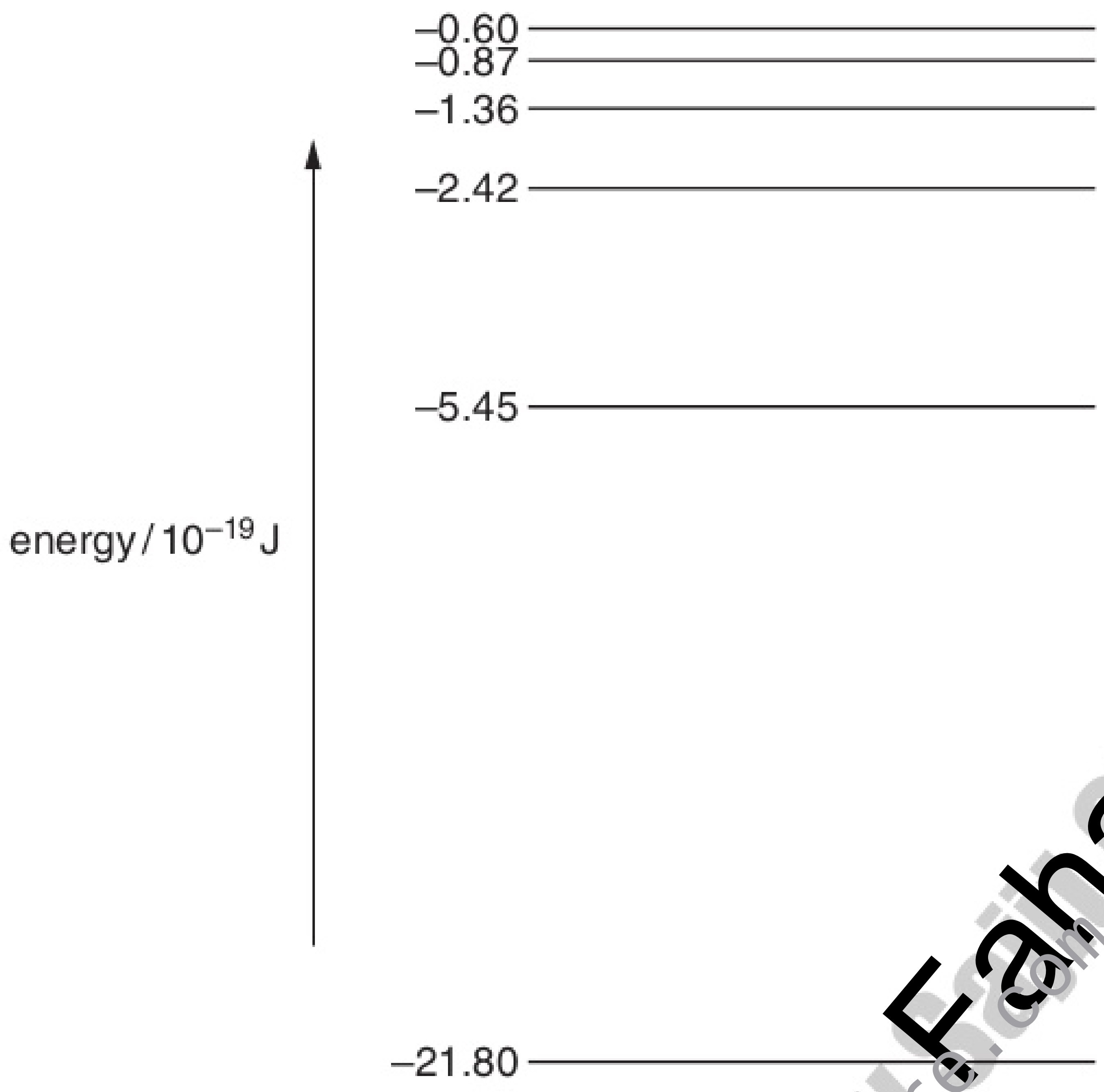

Fig. 7.3 (not to scale)

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]

For Examiner's Use

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

(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.

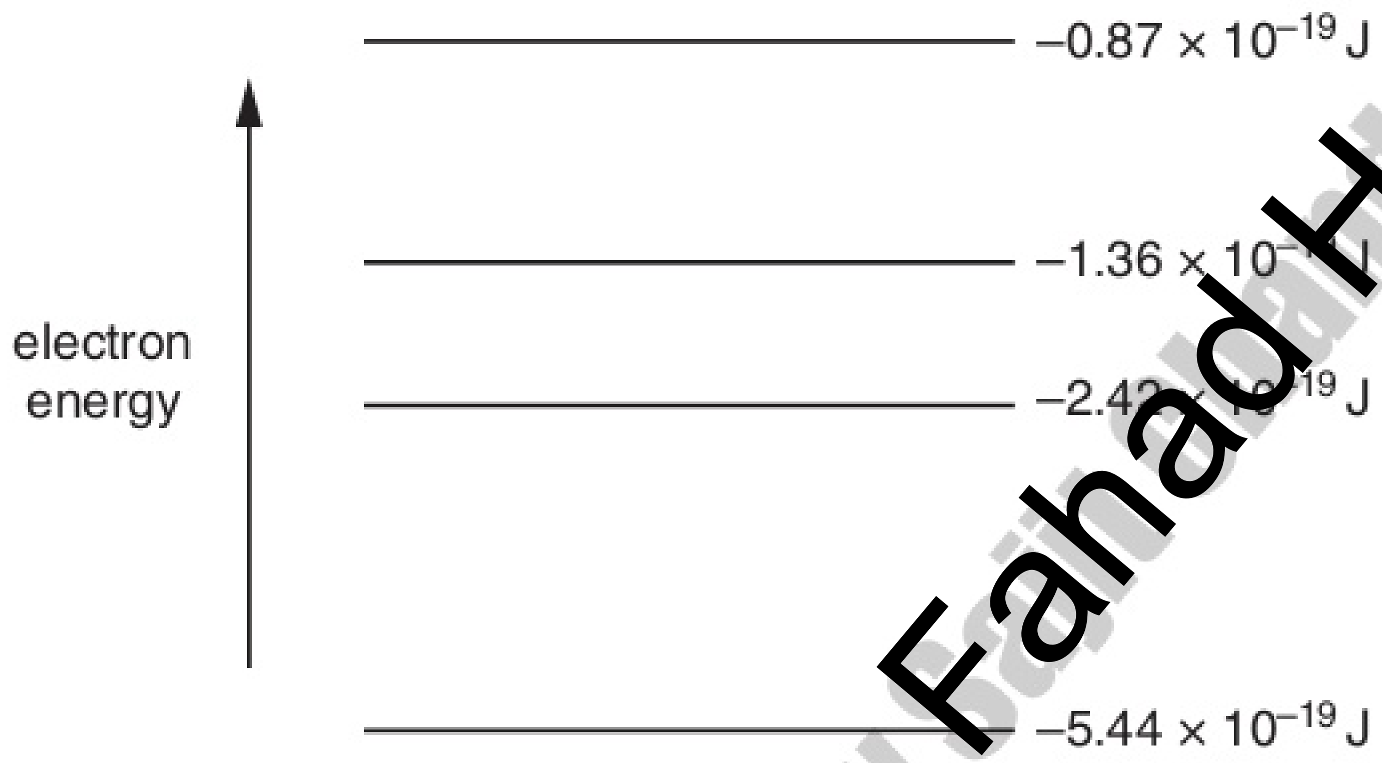

Fig. 7.1 (not to scale)

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]

For Examiner's Use

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]

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]

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]

For Examiner's Use

(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]

For Examiner's Use

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.

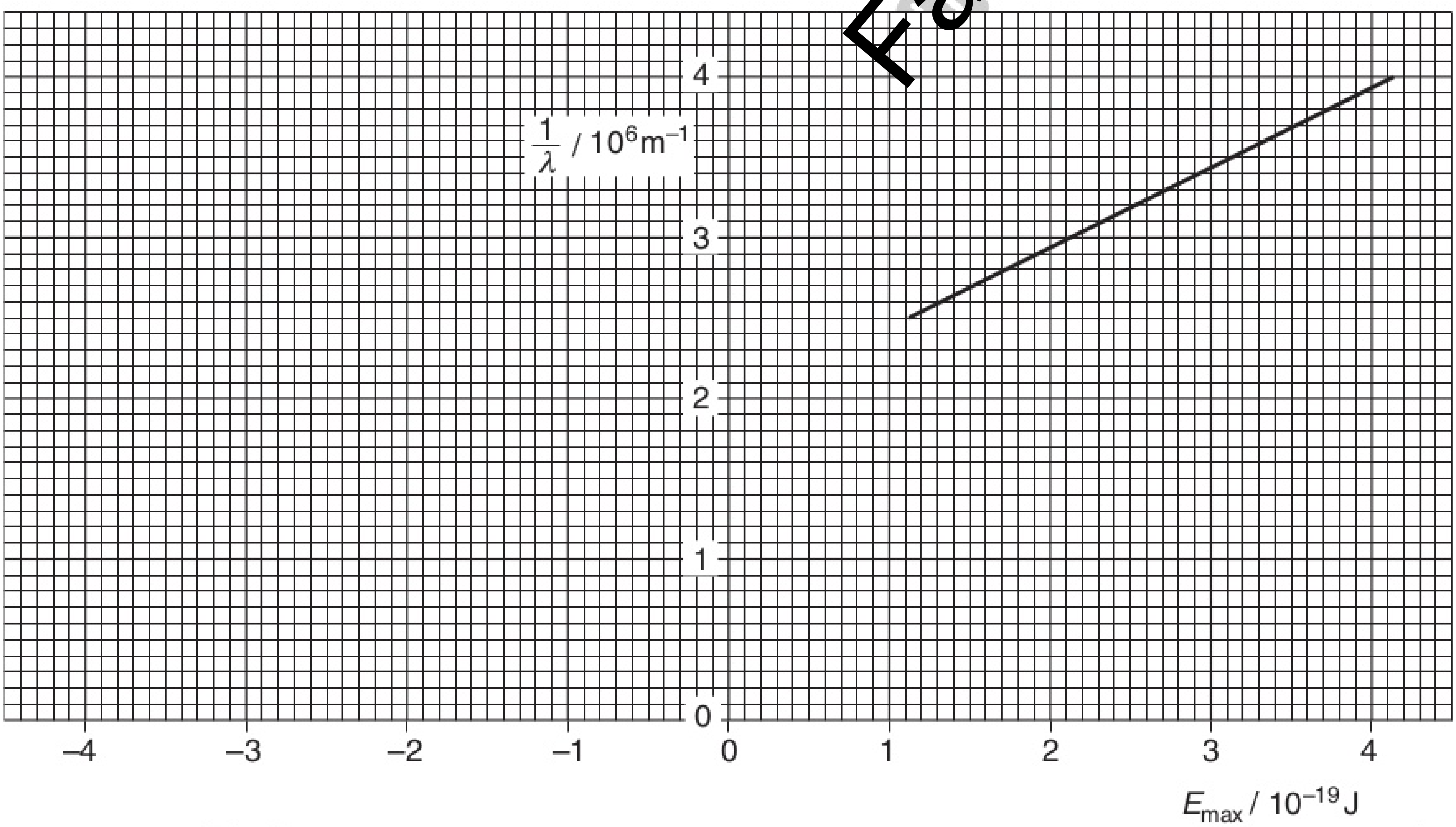

Fig. 7.1

(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]

For Examiner's Use

(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]

For Examiner's Use

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]

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]

(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.

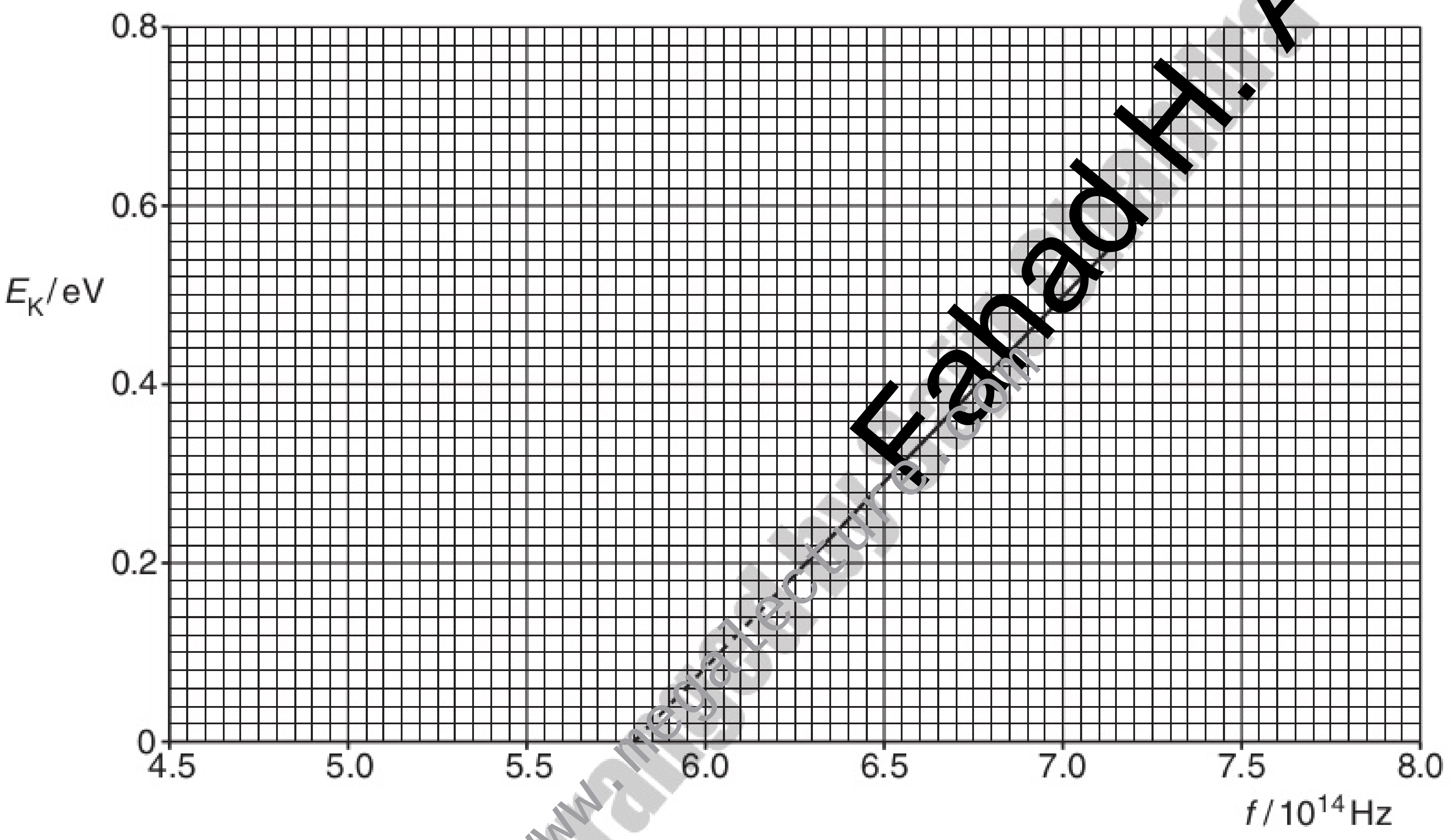

Fig. 7.1

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]

For Examiner's Use

(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]

For Examiner's Use

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]

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.

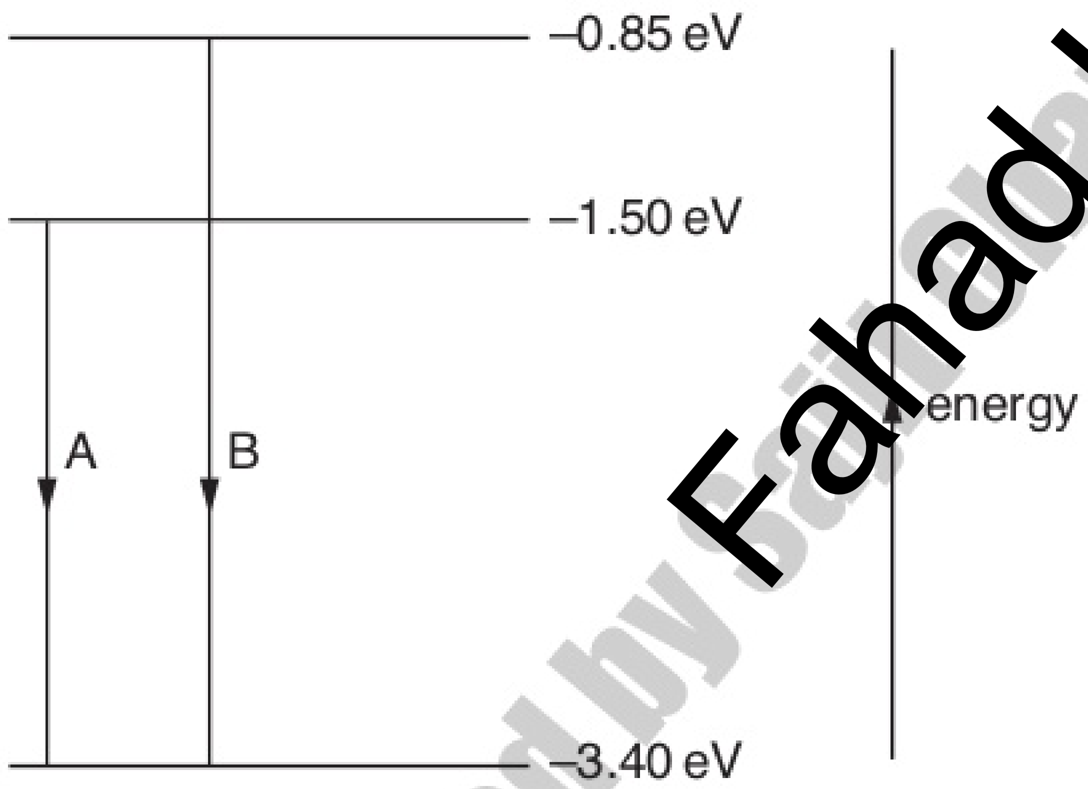

Fig. 7.1

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.

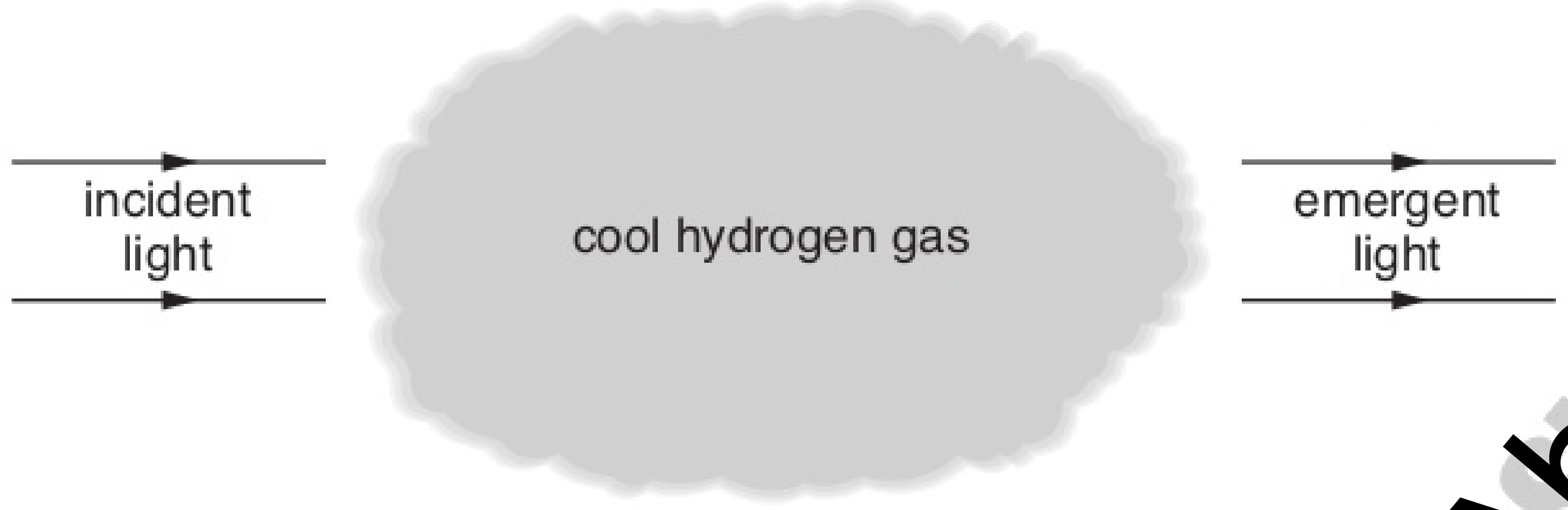

Fig. 7.2

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

....

....

....

....

....

....[4]

For Examiner's Use

For Examiner's Use

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.

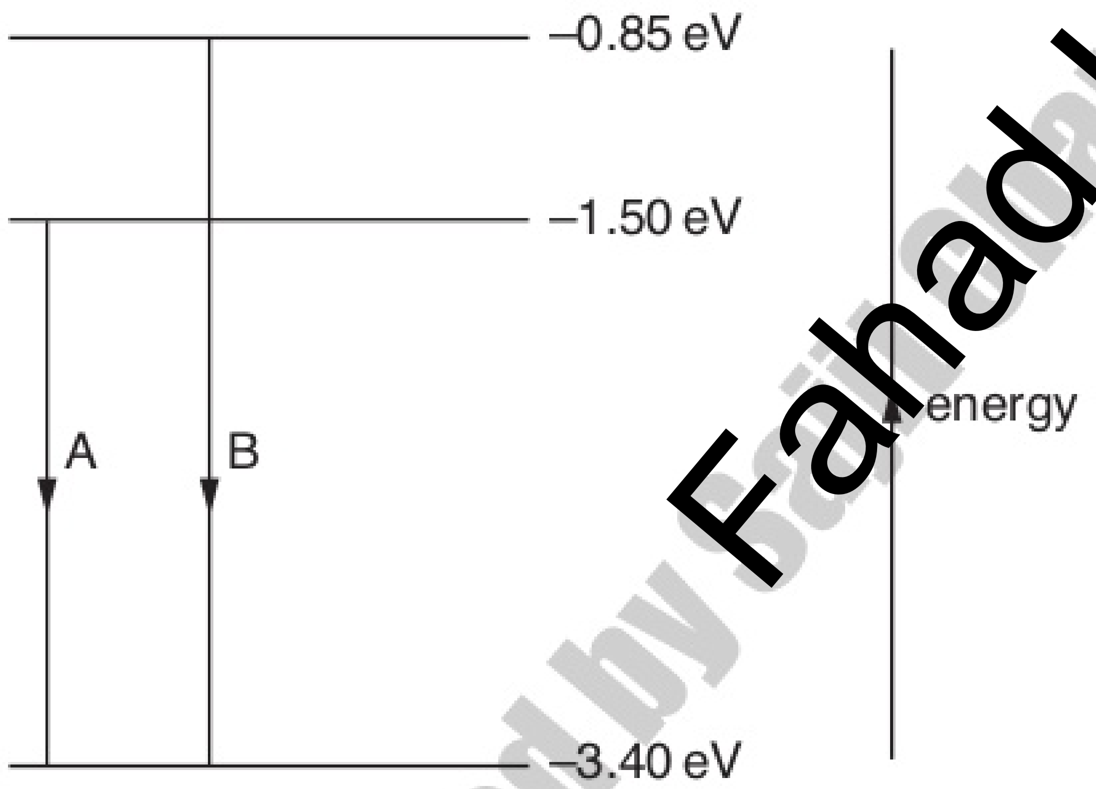

Fig. 7.1

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]

For Examiner's Use

(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.

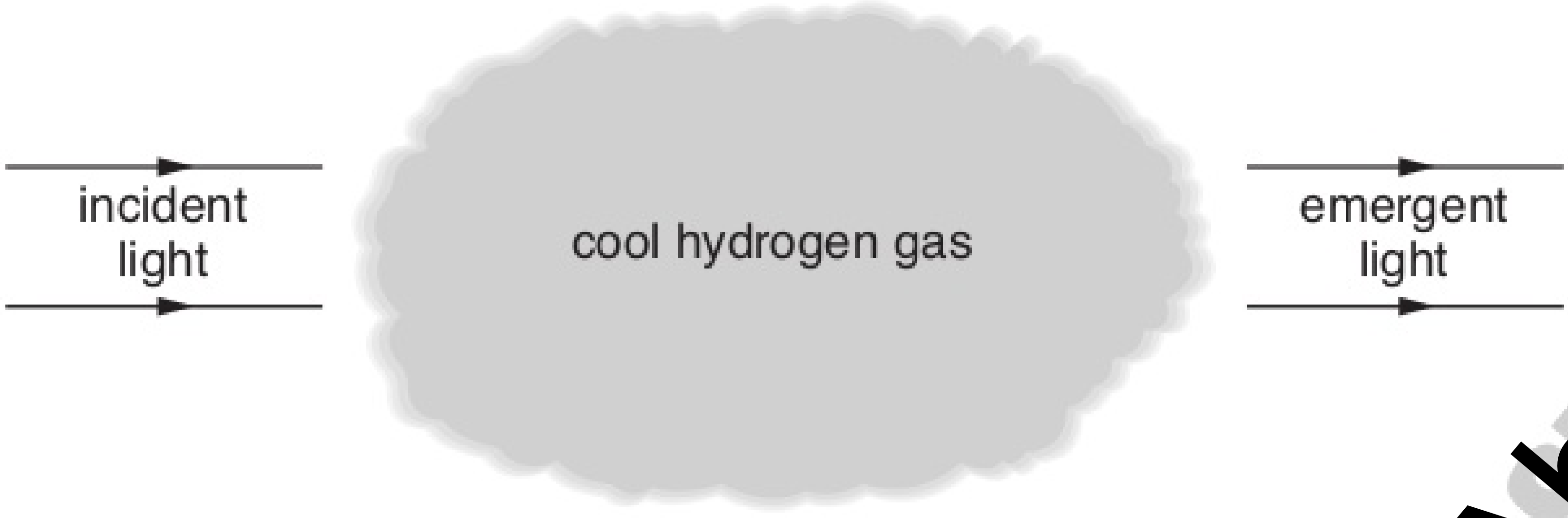

Fig. 7.2

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

....

....

....

....

....

....[4]

For Examiner's Use

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]

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

....

....

....[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]