1 In 1905 Einstein presented a theory to explain the photoelectric effect using the concept of quantisation of radiation proposed by Planck in 1900.

(a) Show, with the aid of a suitably labelled diagram, the arrangement of apparatus that could be used to demonstrate the photoelectric effect. Describe how you would use the apparatus and what would be observed.

In your answer you should make clear how your observations provide evidence for the photoelectric effect.

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(b) Describe how the photoelectric effect can be explained in terms of the physics of quantum behaviour.

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[Total: 10]

2 This question is about an experiment to measure the Planck constant *h* using light-emitting diodes (LEDs).

(a) Each LED used in the experiment emits monochromatic light. The wavelength λ of the emitted photons is determined during the manufacturing process.

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 equation $eV_{min} = hc/\lambda$.

Explain the meaning of this equation in words.

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.... **[2]**

(b) Describe the experiment that uses the circuit of Fig. 7.1 to generate the data shown in the table. The wavelength value for each LED is provided by the manufacturer.

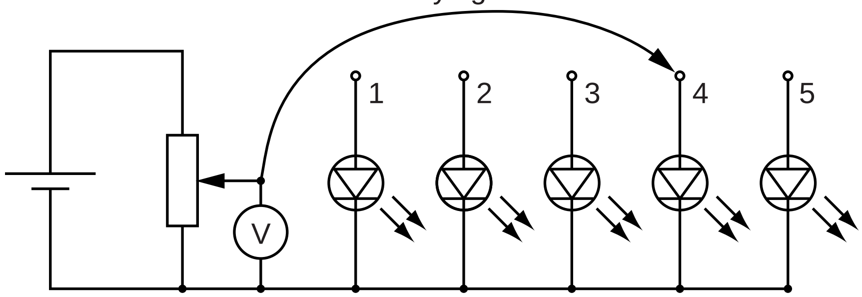

Fig. 7.1

LED	λ/nm	$1/\lambda$ /10^6 m^{-1}	average V_{min}/ V
1 red	627	1.59	1.98
2 yellow	590	1.69	2.10
3 green	546	1.83	2.27
4 blue	468		2.66
5 violet	411		3.02

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(c) (i) Complete the table and use the data to complete the graph of Fig. 7.2. Three of the points have been plotted for you.

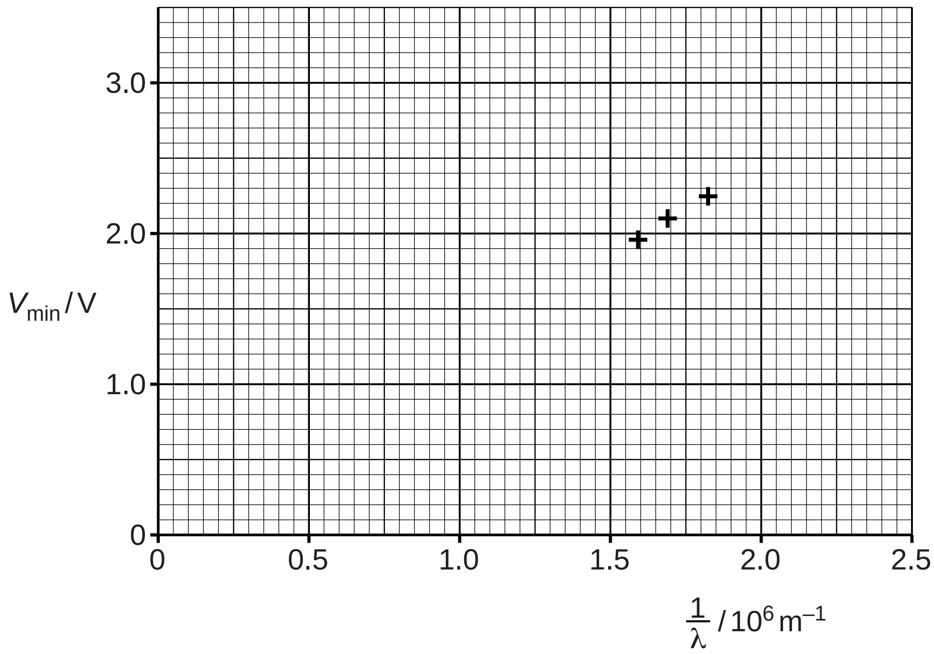

Fig. 7.2

Draw the line of best fit. Show that the gradient is about 1.2×10^{-6} V m. Show your working clearly.

gradient = ... V m **[4]**

(ii) Use the equation given in **(a)** to show that the gradient of the line in Fig. 7.2 is equal to *hc/e*.

[2]

(iii) Calculate a value for the Planck constant using your value in **(i)** for the gradient of the graph. Show your working.

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

[Total: 13]

3 **(a)** State **one** experiment for each case which provides evidence that electromagnetic radiation can behave like

(i) a stream of particles, called *photons*

.... **[1]**

(ii) waves.

.... **[1]**

(b) A beam of ultraviolet light is incident on a clean metal surface. The graph of Fig. 7.1 shows how the maximum kinetic energy KE_{max} of the electrons ejected from the surface varies with the frequency f of the incident light.

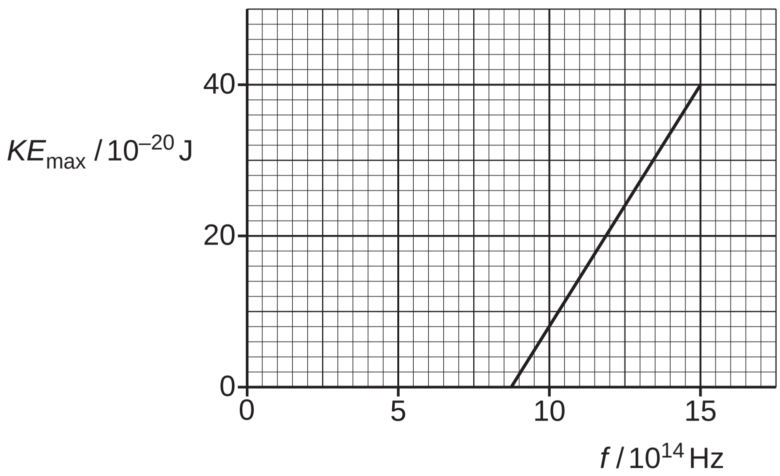

Fig. 7.1

(i) Define the work function ϕ of the metal.

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(ii) Write down the relationship between KE_{max} and *f*. Use it to explain why the *y*-intercept of the graph in Fig. 7.1 is equal to the work function of the metal and the gradient of the line is equal to the Planck constant.

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(iii) Use data from Fig. 7.1 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]**

[Total: 11]

4 **(a)** Kirchhoff's first and second laws can be used to analyse any electrical circuit. They are a consequence of the conservation of physical quantities in the circuit.

(i) State Kirchhoff's **first** law and the physical quantity conserved.

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(ii) State Kirchhoff's **second** law and the physical quantity conserved.

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(b) A physical quantity is also conserved in the photoelectric effect. Describe and explain the photoelectric effect.

In your answer you should link the description to the conservation of this quantity.

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[Total: 10]