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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.... **[5]**

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

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.... **[5]**

[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.

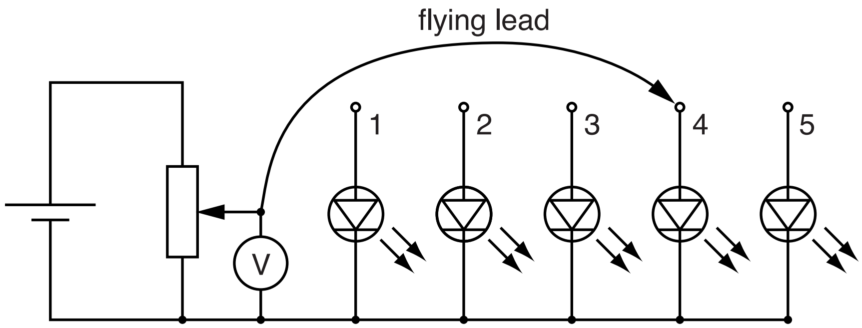

Fig. 7.1

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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.... **[3]**

(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.

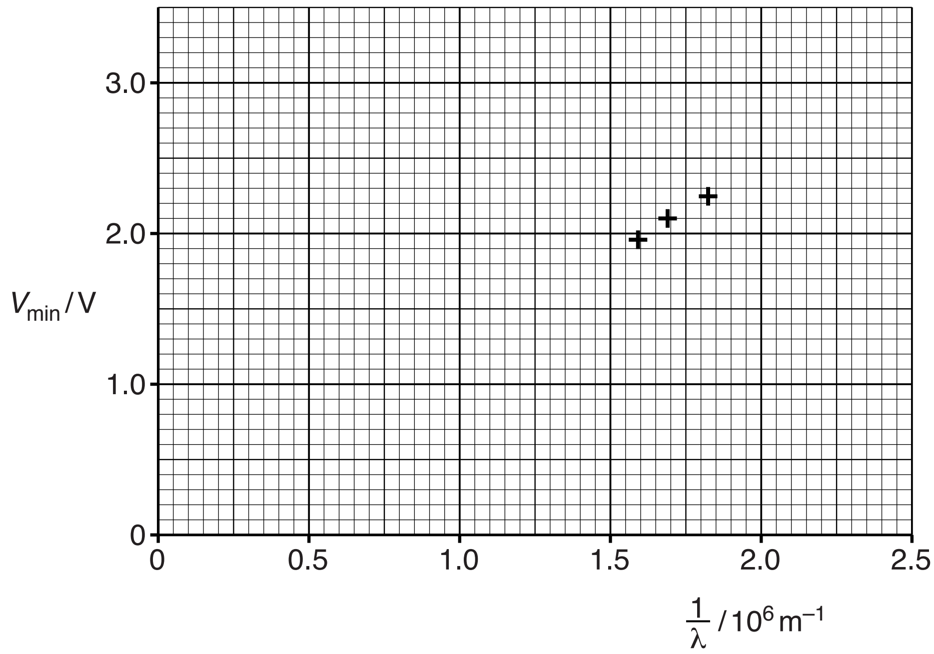

Fig. 7.2

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.

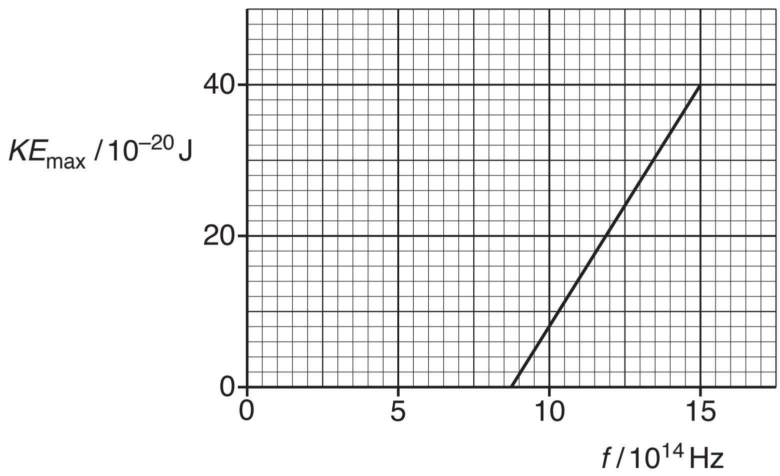

Fig. 7.1

(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]

Question			Expected Answers	Marks	Additional Guidance
1	a		A (clean) zinc plate mounted on the cap of a gold-leaf electroscope. Plate initially charged negatively A u-v lamp shining on plate The gold leaf collapses as the charge leaks away from the plate (when ultra-violet light is incident on the zinc plate) so experiment indicates the emission of negative charge/electrons	B1 B1 B1 B1 B1	first 3 marks can be awarded from diagram or description QWC mark
		Or	A simple photocell, eg two plates in a vacuum envelope A (12 V) dc supply is connected to the photocell and (nano)ammeter. A suitable frequency/u-v lamp shining on one plate The presence of u-v /blue light causes a current in the circuit. so experiment indicates the emission of negative charge/electrons	B1 B1 B1 B1 B1	**accept** photocell made of clean magnesium ribbon surrounded by fine copper gauze first 3 marks can be awarded from diagram or description **ignore** polarity of supply QWC mark
		Or	A (potassium) photocell connected across a (high impedance) voltmeter. Incident light of different frequencies; produced either by white light source and colour filters of known spectral range or by using a diffraction grating or prism to produce a first order spectrum. Different p.d.s are set up across the electrodes of the photocell (when the photocathode is illuminated with light of different frequencies). so experiment indicates the emission of negative charge	B1 B1 B1 B1 B1	first 3 marks can be awarded from diagram or description QWC mark
	b		Individual photons are absorbed by individual electrons in the metal surface. These electrons must have absorbed sufficient energy to overcome the work function energy of the metal/to reach the minimum energy to release an electron from the surface **or** only photons with energies above the work function energy will cause photoelectron emission Concept of instantaneous emission Number of electrons emitted also depends on light intensity Einstein's photoelectric energy equation in symbols with symbols explained, ie (energy of photon) = (work function of metal) + (maximum possible kinetic energy of emitted electron)	B1 B1 B1 B1 B1 B1	**stop marking after the first five marking points, ie ticks and crosses** **not** photons are absorbed by electrons; 1 to 1 relationship must be implied **accept** definition of work function energy **accept** shorter λ/higher f photon causes higher (kinetic) energy electron **accept** full word equation without symbols for 2 marks maximum 5 marks
			Total question 7	**10**	

Question			Answer	Marks	Guidance
2	**(a)**		the energy of an electron✓ equals the energy of the (emitted) photon✓	B1 B1	**alt:** the electron energy✓ is converted into the energy of the emitted photon✓ **or** the minimum energy✓ of an electron required to produce a photon✓/AW
A **A** **A**	**(b)**		Adjust the potential divider to low/zero voltage connect flying lead to one LED increase voltage until LED just lights/strikes repeat several times and average to find V_{min} repeat for each LED shield LED inside opaque tube to judge strike more accurately	B1 B1 B1 B1 B1 B1	**max** 3 marks
A **A** **A**	**(c)**	**(**	values of 1/λ calculated correctly: 2.14 and 2.43 2 points plotted correctly line of best fit drawn through origin gradient = 1.24×10^{-6} (V m)	B1 B1 B1 B1	**not** 2.13 unless this is second rounding error in paper **ecf** calculated values in table working **must be shown** to score the mark **allow ecf** for correct gradient from line drawn
		(ii)	gradient of line = V λ from eV = hc/ λ Vλ = hc/e	B1 B1	**must have** clear indication that V λ is gradient of graph
		(iii)	1.24×10^{-6} = hc/e h = $1.24 \times 10^{-6} \times 1.6 \times 10^{-19} / 3.0 \times 10^{8}$ h = 6.6(1) $\times 10^{-34}$ (J s)	 M1 A1	**ecf (c)(i)** correct substitution into equation mark ans = 5.3 x grad (ignoring all powers of 10)
			Total	**13**	

Question			Answer	Marks	Guidance
3	(a)	(	photoelectric effect (experiment) **or** (discrete) counting of gamma rays **or** Compton effect	B1	**NOT** the gold leaf/ the zinc plate experiment, etc.
		(ii)	Young's slits (experiment)	B1	**accept** any interference/diffraction experiment, e.g. using a diffraction grating, a double slit experiment, etc.
	(b)	(i)	φ is the minimum energy required to release an electron from the metal/surface	B1	**allow** escape from
		(ii)	$KE_{max} = hf - φ$ or $hf = φ + KE_{max}$ **the straight line equation is y = mx + c (where m is the gradient and c the y-intercept)** hence giving c = (-) φ and m = h	B1 **M1** A1	can be copied from the data sheet
		(iii)1	**$h = 32 \times 10^{-20}/5 \times 10^{14}$ or $40 \times 10^{-20}/6.25 \times 10^{14}$ or $20 \times 10^{-20}/3 \times 10^{14}$ etc** $= 6.4 \times 10^{-34}$ (J s)	**M1** A1	any sensible attempt at gradient gains 1 mark check that answer is consistent with figures and not just quoted, e.g. 6.7 for third set of data above
		(iii)2	$8.75 \pm 0.25 \times 10^{14}$ (Hz)	B1	tolerance is to within the grid square **N.B.** SF applies i.e answer must be 9.0 NOT 9
		(iii)3	$φ = 6.4 \times 10^{-34} \times 8.75 \times 10^{14}$ $= 5.6 \times 10^{-19}$ (J)	C1 A1	**ecf (b)(iii)1,2 or ecf b(iii) 2** x $6.6(3) \times 10^{-34}$ ans = **1** x **2**; 5.8×10^{-19} (J) if use $h = 6.6 \times 10^{-34}$ **allow** use of $φ = hf - KE_{max}$ at (15,40) for example
			Total	**11**	

Question			Expected Answers	M	Additional Guidance
4					
	a	**i**	(sum of/total) current into a junction equals the (sum of/total) current out conservation of charge	B1 B1	total vector sum of currents is zero
		ii	(sum of) e.m.f.s = (sum /total of) p.d.s/sum of voltages in/around a (closed) loop (in a circuit) energy is conserved	B1 B1	
	b		a photon is absorbed by an electron (in a metal surface); causing electron to be emitted (from surface). Energy is conserved (in the interaction).	B1 B1 B1	**not** hits QWC mark
			Only photons with energy/frequency above the work function energy/threshold frequency will cause emission Reference to Einstein's photoelectric energy equation (energy of photon) = (work function of metal) + (maximum possible kinetic energy of emitted electron) work function energy is the <u>minimum</u> energy to release an electron from the surface Number of electrons emitted also depends on light intensity Emission is instantaneous	B1 B2 B1 B1 B1	3 marks from 6 marking points in symbols only scores 1 mark out of 2, i.e. selects from formula sheet
			Total question 5	**10**	