PRESTON MANOR

Physics Exam Pack

Photoelectric Effect

Name:

Date:

Question / Paper	Mark

7 Fig. 7.1 shows an electrical circuit, which includes a photocell.

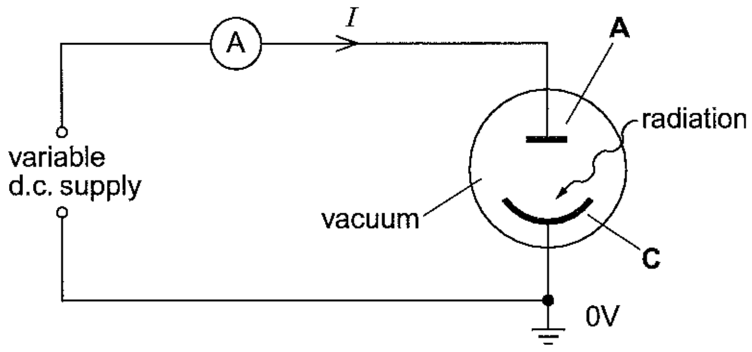

Fig. 7.1

The photocell consists of a metal plate **C** that is exposed to electromagnetic radiation. The photoelectrons emitted travel towards the electrode **A**. A sensitive ammeter measures the current in the circuit.

The plate **C** is illuminated with ultraviolet radiation of constant intensity and of wavelength 2.5×10^{-7} m. Fig. 7.2 shows how the photoelectric current I in the circuit varies with the potential difference V between **A** and **C**.

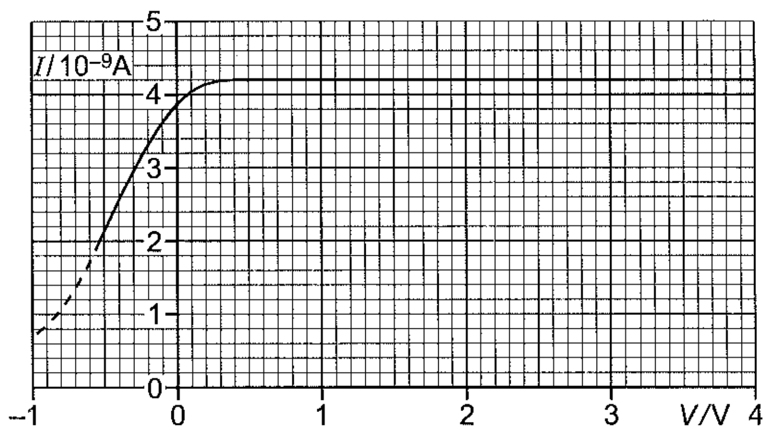

Fig. 7.2

(a) Use Fig. 7.2 to show that when the potential difference V is 2.0V the number of electrons reaching the electrode **A** per second is $2.6 \times 10^{10}\,s^{-1}$.

[3]

(b) The metal of plate **C** has work function energy 2.2 eV. Calculate the maximum kinetic energy in joules of the emitted photoelectrons from this plate.

kinetic energy = ... J [4]

(c) **(i)** State how the maximum energy of the photoelectrons emitted from plate **C** depends on the intensity of the incident radiation.

....

....[1]

(ii) State and explain how the photoelectric current depends on the intensity of the radiation.

....

....

....

....[2]

[Total: 10]

END OF QUESTION PAPER

Question			Expected Answers	Marks	Additional Guidance
7	a		$Q = It$ (current or charge =) 4.2×10^{-9} (number per second =) $\frac{4.2\times10^{-9}}{1.6\times10^{-19}}$ $2.6(3) \times 10^{10}$ (s^{-1})	C1 C1 C1 A0	**Allow** 3 marks for: number per second = $\frac{4.2\times10^{-9}}{1.6\times10^{-19}}$ **Allow** 2 marks for bald 2.6<u>3</u> × 10^{10} (s^{-1}) **Allow** 2 marks for $\frac{4.1\times10^{-9}}{1.6\times10^{-19}}(=2.5(6)\times10^{10})$ - misread graph **Allow** 2 marks for $\frac{4.2}{1.6\times10^{-19}}(=2.63\times10^{19})$ - POT error **Reject** bald answer of 2.6 × 10^{10} (s^{-1}) – since answer is given
	b		$\phi = 1.6\times10^{-19}\times2.2(=3.52\times10^{-19})$ $hf = \phi + KE_{(max)}$ / $\frac{hc}{\lambda} = \phi + KE_{(max)}$ KE = $(\frac{6.63\times10^{-34}\times3.0\times10^{8}}{2.5\times10^{-7}}) - 3.52\times10^{-19}$ kinetic energy = 4.4(36) × 10^{-19} (J)	C1 C1 C1 A1	**Allow** 3 marks if candidate reaches as far as this third marking point – any subject (**Note**: frequency = 1.2 × 10^{15} (Hz)) **Allow** all 4 marks for a bald 4.4 × 10^{-19} (J) **Allow** 2 sf or more for the answer **Special case**: 4 × 10^{-19} (s^{-1}) scores 3 marks
	c	i	No change (AW)	B1	
		ii	The (photoelectric) current is <u>proportional</u> to the intensity (AW) Increasing the intensity increases the (rate of) photons	B1 B1	These are **independent** marks For the second marking point the reference must be to the **photons** and not the electrons (since this idea has already been given a mark above)
			Total	**10**	

6 **(a)** State **one** main property of an electromagnetic wave.

....

....[1]

(b) Arrange the following electromagnetic radiations in the order of increasing wavelengths. Start with the **shortest** wavelength.

infrared visible light gamma rays microwaves

....[1]

(c) The table below shows the work function energies of some metals.

metal	work function energy (eV)
beryllium	5.0
magnesium	3.7
potassium	2.3
silver	4.7
zinc	4.3

(i) Define the *work function energy* of a metal.

....

....[1]

(ii) State and explain which metal has the **lowest** threshold frequency.

....

....

....[2]

6

(a) Any one from: — B1

Travel through vacuum / 'free space'
Travel at the speed of light / c / 3×10^8 m s^{-1} (in vacuum)
They are all transverse waves / can be polarised
Consist of oscillating electric / magnetic fields
Consist of photons

(b) gamma rays, visible light, infrared and microwaves — B1

(c)(i) The minimum energy required to remove an electron (from the metal surface) — B1

(c)(ii) Potassium (has the lowest threshold frequency) — M1

$\phi = hf_{(o)}$ with some explanation / $f_{(o)} \propto \phi$ / threshold frequency is (directly) proportional to work function (energy) — A1

(c)(iii)1. Any three from the statements 1 to 4:

1. Photon mentioned — B1
2. A single photon interacts with a single electron — B1
3. Energy is conserved between photon-electron interaction (wtte) — B1
4. Electron is released when photon energy > / = work function (energy) / frequency > / = threshold frequency — B1

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5. Electrons have a range of KE because some electrons are 'tightly held' / are 'deep below the surface' / electrons make collisions with atoms / ions — B1

(c)(iii)2. hf or $\frac{hc}{\lambda} = \phi + KE_{(max)}$ / $f = 9.38 \times 10^{14}$ (Hz) / ($hf =$) 6.22×10^{-19} (J) — C1

$\phi = 1.6 \times 10^{-19} \times 3.7$ $(= 5.92 \times 10^{-19})$ — C1

$$KE_{(max)} = \left(\frac{6.63 \times 10^{-34} \times 3.0 \times 10^8}{3.2 \times 10^{-7}}\right) - 5.92 \times 10^{-19}$$ — C1

maximum kinetic energy = 3.0×10^{-20} (J) — A0

(c)(iii)3. $\lambda = \frac{h}{mv}$ / $\lambda = \frac{h}{p}$ — C1

KE = $\frac{1}{2}mv^2$

$v = \sqrt{(2 \times 3.0 \times 10^{-20}) / 9.11 \times 10^{-31}}$ $(= 2.57 \times 10^5)$ — C1

$$\lambda = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 2.57 \times 10^5}$$

$\lambda = 2.8 \times 10^{-9}$ (m) — A1

(iii) A plate made of magnesium is illuminated with electromagnetic waves of wavelength 3.2×10^{-7} m. The electrons emitted from the surface of the plate have a range of kinetic energies.

1 Describe how the incident radiation interacts with the metal to release electrons from its surface and explain why these electrons are emitted with a range of kinetic energies.

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....[4]

2 Show that the maximum kinetic energy of the electrons emitted from the surface of the magnesium plate is 3.0×10^{-20} J.

[3]

3 Calculate the de Broglie wavelength of an electron emitted with maximum kinetic energy.

wavelength = ... m [3]

[Total: 15]

END OF QUESTION PAPER

6

(a) Any <u>one</u> from: B1
Travel through vacuum / 'free space'
Travel at the speed of light / c / 3×10^8 <u>m s^{-1}</u> (in vacuum)
They are all transverse waves / can be polarised
Consist of oscillating electric / magnetic fields
Consist of photons

(b) gamma rays, visible light, infrared and microwaves B1

(c)(i) The <u>minimum</u> energy required to remove an electron (from the metal surface) B1

(c)(ii) Potassium (has the lowest threshold frequency) M1
$\phi = hf_{(o)}$ with some explanation / $f_{(o)} \propto \phi$ / threshold frequency is (directly) proportional to work function (energy) A1

(c)(iii)1. Any <u>three</u> from the statements 1 to 4:

1. Photon mentioned B1
2. A single photon interacts with a single electron B1
3. Energy is conserved between photon-electron interaction (wtte) B1
4. Electron is released when photon energy > / = work function (energy) / frequency > / = threshold frequency B1

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5. Electrons have a range of KE because some electrons are 'tightly held'/ are 'deep below the surface' / electrons make collisions with atoms / ions B1

(c)(iii)2. hf or $\frac{hc}{\lambda} = \phi + KE_{(\max)}$ / $f = 9.38 \times 10^{14}$ (Hz) / ($hf =$) 6.22×10^{-19} (J) C1

$\phi = 1.6 \times 10^{-19} \times 3.7 \ (= 5.92 \times 10^{-19})$ C1

$KE_{(\max)} = (\frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{3.2 \times 10^{-7}}) - 5.92 \times 10^{-19}$ C1

maximum kinetic energy = 3.0×10^{-20} (J) A0

(c)(iii)3. $\lambda = \frac{h}{mv}$ / $\lambda = \frac{h}{p}$ C1

KE = $\frac{1}{2}mv^2$

$v = \sqrt{(2 \times 3.0 \times 10^{-20}) / 9.11 \times 10^{-31}} \ (= 2.57 \times 10^{5})$ C1

$\lambda = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 2.57 \times 10^{5}}$

$\lambda = 2.8 \times 10^{-9}$ (m) A1

2 the current from the battery.

current = ... A [1]

(iii) With the switch **S closed**, the current in the resistor **R** is 20 A. Explain why the lamps dim when the switch is closed.

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....

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.... [2]

[Total: 12]

6 (a) State what is meant by the *photoelectric effect.*

....

.... [1]

(b) Explain why electrons are released from a particular metal when it is illuminated by weak blue light, but not when it is illuminated by very intense red light.

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.... [4]

(d) For a particular metal, electromagnetic radiation of frequency 1.36×10^{15} Hz incident on its surface releases electrons with a maximum kinetic energy of 5.82×10^{-19} J.

(i) Suggest why the electrons emitted from the metal have a range of kinetic energies.

....

.... **[1]**

(ii) Use Einstein's photoelectric equation to calculate

1 the work function energy of the metal

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

2 the maximum kinetic energy of the electrons when the frequency of the incident radiation is halved.

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

[Total: 15]

END OF QUESTION PAPER

Question			Expected Answers	Marks	Additional Guidance
6	a		Removing electron(s) using light / photons/ e.m waves / e m radiation (from metal surface)	B1	
	b		1. Blue light has higher frequency / shorter wavelength (than the red light) 2. Energy of blue light photon is greater (than that of red light) 3. The energy of blue light photon > / = work function (energy) (ora) 4. Intensity is related to rate of photons / does not change energy of photon	B1 B1 B1 B1	**Show** ticks on scoris Allow The frequency of blue light >/= threshold frequency (ora)
	c	i	**F** marked correctly on the *f*-axis **W** marked correctly on the vertical axis	B1 B1	
		ii	Line shifts to the 'right' / 'down' Gradient of line remains the same because it is equal to Planck constant / *h*	B1 M1 A1	
	d	i	Not all are emitted from the surface / Some collide (with other atoms)	B1	
	d	ii 1.	$hf = \phi + KE_{max}$ / $\phi = (6.63 \times 10^{-34} \times 1.36 \times 10^{15}) - 5.82 \times 10^{-19}$ $= 9.02 \times 10^{-19} - 5.82 \times 10^{-19}$ $\phi = 3.20 \times 10^{-19}$ (J)	C1 A1	**Bald** 3.20×10^{-19} (J) scores 2/2
		ii 2.	kinetic energy = $(6.63 \times 10^{-34} \times 0.68 \times 10^{15}) - 3.20 \times 10^{-19}$ kinetic energy = 1.31×10^{-19} (J)	C1 A1	Possible ECF from ii.1 **Bald** 1.3×10^{-19} (J) scores 2/2 – allow 2 sf answer
			Total	**15**	

6 **(a)** A 5.0 eV photon can cause the photoelectric effect from most metals.

(i) State what is meant by the *photoelectric effect.*

....

.... **[1]**

(ii) State what is meant by an *electron volt* (eV).

....

.... **[1]**

(iii) Calculate the value of 5.0 eV in SI units.

value = ... unit .... **[1]**

(b) A photon of energy 8.0×10^{-19} J incident on a clean zinc surface can cause photoelectric emission. The maximum kinetic energy of an electron emitted from the surface is 1.1×10^{-19} J.

(i) **1** Define the term *work function* of a metal.

....

.... **[1]**

2 Calculate the work function for zinc.

work function = ... unit .... **[1]**

(ii) **1** Show that the maximum speed v of an electron emitted from the surface is about $5 \times 10^5\,m\,s^{-1}$.

[2]

2 Calculate the de Broglie wavelength of an electron emitted from the surface at the maximum speed.

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

(c) The spacing between atoms in a thin sheet of graphite is about 2.5×10^{-10} m.

(i) A beam of electrons in a vacuum can travel through a thin sheet of graphite placed perpendicular to the beam to produce a pattern of **rings** on a fluorescent screen beyond the graphite sheet. Explain why this pattern is produced.

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.... **[3]**

(ii) Explain whether or not the electrons in **(b)(ii)** would be suitable for use in such an experiment.

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.... **[1]**

[Total: 14]

Question			Answer	Marks	Guidance
6	(a)	(i)	emission of electron(s) from a <u>metal</u> (surface) when photon(s)/ light/uv/em radiation are incident (on surface)	B1	**allow** singular electron and absorption of photon
		(ii)	energy to accelerate/move an electron through a p.d. of 1 V/AW	B1	**not** 1.6×10^{-19} J
		(iii)	$5.0 \times 1.6 \times 10^{-19} = 8.0 \times 10^{-19}$ J	B1	**allow** 8 for 8.0; no mark if unit incorrect
	(b)	(i)1	the <u>minimum</u> energy required to release an electron from the <u>surface</u> of the metal	B1	
		(i)2	$\varphi = 8.0 \times 10^{-19} - 1.1 \times 10^{-19}$ $= 6.9 \times 10^{-19}$ J	B1	no mark if unit incorrect unless unit in **a(iii)** incorrect
		(ii)1	$\frac{1}{2}mv^2 = 1.1 \times 10^{-19}$ $v^2 = 2.2 \times 10^{-19}/9.11 \times 10^{-31}$ ($= 2.4 \times 10^{11}$) $v = 4.9 \times 10^5$ (m s^{-1})	C1 M1 A0	**accept ora** substitute 5×10^5 to find $E = 1.1 \times 10^{-19}$
		(ii)2	$\lambda = h/mv$ $= 6.63 \times 10^{-34} / 9.11 \times 10^{-31} \times 4.9 \times 10^5$ $= 1.5 \times 10^{-9}$ (m)	C1 C1 A1	**accept** 1.46×10^{-9} if using $v = 5 \times 10^5$
A A A	(c)	(i)	Electrons behave as waves/diffract (observable because) gaps/atoms are of similar wavelength to electrons <u>regular/ordered</u> pattern of atoms/atoms act as a grating/AW allowing interference to produce pattern on screen/AW rings occur because atomic 'crystals' at all possible orientations to beam/AW	B1 B1 B1 B1 B1	**allow** graphite for atoms **max** 3 from 5 marking points
		(ii)	wavelength is too large to produce a diffraction pattern/electrons not travelling fast enough/AW	B1	**ecf (b)(ii)2**; e.g. for AW: wavelength is about 10 times atomic spacing **or** wavelength is different to spacing
			Total	**14**	

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Question 4 begins on page 10

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7 **(a)** A helium-neon laser emits red light of wavelength 6.3×10^{-7} m.

(i) Show that the energy of a single photon is about 3×10^{-19} J.

[2]

(ii) The power of the laser beam is 1.0 mW. Show that about 3×10^{15} photons are emitted by the laser each second.

[1]

(iii) The photons of red light are emitted by the neon atoms in the gas inside the laser.

Explain what *energy levels* are and how they can be used to explain the emission of photons from atoms.

In your answer take care to make your explanation clear.

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.... **[4]**

(iv) Another laser emits blue light. The power in its beam is also 1.0 mW.

Explain why the laser emitting blue light emits fewer photons per second compared with a laser of the same power emitting red light.

....

....

.... **[2]**

(b) A photodiode is a circuit component which can be used to convert a light signal into an electrical one. Fig. 7.1 shows an enlarged cross-section through a photodiode to illustrate how it is constructed. Light incident on the thin transparent conducting surface layer of the diode passes through it to be absorbed in the insulating layer. The energy of each photon is sufficient to release one electron in the insulating layer. The potential difference V applied across the insulating layer causes these electrons to move to one of the conducting layers.

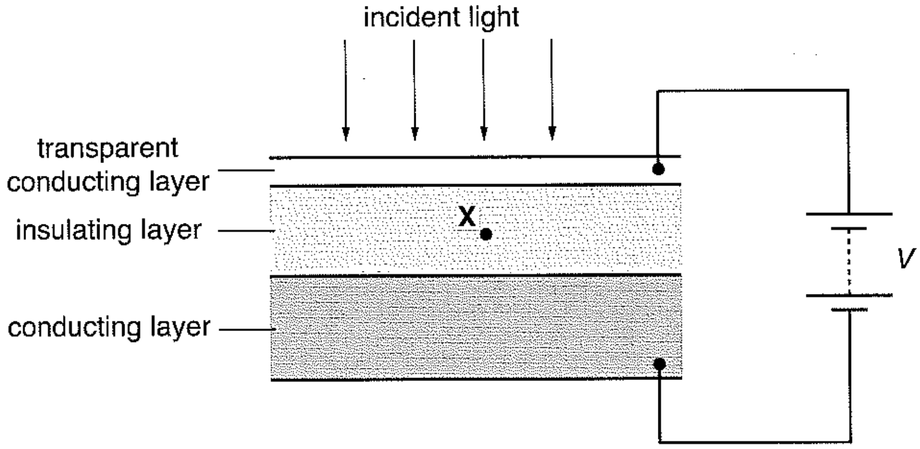

Fig. 7.1

(i) Draw an arrow on Fig. 7.1 to show the direction of motion of an electron released at point **X** in the centre of the insulating layer. **[1]**

(ii) The red light from the laser in **(a)** is incident on the photodiode. Experiments show that only 20% of the red light photons release electrons in the insulating layer and hence in the circuit of Fig. 7.1. Calculate the current through the photodiode.

current = ... A **[3]**

(iii) Suggest one reason why the efficiency of the photodiode is less than 100%.

....

.... **[1]**

[Total: 14]

Question			Expected Answers	Marks	Additional Guidance
7					
	a	i	$E = hc/\lambda = 6.63 \times 10^{-34} \times 3.0 \times 10^{8} / 6.3 \times 10^{-7}$ $= 3.16 \times 10^{-19}$ (J)	M1 A1	mark is for correct substitution into formula min of 2 sig figs;**allow** 3.1 for $h = 6.6 \times 10^{-34}$
		ii	$1.0 \times 10^{-3}/3(.2) \times 10^{-19}$ ($= 3.1 \times 10^{15}$)	B1	**accept** 3×10^{15}; the mark is for the expression
		iii	energy levels explanation: electrons have discrete energies in atom/AW each photon produced by electron moving between levels photon energy equal to energy difference between levels electron loses energy/making transition in correct direction	B1 B1 B1 B1	QWC mark good diagram can score marks **allow** $E_1 - E_2 = hf$ or similar
		iv	blue light has a higher frequency/shorter wavelength than red light energy per photon is higher (so fewer needed to produce one mW)	B1 B1	
	b	i	vertical arrow up approximately through **X**	B1	**allow** tolerance e.g. ± 10°
		ii	$I = 0.2\,ne$; $= 0.2 \times 3.2 \times 10^{15} \times 1.6 \times 10^{-19}$ $= 1.0(24) \times 10^{-4}$ (A) or 0.10 mA (9.6×10^{-5} if using 3×10^{15})	C2 A1	**max** 2 marks if forget 0.2 factor 0.51 mA (0.48) if forget 0.2 factor
		iii	reflection/absorption at top layer; light/some photons reach bottom layer; photons below threshold energy/photons absorbed by electrons without release; recombination of ion pairs in insulating layer; scattering of light/photons out of insulating layer	B1	**award** mark for any sensible comment; see examples given
			Total question 7	**14**	
Question			**Expected Answers**	**Marks**	**Additional Guidance**
8					
	a	i	paths spread out after passing through a gap or around an obstacle/AW	B1	
		ii	wavelength of electrons must be comparable/of the order of magnitude of the atomic spacing	M1 A1	**allow** electrons behave as waves/AW **allow** must be about 10^{-10} m
	b		$\lambda = h/mv$ $v = 6.6(3) \times 10^{-34} / 9.1(1) \times 10^{-31} \times 1.2 \times 10^{-10}$ $= 6.0$ or 6.1×10^{6} (m s^{-1})	C1 M1 A1	mark for selecting formula correct manipulation and subs. shown **give** all 3 marks for answers to 3 figs or more: i.e. 6.04, 6.06 or 6.07
	c	i	$eV = ½mv^2$ $V = mv^2/2e = 9.1 \times 10^{-31} \times (6.0 \times 10^{6})^2/2 \times 1.6 \times 10^{-19}$ $= 1.0(2) \times 10^{2}$ (V)	C1 C1 A1	mark for algebraic equation mark for correct substitution **give** 1 mark max for k.e. $= 1.6(4) \times 10^{-17}$ J using 6.1 gives 104 (V)
		ii	electrons should be repelled by cathode and/or attracted by anode **or** they will be attracted back to the cathode/slowed down if cathode positive	B1	**award** mark if answer indicates this idea
			Total question 8	**10**	

19 **(a)** State what is meant by the *photoelectric effect*.

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.... **[1]**

(b) 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]**

(c) 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.

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.... **[1]**

Question			Answer	Marks	Guidance
19	(a)		The emission of electrons from the surface of a metal when electromagnetic waves (of frequency greater than the threshold frequency) are incident on the metal.	B1	
	(b)		The wave model cannot explain why there is a threshold frequency for metals. The new model / photon model proposed one-to-one interaction between photons and electrons and this successfully explained why threshold frequency exists. Any further one from: Energy of photon (hf) must be greater than or equal to work function of metal. The kinetic energy of emitted electrons was independent of the incident intensity. Correct reference to hf = Φ + KEmax	B1 B1 B1	
	(c)	(i)	$E=\frac{6.63\times10^{-34}\times3.0\times10^{8}}{380\times10^{-9}}$ or $\phi=1.1\times1.6\times10^{-19}$ $\frac{6.63\times10^{-34}\times3.0\times10^{8}}{380\times10^{-9}}=1.1\times1.6\times10^{-19}+\frac{1}{2}\times9.11\times10^{-31}v^2$ speed = 8.7×10^{5} (m s^{-1})	C1 C1 A1	This is substituting values into $\frac{hc}{\lambda}=\phi+\frac{1}{2}mv^2$
		(ii)	The energy of a photon depends only on wavelength or frequency, so intensity does not change the maximum speed of the photoelectrons.	B1	
			Total	8	

7 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]

END OF QUESTION PAPER

Question			Expected Answers	Marks	Additional Guidance
7	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**	

6 **(a)** A parallel beam of red light of wavelength 6.3×10^{-7} m from a laser is incident normally on a diffraction grating as shown in Fig. 6.1.

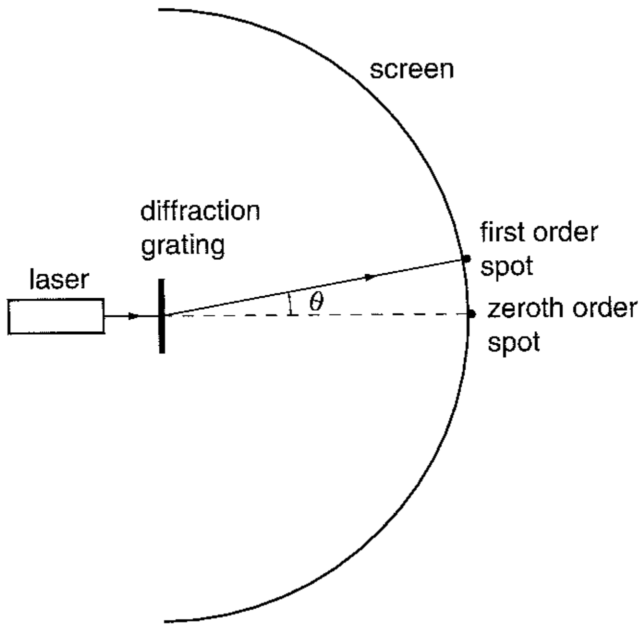

Fig. 6.1

Bright red spots are observed on the curved screen placed beyond the grating.

(i) The diffraction grating has 300 lines per millimetre. Show that the separation d between adjacent lines of the grating is 3.3×10^{-6} m.

[1]

(ii) Calculate the angle θ at which the first order red spot is seen. This is the first spot away from the straight through position.

θ = ... degrees **[3]**

(iii) The screen curves around the full 180° in front of the grating. Explain why there are eleven bright red spots on the screen.

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.... **[3]**

(b) Calculate

(i) the energy of each photon of light emitted by the laser at a wavelength of 6.3×10^{-7} m

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

(ii) the number of photons emitted each second to produce a power of 0.50 mW.

number = ... **[2]**

(c) **(i)** A beam of electrons in a vacuum can travel through a thin sheet of graphite perpendicular to the beam to produce a diffraction pattern of rings on a fluorescent screen beyond the graphite sheet. Explain why this pattern is produced.

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.... **[3]**

(ii) Calculate

1 the speed v of electrons with a de Broglie wavelength of 5.0×10^{-11} m

v = ... $m\,s^{-1}$ **[2]**

2 the potential difference V required to accelerate the electrons to this speed.

V = ... V **[3]**

[Total: 19]

Question			Expected Answers	Marks	Additional Guidance
6	(a)	(i)	line spacing d = 1/(300 x 1000) (= 3.3×10^{-6} (m))	B1	look for clear reasoning to award mark
		(ii)	sin θ = λ/d = $6.3 \times 10^{-7}/3.3 \times 10^{-6}$ = 0.19 θ = 11 degrees	C1 C1 A1	rounding error of 0.2 here gives 11.9° 11.9° gets 2 marks
		(iii)	spots can be seen where n = d sin θ/λ maximum n when sin θ = 1 (giving n = 5.3) so n =5 can be seen thus 5 spots on either side of straight through + straight through = 11	B1 B1 B1	**accept** basic idea of orders for first mark N.B. calculation not necessary
	(b)	(i) (ii)	ε = hc/λ = $6.6 \times 10^{-34} \times 3.0 \times 10^{8}/6.3 \times 10^{-7}$ = 3.14×10^{-19} (J) $5.0 \times 10^{-4}/3.14 \times 10^{-19}$ = 1.6×10^{15}	C1 A1 C1 A1	 **accept** 3.2×10^{-19} (J) **ecf** from **b(i)1**
	(c)	(i)	Electrons behave as waves/have a wavelength diffraction observable because gaps/atoms are similar to wavelength of electrons regular pattern of atoms acts as a grating allowing constructive interference to produce pattern on screen/AW rings occur because atomic 'crystals' at all possible orientations to beam/AW	B1 B1 B1 B1 B1	max 2 out of next 4 marking points **can** gain first 'waves' mark here as well as second mark if first line not written explicitly
		(ii) 1 2	λ = h/mv = $6.63 \times 10^{-34}/9.1 \times 10^{-31}$v v = $6.63 \times 10^{-34}/9.1 \times 10^{-31} \times 5.0 \times 10^{-11}$ v = 1.5×10^{7} (m s^{-1}) ½mv^2 = eV ½ x $9.1 \times 10^{-31} \times 2.25 \times 10^{14} = 1.6 \times 10^{-19}$V V = 6.4×10^{2} (V)	C1 A1 C1 C1 A1	 using 6.6 instead of 6.63 gives 1.45×10^{7} using v =1.45×10^{7} gives 600 V
			Total question 6	**19**	

7 **(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.

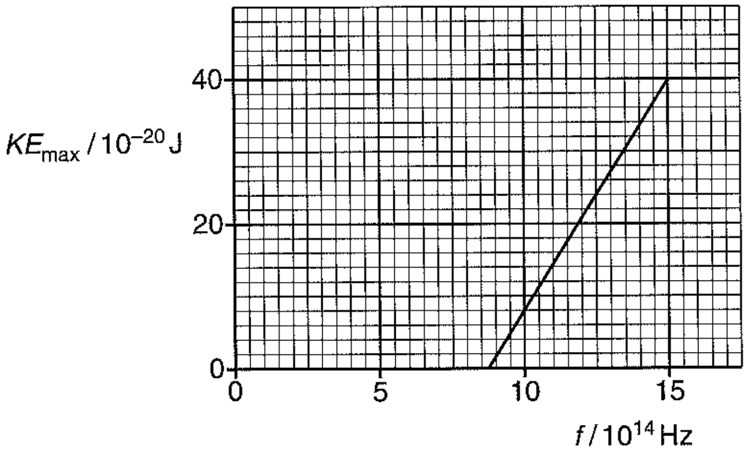

Fig. 7.1

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

....

....

....

.... [1]

(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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....

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....

....

.... **[3]**

(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]

END OF QUESTION PAPER

Question			Answer	Marks	Guidance
7	(a)	(i)	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)	$KE_{max} = hf - \varphi$ or $hf = \varphi + KE_{max}$ **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	$\varphi = 6.4 \times 10^{-34} \times 8.75 \times 10^{14}$ $= 5.6 \times 10^{-19}$ (J)	C1 A1	**ecf (b)(iii)1,2 or ecf b(iii) 2** $\times 6.6(3) \times 10^{-34}$ ans = **1** x **2**; 5.8×10^{-19} (J) if use $h = 6.6 \times 10^{-34}$ **allow** use of $\varphi = hf - KE_{max}$ at (15,40) for example
			Total	**11**	

5 **(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.

....

....

.... **[2]**

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

....

....

....

.... **[2]**

(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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.... **[6]**

[Total: 10]

Question			Expected Answers	M	Additional Guidance
5					
	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**	

4 A photoelectric cell is an electronic device that can detect photons.

(a) Fig. 4.1 shows a cross-section through a simple photocell.

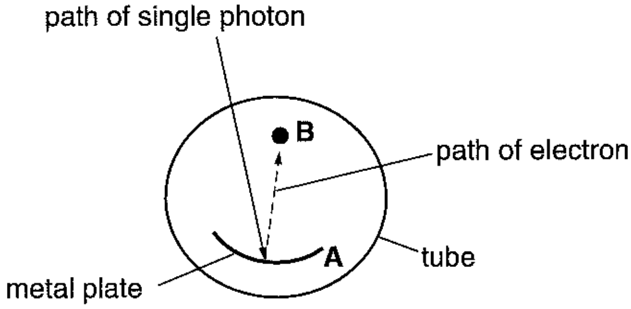

Fig. 4.1

A metal plate **A** is coated with potassium in an evacuated transparent tube. A photon entering the tube is absorbed by the plate, causing one electron to be released from the surface towards the collector rod **B**.

(i) State the name of this process.

.... **[1]**

(ii) Potassium has a work function of 3.5×10^{-19} J.

1 Define the term *work function*.

....

.... **[1]**

2 Calculate the threshold frequency of potassium.

threshold frequency = ... Hz **[2]**

(iii) The photon incident on plate **A** has a wavelength of 4.2×10^{-7} m. Show that its energy is about 5×10^{-19} J.

[2]

(iv) Calculate the maximum kinetic energy of the electron emitted from the potassium surface of plate **A**.

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

(b) An electron is released with zero speed from plate **A**. It is accelerated from plate **A** through a potential difference of 12V to the metal rod **B** in Fig. 4.1.

(i) **1** State the increase in kinetic energy of the electron in electronvolts (eV).

increase in k.e. = ... eV **[1]**

2 Show that this increase is about 2×10^{-18} J.

[1]

(ii) Calculate the speed of the electron as it hits rod **B**.

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

(c) The photocell is connected to a 12V d.c. supply through a very sensitive ammeter. Light of wavelength 4.2×10^{-7} m shines on plate **A**. The plate absorbs 1.2×10^{-6} J of light energy every second. One per cent of the absorbed photons cause electrons to be emitted from the plate. Estimate the current in the circuit.

current = ... A **[3]**

[Total: 16]

Question			Expected Answers	M	Additional Guidance
4					
	a	i	photoelectric effect/emission	B1	
		ii1	the <u>minimum</u> energy (required) to release an electron (from the surface of the metal)	B1	
		ii2	$3.5 \times 10^{-19} = 6.6 \times 10^{-34}$ f f = 5.3×10^{14} (Hz)	C1 A1	
		iii	$\varepsilon = hc/\lambda = 6.6 \times 10^{-34} \times 3.0 \times 10^{8} / 4.2 \times 10^{-7}$ $= 4.7 \times 10^{-19}$ (J)	C1 A1	no second mark unless there is evidence of the calculation being done
		iv	$\frac{1}{2}mv^2 = 4.7 \times 10^{-19} - 3.5 \times 10^{-19}$ $= 1.2 \times 10^{-19}$ (J)	C1 A1	mark for using the p.e. equation **accept** 1.5×10^{-19} from those using 5×10^{-19} J
	b	i1 ii2	12 (eV) $\varepsilon = eV = 12 \times 1.6 \times 10^{-19} = 1.92 \times 10^{-18}$ (J)	B1 A1	 **ecf(b)(i)1**
		ii	$\frac{1}{2}mv^2 = 2.0 \times 10^{-18}$ $v^2 = 2 \times 2.0 \times 10^{-18} / 9.1 \times 10^{-31} = 4.4 \times 10^{12}$ $v = 2.1 \times 10^{6}$ (m s^{-1})	C1 C1 A1	$\frac{1}{2}mv^2 = 12$ scores 0/3 **accept** 1.9×10^{-18} from **(b)(i)2** giving v = 2.0(5) x 10^{6}
	c		e's emitted/s = $1.2 \times 10^{-8} / 5 \times 10^{-19} = 2.4 \times 10^{10}$ current = $2.4 \times 10^{10} \times 1.6 \times 10^{-19}$ $= 3.8 \times 10^{-9}$ (A) to 4.1×10^{-9} (A)	C1 C1 A1	using 4.7×10^{-19} gives 2.55×10^{10} omitting 1% scores as a POT error allow 4 nA as the question states 'estimate'
			Total question 4	**16**	

7 **(a)*** 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 $eV_{min} = hc/\lambda$.

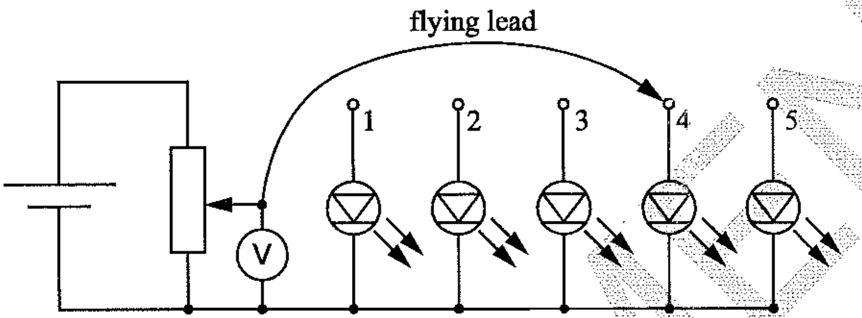

Fig. 7.1

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.

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.... [6]

(b) 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.

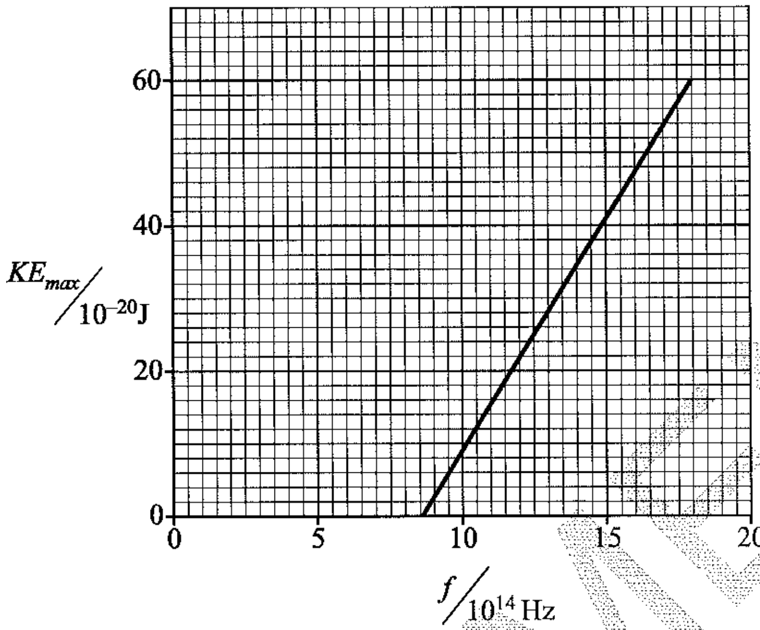

Fig.7.2

(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]**

END OF QUESTION PAPER

Question			Answer	Marks	Guidance
7	(a)*		**Level 3 (5–6 marks)** at least E3,4 and 2 or 5 at least P1,2 and 5 *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** expect 3 points from E and 2 points from P or 2 points from E and 3 points from P *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* **Level 1 (1–2 marks)** at least 2 points from E and 1 point from P or vice versa. *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.	B1 x 6	**Experiment (E)** 1. Adjust the potential divider to low or zero voltage 2. connect flying lead to one LED 3. increase voltage until LED just lights or strikes 4. repeat several times and average to find V_{min} 5. repeat for each LED 6. shield LED inside opaque tube to judge strike more accurately. **Processing (P)** 1. a graph of V_{min} against $1/\lambda$ will be a straight line 2. through the origin 3. so need to calculate values of $1/\lambda$ 4. then draw line of best fit through origin 5. gradient $G = V_{min}\,\lambda = hc/e$ 6. hence $h = eG/c$
	(b)	(i)	The wave-model cannot explain the cut-off frequency/threshold frequency Nor why the KE of the electrons is dependent on frequency	B1 B1	Allow reverse argument in terms of photons, e.g. the photon-model can explain the threshold frequency and why the KE of the electrons is dependent on frequency.

Question			Answer	Marks	Guidance
		(ii)	$h = 32 \times 10^{-20}/5 \times 10^{-14}$ $= 6.4 \times 10^{-34}$ (J s)	C1 A1	sensible attempt at gradient gains 1 mark
		(iii)	$8.75 \pm 0.25 \times 10^{14}$ (Hz)	B1	tolerance is to within grid square
		(iv)	$\varphi = 6.4 \times 10^{-34} \times 8.75 \times 10^{14}$ $= 5.6 \times 10^{-19}$ (J)	C1 A1	**ecf (b)(i)(ii)**
			Total	**13**	

8 In a demonstration experiment of the photoelectric effect, light of wavelength 440 nm incident on a clean metal surface causes electrons to be emitted. No electrons are emitted from the surface when the wavelength of the incident light is greater than 550 nm.

(a) (i) Define the term *work function.*

....

.... [2]

(ii) Explain how the work function is related to the threshold frequency.

....

....

.... [2]

(iii) Calculate the value of the work function for this metal.

work function = ... J [2]

(b) (i) Show that the maximum speed of the emitted electrons in the experiment is about $4.5 \times 10^5\,\text{m}\,\text{s}^{-1}$.

[3]

(ii) Calculate the minimum de Broglie wavelength of an emitted electron.

wavelength = ... m **[2]**

(c) The light source for this experiment is a discharge lamp containing excited atoms which emit light at several wavelengths. Fig. 8.1 shows the three lowest energy levels of one of these atoms, labelled $n = 1$, 2 and 3.

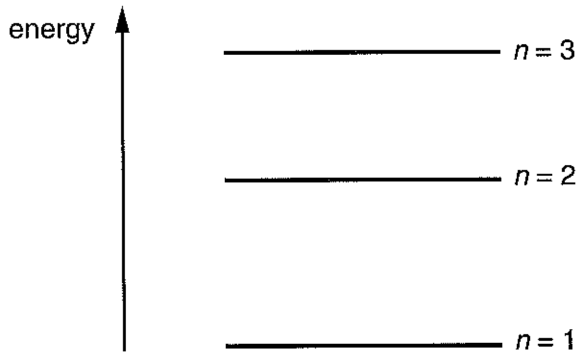

Fig. 8.1

Electron transitions between these energy levels can produce three different wavelengths of radiation. The transition between $n = 2$ and $n = 1$ causes the 440 nm photons.

(i) Photons at 590 nm are also emitted. Which transition causes these photons?

.... **[1]**

(ii) Hence calculate the wavelength of the photons emitted by the third transition.

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

[Total: 15]

END OF QUESTION PAPER

Question			Answer	Marks	Guidance
8	a	i	energy φ required for an electron to escape from metal surface the minimum energy........	M1 A1	inclusion of the word minimum in the sentence scores the second mark
		ii	a photon with less than the threshold frequency f_0 cannot cause electron emission/AW so work function = h (threshold frequency)	B1 B1	**allow** $\varphi = hf_0$ when the symbols φ and f_0 have been defined somewhere in the question
		iii	$\varphi = hc/\lambda$ $= 6.63 \times 10^{-34} \times 3.0 \times 10^8/550 \times 10^{-9}$ $= 3.6 \times 10^{-19}$ (J)	C1 A1	
	b	i	$KE_{max} = hf - \varphi$ or $hf = \varphi + KE_{max}$ $hf = 6.63 \times 10^{-34} \times 3.0 \times 10^8/440 \times 10^{-9} = 4.5 \times 10^{-19}$ J $½mv^2 = 9 \times 10^{-20}$ giving $v^2 = 1.8 \times 10^{-19}/9.1 \times 10^{-31}$ $v = 4.45 \times 10^5$ (m s^{-1})	C1 B1 B1 A0	**ecf (a)(iii)** allow 4.5 or 4.4 x 10^5
		ii	$\lambda = h/mv = 6.63 \times 10^{-34}/9.1 \times 10^{-31} \times 4.5 \times 10^5$ $\lambda = 1.6 \times 10^{-9}$ (m)	C1 A1	allow 1.7×10^{-9} for $v = 4.4 \times 10^5$
	c	i	n = 3 to n = 2	B1	**allow** between **or** and **when** there is a downward arrow on Fig. 8.1
		ii	$E_{32} + E_{21} = E_{31}$ $hc/\lambda_{32} + hc/\lambda_{21} = hc/\lambda_{31}$ $1/590 + 1/440 = 1/252$ so $\lambda_{31} = 250 \times 10^{-9}$ (m)	C1 C1 A1	**accept** equation using $1/\lambda$ **or** $1/590 + 1/440 = 1/\lambda_{31}$ **allow** 2 or 3 sf **allow** 2/3 for using 550 for 590 nm giving 244 nm
			Total	**15**	

6 In an experiment it is observed that when blue light is shone on a clean metal surface electrons are emitted, but with red light there is no electron emission.

(a) State the name of the effect observed in this experiment.

.... [1]

(b) Describe Einstein's theory to explain these observations.

In your answer you should include technical terms to explain how the physics of quantum behaviour is used to explain the observations.

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.... [4]

(c) The longest wavelength of light incident on the metal surface which causes electrons to be emitted is 480 nm.

(i) Show that the work function of the metal is about 4×10^{-19} J.

[3]

(ii) Calculate the maximum speed of an emitted electron when a photon of energy 5.2×10^{-19} J is incident on the metal surface.

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

(d) (i) Describe briefly one piece of evidence for believing that electrons sometimes behave like waves.

....

....

....

.... **[2]**

(ii) Calculate the de Broglie wavelength of an electron moving at $500\,km\,s^{-1}$.

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

END OF QUESTION PAPER

Question			Answer	M	Guidance
6					
	a		photoelectric effect	B1	
	b		**1.**Individual photons are absorbed by individual electrons (in the metal surface)/ one to one interaction/AW **2.**Only photon with energy above the work function energy will cause photoelectron emission/idea of threshold frequency **3.**Photon energy is proportional to frequency **4.**(therefore) blue photons with higher f/shorter λ will cause photoemission but red photons will not. **5.**$hf - \phi = KE_{max}$ is the equation resulting from conservation of energy **or** resulting from the meaning of each term **6.**A wave model does not explain instantaneous emission	B1 B1 B1 B1 B1 B1	**max** 4 from 6 marking points **allow** work function (of a metal surface) is minimum energy for photoemission **allow** shorter wavelength light has higher energy (hc/λ) or higher frequency higher energy (hf) **or** ....red photons with lower f/longer λ..... *max* must be present to score mark; equation stated in words: photon e. – w.f. = max ke of *e* to score full marks (4) the answer **must include** two terms out of *photon, work function* and *threshold frequency/wavelength* (QWC mark)
	c	i	work function = $\phi = hc/\lambda$ $\varphi = 6.6 \times 10^{-34} \times 3.0 \times 10^{8} / 4.8 \times 10^{-7}$ $= 4.1(4) \times 10^{-19}$ (J)	C1 M1 A1	allow $\phi = hf$ ($f = 6.25 \times 10^{14}$) and $f = c/\lambda$ must show answer <u>initially</u> to 2 or 3 SF; ignore any <u>final</u> rounding down to 1 SF
		ii	$E - \phi = \frac{1}{2}mv^2$ $(5.2 - 4.1) \times 10^{-19} = 1.1 \times 10^{-19} = \frac{1}{2}mv^2$ $v = \sqrt{(2 \times 1.1 \times 10^{-19} / 9.1 \times 10^{-31})}$ $v = 4.9 \times 10^{5}$ (m s^{-1})	C1 C1 A1	can use 4.14 or 4 instead of 4.1 **allow** 5.1×10^{5} (m s^{-1}) using $\phi = 4 \times 10^{-19}$ or 4.8×10^{5} (m s^{-1}) using $\phi = 4.14 \times 10^{-19}$
	d	i	electrons passing through a thin sheet of graphite are diffracted/produce diffraction rings on a fluorescent screen	M1 A1	any suitable/reasonably plausible situation what is observed/ interpretation
		ii	$\lambda = h/mv$ $\lambda = 6.63 \times 10^{-34} / 5.0 \times 10^{5} \times 9.1 \times 10^{-31}$ $\lambda = 1.5 \times 10^{-9}$ (m)	C1 C1 A1	1.46 to 3 SF
			Total question 6	**16**	