PRESTON MANOR

Physics Exam Pack

Wave-Particle Duality

Name: Date:

Question / Paper	Mark

6 **(a)** Write the de Broglie equation in words. Without the aid of calculations, explain why electrons can be diffracted by matter (e.g. graphite), whereas a ball thrown through an open window does not show any observable diffraction effects.

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..... **[4]**

(b) Calculate the de Broglie wavelength of an electron travelling at a speed of 2.5% of the speed of light in a vacuum.

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

[Total: 7]

Question			Expected Answers	Marks	Additional Guidance
6	a		Any <u>four</u> from:		**Must show ticks on the script to indicate where marks are being awarded**
			$\lambda = \frac{h}{mv}$	M1	
			λ = wavelength, m = mass (of particle) h = Planck constant and v = speed (of particle)	A1	
			λ (of electron) is similar to separation between / size of atoms (wtte)	B1	
			λ of electron ~ 10^{-10} <u>m</u>	B1	**Allow** Wavelength in the range (10^{-9} to 10^{-13}) <u>m</u>
			The wavelength of the ball is (very) small compared with the window gap (wtte)	B1	For this mark, there must be clear reference to the size / width /gap of window; hence no mark for 'wavelength of electron is very small'
	b		speed = $0.025 \times 3.0 \times 10^8$ or 7.5×10^6 (m s^{-1})	C1	
			$\lambda = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 7.5 \times 10^6}$	C1	Allow 2 marks for correct substitution of all numbers in the equation – any subject
			$\lambda = 9.7 \times 10^{-11}$ (m)	A1	**Allow** 3 marks for a bald answer of 9.7×10^{-11} (m)
			Total	7	

6 Fig. 6.1 shows part of the apparatus for an experiment in which electrons travel through a thin layer of graphite (carbon atoms) and emerge to produce concentric rings on a fluorescent screen.

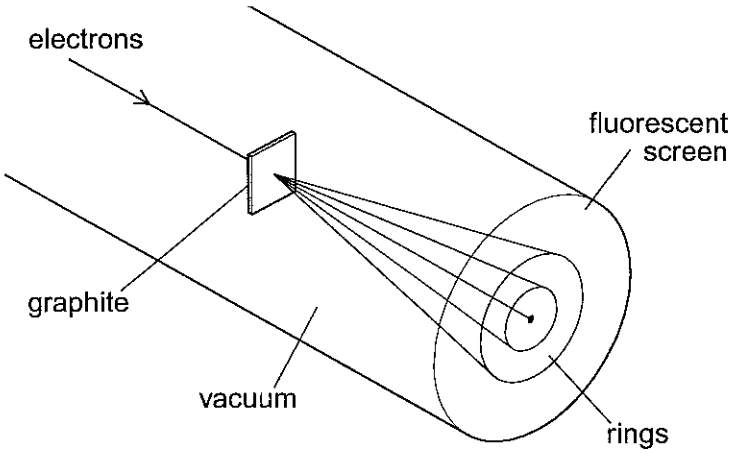

Fig. 6.1

(a) Use the ideas of de Broglie to explain how this experiment demonstrates the wave-nature of electrons.

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.....[4]

(b) Fast moving electrons can be used to investigate the structure of materials. The electrons should have a de Broglie wavelength similar to that of X-rays.

(i) State a typical value for the wavelength of X-rays in metres.

.....[1]

(ii) Calculate the speed of an electron with a de Broglie wavelength equal to your value in **(b)(i)**.

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

[Total: 7]

Question			Expected Answers	Marks	Additional Guidance
6	a		Any <u>four</u> from: 1. Electrons <u>travel</u> / <u>move</u> as 'waves' 2. Electrons are diffracted 3. Diffraction by atomic planes / gaps between atoms / atoms (AW) 4. The wavelength of the electron is similar to atomic separation / gap / size (AW) 5. Reference to $\lambda = \frac{h}{mv}$ / $\lambda = \frac{h}{p}$ 6. where λ = wavelength, h is Planck constant, m = mass (of electron) and v = speed / velocity (or p = momentum)	B1 × 4	**Must show ticks on the script to indicate where marks are being awarded** **Not** Electrons 'pass through' as waves for first marking point **Not** 'diffracted by *gaps / holes* in graphite' for marking point 3. **Marking point 6. can only be scored if the de Broglie equation is given**
	b	i	Allow a number in the range 1 ×10^{-13} (m) to 5 ×10^{-6} (m)	B1	
		ii	speed = h/(9.11 × 10^{-31} × answer to (b)(i)) correct value for the speed	C1 A1	The first mark is for correct substitution of their value for wavelength – the value for h is not required. It is the same as: speed = 7.28 × 10^{-4}/(b)(i) **Allow** 2 marks for a bald correct answer (in m s^{-1}) The answer must be 2 sf or more
			Total	7	

7 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.

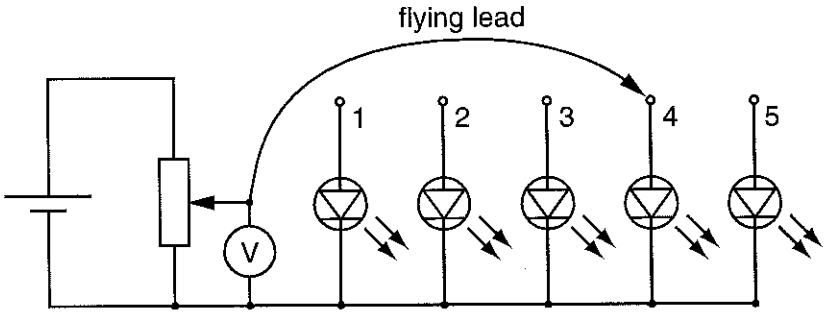

Fig. 7.1

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.

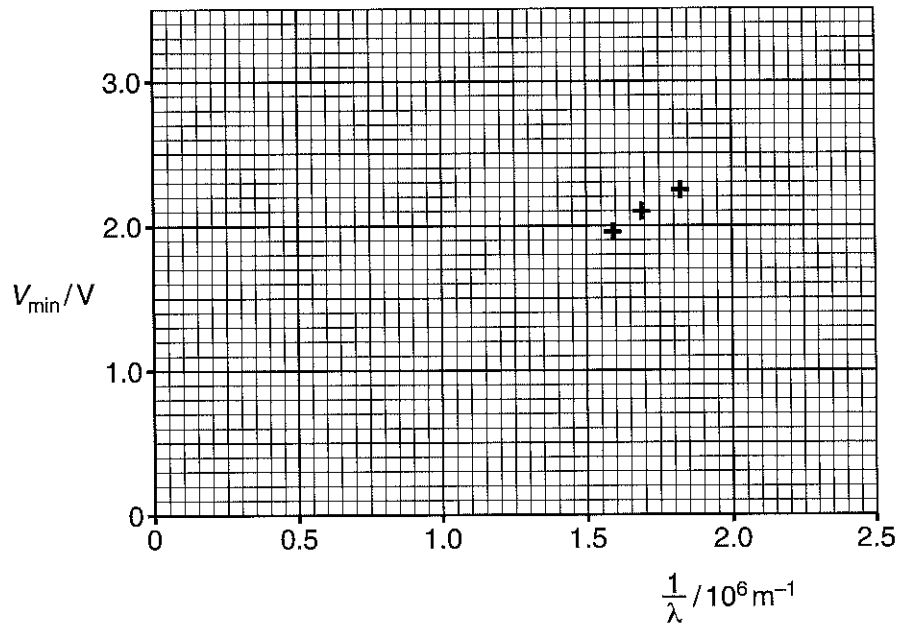

Fig. 7.2

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]

END OF QUESTION PAPER

Question			Answer	Marks	Guidance
7	(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)	(i)	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)	$1.24 \times 10^{-6} = hc/e$ $h = 1.24 \times 10^{-6} \times 1.6 \times 10^{-19} / 3.0 \times 10^{8}$ $h = 6.6(1) \times 10^{-34}$ (J s)	 M1 A1	**ecf (c)(i)** correct substitution into equation mark ans = 5.3 x grad (ignoring all powers of 10)
			Total	**13**	
			SCAN DOWN TO CHECK NO ANSWERS ON PAGE 18		

5 This question is about electrons and photons.

(a) Both electrons and photons can be considered as particles. State **two** differences between their properties.

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..... **[2]**

(b) An electron is accelerated from rest through a p.d. of 5000V.

(i) Show that the energy gained by the electron is 8.0×10^{-16}J.

[2]

(ii) Show that the speed of the electron is about $4 \times 10^{7}\,m\,s^{-1}$.

[3]

(c) **(i)** Explain what is meant by the de Broglie wavelength of an electron.

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..... **[1]**

(ii) Calculate the de Broglie wavelength of the electron in **(b)**.

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

(d) Calculate the wavelength of a photon of energy 8.0×10^{-16} J.

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

(e) Photons of energy 9.0×10^{-19} J are incident on a clean tungsten surface causing electrons to be emitted.

(i) State the name of this process.

..... **[1]**

(ii) Calculate the maximum kinetic energy of the emitted electrons. Tungsten has a work function of 7.2×10^{-19} J.

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

(iii) Explain why your answer to **(ii)** is a maximum value.

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..... **[2]**

[Total: 19]

Question			Answer	Marks	Guidance
5	(a)		electrons have mass, photons have zero mass electrons have charge, photons are uncharged photons travel at <u>speed of light</u>	B1 B1	**max** 2 marks from 3 marking points lower speed of electrons **not** required for mark
	(b)	(i)	energy = eV = 1.6 x 10^{-19} x 5000 =8.0 x 10^{-16} (J)	C1 A1	**accept** 8 x 10^{-16} (J) (no SF error)
		(ii)	½mv^2 = 8.0 x 10^{-16} v^2 = 1.76 x 10^{+15} v = 4.2 x 10^7 (m s^{-1})	C1 C1 A1	 evidence of calculation required
	(c)	(i)	electron wavelength depends on its speed/momentum	B1	**accept** de Broglie equation with labels defined
		(ii)	λ = h/mv λ = 6.63 x 10^{-34}/(9.1 x 10^{-31} x 4.2 x 10^7) = 1.7 x 10^{-11} (m)	C1 C1 A1	select formula substitution; **allow** 4 x 10^7 **allow** 1.8 x 10^{-11} (m)
	(d)		E = hc/ λ λ = 6.63 x 10^{-34} x 3.0 x 10^8/8.0 x 10^{-16} = 2.5 x 10^{-10} (m)	C1 C1 A1	select equation substitute and manipulate answer 2.49 x 10^{-10} (m)
	(e)	(i)	photoelectric effect / emission	B1	
		(ii)	KE_{max} = hf – φ or hf = φ + KE_{max} 9.0 x 10^{-19} – 7.2 x 10^{-19} = 1.8 x 10^{-19} (J)	C1 A1	can be copied from data sheet
		(iii)	Electrons in the metal have a range of energies most require more than the w.f. energy to escape from the surface/AW	B1 B1	w.f. is <u>minimum</u> energy to escape from surface /AW <u>max</u> k.e. given when w.f. subtracted from photon energy **or** photon gives all of its energy to one electron
			Total	19	

8 In 1927 it was shown by experiment that electrons can produce a diffraction pattern.

(a) (i) Explain the meaning of the term *diffraction*.

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..... **[1]**

(ii) State the condition necessary for electrons to produce observable diffraction when passing through matter, e.g. a thin sheet of graphite in an evacuated chamber.

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..... **[2]**

(b) Show that the speed of an electron with a de Broglie wavelength of 1.2×10^{-10} m is 6.0×10^{6} m s^{-1}.

[3]

(c) The electrons in **(b)** are accelerated to a speed of 6.0×10^6 $m s^{-1}$ using an electron gun shown diagrammatically in Fig. 8.1.

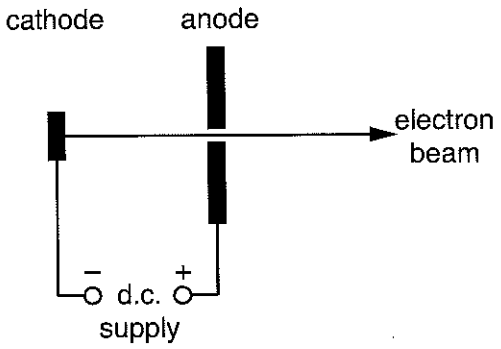

Fig. 8.1

(i) Calculate the potential difference V across the d.c. supply between the cathode and the anode.

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

(ii) Suggest why, in an electron gun, the cathode is connected to the negative terminal of the supply rather than the positive terminal.

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..... **[1]**

[Total: 10]

END OF QUESTION PAPER

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 $(9.6 \times 10^{-5}$ if using $3 \times 10^{15})$	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	$eV = \frac{1}{2}mv^2$ $V = mv^2/2e = 9.1 \times 10^{-31} \times (6.0 \times 10^{5})^2 / 2 \times 1.6 \times 10^{-19}$ $= 1.0(2) \times 10^{2}$ (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**	

6 **(a)** In atomic physics electron energies are often stated in *electronvolts* (eV).

Define the *electronvolt*. State its value in joule.

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..... **[2]**

(b) An electron is accelerated from rest through a potential difference of 300V.

(i) Calculate the final kinetic energy of the electron

1 in eV

kinetic energy = ... eV **[1]**

2 in J.

kinetic energy = ... J **[1]**

(ii) Show that the final speed of the electron is about $1 \times 10^7\,m\,s^{-1}$.

[2]

(c) **(i)** Explain what is meant by the *de Broglie wavelength* of an electron.

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..... **[2]**

(ii) Calculate the de Broglie wavelength of the electron in **(b)**.

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

[Total: 10]

Question			Expected Answers	M	Additional Guidance
6					
	a		an eV is the energy acquired by an electron accelerated/moves through a p.d. of 1 V 1 eV = 1.6×10^{-19} J	B1 B1	
	b	i	300 (eV) 4.8×10^{-17} (J)	B1 B1	1 mark if write correct answers on wrong lines **ecf** for (first answer) x 1.6×10^{-19} e.g. 7.68×10^{-35} using 4.8×10^{-17}
		ii	$\frac{1}{2}mv^2 = 4.8 \times 10^{-17} \Rightarrow v^2 = 9.6 \times 10^{-17} / 9.1 \times 10^{-31}$ (= 1.06×10^{14}) $v = 1.03 \times 10^7$ (m s^{-1})	M1 A1	**allow** 1 mark only for $v^2 = 2 \times$ **b(i)**/ 9.1×10^{-31} if **b(i)** incorrect **allow** 1.0×10^7, 1×10^7 is not acceptable
	c	i	Electrons are observed to behave as waves/show wavelike properties where the electron wavelength depends on its speed/momentum	B1 B1	**accept** by being diffracted (by a crystal lattice)/AW **accept** de Broglie eqn with m,v or p defined
		ii	$\lambda = h/mv = 6.63 \times 10^{-34} / (9.1 \times 10^{-31} \times 1.03 \times 10^7)$ $= 7.1 \times 10^{-11}$ (m)	C1 A1	**allow** 1 mark for 3.9 or 4.0×10^{-14} (m) caused by subs m_p for m **allow** 7.3×10^{-11} (m)
			Total question 6	**10**	