Name: _____

Quantum

Date:

Time:

Total marks available:

Total marks achieved: _____

Mark Scheme

Q1.

Question Number	Acceptable Answers		Additional guidance	Mark
	• Use of $p = mv$ using mass of electron • Use of $\lambda = \frac{h}{p}$ • $\lambda = 3.3 \times 10^{-11}$ m	(1) (1) (1)	Example of Calculation $\lambda = \frac{6.63 \times 10^{-34}\ \text{J s}}{9.11 \times 10^{-31}\text{kg} \times 2.2 \times 10^{7}\ \text{m s}^{-1}}$ $\lambda = 3.3 \times 10^{-11}$ m	3

Q2.

Question Number	Answer		Mark
(a) (i)	Use of $\lambda = h/p$ and $p = mv$ **Or** $v = h/m\lambda$ Use of $m = 9.11 \times 10^{-31}$ kg $v = 7.28 \times 10^{6}$ m s^{-1} Example of calculation $\lambda = h/mv$ $v = 6.63 \times 10^{-34}$ J s /(9.11×10^{-31} kg $\times 1.0 \times 10^{-10}$ m) $v = 7.28 \times 10^{6}$ m s^{-1}	(1) (1) (1)	3
(a) (ii)	Use of $E_k = ½\ mv^2$ **Or** $E_k = p^2/2m$ **Or** see $E_k = 2.41 \times 10^{-17}$ J Divided by 1.60×10^{-19} $E_k = 151$ eV (accept values in range 150 – 152 eV) (ecf value of v from (a)) Example of calculation $E_k = ½ (9.11 \times 10^{-31}$ kg$)(7.28 \times 10^{6}$ m s$^{-1})^2$ / (1.60×10^{-19} J eV^{-1}) $E_k = 151$ eV	(1) (1) (1)	3
(b)	The wavelength is similar in size to the nucleus The wavelength /nucleus is (much) smaller / 10^{-15}m / 10^{-14} m (if value is not given, 'wavelength is small' or 'wavelength is very small' is not sufficient)	(1) (1)	2

Q3.

Question Number	Answer		Mark
(a)	The wavelength (associated) with a particle/electron with a given momentum **Or** $\lambda = h/p$ all terms defined	(1) (1) (1) (1)	2
(b)(i)	Use of $E_k = eV$ Use of $E_k = p^2/2m$ **Or** use of $E_k = mv^2/2$ **and** $p = mv$ Momentum = 1.21×10^{-23} kg m s^{-1} Example of calculation $E_k = 1.6 \times 10^{-19}$ C× 500 V $p^2 = 2\,m\,E_k = 2 \times 9.11 \times 10^{-31}$ kg × $(1.6 \times 10^{-19} \times 500)$ J $p = 1.21 \times 10^{-23}$ kg m s^{-1}	(1) (1) (1)	3
(b)(ii)	Use of $\lambda = h/p$ $\lambda = 5.49 \times 10^{-11}$ m (ecf value of p from (i)) (show that value gives 6.63×10^{-11} m) Example of calculation $p = 6.63 \times 10^{-34}$ J s / 1.21×10^{-23} kg m s^{-1} $\lambda = 5.49 \times 10^{-11}$ m	(1) (1)	2
	Total for question		7

Q4.

Question Number	Acceptable Answer	Additional Guidance	Mark
	• The deflection/fields experiments indicate that electrons have a mass (and a charge) **Or** the deflection/fields experiments indicate that electrons have particle behaviour. (1) • The diffraction experiments indicate that electrons must have a wave nature (1) • Idea that a model of electron behaviour must include wave-particle duality (1)	In MP1 allow a description of deflection e.g. electrons are deflected by (electric and magnetic) fields indicating that they have a mass (and charge)	3

Q5.

Question Number	Acceptable answers		Additional guidance	Mark
	• Use of $E_K = p^2 / 2m$	(1)	MP1 accept use of $p = mv$ **and** Use of $E_k = ½ mv^2$ MP4 accept (n + ½) λ or n λ respectively Example of calculation $p = \sqrt{(2 \times 9.11 \times 10^{-31}\ \text{kg} \times 9.6 \times 10^{-17}\ \text{J})}$ $p = 1.32 \times 10^{-23}\ \text{kg m s}^{-1}$ $\lambda = 6.63 \times 10^{-34}\ \text{Js} / 1.32 \times 10^{-23}\ \text{kg m s}^{-1}$ $\lambda = 5.0 \times 10^{-11}\ \text{m}$	6
	• Use of $\lambda = h/p$	(1)		
	• $\lambda = 5.0 \times 10^{-11}$ (m) calculated from E_K **Or** $E_K = 9.7 \times 10^{-17}$ (J) calculated fro $\lambda = 5.0 \times 10^{-11}$ m **Or** $p = 1.3 \times 10^{-23}$ (kg m s^{-1}) calculated from E_K **and** $p = 1.3 \times 10^{-23}$ (kg m s^{-1}) calculated from $\lambda = 5.0 \times 10^{-11}$ m	(1)		
	• path difference at X is $\lambda/2$ **Or** path difference at Y is λ	(1)		
	• (electron) waves at X are in antiphase **Or** (electron) waves at Y are in phase	(1)		
	• at X destructive interference/superposition takes place **Or** at Y constructive interference/superposition takes place	(1)		

Q6.

Question Number	Acceptable Answer	Additional Guidance	Mark
*	This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The table shows how the marks should be awarded for indicative content and structure and lines of reasoning. Number of indicative marking points seen in answer / Number of marks awarded for indicative marking points 6 / 4 5–4 / 3 3–2 / 2 1 / 1 0 / 0 Number of marks awarded for structure of answer and sustained line of reasoning Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout / 2 Answer is partially structured with some linkages and lines of reasoning / 1 Answer has no linkages between points and is unstructured / 0	IC Points / IC Mark / Max linkage mark avail. / Max final mark 6 / 4 / 2 / **6** 5 / 3 / 2 / **5** 4 / 3 / 1 / **4** 3 / 2 / 1 / **3** 2 / 2 / 0 / **2** 1 / 1 / 0 / **1** 0 / 0 / 0 / **0** IC3 and IC4 must include a mention of the walls/container	**6**

	Indicative content: 1. As the temperature of the gas increases the (average) speed/E_k of the atoms increases 2. Greater speed/E_k so the momentum of the atoms increases 3. The rate/frequency of collision of atoms with the container walls increases **Or** the time between collisions with the walls decreases 4. The rate of change of momentum at the walls increases 5. Rate of change of momentum is equal to the force 6. Pressure is $\frac{\text{force}}{\text{area}}$ and the force (on the walls) is greater		

Q7.

<table>
<tr><th>Question Number</th><th>Acceptable answers</th><th>Additional guidance</th><th>Mark</th></tr>
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<td>*</td>
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This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning.

Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

The following table shows how the marks should be awarded for indicative content.
<table>
<tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr>
<tr><td>6</td><td>4</td></tr>
<tr><td>5 - 4</td><td>3</td></tr>
<tr><td>3 - 2</td><td>2</td></tr>
<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
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The following table shows how the marks should be awarded for structure and lines of reasoning
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<tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
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<tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr>
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	Indicative content • This is a diffraction/interference pattern • Electrons behave as waves • As speed/momentum increases the circles get smaller • $n\lambda = d\sin\theta$ used to justify that as θ decreases λ decreases • Refers de Broglie equation ($\lambda = h/p$) to confirm that as speed/momentum increases, wavelength decreases. • Crystal has a regular/layered structure	**PP2** Do not credit 'electrons behave as waves or particles' on its own **PP3** accept circles get condensed for circles get smaller **PP4** do **not** credit use of equation to justify λ same size as gaps in crystal or to measure the gaps in the graphite **PP6** small gaps at uniform distances/lengths **Or** accept that graphite is made up of more than a single crystal	**6**

Q8.

Question Number	Acceptable answers	Additional guidance	Mark
(a)(i)	• Use of $\lambda = h/p$ **and** $v = f\lambda$ **(1)** • Momentum of photon = 3.3 × 10^{-27} (N s) **(1)**	Example of calculation Momentum of photon = $p = hf/c$ = 6.63 × 10^{-34} J s × 1.5 × 10^{15} Hz ÷ 3.00 × 10^{8} m s^{-1} = 3.315 × 10^{-27} N s	**2**

Question Number	Acceptable answers	Additional guidance	Mark
(a)(ii)	• Momentum transfer = 6.6 × 10^{-27} (N s) **(1)**	Ecf momentum from (i) in parts (a)(ii) and (c)	**1**

Question Number	Acceptable answers	Additional guidance	Mark
(b)(i)	• Use of $hf = \varphi + ½ mv^2_{max}$ **(1)** • Use of $E_K = ½ mv^2$ **(1)** • $v = 8.4 \times 10^5$ (m s^{-1}) **(1)**	Example of calculation $hf = \varphi + ½ mv^2_{max}$ hf = 6.63 × 10^{-34} J s × 1.5 × 10^{15} Hz = 9.95 × 10^{-19} J $hf - \varphi$ = 9.95 × 10^{-19} J − 6.7× 10^{-19} J = 3.25 × 10^{-19} J 3.25 × 10^{-19} J = ½ × 9.11 × 10^{-31} kg × v^2 v = 8.4 × 10^5 m s^{-1}	**3**

Question Number	Acceptable answers	Additional guidance	Mark
(b)(ii)	• Use of $p = mv$ (1) • Momentum of photoelectron = 7.7×10^{-25} N s (1)	Example of calculation $p = 9.11 \times 10^{-31}$ kg $\times$ 8.4×10^{5} m s^{-1} Momentum of photoelectron = 7.68×10^{-25} N s MP2: Using show that value $p = 7.3 \times 10^{-25}$ N s	2

Question Number	Acceptable answers	Additional guidance	Mark
(c)	An explanation that refers to the following points: • the change in momentum of the graphene oxide is the same as the change in momentum of the photoelectron (1) • so the (change in) momentum is much larger for the photoelectron than for the reflected photon (1)	Accept converse statement and answer that is consistent with candidate's values in (a) and (b)	2