The Photoelectric Effect Mark Scheme

Q1.

Question Number	Answer	Mark
	The only correct answer is C **A** *is not correct because* photoelectrons are released instantly, so this statement is true **B** *is not correct because* there is a minimum frequency for photoelectrons to be released, so this statement is true **D** *is not correct because* the energy of a photon $E = hf$ so this statement is true	1

Q2.

Question Number	Answer	Mark
	The only correct answer is C because wave nature would predict a greater emission rate with a greater incident power A because instantaneous emission is only predicted by particle nature B because dependence of maximum kinetic energy on frequency is only predicted by particle nature D because minimum frequency for emission is only predicted by particle nature	1

Q3.

Question Number	Acceptable answer	Additional guidance	Mark
	D	The only correct answer is **D**: a wave of greater intensity would still transfer energy at a greater rate which could release photoelectrons at a greater rate even if they could absorb energy continuously A is not correct because time would be required for absorption of sufficient wave energy B is not correct because absorption of sufficient wave energy would occur over time C is not correct because at higher intensities the waves would have higher amplitudes and energy could increase over time to higher values	1

Q4.

Question Number	Answer	Mark
(a)	Lowest / minimum frequency (of light / photons incident on a metal) that will cause electrons to be emitted (from surface) **Or** the frequency of (light / photons) that will cause electrons to be emitted (from the surface of a metal) with zero kinetic energy (1) (accept only just emitted)	1

Q5.

Question Number	Acceptable answers	Additional guidance	Mark
(a)	the lowest frequency (of incident radiation) that will cause the emission of (photo)electrons (from the surface)		**(1)**

Q6.

Question Number	Acceptable answers	Additional guidance	Mark
	An explanation that makes reference to the following points: • Electrons (in the dust particles) absorb the energy of photons (in UV ray) (1) (1) • One photon interacts with one electron (1) • And the electron is released from the surface of the dust particle (leaving dust particle charged)		3

Q7.

Question Number	Acceptable answers	Additional guidance	Mark
	• One electron absorbs one photon **(1)** • Photon energy is proportional to frequency **Or** Photon energy is equal to hf **(1)** • The (photon) energy is less than the work function of the metal (if frequency is below the threshold) **Or** electron gains insufficient energy to be released (if frequency is below a certain value) **(1)**		3

Q8.

Question Number	Answer	Additional Guidance	Mark
	• one photon interacts with one electron (1) • when the energy of the photon is equal to or greater than the work function (of the metal) an electron is released (1) • energy of photon = hf so there is a minimum/threshold frequency (1)		3

Q9.

Question Number	Acceptable Answer	Additional Guidance	Mark
	The student's answer should • Include the idea that 'threshold' refers to a (minimum) frequency (1) • state that photons have an energy given by hf (1) • recognise that the energy used to release electrons is called the work function (1) • include the idea that one photon is absorbed by one electron (1)	For MP1, accept that wavelength has to be below a certain 'threshold' **Max 3** if the response is not a discussion of the student's answer	**4**

Q10.

(b)	Idea that one photon is absorbed by one electron (1) Photon energy given by $E = hf$ **Or** photon energy increases with frequency (1) The idea that there is a minimum energy needed for emission of a (photo)electron (1) (So) emission of electrons only occurs if frequency of light greater than the threshold frequency **Or** threshold frequency is the minimum frequency for the emission of (photo)electrons (1)	**4**

Q11.

Question Number	Answer		Mark
(a)	Quantum of … **Or** (discrete) packet of … **Or** discrete quantity of …	**(1)**	
	(To score the mark must refer to something relevant e.g. light / energy) Of electromagnetic radiation/energy	**(1)**	**2**
*** (b)**	(QWC – Work must be clear and organised in a logical manner using technical wording where appropriate)	**(1)**	
	describe relevant interaction between single photon and single electron		
	photon energy depends on frequency **Or** reference to $E = hf$ (must be link to photons/light)	**(1)** **(1)**	
	if photon energy greater than work function, electron emitted (immediately)	**(1)**	
	whereas for waves energy could build up **Or** with waves that the electron can absorb energy continuously or over time	**(1)**	**5**
	so any frequency should work **Or** but this build up doesn't happen		

Q12.

Question Number	Acceptable Answers		Additional guidance	Mark
	Max 6 **Similarities**			
	• An electron absorbs a photon **Or** electrons gain energy from a photon	(1)		
	• photons need a minimum amount of energy	(1)		
	• So light must be above a certain frequency	(1)		
	• increasing the light intensity increases the number of electrons (released per sec)	(1)		
	• Evidence for the particle model of light	(1)		
	Differences			
	• In the photoelectric effect electrons are released from the surface	(1)		
	• But electrons remain within the LDR	(1)		**6**
	• Photoelectric effect occurs in metals **Or** LDR is a semiconductor	(1)		

Q13.

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<tr><td>1</td><td>1</td></tr>
<tr><td>0</td><td>0</td></tr>
</table>
Particle model

One photon interacts with one electron
And each photon has energy proportional to the frequency, Or reference to $E=hf$
The electron is emitted (instantly) only if the energy of the photon is greater than the work function (of the metal)
Or The electron is emitted (instantly) only if the energy of the photon is greater than the energy needed for an electron to break free (from metal surface)
Any photon energy over and above the work function is gained by the electron as kinetic energy

Wave model

It would be expected that the energy of the electron would build up and eventually be emitted.
The (kinetic) energy of the (emitted) electrons would depend on the intensity of the wave (and not the frequency)

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</table>
Linkage marks
<table>
<tr><th>Indicative content points</th><th>Possible linkage marks</th></tr>
<tr><td>0, 1</td><td>0</td></tr>
<tr><td>2, 3</td><td>1</td></tr>
<tr><td>4, 5, 6 with points from both models</td><td>2</td></tr>
</table>
</td>
<td>6</td>
</tr>
</table>

Q14.

Question Number	Acceptable Answers	Additional guidance	Mark
	• (High intensity of light means) photons strike the photocell at a greater rate (1) • One to one interaction between photons and electrons (1) • So Electrons released at a greater rate (1) • So greater current/charge/power in external circuit (1)		4

Q15.

Question Number	Acceptable Answer	Additional Guidance	Mark
(i)	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:	Guidance on how the mark scheme should be applied: The mark for indicative content should be added to the mark for lines of reasoning. For example, an answer with five indicative marking points which is partially structured with some linkages and lines of reasoning scores 4 marks (3 marks for indicative content and 1 mark for partial structure	

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

The following table shows how the marks should be awarded for structure and lines of reasoning:

	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

and some linkages and lines of reasoning). If there are no linkages between points, the same five indicative marking points would yield an overall score of 3 marks (3 marks for indicative content and no marks for linkages).

Indicative content

- photon energy discrete/quantised
- one photon transfers all of its energy to one electron
  Or one photon cause the emission of one (photo)electron
- photon must have energy greater than / equal to work function energy to release (photo)electron
- reference to $E = hf$
- if light was a wave, energy could build up
- if light was a wave, any frequency could provide sufficient energy in time there would be a current for all frequencies

(6)

Q16.

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</table>
Indicative content

photon energy $E = hf$
photon energy must be greater than work function (of metal) for photon to provide enough energy for photoemission
UV photons have sufficient energy for photoemission but lab light photons do not
one photon interacts with one electron
with larger area more photons are absorbed/incident in a given time
more electrons are emitted in a given time (so the charge is lost more quickly)

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</table>
IC2 accept answers in terms of threshold frequency
IC5 & 6 there must be the idea of 'rate' once
<table>
<tr><th>Number of IC points awarded</th><th>Possible linkage marks</th></tr>
<tr><td>0,1</td><td>0</td></tr>
<tr><td>2, 3</td><td>1</td></tr>
<tr><td>4, 5, 6</td><td>2</td></tr>
</table>
</td>
<td>6</td>
</tr>
</table>

Q17.

Question Number	Answer		Mark
(a)	**When illuminated:**		
	Use of the word photon	(1)	
	photons/light cause emission of (photo)electrons	(1)	
	Idea that (photo) electrons form a current	(1)	
	photon energy greater than or equal to work function.	(1)	
	In darkness:		
	No photons so no photoelectrons released	(1)	5

(cii)	**Max 3**		
	Size of the gap (in the soundtrack) determines the amount of light	(1)	
	Amount of light determines number of photons	(1)	
	Number of photons determines number of (photo) electrons (released by phototube)	(1)	
	Number of electrons determines size of current (in the circuit)	(1)	3
	(Combining MP 1 and 2 by writing "size of the gap determines number of photons" scores 1 mark. Combining MP 2 and 3 by writing "the amount of light determines number of (photo) electrons" also scores 1 mark)		

Q18.

Question Number	Acceptable answers		Additional guidance	Mark
(a)	• (UV radiation consists of) photons	(1)	Accept quanta/packets of energy	
	• One photon interacts with one electron **Or** energy of photon depends on frequency	(1)		
	• Electrons released if energy (of photon) greater than work function **Or** frequency is greater than threshold frequency **Or** energy supplied is sufficient to remove electron	(1)		3

Question Number	Acceptable answers		Additional guidance	Mark
(c)	**Max 4** Valid because: • Moon and photocell both have vacuum • Both demonstration and theory use photoelectric effect Not valid because: • Different wavelengths in each case • On the moon there is dust not metal • Dust is free to move but the metal plate is fixed • On the moon UV removes electrons from (individual) <u>atoms</u> **and** in the demo light removes electrons from metal <u>surface</u> • Demonstration is based on photoelectric effect but effect on moon could be ionisation	(1) (1) (1) (1) (1) (1)	Full marks can only be scored if a correct link is made between at least one physics point and the demonstration being valid or not valid Accept the same concept for photoelectric effect Accept one uses light the other UV Accept different materials for MP4	**4**

Q19.

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Indicative Content

Intensity of UV greater at higher altitude
or
Intensity of UV is greater for the spacecraft
(because UV) radiation/light is absorbed in the atmosphere
or
light from the sun is reflected from the atmosphere
Higher intensity of radiation increases the number of photons(/second)
or
the number of photons incident (/second) on the spacecraft is greater
E ∝ frequency so energy of photon does not depend on altitude (so photoelectric effect still occurs)
One electron to one photon
The rate of released electrons from the spacecraft is greater

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Accept alternative argument wrt the aeroplane
</td>
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Q20.

Question Number	Acceptable answers	Additional guidance	Mark
	An explanation that makes reference to the following points: • (At 90°) the photons/UV spread over a smaller area (than at angles less than 90°) **Or** (At 90°) the intensity of the UV is higher **(1)** • (At 90°) there is a maximum/larger number of (incident) photons (per unit area per second) **(1)** • So a greater number of (photo)electrons are released (per unit area) **Or** More electrons absorb a photon (per unit area) **(1)**		3

Q21.

Question Number	Acceptable Answer	Additional Guidance	Mark
(a)	• As graphene is only 1 atom thick so the CSA/thickness is far smaller than for a sample of steel **Or** most applications need a thickness greater than one atom **Or** if more than one layer of graphene is used it will be weaker or the bonds between the layers will not be strong **Or** Graphene is difficult to manufacture because it has only one atomic layer **(1)** • Although graphene has a greater breaking stress it will break at a lower force **(1)**	MP1: accept graphene can only be 1 atom thick but steel can be any thickness (MP1, treat references to cost/energy as neutral)	2

Question Number	Acceptable Answer		Additional Guidance	Mark
(b)	• Use of depth of graphite = 100 × diameter of 1 carbon atom	(1)	Example of calculation Depth of graphite = $100 \times 1.4 \times 10^{-10}$ m = 1.4×10^{-8} m	
	• Use of cross-sectional area = depth × (0.5×10^{-3} m)	(1)	CSA = 1.4×10^{-8} m × 0.50×10^{-3} m = 7.0×10^{-12} m^2	
	• Use of $\rho = \frac{RA}{l}$	(1)	$\rho = \frac{1.029 \times 10^{6}\Omega \times 7.0 \times 10^{-12}\text{m}^2}{0.200\text{ m}} =$	
	• $\rho = 3.6 \times 10^{-5}\ \Omega$ m **Or** 36 μΩ m		$3.6 \times 10^{-5}\ \Omega$ m	4

Question Number	Acceptable Answer		Additional Guidance	Mark
(c)	**Max 3**			
	• Silicon will only release a (photo) electron for a limited range of frequencies/wavelengths	(1)	MP1: accept single frequency for limited range	
	• Silicon releases only one (photo) electron per incident photon	(1)		
	• Greater current (for the same illumination) in graphene	(1)		
	• Graphene (cells are) more efficient **Or** graphene cells could be smaller / cheaper / thinner			3

Q22.

Question Number	Acceptable answers	Additional guidance	Mark
(i)	• The (minimum) frequency at/above which electrons are **(1)** released	Accept frequency below which electrons are not released	1
(ii)	An explanation that makes reference to the following points: • With waves, energy would build up **(1)** • A photoelectron would (eventually have enough energy to) be emitted with any frequency, (which is not observed) **(1)**		2

Q23.

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	Indicative content Observations • Photoelectrons emitted instantaneously when radiation incident on surface • There is no photoemission below the threshold frequency • The maximum ke of the photoelectrons is independent of the intensity of the incident radiation • The rate of photoemission is proportional to the intensity of the incident radiation Models • One photon is absorbed by one electron **Or** all of the energy of one photon is transferred to one electron • With waves, energy can be supplied to the electron continuously **Or** with waves, energy can 'build up'	There are 4 observations and 2 models. Linkage is demonstrated by linking observations and models. Two linkage marks can only be awarded if reference is made to both models and more than one observation	6