Photoelectric Effect & Wave Particle Duality

Mark Scheme 1

Level	International A Level
Subject	Physics
Exam Board	CIE
Topic	Quantum Physics
Sub Topic	Photoelectric Effect & Wave Particle Duality
Paper Type	Theory
Booklet	Mark Scheme 1

Time Allowed: **65 minutes**

Score: **/54**

Percentage: **/100**

A*	A	B	C	D	E	U
>85%	'77.5%	70%	62.5%	57.5%	45%	<45%

1	(a) (i)	$p = h/\lambda$		
		$= (6.63 \times 10^{-34})/(6.50 \times 10^{-12})$	C	
		$= 1.02 \times 10^{-22}$ N s	A	[2]
	(ii)	$E = hc/\lambda$ or $E = pc$		
		$= (6.63 \times 10^{-34} \times 3.00 \times 10^{8})/(6.50 \times 10^{-12})$	C	
		$= 3.06 \times 10^{-14}$ J	A	[2]
	(b) (	$0.34 \times 10^{-12} = (6.63 \times 10^{-34})/(9.11 \times 10^{-31} \times 3.0 \times 10^{8}) \times (1 - \cos\theta)$	C	
		$\theta = 30.7°$	A1	[2]
	(ii)	deflected electron has energy	M1	
		this energy is derived from the incident photon	A1	
		deflected photon has less energy, longer wavelength (so $\Delta\lambda$ always positive)	B1	[3]
2	(a)	packet/quantum/discrete amount of energy	M1	
		of electromagnetic energy/radiation/waves	A1	[2]
	(b) (i)	arrow below axis and pointing to right	B1	[1]
	(ii) 1.	$E = hc/\lambda$		
		$= (6.63 \times 10^{-34} \times 3.0 \times 10^{8})/(6.80 \times 10^{-12})$	C1	
		$= 2.93 \times 10^{-14}$ J (*accept 2 s.f.*)	A1	[2]
	2.	energy of electron $= (3.06 - 2.93) \times 10^{-14}$		
		$= 1.3 \times 10^{-15}$ J	C1	
		speed $= \sqrt{(2E/m)}$	C1	
		$= 5.4 \times 10^{7}$ m s^{-1}	A1	[3]
	(c)	momentum is a vector quantity	B1	
		either must consider momentum in two directions		
		or direction changes so cannot just consider magnitude	B1	[2]

3 **(a)** discrete amount / packet / quantum of energy — M1
of electromagnetic radiation / EM radiation — A1 [2]

(b) (i) $E = hc/\lambda$
$= (6.63 \times 10^{-34} \times 3.0 \times 10^{8})/(570 \times 10^{-9}) = 3.49 \times 10^{-19}$ J — A [1]

(ii) number $= (2.7 \times 10^{-3})/(3.5 \times 10^{-19})$ — C
$= 7.7 \times 10^{15}$ — A1 [2]

2. momentum of photon $= h/\lambda$ — C1
$= (6.63 \times 10^{-34})/(570 \times 10^{-9})$
$= 1.16 \times 10^{-27}$ kg m s^{-1} — C1

change in momentum $= 1.16 \times 10^{-27} \times 7.7 \times 10^{15}$
$= 8.96 \times 10^{-12}$ kg m s^{-1} — A1 [3]

(*allow E = pc route to 9 × 10^{-12}*)

(c) pressure = (change in momentum per second) / area
$= (8.96 \times 10^{-12})/(1.3 \times 10^{-5})$
$= 6.9 \times 10^{-7}$ Pa — A1 [2]

4 **(a** e.g. no time delay between illumination and emission
max. (kinetic) energy of electron dependent on frequency
max. (kinetic) energy of electron independent of intensity
rate of emission of electrons dependent on/proportional to intensity
(*any three separate statements, one mark each, maximum 3*) — B3 [3]

(b) (i) (photon) interaction with electron may be below surface — B1
energy required to bring electron to surface — B1 [2]

(ii) **1.** threshold frequency = 5.8×10^{14} Hz — A1 [1]

2. $\Phi = hf_0$ — C1
$= 6.63 \times 10^{-34} \times 5.8 \times 10^{14}$
$= 3.84 \times 10^{-19}$ (J) — C1
$= (3.84 \times 10^{-19})/(1.6 \times 10^{-19})$
$= 2.4$ eV — A1 [3]

or

$hf = \Phi + E_{MAX}$ — (C1)
chooses point on line and substitutes values E_{MAX}, f and h into equation with the units of the hf term converted from J to eV — (C1)
$\Phi = 2.4$ eV — (A1)

5	**(a**	photon energy $= hc/\lambda$		
		$= (6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / (590 \times 10^{-9})$	C	
		$= 3.37 \times 10^{-19}$ J	C	
		number $= (3.2 \times 10^{-3}) / (3.37 \times 10^{-19})$		
		$= 9.5 \times 10^{15}$ (allow 9.4×10^{15})	A	[3]
	(b) **(i)**	$p = h/\lambda$	C1	
		$= (6.63 \times 10^{-34}) / (590 \times 10^{-9})$		
		$= 1.12 \times 10^{-27}$ kg m s^{-1}	C1	
		total momentum $= 9.5 \times 10^{15} \times 1.12 \times 10^{-27}$		
		$= 1.06 \times 10^{-11}$ kg m s^{-1}	A1	[3]
	(ii)	force $= 1.06 \times 10^{-11}$ N	A1	[1]

6	**(a**	*either* if light passes through suitable film / cork dust etc.	M1	
		diffraction occurs and similar pattern observed	A1	
		or concentric circles are evidence of diffraction	(M1)	
		diffraction is a wave property	(A1)	[2]
	(b)	(speed increases so) momentum increases	M1	
		$\lambda = h/p$ so λ decreases	M1	
		hence radii decrease	A1	[3]
		(*special case: wavelength decreases so radii decreases – scores 1/3*)		
		or		
		(speed increases so) energy increases	(B1)	
		$\lambda = h / \sqrt{(2Em)}$ so λ decreases	(M1)	
		hence radii decrease	(A1)	
	(c)	electron and proton have same (kinetic) energy	C1	
		either $E = p^2 / 2m$ *or* $p = \sqrt{(2Em)}$	C	
		ratio $= p_e / p_p = \sqrt{(m_e / m_p)}$	C	
		$= \sqrt{\{(9.1 \times 10^{-31}) / (1.67 \times 10^{-27})\}}$		
		$= 2.3 \times 10^{-2}$	A1	[4]