Photoelectric Effect & Wave Particle Duality

Mark Scheme 2

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 2

Time Allowed: **90 minutes**

Score: **/75**

Percentage: **/100**

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

1	(a)	(i)	minimum photon energy	B1	
			minimum energy to remove an electron (from the surface)	B1	[2]
		(ii)	*either* maximum KE is photon energy - work function energy		
			or max KE when electron ejected from the surface	B1	
			energies lower than max because energy required to bring electron to the surface	B1	[2]
	(b)	(i)	threshold frequency= 1.0×10^{15} Hz *(allow $\pm 0.05 \times 10^{15}$)*	C1	
			work function energy = hf_0	C1	
			: $6.63 \times 10^{-34} \times 1.0 \times 10^{15}$		
			= 6.63×10^{-19} J	A1	[3]
			(allow alternative approaches based on use of co-ordinates of points on the line)		
		(ii)	sketch: straight line with same gradient	M1	
			displaced to right	A1	[2]
		(iii)	intensity determines number of photons arriving per unit time	B1	
			intensity determines number of electrons per unit time (not energy)	B1	[2]

2	(a	(i)	lowest frequency of e.m. radiation	M1	
			giving rise to emission of electrons (from the surface)	A1	[2]
		(ii)	$E = hf$	C1	
			threshold frequency = $(9.0 \times 10^{-19}) / (6.63 \times 10^{-34})$		
			= 1.4×10^{15} Hz		[2]
	(b)		*either* 300 nm ≡ 10×10^{15} Hz (and 600 nm ≡ 5.0×10^{14} Hz)		
			or 300 nm ≡ 6.6×10^{-19} J (and 600 nm ≡ 3.3×10^{-19} J)		
			or zinc λ_0 = 340 nm, platinum λ_0 = 220 nm (and sodium λ_0 = 520 nm)	M1	
			emission from sodium <u>and</u> zinc	A1	[2]
	(c)		each photon has larger energy	M1	
			fewer photons per unit time	M1	
			fewer electrons emitted per unit time	A1	[3]

3	**(a**	discrete quantity / packet / quantum of energy of electromagnetic radiation	B1	
		energy of photon = Planck constant × frequency	B1	[2]
	(b)	threshold frequency (1)		
		rate of emission is proportional to intensity (1)		
		max. kinetic energy of electron dependent on frequency (1)		
		max. kinetic energy independent of intensity (1)		
		(*any three, 1 each, max 3*)	B3	[3]
	(c)	*either* $E = hc/\lambda$ *or* $hc/\lambda = eV$	C1	
		λ = 450 nm to give work function of *3.5 eV*		
		energy = 4.4×10^{-19} or 2.8 eV to give λ = 355 nm	M1	
		2.8 eV < 3.5 eV so no emission 355 nm < 450 nm so no	A1	[3]
		or work function = 3.5 eV		
		threshold frequency = 8.45×10^{14} Hz	C1	
		450 nm = 6.67×10^{14} Hz	M1	
		6.67×10^{14} Hz < 8.45×10^{14} Hz		
4	**(a**	wavelength associated with a particle	M1	
		that is moving	A1	[2]
	(b)	**(** kinetic energy = $1.6 \times 10^{-19} \times 4700$	C1	
		= 7.52×10^{-16} J		
		either energy = $p^2/2m$ *or* $E_K = ½mv^2$ *and* $p = mv$	C1	
		$p = \sqrt{(7.52 \times 10^{-16} \times 2 \times 9.1 \times 10^{-31})}$	C1	
		= 3.7×10^{-23} N s		
		$\lambda = h/p$	C1	
		= $(6.63 \times 10^{-34}) / (3.7 \times 10^{-23})$		
		= 1.8×10^{-11} m	A1	[5]
	(ii)	wavelength is about separation of atoms	B1	
		can be used in (electron) diffraction	B1	[2]

5	**(a**	minimum energy to remove an electron from the metal/surface	B1	[1]
	(b)	gradient = 4.17×10^{-15} *(allow 4.1 → 4.3)*	C1	
		$h = 4.15 \times 10^{-15} \times 1.6 \times 10^{-19}$ *or* h = 4.1 to 4.3×10^{-15} <u>eV s</u>	A1	
		$= 6.6 \times 10^{-34}$ J s	A0	[2]
	(c)	graph: straight line parallel to given line		
		with intercept at any higher frequency	B1	
		intercept at between 6.9×10^{14} Hz and 7.1×10^{14} Hz	B1	[3]

6	**(a**	**(i)**	packet/quantum of energy	M1	
			of electromagnetic radiation	A1	[2]
		(ii)	<u>minimum</u> energy to cause emission of an electron (from surface)	B1	[1]
	(b)	**(i)**	$hc/\lambda = \Phi + E_{max}$	M1	
			c and *h* explained	A1	[2]
		(ii)	**1.** *either* when $1/\lambda = 0$, $\Phi = -E_{max}$		
			or evidence of use of *x*-axis intercept from graph		
			or chooses point close to the line and substitutes values of $1/\lambda$ and E_{max} into $hc/\lambda = \Phi + E_{max}$	C1	
			$\Phi = 4.0 \times 10^{-19}$ J (allow $\pm 0.2 \times 10^{-19}$ J)	A1	[2]
			2. *either* gradient of graph is $1/hc$	C1	
			gradient = $4.80 \times 10^{24} \rightarrow 5.06 \times 10^{24}$	M1	
			$h = 1/(\text{gradient} \times 3.0 \times 10^{8})$		
			$= 6.6 \times 10^{-34}$ J s → 6.9×10^{-34} J s	A1	
			or chooses point close to the line and substitutes values of $1/\lambda$ and E_{max} into $hc/\lambda = \Phi + E_{max}$	(C1)	
			values of $1/\lambda$ and E_{max} are correct within half a square	(M1)	
			$h = 6.6 \times 10^{-34}$ J s → 6.9×10^{-34} J s	(A1)	[3]

(Allow full credit for the correct use of any appropriate method)
*(Do not allow 'circular' calculations in **part 2** that lead to the same value of Planck constant that was substituted in **part 1**)*

7	**(a)**	for a wave, electron can 'collect' energy continuously	B1	
		for a wave, electron will always be emitted / electron will be emitted at all frequencies…..	M1	
		after a sufficiently long delay	A1	[3]
	(b) (	*either* wavelength is longer than threshold wavelength *or* frequency is below the threshold frequency *or* photon energy is less than work function	B1	[1]
	(ii)	$hc / \lambda = \phi + E_{MAX}$	C1	
		$(6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / (240 \times 10^{-9}) = \phi + 4.44 \times 10^{-19}$	C1	
		$\phi = 3.8 \times 10^{-19}$ J (*allow* 3.9×10^{-19} J)		[3]
	(c) (	photon energy larger	M1	
		so (maximum) kinetic energy is larger	A1	[2]
	(ii)	fewer photons (per unit time)	M1	
		so (maximum) current is smaller	A1	[2]
8	**(a)**	wavelength of wave associated with a particle	M1	
		that is moving	A1	[2]
	(b) (i)	energy of electron $= 850 \times 1.6 \times 10^{-19}$	M1	
		$= 1.36 \times 10^{-16}$ J		
		energy $= p^2 / 2m$ *or* $p = mv$ <u>and</u> $E_K = ½mv^2$		
		momentum $= \sqrt{(1.36 \times 10^{-16} \times 2 \times 9.11 \times 10^{-31})}$	M1	
		$= 1.6 \times 10^{-23}$ N s	A0	[2]
	(ii)	$\lambda = h / p$	C1	
		wavelength $= (6.63 \times 10^{-34}) / (1.6 \times 10^{-23})$		
		$= 4.1 \times 10^{-11}$ m	A1	[2]
	(c)	diagram or description showing:		
		electron beam in a vacuum	B1	
		incident on <u>thin</u> metal target / carbon <u>film</u>	B1	
		fluorescent screen	B1	
		pattern of concentric rings observed	M1	
		pattern similar to diffraction pattern observed with visible light	A1	[5]