22. Quantum Physics

22.1 Energy and momentum of a photon

Paper 4

Marking Scheme

Q1.

(a)	packet / quantum of energy	**M1**
	of electromagnetic radiation	**A1**
(c)(i)	0.032 MeV	**A1**
(c)(ii)	momentum = E / c	**C1**
	momentum = $(0.032 \times 1.60 \times 10^{-13}) / (3.00 \times 10^{8})$ $= 1.7 \times 10^{-23}$ N s	**A1**

Q2.

(b)(i)	$E = hf$ **and** $\lambda = c / f$	**C1**
	$E = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / (488 \times 10^{-9})$ $= 4.08 \times 10^{-19}$ J	**A1**

Q3.

(a)(i)	$p = E / c$	**M1**
	$E = hc / \lambda$ and completion of algebra leading to $p = h / \lambda$	**A1**
(a)(ii)	wavelength = $(6.63 \times 10^{-34}) / (9.5 \times 10^{-28}) = 700 \times 10^{-9}$ m so red	**B1**
(b)(i)	power = intensity × area	**C1**
	number per unit time = $(160 \times 2.5 \times 10^{-6}) / (9.5 \times 10^{-28} \times 3.00 \times 10^{8}) = 1.4 \times 10^{15}$ s^{-1}	**A1**
(b)(ii)	pressure = force / area	**C1**
	force = rate of change of momentum $= 2 \times 9.5 \times 10^{-28} \times 1.4 \times 10^{15}$	**C1**
	pressure = $(2 \times 9.5 \times 10^{-28} \times 1.4 \times 10^{15}) / (2.5 \times 10^{-6})$ $= 1.1 \times 10^{-6}$ Pa	**A1**
(c)	photons have greater momentum **or** fewer photons per unit time	**B1**
	greater photon momentum but smaller number of photons (per unit time) so pressure is the same	**B1**

Q4.

(a)	packet / quantum of energy	**M1**
	of electromagnetic radiation	**A1**

Q5.

(b)(i)	photon energy = hf	**C1**
	number per unit time = $8.36 \times 10^{-3} / (1.36 \times 10^{15} \times 6.63 \times 10^{-34})$ $= 9.27 \times 10^{15}$ s^{-1}	**A1**

Q6.

(b)(i)	$E = hc / \lambda$ **or** $E = hf$ **and** $c = f\lambda$	**C1**
	$E = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / (250 \times 10^{-9})$	**C1**
	$(= 7.96 \times 10^{-19}$ J) = 5.0 eV	**A1**

Q7.

(a)	quantum of energy	**M1**
	of electromagnetic radiation	**A1**
(b)(i)	energy = hc / λ **or** energy = hf **and** $f = c / \lambda$	**C1**
	$0.57 \times 10^6 \times 1.60 \times 10^{-19} = (6.63 \times 10^{-34} \times 3.00 \times 10^8) / \lambda$ $\lambda = 2.2 \times 10^{-12}$ m	**A1**
(b)(ii)	$p = h / \lambda$	**C1**
	$= (6.63 \times 10^{-34}) / (2.2 \times 10^{-12})$ $= 3.0 \times 10^{-22}$ N s	**A1**
	or	
	$p = E / c$	**(C1)**
	$= (0.57 \times 10^6 \times 1.60 \times 10^{-19}) / (3.00 \times 10^8)$ $= 3.0 \times 10^{-22}$ N s	**(A1)**
(c)(i)	mass (of Sm-157 nucleus) = $157 \times 1.66 \times 10^{-27}$ **or** mass (of Sm-157 nucleus) = $0.157 / (6.02 \times 10^{23})$	**C1**
	recoil speed = $(3.00 \times 10^{-22}) / (157 \times 1.66 \times 10^{-27})$ $= 1.2 \times 10^3$ m s^{-1}	**A1**
(c)(ii)	$(1.2 \times) 10^3$ m s^{-1} is <u>much</u> less than $(3.0 \times) 10^8$ m s^{-1}	**B1**

Q8.

(a)(ii)	$p = h / \lambda$ **and** $E = hc / \lambda$ **or** $E = pc$	**C1**
	$p = (8.2 \times 10^{-14}) / (3.0 \times 10^8)$ $= 2.7 \times 10^{-22}$ N s	**A1**

Q9.

(a)(i)	quantum of energy	**M1**
	of electromagnetic radiation	**A1**
(a)(ii)	arrow (on Fig. 11.1) pointing upwards and to the right	**B1**
(b)(i)	$\lambda = h / p$	**C1**
	$p = (6.63 \times 10^{-34}) / (544 \times 10^{-9})$ $= 1.22 \times 10^{-27}$ N s	**A1**
(b)(ii)	energy $= hc / \lambda$	**C1**
	$= 6.63 \times 10^{-34} \times 3.00 \times 10^8 \times (540^{-1} - 544^{-1}) \times 10^9$ $= 2.7 \times 10^{-21}$ J	**A1**
(c)	(smaller wavelength corresponds to) greater photon energy	**B1**
	any one point from: • (deflected) photon loses energy (so not possible) • (deflected) photon would need to gain energy (so not possible) • electron would need to lose energy (so not possible) • initially electron energy is zero (so not possible)	**B1**

Q10.

(b)(i)	photon energy $= hc / \lambda$	**C1**
	$= (6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / (380 \times 10^{-9})$ $(= 5.23 \times 10^{-19}\ \text{J})$	**C1**
	$= 3.3\ \text{eV}$	**A1**
(c)	$\lambda = h / p$	**C1**
	$p = (6.63 \times 10^{-34}) / (380 \times 10^{-9})$ $= 1.74 \times 10^{-27}\ \text{N s}$	**C1**
	force $= 1.74 \times 10^{-27} \times 7.6 \times 10^{14}$ $= 1.3 \times 10^{-12}\ \text{N}$	**A1**

Q11.

(a)	packet/quantum of energy	**M1**
	of electromagnetic radiation	**A1**
(b)(i)	$E = hc / \lambda$	**C1**
	$1.18 \times 1.60 \times 10^{-13} = (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / \lambda$ $\lambda = 1.05 \times 10^{-12}\ \text{m}$	**A1**
(b)(ii)	$\lambda = h / p$ **or** $E = pc$	**C1**
	$p = (6.63 \times 10^{-34}) / (1.05 \times 10^{-12})$ **or** $p = (1.18 \times 1.60 \times 10^{-13}) / (3.00 \times 10^{8})$ leading to $p = 6.3 \times 10^{-22}\ \text{N s}$	**B1**
(c)	$6.3 \times 10^{-22} = 60 \times 1.66 \times 10^{-27} \times v$	**C1**
	$v = 6.3 \times 10^{3}\ \text{m s}^{-1}$	**A1**

Q12.

(b)(i)	**1.** photon energy $= hc / \lambda$	**C1**
	$= (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / (280 \times 10^{-9})$ $= 7.1 \times 10^{-19}\ \text{J}$	**A1**
	2. electron energy $= (7.1 - 5.5) \times 10^{-19}\ \text{J}$	**C1**
	$½ \times 9.11 \times 10^{-31} \times v^2 = (7.1 - 5.5) \times 10^{-19}$	**C1**
	$v = 5.9 \times 10^{5}\ \text{m s}^{-1}$	**A1**

Q13.

(a)(i)	packet/quantum/discrete amount of energy	**M1**
	of electromagnetic radiation	**A1**

Q14.

(b)(i)	packet/quantum/discrete amount of energy	**M1**
	of electromagnetic radiation	**A1**
(b)(ii)	$E = hc / \lambda$	**C1**
	$= (6.63 \times 10^{-34} \times 3.00 \times 10^{8}) / (420 \times 10^{-9})$ $= 4.7 \times 10^{-19}\ \text{J}$	**A1**

Q15.

(a)	discrete amount/quantum/packet of <u>energy</u>	**M1**
	of electromagnetic radiation	**A1**
(b)(i)	energy = hc/λ	**C1**
	$\lambda = (6.63 \times 10^{-34} \times 3.00 \times 10^{8})/(0.51 \times 10^{6} \times 1.60 \times 10^{-19})$ $= 2.4 \times 10^{-12}$ m	**A1**
(b)(ii)	$p = h/\lambda$ $= (6.63 \times 10^{-34})/(2.44 \times 10^{-12})$ **or** $p = E/c$ $= (0.51 \times 1.60 \times 10^{-13})/(3.00 \times 10^{8})$	**C1**
	$p = 2.7 \times 10^{-22}$ N s	**A1**
(c)(ii)	(momentum is conserved so) nucleus must have momentum in opposite direction to photon	**B1**