

**Q1.**

7	(a)	$\lambda = h/p$ or $\lambda = h/mv$ with $\lambda$ , $h$ and (or $mv$ ) $p$ identified	M1 A1	[2]
	(b)	$E = \frac{1}{2} mv^2$ $= p^2/2m$ or $v = \sqrt{2E/m}$ , <u>hence</u> $\lambda = h/\sqrt{2mE}$	C1 M1 A0	[2]
	(c)	$E = qV$ $(0.4 \times 10^{-9})^2 \times 2 \times 9.11 \times 10^{-31} \times 1.6 \times 10^{-19} \times V = (6.63 \times 10^{-34})^2$ $V = 9.4 \text{ V}$ (2 s.f. scores 2/3)	C1 C1 A1	[3]
			<b>Total</b>	[7]

**Q2.**

7	(a)	'uniform' distribution	B1	[1]
	(b)	concentric rings	B1	[1]
	(c)	higher speed, more momentum $\lambda = h/p$ so $\lambda$ decreases and ring diameter decreases	M1 M1 A1	[3]

**Q3.**

5	(a)	(i) packet/discrete quantity/quantum (of energy) of e.m. radiation	B1	[1]
		(ii) either $E = (6.63 \times 10^{-34} \times 3 \times 10^8)/(350 \times 10^{-9})$ or $E = (6.63 \times 10^{-34} \times 8.57 \times 10^{14})$ $E = 5.68 \times 10^{-19} \text{ J}$	M1 A0	[1]
		(iii) 0.5	B1	[1]
	(b)	(i) energy of photon to cause emission of electron <u>from surface</u> <i>either</i> with zero k.e <i>or</i> photon energy is minimum	M1 A1	[2]
		(ii) correct conversion eV $\rightarrow$ J or J $\rightarrow$ eV seen once photon energy must be greater than work function 350 nm wavelength and potassium metal	B1 C1 A1	[3]

**Q4.**

- 7 (a) charge is quantised / discrete quantities B1 [1]
- (b) (i) parallel so that the electric field is uniform / constant B1  
 horizontal so that *either* oil drop will not drift sideways  
*or* field is vertical B1 [2]  
*or* electric force is equal to weight
- (ii)  $qE = mg$  C1  
 $q \times 850 / (5.4 \times 10^{-3}) = 7.7 \times 10^{-15} \times 9.8$  C1  
 $q = 4.8 \times 10^{-19} \text{ C}$  and is negative A1 [3]
- (c) charge changes by  $1.6 \times 10^{-19} \text{ C}$  between droplets / integral multiples M1  
 so charge on electron is  $1.6 \times 10^{-19} \text{ C}$  A0 [1]

**Q5.**

- 8 (a) wave theory predicts any frequency would give rise to emission of electron M1  
 if exposure time is sufficiently long A1  
 photon has (specific value of) energy dependent on frequency M1  
 emission if energy greater than threshold / work function / energy to remove A1 [4]  
 electron from surface
- (b) photon is packet/quantum of energy M1  
 of electromagnetic radiation A1  
 (photon) energy =  $h \times$  frequency B1 [3]
- every particle has an (associated) wavelength B1  
 wavelength =  $h / p$  M1  
 where  $p$  is the momentum (of the particle) A1 [3]

**Q6.**

- 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) (i) *either* wavelength is longer than threshold wavelength  
*or* frequency is below the threshold frequency B1 [1]  
*or* photon energy is less than work function
- (ii)  $hc / \lambda = \phi + E_{\text{MAX}}$  C1  
 $(6.63 \times 10^{-34} \times 3.0 \times 10^8) / (240 \times 10^{-9}) = \phi + 4.44 \times 10^{-19}$  C1  
 $\phi = 3.8 \times 10^{-19} \text{ J}$  (allow  $3.9 \times 10^{-19} \text{ J}$ ) A1 [3]
- (c) (i) 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]

**Q7.**

- 7 (a) wavelength of wave associated with a particle that is moving M1 A1 [2]
- (b) (i) energy of electron =  $850 \times 1.6 \times 10^{-19}$   
 $= 1.36 \times 10^{-16}$  J M1  
 energy =  $p^2 / 2m$  or  $p = mv$  and  $E_K = \frac{1}{2}mv^2$   
 momentum =  $\sqrt{(1.36 \times 10^{-16} \times 2 \times 9.11 \times 10^{-31})}$  M1  
 $= 1.6 \times 10^{-23}$  Ns 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 thin metal target / carbon film B1  
 fluorescent screen B1  
 pattern of concentric rings observed M1  
 pattern similar to diffraction pattern observed with visible light A1 [5]

**Q8.**

- 8 (a) packet/quantum/discrete amount of energy of electromagnetic radiation M1 A1  
 (allow 1 mark for 'packet of electromagnetic radiation')  
 energy = Planck constant  $\times$  frequency (seen here or in b) B1 [3]
- (b) each (coloured) line corresponds to one wavelength/frequency B1  
 energy = Planck constant  $\times$  frequency  
 implies specific energy change between energy levels B1  
 so discrete levels A0 [2]

**Q9.**

- 6 (a) oil drop charged by friction/beta source B1  
 between parallel metal plates B1  
 plates are horizontal (1)  
 adjustable potential difference/field between plates B1  
 until oil drop is stationary B1  
 $mg = q \times V/d$  B1  
 symbols explained (1)  
 oil drop viewed through microscope (1)  
 $m$  determined from terminal speed of drop (when p.d. is zero) (1)  
 (any two extras, 1 each) B2 [7]
- (b)  $3.2 \times 10^{-19}$  C A1 [1]

**Q10.**

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

### Q11.

- 7 (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 =  $(9.0 \times 10^{-19}) / (6.63 \times 10^{-34})$   
 $= 1.4 \times 10^{15}$  Hz A1 [2]
- (b) either 300 nm  $\equiv 10 \times 10^{15}$  Hz (and 600 nm  $\equiv 5.0 \times 10^{14}$  Hz)  
or 300 nm  $\equiv 6.6 \times 10^{-19}$  J (and 600 nm  $\equiv 3.3 \times 10^{-19}$  J)  
or zinc  $\lambda_0 = 340$  nm, platinum  $\lambda_0 = 220$  nm (and sodium  $\lambda_0 = 520$  nm) M1  
emission from sodium and zinc A1 [2]
- (c) each photon has larger energy M1  
fewer photons per unit time M1  
fewer electrons emitted per unit time A1 [3]

### Q12.



- 7 (a) each wavelength is associated with a discrete change in energy  
discrete energy change / difference implies discrete levels M1  
A1 [2]
- (b) (i) 1. arrow from  $-0.54$  eV to  $-0.85$  eV, labelled L B1 [1]  
2. arrow from  $-0.54$  eV to  $-3.4$  eV, labelled S B1 [1]  
(two correct arrows, but only one label – allow 2 marks)  
(two correct arrows, but no labels – allow 1 mark)
- (ii)  $E = hc / \lambda$  C1  
 $(3.4 - 0.54) \times 1.6 \times 10^{-19} = (6.63 \times 10^{-34} \times 3.0 \times 10^8) / \lambda$  C1  
 $\lambda = 4.35 \times 10^{-7}$  m A1 [3]
- (c)  $-1.50 \rightarrow -3.4 = 1.9$  eV  
 $-0.85 \rightarrow -3.4 = 2.55$  eV (allow 2.6 eV)  
 $-0.54 \rightarrow -3.4 = 2.86$  eV (allow 2.9 eV)  
3 correct, 2 marks with  $-1$  mark for each additional energy  
2 correct, 1 mark but no marks if any additional energy differences B2 [2]

**Q13.**

- 2 (a)  $E = hc / \lambda = (6.63 \times 10^{-34} \times 3.0 \times 10^8) / (486 \times 10^{-9})$  ..... C1  
 $= 4.09 \times 10^{-19}$  J ... (allow 2 sf) ..... A1 [2]
- (b) energy level drawn at  $4.09 \times 10^{-19}$  J ..... B1  
transition  $4.09 \times 10^{-19}$  to zero clear ..... B1  
transition  $4.09 \times 10^{-19}$  to  $3.03 \times 10^{-19}$  clear ..... B1 [3]  
(-1 for reversed arrows, -1 for extra level at 1.06)

**Q14.**

- 6 (a) packet/quantum of energy ..... M1  
energy =  $hf$  ..... A1 [2]
- (b) e.g. threshold frequency outlined  
max. k.e. independent of intensity  
max. k.e. dependent on frequency (n.b. NOT proportional)  
photoelectric current depends on intensity  
instantaneous emission .... (1 each, max 3) ..... B3 [3]
- (c) (i) photons have same energy so  $E_{\max}$  unchanged  
intensity OR number of photons per unit time is halved,  
so  $\frac{1}{2}n$  OR  $n$  reduced ..... B1  
(allow 1 mark for statement that  $E_{\max}$  unchanged and  $n$  reduced)
- (ii) photons have higher energy so  $E_{\max}$  increases ..... B1  
but fewer photons per unit time so  $n$  decreases ..... B1 [4]  
(allow 1 mark for statement that  $E_{\max}$  increases and  $n$  reduced)  
(allow any argument based on increased efficiency)

**Q15.**

- 7 (a) (i) quantum/packet/discrete amount of energy  
electromagnetic mentioned M1  
A1 [2]
- (ii) max. k.e. corresponds to electron emitted from surface  
energy is required to bring electron to surface B1  
B1 [2]
- (b) at higher frequency, fewer photons (per second) for same intensity M1  
so rate of emission decreases A1 [2]  
(allow argument based on photoelectric efficiency)

**Q16.**

- 7 (a) e.g. 'instantaneous' emission (of electrons)  
threshold frequency below which no emission  
(max) electron energy dependent on frequency  
(max) electron energy not dependent on intensity  
rate of emission (of electrons) depends on intensity  
(any three sensible suggestions, 1 each) B3 [3]
- (b) (i) 'packet' / quantum of energy M1  
of electromagnetic energy / radiation A1 [2]
- (ii) discrete wavelengths mean photons have particular energies M1  
energy of photon determined by energy change of (orbital) electron M1  
so discrete energy levels A0 [2]
- (c) (i) three energy changes shown correctly B1  
arrows 'pointing' in correct direction B1  
wavelengths correctly identified B1 [3]
- (ii) chooses  $\lambda = 486 \text{ nm}$  C1  
 $\Delta E = hc / \lambda$  C1  
 $= (6.63 \times 10^{-34} \times 3.0 \times 10^8) / (4.86 \times 10^{-9})$   
 $= 4.09 \times 10^{-19} \text{ J}$  (allow 2 s.f.) A1 [3]

**Q17.**

- 7 (a) each line corresponds to a (specific) photon energy ..... B1  
photon emitted when electron changes its energy level ..... B1  
discrete energy changes so discrete levels ..... B1 [3]
- (b) (i)  $E = hc / \lambda$  ... (allow ratio ideas) ..... C1  
 $= (6.63 \times 10^{-34} \times 3.0 \times 10^8) / (486 \times 10^{-9})$   
 $= 4.09 \times 10^{-19} \text{ J}$  ..... A1 [2]
- (ii) four transitions to/from  $-5.45 \times 10^{-19} \text{ J}$  level ..... B1  
all transitions shown from higher to lower energy (level) ..... B1 [2]

[Total: 7]

**Q18.**

- 7 (a) (i) e.g. electron / particle diffraction B1 [1]  
 (ii) e.g. photoelectric effect B1 [1]
- (b) (i) 6 A1 [1]  
 (ii) change in energy =  $4.57 \times 10^{-19}$  J  
 $\lambda = hc / E$  C1  
 $= (6.63 \times 10^{-34} \times 3.0 \times 10^8) / (4.57 \times 10^{-19})$   
 $= 4.4 \times 10^{-7}$  m A1 [2]

### Q19.

- 8 (a) minimum frequency for electron to be emitted (from surface) of electromagnetic radiation / light / photons M1  
 A1 [2]
- (b)  $E = hc / \lambda$  or  $E = hf$  and  $c = f\lambda$  C1  
 either threshold wavelength =  $(6.63 \times 10^{-34} \times 3.0 \times 10^8) / (5.8 \times 10^{-19})$   
 $= 340$  nm  
 or energy of 340 nm photon =  $4.4 \times 10^{-19}$  J  
 or threshold frequency =  $8.7 \times 10^{14}$  Hz  
 or 450 nm  $\rightarrow 6.7 \times 10^{14}$  Hz  
 appropriate comment comparing wavelengths / energies / frequencies  
 so no effect on photo-electric current B1  
 B1 [4]

### Q20.

- 7 (a) each line represents photon of specific energy photon emitted as a result of energy change of electron specific energy changes so discrete levels M1  
 M1  
 A1 [3]
- (b) (i) arrow from  $-0.85$  eV level to  $-1.5$  eV level B1 [1]
- (ii)  $\Delta E = hc / \lambda$  C1  
 $= (1.5 - 0.85) \times 1.6 \times 10^{-19}$  C1  
 $= 1.04 \times 10^{-19}$  J  
 $\lambda = (6.63 \times 10^{-34} \times 3.0 \times 10^8) / (1.04 \times 10^{-19})$   
 $= 1.9 \times 10^{-6}$  m A1 [3]
- (c) spectrum appears as continuous spectrum crossed by dark lines B1  
 two dark lines B1  
 electrons in gas absorb photons with energies equal to the excitation energies M1  
 light photons re-emitted in all directions A1 [4]

### Q21.

- 7 (a) (i) packet/quantum of energy of electromagnetic radiation M1  
A1 [2]
- (ii) minimum 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  
 $h = 1/(\text{gradient} \times 3.0 \times 10^8)$   
=  $6.6 \times 10^{-34}$  Js  $\rightarrow 6.9 \times 10^{-34}$  Js 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)  
 $h = 6.6 \times 10^{-34}$  Js  $\rightarrow 6.9 \times 10^{-34}$  Js (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**)

## Q22.

- 8 (a) discrete quantity / packet / quantum of energy of electromagnetic radiation B1  
energy of photon = Planck constant  $\times$  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  
 $\lambda = 450$  nm to give work function of 3.5 eV M1  
energy =  $4.4 \times 10^{-19}$  or 2.8 eV to give  $\lambda = 355$  nm A1 [3]  
2.8 eV < 3.5 eV so no emission 355 nm < 450 nm so no
- or* work function = 3.5 eV  
threshold frequency =  $8.45 \times 10^{14}$  Hz C1  
450 nm =  $6.67 \times 10^{14}$  Hz M1  
 $6.67 \times 10^{14}$  Hz <  $8.45 \times 10^{14}$  Hz A1

## Q23.



- 7 (a) wavelength associated with a particle that is moving M1  
A1 [2]
- (b) (i) kinetic energy =  $1.6 \times 10^{-19} \times 4700$   
 $= 7.52 \times 10^{-16} \text{ J}$   
*either energy =  $p^2/2m$  or  $E_k = \frac{1}{2}mv^2$  and  $p = mv$*   
 $p = \sqrt{(7.52 \times 10^{-16} \times 2 \times 9.1 \times 10^{-31})}$   
 $= 3.7 \times 10^{-23} \text{ N s}$   
 $\lambda = h/p$   
 $= (6.63 \times 10^{-34}) / (3.7 \times 10^{-23})$   
 $= 1.8 \times 10^{-11} \text{ m}$  C1  
C1  
C1  
A1 [5]
- (ii) wavelength is about separation of atoms  
 can be used in (electron) diffraction B1  
B1 [2]

**Q24.**

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

**Q25.**

- 7 (a) (i) minimum photon energy  
minimum energy to remove an electron (from the surface) B1  
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 B1 [2]  
the surface
- (b) (i) threshold frequency =  $1.0 \times 10^{15}$  Hz (allow  $\pm 0.05 \times 10^{15}$ ) C1  
work function energy =  $hf_0$  C1  
 $= 6.63 \times 10^{-34} \times 1.0 \times 10^{15}$   
 $= 6.63 \times 10^{-19}$  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]

## Q26.

- 8 (a) discrete and equal amounts (of charge) B1 [1]  
*allow: discrete amounts of  $1.6 \times 10^{-19}$  C/elementary charge/e*  
*integral multiples of  $1.6 \times 10^{-19}$  C/elementary charge/e*
- (b) weight =  $qV/d$   
 $4.8 \times 10^{-14} = (q \times 680)/(7.0 \times 10^{-3})$  C1  
 $q = 4.9 \times 10^{-19}$  C A1 [2]
- (c) elementary charge =  $1.6 \times 10^{-19}$  C (allow  $1.6 \times 10^{-19}$  C to  $1.7 \times 10^{-19}$  C) M0  
*either* the values are (approximately) multiples of this C1  
*or* it is a common factor A1 [2]  
it is the highest common factor

## Q27.

- 9 (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 =  $5.8 \times 10^{14}$  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)

### Q28.

8 (a) photon energy =  $hc/\lambda$  C1  
 $= (6.63 \times 10^{-34} \times 3.0 \times 10^8) / (590 \times 10^{-9})$  C1  
 $= 3.37 \times 10^{-19}$  J

number =  $(3.2 \times 10^{-3}) / (3.37 \times 10^{-19})$  A1 [3]  
 $= 9.5 \times 10^{15}$  (allow  $9.4 \times 10^{15}$ )

(b) (i)  $p = h/\lambda$  C1  
 $= (6.63 \times 10^{-34}) / (590 \times 10^{-9})$   
 $= 1.12 \times 10^{-27}$  kg ms<sup>-1</sup> C1

total momentum =  $9.5 \times 10^{15} \times 1.12 \times 10^{-27}$  A1 [3]  
 $= 1.06 \times 10^{-11}$  kg ms<sup>-1</sup>

(ii) force =  $1.06 \times 10^{-11}$  N A1 [1]

### Q29.

8 (a) photon 'absorbed' by electron B1  
 photon has energy equal to difference in energy of two energy levels B1  
 electron de-excites emitting photon (of same energy) in any direction B1 [3]

(b) (i)  $E = hc/\lambda$  C1  
 $= (6.63 \times 10^{-34} \times 3 \times 10^8) / (435 \times 10^{-9})$  C1  
 $= 4.57 \times 10^{-19}$  J (allow 2 s.f.) C1  
 $= (4.57 \times 10^{-19}) / (1.6 \times 10^{-19})$  (eV)  
 $= 2.86$  eV (allow 2 s.f.) A1 [4]

(ii) arrow pointing in either direction between  $-3.41$  eV and  $-0.55$  eV B1 [1]

### Q30.

- 7 (a) *either* charge exists in discrete and equal quantities  
or multiples of elementary charge/ $e/1.6 \times 10^{-19} \text{ C}$  B1 [1]
- (b) (i) force due to magnetic field must be upwards  
B-field into the plane of the paper B1 [2]
- (ii) sketch showing: deflection consistent with force in (b)(i)  
reasonable curve B1 [2]

**Q31.**

- 8 (a) discrete amount/packet/quantum of energy  
of electromagnetic radiation/EM radiation M1 [2]
- (b) (i)  $E = hc/\lambda$   
 $= (6.63 \times 10^{-34} \times 3.0 \times 10^8)/(570 \times 10^{-9}) = 3.49 \times 10^{-19} \text{ J}$  A1 [1]
- (ii) 1. number =  $(2.7 \times 10^{-3})/(3.5 \times 10^{-19})$   
 $= 7.7 \times 10^{15}$  C1 [2]
2. momentum of photon =  $h/\lambda$   
 $= (6.63 \times 10^{-34})/(570 \times 10^{-9})$   
 $= 1.16 \times 10^{-27} \text{ kg m s}^{-1}$  C1 [2]
- change in momentum =  $1.16 \times 10^{-27} \times 7.7 \times 10^{15}$   
 $= 8.96 \times 10^{-12} \text{ kg m s}^{-1}$  A1 [3]
- (allow  $E = pc$  route to  $9 \times 10^{-12}$ )
- (c) pressure = (change in momentum per second)/area C1  
 $= (8.96 \times 10^{-12})/(1.3 \times 10^{-5})$   
 $= 6.9 \times 10^{-7} \text{ Pa}$  A1 [2]

**Q32.**

- 1 (a) charge is quantised/enabled electron charge to be measured B1 [1]
- (b) all are (approximately)  $n \times (1.6 \times 10^{-19} \text{ C})$  M1  
so  $e = 1.6 \times 10^{-19} \text{ C}$  (allow 2 sig. fig. only) A1 [2]  
*summing charges and dividing ten, without explanation scores 1/2*
- Total ... [3]





