Q1.

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

Q2.

7	(a)	'uniform' distribution	B1	[1]
	(b)	concentric rings	B1	[1]
	(c)	higher speed, more momentum	M1	
		$\lambda = h / p$	M1	
		so λ decreases and ring diameter decreases	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 $E = (6.63 \times 10^{-34} \times 8.57 \times 10^{14})$	M1	
			$E = 5.68 \times 10^{-19}$ J	A0	[1]
		(iii)	0.5	B1	[1]
	(b)	(i)	energy of photon	M1	
			to cause emission of electron from surface		
			either with zero k.e or photon energy is minimum	A1	[2]
		(ii)	correct conversion eV → J or J → eV seen once	B1	
			photon energy must be greater than work function	C1	
			350 nm wavelength and potassium metal	A1	[3]

Q4.

MEGA LECTURE

| 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
           or   electric force is equal to weight   B1   [2]

(ii) $qE = mg$ C1
$q \times 850 / (5.4 \times 10^{-3}) = 7.7 \times 10^{-15} \times 9.8$ C1
$q = 4.8 \times 10^{-19}$ C and is negative   A1   [3]

(c) charge changes by 1.6×10^{-19} C between droplets / integral multiples   M1
so charge on electron is 1.6×10^{-19} 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
electron from surface   A1   [4]

(b) photon is packet/quantum of energy   M1
of electromagnetic radiation   A1
(photon) energy $= h \times$ frequency   B1   [3]

every <u>particle</u> 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
     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)   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		M1	
		that is moving		A1	[2]

(b) (i) energy of electron = $850 \times 1.6 \times 10^{-19}$ M1
               = 1.36×10^{-16} J
energy = $p^2 / 2m$ or $p = mv$ <u>and</u> $E_K = \frac{1}{2}mv^2$
momentum = $\sqrt{(1.36 \times 10^{-16} \times 2 \times 9.11 \times 10^{-31})}$ M1
                = 1.6×10^{-23} N s   A0   [2]

(ii) $\lambda = h / p$ C1
wavelength = $(6.63 \times 10^{-34}) / (1.6 \times 10^{-23})$
             = 4.1×10^{-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]

Q8.

8	(a)	packet/quantum/discrete amount of energy	M1	
		of electromagnetic radiation	A1	
		(allow 1 mark for 'packet of electromagnetic radiation')		
		energy = Planck constant × frequency *(seen here or in b)*	B1	[3]

(b) each (coloured) line corresponds to one wavelength/frequency   B1
energy = Planck constant × 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) 3.2×10^{-19} C   A1   [1]

Q10.

7   (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
         = 6.6×10^{-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]

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   = $(9.0 \times 10^{-19}) / (6.63 \times 10^{-34})$
                    = 1.4×10^{15} Hz   A1   [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]

Q12.

7 (a) each wavelength is associated with a discrete <u>change</u> in energy M1
discrete energy <u>change</u> / difference implies discrete levels .... 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 4.09×10^{-19} J B1
transition 4.09×10^{-19} to zero clear B1
transition 4.09×10^{-19} to 3.03×10^{-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 ½n 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.

MEGA LECTURE

7 (a) (i)	quantum/packet/discrete amount of energy	M1	
	electromagnetic mentioned	A1	[2]
(ii)	max. k.e. corresponds to electron emitted from surface	B1	
	energy is required to bring electron to surface	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) <u>electron</u> energy dependent on frequency		
	(max) <u>electron</u> 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 $\lambda = 486$ nm	C1	
	$\Delta E = hc / \lambda$	C1	
	$= (6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / (4.86 \times 10^{-9})$		
	$= 4.09 \times 10^{-19}$ 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	
	$= (6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / (486 \times 10^{-9})$		
	$= 4.09 \times 10^{-19}$ J	A1	[2]
(ii)	four transitions to/from -5.45×10^{-19} 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 = 4.57×10^{-19} J
              $\lambda = hc / E$ C1
              = $(6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / (4.57 \times 10^{-19})$
              = 4.4×10^{-7} m   A1   [2]

Q19.

8   (a) minimum frequency for electron to be emitted (from surface)   M1
         of electromagnetic radiation / light / photons   A1   [2]

    (b) $E = hc / \lambda$ or $E = hf$ <u>and</u> $c = f\lambda$ 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 = 4.4×10^{-19} J
         or   threshold frequency = 8.7×10^{14} Hz
         or   450 nm → 6.7×10^{14} Hz   A1
         appropriate comment comparing wavelengths / energies / frequencies   B1
         so no effect on photo-electric current   B1   [4]

Q20.

7   (a) each line represents photon of specific energy   M1
         photon emitted as a result of energy change of electron   M1
         specific energy changes so discrete levels   A1   [3]

    (b) (i)   arrow from –0.85 eV level to –1.5 eV level   B1   [1]

        (ii) ΔE = hc / λ C1
                  = $(1.5 - 0.85) \times 1.6 \times 10^{-19}$ C1
                  = 1.04×10^{-19} J
              λ = $(6.63 \times 10^{-34} \times 3.0 \times 10^{8})/(1.04 \times 10^{-19})$
                  = 1.9×10^{-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.

MEGA LECTURE

7	(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 $= 4.80 \times 10^{24} \to 5.06 \times 10^{24}$ M1

                   $h = 1/(\text{gradient} \times 3.0 \times 10^8)$

                      $= 6.6 \times 10^{-34}$ Js $\to 6.9 \times 10^{-34}$ 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 $\to 6.9 \times 10^{-34}$ 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 × 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*

       energy $= 4.4 \times 10^{-19}$ or 2.8 eV   to give $\lambda = 355$ 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 $= 8.45 \times 10^{14}$ Hz   C1

       450 nm $= 6.67 \times 10^{14}$ Hz   M1

       6.67×10^{14} Hz $< 8.45 \times 10^{14}$ Hz   A1

Q23.

MEGA LECTURE

7	(a)	wavelength associated with a particle	M1	
		that is moving	A1	[2]

(b) (i) kinetic energy = $1.6 \times 10^{-19} \times 4700$ C1
              = 7.52×10^{-16} J
     either energy = $p^2/2m$ or $E_K = \frac{1}{2}mv^2$ and $p = mv$ C1
     $p = \sqrt{(7.52 \times 10^{-16} \times 2 \times 9.1 \times 10^{-31})}$ C1
       = 3.7×10^{-23} Ns
     $\lambda = h/p$ 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]

Q24.

7   (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 $p = \sqrt{(2Em)}$ C1
     ratio = $p_e / p_p = \sqrt{(m_e / m_p)}$ C1
       = $\sqrt{\{(9.1 \times 10^{-31}) / (1.67 \times 10^{-27})\}}$
       = 2.3×10^{-2} A1   [4]

Q25.

7	(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

$= 6.63 \times 10^{-34} \times 1.0 \times 10^{15}$

$= 6.63 \times 10^{-19}$ 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 1.6×10^{-19}C/elementary charge/e

integral multiples of 1.6×10^{-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 = 1.6×10^{-19} C   (*allow* 1.6×10^{-19} C to 1.7×10^{-19} C)   M0

either the values are (approximately) multiples of this

or it is a common factor   C1

it is the highest common factor   A1 [2]

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 = 5.8×10^{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 $= hc/\lambda$
$= (6.63 \times 10^{-34} \times 3.0 \times 10^{8})/(590 \times 10^{-9})$ C1
$= 3.37 \times 10^{-19}$ J   C1

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

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.

MEGA LECTURE

7 (a) *either* charge exists in discrete and <u>equal</u> quantities
   or multiples of elementary charge/e/1.6×10^{-19} C   B1 [1]

   (b) (i)   force due to magnetic field must be upwards   B1
            B-field into the plane of the paper   B1 [2]

        (ii) sketch showing: deflection consistent with force in (b)(i)   B1
                              reasonable curve   B1 [2]

Q31.

8 (a) discrete amount/packet/quantum of <u>energy</u>   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   A1 [1]

        (ii) 1.   number $= (2.7 \times 10^{-3})/(3.5 \times 10^{-19})$ C1
                   $= 7.7 \times 10^{15}$ 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   C1
                 $= (8.96 \times 10^{-12})/(1.3 \times 10^{-5})$
                 $= 6.9 \times 10^{-7}$ Pa   A1 [2]

Q32.

1 (a)   charge is quantised/enabled electron charge to be measured   B1 [1]

   (b)   <u>all</u> are (approximately) n x $(1.6$ x 10^{-19} C)   M1
              so $e = 1.6$ x 10^{-19} C (allow 2 sig. fig. only   A1 [2]
              summing charges and dividing ten, without explanation scores 1/2
                                                                          Total   [3]