M1.(a) (Constructive) interference / superposition occurs
or
Waves arrive in phase so produce maximum intensity
Diffraction alone is not enough

B1
1

(b) Correct substitution of numerical value in h / mv irrespective of powers of 10

C1

2.1×10^{-11} (m)

A1
2
[3]

M2.A
[1]

M3.C
[1]

M4.D
[1]

M5.B
[1]

M6.(a) (electron) diffraction / interference / superposition ✓

Accept derfraction

1

(b) (*use of* $\lambda = h / mv$)

$\lambda = 6.63 \times 10^{-34} / (9.11 \times 10^{-31} \times 2.5 \times 10^{5})$ ✓

$\lambda = 2.9 \times 10^{-9}$m ✓ ✓ (2 sig figs.)

3

(c) $v = 2.5 \times 10^{5} / 207$ ✓

$v = 1200$ m s^{-1} ✓

OR use $v = h / m\lambda$ with CE from part (b)

Answer alone gets 2 marks

2

[6]

M7. (a) (i) <u>minimum energy</u> required ✓

to remove electron from metal (surface) OR cadmium OR the material ✓

2

(ii) photons have energy dependent on frequency OR energy of photons constant ✓

one to one interaction between photon and electron ✓

Max KE = photon energy – work function in words or symbols ✓

more energy required to remove deeper electrons ✓

4

(iii) *(use of* $hf = \Phi + E_{k(max)}$*)*

$6.63 \times 10^{-34} \times f = 4.07 \times 1.60 \times 10^{-19}$ ✓ + 3.51×10^{-20} ✓

$f = 1.04 \times 10^{15}$ (Hz) OR 1.03×10^{15} (Hz) ✓ ✓ (3 sig figs)

4

(b) theory makes predictions tested ✓ by repeatable/checked by other scientists/peer reviewed (experiments) OR new evidence that is repeatable/checked by other scientists/peer reviewed✓

2

[12]

M8. (a) passed them between charged plates / near charged object

or

use magnetic field

M1

correct deviation

or

circular path in direction indicating negative charge

A1

2

(b) diffraction

B1

electron is behaving as a wave

B1

2

(c) (i) $p = h/\lambda$ or **substitution of wavelength** into $\lambda = h/p$ *or* $\lambda = h/mv$

C1

2.76 or 2.8×10^{-19}

A1

kg m s^{-1} / N s / J s m^{-1} / J Hz^{-1} m^{-1}

B1

3

(ii) $E_K = p^2/2m$ or quotes $p = mv$ **and** $E_k = ½ mv^2$ (symbols or numbers)

C1

4.1 or 4.2 × 10^{-8} (J)

A1

2

[9]

M9. (a) (i) when electrons/atoms are in their lowest/minimum energy (state) **or** most stable (state) they (are in their ground state) ✓

1

(ii) in either case an electron receives (exactly the right amount of) energy ✓

excitation promotes an (orbital) electron to **a higher energy/up a** level ✓

ionisation occurs (when an electron receives enough energy) **to leave** the atom ✓

3

(b) electrons occupy discrete energy levels ✓

and need to absorb an exact amount of/enough energy to move to a higher level ✓

photons need to have certain frequency to provide this energy **or** e = hf ✓

energy required is the same for a particular atom or have different energy levels ✓

all energy of photon absorbed ✓

in 1 to 1 interaction or clear **a/the photon** and **an/the electron**s ✓

4

(c) energy = 13.6 × 1.60 × 10^{-19} = 2.176 × 10^{-18} (J) ✓

hf = 2.176 × 10^{-18} ✓

$f = 2.176 \times 10^{-18} \div 6.63 \times 10^{-34} = 3.28 \times 10^{15}$ Hz ✓ 3 sfs ✓

4

[12]

M10. correct substitution into formula, condone power of ten error

C1

8.7×10^{-10} (m)

A1

[2]

M11. (a) (i) *hf* is energy available/received **or** same energy from photons **(1)**

energy required to remove the electron varies (hence kinetic energy of electrons will vary) **(1)**

2

(ii) (work function is the) minimum energy needed to release an electron **(1)**
(or not enough energy to release electron)

below a certain frequency energy of **photon** is less than work function **or** energy of **photon** correctly related to *f* **(1)**

2

(iii) joule **(1)** (accept eV)

1

(b) (i) (use of $E = hf$)
energy = $6.63 \times 10^{-34} \times 1.5 \times 10^{15}$ **(1)**
energy = 9.9×10^{-19} (J) **(1)**

2

(ii) number of photons per second = $3.0 \times 10^{-10} / 9.9 \times 10^{-19}$ **(1)**

number of photons per second = 3.0×10^{8} **(1)**

2

(c) (i) (time taken = $6.8 \times 10^{-19} / 3 \times 10^{-22}$)

time taken = 2.3×10^{3} s **(1)**

1

(ii) light travels as particles/ photons **(1)**
(or has a particle(like) nature)

(which transfer) energy in discrete packets **(1)**
or 1 to 1 interaction
or theory rejected/modified (in light of validated evidence)

2

[12]