Quantum Physics MS

M1. (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]

M2. (a)

QWC	descriptor	mark range
good-excellent	The candidate provides a comprehensive and logical explanation which recognises that light consists of photons of energy *hf* and that an electron at or near the metal surface can only gain the energy of a single photon when it interacts with a photon. In addition, the candidate should recognise the significance of the work function (of the metal) in this context in relation to the maximum kinetic energy that an emitted electron can have. The candidate should also provide some indication of why the kinetic energy of an emitted electron may be less than the maximum kinetic energy. Although the term 'work function' might not be defined or used, the candidate's explanation should clearly state that each electron needs a minimum amount of energy to escape from the metal.	**5-6**
modest-adequate	The candidate provides a logical and coherent explanation which includes the key ideas including recognition that light consists of photons of energy *hf* and that an electron at or near the metal surface can only gain the energy of a single photon when it interacts with a photon. In addition, the candidate should be aware that each electron needs a minimum amount of energy to escape from the metal. They should appreciate that the kinetic energy of an emitted electron is equal to the difference between the energy it gains from a photon and the energy it needs (or uses) to escape from the metal. However, the explanation may lack a key element such as why the kinetic energy of the emitted electrons varies.	**3-4**
poor-limited	The candidate provides some correct ideas including recognition that light consists of photons of energy *hf* and that electrons in the metal (or at its surface) absorb photons and thereby gain energy. Their ideas lack coherence and they fail to recognise or use in their explanation the key idea that one photon is absorbed by one electron.	**1-2**

The explanations expected in a good answer should include most of the following physics ideas

energy is needed to remove an electron from the surface

work function φ (of the metal) is the minimum energy needed by an electron to escape from the surface

light consists of photons , each of energy $E = hf$

one photon is absorbed by one electron

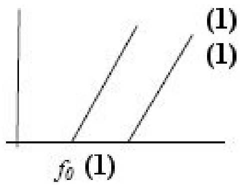
an electron can escape (from the surface) if $hf > \varphi$

kinetic energy of an emitted electron cannot be greater than $hf - \varphi$

an electron below the surface needs to do work/uses energy to reach the surface

kinetic energy of such an electron will be less than $hf - \varphi$

(b) (i)



(ii) parallel line, higher threshold frequency **(1)(1)**

(iii) Planck's constant **(1)**

4

(c) (use of $hf_0 = \phi$)

$hf = 6.63 \times 10^{-34} \times 2 \times 5.6 \times 10^{14}$ **(1)**

$\phi = 3.7(1) \times 10^{-19}$ J **(1)**

$E_k = 2 \times 3.7 \times 10^{-19} - 3.7 \times 10^{-19} = 3.7 \times 10^{-19}$ J **(1)**

3

[13]

M3. (a) **The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.**

The candidate's answer will be assessed holistically. The answer will be assigned to one of the three levels according to the following criteria.

High Level (good to excellent) 5 or 6 marks

The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

The candidate provides a comprehensive and coherent description which includes a clear explanation of threshold frequency and why this cannot be explained by the wave theory. The description should include a clear explanation of the photon model of light and this should be linked to the observations such as threshold frequency, the lack of time delay or mentions 1 to 1 interaction, the could not be explained by the wave model.

Intermediate Level (modest to adequate) 3 or 4 marks

The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

The candidate provides an explanation of threshold frequency and work function. The candidate explains the photon model of light and how this can provide an explanation of threshold frequency, eg relates energy of photon to frequency or talks about packets of energy.

Low Level (poor to limited) 1 or 2 marks

The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may only be partly appropriate.

States what is meant by photoelectric effect. Knowledge of photons/packets of energy.

The explanation expected in a competent answer should include a coherent account of the significance of threshold frequency and how this supports the particle nature of electromagnetic waves.

- threshold frequency minimum frequency for emission of electrons
- if frequency below the threshold frequency, no emission even if intensity increased
- because the energy of the photon is less than the work function
- wave theory can not explain this as energy of wave increases with intensity
- light travels as photons
- photons have energy that depends on frequency
- if frequency is above threshold photon have enough energy
- mention of lack of time delay

max 6

(b) (i) use of $E_k = \frac{1}{2}mv^2$

$\frac{1}{2} \times 6.6 \times 10^{-27}$ **(1)** $\times\ v^2 = 9.6 \times 10^{-13}$ **(1)**

$v^2 = 2.91 \times 10^{-14}$ (or $v = \sqrt{2.91 \times 10^{-14}}$) **(1)**

($v = 1.7 \times 10^7$ m s^{-1})

3

(ii) (use of $p = mv$)

$p = 6.6 \times 10^{-27} \times 1.7 \times 10^7$ **(1)**

$p = 1.1 \times 10^{-19}$ **(1)** kg m s^{-1}/N s **(1)**

3

(iii) (use of $\lambda = \frac{h}{mv}$)

$\lambda = 6.63 \times 10^{-34}/1.1 \times 10^{-19}$ **(1)**

$\lambda = 5.9 \times 10^{-15}$ m **(1)** (6.03×10^{-15} m)

2

[14]

M4. (a) (i) the (maximum) kinetic energy/speed/velocity/momentum of released electrons increases **(1)**

this is because increasing the frequency of the photons increases their energy **or** correct application of photoelectric equation **(1)**

(ii) the number of electrons emitted (per second) increases **(1)**

because there are now more photons striking the metal surface (per second) **(1)**

4

(b) experiment/observation needs to be performed (to test a theory) **(1)**

the results of (the experiment) need to be proved/repeatable/replicated/ confirmed **(1)**

[**or** threshold frequency **(1)** could not be explained by the wave model **(1)**]

2

(c) (i) (use of $\phi = hf_0$)

$\phi = 6.63 \times 10^{-34} \times 5.5 \times 10^{14}$ **(1)**

$\phi = 3.65 \times 10^{-19}$ **(1)** J **(1)**

(ii) $E_k = 6.63 \times 10^{-34} \times 6.2 \times 10^{14}$ **(1)** $- 3.65 \times 10^{-19}$ **(1)**

$E_k = 4.6 \times 10^{-20}$ J (accept 5.1×10^{-20} J) **(1)**

6

[12]

M5. (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 $hf = Ø + E_{k(max)}$)*

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

$f = 1.04 \times 10^{15}$ (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]

M6. (a) (i) (3.40-1.51 = 1.89)

$\Delta E = 1.89 \times 1.60 \times 10^{-19}$(J) **(1)**

(= 3.02×10^{-19}(J))

$$f\left(= \frac{\Delta E}{h}\right) = \frac{3.02 \times 10^{-19}}{6.63 \times 10^{-34}}$$ **(1)**

(=4.56×10^{14}Hz)

(ii) $$\lambda\left(= \frac{c}{f} = \frac{3.00 \times 10^{8}}{4.56 \times 10^{14}}\right) = 6.5(8) \times 10^{-7}\,\text{m}$$ **(1)**

(use of $f = 4.6 \times 10^{14}$ gives $\lambda = 6.5 \times 10^{-7}$m)

3

(b) (i) 6 (wavelengths) **(1)**

(ii) (1.51–0.85) = 0.66(eV) **(1)**

2

(c) mercury vapour at low pressure is conducting **(1)**
atoms of mercury are excited by electron impact **(1)**
producing (mainly) ultra violet radiation **(1)**
which is absorbed/ excites the coating **(1)**
which, upon relaxing, produces visible light **(1)**
electrons cascade down energy levels **(1)**

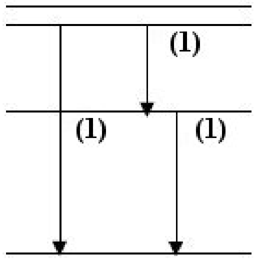
3

[8]

M7. (a) ionisation energy = 13.6eV **(1)**

1

(b) (i)



(ii) energy in Joules = 1.90 **(1)** × 1.6 × 10^{-19} = 3.04 × 10^{-19} (J) **(1)**
(use of $E = hc/\lambda$)

3.04 × 10^{-19} = 6.63 × 10^{-34} × 3 × $10^{8}/\lambda$ **(1)**
(working/equation must be shown)

λ = 6.54 × 10^{-7} m **(1)(1)** (2 or 3 sf for second mark)
(accept 0.65 which gives an answer of λ = 1.91 × 10^{-6} m)

8

[9]

M8. (a) (i) when an atom loses an orbiting electron (and becomes charged) **(1)**

(ii) $\frac{4.11 \times 10^{-17}}{1.6 \times 10^{-19}}$ = 260 (eV) **(1)** (257 (eV))

2

(b) (i) the electron in the ground state leaves the atom **(1)**
with remaining energy as kinetic energy (0.89 × 10^{-17} J) **(1)**

(ii) the orbiting electrons fall down **(1)**
to fill the vacancy in the lower levels **(1)**
various routes down are possible **(1)**
photons emitted **(1)**
taking away energy **(1)**

Max 4

(c) E to D and D to B **(1)**

both in correct order **(1)**

2

[8]

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 = $13.6 \times 1.60 \times 10^{-19} = 2.176 \times 10^{-18}$ (J) ✓

$hf = 2.176 \times 10^{-18}$ ✓

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

4

[12]

M10. (a) (i) an electron/atom is at a higher level than the ground state **(1)**

or electron jumped/moved up to another/higher level

1

(ii) electrons (or electric current) flow through the tube **(1)**

and collide with orbiting/atomic electrons or mercury atoms **(1)**

raising the electrons to a higher level (in the mercury atoms) **(1)**

3

(iii) photons emitted from mercury atoms are in the **ultra violet** (spectrum) **or** high energy photons **(1)**

these photons are absorbed by the powder **or** powder changes frequency/wavelength **(1)**

and the powder emits photons in the visible spectrum **(1)**

incident photons have a variety of different wavelengths **(1)**

max 3

(b) (i) (use of $E = hf$)

$-0.26 \times 10^{-18} - 0.59 \times 10^{-18}$ **(1)** $= 6.63 \times 10^{-34} \times f$ **(1)**

$f = 0.33 \times 10^{-18}/(6.63 \times 10^{-34}) = 5.0 \times 10^{14}$ (Hz) **(1)**

3

(ii) **one** arrow between n = 3 and n = 2 **(1)** in correct direction **(1)**

2

[12]

M11. (a) (i) k.e. = $\frac{4.1 \times 10^{-18}}{1.6 \times 10^{-19}}$ **(1)**

= 26 (eV) **(1)** (25.6 eV)

(ii) (use of $\lambda_{dB} = \frac{h}{mv}$ gives) $\lambda_{dB} = \frac{6.6 \times 10^{-34}}{9.1 \times 10^{-31} \times 3.0 \times 10^{6}}$ **(1)**

$= 2.4 \times 10^{-10}$ m **(1)** (2.42×10^{-10} m)

4

(b) (use of $hf = E_1 - E_2$ gives) $f = \frac{(0.90 - 0.21) \times 10^{-18}}{6.6 \times 10^{-34}}$ **(1)**

(= 1.05×10^{15} (Hz))

(use of $\lambda = \frac{c}{f}$ gives) $\lambda = \frac{3.0 \times 10^{8}}{1.05 \times 10^{15}}$ **(1)**

$= 2.9 \times 10^{-7}$ m **(1)** (2.86×10^{-7} m)

3

[7]

M12. (a) (i) (use of $\lambda = \frac{h}{mv}$ gives) $v = \frac{6.63 \times 10^{-34}}{9.11 \times 10^{-31} \times 3.2 \times 10^{-8}}$ **(1)**

$= 2.3 \times 10^{4}$ m s^{-1} **(1)** (2.27×10^{4} m s^{-1})

(ii) (use of λ inversely proportional to *m* when *v* is constant, gives)

$\lambda_p \left(= \lambda_e \frac{m_e}{m_p} \right) = \frac{3.2 \times 10^{-8} \times 9.11 \times 10^{-31}}{1.67 \times 10^{-27}}$ **(1)**

$= 1.7 \times 10^{-11}$ m **(1)**

[or $\lambda \left(= \frac{h}{mv} \right) = \frac{6.63 \times 10^{-34}}{1.67 \times 10^{-27} \times 2.27 \times 10^{4}}$

$= 1.7 \times 10^{-11}$ m (1.746×10^{-11} m)]

(allow C.E. for value of v from (a) (i**)**

4

(b) (i) diffraction (experiments) **(1)**

(ii) easier to obtain electrons (to accelerate)
[or easier to get λ same size as scattering object] **(1)**

2
QWC 2

[6]