

1. (a) Calculation of energy required by atom (1)
 Answer [1.8 (eV)] (1)
Example of answer:
 Energy gained by atom = 13.6 eV – 3.4 eV = 10.2 eV
 KE of electron after collision = 12 eV – 10.2 eV = 1.8 eV 2

- (b) Use of $E = hf$ and $c = f\lambda$ (1)
 Conversion of eV to Joules (1)
 Answer = $[1.22 \times 10^{-7} \text{ m}]$ (1)
Example of answer
 $E = hf$ and $c = f\lambda$ $E = hc/\lambda$
 $\lambda = (6.63 \times 10^{-34} \text{ J s} \times 3 \times 10^8 \text{ m s}^{-2}) \div (10.2 \text{ eV} \times 1.6 \times 10^{-19} \text{ C})$
 $\lambda = 1.21 \times 10^{-7} \text{ m}$ 3

[5]

2. (a) Diffraction is the change in direction of wave or shape or wavefront (1)
 when the wave passes an obstacle or gap (1) 2

- (b) The energy of the wave is concentrated into a photon (1)
 One photon gives all its energy to one electron (1) 2

- (c) Energy of photon increases as frequency increases OR reference to $E = hf$ (1)
 Electrons require a certain amount of energy to break free and this corresponds to a minimum frequency (1) 2

[6]

3. (a) Meaning of statement
 $(5.89 \times 10^{-19} \text{ J} / \text{work function})$ is the energy needed to remove an electron [allow electrons] from the (magnesium) surface/plate
Consequent mark
Minimum energy stated or indicated in some way [e.g. at least /or more] (1) 2

- (b) (i) Calculation of time
 Use of $P = IA$ (1)
 Use of $E = Pt$ (1)
 [use of $E = IAt$ scores both marks]
 Correct answer [210 (s), 2 sig fig minimum, no u.e.] (1)
 [Reverse argument for calculation leading to either intensity, energy or area gets maximum 2 marks]
 Example calculation:
 $t = (5.89 \times 10^{-19} \text{ J}) / (0.035 \text{ W m}^{-2} \times 8 \times 10^{-20} \text{ m}^2)$ 3

- (ii) How wave-particle duality explains immediate photoemission
 QOWC (1)
Photon energy is hf / depends on frequency / depends on wavelength (1)
One/Each photon ejects **one/an** electron (1)
 The (photo)electron is ejected **at once/immediately** (1)
 [not just 'photoemission is immediate'] 4

[9]

4. (a) Blue light:
 Wavelength / frequency / (photon) energy 1

- (b) (i) Frequency:
 Conversion of either value of eV to Joules
 Use of $f = E / h$
 Correct frequency range [$4.8 \times 10^{14} - 8.2 \times 10^{14}$ Hz **or** range = 3.4×10^{14} Hz]
 [no penalty for rounding errors]
 eg.
 $2 \text{ eV} = 2 \times 1.6 \times 10^{-19} = 3.2 \times 10^{-19} \text{ J}$
 $= 6.63 \times 10^{-34} \times f$
 $f = 4.8 \times 10^{14} \text{ Hz}$
 $3.4 \text{ eV} = 3.4 \times 1.6 \times 10^{-19} = 5.4 \times 10^{-19} \text{ J}$
 $f = 8.2 \times 10^{14} \text{ Hz}$ 3

- (ii) Diagrams:
 Downward arrow from top to bottom level
 On larger energy gap diagram 2

- (c) (i) Resistivity drop:
 Less heating / less energy lost / greater efficiency / lower voltage needed / less power lost 1

- (ii) Resistance:
 Recall of $R = \rho L/A$
 Use of $R = \rho L/A$
 Correct answer [80(Ω)] [allow 80–84 (Ω) for rounding errors]

Eg.

$$R = (2 \times 10^{-2} \times 5.0 \times 10^{-3}) / (3.0 \times 10^{-3} \times 4.0 \times 10^{-4})$$

$$= 83 \Omega$$

3

[10]

5. (a) Part of spectrum

Light / Visible / red (1)

1

Calculation of work function

Use of $\phi = hc/\lambda$ (1)

3.06×10^{-19} [2 sig fig minimum] (1)

2

$$(6.63 \times 10^{-34} \text{ J s})(3.00 \times 10^8 \text{ m s}^{-1}) / (6.5 \times 10^{-7} \text{ m})$$

$$= 3.06 \times 10^{-19} \text{ J}$$

- (b) (i) Meaning of stopping potential

Minimum potential difference between C and A / across the photocell (1)

Which reduces current to zero OR stops electrons reaching A / crossing the gap / crossing photocell (1)

2

- (ii) Why the graphs are parallel

Correct rearrangement giving $V_s = hf/e - \phi/e$ (1)

Gradient is h/e which is constant / same for each metal (1)

[Second mark can be awarded without the first if no rearrangement is given, or if rearranged formula is wrong but does represent a linear graph with gradient h/e]

2

[7]

6. (a) (i) Table

λ f

2.4 (110)

1.2 220

0.8 330

All wavelengths correct (2)

[One or two wavelengths correct gets 1]

Both frequencies correct (1)

[Accept extra zero following wavelength figure, e.g. 2.40.

Accept units written into table, e.g. “2.4 m”, “220 Hz”]

3

(ii) Why nodes
 String cannot move / no displacement / zero amplitude /
 no oscillation / phase change of π on reflection / two waves
 cancel out / two waves are exactly out of phase (1)
 (OR have phase difference of π OR half a cycle) /
 destructive interference 1

(b) Why waves with more nodes represent higher energies
 More nodes means shorter wavelength (1)
 Momentum will be larger (1)
 [OR Allow 1 mark for "More nodes means higher frequency and $E = hf$ "] 2

[6]

7. (a) Why statement correct
 Blue photon has more energy than red photon (1)
 Why statement incorrect
 Blue beam carries less energy per unit area per second / Blue beam
 carries less energy per second / Blue beam carries less energy per
 unit area / Blue beam has lower intensity and intensity = energy per unit
 area per second
 Additional explanation
 [Under "correct"] Blue has a higher frequency (OR shorter wavelength) /
 [Under "incorrect"] Blue beam has fewer photons (1)
 [Allow reverse statements about Red throughout part a] 3

(b) (i) Meaning of work function
 Energy to remove an electron from the surface (OR
 metal OR substance) (1)
 [Don't accept "from the atom". Don't accept "electrons".]
 Minimum energy... / Least energy... / Energy to just...
 / ...without giving the electron any kinetic energy (1) 2

(ii) Calculation of threshold frequency
 Use of $\phi = hf_0$ (1)
 Correct answer [6.00×10^{14} Hz] (1)
 e.g.
 $(3.98 \times 10^{-19} \text{ J}) / (6.63 \times 10^{-34} \text{ J s}) = 6.00 \times 10^{14} \text{ Hz}$ 2

[7]

8. (a) Which transition
 Use of $(\Delta)E = hc/\lambda$ OR $(\Delta)E = hf$ and $f = c/\lambda$ (1)
 Use of 1.6×10^{-19} (1)
 Correct answer [1.9 eV] (1)
 C to B / -1.5 to -3.4 (1)
 [Accept reverse calculations to find wavelengths]
 e.g.
 $(6.63 \times 10^{-34} \text{ J s})(3.00 \times 10^8 \text{ m s}^{-1}) /$
 $(656 \times 10^{-9} \text{ m})(1.6 \times 10^{-19} \text{ J eV}^{-1})$
 = 1.9 eV 4
- (b) Explanation of absorption line
 QOWC (1)
 Light of this wavelength is absorbed by hydrogen (1)
 In the outer part of the Sun (OR Sun's atmosphere) (1)
 Absorbed radiation is reemitted in all directions (1)
 Transition from B to C (OR -3.4 to -1.5) (1) Max 4
- (c) Why galaxy receding
 Wavelength increased (OR stretched) / red shift /
 frequency decreased 1
9. (a) Work function:
Energy needed for an electron to escape the surface /
 to be released (from the metal) (1) 1
- (b) How current produced:
 Any 3 from:
Photon of light passes energy to an electron
 If energy above the work function/frequency above threshold (1)(1)
 Electron released as a photoelectron / photoelectron released /
 surface electron released (1)
 Moving electrons produce a current 3
- (c) (i) Intensity of light increased:
 More electrons released (1)
- (ii) Frequency of light increased:
 Electrons gain more (kinetic) energy (1) 2

[9]

- (d) Photon energy:
 Use of $f = v/\lambda$ or $E = hc/\lambda$ (1)
 Correct answer for E (4.7×10^{-19} J or 2.96 eV) (1)
 [allow 3.0 eV] 2

Example:

$$f = v/\lambda = 3 \times 10^8 / 4.2 \times 10^{-7} = 7.1 \times 10^{14} \text{ Hz}$$

$$E = hf = 4.7 \times 10^{-19} \text{ J or } 2.96 \text{ eV}$$

OR

$$E = hc/\lambda = 3 \times 10^8 \times 6.63 \times 10^{-34} / 4.2 \times 10^{-7} \\ = 4.7 \times 10^{-19} \text{ J or } 2.96 \text{ eV}$$

- (e) Max kinetic energy:
 Knowledge that $ke_{\text{max}} = \text{energy calculated in (d)} - \phi$ (1)
 Correct answer for ke_{max} (0.26 eV or 4.2×10^{-20} J)
 [allow 0.25–0.26 eV or $4.1 - 4.2 \times 10^{-20}$ J and allow ecf from (d)] (1) 2

Example:

$$ke_{\text{max}} = 2.96 \text{ eV} - 2.7 \text{ eV}$$

$$= 0.26 \text{ eV}$$

- (f) (i) Why current reduced:
 Many / some electrons will not have enough (kinetic) energy
 to reach the anode / only electrons with large (kinetic) energy
 will reach the anode (1) 1
- (ii) Stopping potential:
 $eV = (-) ke$
 $V = ke / e = \underline{0.26V}$ (1) 1

[12]

10. (a) [Treat parts (i) and (ii) together. Look for any FIVE of the following points. Each point may appear and be credited in either part (i) or part (ii)]
- (i)
- Light (OR radiation OR photons) releases electrons from cathode
 - Photon energy is greater than work function / frequency of light > threshold frequency / flight > f_0 / wavelength of light is shorter than threshold wavelength / $\lambda < \lambda_0$
 - PD slows down the electrons (OR opposes their motion OR creates a potential barrier OR means they need energy to cross the gap)
 - Electrons have a range of energies / With the PD, fewer (OR not all) have enough (kinetic) energy (OR are fast enough) to cross gap
 - Fewer electrons reach anode / cross the gap

- (ii) • (At or above V_s) no electrons reach the anode / cross the gap
- Electrons have a maximum kinetic energy / no electrons have enough energy (OR are fast enough) to cross

ANY FIVE (1)(1)(1)(1)(1)

[Don't worry about whether the candidate is describing the effect of increasing the reverse p.d. (as the question actually asks), or simply the effect of having a reverse p.d.] 5

(b) Effects on the stopping potential

- (i) No change **(1)**
- (ii) Increases **(1)** 2

[Ignore incorrect reasons accompanying correct statements of the effect]

[7]

11. (a) Explain how vapour emits light

electrons excited to higher energy levels **(1)**
 as they fall they emit photons/electromagnetic radiation/waves/energy **(1)** 2

(b) (i) Meaning of spectral line

(when the light is split up) each frequency/wavelength/photon energy is seen as a separate/discrete line (of a different colour) **(1)** 1

(ii) Calculation of frequency

Recall of $v = f\lambda$ **(1)**
 Correct answer [$f = 5.1 \times 10^{14}$ Hz] **(1)** 2
 Example of calculation:
 $v = f\lambda$
 $3.0 \times 10^8 \text{ m s}^{-1} = f \times 589 \times 10^{-9} \text{ m}$
 $f = 5.1 \times 10^{14} \text{ Hz}$

(c) Explanation of different colours

different colours = different freq/wavelengths / photons of different energies **(1)**
 photon energy/frequency/wavelength depends on difference between energy levels **(1)**
 diff atoms have diff energy levels/diff differences in levels **(1)** 3

- (d) Explanation of transverse waves
 variation in E or B-field /oscillations/vibrations/displacement
 at right angles/perpendicular to direction of travel/propagation
 [not just motion or movement for both 1st and 3rd part] (1) 1

[9]

12. (a) (i) Energy level diagram:
 • Arrow showing electron moving from lower level to a higher level (1)
 • Arrow downwards from higher to lower level [must show smaller energy change than upward arrow] (1) 2

- (ii) Missing energy:
 Causes a rise in temperature of a named item (1) 1

- (iii) Range of energies:
 Minimum energy when $\lambda = 400 \times 10^{-9} \text{ m}$ (1)
 Use of $f = c/\lambda$ (1)
 Use of $E = hf$ (1)
 Correct answer [3.1 eV] (1)
 [allow 3.0 – 3.3 eV for rounding errors] [no u.e] 4
 eg. $f = 3 \times 10^8 / 400 \times 10^{-9}$
 $= 7.5 \times 10^{14} \text{ Hz}$
 $E = hf = 5.0 \times 10^{-19} \text{ J}$
 $E = 3.1 \text{ eV}$

- (b) Detecting forgeries:
 Forgery would glow / old painting would not glow (1) 1

[8]

13. (a) Solar Power
 Use of $P = I\pi r^2$ [no component needed for this mark] (1)
 Use of $\cos 40$ or $\sin 50$ (with I or A) (1)
 2.2 [2 sf minimum. No ue] (1) 3
 e.g. $P = 1.1 \times 10^3 \text{ W m}^{-2} \times \cos 40 \times \pi(29 \times 10^{-3} \text{ m})^2$
 $= 2.2 \text{ W}$

- (b) Energy
 Use of $E = Pt$ (1)
 $1.8 \times 10^4 \text{ J} / 2.0 \times 10^4 \text{ J}$ (1) 2
 e.g. $E = 2.2 \text{ W} \times (2.5 \times 3600 \text{ s})$
 $= 2.0 \times 10^4 \text{ J}$

[5]

14. (a) Graph
 Straight line with positive gradient (1)
 Starting the straight line on a labelled positive f_0 (1)
 [Curved graphs get 0/2. Straight line below axis loses mark 2 unless that bit is clearly a construction line.] 2

- (b) Work function
 From the y intercept (1)
 [Accept if shown on graph]
 OR Given by gradient $\times f_0$ (or $h \times f_0$) [Provided that f_0 is marked on their graph, or they say how to get it from the graph]
 OR Read f and E_k off graph and substitute into $E_k = hf - \phi$
 [Curved graph can get this mark only by use of hf_0 or equation methods.] 1

- (c) Gradient
 Gradient equals Planck constant (1) 1
 [Curved graph can't get this mark]

[4]

15. (a) Wavelength
 eV to J (1)
 Use of $\Delta E = hf$ (1)
 Use of $c = f\lambda$ (1)
 1.8×10^{-11} [2 sf minimum. No ue] (1) 4
 e.g. $f =$
 $(-1.8 \text{ keV} - (-69.6 \text{ keV})) \times (10^3 \times 1.6 \times 10^{-19} \text{ J keV}^{-1}) / 6.6 \times 10^{-34} \text{ J s}$
 $= 1.64 \times 10^{19} \text{ Hz}$
 $\lambda = 3.00 \times 10^8 \text{ m s}^{-1} / 1.64 \times 10^{19} \text{ Hz}$
 $= 1.8 \times 10^{-11} \text{ m}$

- (b) Type
 X rays [Accept gamma rays] (1) 1

[5]

16. Meaning of energy level

Specific allowed energy/energies (of electron in an atom)(1) 1

Meaning of photon

Quantum/packet/particle of energy/radiation/light/electromagnetic wave (1) 1

Formula for photon energy

$E_2 - E_1$ (1) 1

[Allow $E_1 + E_{\text{photon}} = E_2$]

Explanation of photon wavelengths

Same energy change / same energy difference / energy the same (1) 1

Meaning of coherent

Remains in phase / constant phase relationship(1) 1

17. (a) Explanation

QOWC (1)

UV/red photon (1) 2

$E_{\text{UV}} > E_{\text{R}}$ / $f_{\text{uv}} > f_{\text{R}}$ (1)

$E_{\text{UV}} > \Phi$ / $f_{\text{uv}} > f_{\text{TH}}$ (so electron can break free) (1)

One photon absorbed by one electron (1)

Both metal plate and electron are negative or repel (each other) (1) max 2

(b) (i) Intensity red light increased

nothing / no discharge (1)

(ii) Intensity of UV increased

(Coulombmeter) discharges quicker (1) 2

(c) Max KE

Use of $E = hc/\lambda$ (1)

conversion of eV to J or vice versa i.e. appropriate use of 1.6×10^{-19} (1)

Subtraction $hc/\lambda - \Phi$ [must use same units] or use of full equation (1)

max KE = 2.2×10^{-19} J (1) 4

[Candidates may convert photon energy to eV leading to max KE = 1.4 eV]

[10]

18. Explanation of 'excited'
 Electrons/atoms gain energy (1)
 and electrons move to higher (energy) levels (1) 2
 [Credit may be gained for diagrams in this and the next 3 parts]

Explanation of how radiation emitted by mercury atoms
 Electrons (lose energy as they) drop to lower levels (1)
 Emit photons / electromagnetic radiation (1) 2

Explanation of why only certain wavelengths are emitted
 Wavelength (of photon) depends on energy (1)
 Photon energy depends on difference in energy levels (1)
 Levels discrete / only certain differences / photon energies possible (1) 3
 (and therefore certain wavelengths)

Why phosphor emits different wavelengths to mercury
 Different energy levels / different differences in energy levels (1) 1

Calculation of charge
 $Q = It$ (1)
 $= 0.15 \text{ A} \times 20 \times 60\text{s}$
 $= 180 \text{ C}$ (1) 2

[10]

19. Example of light behaving as a wave
 Any one of:
 • diffraction
 • refraction
 • interference
 • polarisation (1) 1

What is meant by monochromatic

Single colour / wavelength / frequency (1) 1

Completion of graph

Points plotted correctly [-1 for each incorrect point] (1) (1)

Line of best fit added across graph grid (1) 3

What eV_s tells us

Maximum (1)

Kinetic energy of the electrons / $\frac{1}{2}mv^2$ of electrons (1) 2

Threshold frequency for sodium

Correct reading from graph: 4.3×10^{14} Hz (1) 1

[Accept $4.1 \times 10^{14} - 4.7 \times 10^{14}$ Hz]

Work function

$$f = hf_0 = 6.63 \times 10^{-34} \text{ J s} \times 4.3 \times 10^{14} \text{ Hz (1)}$$

$$= 2.9 \times 10^{-19} \text{ J [Allow ecf] (1)} \quad 2$$

Why threshold frequency is needed

- Electron requires certain amount of energy to escape from surface (1)
- This energy comes from one photon of light (1)
- $E = hf$ (1)

Max 2

[12]

20. Photoelectric effect

(a) Explanation:

Particle theory: one photon (interacts with) one electron (1)

Wave theory allows energy to 'build up', i.e. time delay (1) 2

(b) Explanation:

Particle theory: f too low then not enough energy (is released by photon to knock out an electron) (1)

Wave theory: Any frequency beam will produce enough energy (to release an electron, i.e. should emit whatever the frequency) (1) 2

[4]

21. Description of photon

Packet/quantum/particle of energy [accept $E = hf$ for energy] (1) (1)

[allow {packet/quantum/particle} of {light/e-m radiation/e-m wave} etc for (1) X] 2
[zero marks if error of physics such as particle of light with negative charge]

Show that energy to move electron is about 8×10^{-20} J

$$W = QV \text{ (1)}$$

$$= 1.6 \times 10^{-19} \text{ C} \times 0.48 \text{ V}$$

$$= 7.7 \times 10^{-20} \text{ J [no ue]} \text{ (1)} \quad 2$$

Calculate efficiency of photon energy conversion

$$\text{Efficiency} = (7.7 \times 10^{-20} \text{ J} \div 4.0 \times 10^{-19} \text{ J}) \text{ [ecf]} \text{ (1)}$$

$$= 0.19 \text{ or } 19 \% \text{ (1)} \quad 2$$

[6]

22. Diagram

One arrow straight down (from -3.84 to -5.02) (1)

Two arrows down (from -3.84 to -4.53 , then -4.53 to -5.02) (1) 2

Transition T

T from -5.02 to -1.85 upwards (1) 1

Kinetic energy values and explanation of what has happened to lithium atom in each case

0.92 eV (1)

Atom stays in -5.02 (eV) level/nothing happens to it (1)

0.43 eV (1)

Atom excited to -4.53 (eV) level (1) 4

Full credit is given to candidates who take the k.e. of the electron to be 0.92 J after collision. Any TWO correct energies with correct statement.

[7]

23. Incident photon energies

Use of $E = hf$ (1)

Use of $c = f\lambda$ [ignore $\times 10^X$ errors] (1)

$\div e$ (1)

For 320 nm $E = 3.9$ (eV) **and** 640 nm $E = 1.9$ (eV) (1) 4

Photocurrent readings

Work function of Al > 3.9 / energies of the incident photons
OR threshold frequency is greater than incident frequencies (1)

For Li ($\phi = 2.3 \text{ eV} / f = 5.6 \times 10^{14} \text{ Hz} / \lambda = 540 \text{ nm}$ hence) a photocurrent
at 320 nm but not 640 nm (1)

If intensity $\times 5$ then photocurrent $\times 5$ (1) 3

Stopping Potential

$KE_{\text{max}} = 4.00/3.88 - 2.30 = 1.7/1.58$ [ignore anything with only e] (1)

$V_s = 1.7/1.58 \text{ V}$ (1) 2

[9]

24. Ionisation energy

$(10.4 \text{ eV}) \times (1.6 \times 10^{-19} \text{ J eV}^{-1})$ (1)

$(-) 1.66 \times 10^{-18} \text{ (J)}$ (1) 2

Kinetic energy

0.4 (eV) (1) 1

Transition

Use of $E = hc/\lambda$ (1)

3.9 (eV) (1)

Transition is from $(-)1.6 \text{ eV}$ to $(-)5.5 \text{ eV}$ 3

[6]

25. Deductions about incident radiations

(i) Radiations have same frequency/same wavelength/ same photon energy (1)

(ii) Intensity is greater in (a) than in (b) (1) 2

Sketch graph (c)

Line of similar shape, starting nearer the origin on negative V axis (1) 1

Maximum speed

Use of $E = hf$ (1)

Subtract $7.2 \times 10^{-19} \text{ (J)}$ (1)

Equate to $\frac{1}{2} m v^2$ (1)

$3.1 \times 10^6 \text{ ms}^{-1}$ (1) 4

[7]

26. Wavelength

Distance between two points in phase (1)

Distance between successive points in phase (1) 2

[May get both marks from suitable diagram]

Sunburn more likely from UV

UV (photons) have more energy than visible light (photons) (1)

Since shorter wavelength / higher frequency (1) 2

What happens to atoms

Move up energy levels/excitation/ionization (1)

Correctly related to electron energy levels (1) 2

[6]

27. Error in circuit diagram

Cell needs to be reversed (1)

Any one point from:

- electrons released from the magnesium
- copper wire needs to be positive to attract electrons (1) 2

Completion of sentence

UV is made up of particles called photons (1) 1

UV and visible light

- (i) UV has shorter wavelength/higher frequency/higher photon energy (1)
- (ii) Both electromagnetic radiation/both transverse waves/same speed (in vacuum) (1) 2

Explanation of why low intensity UV light produces a current

Any three points from:

- reference to photons or $E = hf$
- frequency > threshold frequency
- electron must have sufficient energy to be released
- UV photons have more energy
- electron is released by ONE photon
- brighter light just means more photons (1) (1) (1) Max 3

Why current stopped

Glass prevents UV reaching magnesium (1) 1

[9]

28. Description

Electron (near surface of cathode) absorbs photon and gains energy (1)

Work function is energy needed for electron to escape from surface (1)

Electrons released in this way are called photoelectrons (1) 3

Lowest frequency of radiation

$$f_0 = E/h \text{ (1)}$$

$$= 2.90 \times 10^{-19} \text{ J} / 6.63 \times 10^{-34} \text{ J s (1)}$$

$$= 4.37 \times 10^{14} \text{ Hz (1) 3}$$

Suitability of potassium

$$\lambda = 3 \times 10^8 \text{ m s}^{-1} / 4.37 \times 10^{14} \text{ Hz [use of lowest frequency] (1)}$$

$$6.86 \times 10^{-7} \text{ m [with suitable comment] (1)}$$

OR

$$f = 3 \times 10^8 \text{ m s}^{-1} / 4.0 \times 10^{-7} \text{ and } f = 3 \times 10^8 \text{ m s}^{-1} / 7.0 \times 10^{-7} \text{ [uses range of } \lambda \text{] (1)}$$

$$f = 7.5 \times 10^{14} \text{ Hz to } 4.3 \times 10^{14} \text{ Hz [with suitable comment] (1) 2}$$

[Suitable comment – e.g. this is within range of visible light/almost all of the visible light photons will emit photoelectrons]

Maximum kinetic energy

Use of $E = hc/\lambda$ AND minimum wavelength (1)

$$\text{Max photon energy} = hc/\lambda = 6.63 \times 10^{-34} \text{ J s} \times 3 \times 10^8 \text{ m s}^{-1} / (400 \times 10^{-9} \text{ m})$$

$$= 4.97 \times 10^{-19} \text{ J [no u.e]}$$

Max k.e. = max photon energy – work function [or use equation]

$$= 4.97 \times 10^{-19} \text{ J} - 2.90 \times 10^{-19} \text{ J}$$

$$= 2.07 \times 10^{-19} \text{ J [allow ecf if wrong wavelength used] [no u.e] (1) 3}$$

Why some photoelectrons will have less than this k.e.

One point from:

- photon energy might be transferred to electron below surface
- so some energy transferred to atoms on the way to surface
- hence electron leaves surface with less energy than max
- max is for electron from the surface
- lower energy photon responsible for emission (1)

1

[12]

29. Table

Radio waves	Sound waves
Transverse	Longitudinal
Travel much faster than sound	Travel more slowly
(Can) travel in a vacuum	Cannot travel in a vacuum
Can be polarised	Not polarised
Electromagnetic	Pressure/Mechanical wave

Any three of the above

Max 3

Assumption

Attempt to calculate area (1)

Intensity = 0.02 kW m^{-2} OR 20 W m^{-2} (1)

Efficiency at *collector* is 100%/beam perpendicular to *collector*

Power

Use of $I P/4\pi r^2$ (1)

Power = $3.3 \times 10^{17} \text{ W}$ [ecf their I]

No energy "lost" due to atmosphere (not surroundings) OR Inverse square applies to this situation (1)

More efficient method

Use a laser (maser) / reference to beaming/ray (1)

1

[10]

30. Ionisation energy

Use of $\times 1.6 \times 10^{-19}$

2.2×10^{-18} [No u.e.] (1)

2

Addition to diagram

- (i) From 4 to 3 labelled R / (i) (1)
(ii) From 1 to 4 labelled A / (ii) (1) 2

Emission spectrum

Hydrogen 'excited' in a discharge/thin tube/lamp [not bulb] (1)

Viewed through a diffraction grating/prism/spectrometer (1)

Appearance of emission spectrum

A series of lines / colours on a *dark* background [accept bands] (1) 3

Region of spectrum

Radio/microwave (1) 1

Speed of galaxy and deduction

$\Delta \lambda = 8 \text{ (mm)} / 211 - 203 \text{ (mm)}$ (1)

Use of 3×10^8 (1)

$v = 1.1(4) \times 10^7 \text{ ms}^{-1}$ [No e.c.f.] (1)

Moving towards Earth (us) (1) 4

[12]

31. Photoelectric effect

Any two features and explanation from the following:

Feature: Experiments show $k.e_{(\max)} \propto f$, OR not intensity
[Accept depends upon] (1)

Explanation: Photon energy $\propto f$ (1)
[Consequent]

$k.e_{(\max)} \propto$ intensity is a wave theory (1)

Feature: Emission of photoelectrons immediate (1)

Explanation: One photon releases one electron particle theory (1)
[Consequent] Wave theory allows energy to "build up" (1)

Feature: (Light) below a threshold frequency cannot release electrons (1)

Explanation: Particle theory- f too low as not enough energy is released

[Consequent] by photon to knock out an electron (1)

Wave theory- if leave a low frequency beam on long enough, it will produce enough energy to release an electron (1)

[Max 5]

32. Planck constant

Realise that h is the gradient

Correct attempt to find gradient [but ignore unit errors here]

$$h = (6.3 \text{ to } 6.9) \times 10^{-34} \text{ J s} \quad [\text{No bold answers}] \quad 3$$

Work function

Use of hf_0 / use intercept on T axis/use of $\phi = hf - T$ (1)

$$\phi = (3.4 \text{ to } 3.9) \times 10^{-19} \text{ J} \quad [-1 \text{ if -ve}] \quad [2.1 \text{ to } 2.4 \text{ eV}] \quad (1) \quad 2$$

[5]

33. Energy of photon of light

$$E = hf = 6.63 \times 10^{-34} \text{ J s} \times 6.0 \times 10^{14} \text{ Hz} = 3.98 \times 10^{-19} \text{ (J)} \quad 1$$

Graph

Points correct ($\pm \frac{1}{2}$ square) (2)

Single straight line of best fit (NOT giving intercept below 4.5×10^{14}) (1)

Line drawn as far as f axis (1) 4

Value for h

Large triangle [at least 7 cm on K.E. axis] (1)

$$\text{Gradient} = \text{e.g. } (6.05 - 4.55) \times 10^{14} / 1.0 \times 10^{-19} = 1.5 \times 10^{33} \quad (1)$$

$$h = 1/\text{gradient} = 6.67 \times 10^{-34} \text{ J s} \quad (1) \quad 3$$

-

Value of ϕ

Reading co-ordinates of a fixed point on graph (e.g. 0, 4.55×10^{14}) (1)

ϕ from equation, e.g.

so $\phi = \text{frequency intercept} \times h$

$$= \text{e.g. } 4.55 \times 10^{14} \times 6.67 \times 10^{-34}$$

$$= 3.03 \times 10^{-19} \text{ J} \quad (1) \quad 2$$

Explanation

Not enough energy [OR frequency too low]

For 2nd mark, numerical/added detail required,

e.g calculation: $E = 6.63 \times 10^{-34} \times 4.5 \times 10^{14} \text{ Hz} = 2.98 \times 10^{-19} < \phi$

OR threshold frequency read from graph

2

[12]

34. Explanation of “coherent”

In / constant phase (difference) (1)

symbol 51 \f "Monotype Sorts" \s 123 (1)

1

Power delivered by laser

$$P = \frac{40}{400 \times 10^{-15}} \text{ (1)}$$

$$= 1 \times 10^{14} \text{ W (1)}$$

2

Energy level change

$$\nu = f\lambda / f = \frac{3 \times 10^8}{1050 \times 10^{-9}} \text{ [-1 if omit } 10^{-9}] \text{ (1)}$$

$$\text{Use of } E = hf / 6.6 \times 10^{-34} \times \frac{3 \times 10^8}{1050 \times 10^{-9}} \text{ (1)}$$

[If $f = 1/T$ used, give this mark]

$$= 1.9 \times 10^{-19} \text{ J (1)}$$

3

[6]

35. Calculation:

$$E = hc/\lambda \text{ [seen or implied] (1)}$$

physically correct substitutions (1)

$$\div 1.6 \times 10^{-19} \text{ eV J}^{-1} \text{ (1)}$$

$$5.78 \text{ eV (1)}$$

4

Maximum kinetic energy:

$$3.52 \text{ eV [ecf but not if -ve.] (1)}$$

Stopping potential:

3.52 V [Allow e.c.f., but not signs] (1) 2

Annotated graph:

Position of S (1)

Cuts V axis between origin and existing graph (1)

Similar shape [I levels off up/below existing line] (1) 3

[9]

36. Energy of photon of green light:

$$f = \frac{c}{\lambda} = \frac{3 \times 10^8 \text{ m s}^{-1}}{5.58 \times 10^{-7} \text{ m}} = 5.38 \times 10^{14} \text{ Hz (1)}$$

$$E = hf = 6.63 \times 10^{-34} \text{ J s} \times 5.38 \times 10^{14} \text{ Hz (1)}$$

$$= 3.56 \times 10^{-19} \text{ J} \quad 2$$

Diagram:

Larger gap identified (1)

Downwards arrow between levels of same element (1)



2

[4]

37. Diffraction:

The spreading out of waves when they pass through a narrow slit or around an object (1)

Superposition:

Two or more waves adding (1)

to give a resultant wave [credit annotated diagrams] (1)

Quantum:

A discrete/indivisible quantity (1) 4

Particles:

Photon/electron (1) 1

What the passage tells us:

Any 2 points from:

- large objects can show wave-particle duality
- quantum explanations now used in “classical” solutions
- quantum used to deal with sub-atomic particles and classical with things we can see

Max 2

[7]

38. Ionisation energy of atomic hydrogen:

$$13.6 \text{ eV OR } 2.18 \times 10^{-18} \text{ J } [- \text{sign, } \mathbf{X}] \quad \mathbf{(1)}$$

1

Why energy levels are labelled with negative numbers:

Work/energy is needed to raise the electrons/atoms to an energy of 0 eV, so must start negative $\mathbf{(1)(1)}$

OR

Work/energy is given out when the electrons/atoms move to the ground state, so energy now less than 0, i.e. negative $\mathbf{(1)(1)}$

OR

the ground state is the most stable/lowest energy level of the electrons/atoms and must be less than 0, i.e. negative $\mathbf{(1)(1)}$

2

[1st mark essential: e^- highest/maximum/surface/ionised/free has energy = 0eV

2nd mark: raising levels means energy in OR falling levels means energy out \therefore negative levels]

Wavelength of photon:

$$\Delta E = 1.89 \text{ (eV)} \quad \mathbf{(1)}$$

Convert ΔE to joules, i.e. $\times(1.6 \times 10^{-19})$

OR

$$\lambda = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.89 \times (1.6 \times 10^{-19})} \quad \mathbf{[Their E]} \quad \mathbf{(1)}$$

$$= 6.6 \times 10^{-7} \text{ (m)} \quad \mathbf{[6.5 - 6.7]} \quad \mathbf{(1)}$$

3

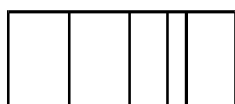
Production of line spectrum of atomic hydrogen in a laboratory:

Source – hydrogen discharge tube/hydrogen lamp/low p hydrogen with high V across (1)

(view through) diffraction grating/prism/spectrometer/spectroscope (1)

2

Sketch:



A few vertical **lines** on a blank background OR sharp bands

Dark on light/light on dark NOT equally spaced (1)

1

Absorption spectrum:

White light through gas in container (1)

Diffraction grating/prism/spectrometer (1)

Must be dark lines on bright background (1)

[9]

39. Threshold wave:

Electron requires certain amount of energy to escape from surface (1)

This energy comes from one photon (1)

Use of $E = hf$ (1)

(So photon needs) minimum frequency (1)

Hence maximum wavelength

OR use of $E = hc/\lambda$ (1)

Max 4

Work function:

$$f = c/\lambda = 3.0 \times 10^8 / 700 \times 10^{-9} \text{ m (1)}$$

$$= 4.28 \times 10^{14} \text{ Hz (1)}$$

$$E = hf = 6.63 \times 10^{-34} \text{ J s} \times 4.28 \times 10^{14} \text{ Hz} = 2.84 \times 10^{-19} \text{ (J) [Allow e.c.f.] (1)} \quad 3$$

Circuit :

Circuit showing resistors only in series (1)

Potentials labelled (1)

[Use of potential divider – allowed]

Resistor values 1: 1: 1 OR 1:2 (1)

Max 2

Suggestion:

Cosmic rays travel more slowly than light (1)

1

[10]

40. Calculation of kinetic energy:

$$f = \frac{3 \times 10^8 \text{ m s}^{-1}}{\lambda} \quad (E = hf = 1.63 \times 10^{-17} \text{ J}) \quad (1)$$

ϕ converted to J: $6.20 \times 1.6 \times 10^{-19}$ OR Photon energy converted to eV: $1.63 \div 1.6 \times 10$

(Subtract to obtain kinetic energy)

Kinetic energy = $(1.5 - 1.56) \times 10^{-17}$ J [OR 95.7/97.4 eV]

[Beware 1.6398 0/3; > 101 eV 0/3]

Demonstration of speed of electrons:

$$1.53 \times 10^{-17} \text{ J} = \frac{1}{2} \times 9.11 \times 10^{-31} \text{ kg} \times v^2 \quad (1)$$

[e.c.f their kinetic energy in joules]

$$v = 5.8 \times 10^6 \text{ m s}^{-1} \quad (1)$$

[If v is not between 5 and 7 must comment to get mark]

[5]

41. Explanation of line spectra:

Specific frequencies or wavelengths (1)

Detail, e.g. absorption/emission (1)

OR within narrow band of wavelengths

2

Explanation how line spectra provide evidence for existence of energy levels in atoms:

Photons (1)

Associated with particular energies (1)

Electron transitions (1)

Discrete levels (to provide line spectra) (1)

3

[5]

42. Explanation:

Photons/quanta

Photon releases / used electron

Energy/frequency of red < energy/frequency of ultra violet

Red insufficient energy to release electrons so foil stays

4

Ultraviolet of greater intensity: foil/leaf collapses quicker/faster

Red light of greater intensity: no change/nothing

2

Observations if zinc plate and electroscope were positively charged:

Foil rises

or Foil stays same/nothing

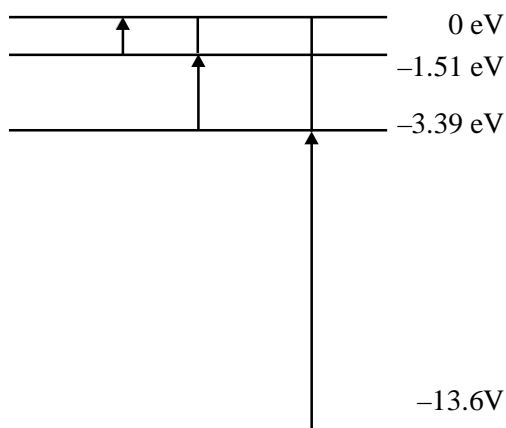
as electrons released it becomes more positive

Released electrons attracted back by positive plate/more difficult to release electrons

2

[8]

43. Energy level diagram:



- 13.6 → 0

- 1.51 → 0 AND - 3.39 → 0 ONLY

2

Why level labelled – 13.6 eV is called ground state:
Correct reference to stability/lowest energy state/level of
the electron/ atom/hydrogen

1

Transition which would result in emission of light of wavelength 660 nm:

Correct use of $c = f\lambda$ or $E = hc/\lambda$ or $f = \frac{3 \times 10^8 \text{ ms}^{-1}}{660 \times 10^{-9} \text{ m}}$

Correct use of eV/J i.e. $\div 1.6 \times 10^{-19}$

$$\Delta E = 1.88$$

Transition = 1.5 \rightarrow 3.39

[May be a downward arrow on diagram]

4

[7]

44. Use of graph to estimate work function of the metal:

$$\phi = (6.63 \times 10^{-34} \text{ J s}) (6.0 \times 10^{14} \text{ Hz}) - (\text{some value})$$

Value in brackets: $(1.6 \times 10^{-19} \times 0.5 \text{ J})$

$$3.2 \times 10^{-19} \text{ J or } 2 \text{ eV}$$

3

Addition to axes of graph A obtained when *intensity* of light increased:

A starts at –0.5

A \rightarrow larger than /max

Addition to axes of graph B obtained when *frequency* of light increased:

B starts at less than – 0.5

B \rightarrow same of lower than /max

4

[7]

45. Ionisation energy:

$$2810 \text{ eV} \quad (4.5 \times 10^{-16} \text{ J}) \quad (1)$$

Calculation of maximum wavelength:

Energy in eV chosen above converted to joules (1)

Use of $\lambda = c/f$ (1)

$$\text{Maximum wavelength} = 4.4 \times 10^{-10} \text{ m} \quad (1)$$

Part of electromagnetic spectrum:

γ -ray / X-ray (1)

5

Calculation of the de Broglie wavelength:

$$\lambda = h/p \quad p \text{ identified as momentum} \quad (1)$$

Either m or v correctly substituted (1)

$$\text{Wavelength} = 1.1 \times 10^{-13} \text{ m} \quad (1)$$

3

[Total 8 marks]

46. Experiments on the photoelectric effect show that

- the kinetic energy of photoelectrons released depends upon the frequency of the incident light and not on its intensity,
- light below a certain threshold frequency cannot release photoelectrons.

How do these conclusions support a particle theory but not a wave theory of light?

Particle theory: $E = hf$ implied packets/photons (1)

One photon releases one electron giving it k.e. (1)

Increase $f \Rightarrow$ greater k.e. electrons (1)

Lower f ; finally $ke = 0$ ie no electrons released Waves (1)

Energy depends on intensity / (amplitude)² (1)

More intense light should give greater k.e.—NOT SEEN (1)

More intense light gives more electrons but no change in maximum kinetic energy (1)

Waves continuous \therefore when enough are absorbed electrons should be released—NOT SEEN (1)

(6 marks)

Calculate the threshold wavelength for a metal surface which has a work function of 6.2 eV.

$$6.2\text{eV} \times 1.6 \times 10^{-19} \text{ C} \quad (1)$$

$$\text{Use of } \lambda = \frac{hc}{E} \quad (1)$$

$$\text{Threshold wavelength} = 2.0 \times 10^{-7} \text{ m} \quad (1)$$

To which part of the electromagnetic spectrum does this wavelength belong?

$$\text{UV ecf their } \lambda \quad (1)$$

(4 marks)
[Total 10 marks]