1. (a) Calculation of energy required by atom **(1)**
Answer [1.8 (eV)] **(1)**

<u>Example of answer:</u>
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 = [1.22×10^{-7} m] **(1)**

<u>Example of answer</u>
$E = hf$ and $c = f\lambda$ $E = hc/\lambda$
$\lambda = (6.63 \times 10^{-34}$ J s $\times 3 \times 10^{8}$ m s^{-2}) ÷ (10.2 eV $\times 1.6\times 10^{-19}$ C)
$\lambda = 1.21 \times 10^{-7}$ 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

(5.89×10^{-19} J / work function) is the energy needed to remove an electron [allow electrons] from the (magnesium) <u>surface</u>/<u>plate</u>

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 eV = 2 × 1.6x 10–19 = 3.2 × 10–19 J
$= 6.63 \times 10^{-34} \times f$
$f = 4.8 \times 10^{14}$ Hz
$3.4\ \text{eV} = 3.4 \times 1.6 \times 10^{-19} = 5.4 \times 10^{-19}$ J
$f = 8.2 \times 10^{14}$ 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 Ω 3

[10]

5. (a) Part of spectrum
Light / Visible / red **(1)** 1

Calculation of work function
Use of $\varphi = hc/\lambda$ **(1)**
3.06×10^{-19} [2 sig fig minimum] **(1)** 2

$(6.63 \times 10^{-34}$ J s$)(3.00 \times 10^{8}$ m s$^{-1})/(6.5 \times 10^{-7}$ m$)$
$= 3.06 \times 10^{-19}$ 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 $V_s = hf/e - \varphi/e$ **(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 $\varphi = hf_0$ **(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.

$(6.63 \times 10^{-34}$ J s$)(3.00 \times 10^{8}$ m s$^{-1})/$
$(656 \times 10^{-9}$ m$)(1.6 \times 10^{-19}$ 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]

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

(d) <u>Photon energy:</u>

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:

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

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

OR

$E = hc/\lambda = 3 \times 10^8 \times 6.63 \times 10^{-34} / 4.2 \times 10^{-7}$

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

(e) <u>Max kinetic energy:</u>

Knowledge that ke_{max} = energy calculated in (d) – ϕ **(1)**

Correct answer for ke_{max} (0.26 eV or 4.2×10^{-20} J)

[allow 0.25–0.26 eV or 4.1 – 4.2×10^{-20} J and allow ecf from (d)] **(1)** 2

Example:

ke_{max} = 2.96 eV – 2.7 eV

= 0.26 eV

(f) (i) <u>Why current reduced:</u>

Many / some electrons will not have enough (kinetic) <u>energy</u> to reach the anode / only electrons with large (kinetic) energy will reach the anode **(1)** 1

(ii) <u>Stopping potential:</u>

eV = (–) ke

V = ke / e = <u>0.26V</u> **(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 > fo / 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:

$v = f\lambda$

3.0×10^{8} m s^{-1} $= f \times 589 \times 10^{-9}$ m

$f = 5.1 \times 10^{14}$ 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 $\lambda = 400 \times 10^{-9}$ 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. $f = 3 \times 10^{8} / 400 \times 10^{-9}$
$= 7.5 \times 10^{14}$ Hz

$E = hf = 5.0 \times 10^{-19}$ J
$E = 3.1$ 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. $P = 1.1 \times 10^{3}$ W m^{-2} $\times \cos 40 \times \pi(29 \times 10^{-3}$ m$)^2$
= 2.2 W

(b) Energy

Use of $E = Pt$ **(1)**

1.8×10^4 J/2.0×10^4J **(1)** 2

e.g. $E = 2.2\text{W} \times (2.5 \times 3600 \text{ s})$

$= 2.0 \times 10^4$ J

[5]

14. (a) Graph

Straight line with positive gradient **(1)**

Starting the straight line on a labelled positive f_o **(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 × 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 $E_k = hf - \varphi$

[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 =

$(-1.8 \text{ keV} - (-69.6 \text{ keV})) \times (10^3 \times 1.6 \times 10^{-19} \text{ J keV}^{-1}) / 6.6 \times 10^{-34}$ J s

$= 1.64 \times 10^{19}$ Hz

$\lambda = 3.00 \times 10^8 \text{ m s}^{-1} / 1.64 \times 10^{19}$Hz

$= 1.8 \times 10^{-11}$ 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 $E_1 + E_{photon} = E_2$]

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

$E_{UV} > E_R$ / f_{uv} ***(1)***
$E_{UV} > \Phi$ / $f_{uv} > f_{TH}$ (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 one 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)**

$= 0.15 \text{ A} \times 20 \times 60\text{s}$

$= 180$ 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 / ½ mv^2 of electrons **(1)** 2

Threshold frequency for sodium

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

[Accept 4.1×10^{14} – 4.7×10^{14}Hz]

Work function

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

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

$W = QV$ **(1)**

$= 1.6 \times 10^{-19}$ C × 0.48 V

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

Calculate efficiency of photon energy conversion

Efficiency = (7.7×10^{-20} J ÷ 4.0×10^{-19} J) [ecf] **(1)**

= 0.19 or 19 % **(1)** 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 × 10^{X} errors] **(1)**
÷ 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 (φ = 2.3 eV / f = 5.6 × 10^{14} Hz / λ = 540 nm hence) a photocurrent at 320 nm but not 640 nm **(1)**
If intensity × 5 then photocurrent × 5 **(1)** 3

Stopping Potential
KE_{max} = 4.00/3.88 –2.30 = 1.7/1.58 [ignore anything with only e] **(1)**
Vs = 1.7/1.58 V **(1)** 2

[9]

24. Ionisation energy

(10.4 eV) × (1.6 × 10^{-19} J eV^{-1}) **(1)**
(–) 1.66 × 10^{-18}(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 eV to (–)5.5 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 × 10^{-19} (J) **(1)**
Equate to ½ $m\upsilon^2$ **(1)**
3.1 × 10^6 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

$f_0 = E/h$ **(1)**

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

= 4.37×10^{14} Hz **(1)** 3

Suitability of potassium

$\lambda = 3 \times 10^8$ m s^{-1} / 4.37×10^{14} Hz [use of lowest frequency] **(1)**
6.86×10^{-7} m [**with** suitable comment] **(1)**

OR

$f = 3 \times 10^8$ m s^{-1} / 4.0×10^{-7} **and** $f = 3 \times 10^8$ m s^{-1} / 7.0×10^{-7} [uses range of λ] **(1)**
$f = 7.5 \times 10^{14}$ Hz to 4.3×10^{14} 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)**

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

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

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

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

$= 2.07 \times 10^{-19}$ 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 = 3.3×10^{17} 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 (mm) / 211 - 203 (mm) **(1)**

Use of 3×10^8 **(1)**

$\upsilon = 1.\ 1(4) \times 10^7\ \text{ms}^{-1}$ [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: [Consequent] Photon energy $\propto f$ **(1)**

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

Feature: Emission of photoelectrons immediate **(1)**

Explanation: [Consequent] One photon releases one electron particle theory **(1)**
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. <u>Planck constant</u>
Realise that h is the gradient
Correct attempt to find gradient [but ignore unit errors here]
$h = (6.3 \text{ to } 6.9) \times 10^{-34}$ J s [No **bald** answers] 3

<u>Work function</u>
Use of hf_0 / use intercept on T axis/use of $\phi = hf - T$ **(1)**
$\phi = (3.4 \text{ to } 3.9) \times 10^{-19}$ J [-1 if –ve] [2.1 to 2.4 eV] **(1)** 2

[5]

33. <u>Energy of photon of light</u>

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

<u>Graph</u>

Points correct (± ½ 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

<u>Value for h</u>

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

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

<u>h = 1/gradient</u> $= 6.67 \times 10^{-34}$ J s **(1)** 3

–

<u>Value of ϕ</u>

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

ϕ from equation, e.g.

so ϕ = frequency intercept × h

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

= 3.03×10^{-19} J **(1)** 2

Explanation

Not enough energy [OR frequency too low]

For 2nd mark, numerical/added detail required,

e.g calculation: $E = 6.63 \times 10^{-34} \times 4.5 \times 10^{14}$ 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

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

$= 1 \times 10^{14}$ W **(1)** 2

Energy level change

$\upsilon = f\lambda\, /\, f = \dfrac{3 \times 10^{8}}{1050 \times 10^{-9}}$ [–1 if omit 10^{-9}] **(1)**

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

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

$= 1.9 \times 10^{-19}$ J **(1)** 3

[6]

35. Calculation:

$E = hc/\lambda$ [seen or implied] **(1)**
physically correct substitutions **(1)**
$\div\ 1.6 \times 10^{-19}$ eV J^{-1} **(1)**
5.78 eV **(1)** 4

Maximum kinetic energy:
3.52 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 <u>between</u> origin and existing graph **(1)**
Similar shape [I levels off up/below existing line] **(1)** 3

[9]

36. Energy of photon of green light:

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

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

$= 3.56 \times 10^{-19}$ J 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 eV OR 2.18×10^{-18} J [– sign, ***X***] **(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 **(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 **(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 **(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 ∴ negative levels]

Wavelength of photon:

ΔE = 1.89 (eV) **(1)**

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

OR

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

$= 6.6 \times 10^{-7}$ (m) [6.5 – 6.7] **(1)**

3

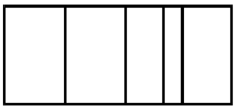
Production of line spectrum of atomic hydrogen in a laboratory:

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:

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

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

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

$f = \dfrac{3\times10^{8}\ m\,s^{-1}}{\lambda}$ ($E = hf = 1.63 \times 10^{-17}$ J) **(1)**

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

1.53×10^{-17} J = ½ × 9.11×10^{-31} kg × υ^2 **(1)**
[e.c.f their kinetic energy in joules]

$\upsilon = 5.8 \times 10^{6}$ m s^{-1} **(1)**
[If υ 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 or 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

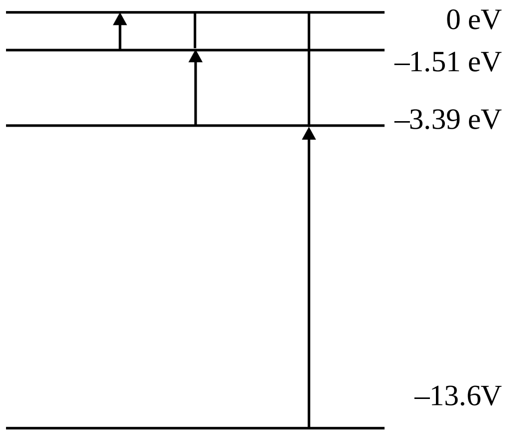
Ultraviolet of greater intensity: foil/leaf collapses quicker/faster
Red light of greater intensity: no change/nothing 2

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:



$-13.6 \rightarrow 0$

$-1.51 \rightarrow 0$ AND $-3.39 \rightarrow 0$ 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 =fλ or E = hc/λ or f =* $\frac{3 \times 10^8 \text{ ms}^{-1}}{660 \times 10^{-9} \text{ m}}$

Correct use of eV/J i.e. ÷ 1.6×10^{-19}

$\Delta E = 1.88$

Transition = 1.5 → 3.39

[May be a downward arrow on diagram] 4

[7]

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

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

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

3.2×10^{-19} J *or* 2 eV 3

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

A starts at –0.5

A → larger than /max

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

B starts at less than – 0.5

B → same of lower than /max 4

[7]

45. Ionisation energy:

2810 eV   (4.5×10^{-16} J)   **(1)**

Calculation of maximum wavelength:

Energy in eV chosen above converted to joules   **(1)**

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

Maximum wavelength = 4.4×10^{-10} m   **(1)**

Part of electromagnetic spectrum:

γ-ray / X-ray   **(1)**   **5**

Calculation of the de Broglie wavelength:

$\lambda = h/p$ p identified as momentum   **(1)**

Either m or υ correctly substituted   **(1)**

Wavelength = 1.1×10^{-13} m   **(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 ⇒ greater k.e. electrons   (1)

Lower f; finally ke = O 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 ∴ 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.

6.2eV × 1.6 × 10^{-19} C (1)

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

Threshold wavelength = **2.0 × 10^{-7} m (1)**

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

UV ecf their λ (1)

(4 marks)
[Total 10 marks]