Quantum physics practice question answers

1. How electron gun creates beam of electrons

   Any four from:
   1. hot filament (1)
   2. thermionic emission / electrons have enough energy to leave (1)
   3. anode and cathode / ± electrodes [identified] (1)
   4. E-field OR force direction OR cause of acceleration (1)
   5. collimation [eg gap in anode identified as causing beam] (1)
   6. need for vacuum (1)  

   Max 4

   Speed of electrons

   (eV =) \( \frac{1}{2} mv^2 \) (1)

   Use of eV [ie substituted or rearranged] (1)

   Answer \( [1.09 \times 10^7 \text{ m s}^{-1}] \) (1)

   \( 1.6 \times 10^{-19} \times 340 \text{ (J)} = \frac{1}{2} \times 9.11 \times 10^{-31} \text{ (kg)} \times v^2 \)

   \( v = 1.09 \times 10^7 \text{ m s}^{-1} \)

   Definition of term electric field

   Region/area/space in which charge experiences force (1)

   Vertical acceleration of electrons due to field

   [Bald answer =0]

   Use of equation \( E = \frac{V}{d} \) (1)

   \( E = V/d = 2500 \text{ V} \div 0.09 \text{ m} = 28 \text{ (kV m}^{-1}) \)

   Rearranged equation \( E = F/q \) or substitution into it (1)

   \( F = Eq = 28000 \times 1.6 \times 10^{-19} \text{ (N)} \times 4.4 \times 10^{-15} \text{ (N)} \)

   Equation \( F = ma \) seen or substitution into it (1)

   \( A = F/m = \frac{4.4 \times 10^{-15} \text{ (N)}}{9.11 \times 10^{-31} \text{ (hg)}} \)

   \( = 4.9 \times 10^{15} \text{ (m s}^{-2}) \) (1)

   [at least 2 sig fig needed] [No u.e.] [Reverse calculation max 3]
2. **How ions are accelerated**

Electric field exists between +, – electrodes (1)

⇒ force on ions / force → acceleration (1)

**Speed of xenon atom**

\[ eV = \frac{1}{2} m \nu^2 / eV = E_k \] (1)

⇒ \( \nu = \sqrt{2eV / m} \) (1)

\[ \nu = \sqrt{2 \times 1.6 \times 10^{-19} \times (1060 + 225)} \] (1)

\[ = 4.3 \times 10^4 \text{ m s}^{-1} \] [No u.e.] (1)

**Thrust on space probe**

Force = rate of change of momentum (1)

\[ = 2.1 \times 10^{-6} \times 43 \ 000 \text{ N} \] (1)

\[ = 0.090 \text{ N} \] (1)

[Using 4 \times 10^4 \text{ m s}^{-1} gives \( F = 0.084 \text{ N} \)]

**Reason for reduced thrust**

Xenon ions attracted back OR similar (1)

**Why ion drives maybe preferable**

Any two from:

- less fuel required in total
- for example, 66 kg for a year
- thrust provided for longer/fuel lasts longer/accelerates for longer
- lower payload for initial launch/ion drive lighter (1) (1)

3. **\( E = hf \)/photon energy is proportional to frequency** (1)

Photon energy must be greater than work function/minimum required to liberate electron (1)

\[ hf = \phi + \frac{1}{2} m \nu^2 \] max \( E_k = \frac{1}{2} m \nu^2 \) max = \( hf - \phi \)

\[ E_k = (6.63 \times 10^{-34} \text{ J s} \times 1.70 \times 10^{18} \text{ Hz}) - 9.61 \times 10^{-16} \text{ J} \] (1)

\[ = 1.127 \times 10^{-15} \text{ J} - 9.61 \times 10^{-16} \text{ J} \] (1)

\[ = 1.66 \times 10^{-16} \text{ J} \] (1)
4. 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. 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 \( E = \frac{hc}{\lambda} \) (1)
   Work function:
   \( f = \frac{c}{\lambda} = 3.0 \times 10^8 / 700 \times 10^{-9} \text{ m} \) (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) 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) 2
   Suggestion:
   Cosmic rays travel more slowly than light (1) 1

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6. **Energy of photon of light**

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

**Graph**

- Points correct (± ½ square) (2)
- Single straight line of best fit (NOT giving intercept below \(4.5 \times 10^{14}\)) (1)
- Line drawn as far as \(f\) axis (1)
- Value for \(h\)
  - 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)
  - \(h = 1/\text{gradient} = 6.67 \times 10^{-34} \text{ J s}\) (1)
- Value of \(\phi\)
  - Reading co-ordinates of a fixed point on graph (e.g. 0, \(4.55 \times 10^{14}\)) (1)
  - \(\phi\) from equation, e.g.
  - so \(\phi = \text{frequency intercept} \times h\)
  - = e.g. \(4.55 \times 10^{14} \times 6.67 \times 10^{-34}\)
  - = \(3.03 \times 10^{-19} \text{ J}\) (1)

**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]

7. **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)
- **Lowest frequency of radiation**
  - \(f_0 = E/h\) (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)
- **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)

[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 $E = h\nu$ AND minimum wavelength (1)

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

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

**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)

3

8. **Polymer**

Long chain (1)

molecules / of atoms / monomers / units (1)

**Energy of photon of ultraviolet light**

$f = c/2.5 \times 10^{-7}$ (1)

= $1.2 \times 10^{15}$

Use of $E = hf$ (1)

$6.63 \times 10^{-34} \times 1.2 \times 10^{15} = 8.0 \times 10^{-19} \text{ J}$ (1)

**Process of ultraviolet absorption**

Energy level diagram with three or more lines used (1)

Words: electron and photon in context (1)

Arrow up/electron excitation when absorbing ultraviolet light (1)

Arrow down to intermediate level or from intermediate level emits blue (1)

**Energy level diagram**

Energy level *bands* (1)

**Brightness of posters**

(Invisible) ultraviolet absorbed (1)

(Re–)emitted as (visible blue) light (1)
9. **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 \( 8 \times 10^{-20} \) J

\[
W = QV \quad (1)
\]

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

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

Calculate efficiency of photon energy conversion

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

\[
= 0.19 \text{ or } 19 \% \quad (1) 
\]

10. **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

\[
Q = It \quad (1)
\]

\[
= 0.15 \text{ A} \times 20 \times 60 \text{ s}
\]

\[
= 180 \text{ C} \quad (1) 
\]

11. **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)

Completion of graph
Points plotted correctly [−1 for each incorrect point] (1) (1)
Line of best fit added across graph grid (1) 3

What $eV$ 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: $4.3 \times 10^{14}$ Hz (1) 1
[Accept $4.1 \times 10^{14} - 4.7 \times 10^{14}$Hz]

Work function
$f = hf_0 = 6.63 \times 10^{-34} \text{ J s} \times 4.3 \times 10^{14} \text{ Hz (1)}$
$= 2.9 \times 10^{-19} \text{ J [Allow ecf] (1)}$ 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. 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