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 =) ½ mv^2 **(1)**

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

Answer [1.09×10^7 m s^{-1}] **(1)**

$1.6 \times 10^{-19} \times 340$ (J) = ½ $\times 9.11 \times 10^{-31}$ (kg) $\times v^2$

v =1.09×10^7 m s^{-1} 3

Definition of term electric field

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

ertical acceleration of electrons due to field

[Bald answer =0]

Use of equation $E = V/d$ **(1)**

$E = V/d$ = 2500 V ÷ 0.09 m = 28 (kV m^{-1})

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

$F = Eq$ = 28 000 $\times 1.6 \times 10^{-19}$ (N) 4.4×10^{-15} (N)

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

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

= 4.9×10^{15} (m s^{-2}) **(1)** 4

[at least 2 sig fig needed] [No u.e.] [Reverse calculation max 3]

[12]

2. How ions are accelerated

Electric field exists between +, – electrodes **(1)**

$\Rightarrow$ force on ions / force $\rightarrow$ acceleration **(1)** 2

Speed of xenon atom

$eV = \frac{1}{2} mv^2 / eV = E_k$ **(1)**

$\Rightarrow v = \sqrt{2eV/m}$ **(1)**

$= \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times (1060 + 225)}{2.2 \times 10^{-25}}} ms^{-1}$ **(1)**

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

Thrust on space probe

Force = rate of change of momentum **(1)**

$= 2.1 \times 10^{-6} \times 43\,000$ N **(1)**

$= 0.090$ N **(1)** 3

[Using 4×10^4 m s^{-1} gives $F = 0.084$ N]

Reason for reduced thrust

Xenon ions attracted back OR similar **(1)** 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)** 2

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3. $E = hf$ /photon energy is proportional to frequency **(1)**
Photon energy must be greater than work function/minimum required to liberate electron **(1)** 2

$hf = \phi + \frac{1}{2} mv^2$ max $E_k = \frac{1}{2} mv^2$ max $= hf - \phi$

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

$= 1.127 \times 10^{-15}$ J $- 9.61 \times 10^{-16}$ J **(1)**

$= 1.66 \times 10^{-16}$ J **(1)** 3

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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

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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 $E = hc/\lambda$ **(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

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6. Energy of photon of light

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

Graph

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

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/gradient = 6.67×10^{-34} J s **(1)** 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 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]

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)** 3

Lowest frequency of radiation

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

= 2.90×10^{-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 $\times$ 3×10^{8} m $s^{-1}/(400 \times 10^{-9}$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 $- 2.90 \times 10^{-19}$ 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]

8. Polymer

Long chain **(1)**

molecules / of atoms / monomers / units **(1)** 2

Energy of photon of ultraviolet light

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

$= 1.2 \times 10^{15}$

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

$6.63 \times 10^{-34} \times 1.2 \times 10^{15} = 8.0 \times 10^{-19}$ J **(1)** 3

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)** 4

Energy level diagram

Energy level *bands* **(1)** 1

Brightness of posters

(Invisible) ultraviolet absorbed **(1)**

(Re–)emitted as (visible blue) light **(1)** 2

[12]

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 8×10^{-20} J

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

$= 1.6 \times 10^{-19}$ C $\times$ 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 $\div$ 4.0×10^{-19} J) [ecf] **(1)**

= 0.19 or 19 % **(1)** 2

[6]

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

$Q = It$ **(1)**

= 0.15 A $\times$ 20 $\times$ 60s

= 180 C **(1)** 2

[10]

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)** 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 $4.1 \times 10^{14} – 4.7 \times 10^{14}$Hz]

Work function

$f = hf_0 = 6.63 \times 10^{-34}$ J s $\times$ 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]

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 $E_1 + E_{photon} = E_2$]

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