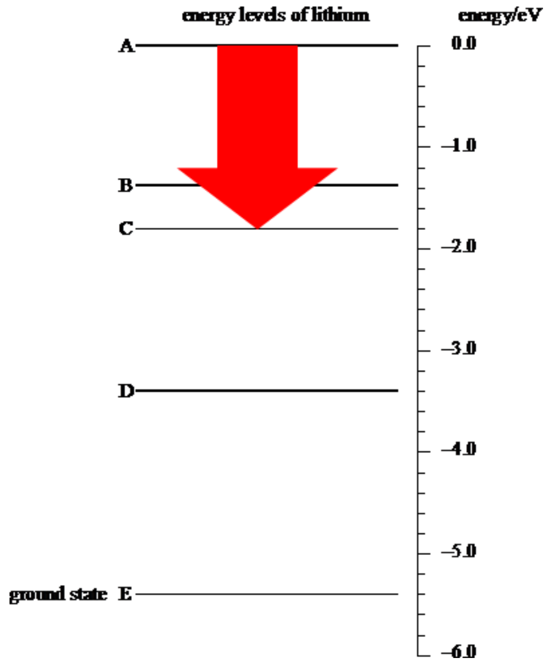
AS Revision questions – Quantum Phenomena and Electricity



Q1. (a) State what happens in an atom when line spectra are produced.

Electrons move from one energy level (or orbit) to a higher one (1 mark) when they absorb energy from an incoming photon or interact with electrons of high kinetic energy. A photon (of electromagnetic energy) of a fixed frequency/wavelength (1 mark) is then given out when the electron de-excites, moves to a lower energy orbital.

Key thing here is to say that the photons emitted are of discrete values.

(2 maximum)

(b) The diagram on the right represents some energy levels of the lithium atom.

(i) Calculate the ionisation energy, in J, of the lithium atom.

Ionisation occurs when the electron is freed from the atom – jumps from its ground state to freedom! It therefore needs an input of

5.4eV **(1 mark)**

1eV = 1.6×10^{-19}J

Input needed is therefore $5.4 \times 1.6 \times 10^{-19}$J

= 8.6×10^{-19}J **(1 mark)**

(ii) An excited lithium atom may emit radiation of wavelength 6.1×10^{-7}m.

Show that the frequency of this radiation is approximately 5.0×10^{14}Hz.

$c = f\lambda$ therefore $f = c/\lambda = 3.0 \times 10^{8}/6.1 \times 10^{-7}$ **(1 mark)**

= 4.9×10^{14} Hz **(1 mark)**

(iii) Calculate the energy, in J, of each photon of this radiation.

$E = hf = 6.63 \times 10^{-34} \times 4.9 \times 10^{14}$ **(1 mark)**

$= 3.2 \times 10^{-19}$J **(1 mark)**

(iv) Draw, on the diagram, an arrow between two energy levels which shows the transition responsible for the emission of a photon of energy 1.8 eV. (see diagram) Emission – therefore falls to lower energy state…

(v) Two transitions emit radiation of similar frequencies. One of them is the transition between B and D. What is the other? D to E

(vi) A transition between which two levels would give radiation of the longest possible wavelength? B to C (Longest wavelength is shortest frequency – or lowest energy!)

(9)

(Total 11 marks)

2. Use data from the Data Sheet in this question.

(a) (i) Define the *electron volt.*

An electron volt is the energy gained **(1 mark)** by an electron as it moves through a potential difference of 1 V **(1 mark)**

(ii) Show that the speed of an electron accelerated through a potential difference of 6.0kV is 4.6×10^7 m s^{-1}.

Energy gained by electron being accelerated is 6.0 keV = $1.6 \times 10^{-19} \times 6.0 \times 10^3$ J

$\frac{1}{2}mv^2$ = energy in joules = eV **(1 mark)**

$v^2 = \dfrac{2 \times 1.6 \times 10^{-19} \times 6000}{9.1 \times 10^{-31}}$ **(1 mark)** so v = 4.6×10^7 ms^{-1}

(4)

(b) State what is meant by the duality of the nature of electrons.

Electron behavior can sometimes be best described as that of a waves and at other times as that of a particle **(1 mark)**

(1)
(Total 5 marks)

3. (a) Electrons and electromagnetic waves exhibit properties of both waves and particles. Suggest evidence which indicates that

(i) electrons have wave properties, Electron diffraction

(ii) electromagnetic radiation has particle properties, The photoelectric effect.

(iii) electromagnetic radiation has wave properties. Interference or diffraction or refraction

(3)

(b) Calculate the de Broglie wavelength of an electron travelling at 5.0×10^6 m s^{-1}. You should ignore relativistic effects.

(momentum of electron =) p = *mv* = $9.11 \times 10^{-31} \times 5.0 \times 10^6$

= 4.56×10^{-24} kg ms^{-1} **(1 mark)**

$\lambda_{dB} = h/p$ = $6.6(3) \times 10^{-34} / 4.56 \times 10^{-24}$ **(1 mark)**

= 1.5×10^{-10} m **(1 mark)** (1.45×10^{-10} m)

(3)
(Total 6 marks)

4. $E = 0$ ———— ionisation level

$E_2 = -2.42 \times 10^{-19}$ J ———— level 2

$E_1 = -5.48 \times 10^{-19}$ J ———— level 1

$E_0 = -2.18 \times 10^{-18}$ J ———— ground state

The diagram represents some of the energy levels of an isolated atom. An electron with a kinetic energy of 2.0×10^{-18} J makes an inelastic collision with an atom in the ground state. Inelastic means that kinetic energy is not conserved.

(a) Calculate the speed of the electron just before the collision.

You cannot use the deBroglie equation here… it is not a wave/particle thing… just a particle with KE! You only use the dB equation with electrons when you look for their wavelength!

Kinetic energy $E = \frac{1}{2}mv^2$

$$v\left(=\sqrt{\frac{2E}{m}}\right) = \sqrt{\frac{2\times 2.0\times 10^{-18}}{9.1\times 10^{-31}}} \quad \textbf{(1 mark)}$$

$= 2.1\times 10^{6}$ m s^{-1} **(1 mark)**

(2)

(b) (i) Show that the electron can excite the atom to level 2.

Energy difference between E_2 and E_0 = 1.94×10^{-18} J **(1 mark)** which is less than the electron kinetic energy **(1 mark).** It could therefore collide (interact) with an electron in the ground state of the atom and transfer the required excitation energy to it, enabling it to jump to the higher energy level.

(ii) Calculate the wavelength of the radiation that will result when an atom in level 2 falls to level 1 and state the region of the spectrum to which this radiation belongs.

$\Delta E = (E_2 - E_1) = 3.06 \times 10^{-19}$ **(1 mark)**

$\Delta E = hf = hc/\lambda$

$\lambda = \dfrac{6.63\times 10^{-34}\times 3.0\times 10^{8}}{3.06\times 10^{-19}}$ **(1 mark)** = 6.5×10^{-7} m **(1 mark)** = 650nm

infrared or visible red region **(1 mark)**

(6)

(c) Calculate the minimum potential difference through which an electron must be accelerated from rest in order to be able to ionise an atom in its ground state with the above energy level structure.

For ionization to occur it must supply 21.8×10^{-19} J **(1 mark)**

= $(21.8 \times 10^{-19})/(1.6 \times 10^{-19})$ = 13.6 eV so the electron would have to be accelerated through a potential difference of 13.6V **(1 mark)**

(2)

(Total 10 marks)

5. When a clean metal surface in a vacuum is irradiated with ultraviolet radiation, electrons are emitted from the metal. The following equation relates the frequency of the incident radiation to the kinetic energy of the emitted electrons.

$$hf = \phi + E_K$$

(a) Explain what each of the following terms represents in the above equation. Note that it wants an explanation – not just the name!

(i) hf is the **energy** of the incoming **photon** of electromagnetic radiation

(ii) ϕ is the **work function** of the metal – the **minimum energy** required to release an electron from the surface.

(iii) E_K is the **maximum kinetic energy** of the ejected photoelectron.

(3)

(b) (i) State what would happen to the number of photoelectrons ejected per second if the ultraviolet source were replaced by a source of red light of the same intensity but of frequency less than ϕ / h (*threshold frequency*).

Here it is 'state' not 'explain why what you state happens'!

No photoelectrons would be emitted **(1 mark)**

(ii) What would the wave theory of light predict about the effect of using the red light source instead of an ultraviolet source?

The wave theory predicts photoelectrons would be emitted with red light (or at any frequency for that matter!) (1 mark)… with waves it is the intensity that will count and the time that the energy is shone onto the surface… bright enough for long enough and electrons should be emitted…. As that isn't the case we need the quantum explanation!

(iii) Use the photon theory of light (also called the quantum theory) to explain the effect of using the red light source instead of an ultraviolet source.

Only one photon is absorbed is by one electron **(1 mark)** and it transfers all of its energy to that electron. The electron will be emitted from the metal surface if photon energy [or *hf*] is greater than ϕ (or not if < ϕ) **(1 mark).** Red light photon energy < ϕ **(1 mark)** so red light would never release photoelectrons no matter what intensity it was.

(3)

(c) Monochromatic radiation of wavelength 3.00×10^{-7} m ejects photoelectrons at kinetic energies of up to 3.26×10^{-19} J when incident on a clean metal surface. Calculate the work function of the metal, in J.

Energy of photon = E = hf = hc/λ **(1 mark)**

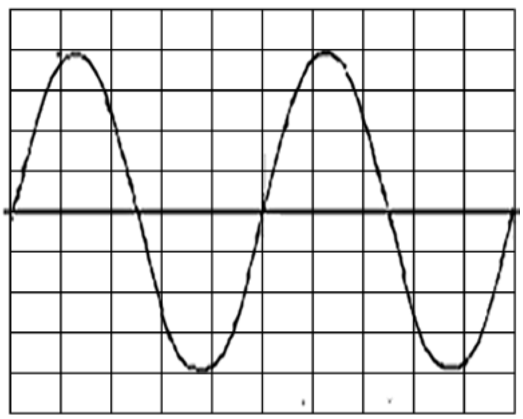
$$hf/\lambda = \phi + KE_{max}$$

$$\phi = \frac{6.63\times10^{-34}\times3.00\times10^{8}}{3.00\times10^{-7}} - 3.26\times10^{-19} \text{ (1 mark)}$$

$$\phi = 3.4\times10^{-19}\text{ J (1 mark)}$$

(2 max)
(Total 8 marks)

6. A cathode ray oscilloscope is used to study the waveform of a sinusoidal alternating voltage of frequency 100 Hz and peak voltage 2.0 V. If the time base is set to 2.0 ms div^{-1} and the voltage sensitivity is 0.5 V div^{-1}, draw, in the grid below, the trace you would expect to see on the screen.



T = 1/f = 1/100 = 0.01 s = 10 ms **(1 mark)**

= 5 divisions on graph **(1 mark)**

Amplitude of four squares **(1 mark)**

Sinusoidal wave shape (line gradient must be changing and distance between crests and troughs symmetric) **(1 mark)**

Two cycles drawn – trace fills the screen **(1 mark)**

(Total 4 marks MAX)

7. In each of the following circuits the battery has negligible internal resistance and the bulbs are identical.

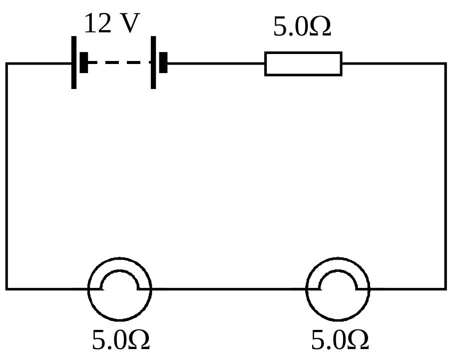


figure 1

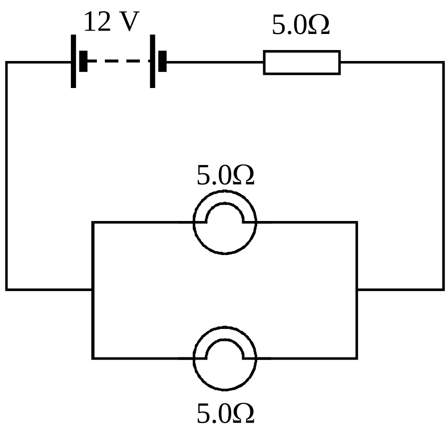


figure 2

(a) For the circuit shown in figure 1 calculate

(i) the current flowing through each bulb,

The bulbs and resistor are in series so the same current will flow through each.

Total p.d. = 12V   total resistance = 15Ω

V = IR so I = V/R = 12/15 = 0.80A **(1 mark)**

(ii) the power dissipated in each bulb.

$P = I^2R = (0.80)^2 \times 5 = 3.2W$ **(1 mark)**

(2)

(b) In the circuit shown in figure 2 calculate the current flowing through each bulb.

Parallel arrangement of resistors = 2.5Ω

Total resistance = 5 + 2.5 = 7.5Ω **(1 mark)**   Total p.d. = 12V

V = IR so I_{total} = V/R = 12/7.5 = 1.60 (A) **(1 mark)**

Current through each bulb = 1.6/2 = 0.80A **(1 mark)**

(3)

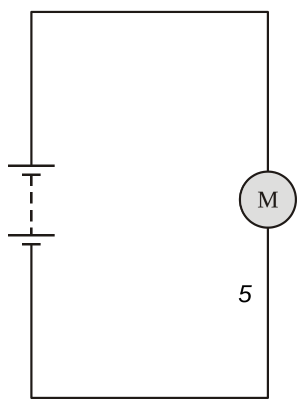
(c) Explain how the brightness of the bulbs in figure 1 compares with the brightness of the bulbs in figure 2.

The bulbs have the same brightness **(1 mark)** because same current **(1 mark)** is flowing through them.

(2)

(Total 7 marks)

8. The battery of an electric car consists of 30 cells, connected in series, to supply current to the motor, as shown in the figure below.



(a) Assume that the internal resistance of each cell is negligible and that the pd across each cell is 6.0 V.

(i) State the pd across the motor. 30 x 6.0 = 180V **(1 mark)**

(ii) The battery provides 7.2 kW to the motor when the car is running. Calculate the current in the circuit.

P = IV so I = P/V **(1 mark)** = 7200 /180 = 40A **(1 mark)**

(iii) The battery can deliver this current for two hours. Calculate how much charge the battery delivers in this time.

(Use Q = It or reason it out) 40 A = 40 C/s so in two hours you get

$40 \times 2 \times 60^2$ **(1 mark)** = 2.88×10^5C = 2.9×10^5C **(1 mark)**

(iv) Calculate the energy delivered to the motor in the two hour period.

W = QV **(1 mark)** or Pt or VIt

= $2.9 \times 10^5 \times 180 = 52 \times 10^6$J **(1 mark)**

(7)

(b) In practice, each cell has a small but finite internal resistance. Explain, without calculation, the effect of this resistance on

- the current in the circuit, and
- the time for which the battery can deliver the current in part (a)(ii).

You may assume that the motor behaves as a constant resistance.

The pd across the external resistance would be lower **(1 mark)** because the terminal p.d. will be less than the EMF(or because of resistance in each cell the total resistance in the circuit would be greater) therefore the current in circuit is lower than would be expected **(1 mark)**

The lower current means that the charge is delivered at a lower rate therefore the time for which the current can flow is increased **(1 mark)**

(3)
(Total 10 marks)

9. (a) A steady current of 0.25 A passes through a torch bulb for 6 minutes. Calculate the charge which flows through the bulb in this time.

ΔQ = It **(1 mark)** = $0.25 \times 6 \times 60 = 90$ C **(1 mark)**

(2)

(b) The torch bulb is now connected to a battery of negligible internal resistance. The battery supplies a steady current of 0.25 A for 20 hours. In this time the energy transferred in the bulb is 9.0×10^4 J. Calculate

(i) the potential difference across the bulb,

V = W/Q **(1 mark)** [or $E = VIt$] = $9.0 \times 10^4 / (0.25 \times 20 \times 60^2) = 5.0$V **(1 mark)**

(ii) the power of the bulb.

$P = W/t = 9.0 \times 10^4 / (20 \times 60^2) = 1.25W$ **(1)**

(3)
(Total 5 marks)

10. A student investigates the variation of electric potential with distance along a strip of conducting paper of length *l* and of uniform thickness. The strip tapers uniformly from a width 4*w* at the broad end to 2*w* at the narrow end, as shown in **Figure 1**. A constant pd is applied across the two ends of the strip, with the narrow end at positive potential, *V**l*, and the broad end at zero potential. The student aims to produce a graph of pd against distance *x*, measured from the broad end of the strip.

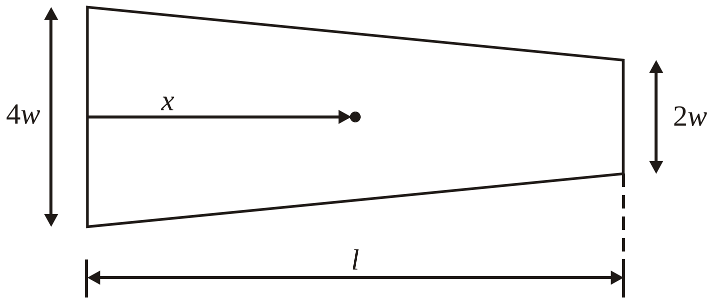


Figure 1

(a) Draw a labelled circuit diagram which would be suitable for the investigation.

Circuit diagram to show:

- wide end of conducting strip to – of battery, narrow end to + **(1 mark)**
- voltmeter between wide end and probe **(1 mark)**

(2)

(b) The student obtained some **preliminary measurements** which are shown below.

pd, *V*/V	0	2.1	4.5	7.2
Distance, *x*/m	0	0.100	0.200	0.300

By reference to the physical principles involved, explain why the increase of *V* with *x* is greater than a linear increase.

Narrow resistor has a smaller cross sectional area **(1 mark)** and therefore a smaller resistance. Resistance increases as *x* increases **(1 mark)** because strip becomes narrower (as *x* increases) **(1 mark)**. Current is constant throughout strip **(1 mark)** voltage = current × resistance , so the voltage gradient increases as *x* increases **(1 mark)**

(4)

(Total 6 marks)