QUANTUM PHYSICS II

Challenging **MCQ** questions by The Physics Café

Compiled and selected by The Physics Cafe

1 A beam of 40 eV electrons traveling in the positive x-direction passes through a slit that is parallel to the y-axis and 5.0 μm wide. The diffraction pattern is recorded on a screen 2.5 m from the slit.

(i) State Heisenberg's Uncertainty Principle.

-- [1]

(ii) What is the speed of the electrons?

[1]

(iii) In single-slit diffraction, the first minima of the central diffraction pattern occurs at $\sin\theta = \frac{\lambda}{D}$, where D is the width of the slit. Based on the angle of diffraction of the first minima of the central diffraction pattern, calculate the maximum y-component of the momentum of an electron just after it has passed through the slit.

[2]

(iii) Hence, estimate the minimum uncertainty in the y-coordinate of an electron just after it has passed through the slit.

[2]

Ans **i** It is not possible to measure position or momentum (or energy and time interval during which an object is in that state) of an object precisely at the same time.
Note: Definition for Heisenberg position-momentum is if measurement of position is made with precision Δx and a simultaneous measurement of momentum in the x-direction is made with precision Δp, then the product of the two uncertainties can never be smaller than $\frac{h}{4\pi}$

ii By conservation of energy,
Loss in electric potential energy = Gain in Kinetic energy of the electron,

$$40 \text{ eV} = \tfrac{1}{2} mv^2$$

horizontal speed of the electrons, v = $\sqrt{(2 \times 40 \times 1.6\times10^{-19} / 9.11\times10^{-31})}$
= *3.748 x10*^{6}
= *3.75x10*^{6} ms^{-1}

iii Using De Broglie's relationship: $\lambda = h/p$
= $6.63\times10^{-34}/9.11\times10^{-31}\times3.748\times10^6$
= 0.1942 nm

$$\sin\theta = \frac{\lambda}{D} = 3.88\times10^{-5}$$

Now $\tan\theta = \frac{p_y}{p_x} \Rightarrow p_y = \left(3.4148\times10^{-24}\right)\left(3.88\times10^{-5}\right) = 1.32\times10^{-28}\, kgms^{-1}$

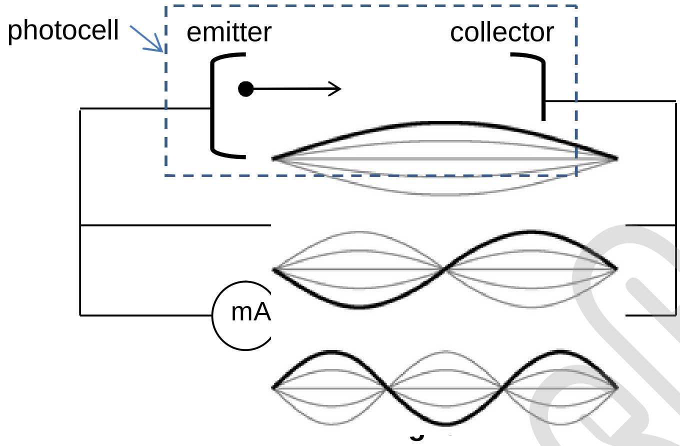
Therefore maximum y-component of the momentum of an electron = $1.32\times10^{-28}\, kgms^{-1}$

iv $\Delta p_y \approx 1.32\times10^{-28}\, kgms^{-1}$

$$\Delta y\ \Delta p_y \geq \frac{\hbar}{2} \Rightarrow \Delta y \geq \frac{\hbar}{2\Delta p_y} \approx 3.98\times10^{-7}\, m$$

2 **(a)** A student connects a photocell to a battery and finds that when the photocell is exposed to monochromatic radiation, a current flows only when the potential difference across the photocell is less than 1.6 V. The work function of the photocell is 2.0 x 10^{-19} J.

(i) Draw the symbol of the battery in Fig. 5.1, paying particular attention to the polarities of the battery. [1]



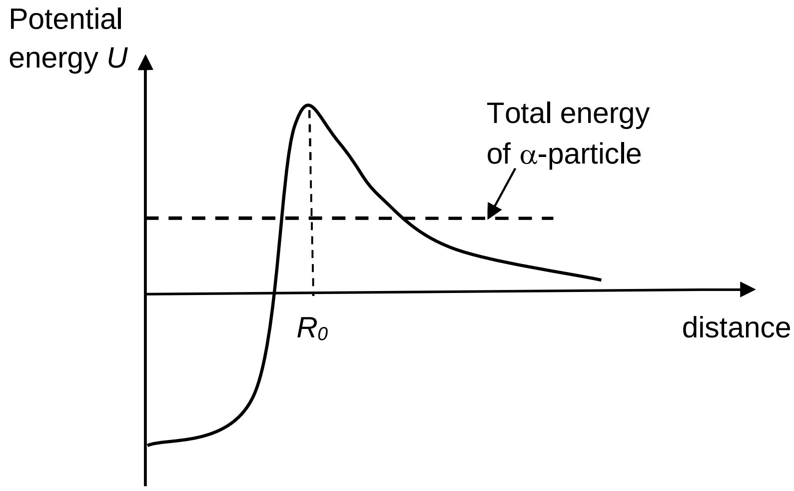
(ii) Determine the maximum energy of the emitted electrons.

maximum energy = ………………… J [2]

(iii) Determine the wavelength of the radiation used.

wavelength = ……………….. m [2]

(b) Fig. 5.2 shows how the potential energy of an α-particle inside a nucleus varies with distance and the dotted line represents the total energy of an α-particle. R_0 is the radius of the nucleus. Classically, it is impossible for an α-particle to escape. However, an interesting quantum mechanical effect occurs in alpha decay.



beam of

Explain how alpha decay occurs.

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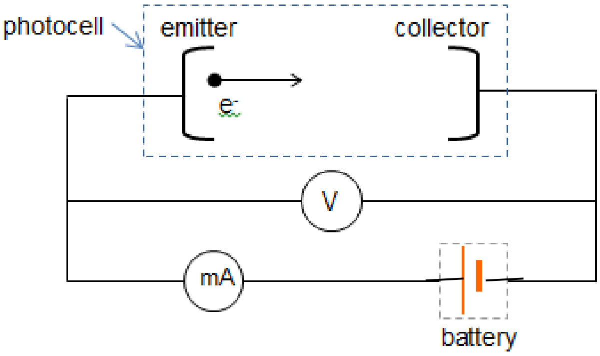
…………………………………………………………………………………………………… [3]

(c) A neutron is confined within an atomic nucleus of size 1.0×10^{-14} m. Taking the uncertainty in the position of the neutron to be equal to the size of the nucleus, calculate the minimum uncertainty with which the velocity of the neutron can be simultaneously measured.

uncertainty in velocity = ………………… $m\ s^{-1}$ [2]

Ans **(a)** **(i)**



[1]

(ii) $KE_{max} = eV_s = (1.6 \times 10^{-19})(1.6)$ [1]
$= \mathbf{2.56 \times 10^{-19}\ J}$ [1]

(iii) From $hf = \phi + KE_{max}$
$hf = 2.0 \times 10^{-19} + 2.56 \times 10^{-19}$ [1]
$\Rightarrow f = 6.88 \times 10^{14}$ Hz
$\Rightarrow \lambda = \mathbf{4.36 \times 10^{-7}\ m}$ (2 sf) [1]

(b) Even though the total energy of the α-particle is less than the potential energy barrier, the α-particle can behave as a wave and be associated with a wave function. [1]

The square of the amplitude of the wave function represents the probability of locating the particle at that point. Since the barrier is not wide enough and high enough, the wave function of the α-particle is non-zero outside the potential energy barrier. [1]

When this happens, the α-particle is said to have quantum-tunnelled through the barrier and appears outside the barrier. [1]

(c) Given $\Delta x = 1.0 \times 10^{-14}$ m.

$\Delta p = \dfrac{h}{4\pi\,\Delta x}$

$\geq \dfrac{6.63\times10^{-34}}{4\pi\left(1.0\times10^{-14}\right)}$

$\geq 5.276\times10^{-21}$ kg m s^{-1} [1]

Min $\Delta v = \dfrac{\Delta p}{m} = \dfrac{5.276\times10^{-21}}{1.67\times10^{-27}}$ {accept $m = 1.66 \times 10^{-27}$}

$= 3.16 \times 10^{6}$ m s^{-1} [1]

3 The probe tip of a Scanning Tunnelling Microscope (STM) is positioned a distance *d* away from its investigated metal surface.

(a) Sketch 2 graphs to show how the transmission coefficient and reflection coefficient varies with *d*. Label the graph T and R respectively. [2]

(b) Given that $k = 1.25 \times 10^{10}$ m^{-1}, at $d = 1.84 \times 10^{-10}$ m, the transmission coefficient is T_1. When *d* is doubled, the transmission coefficient is T_2. Determine the ratio of T_2 / T_1.

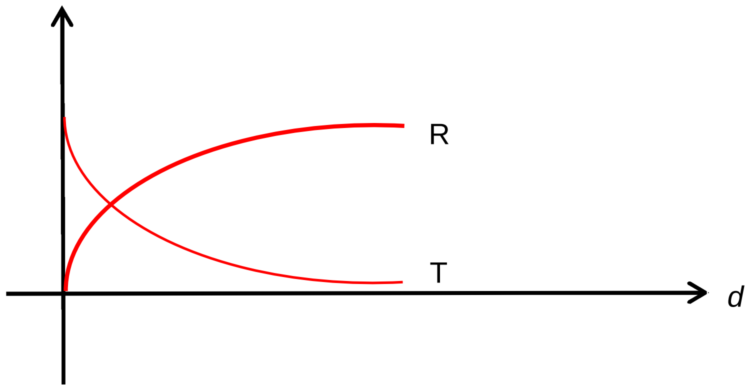
T_2 / T_1 = ……………………….. [2]

(c) State the significance of your answer in **(b)**.

………………………………………………………………………………………………

……………………………………………………………………………………………… [1]

Ans (a)



(b) $\frac{T_2}{T_1} = \frac{e^{-2kd_2}}{e^{-2kd_1}}$

$\frac{T_2}{T_1} = e^{2k(d_1-d_2)}$

$\ln \frac{T_2}{T_1} = 2(1.25\text{x}10^{10})(-1.84\text{x}10^{-10})$

$\frac{T_2}{T_1}$ = 0.0101

(c) A small change in *d* leads to a big change in transmission coefficient.