Department of Physics
University of California San Diego

Modern Physics (2D)
Prof. V. Sharma
Quiz # 6

Some Relevant Formulae, Constants and Identities

$p = \gamma m u$; $E = KE + mc^2 = \gamma mc^2$

$E^2 = (pc)^2 + (mc^2)^2$

Bragg's Law: $n\lambda = 2d\sin\theta$

$\lambda = \frac{h}{p}$; $\Delta x . \Delta p \geq \frac{h}{4\pi}$; $\Delta E . \Delta t \geq \frac{h}{4\pi}$

Coulomb's constant $k = 8.988 \times 10^9 N.m^2/C^2$

Planck's constant $h = 6.626 \times 10^{-34} J.s = 4.136 \times 10^{-15} eV.s$

$1 \text{ eV} = 1.60 \times 10^{-19}$ J

Electron mass $= 9.1 \times 10^{-31}$ Kg $= 0.511 \text{ MeV}/c^2$

Proton mass $= 938.3 \text{ MeV}/c^2$, Neutron mass $= 939.6 \text{ MeV}/c^2$

Speed of light in vaccum $c = 2.998 \times 10^8$ m/s

Electron charge $= 1.602 \times 10^{-19}$ C

Energy in Hydrogen atom $E_n = \frac{-ke^2}{2a_0}\left(\frac{1}{n^2}\right) = \left(\frac{-13.6 \text{ eV}}{n^2}\right)$

Pl. write you answer in the Blue Book in indelible ink. Make sure your code number is prominently displayed on each page. Ask the proctor if you do not understand the question.

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Problem 1: Across The Universe [12 pts]

An air rifle is used to shoot 1.0g particles at 100m/s through a hole of diameter 2.0mm. How far from the rifle must an observer be to see the beam of particles spread by 1.0cm because of the uncertainty principle? Compare the answer with the size of the universe (approx. 2×10^{26} m**).**

Hint: First draw a schematic diagram of the process.

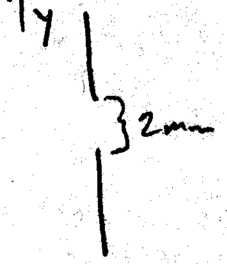
Problem 2: A Nuclear Cinderella Act [8 pts]

It is possible for some subatomic particle to "violate" conservation of energy by creating and later reabsorbing another particle. For example, proton can emit a (virtual) positively charged pion π^+ according to $p \rightarrow n + \pi^+$ where n represents a neutron. The π^+ has a mass of 140 MeV/c^2. The re-absorption must occur within a time Δt consistent with the uncertainty principle. In such scenario (a) by how much energy ΔE is the energy conservation violated? (ignore kinetic energies of particles) (b) For how long Δt can the virtual π^+ meson exist? (c) Assuming the particle is moving at speed of light, how far from the nucleus could it get in time Δt ? How does this distance compare with the range of the Strong Nuclear force of approx. 1fm.

Welcome...

to Phys 2D Quiz 6 Solutions!

1) Since the particles pass through a hole of width 2 mm, ~~say~~ they have $\Delta y = 1\,mm$ (or you can take $\Delta y = 2\,mm$ too).

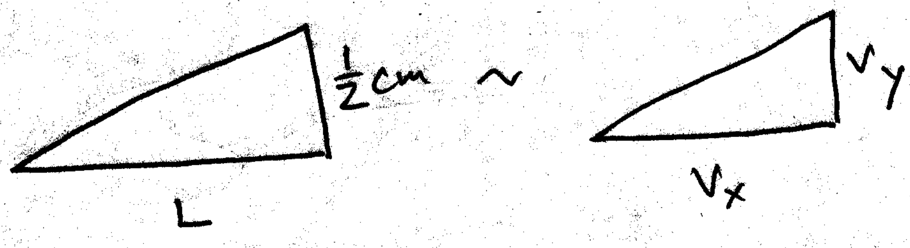


$$\therefore \quad \Delta y \, \Delta p_y = \frac{\hbar}{2} \Rightarrow \Delta v_y = \frac{\hbar}{2m\,\Delta y}$$

Since we can take $v_y \approx \langle v_y \rangle + \Delta v_y = \Delta v_y$,

$$v_y = \frac{\hbar}{2m\,\Delta y} \doteq 5.27\times10^{-29}\ m/s$$

Now, the particles travel a distance L in the horizontal direction, and end up a distance $\frac{1}{2}$ cm in the vertical direction (I took the spread to have diameter 1 cm, but you could also call that the radius). We get 2 similar Δ's:



$$\Rightarrow \quad \frac{L}{v_x} = \frac{\frac{1}{2}\,cm}{v_y} \Rightarrow L = 0.5\,cm\left(\frac{v_x}{v_y}\right) = (5\times10^{-3}\,m)\left(\frac{100\,m/s}{5.27\times10^{-29}\,\frac{m}{s}}\right.$$

$\Rightarrow$ $\boxed{L = 9.49 \times 10^{27}\ m}$ bigger than the Universe!

2]

a] This is just the difference in masses, so

$$\Delta E = (m_n + m_\pi - m_p)c^2 = \boxed{141.3\ MeV}$$

b] So take $\Delta E \Delta t = \frac{\hbar}{2}$ $\Rightarrow$ $\Delta t = \frac{\hbar}{2\Delta E}$

$$= \boxed{2.33 \times 10^{-24}\ s}$$

c] $\text{Dist} = c(2.33 \times 10^{-24}\ s) = \boxed{6.99 \times 10^{-16}\ m}$

This is within 1 fm, smaller than the nucleus.