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Modern Physics (2D)
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Quiz # 5 (Feb 14 2003)

Some Relevant Formulae, Constants and Identities

$E = \gamma mc^2; K = \gamma mc^2 - mc^2; p = \gamma mu$

$\lambda = \frac{h}{p}$

$\Delta x . \Delta p \geq \frac{h}{4\pi}$ and $\Delta E . \Delta t \geq \frac{h}{4\pi}$

Bragg Scattering : $n\lambda = 2d\sin\theta$

Compton Scatter: $\Delta\lambda = \left(\frac{h}{m_e c}\right)(1-\cos\theta) = (0.0243\dot{A})(1-\cos\theta)$

Planck's Constant $h = 6.626\times10^{-34}$ J.s $= 4.136\times10^{-15}$ eV.s

1 eV = 1.60×10^{-19} J

In the Hydrogen atom $E_1 = -13.6\ eV$

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

Neutron Mass $= 939.6$ MeV/c^2 $= 1.675\times 10^{-27}$ Kg

Speed of Light in Vaccum $c = 2.998\times 10^8$ m/s

Pl. write you answer in the Blue Book in indelible ink. Make sure your code number is prominently displayed on each page.

If you have trouble understanding the question, pl. ask the proctor

Problem 1 : Seeing is Believing [10 pts] :

Suppose we wish to test the possibility that electron in a Hydrogen atom moves in circular orbits (as proposed by Bohr) by "viewing" it with photons of sufficiently small wavelength, say $\lambda = 0.1\ \dot{A}$. (a) What would be the energy of such a photon? (b) How much energy would such a photon transfer to a free electron in a head-on Compton scattering collision? (c) how does this imparted energy compare with the Ionization energy of the Hydrogen atom? Does the idea of "viewing" the electron at different points in its orbit make sense?

Problem 2: Neutron & Electron Inside Nucleus [10 pts]:

A Neutron (a neutral particle with mass similar to that of a proton) in an atomic nucleus is bound to other neutrons and protons by a Strong attractive nuclear force that can confine (hold together) particles with kinetic energies of about 5 MeV. Assume that the size of the nucleus is 10 fm. (a) What is the kinetic energy of a neutron that is localized within a region of this size? (b) What would be the kinetic energy of an electron localized within a region of this size? (c) Which of the two particles could be confined within the nucleus? (d) For which of the two particles would you need to use the relativistic form for momentum?

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1]

a] $E = \frac{hc}{\lambda} = \boxed{124\ \text{keV}}$

b] $\Delta\lambda = \frac{h}{m_e c}(1 - \cos 180°)$, since it's a head-on collison

$$= 2(0.0243\ \text{Å}) = 0.0486\ \text{Å}$$

So $\lambda' = 0.1486\ \text{Å}$

The change in the photon's energy is $hc\left(\frac{1}{\lambda'} - \frac{1}{\lambda}\right) = -40.6\ \text{keV}$

So the electron gets $\boxed{40.6\ \text{keV}}$.

c] Ionization energy is 13.6 eV, so the electron gets way more energy than what's necessary to ionize the atom. This means it gets knocked out of the atom, so "viewing" it again at a different point in its orbit does not make sense — it's gone!

2]

a] $\Delta p = \frac{\hbar}{2\Delta x} = 5.27\times10^{-21}\ \frac{kg\cdot m}{s} = 9.9\ \frac{MeV}{c}$

So $KE = E - mc^2 = \sqrt{p^2c^2+m^2c^4} - mc^2 =$ **52 KeV**

using $m = 939.6\ MeV/c^2$.

(Note: Here I used $p = \langle p\rangle + \Delta p \simeq \Delta p$ since $\langle p\rangle = 0$).

b] Δp same as part a, but now we need to use the mass of the electron to compute the KE:

$KE = \sqrt{p^2c^2+m^2c^4} - mc^2 =$ **9.4 MeV**

↑ That's an M.

c] The **neutron**. The KE of the electron is bigger than 5 MeV, but the KE of the neutron isn't.

d] The **electron**, since 9.4 MeV ≫ 0.511 MeV ($KE \gg mc^2$).

The neutron is non-relativistic, since 52 KeV ≪ 939 MeV.

Or, you could figure out that $v \ll c$ for the neutron but not for the electron.