Reading: This week: Griffiths Chapter 1, and any good intro text (eg, the Mechanical Universe chap 50, or Liboff Chapter 2) on the classic experiments of QM. Next week: Griffiths chapter 2.

Problems: Due in class or the Ph12 IN box in 1st floor East Bridge, 10:30 AM, Thursday, 1/15/15.

I.1 Rutherford Scattering. Determine the distance of closest approach of protons to gold nuclei in head-on collisions in which the protons have kinetic energies of (a) 10 MeV, and (b) 80 MeV, and compare the results with the nuclear radius. (You can calculate the nuclear radius by assuming the nucleus to be an assemblage of close-packed spheres of radius 1 fm). In which of these two cases would the proton “touch” the nucleus? In that case, determine the kinetic energy of the proton when it “touches” the nucleus. Plot the distance of closest approach as a function of kinetic energy (label the axes!).

I.2 Hydrogen as a structure of minimum energy. The de Broglie hypothesis leads to the conclusion that the Hydrogen atom has its observed size because it minimizes the total energy of the system: larger size means longer de Broglie wavelength, and therefore smaller momentum and kinetic energy, while smaller size means smaller radius and thus lower potential energy, since the potential well is deepest near the nucleus. The observed size is a compromise which minimizes the sum of kinetic and potential energies.

a) Write down an expression for the total energy in terms of the momentum $p$ and position relative to the nucleus $r$, keeping kinetic and potential energy terms separate. Then demand that the orbit circumference be one de Broglie wavelength. Obtain an expression for the total energy as a function of radius.

b) Find the radius that minimizes the total energy, and the energy at that point. Compare with the Bohr model.

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I.3 **de Broglie wavelengths.** A criterion which discerns if a given configuration is classical or quantum mechanical may be stated in terms of the de Broglie wavelength $\lambda$. If $L$ is a scale length characteristic to the physical system in question, then if $\lambda \ll L$, classical physics is appropriate; if $\lambda \geq L$, quantum mechanics is required to describe the behavior. Use these criteria to describe which physics is relevant to the following physical systems:

a) An atomic electron. For the typical length, choose the Bohr radius; for typical energy, choose the Rydberg.

b) A proton in a nucleus. For nuclear size, choose $\simeq 10^{-13}$ cm (1 fermi). For energy choose $\simeq 10$ MeV.

c) An electron in a vacuum tube operating at 10 kV.

d) Electrons in solids: Griffiths problem 1.18a.

e) Atoms in gases: Griffiths problem 1.18b. and temperature 300 K.

I.4 **Ehrenfest’s Theorem for momenta.** Griffiths problem 1.7.

I.5 **Conservation of energy and unstable particles.** Griffiths problem 1.15. Plot $P(t)$, using both linear and logarithmic y-axes.

I.6 **Classical hard-sphere scattering.** Griffiths problem 11.1. **Do not hand in.** As it says in Griffiths, it isn’t an easy problem, but the answer is there. The problem is also discussed in my hand-written class notes for week 1, pages 9-11 (link on class website), and is worked out in, eg, Eisberg & Resnick.

This problem is familiar to billiards players, at least, if they know how to work in center of mass coordinates. Recall that Rutherford was able to interpret the results of his scattering experiments using only classical mechanics; if it required quantum mechanics, the development of quantum mechanics would probably have been delayed. You will do the quantum version of this problem (which is much harder) in Ph 125. In this class, we will do the problem in 1 dimension (which is much easier), where the result is not a cross section (with units of area) as a function of angle, but simply the unitless reflection and transmission coefficients; this is how we understand *quantum tunnelling.*