Physics 457 Problem Set 2

Due in Class, January 22, 2005

1. The neutron's magnetic moment provides evidence that the neutron is a composite particle, but how do its constituents conspire to produce the magnetic moment. Consider two models of the neutron's magnetic moment, each appropriate at a specific scale: the quark model (scale $<<$ 1 fm) and the pion-nucleon model (scale $\approx$ 1 f).

a.) In the quark model, the "valence" properties of the neutron arise due to three quarks with properties (i.e. spin, charge, color), which are not completely cancelled – these three quarks give the neutron is values, hence the term valence quarks. The neutron's net quark content is (udd), and the spin wave function results in the u-quark with a probability 2/6 of being spin-up; and the d-quark with a probability of 5/6 of being spin up in a spin-up neutron. Use this and the Dirac-moments of u and d quarks with mass $m_q = m_N/3$ to estimate the composite neutron's magnetic moment.

b.) In the pion-nucleon model the neutron is a combination of the Dirac neutron ($\mu_n = 0$) and a series expansion of other terms. The simplest/leading term iis a proton with a π^- with orbital angular momentum $l = 1$. **Find the"fraction of the neutron" due to this leading term that would produce the neutron magnetic moment** $\mu_n = -1.91\ \mu_N$**.** This requires addition of spin angular momentum $\vec{s}$) and orbital angular momentum $\vec{L}$ to form the $j = 1/2$ neutron, where the total angular momentum is $\vec{J} = \vec{L} + \vec{s}$. (You'll need to review/learn addition of angular momentum and Clebsch-Gordon coefficients.)

The neutron magnetic moment is defined by $< \psi|\vec{\mu}|\psi >= -1.91\mu_N < \psi|\vec{J}|\psi >$, where $\vec{J} = \vec{L} + \vec{S}$.

2. Consider a neutron incident on a target of species A with number density n_T (atoms per m^3) and length L. The neutron scattering cross section is isoptropic with

$$\sigma_{nA} = \frac{d\sigma(\theta)}{d\Omega} = \text{const.}$$

Show that the probability that the neutron does **not** scatter in the target is given by

$$e^{-\frac{L}{\lambda}}$$

b.) Find λ in terms of σ_{nA} and n.

3. Plot, quantitatively $\sigma(\theta)$ for Rutherford scattering of α particles ($Z = 2$) incident on a gold target $Z = 79$.

4. An α particle beam of 2×10^{-6} ampere (10^{-6} αs per second) is incident on a gold foil of density $\rho = 19.3 \times 10^3$ kg/m^3 and thickness 100 μ (10^{-4} m). What is the scattering rate for a detector of 5 cm radius located 1 meter from the foil at an angle of 135°.