become possible, what would be the effect of having nucleon substructure within the nucleus? What about point substructure within the nucleon? (Does your answer depend on whether the π^+ has such substructure?)

As is clear from Eq. (2.32), the positions of the minima of the diffraction pattern depend on the momentum of the incident particle. On the other hand, for small angles, if we identify the momentum transfer as

$$q^2 = p^2 \sin^2\theta \approx (p\theta)^2, \tag{2.37}$$

then using (2.32) we can write the locations of the minima of the diffraction pattern as

$$\left(q_{\min}^{(n)}\right)^2 \approx \left(p\theta_{\min}^{(n)}\right)^2 = \frac{n^2h^2}{4R^2}. \tag{2.38}$$

It is clear that in this q^2 variable, the locations of the minima of the diffraction pattern depend only on R, and are independent of the incident momentum. (As it turns out, the size of the nucleon appears to grow with incident energy, and the diffraction pattern shrinks as the scattering energy increases. This growth of the nucleon cross section is not completely understood.)

Problem 2.8 *What are the frequencies that correspond to typical splitting of lines for nuclear magnetic moments in magnetic fields of ≈5 tesla?*

The interaction of a particle of magnetic moment $\vec{\mu}$ with a magnetic field $\vec{B}$ leads to a typical shift in the energy

$$\Delta E = \vec{\mu}\cdot\vec{B} \approx \mu B, \tag{2.39}$$

where μ, B denote the magnitudes of the magnetic moment and the magnetic field, respectively. For particles with typical nuclear magnetic moments in the presence of a 5 T magnetic field, we have:

$$\begin{aligned}\Delta E = \mu_N B &\approx 3.15\times 10^{-14}\,\text{MeV/T}\times 5\,\text{T}\\ &\approx 1.57\times 10^{-13}\,\text{MeV},\end{aligned} \tag{2.40}$$

where we have used (2.30). This shift in the energy will be reflected in a shift in the frequency of the lines by

$$\begin{aligned}\Delta\nu &= \frac{\Delta E}{h} = \frac{\Delta E\times c}{2\pi\hbar c}\\ &\approx \frac{1.57\times 10^{-13}\,\text{MeV}\times 3\times 10^{10}\,\text{cm/sec}}{6\times 197\,\text{MeV}-\text{F}}\\ &\approx 3.95\times 10^{7}/\text{sec} \approx 39\,\text{MHz}.\end{aligned} \tag{2.41}$$

The corresponding wavelength is given by

$$\lambda = \frac{c}{\nu} \approx \frac{3\times 10^{10}\,\text{cm/sec}}{3.95\times 10^{7}/\text{sec}} \approx 7.5\times 10^{2}\,\text{cm} = 7.5\,\text{m}. \tag{2.42}$$

This is in the upper range of short-wave radio frequencies (RF).

Problem 2.9 *Show that when non-relativistic neutrons of kinetic energy E_0 collide head-on with stationary nuclei of mass number A, the smallest energy that elastically-scattered neutrons can have is given approximately by*

$$E_{\min} = E_0\left(\frac{A-1}{A+1}\right)^2.$$

What will be the approximate energies of the neutrons after one, two, and any number j of such consecutive collisions, if the target nucleus is hydrogen, carbon, and iron?

For a neutron incident on a much heavier target nucleus, we see from Eqs. (1.1) and (1.2) of the text that

$$\begin{aligned}m_n v_n^2 &= m_n v_0^2 - m_t v_t^2\\ &= m_n v_0^2 - m_t\times\frac{m_n^2}{m_t^2}\times(\vec{v}_0-\vec{v}_n)^2\\ &= m_n\left[\left(1-\frac{m_n}{m_t}\right)v_0^2 - \frac{m_n}{m_t}\,v_n^2 + \frac{2m_n}{m_t}\,v_0v_n\cos\theta\right]\\ \text{or}\quad (m_t+m_n)v_n^2 &= (m_t-m_n)v_0^2 + 2m_n v_0 v_n\cos\theta,\end{aligned} \tag{2.43}$$

where θ is the scattering angle and v_0, v_n represent the magnitudes of the incident and scattered neutron velocities. It is clear from (2.43)