Introduction to Nuclear and Particle Physics 1 – Tutorial

S. Paul

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Exercise 12 : Form factor of a homogeneously charged sphere

a. Calculate the form factor of a homogeneous, spherical charge distribution:

$$\frac{1}{Z}\rho(r) = \begin{cases} \frac{3}{4\pi R^3} & \text{if } r \leq R, \\ 0 & \text{if } r > R. \end{cases}$$

b. Scattering electrons elastically from carbon, one finds a minimum of the differential cross section at $q \approx 1.8\, fm^{-1}$. What is the radius of a carbon nucleus calculated from this, assuming a homogeneous, spherical charge distribution?

Exercise 13 : Charge radii of nuclei

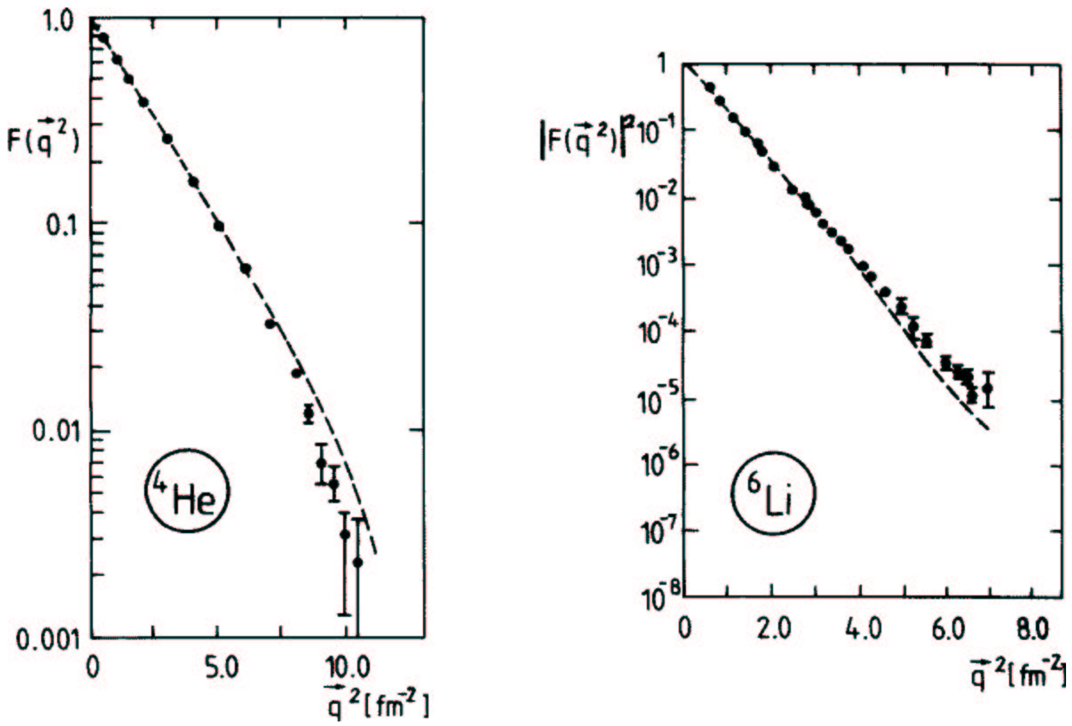
For light nuclei the charge density distribution $\rho(r)$ is well reproduced by a Gaussian distribution $\rho(r) = n \exp(-r^2/\alpha^2)$.

a. Calculate the normalization constant n from $\int d^3x\, \rho(r) = Z$ (proton number).

b. Find an expression for the mean square radius $\left\langle r^2 \right\rangle = \frac{1}{Z}\int d^3x\, r^2 \rho(r)$ as a function of α.

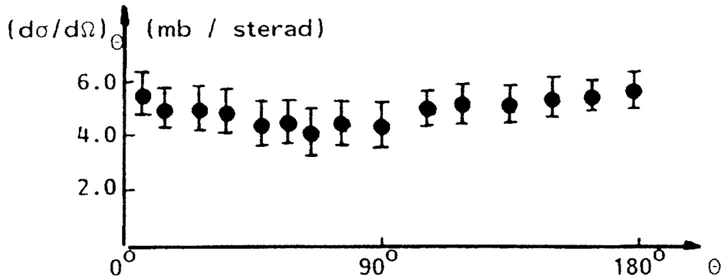
c. Calculate the charge form factor $F(\mathbf{q}^2) = \frac{1}{Z}\int d^3x\, e^{-i\mathbf{q}\cdot\mathbf{r}}\rho(r)$.
Show that $\left\langle r^2 \right\rangle = -6\frac{d}{d\mathbf{q}^2}F(\mathbf{q}^2)\big|_{\mathbf{q}^2=0}$.

d. Estimate the charge radii $\sqrt{\langle r^2 \rangle}$ of the nuclei ^{4}He and ^{6}Li from the measured form factors, shown in the figure below.



Exercise 14 : Neutron - proton scattering

The differential cross section for the scattering of slow neutrons from protons has been measured to have the following shape:



a. Show that the interaction potential between neutron and proton cannot be of the Coulomb type $V(r) = \frac{\text{const.}}{r}$.

b. Estimate the range R of the neutron-proton interaction assuming that it is given by a potential

$$V(r) = \begin{cases} \infty & \text{if } r < R \\ 0 & \text{if } r \geq R \end{cases} \qquad \text{Scattering from a "hard sphere"} \qquad (1)$$

Comment the result.

c. The differential cross sections for proton-proton and neutron-neutron scattering are found to be almost identical. What conclusions can you draw from this?

d. Estimate qualitatively how the differential cross section will change at higher energies.

(*Note*: Units of cross sections: 1 barn = 10^{-24} cm^2, 1 mbarn = 10^{-27} cm^2 = 0.1 fm^2)