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PHYS 303 – Classical Mechanics of Particles and Waves II

Problem Set 4

Due: Thursday, September 26 at 5:00pm

Term: Fall 2024

Instructor: Andrew W. Jackura

Readings

Read sections 9.1–9.3 of Taylor.

Problems

Problem 1. [10 pts.] – Number of Scattering Events

The cross section for scattering a certain nuclear particle by a copper nucleus is 2.0 barns. If 10^9 of these particles are fired through a copper foil of thickness 10 μm, how many particles are scattered? (Copper's density is 8.9 gram/cm^3 and its atomic mass is 63.5. The scattering by any atomic electrons is completely negligible.)

Problem 2. [10 pts.] – Differential Cross Section of Neutron Scattering

Neutrons scatter off a target at several MeV. The differential cross section is measured to be

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}(\theta,\phi) = \sigma_0 \left(1 + 3\cos\theta + 3\cos^2\theta\right) ,$$

where $\sigma_0 \approx 30$ mb / sr.

(**a**) **[5 pts.]** Sketch the differential cross section as a function of $\theta \in [0, \pi]$. At what angle do we expect the largest number of scattered neutrons?

(**b**) **[5 pts.]** Compute the total cross section σ by integrating the differential cross section over all directions.

Problem 3. [25 pts.] – The Orbit of a Comet

A comet of mass m is traveling through space under the gravitational influence of the Sun, mass M. Assume that $M \gg m$. Initially the comet is a long way away, traveling at speed V along a line which, if the Sun exerted no attraction, would pass a distance b from the Sun.

(**a**) **[10 pts.]** Show that the orbits eccentricity is $\epsilon = \sqrt{1 + \alpha^{-2}}$, where α is a constant to be determined from the given variables. What is the shape of the orbit? *Hint:* Conservation of energy may be useful.

(**b**) **[10 pts.]** Determine the perihelion distance and the comet's speed at that point. Write your answer in terms of α from part **(a)**, as well as other given variables.

(**c**) **[5 pts.]** Find the angle through which the comet's trajectory is deflected. Write your answer in terms of α from part **(a)**.

Problem 4. [10 pts.] – Nuclear and Atomic Cross Sections

Here we estimate the typical cross sections for nuclear and atomic systems.

(**a**) **[5 pts.]** A certain nucleus has radius 5 fm. (1 fm = 10^{-15} m.) Find its cross section σ in barns (1 barn = 10^{-28} m^2.)

(**b**) **[5 pts.]** Do the same for an atom of radius 0.1 nm. (1 nm = 10^{-9} m.)

Problem 5. [20 pts.] – Rutherford Scattering

The differential cross section for scattering 6.5 MeV alpha particles at 120° off a silver nucleus is about 0.5 barns/sr. If a total of 10^{10} alphas impinge on a silver foil of thickness 1 μm and if we detect the scattered particles using a counter of area 0.1 mm^2 at 120° and 1 cm from the target, about how many scattered alphas should we expect to count? (Silver has a specific gravity of 10.5, and atomic mass of 108.)