Alpha Particle Spectroscopy

Week of September 20, 2010

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PHYS 4780

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Alpha Particle Spectroscopy

Activity (A) defined as the Count Rate of the source, in units of the total # of disintegrations per second (converted to μC).

In our case, we measured the count rate over a period of time (Live Time) to determine the rate. Uncertainty ΔN at least $(N)^{1/2}$ where N is the number of counts. ΔN in our case is larger than $(N)^{1/2}$, as determined by MCA software.

Other significant quantities: area of the detector (D_{Area} assumed to be 150 mm^2), and the distance between the source and the detector, R_{SD}.

Estimate the uncertainty in the detector area (measured as ~14 mm diameter, but with what precision?).

Estimate the uncertainty in R_{SD}. Propagate to error in solid angle subtended by the detector.

What if the values for A obtained using three different values of R_{SD} vary by more than some (or all) of the estimated uncertainties? What does that say about the uncertainty of the actual vale for A? Make your case in your lab report…

Uncertainty (or error) propagation

1. Additive Variables:

$$y = ax_1 + bx_2 \rightarrow \delta_y = a\delta x_1 + b\delta x_2$$

but, if errors are assumed uncorrelated,
i.e.,; if when $\delta x_1 > 0$, δx_2 may be > 0 or <0 with equal probability,
then we must add errors in quadrature:

$$\delta y = \sqrt{(a\delta x_1)^2 + (b\delta x_2)^2}$$

2. Multiplicative Variables

$$y = ax_1 x_2, \text{ or } \; y = \frac{ax_1}{x_2} \rightarrow \delta y = \frac{a\delta x_1}{x_2} + \frac{ax_1(-\delta x_2)}{(x_2)^2}$$

$$= \frac{a\delta x_1}{x_2} - \frac{ax_1\delta x_2}{x_2^2}.$$

Here it is convenient to form the fractional error,

$$\frac{\delta y}{y} = \frac{x_2}{ax_1}\left[\frac{a\delta x_1}{x_2} - \frac{ax_1\delta x_2}{x_2^2}\right]$$

$$+\frac{\delta x_1}{x_1} - \frac{\delta x_2}{x_2}.$$

Again, in quadrature (but now with fractional errors):

$$\frac{\delta y}{y} = \sqrt{\left(\frac{\delta x_1}{x_2}\right)^2 + \left(\frac{\delta x_2}{x_2}\right)^2}$$

Alpha Source Activity

A (activity) expressed in μC:

$$A = \frac{C}{\Omega_D / 4\pi}$$

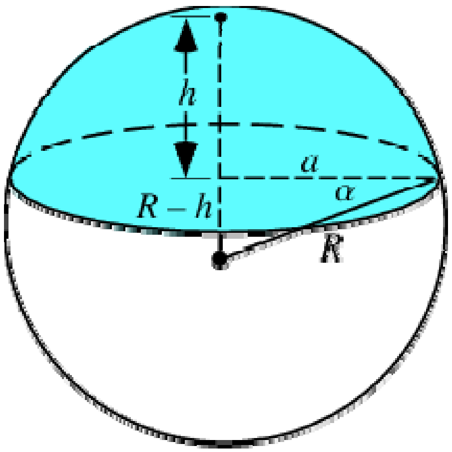
where *C* is the count rate (s^{-1});

Ω_D is the solid angle (sr) subtended by the detector disc;

and 4π (sr) is the solid angle of the full sphere.

Another way to compute the value of $\Omega_D / 4\pi$ is to determine the fractional area of the "spherical cap"* to the full area of the sphere ($4\pi R^2$).

* Spherical cap defined by the disc that is the detector.



Alpha particle interactions with matter

Scattering

Alpha particles interact strongly with electrons due to their net +2e charge (charge on an electron = 1.602×10^{-19} C) – strong Coulomb interactions with atoms' electron "cloud". In general, their interactions with matter are strong due to their charge and large mass. Alphas can be absorbed by the outer layers of human skin (about 40 μm, equivalent to a few cells deep).[portion from Wikipedia]

Strong probability of electron ejection following scattering event (compare atomic or molecular ionization energy to alpha particle energy).

Based on mass considerations alone, alpha particles will experience little deflection (change in direction) when scattering with an electron. Mass ratio on the order of ~1000:1, with momentum conservation indicating a small deflection in any α - e^- scattering event.

Alpha particle interactions with matter

Energy loss

Radioactive nuclei undergoing "natural" decay emit alpha particles with energies typically in the range of 3 - 7 MeV. The β-factor (β =v/c) of these alpha particles is very small. In this case, the nonrelativistic formula for energy loss *dE* of charged particle in matter of length *dx* can be written as:

$$-\frac{dE}{dx} = \frac{4\pi z^2 e^4}{m_e v^2} n_e \ln\left[\frac{m_e v^2}{\bar{I}}\right]$$

where all units are in c.g.s. system with:

z: charge of the incoming particle (in integral units of the electron charge, *e*);

v: velocity of the incoming particle;

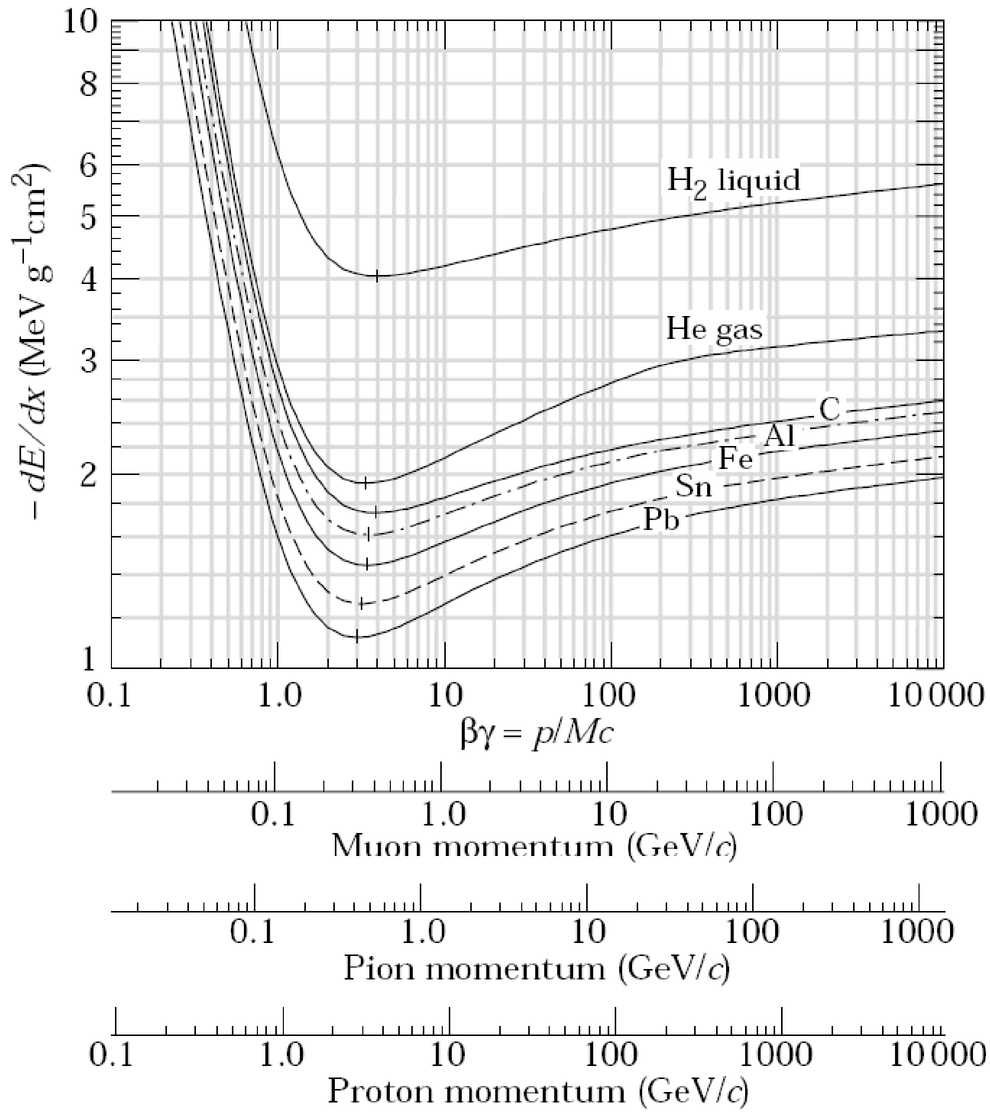
n_e: electron density of the scattering material;

I: average ionization energy of the scattering material;

m_e: electron mass.

Since the numerical number inside the logarithm changes slowly, the energy loss is characterized as proportional to ($z^2 n_e$) and inversely proportional to (v^2). For a given alpha source then, the energy loss is proportional to the electron density of the scattering material n_e.

Alpha particle interactions with matter



Alpha particle scattering: many questions

What is the average energy lost by an α particle to an air molecule in a scattering event?

Cross sections: probability of a scattering event (σ, cm^2). – What is σ for an α particle scattering off an electron? A nucleus? Consider charge, and size.

~ 5×10^{-15} m, or ~5 fm for the nucleus.

~ 100×10^{-12} m, or ~ 100 pm for the size of an atom (approximate size of an electron orbit)…

Others?