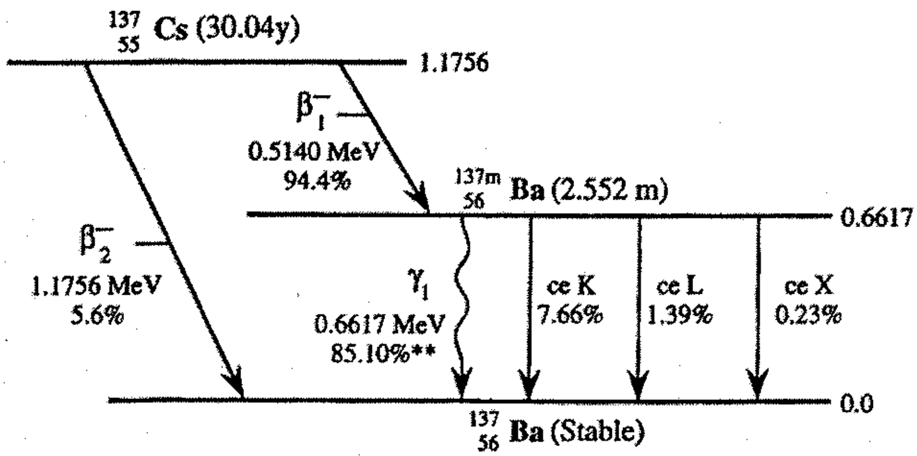
Interactions, Measurements, Theory of Radiation Fall 2003

1. **(10 minutes)** Using the decay scheme shown below, calculate the photon fluence rates produced by a 10-mCi point source of Cs-137 at distances of 2 meters and 4 meters. What is the energy fluence rate at each of these locations? Please state all assumptions.



FP (Nov. 4, 1994)

Radiation	Y_i (%)	E_i (MeV)
β_1^-	94.40	0.1734[a]
β_2^-	5.60	0.4163[a]
γ_1	85.10[b]	0.6617
ce-K, γ_1	7.66	0.6242
ce-L_1, γ_1	1.12	0.6557
ce-L_2, γ_1	0.16	0.6560
ce-L_3, γ_1	0.13	0.6564
$K_{\alpha 1}$ x ray	3.62	0.0322
$K_{\alpha 2}$ x ray	1.96	0.0318
K_{β} x ray	1.32	0.0364[a]
L x ray	1.00	0.0045[a]
Auger-K	0.76	0.0264[a]
Auger-L	7.20	0.0367[a]

[a] Average energy.
[b] Photon yield per transformation of ^{137}Cs; photon yield from each transformation of ^{137m}Ba is 90.11%.

2. **(10 minutes)** If the half-value layer (HVL) for iron is 1.47 cm for 1 MeV photons and the "on contact" exposure rate of a source is 800 mR/h, calculate the following:

a. the photon attenuation coefficient (μ); and

b. the thickness of iron required to reduce the source exposure rate to 150 mR/h.

State all your assumptions.

3. **(10 minutes)** Two, of many, examples of a uniquely quantum mechanical phenomenon are (1) fusion of colliding deuterium and tritium nuclei with kinetic energies insufficient to overcome the repulsive Coulomb potential energy barrier and (2) spontaneous α decay. In these examples, classical physics requires the particles to be permanently separated from each other (in example 1) or permanently bound together (in example 2), while this phenomenon permits the particles actually to fuse or to separate.

(a) (10%) What is this phenomenon called?

(b) (40%) What description of the particles does this phenomenon depend on? In other words, how or what is used to describe particle properties and behavior?

(c) (50%) How do these descriptions explain this phenomenon (exemplified by α decay and fusion cited above)? You may give your answer in words, mathematically, or diagramatically

4. **(15 minutes)** An electron from some unknown source is absorbed by a scintillator where 10^7 eV of energy are dissipated before the electron is captured.

a) (20%) Was the electron's speed initially relativistic? Why?

b) (80%) What was the electron's speed upon entering the scintillator? You may express your answer in purely algebraic form with numerical values of all variables indicated.

5. **(15 minutes)** Consider a surface source: $S_a(\hat{\Omega}) = C\eta^2$ neutrons/cm^2-sec-sr emitting into 2π steradians, where C is a constant, and η is the cosine of the angle between $\hat{\Omega}$ and the surface normal. In terms of the source strength, S_a neutrons/cm^2-sec, find:

a. The constant, C.

b. The angular flux at the surface.

c. The scalar flux at the surface.

6. **(15 minutes)** Sets of polyethylene spheres of different diameters, each with a thermal neutron detector at the center, can be used to evaluate a neutron spectrum. In some cases it is advantageous to add a large sphere with a relatively thin (1/4") lead cover to the set. Lead has a significant (n,2n) cross section above about 10 MeV. Give a qualitative explanation of why these detectors can be used to evaluate neutron spectra, the response of plain polyethylene systems at high neutron energy, and the changes produced by adding the lead to a large moderating sphere.

7. **(15 minutes)** A 662 keV photon enters a NaI(Tl) detector, interacts, and produces a count in a channel of a multichannel analyzer (MCA). Sketch the detector assembly and describe the physics of each step (including the initial interaction) that leads to a pulse of electrons exiting the detector assembly. Then sketch the associated electronics leading to and including the MCA and briefly describe the function of each component.

8. **(10 minutes)** Energetic secondary electrons (delta rays) are thought to be responsible for a significant part of the radiation chemical damage produced by protons and other heavy ions. The stopping power for charged particles can be written as:

$$\frac{dT}{dx} = \left(\frac{4\pi z^2 e^4 NZ}{mv^2}\right) \ln\left(\frac{\sqrt{2}\ mv^2}{\hbar\omega}\right)$$

a. Compare the delta ray energy spectra produced by 2 MeV protons and 8 MeV alpha particles.

b. At a distance of one half of the proton's delta ray range from the track, what is the ratio of the doses produced by the two types of particles mentioned in a.?

c. What fraction of the total dose delivered by an 8 MeV alpha particle is deposited by secondary electrons?

9. **(20 minutes)** A small spherical rain drop (pure H_2O, diameter 0.01 cm) falls through a beam of neutrons. All neutrons are emitted with energies between 8 and 12 keV. Consider the neutrons that reach the drop without colliding with nuclei in the air. Of those neutrons, estimate the fraction that will have one and only one scattering collision in the drop. Your estimate should be accurate to within a relative error of approximately 10%; do not waste time trying to make it more accurate.
[**Hint:** First estimate the fraction that scatter, and then estimate the fraction of those that exit without further collision.]
Cross sections for H and O are shown in the attached figures.

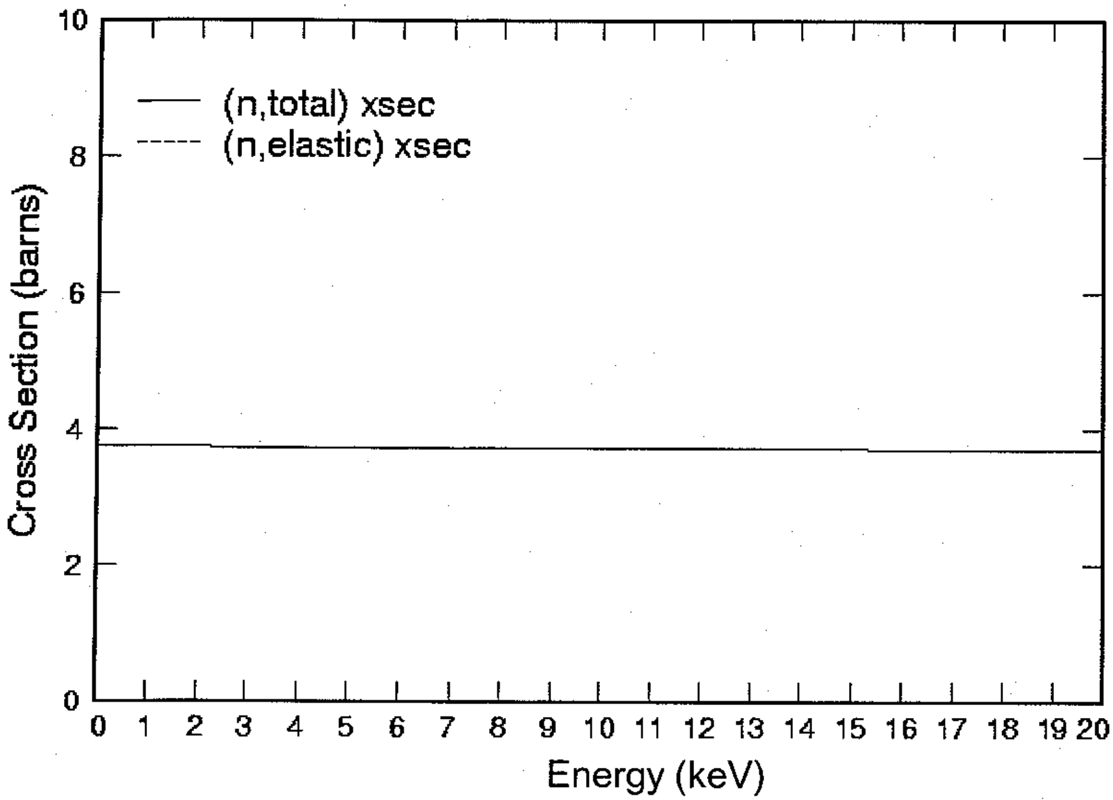


Figure 1. Total and scattering cross sections for ^{16}O. (Lines are on top of each other.)

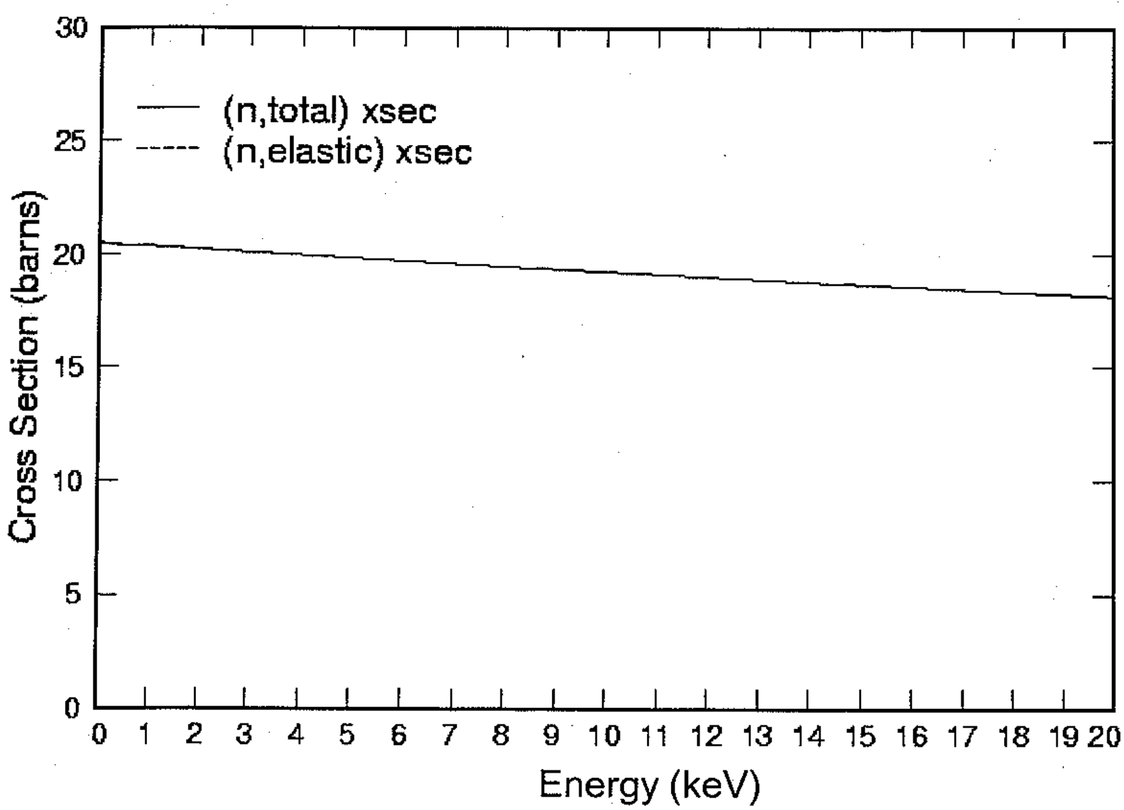


Figure 2. Total and scattering cross sections for ^{1}H. (Lines are on top of each other.)