1 Atomic structure, Bohr's atomic model

Positive nucleus, discretized energy jumps between electron levels.
Atomic Radius

$$R = (1.25\, fm) \cdot A^{1/3} \tag{1}$$

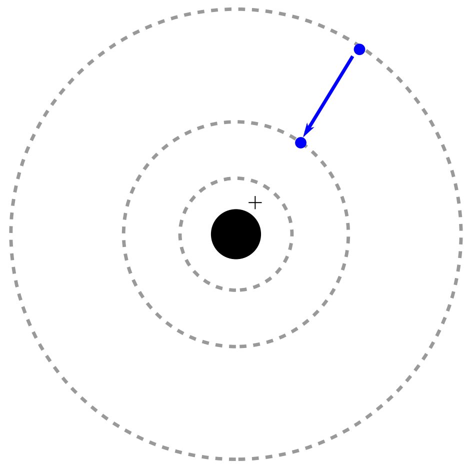

Figure 1: Bohr's Atomic Model Diagram

Gamma energy release when jumping orbits

$$\Delta E = h\nu \tag{2}$$

2 Nuclear structure and estimate of nuclear radii

2.1 Shell Model

Levels of shell within the nucleus, creating the potential well with quantized levels. Max nucleon in each level. Pauli exclusion principal are filled according to the Pauli Exclusion Principle.

Magic Numbers!

2.2 Liquid Drop Model

Number of forces hold the "droplet" together. Binding between atoms occurs between every nucleon with surface tension correction.

$$M = NM_n + ZM_p - \alpha A + \beta A^{2/3} + \gamma \frac{Z^2}{A^{1/3}} \tag{3}$$

3 Binding energy for atoms and nuclei, mass defect

Mass Defect

$$\Delta = ZM(^1H) + NM_n - M \tag{4}$$

Binding Energy

$$BE_a = Z_a M(^1H) + N_a M_n - M_a \tag{5}$$

Binding Energy of Last (Least Bound) Nucleon

$$E_s = [M_n + M(^{A-1}Z) - M(^AZ)] \cdot (931\, \frac{MeV}{amu}) \tag{6}$$

4 Uncertainty and exclusion principles

4.1 Uncertainy Principal

$$\sigma_x \sigma_p \geq \frac{\hbar}{2}$$

Heisenberg. We can only know one property (position or momentum) of anything at one time, the other must be unknown.

4.2 Pauli Exclusion Principal

Nucleons or electrons can only take a certain number of spin states, and if those spin states are filled, must be in the next level. In lithium, with 3 e^-, two can be in the $1s$ level, but the third has to be up a level in the $2s$ because it cannot have the same spin and be in the same level.

5 Radioactive decay, decay rate, activity - concepts and calculations

Activity

$$\alpha(t) = \lambda n(t)$$

$$n(t) = n_0 e^{-\lambda t}$$

$$T_{1/2} = \frac{ln(2)}{\lambda}$$

With production

$$\frac{dn}{dt} = -\lambda n + R \therefore n = n_0 e^{-\lambda t} + \frac{R}{\lambda}(1 - e^{-\lambda t})$$

$$\frac{dn_B}{dt} = -\lambda_B n_B + \lambda_A n_A \therefore n_B = n_{B0} e^{-\lambda_B t} + \frac{n_{A0}\lambda_A}{\lambda_B - \lambda_A}(e^{-\lambda_A t} - e^{-\lambda_B t})$$

6 Energies of emitted radiation during decay

6.1 Beta Decay

Energy Spectrum

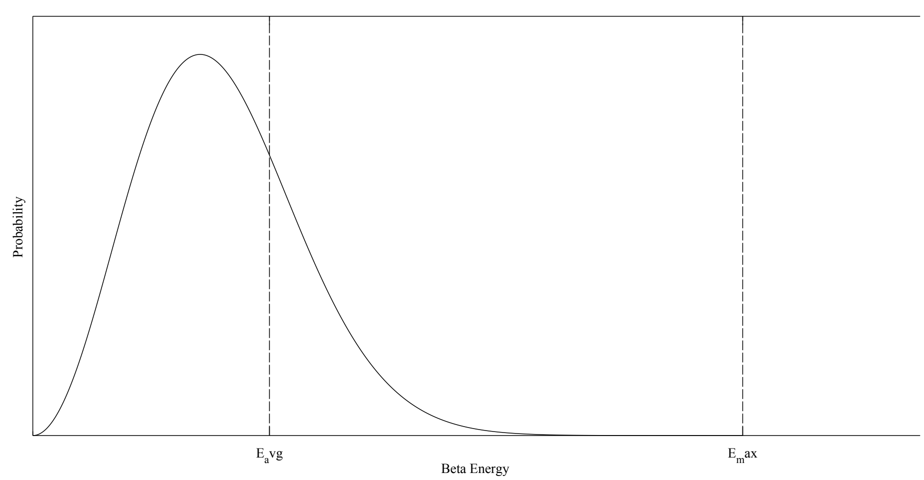

Figure 2: Beta Decay Energy Spectrum Plot

$$\bar{E_\beta} = \frac{1}{3}E_{\beta,max}$$

6.2 Alpha Decay

Mono-Energetic

6.3 Gamma Decay

Mono-energetic

6.4 Neutron Decay

Energy Spectrum

7 Neutron interaction with matter

7.1 Elastic Scattering (n, n)

Conserves momentum and energy, nucleus left in ground state.

$$\sigma_e = 4\pi R^2$$

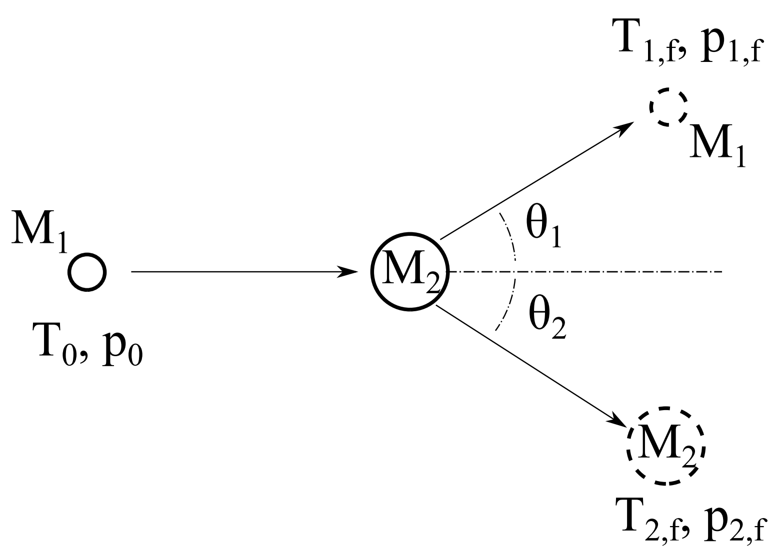

Figure 3: Neutron Elastic Scattering

Energy loss

$$\alpha = \left(\frac{A-1}{A+1}\right)^2$$

$$E'_{min} = \alpha E$$

$$E' = \frac{Em_ec^2}{E(1-cos\theta) + m_ec^2}$$

$$\frac{\overline{E'}}{E} = 0.5(1+\alpha)$$

7.2 Inelastic Scattering (n, n')

Does not conserve momentum, nucleus excited and then de-excited
Has threshold cross section, has to be able to excite the nucleus up to it's first (quantized) state.

7.3 Radiative Capture (n, γ)

Neutron captured by the nucelus and one or more γs are emitted. Exothermic.

7.4 Charged-Particle Interactions (n, α) and (n, p)

Release other nucleons, the α is a He nucleus.

7.5 Neutron-Producing Reactions $(n, 2n)$ and $(n, 3n)$

Extra neutrons may appear as a result of absorption reactions.

7.6 Fission

Upon excitation, the nucleus may split apart. Two step process:

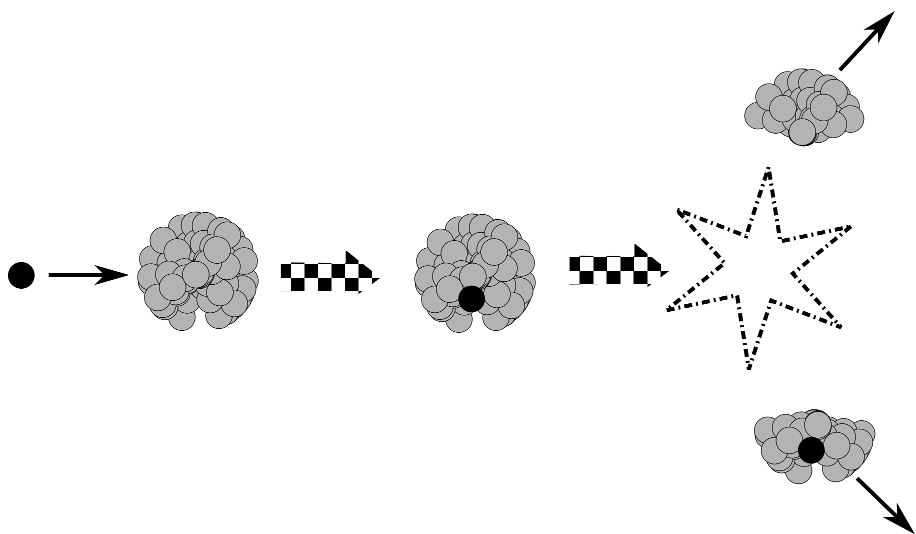

Figure 4: Diagram of Fission as a "Two-Step Process"

7.7 Total Cross Section

At low energies:

$$\sigma_t = 4\pi R^2 + \frac{C}{\sqrt{E}}$$

Resonance region
High Energy smooth and rolling function of energy.

8 Charged particle interaction with matter

Bremsstrahlung - particle accelerated by the coulomb field of the elctrons or nucleus and emitting a photon.
Bragg peak of α's.

$$R = R_a \frac{\rho_a}{\rho} \sqrt{\frac{M}{M_a}} = 3.2 \times 10^{-4} \frac{\sqrt{M}}{\rho} R_a$$

Betas

$$R_{max}\rho = \begin{cases} 0.412E_{max}^{(1.265-0.0954lnE_{max})} & E_{max} < 2.5\,MeV \\ 0.530E_{max} - 0.106 & E_{max} \geq 2.5\,MeV \end{cases}$$

9 Photon interaction with matter

Photoelectric effect - Incident γ interacts with entire atom and disappears, ejecting an atomic electron. The atom recoils with low energy

Compton Scattering - elastic scattering of photon by an electron in the matter.

Pair Production - The photon disappears and a positron and negatron is created.

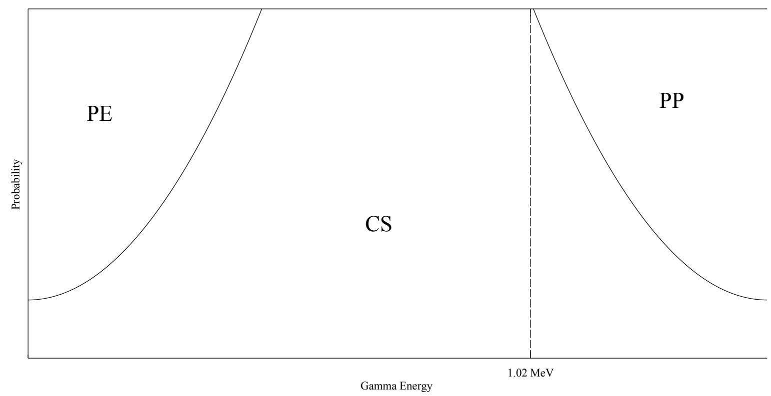

Figure 5: Probabilities of Varying γ Interactions Plot

10 Biological effects of radiation

$$\dot{H} = \dot{D} \times Q$$

Table 1: Quality Factors for Various Types of Radiation

Type	Q
γ	1
β	1
α	10
n	10

11 Shielding, build-up factor

Buildup factor

$$\dot{X} = \dot{X}_0 B_m(\mu a) e^{-\mu a}$$

$$B_p = A_1 e^{-\alpha_1 \mu r} + A_2 e^{-\alpha_2 \mu r}$$

12 Radiation detection principles and technology

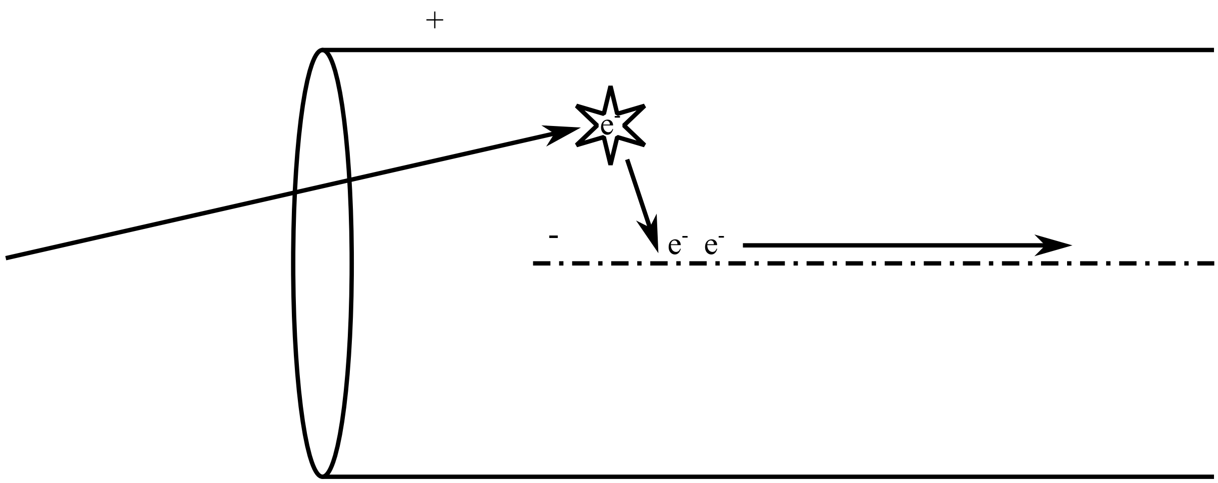

Figure 6: Gas Detector Diagram

Ionizing Chambers (Gas Proportional Counters)

Scintillation Jumps the forbidden gap to emit light then passed through photomultiplier tube.

Cloud Chambers Pass through cloud to show tracks

13 Counting statistics and error propagation

For precision:

$$P(x)dx = \frac{1}{\sqrt{2\pi}} e^{\left[\frac{-(x-m)^2}{2s^2}\right]ds}$$

$$s^2 \approx \sigma^2 = \frac{\sum(x_i - \overline{x}^2)}{N-1}$$

Error Propagation

$$E_y^2 = \left(\frac{\partial y}{\partial x_1}\right)^2 E_{x_1}^2 + \left(\frac{\partial y}{\partial x_2}\right) E_{x_2}^2 + ...$$

14 Radiation protection

14.1 ALARA

14.2 Units

- Roentgen ($R = 2.58 \times 10^{-4} \, \frac{coul}{kg}$)
- Dose ($rad = 0.01 \, \frac{J}{kg} = 0.01 \, Gy$)