Decay Detector For The Study of Isoscalar Giant Monopole Resonances

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Giant Resonances

- Collective excitations of the nuclei
- Discovered in the 1940s while bombarding nuclei with gamma rays
- Monopole resonance is a spherical oscillation
- Isoscalar – neutrons and protons move in phase with one another
- Isovector – neutrons and protons move out of phase with one another

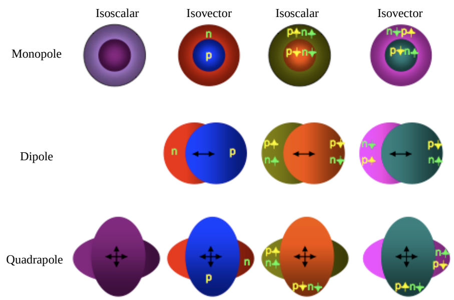

Figure 1: depiction of giant resonance modes (ref. Xinfeng Chen, "Giant Resonance Study By ^{6}Li Scattering"

- **Classical description**: Liquid Drop Model
  - Protons and neutrons are treated as independent fluids
  - Giant resonance can be though of as oscillations of density or shape of these fluids
- **Quantum Mechanical Description**: Nuclear Shell Model
  - Analogous to the electron shell model
  - Neutrons and protons have there own shell system
  - Levels in the system correspond to energy levels that protons and neutrons jump between during various processes
  - Resonance can be thought of by protons and neutrons jumping up to a higher energy level leaving a hole in the lower shell
- Energy Weighted Sum Rule (EWSR) is used to measure the strength of the giant resonance

$$S(Q) \equiv \sum_n (E_n - E_0)\left|\langle n|Q|0\rangle\right|^2 = \frac{1}{2}\langle 0|[Q,[H,Q]]|0\rangle$$

Purpose

- From studying the Isoscalar Giant Monopole Resonance (ISGMR), E_{GMR} can be determined
- E_{GMR} can be used to find K_{nm}, a main component in the nuclear matter equation of state
- Astrophysics:
  - Supernova collapse
  - Neutron Stars

Unstable Nuclei

- Studying ISGMR in unstable nuclei may allow us to determine the dependence of the nuclear incompressibility on (N-Z)/A
- Cannot successfully make a target out of unstable nuclei
- Study the inverse reaction instead
- Normal Kinematics:

$$^{26}Si(^{6}Li,^{6}Li)^{26}Si*$$

- Inverse Kinematics:

$$^{6}Li(^{26}Si,^{26}Si*)^{6}Li$$

Experimental Setup

- Decay particles will hit the decay detector
- Remaining particles will go on to the MDM spectrometer

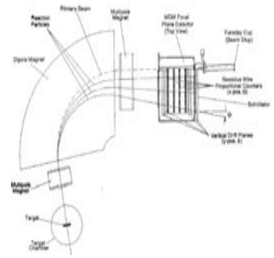

Figure 2: depiction of the experimental setup (ref. Xinfeng Chen, "Giant Resonance Study By ^{6}Li Scattering"

- MDM Spectrometer separates particles of different momentum and charge
- Ionization chamber measures the position
- Scintillator measures the total energy

Decay Detector

- Composed of a layer of horizontal 1 mm thick scintillator strips followed by a layer of vertical 1 mm thick scintillator strips in front of 5 block scintillators

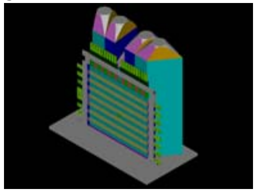

Figure 3: The decay detector (drawing by Dr. Tokimoto)

- Each scintillator is connected to optical fibers that carry the signal to a photomultiplier tube (PMT)
- In the PMT, the photon's energy is converted to an electric signal and is amplified
- Scintillator strips give the angle of the particle as well as the energy loss through the strip
- the strip scintillator is also used for particle ID within the 7 < E/A < 11 (MeV/amu)
- The block scintillators measure the remaining energy of the particle
- 11 < E/A < 70 (MeV/amu) block IDs particles

Stopping Power

- Stopping power is the energy loss per unit length (dE/dx)
- Commonly approximated by the Bethe-Bloch formula

$$-\frac{dE}{dx} = 2\pi a_0^2 m_e c^2 n_e \frac{Z^2}{\beta^2}\left[\ln\left(\frac{2m_e c^2\gamma^2\beta^2 W_{\max}}{I^2}\right) - 2\beta^2 - \delta - 2\frac{C}{Z}\right]$$

$$\beta = \frac{v}{c}$$

$$\gamma = 1\Big/\sqrt{1-\beta^2}$$

- A more convenient form is

$$-\frac{d\varepsilon}{dx} = \frac{Z^2}{m}\frac{1}{(1+\mu)}\frac{\kappa}{(\varepsilon+\varepsilon_0)^{\mu}}$$

- κ, μ, and ε_0 are medium dependent constants that we fit to SRIM table data
- For our purposes, ε is equivalent to β

Predicting Light Output

- Two methods for predicting the light output
- **Birks semi-empirical formula**:
  - Non-linear relationship to the stopping power at low energies

$$\frac{dL}{dx} = \frac{C_0\, dE/dx}{1 + C_1\, dE/dx}$$

  - C_0 is the proportion of the molecules that contribute to the light output
  - C_1 is the proportion of molecules that are quenching sites
- **Energy Deposition By Secondary Electrons (EDSE) Model**:
  - Advantageous for calibrations across numerous ion types
  - Takes into account both ionization density and energy transport concepts
  - Assumes that there exists a "quenching density," ρ_q, which defines a "quenching radius," r_q
  - Below r_q, the scintillator response is assumed to be constant
  - Above r_q, the specific detector response, dL/dx has a linear dependence on the integral of the density of energy deposited by the scattered electrons

$$\rho(r) = \frac{D}{nr^2}\left(1 - \frac{r}{R_{\max}}\right)^{d+1/n}$$

$$D = N_A \rho_{\det}\frac{\langle Z_{\det}\rangle}{\langle A_{\det}\rangle}\frac{e^4}{m_e c^2}\frac{Z^{*2}}{\beta^2}$$

$$\frac{dN_e}{dx} = C\left[\pi\rho_q\left(r_q^2\right) + \int_{r_q}^{R_{\max}} \rho(r)2\pi r\,dr\right]$$

$$\frac{dL}{dx} = C\frac{dN_e}{dx}\left(1 - \mathscr{F}\frac{dN_e/dx}{\mathscr{A} + dN_e/dx}\right)$$

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