Lecture 5
Experimental Nuclear Physics
PHYS 741

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References and Figures from:
- Basdevant et al., “Fundamentals in Nuclear Physics”
- Henley et al., “Subatomic Physics”
From Rutherford to Neutrino Coherent Scattering

\[ \frac{d\sigma}{d(\cos \theta)} = \frac{G_F^2}{8\pi} \left[ Z (4 \sin^2 \theta_W - 1) + N \right]^2 E^2_{\nu} (1 + \cos \theta) \]
Rutherford

• identified nucleus

• demonstrated scattering off nucleus (versus electrons surrounding nucleus)

• measured nuclear radii
Coherent Neutrino Nucleus Scattering

- process at low energies, low momentum transfer
- due to small momentum transfer neutrino interacts simultaneously with all nucleons in nucleus -> amplitudes of wavefunctions are in phase and add up coherently
- CNNS cross-section very large but small momentum transfer makes it very hard to detect

> CNNS can probe physics beyond the standard model
A Slice of Matter - Classical View
A Simplified by Typical Cross-Section Measurement
Examples of Cross-Section

Which one of these cross-sections is affected by Coulomb barrier?

cross-section

Energy
Examples of Cross-Section

exothermic \((n,\gamma)\) and \((n,t)\) have \(1/v\) dependence

\((p,\gamma)\) suppressed at low \(E\) because of Coulomb barrier

\(^6\text{Li}(n,p)\) has energy threshold

excited state of Li appears as a resonance in \(^{7}\text{Li}\) elastic scattering and in \(^6\text{Li}(n,t)\)
Energy Levels of $^7$Li

- Resonance in 4th excited state
Elastic Scattering of Neutrons

for low momenta:
> isotropic

for high momenta:
> angular distribution like diffraction of disk $R$

Anything surprising?

backward scattering from exchange of charged pions
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Fragmentation and Fission

- Fragmentation of $^{129}$Xe on $^{27}$Al
- Collision induced fission of $^{238}$U on a Pb target
Quark Gluon Plasma

- Expansion and cooling
- Compression and heating
- Hadron gas
- Baryon density
- Nuclear $(n_B = 0.14/fm^3)$

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Quark Gluon Plasma

Pressure + Heat (creates pions) → Quark-Gluon Plasma

Temperature $T$ [MeV]

Early universe

Critical point?

Deconfinement and chiral transition

Neutron stars

Color Superconductor?

Net Baryon Density

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Photodissociation

\[ E_{\text{th}} = 2.2 \text{ MeV} \]

giant resonance typical of heavy nuclei
Scattering in Repulsive Force

\[ b = \text{impact parameter} \]
Non-Relativistic Particles in Yukawa Potential

Particle penetration to about $r_0/10$

Yukawa = solid line
Coulomb = dashed line

For $b < r_0$
Potential give nearly same result

For $b >> r_0$
Yukawa scattering less than Coulomb scattering because.... ?

Yukawa force drops much faster with distance

Classical calculation
Rutherford

The models of the Thomson’s atom and Rutherford’s atom; and the expected aberrations of alpha particle in both cases.