Quantum Mechanics
Physics 237

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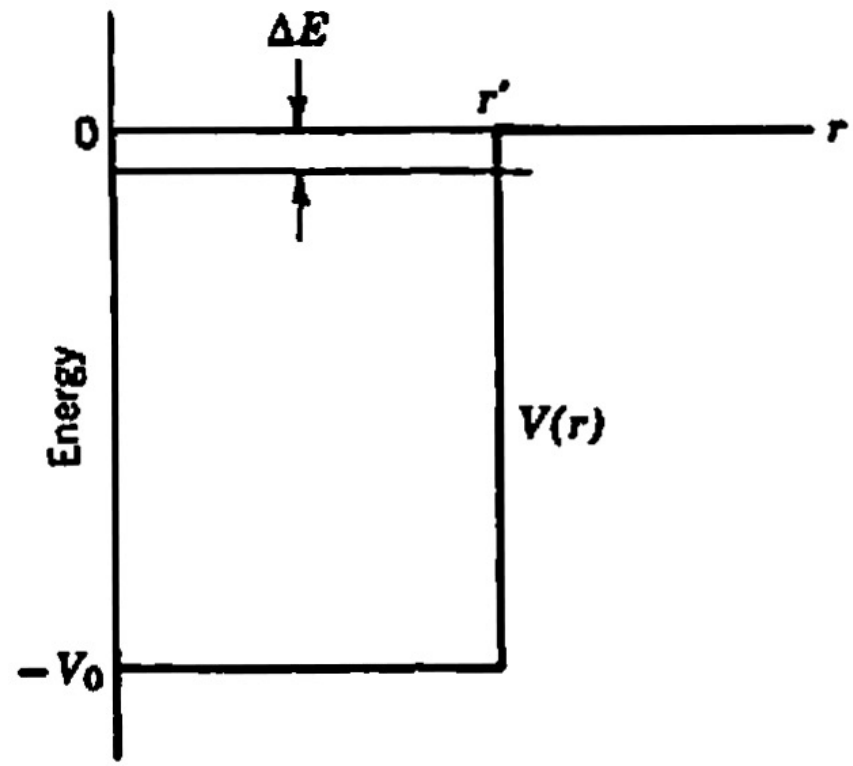
Announcements

- Homework # 9 is due on Friday April 8.
- The last PHY 237 homework (# 10) is due on Friday April 15.
- After that …… only two more exams.

Properties of the deuteron

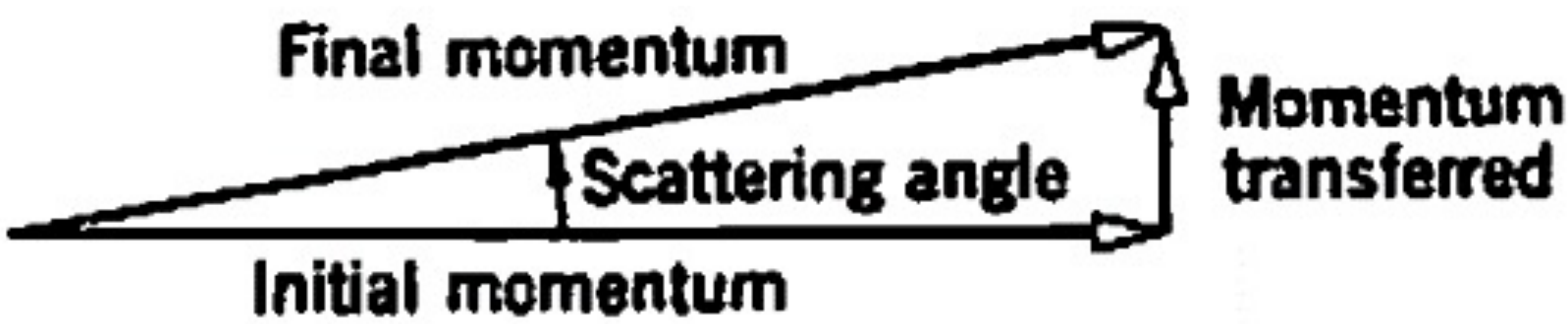
- Weakly bound (-2.2 MeV and no excited states).
- Even parity (even orbital angular momentum).
- Nuclear spin = 1.
- Mixture of $^3S_1$ and $^3D_1$ state.
- No $^1S_0$ state is observed. Tells us something about the spin dependence of the strong force.
- q = 2.7 x 10^{-31} m2.
- $\mu = 0.857\ \mu_N$.
- Charge distribution has a radius of 2.1 fm.



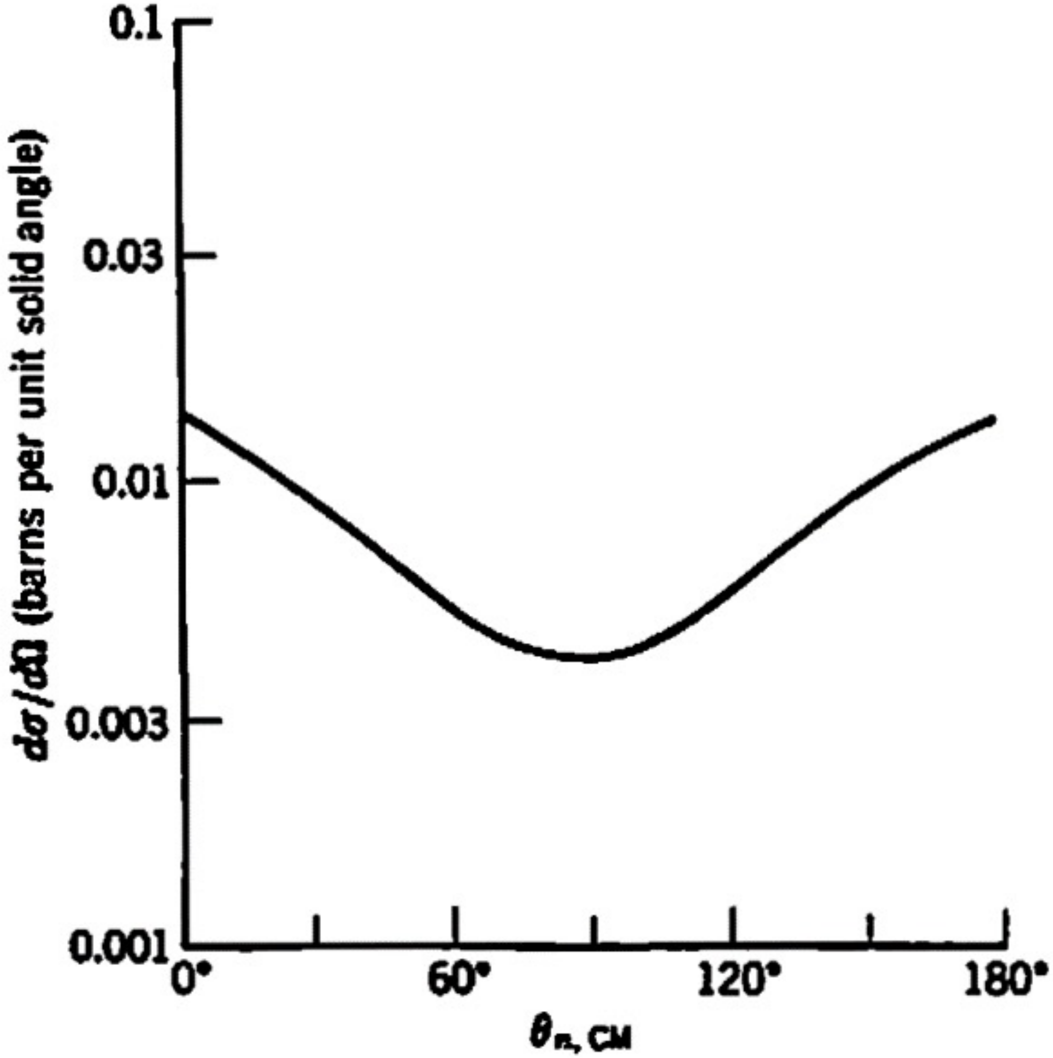
Properties of the strong force

- The strongest force in nature.
- The force is attractive.
- The force has a short range (2 fm).
- The strong force is independent of electric charge.
- The strong force is the sane for a neutron – neutron pair, a neutron – proton pair, and a proton – proton pair.

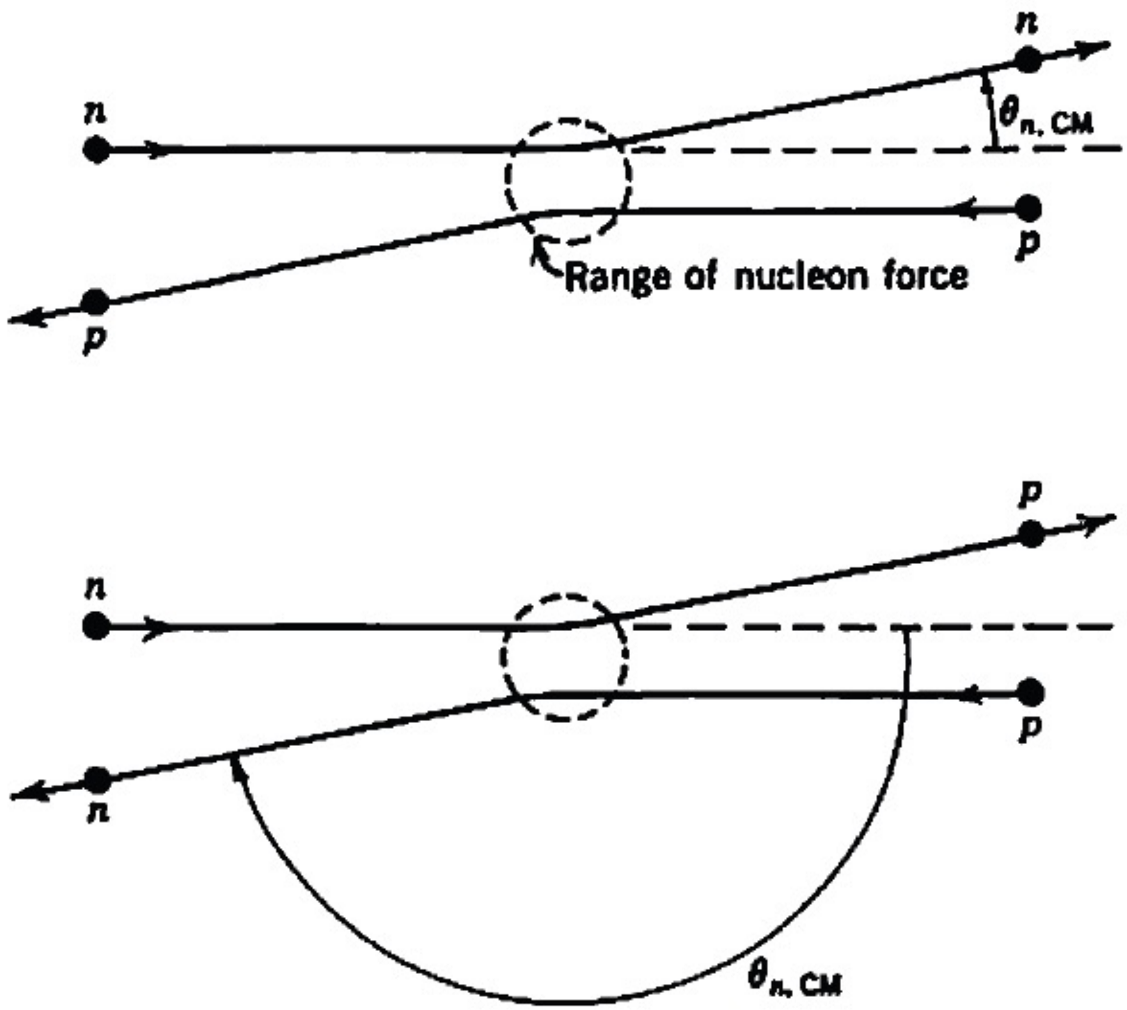
Scattering experiments allow us to problem the nucleon force.



The measured angular distribution is symmetric around 90 degrees.



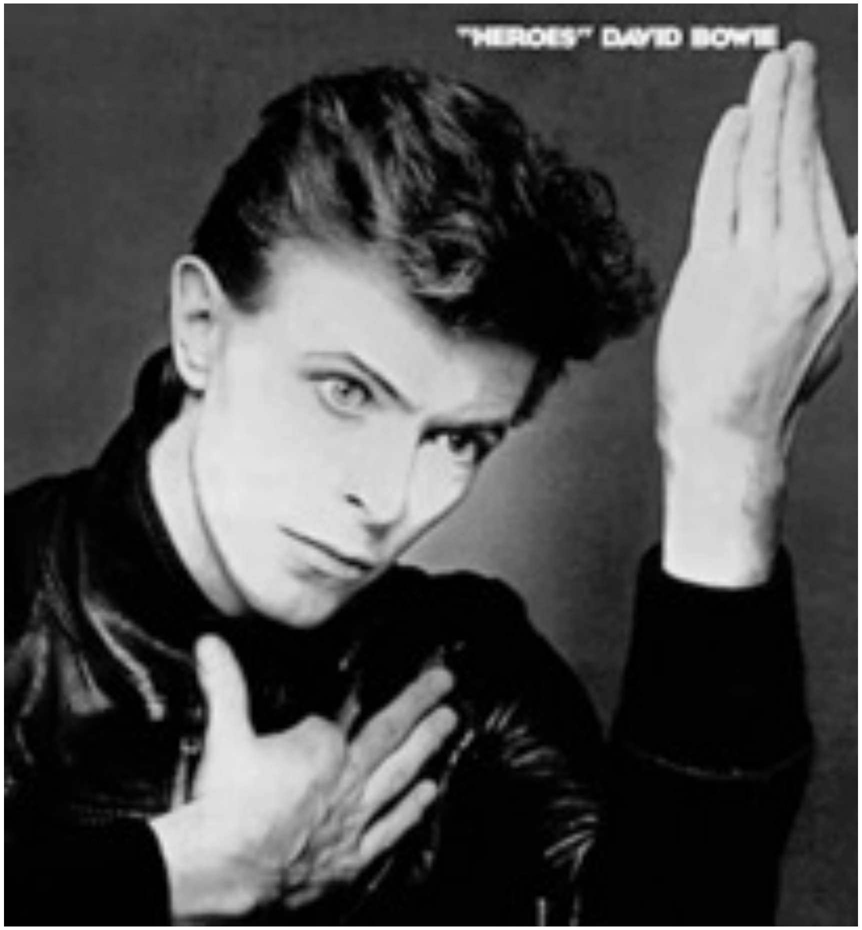
Observed angular distribution explained in terms of the exchange force.



3 Minute 58 Second Intermission.

- Since paying attention for 1 hour and 15 minutes is hard when the topic is physics, let's take a 3 minute 58 second intermission.

- You can:
  - Stretch out.
  - Talk to your neighbors.
  - Ask me a quick question.
  - Enjoy the fantastic music.



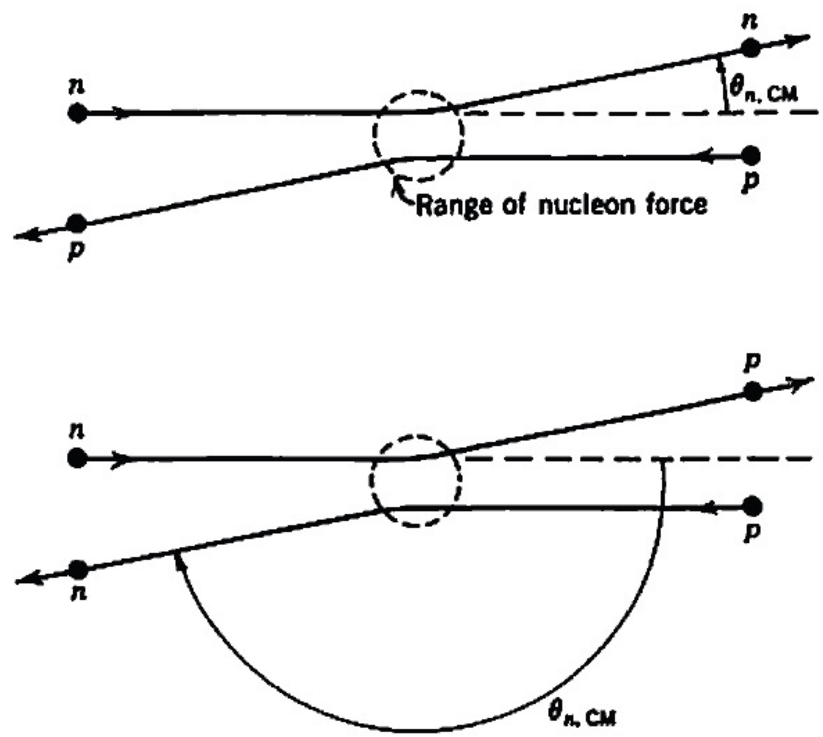
The scattering process.
Linear and angular momentum.

- In the center of mass, both nucleons will have the same linear momentum p.
- Consider what happens when the distance of closest approach r is the range of the nuclear force.
- The angular momentum L is

$$L = \sqrt{\ell(\ell+1)}\hbar \approx p\left(\frac{r}{2}\right) + p\left(\frac{r}{2}\right) = pr$$

- The linear moment and the angular momentum are thus related:

$$p = \frac{\sqrt{\ell(\ell+1)}\hbar}{r}$$

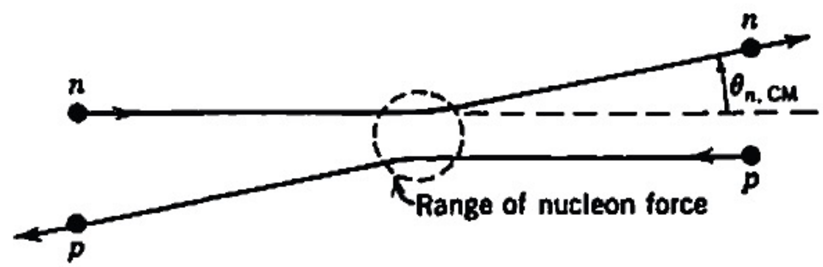


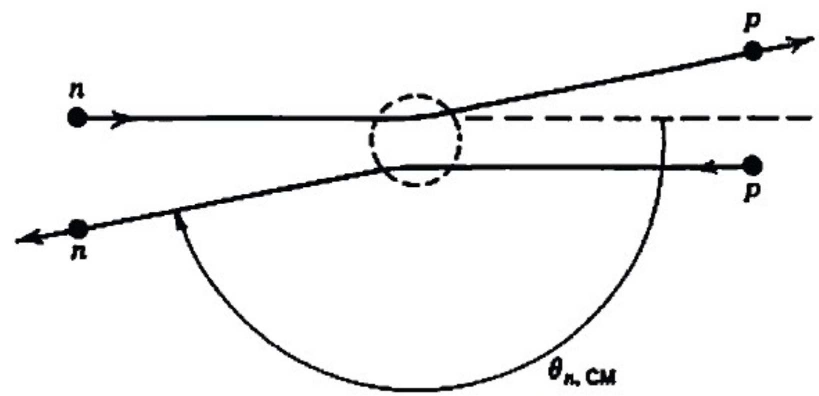
The scattering process. Linear and angular momentum.

- The kinetic energy of the incident nucleons is directly related to their linear momentum and thus their angular momentum:

$$K_p + K_n = 2\frac{p_n^2}{2m_n} = \frac{\ell(\ell+1)\hbar^2}{m_n r^2}$$

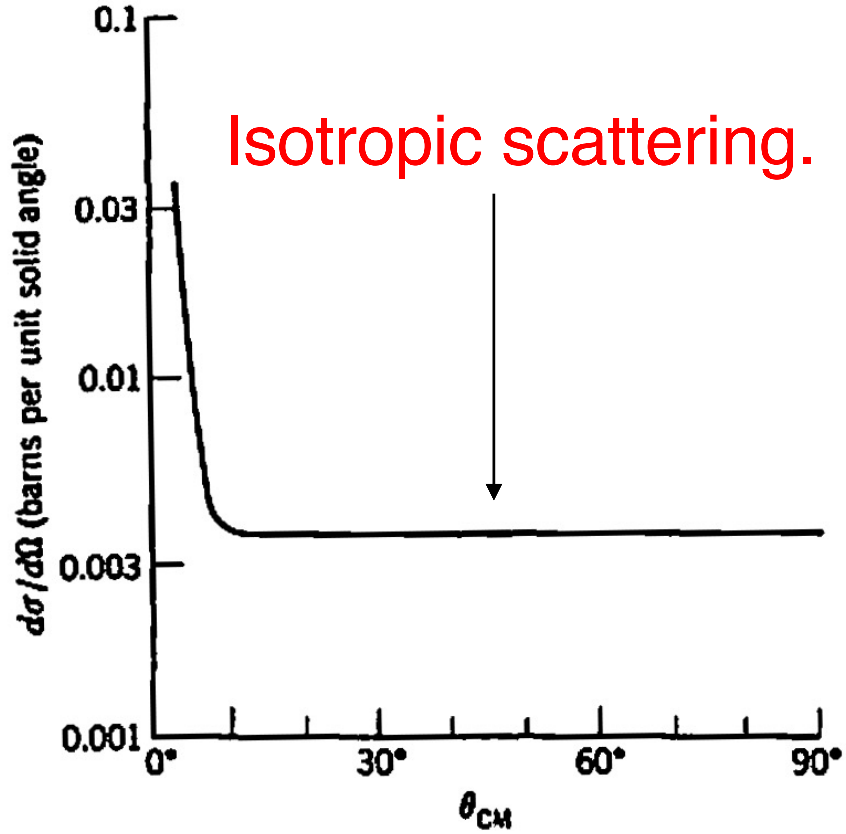
- For a given total kinetic energy, there is thus a maximum angular momentum for which the nuclear force influences the outcome of the reaction.
- For larger angular momenta, the minimum distance will exceed the range of the nuclear force.





The scattering process. Measuring angular distributions.

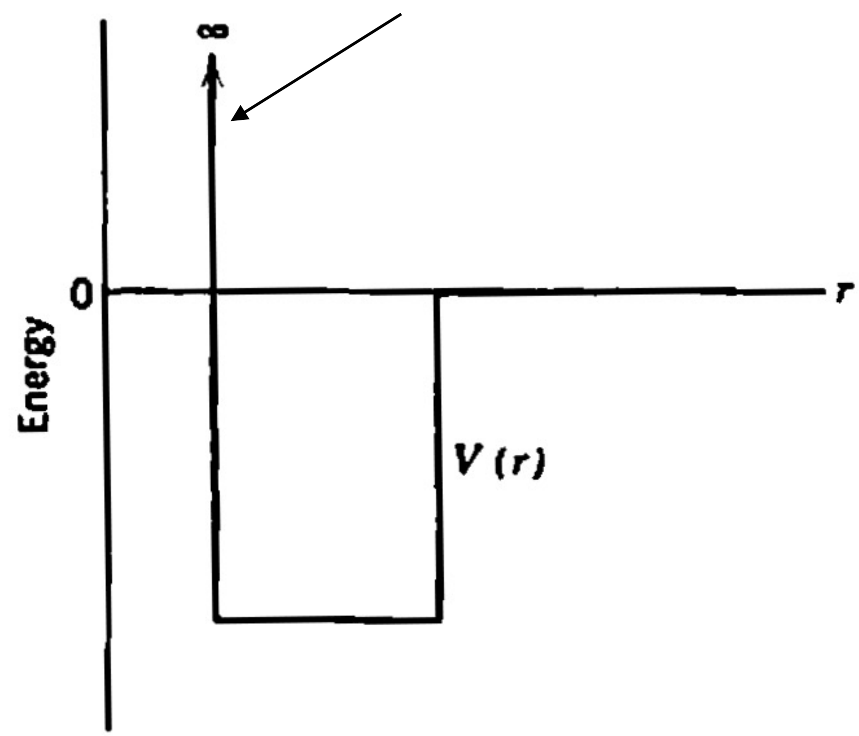
- Typical values for the kinetic energy:
  - $l = 1$: $K = 20$ MeV.
  - $l = 2$: $K = 60$ MeV.
  - $l = 3$: $K = 120$ MeV.
  - $l = 4$: $K = 200$ MeV.
- What do we expect?
  - At 40 MeV (20 MeV in CM):
    - $l = 0$: isotropic scattering.
    - $l = 1$: $V_{scatter} = 0$ MeV.
    - Scattering process: isotropic.
  - At 330 MeV (165 MeV in CM):
    - $l = 0$: isotropic scattering.
    - $l = 1$: $V_{scatter} = 0$ MeV.
    - $l = 2$: non-isotropic scattering.
    - $l = 3$: $V_{scatter} = 0$ MeV.
    - Scattering process: non-isotropic.



Explaining scattering. The repulsive core.

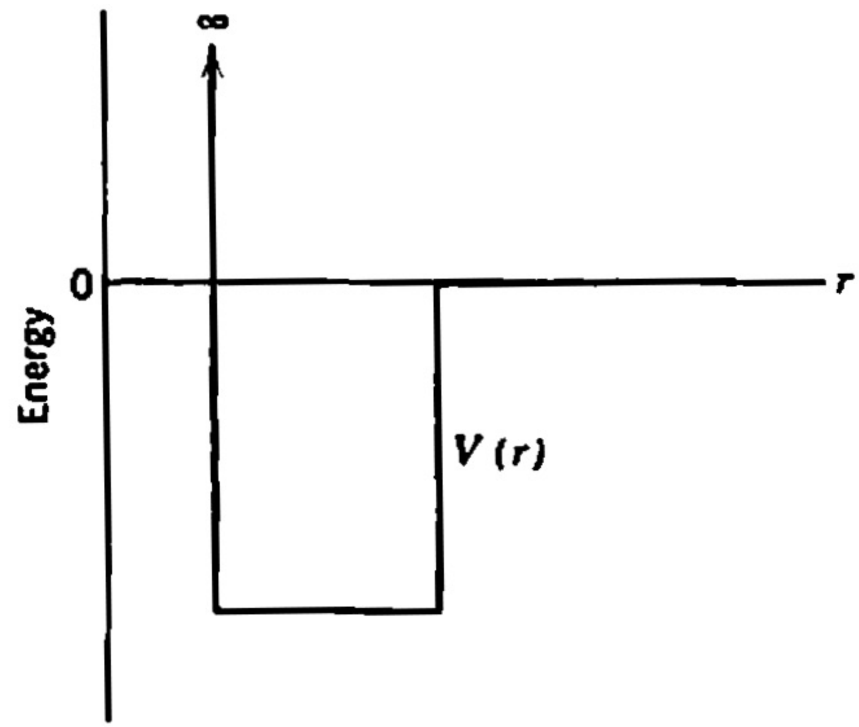
- The isotropic scattering can only be explained by destructive interference between the $l = 0$ and $l = 2$ wavefunctions.
- This requires a repulsive core in the nuclear potential.
- This core, at small distance impacts the $l = 0$ wavefunction, but not the $l = 2$ wavefunction. This is a result of differences in the distance of closest approach.

Repulsive core.

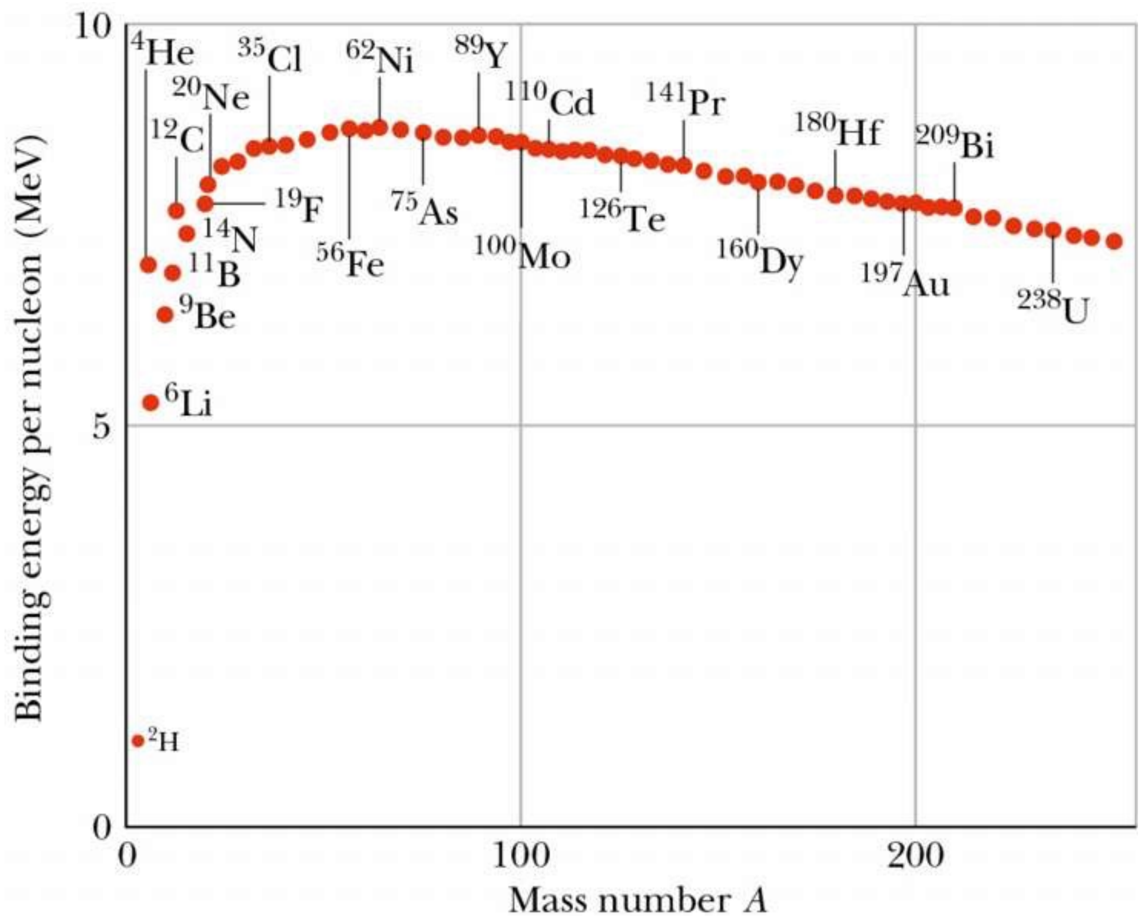


Explaining scattering. The repulsive core.

- Consequences of the repulsive core:
  - Saturation of the nuclear force.
  - Without the repulsive core:
    - all nucleons enclosed within a radius of 2 fm.
    - Nuclear binding energy would be proportional to A.
  - With the repulsive core:
    - Nucleons only interact with their closest neighbors.
    - Average distance between nucleons is 1.2 fm.
    - Nuclear radius is proportional to $A^{1/3}$.



Nuclear binding energy.
Certainly not proportional to *A*.



http://www.physics.ohio-state.edu/~kagan/phy367/Lectures/P367_lec_14.html

What have we learned so far?

- Nucleon potential:
  - Charge independent: strong force between neutrons and protons is the same as the strong force between neutrons and neutrons and between protons and protons.
  - When the two nucleons are in a state with odd l, the nucleon potential will be zero.
  - When the two nucleons are in a state with even l, the nucleon potential will be non-zero.
  - Pauli exclusion principle prohibits certain configurations (see next week).

ENOUGH FOR TODAY?