PROTON - PROTON AND NEUTRON -NEUTRON INTERACTIONS
• Important difference between the scattering of identical nucleons (proton-proton and neutron-neutron scattering) and the scattering of different nucleons (neutron-proton scattering) is the identical projectile and target nucleons must be described by a common wave function

• Only singlet spin states can thus contribute to the scattering - The antisymmetric spin wave function, correspond to a total combined spin of 0; that is, the spin orientations must be different
• There is no experimental way to distinguish the two situations in the figure.
When we square the scattered wave function to calculate the cross section, there will be a term proportional to the interference between the parts of the wave function that give scattering at $\Theta$ and at $-\Theta$. This interference is a purely quantum effect that has no classical analog.
PROTON – PROTON SCATTERING

• wave function must describe both Coulomb and nuclear scattering, and there will be an additional Coulomb-nuclear interference term in the cross section.

• The differential cross section is

\[
\frac{d\sigma}{d\Omega} = \left( \frac{e^2}{4\pi\epsilon_0} \right)^2 \frac{1}{4T^2} \left( \frac{1}{\sin^4(\theta/2)} + \frac{1}{\cos^4(\theta/2)} - \frac{\cos[\eta \ln \tan^2(\theta/2)]}{\sin^2(\theta/2) \cos^2(\theta/2)} \right) - \frac{2}{\eta} (\sin \delta_0) \frac{\cos[\delta_0 + \eta \ln \sin^2(\theta/2)]}{\sin^2(\theta/2)} + \frac{\cos[\delta_0 + \eta \ln \cos^2(\theta/2)]}{\cos^2(\theta/2)} + \frac{4}{\eta^2 \sin^2 \delta_0}
\] 

(4.43)
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• $T$ is the laboratory kinetic energy of the incident proton (assuming the target proton to be at rest)

• $\Theta$ is the scattering angle in the center-of-mass system

• $\delta_0$ the $l=0$ phase shift for pure nuclear scattering.

• $\alpha$ is the fine-structure constant

• Since the two protons are identical, we cannot tell the case in which the incident proton comes out at $\Theta$ and the target proton at $\Theta$ (in the center-of-mass system) from the case $\Theta$.

• Scattering cross section must include a characteristic Coulomb (Rutherford) term $\sin^4(-\Theta) + \cos^4(-\Theta)$.

  This term describes the interference between Coulomb scattering at $-\Theta$ and $-\Theta$. 
• values for the proton-proton scattering length and effective range
  \[ a = -7.82 \pm 0.01 \text{ fm} \]
  \[ r_o = -2.79 \pm 0.02 \text{ fm} \]

• The scattering length, which measures the strength of the interaction, includes Coulomb as well as nuclear effects and thus cannot be compared directly with the corresponding np value.