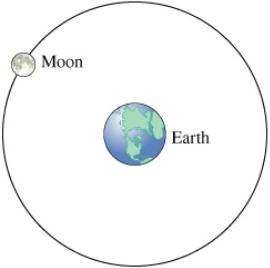
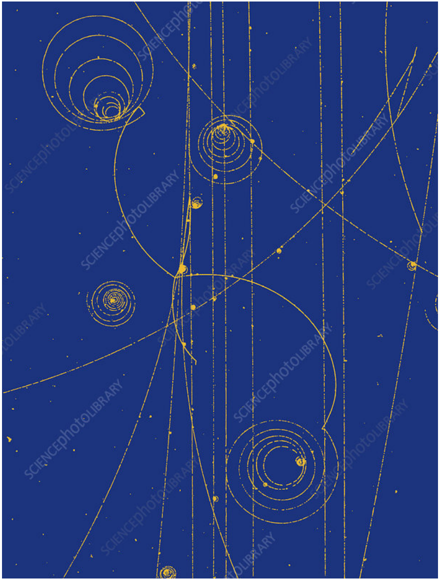
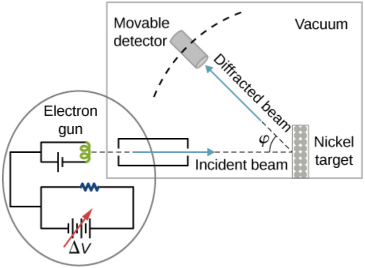
What's a Particle? 1

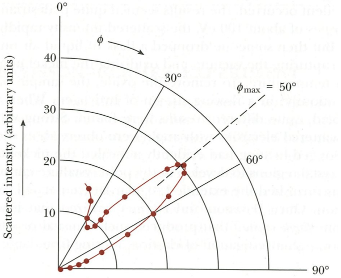




Quantum Collisions - 1 2

Particles transfer energy to other particles by collisions - their trajectories are altered by the forces acting among them. The first figure shows the setup of Davisson and Germer to make an electron beam with $E_e = 54\ \mathrm{eV}$, collide it elastically with a nickel target, and measure the angular distribution. The result is shown in the second figure. The scattered intensity is proportional to the distance of the point from the origin. What is the intensity pattern for elastically scattered electrons? Use the peak near $\phi = 50^\circ$ to extract information about the beam-target interaction.





Quantum Collisions - 1 3

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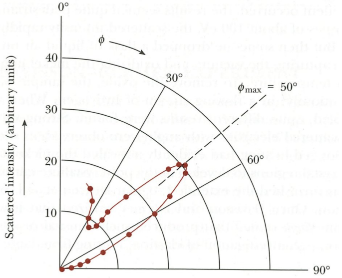
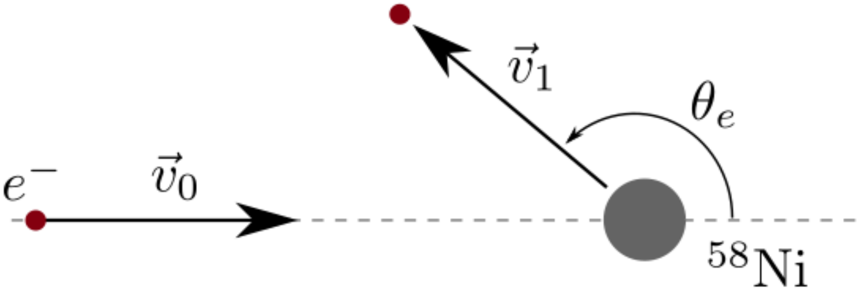
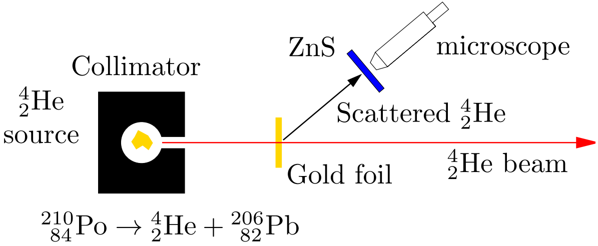


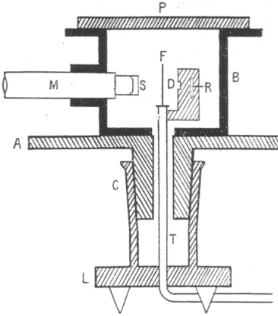
Consider the elastic collision of an electron of energy $E_{beam} = 54\ \mathrm{eV}$ with a $^{58}\mathrm{Ni}$ target. If the scattered electron is detected at an angle $\theta_e = 130^\circ$, what is its energy?



The Differential Cross Section - 1

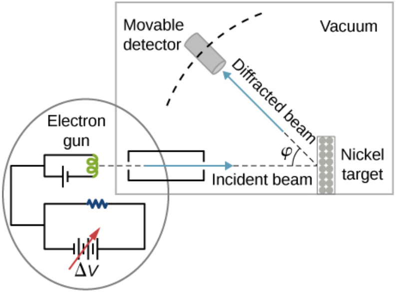
Ernest Rutherford discovered the atomic nucleus in 1913 with the apparatus shown below. What is the distance of closest approach of a $^4\mathrm{He}$ nucleus to the $^{197}_{79}\mathrm{Au}$ target nucleus if only the Coulomb force is active? Is the Coulomb force the only one active? The energy of the $^4\mathrm{He}$ emitted by the $^{210}_{84}\mathrm{Po}$ to make the beam is $\mathrm{E}(^4\mathrm{He}) = 5.407\ \mathrm{MeV}$.



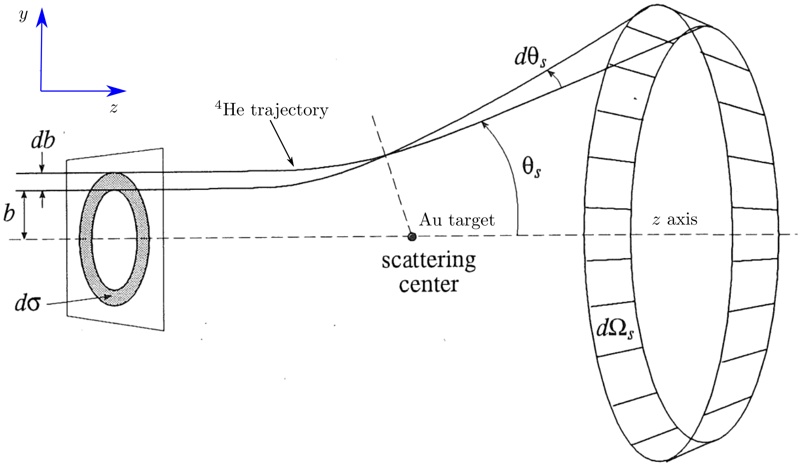


Sim is here.

Davisson and Germer in 1923-1927 measured electron scattering from nickel using the apparatus shown below. Consider scattering an electron off a bare nucleus. What is the distance of closest approach of the electron to the $^{58}_{28}\mathrm{Ni}$ target nucleus if only the Coulomb force is active? Is the Coulomb force the only one active? The energy of the electron is $\mathrm{E(e^-)} = 54\ \mathrm{eV}$. How much does the differential cross section change from 90° to 180°?

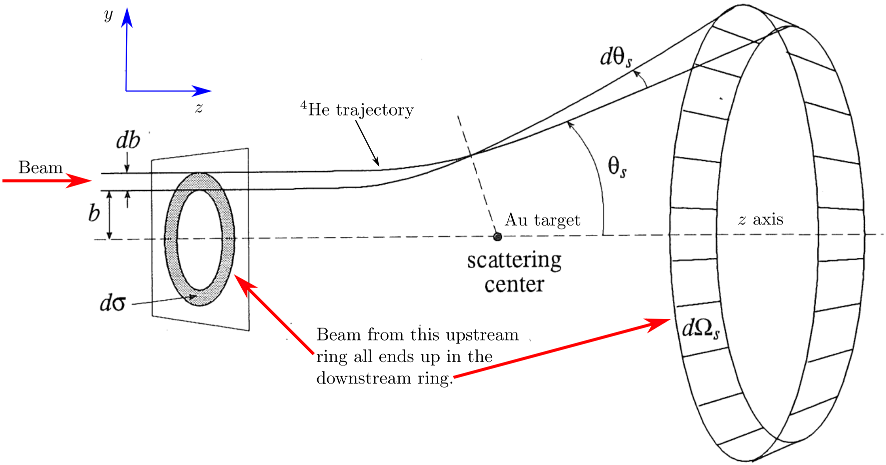


Device built by Davisson and Germer like the one used in their Nobel-Prize winning experiments.



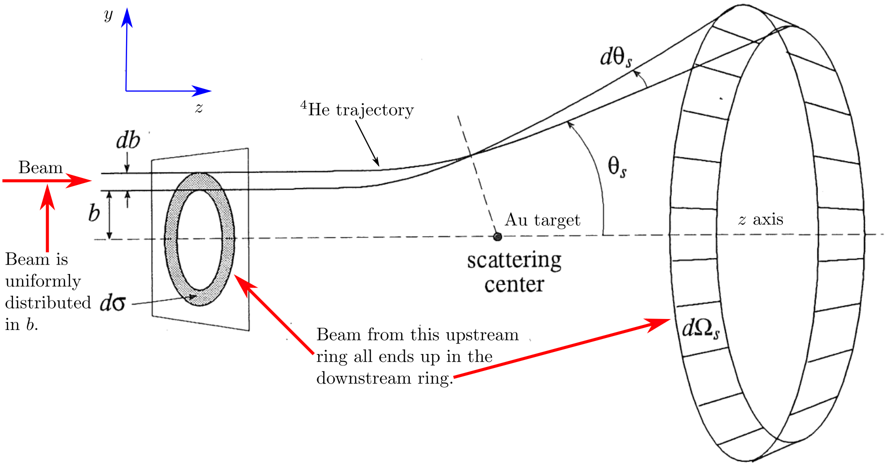
y
z
^{4}He trajectory
db
b
$d\sigma$
$d\theta_s$
θ_s
Au target
scattering center
z axis
$d\Omega_s$

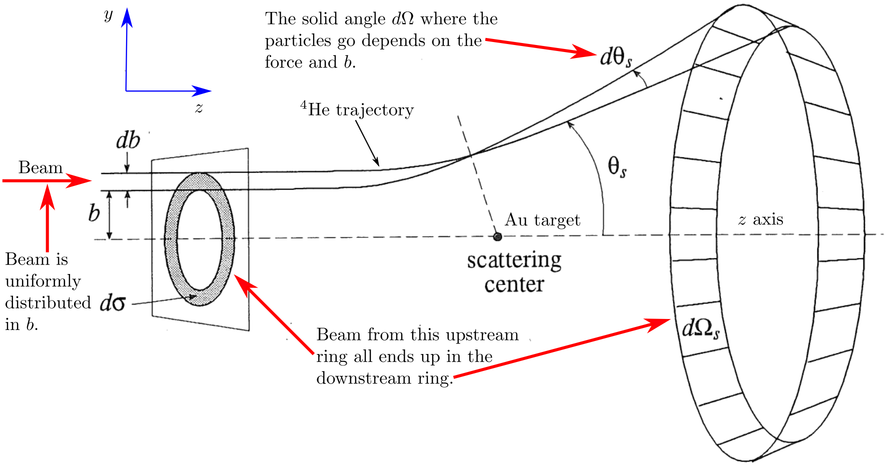
The Differential Cross Section - 4

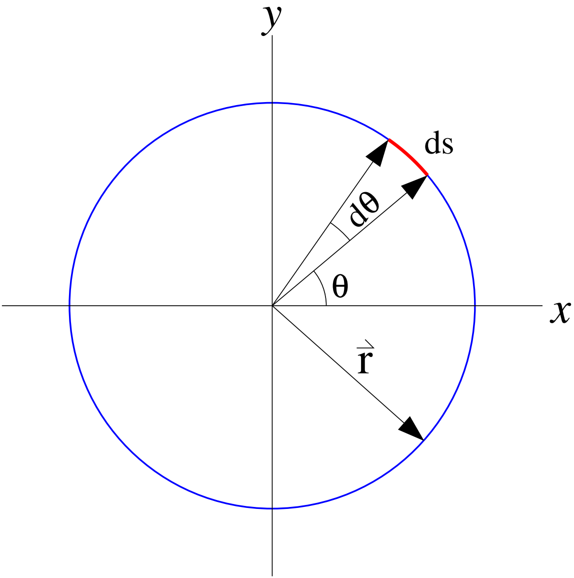


Beam from this upstream ring all ends up in the downstream ring.

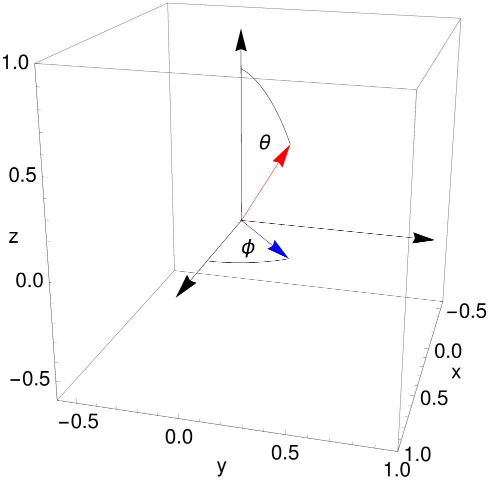
The Differential Cross Section - 5

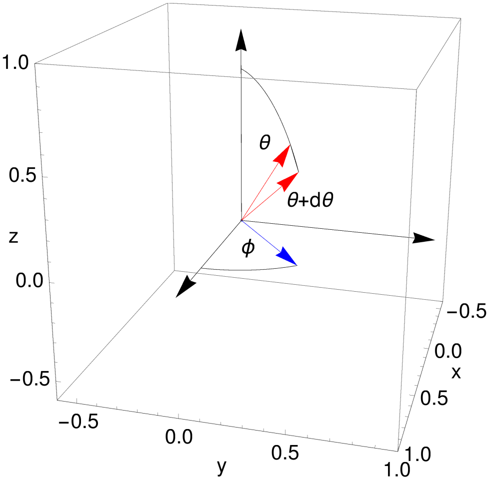


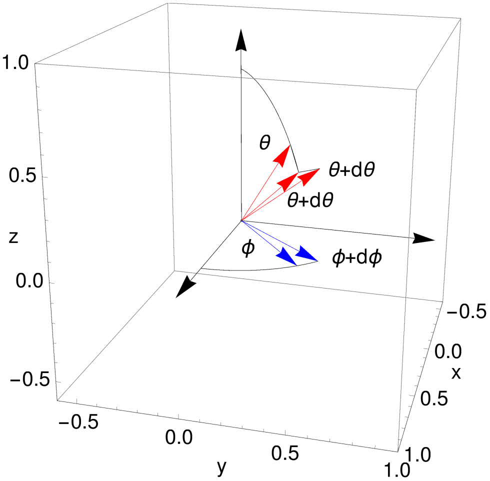

y
z
The solid angle $d\Omega$ where the particles go depends on the force and b.
$d\theta_s$
^{4}He trajectory
db
Beam
b
Beam is uniformly distributed in b.
$d\sigma$
θ_s
Au target
z axis
scattering center
Beam from this upstream ring all ends up in the downstream ring.
$d\Omega_s$

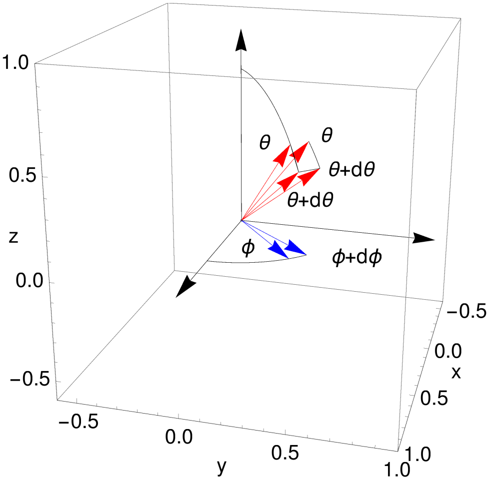


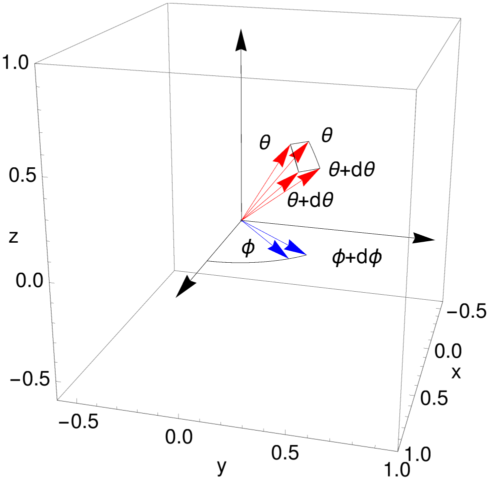
$$d\theta = \frac{ds}{|\vec{r}|}$$


1.0
0.5
z
0.0
−0.5
θ
ϕ
−0.5
0.0
0.5
y
1.0
−0.5
0.0
x
0.5
1.0

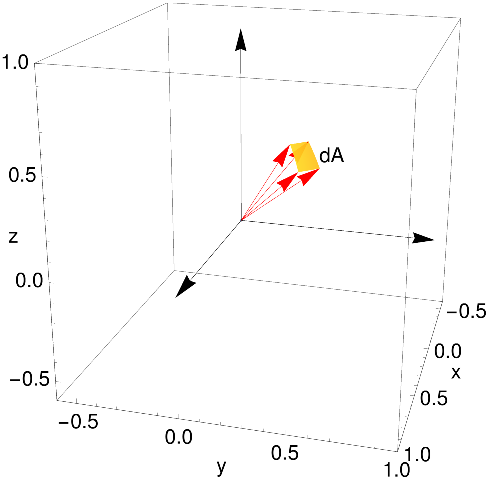

1.0
0.5
z
0.0
−0.5
θ
θ+dθ
ϕ
−0.5
0.0
x
0.5
1.0
−0.5
0.0
y
0.5
1.0

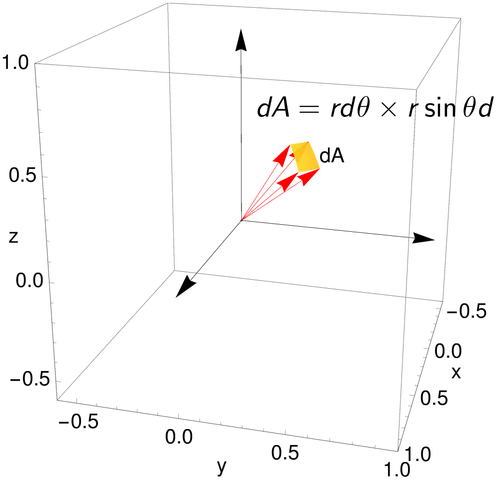

1.0
0.5
z
0.0
−0.5
−0.5
0.0
0.5
y
1.0
−0.5
0.0
x
0.5
1.0
θ
θ+dθ
θ+dθ
ϕ
ϕ+dϕ


1.0
0.5
z
0.0
−0.5
−0.5
0.0
y
0.5
1.0
−0.5
0.0
x
0.5
1.0
θ
θ
θ+dθ
θ+dθ
ϕ
ϕ+dϕ

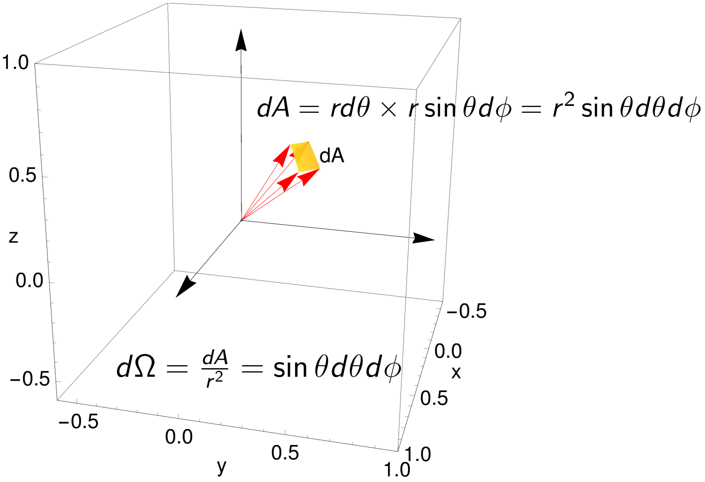


1.0
0.5
z
0.0
−0.5
θ
θ
θ+dθ
θ+dθ
ϕ
ϕ+dϕ
−0.5
0.0
x
0.5
1.0
−0.5
0.0
y
0.5
1.0

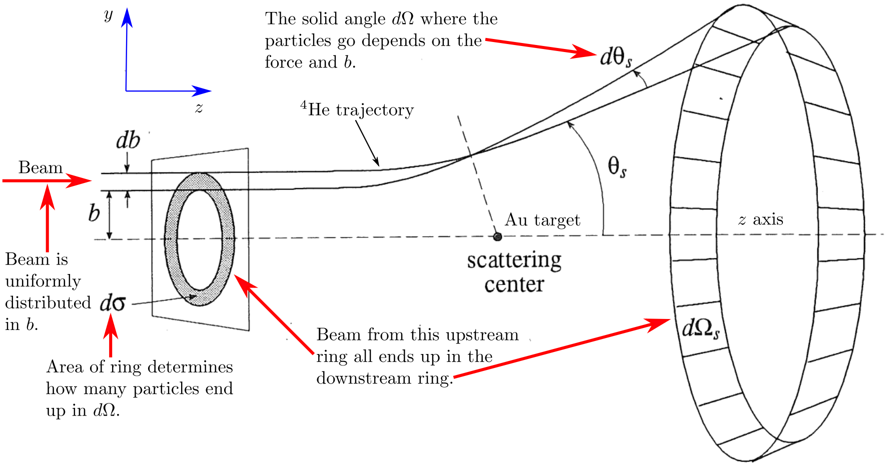

1.0
0.5
z
0.0
−0.5
−0.5
0.0
0.5
y
1.0
−0.5
0.0
x
0.5
1.0
dA



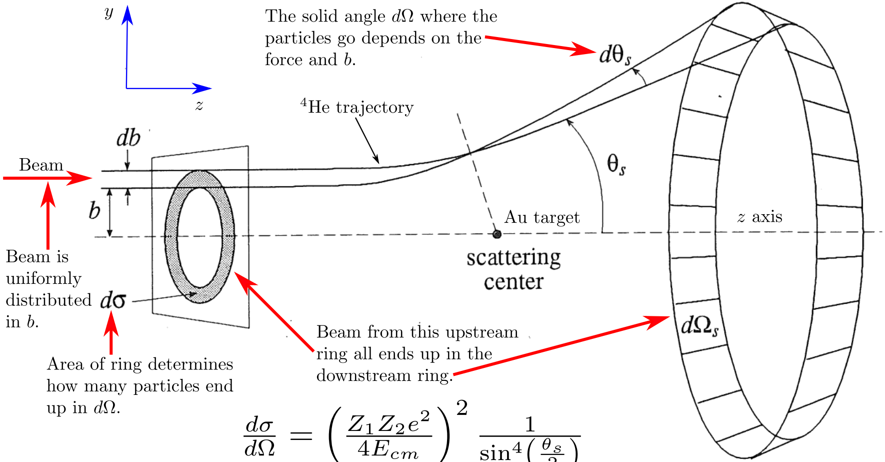
$$dA = rd\theta \times r \sin\theta d\phi = r^2 \sin\theta d\theta d\phi$$



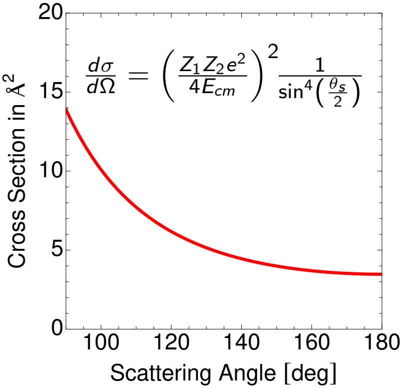
$dA = rd\theta \times r\sin\theta d\phi = r^2 \sin\theta d\theta d\phi$
dA
$d\Omega = \frac{dA}{r^2} = \sin\theta d\theta d\phi$
1.0
0.5
z
0.0
−0.5
−0.5
0.0
0.5
1.0
y
−0.5
0.0
x
0.5
1.0



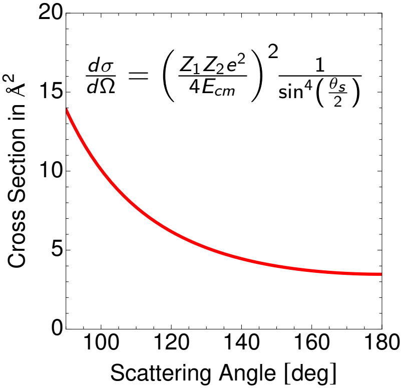
y
z
The solid angle $d\Omega$ where the particles go depends on the force and b.
$d\theta_s$
^{4}He trajectory
db
Beam
b
θ_s
Au target
z axis
scattering center
Beam is uniformly distributed in b.
$d\sigma$
$d\Omega_s$
Beam from this upstream ring all ends up in the downstream ring.
Area of ring determines how many particles end up in $d\Omega$.



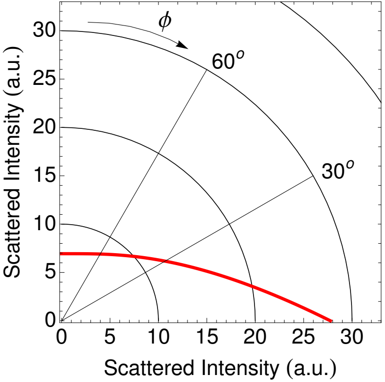
$$\frac{d\sigma}{d\Omega} = \left(\frac{Z_1 Z_2 e^2}{4E_{cm}}\right)^2 \frac{1}{\sin^4\left(\frac{\theta_s}{2}\right)}$$



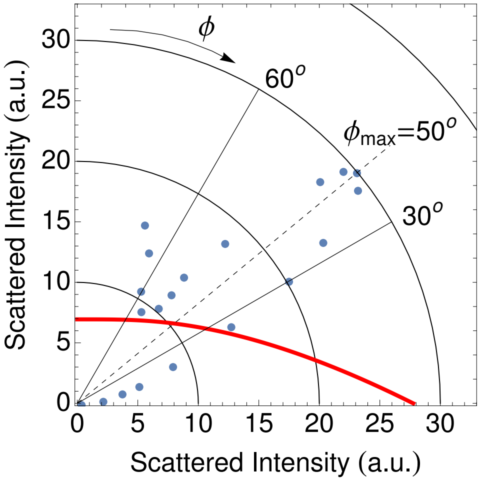
$$\frac{d\sigma}{d\Omega} = \left(\frac{Z_1 Z_2 e^2}{4E_{cm}}\right)^2 \frac{1}{\sin^4\left(\frac{\theta_s}{2}\right)}$$
Cross Section in Å^2
Scattering Angle [deg]
0
5
10
15
20
100
120
140
160
180



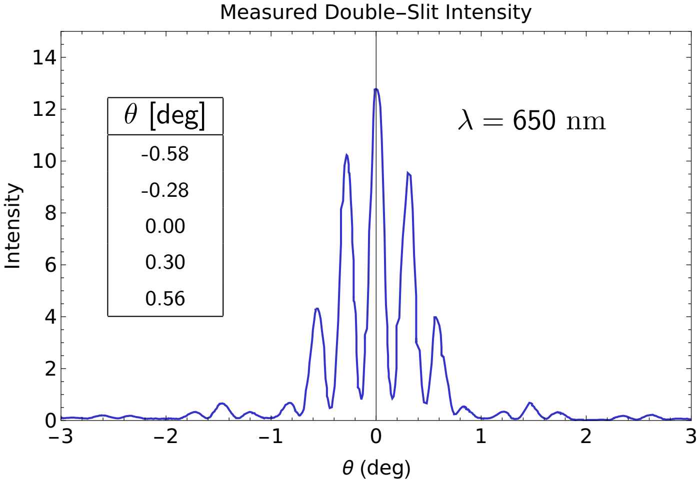
Cross Section in Å^2
Scattering Angle [deg]
$\frac{d\sigma}{d\Omega} = \left(\frac{Z_1 Z_2 e^2}{4E_{cm}}\right)^2 \frac{1}{\sin^4\left(\frac{\theta_s}{2}\right)}$
0
5
10
15
20
100
120
140
160
180

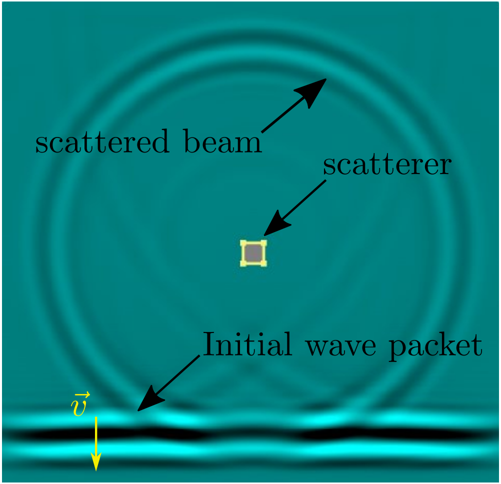


ϕ
60^o
30^o
Scattered Intensity (a.u.)
Scattered Intensity (a.u.)
0
5
10
15
20
25
30


ϕ
60^o
ϕ_{max}=50^o
30^o
30
25
20
15
10
5
0
0
5
10
15
20
25
30
Scattered Intensity (a.u.)
Scattered Intensity (a.u.)

A double slit interference pattern from Physics 132 is shown below. The angular distance of the closest bright spots to the central peak is shown in the inset.





The video is here. The simulations are here (use Scattering 1) and here (use Scattering example and Add 'Box').

1. Maxwell showed that EM waves transmit energy and momentum.

$$p = \frac{energy\ absorbed}{c} = \frac{E}{c}$$

2. Planck used the quantum hypothesis first to explain blackbody light emission.

$$E = hf$$

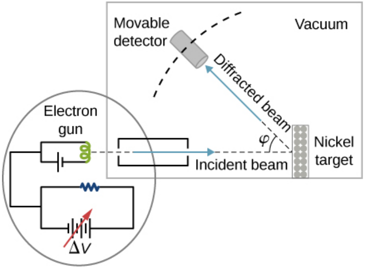
3. Louis de Broglie proposed in 1924 that electrons have wave-like properties.

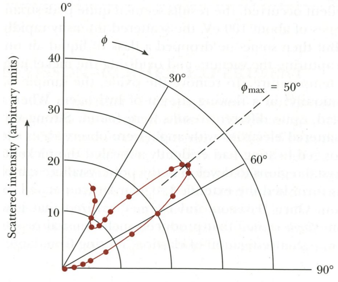
$$p = \frac{E}{c} = \frac{hf}{c} = \frac{h}{\lambda}$$

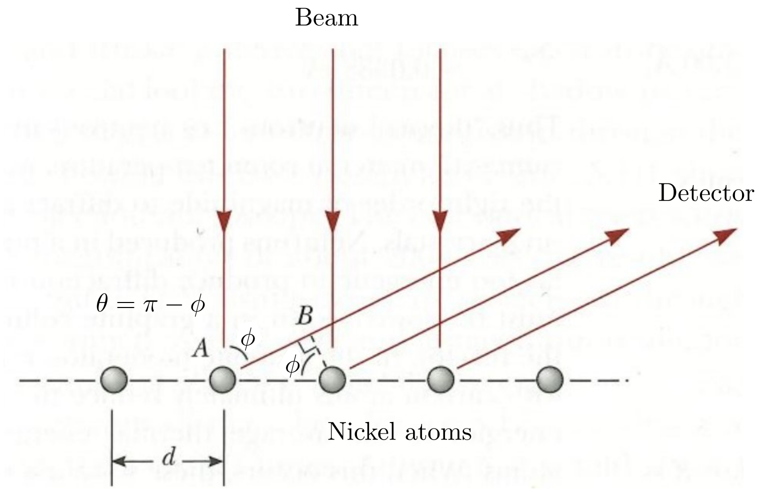
He was a grad student at the University of Paris at the time.

Quantum Collisions - 1

Particles transfer energy to other particles by collisions - their trajectories are altered by the forces acting among them. The first figure shows the setup of Davisson and Germer to make an electron beam with $E_{beam} = 54$ eV, collide it elastically with a nickel target, and measure the angular distribution. The result is shown in the second figure. The scattered intensity is proportional to the distance of the point from the origin. What is the intensity pattern for elastically scattered electrons? Use the peak at $\phi = 50^\circ$ to extract information about the beam-target interaction.







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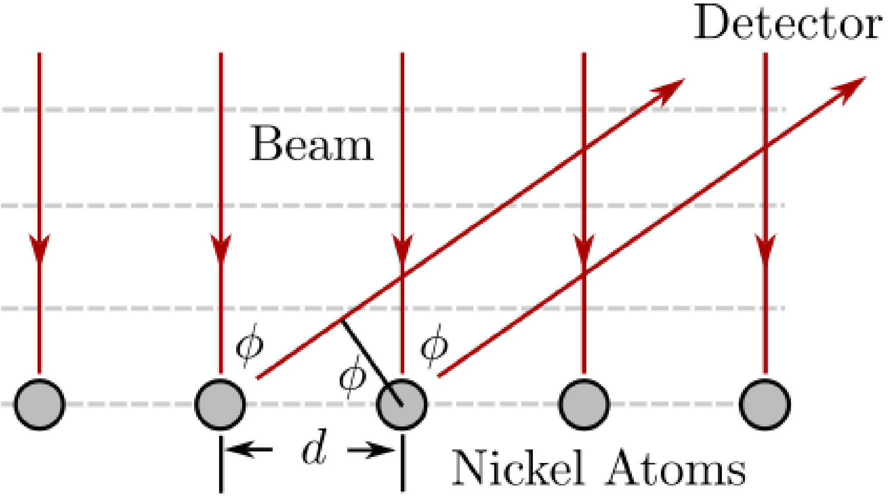
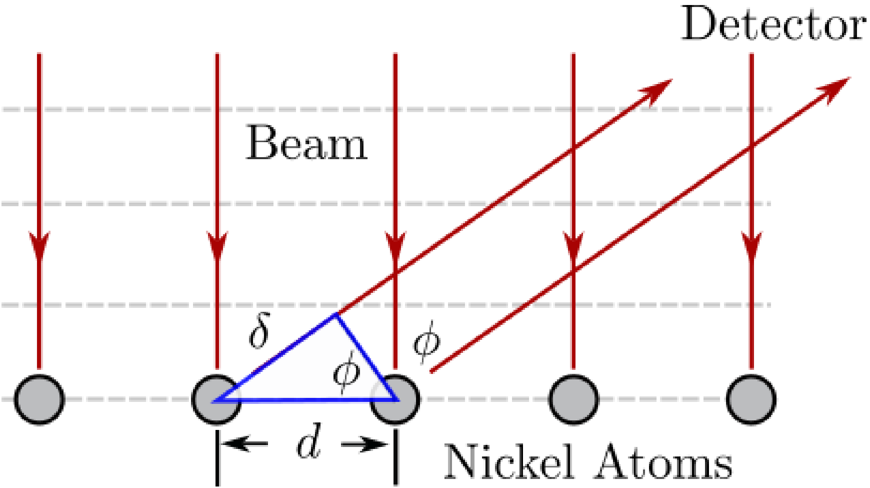
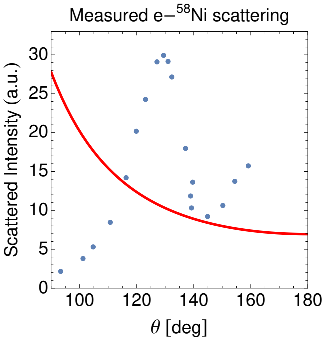


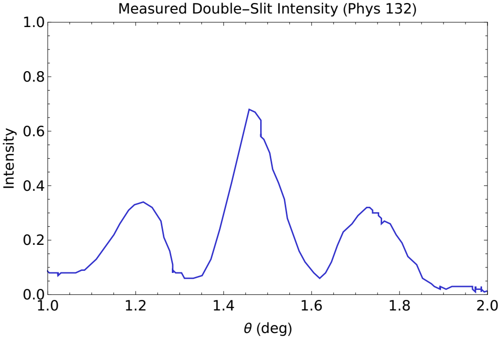
The video is here. The simulations are here (use Scattering 1) and here (use Scattering example and Add 'Box') .

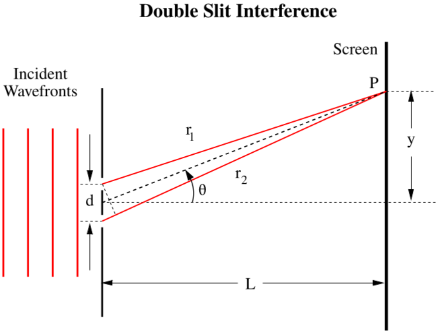


The video is here. The simulations are here (use Scattering 1) and here (use Scattering example and Add 'Box') .

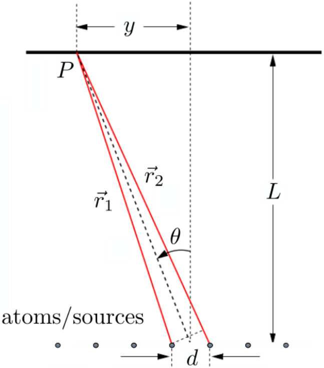
Comparing Angular Distributions







Double Slit Interference
Screen
Incident Wavefronts
P
r_1
r_2
y
d
θ
L



y
P
$\vec{r}_2$
$\vec{r}_1$
L
θ
atoms/sources
d