Python Final Project

# Rutherford Scattering Simulation

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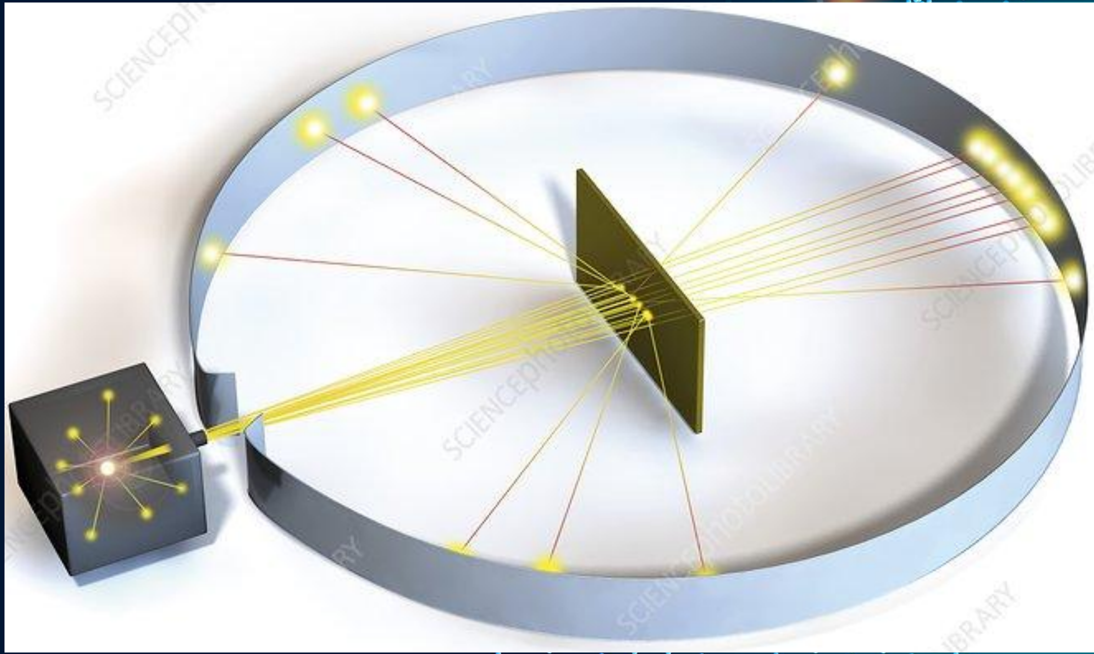
# Background

Science

# Rutherford Scattering

Ernest Rutherford, along with Hans Geiger and Ernest Mardsen, conducted an experiment in 1909 where alpha particles were sent towards a layer of gold foil and their final positions were marked on screen around the gold foil. What was discovered was that the alhpa particles changed direction once it interacted with the gold atoms. This led to the developement of the Rutherford model and also the Bohr Model later on.



# Rutherford Scattering

Rutherford scattering experiment is one of the most famous experiments in physics

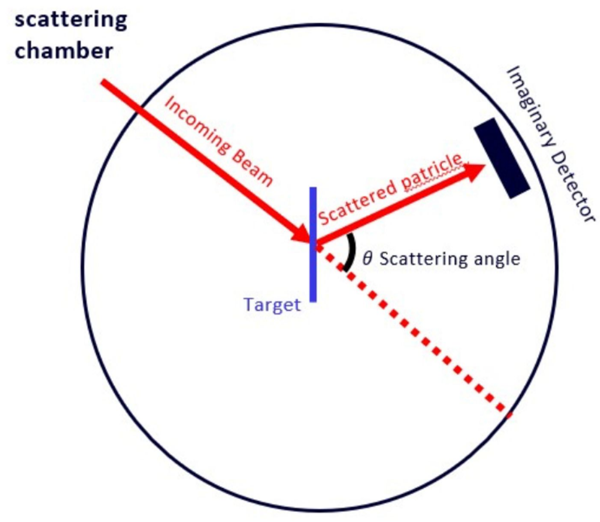
- Demonstrates the nuclear model
- Allows for direct measurement of nuclear charge

$$\frac{d\sigma}{d\Omega} = (\frac{Z_1 Z_2 e^2}{16\pi\epsilon_0 E})^2 sin^{-4}(\frac{\theta}{2})$$ (*1)

The angle distribution of scattered alpha particles can be explained by Coulomb's law, the same equation we use in the simulation:

$$F = ma$$

$$F = F_{Coulomb\ Force} = k\frac{Z_1 Z_2 e^2}{r^2}$$



# Differential Cross Section

Differential Cross Section: Probability of scattering incident particles into θ direction.

Reason for the name

⇨Differential Cross Section has the dimension of Area/Solid Angle (mb/sr)

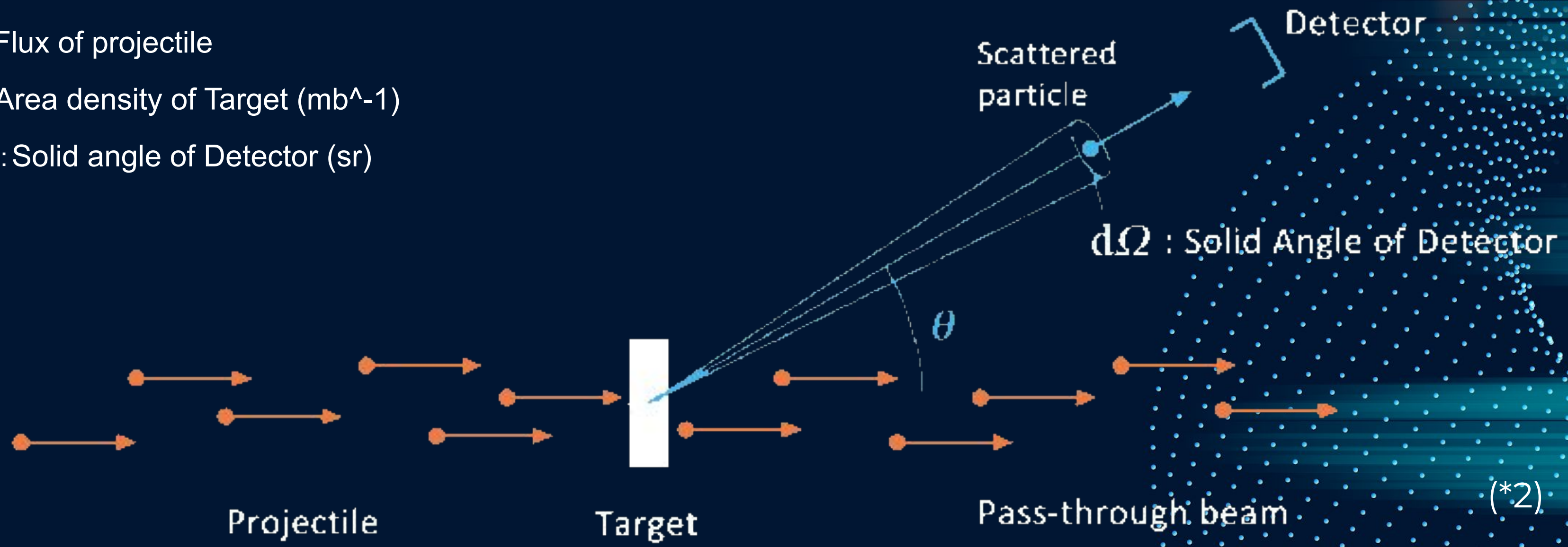
Measured Differential Cross Section: $\sigma(\theta)=Y/XNd\Omega$（σ is propotional to Counts rate Y）

Y ：Counts Rate

X：Flux of projectile

N：Area density of Target (mb^-1)

dΩ：Solid angle of Detector (sr)




(*2)

# Methods
# & Techniques

Beautiful Python

# Python Program

Libraries Imported:

- Numpy
- Matplotlib.pyplot

Uses Object oriented programming

- Created classes for vector properties and particles

# **Object Oriented**
## Particles & Vectors

Particles created with **initial parameters**

- pos [Vector object!] - Position in space
- vel [Vector object!] - Velocity
- acc [Vector object!] - Acceleration
- charge [Scalar]- Charge
- mass [Scalar] - Mass

Particles have the function **move(self, other, dt)**

- This makes a step in the simulation for a given time step “dt”
- Utilizes:
    - Projectile motion equation
    - Differential equations
    - Coulomb’s force

### Coulomb’s Formula

$$F = \frac{1}{4\pi\varepsilon_o\varepsilon_r} \cdot \frac{q_1 q_2}{d^2} = \frac{1}{4\pi\varepsilon_o K} \cdot \frac{q_1 q_2}{d^2}$$

$$F = \frac{1}{4\pi\varepsilon} \cdot \frac{q_1 q_2}{d^2}$$

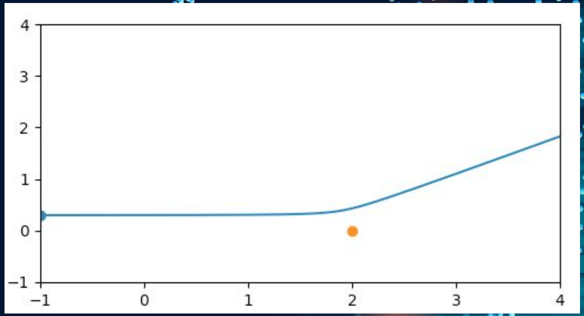
https://byjus.com/jee/coulombs-law/

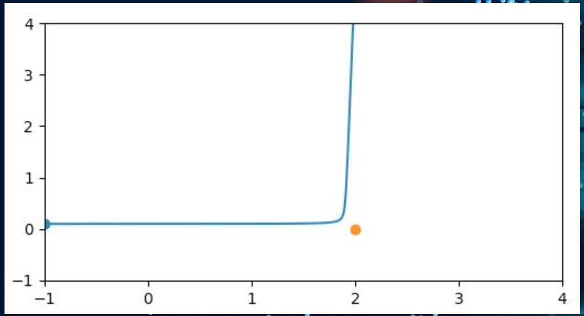
# Testing: Start Simple!

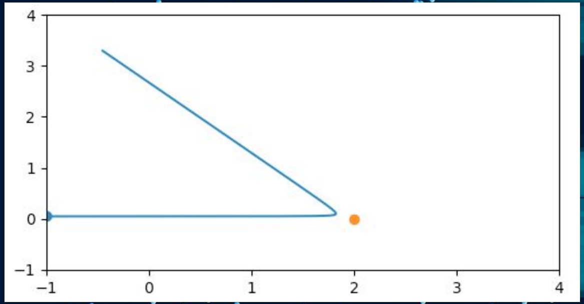
Using Graphs As a Model

- Electrons (9.1e-21 C) were used to simplify the model, but other charges (such as alpha particle's charge of 3.2e-19 C) can be applied
- One Projectile Electron Vs One Stationary Electron
- Multiple Projectile Electrons Vs One Stationary electron

**Graphing with tails allowed us to validate our program!**



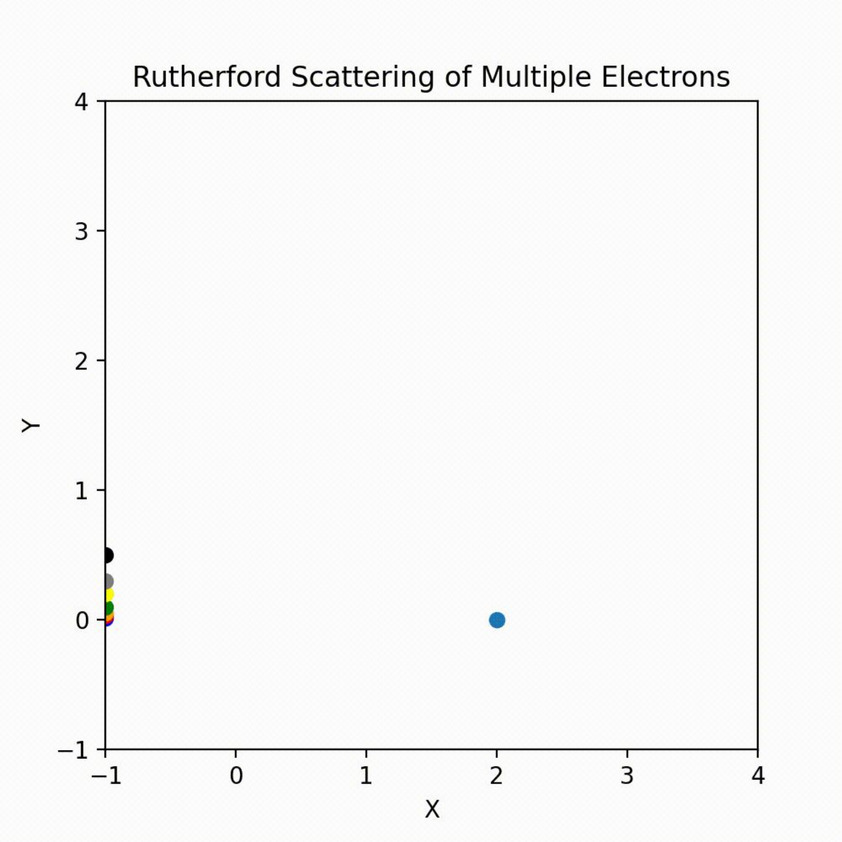
# Findings + Results

MP4/GIF
Interpretations

# Animation as a GIF (Originally an MP4)

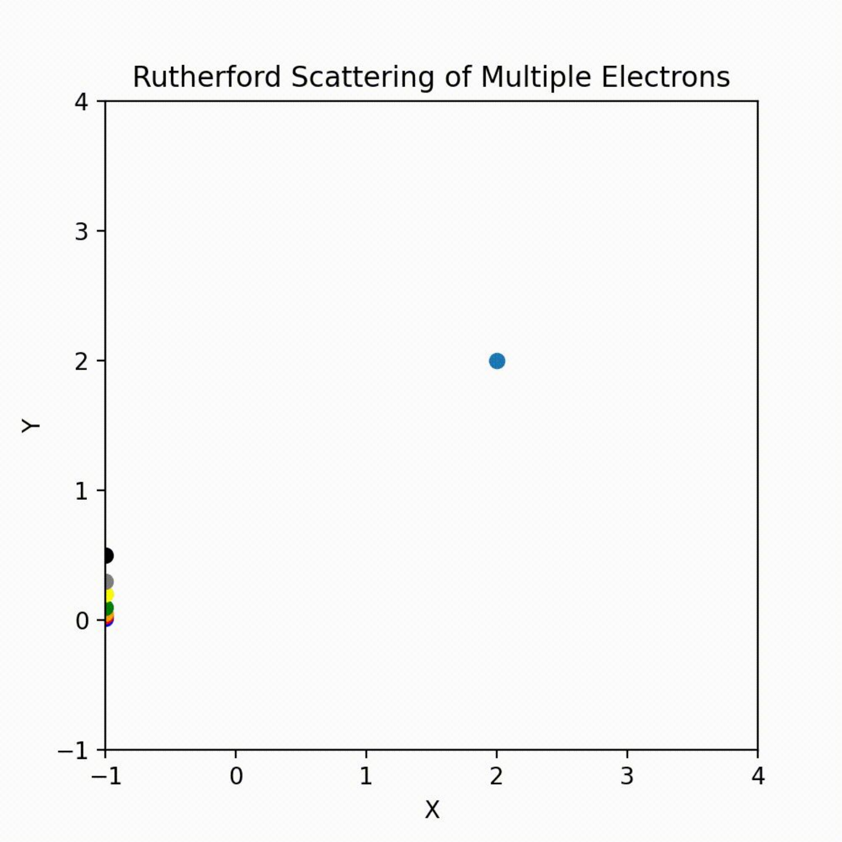
Animation using FFMpegWriter in python

- Provides a visual for interactions between electrons and their repulsive coulomb forces



# Animation as a GIF (Originally an MP4)

Using classes allows the user to vary the initial conditions with little variation of the program



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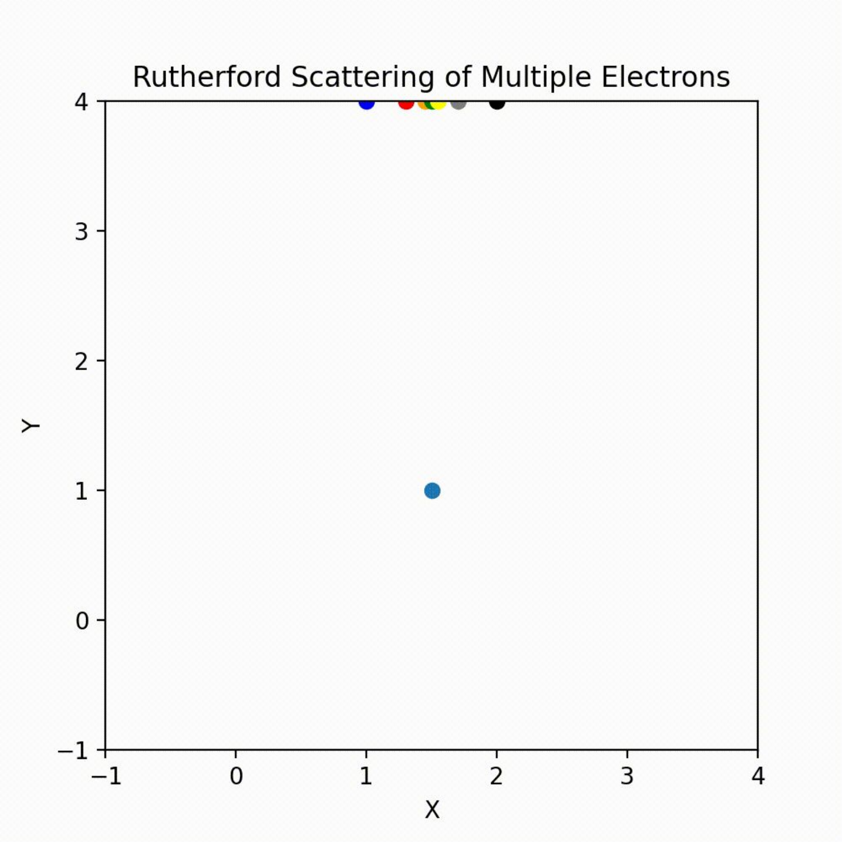
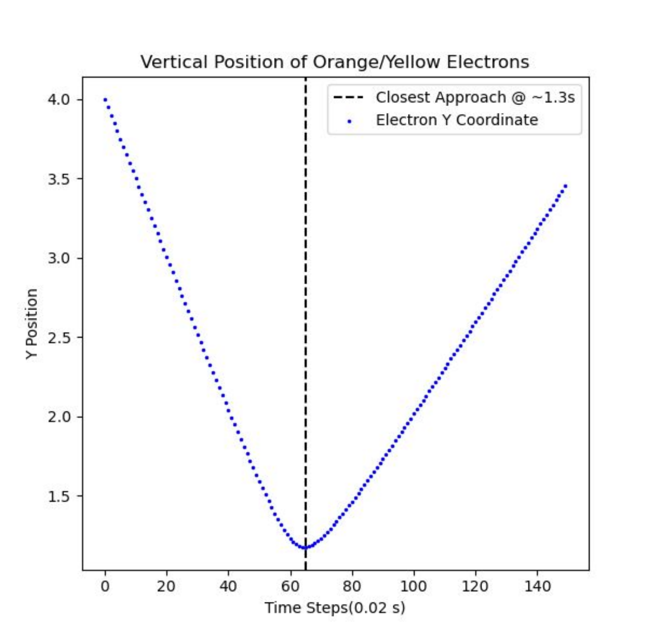


# Interpretation: Data Analysis

- All animations are created from CSV files which can also be used to conduct data analysis
- Dataframes were used in this example

| | X_0.01 | Y_0.01 | X_0.03 | Y_0.03 | X_0.05 | Y_0.05 | X_0.1 | Y_0.1 | X_0.2 | Y_0.2 | X_0.3 | Y_0.3 | X_0.5 | Y_0.5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **0** | 1.000000 | 3.999500 | 1.300000 | 3.999500 | 1.450000 | 3.999500 | 1.5 | 3.999500 | 1.550000 | 3.999500 | 1.700000 | 3.999500 | 2.000000 | 3.999500 |
| **1** | 0.999998 | 3.949514 | 1.299999 | 3.949514 | 1.450000 | 3.949514 | 1.5 | 3.949514 | 1.550000 | 3.949514 | 1.700001 | 3.949514 | 2.000002 | 3.949514 |
| **2** | 0.999991 | 3.899555 | 1.299996 | 3.899557 | 1.449999 | 3.899557 | 1.5 | 3.899557 | 1.550001 | 3.899557 | 1.700004 | 3.899557 | 2.000009 | 3.899555 |
| **3** | 0.999979 | 3.849625 | 1.299991 | 3.849630 | 1.449998 | 3.849631 | 1.5 | 3.849631 | 1.550002 | 3.849631 | 1.700009 | 3.849630 | 2.000021 | 3.849625 |
| **4** | 0.999962 | 3.799725 | 1.299984 | 3.799733 | 1.449996 | 3.799735 | 1.5 | 3.799735 | 1.550004 | 3.799735 | 1.700016 | 3.799733 | 2.000038 | 3.799725 |
| **...** | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| **145** | -0.522003 | -2.688514 | -1.803985 | -1.316116 | -1.630718 | 3.333901 | 1.5 | 4.884548 | 4.630718 | 3.333901 | 4.803985 | -1.316116 | 3.522003 | -2.688514 |
| **146** | -0.540884 | -2.735317 | -1.843825 | -1.347067 | -1.671553 | 3.363546 | 1.5 | 4.935016 | 4.671553 | 3.363546 | 4.843825 | -1.347067 | 3.540884 | -2.735317 |
| **147** | -0.559772 | -2.782132 | -1.883678 | -1.378027 | -1.712400 | 3.393201 | 1.5 | 4.985501 | 4.712400 | 3.393201 | 4.883678 | -1.378027 | 3.559772 | -2.782132 |
| **148** | -0.578666 | -2.828960 | -1.923543 | -1.408996 | -1.753260 | 3.422865 | 1.5 | 5.036002 | 4.753260 | 3.422865 | 4.923543 | -1.408996 | 3.578666 | -2.828960 |
| **149** | -0.597567 | -2.875799 | -1.963420 | -1.439973 | -1.794132 | 3.452539 | 1.5 | 5.086518 | 4.794132 | 3.452539 | 4.963420 | -1.439973 | 3.597567 | -2.875799 |

**Data From Animation on Previous Slide**



# References and Citations

[1]:RUT - Rutherford Scattering
(http://experimentationlab.berkeley.edu/sites/default/files/writeups/RUT.pdf)Page 5 Equation 1
[2]:原子核反応について
(http://www2.yukawa.kyoto-u.ac.jp/~kouichi.hagino/lectures/nuclphys2/notes17-12.pdf) Page 9
[3] Rutherford Scattering
(https://www.sciencephoto.com/media/704924/view/rutherford-scattering-experiment) Page 3