Raksha Dave
B.SC(Physics)
ATMIYA University Rajkot Gujarat

APPS ON PHYSICS- Rutherford Scattering

Reference: Simulation is available on Apps on Physics
Interface: Apps on physics >> Physics of atom >> Rutherford Scattering

Abstract:

Rutherford's scattering experiment explains the nuclear model of an atom. It shows that each atom has a nucleus where most of its mass is focused and electrons revolve around the nucleus in circular orbits.

The simulation is available on **Apps on physics >> Physics of atom >> Rutherford scattering** with the required parameters.

In the experimental configuration alpha particles are bombarded on thin gold foil and their scattering was influenced by electrostatic force. So the resulting hyperbolic (approximately) trajectories of particles led to conclude that atoms mostly have empty space with small, dense, positively charged nucleus at the centre.

Keywords:
Rutherford scattering, gold foil, nucleus, electrostatic force, electrons.

Aim of the Experiment: To investigate the structure of the atom and provide evidence for the existence of nucleus.

Introduction:

The atomic model has evolved over the time, starting from **Dalton's model** which proposed that atoms are indivisible, solid spheres. Then J.J. Thomson's **Plum pudding** model, where negative charges were spread out in a cloud of positive charge.
For the accurate and detailed analysis of atoms **Rutherford proposed** a new atomic model called Rutherford's **atomic model,** which is based on **Scattering of alpha particles** so this is also known as **Rutherford scattering**.

So In this experiment, we aim to verify the existence of a nucleus in every atom. Due to scattering of atoms deflection takes place. This deflection determines the trajectory and that will help to demonstrate the presence of a nucleus.

Procedure:
1. Open **Apps on Physics**.
2. Tap on Rutherford scattering (for reference, see image-1).
3. On the right side, **Control** panel contains two buttons, **Clear trajectories** and **Start**.
4. Enter the atomic number (number of protons) for the scattering of alpha particles (for reference, see image-2).
5. As we vary the atomic number there will be change in the **Deflection angle**. We can also change velocity of alpha particle and impact parameter(distance between the scattering nucleus and the asymptotes of the hyperbola, (for reference see Image-3).
6. All results of the experiment are shown in the right side panel. (for reference, see image-4)
7. We can clear the trajectories or start the App using the buttons provided.(reference, see image-5)

Calculations (reference table-2):

- Projectile atomic number (Z_1) = 2 (for alpha particle)
- Target atomic number (Z_2) = 50 (for tin)
- Elementary charge (e) = 1.602×10^{-19} C
- Vacuum permittivity (ε_0) = 8.854×10^{-12} F/m
- Impact parameter (b) = 14.7 fm = 1.47×10^{-14} m
- Minimal distance (r_{min}) = 34.1 fm = 3.41×10^{-14} m
- Velocity of projectile (V) = 30,000 km/s = 3×10^7 m/s

DEFLECTION ANGLE:

$$\theta = 2 \cdot \arctan\left(\frac{Z_1 Z_2 e^2}{4\pi\varepsilon_0 E} \cdot \frac{1}{b}\right)$$

Energy Calculation in Joules

$$E = \frac{Z_1 Z_2 e^2}{4\pi\varepsilon_0 b r_{\text{min}}}$$

$$E = \frac{(2)(50)(1.602 \times 10^{-19})^2}{4\pi(8.854 \times 10^{-12})(1.47 \times 10^{-14})(3.41 \times 10^{-14})}$$

$$E = 0.0455\,\text{J}$$

CALCULATION FOR DEFLECTION ANGLE:

$$\theta = 2 \cdot \arctan\left(\frac{Z_1 Z_2 e^2}{4\pi\varepsilon_0 E} \cdot \frac{1}{b}\right)$$

Substituting the known values into this formula:

$$\theta = 2 \cdot \arctan\left(\frac{(2)(50)(1.602 \times 10^{-19})^2}{4\pi(8.854 \times 10^{-12})(0.0455)(1.47 \times 10^{-14})}\right)$$

$$\theta \approx 14.7^\circ$$

Result: Results are provided here by performing the experiment for different sets.
Rutherford Scattering: Deflection Angles for various Sets.

TABLE:1

(variable velocity and constant impact parameter)

(1.1)

Atomic number (Z)	Velocity (Km/s)	Impact parameter (fm)	Deflection angle (°)	Minimal distance (fm)
79 (Gold)	30000	20	33.9	27
	35000	20	25.2	25
	40000	20	19.5	23.7
	45000	20	15.4	22.9
	50000	20	12.5	22.3
81 (Thallium)	30000	20	34.7	27.2
	35000	20	25.9	25.1
	40000	20	19.9	23.8
	45000	20	15.8	23
	50000	20	12.8	22.4
82 (lead)	30000	20	35.1	27.3
	35000	20	26.2	25.2
	40000	20	20.2	23.9
	45000	20	16	23
	50000	20	13	22.4
83 (Bismuth)	30000	20	35.5	27.4
	35000	20	26.5	25.3
	40000	20	20.4	23.9
	45000	20	16.2	23
	50000	20	13.2	22.4

(variable impact parameter & constant velocity)
(1.2)

Atomic number (Z)	Velocity (Km/s)	Impact parameter (fm)	Deflection angle (°)	Minimal distance (fm)
79 (Gold)	35000	10	48.2	15.4
	35000	20	25.2	25.0
	35000	30	17.0	34.8
	35000	40	12.81	44.7
	35000	50	10.2	54.7
81 (Thallium)	35000	10	49.3	15.6
	35000	20	25.9	25.1
	35000	30	17.4	34.9
	35000	40	13.1	44.9
	35000	50	10.5	54.8
82 (lead)	35000	10	49.9	15.7
	35000	20	26.2	25.2
	35000	30	17.6	35
	35000	40	13.3	44.9
	35000	50	10.6	54.9
83 (Bismuth)	35000	10	50.4	15.8
	35000	20	26.5	25.3
	35000	30	17.8	35.1
	35000	40	13.4	45
	35000	50	10.8	54.9

(TABLE:2)
(variable atomic number, constant velocity and constant impact parameter)

SET	Z (ATOMIC NUMBER)	V (VELOCITY) (Km/s)	IMPACT PARAMETER (fm)	DEFLECTION ANGLE (°)	MINIMAL DISTANCE (fm)
SET-1	50(Tin)	30000	30	14.7	34.1
SET-2	74(Tungsten)	30000	30	21.6	36.2
SET-3	76(Osmium)	30000	30	22.1	36.4
SET-4	77(Iridium)	30000	30	22.4	36.5
SET-5	78(Platinum)	30000	30	22.7	36.6
SET-6	79 (Gold)	30000	30	23.0	36.7
SET-7	81(Thallium)	30000	30	23.5	36.9
SET-8	82(lead)	30000	30	23.8	37.0
SET-9	83(Bismuth)	30000	30	24.1	37.1

Conclusion:

For the same atomic number as we increase the velocity keeping the impact parameter constant, both deflection angle and minimal distance decrease.

For the same atomic number as we increase the impact parameter keeping the velocity constant, the deflection angle decreases and minimal distance increases.

1. **Atomic Number (Z):** When the atomic number increases, the deflection angle increases. A higher atomic number results in a stronger Coulomb force, causing larger deflection of the projectile.
2. **Velocity (v):** As the velocity of the projectile increases, the deflection angle decreases. Faster particles interact less strongly with the nucleus, leading to smaller deflection angles.
3. **Impact Parameter (b)**: Increasing the impact parameter leads to a smaller deflection angle. A larger impact parameter means the projectile does not come as close to the nucleus, resulting in a weaker interaction and smaller deflection.

Changing Impact Parameter (keeping velocity constant):

Deflection Angle: As the impact parameter increases, the deflection angle decreases. A larger impact parameter means the particle passes farther from the nucleus, resulting in a smaller angle of deflection.

Minimal Distance: The minimal distance increases with the impact parameter. A larger impact parameter means the particle will not approach the nucleus as closely.

Changing Velocity (keeping impact parameter constant):

Deflection Angle: As velocity increases, the deflection angle decreases.

A faster moving particle has more kinetic energy and is less affected by the Coulomb force,

leading to a smaller deflection.

Minimal Distance: The minimal distance decreases with increased velocity.

A faster moving particle can approach the nucleus more closely before being deflected.

The Rutherford scattering experiment confirms the existence of a small, dense, positively charged nucleus at the centre of the atom. The results validate Rutherford's model by showing that alpha particle deflections are due to the Coulomb force between the nucleus of gold foil and other metals with alpha particles, proving that most of the atom's mass and charge are concentrated in its core.

References: https://www.walter-fendt.de/html5/phen/

Image 1: Rutherford Scattering Practical Demonstration

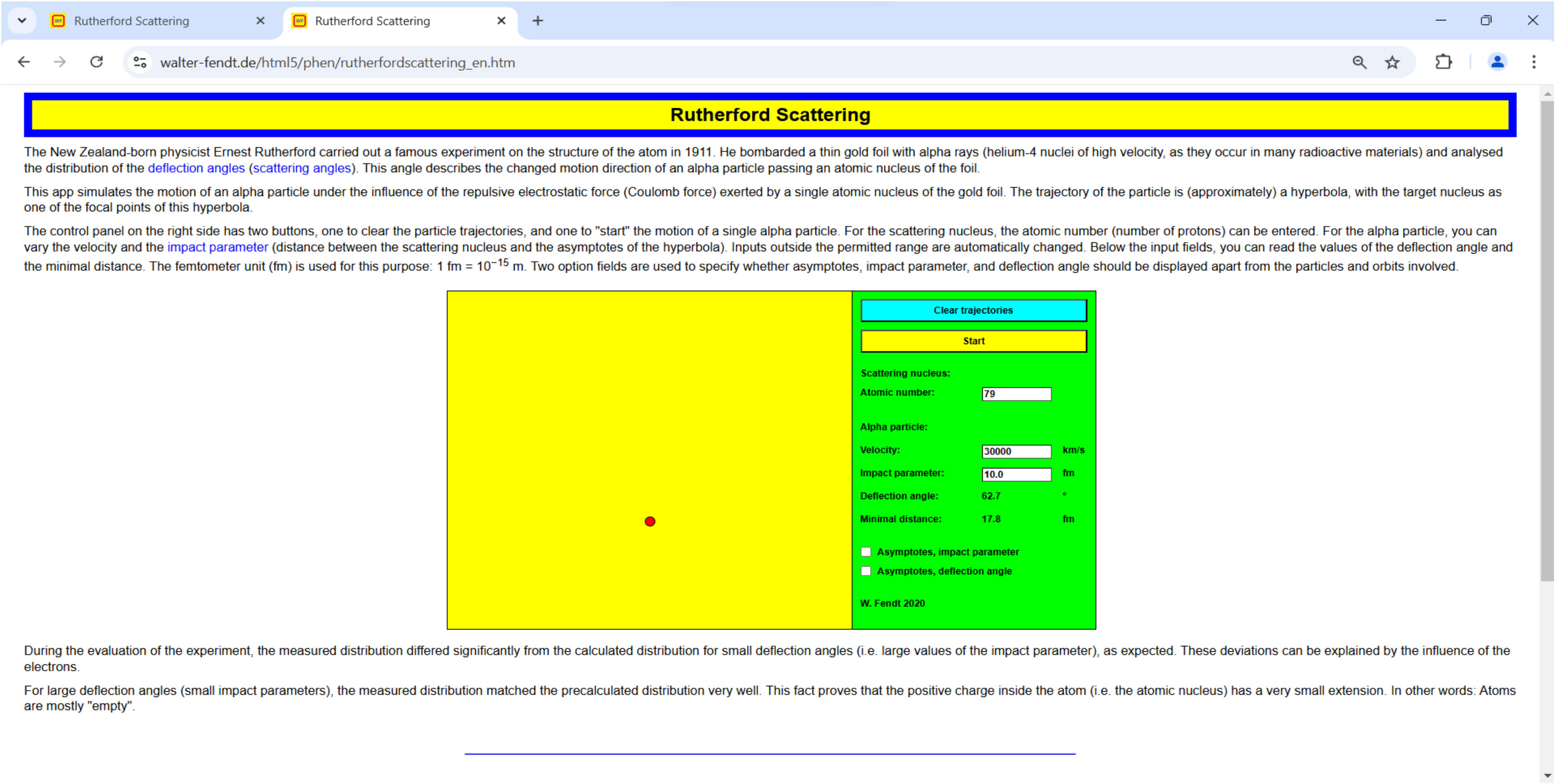


Image 2: simulation is performed for "Z=79".

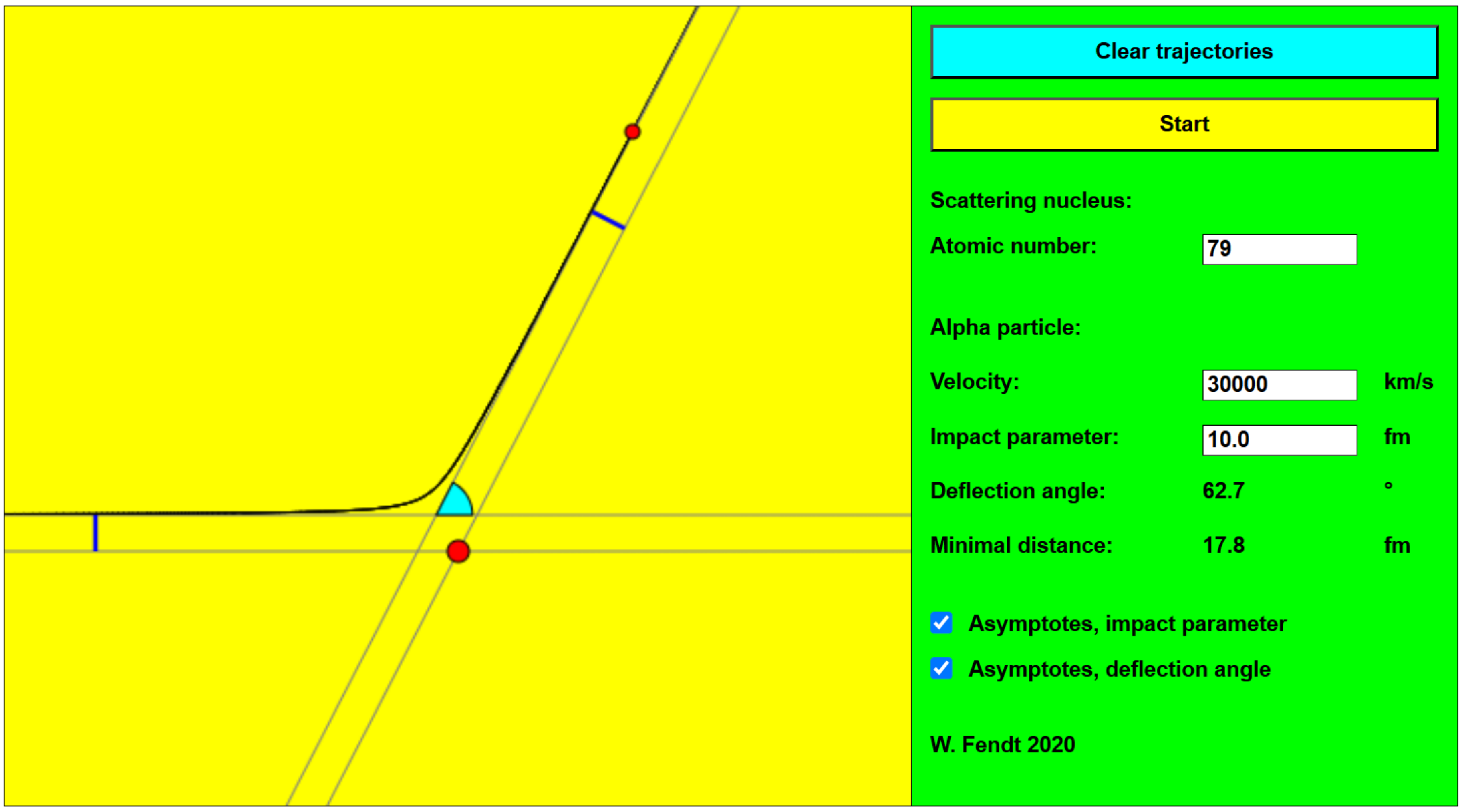


Image 3: Trajectory followed by alpha particle (for single case).

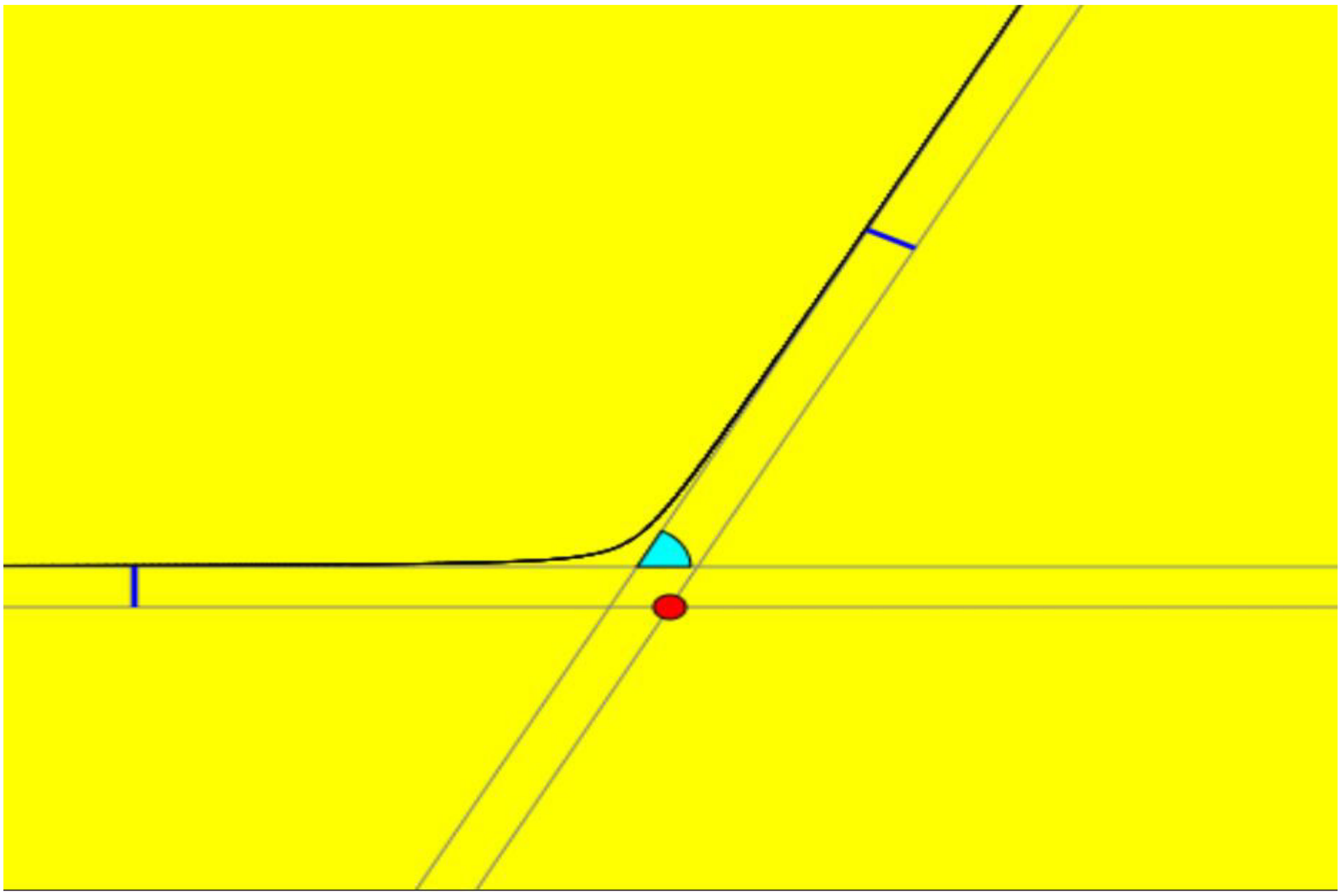
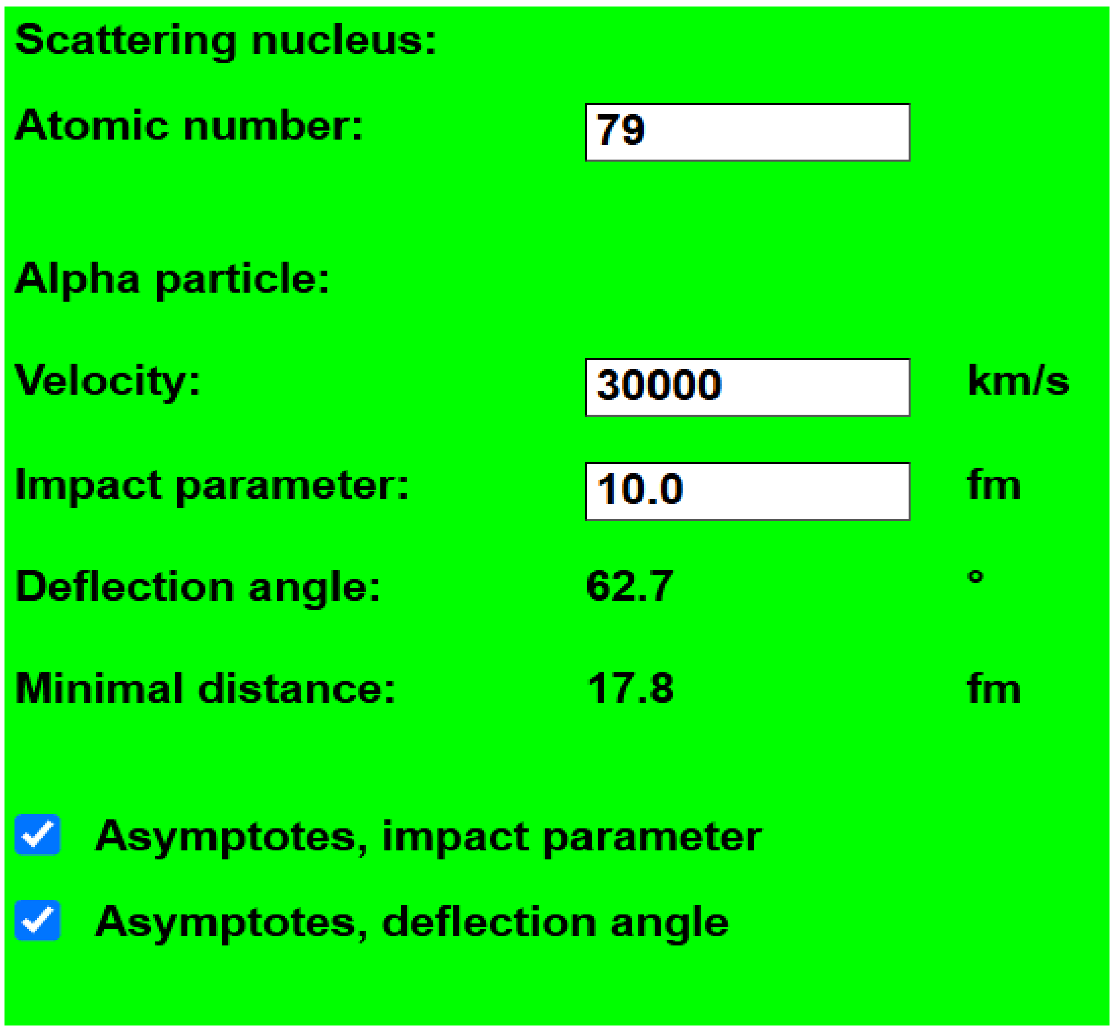
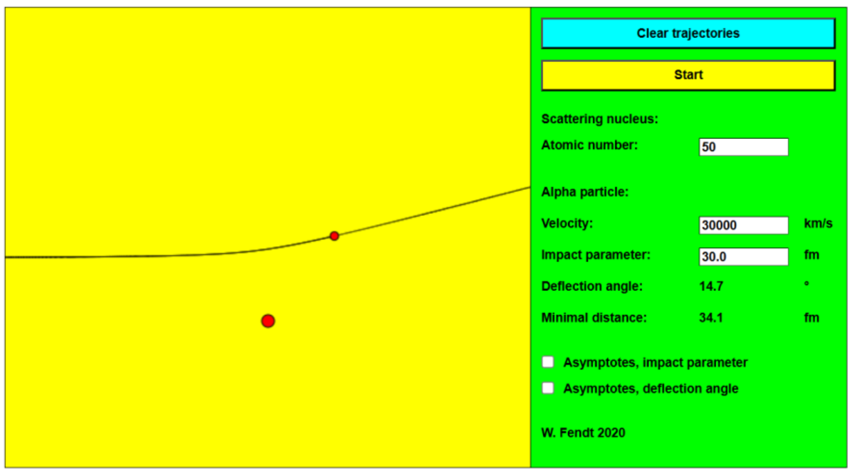


Image 4 : Resultant parameters for the simulation.

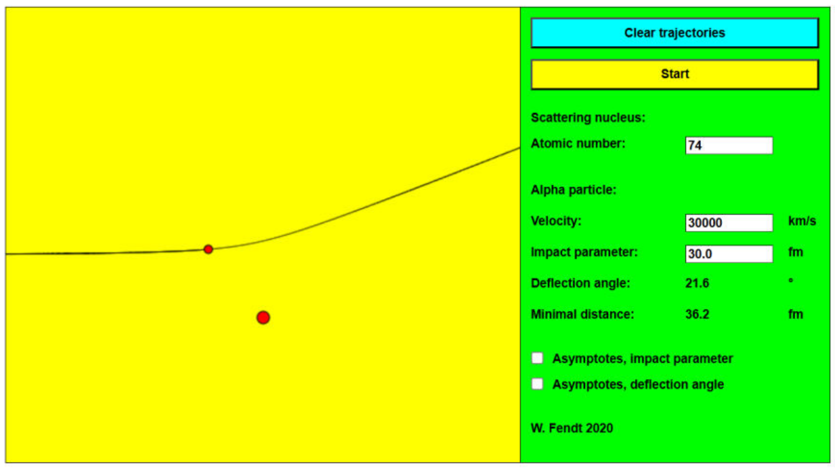


Trajectories for different parameters:

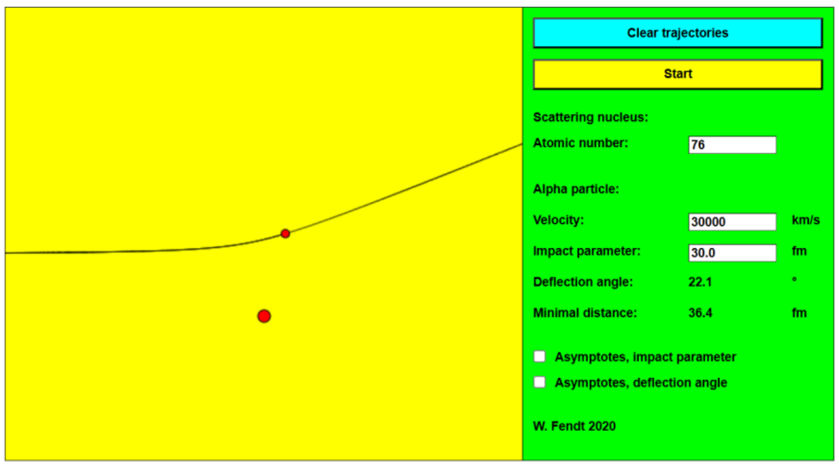
- **<u>(Refers table-2):</u>**



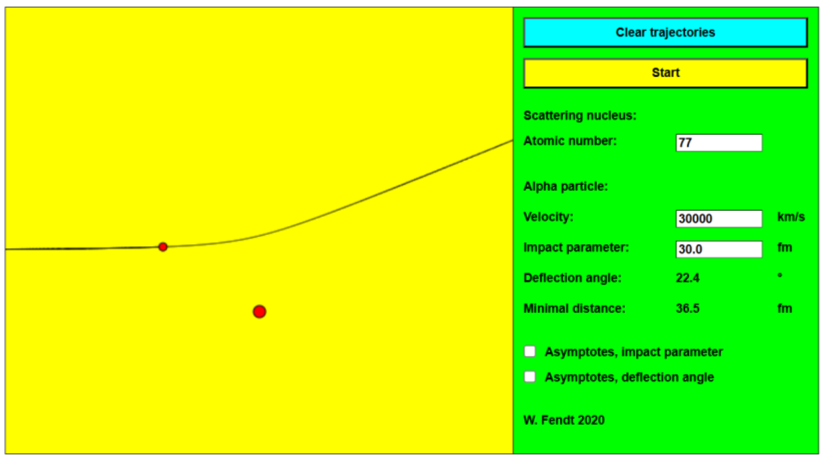
(SET-1)



(SET-2)



(SET-3)



(SET-4)

Image 5: to Clear trajectory or Start.