Collisional Processes in Ionospheric Plasmas: Basic Concepts

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Plasmas School April 27th 2025

Abstract

Collisions within Earth's ionosphere are fundamental to the dynamics of ionized gases and the propagation of electromagnetic waves. Stemming from these interactions (primarily between charged particles (e.g. electrons, ions) and neutral atmospheric species) exhibit strong altitudinal dependence dictating basic phenomena as ionospheric conductivity, energy dissipation and radio wave absorption.

In the lower ionosphere (D and E regions), the frequent collision of electrons with neutrals significantly inhibits electron mobility, thus decreasing plasma conductivity, while significantly attenuating low-frequency radio signals. In addition, these collisions mediate energy and momentum transfer between the ionized and neutral components, playing a key role in driving important processes such as Joule heating and the generation of ionospheric currents.

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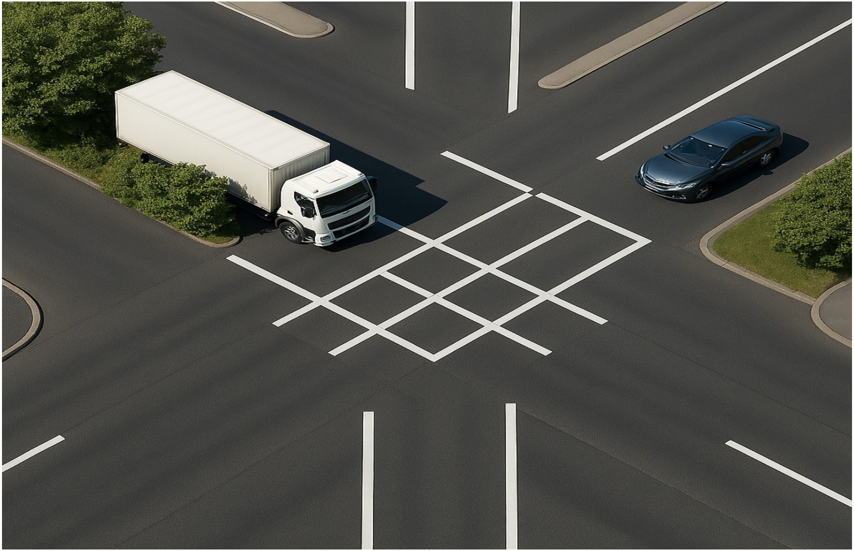

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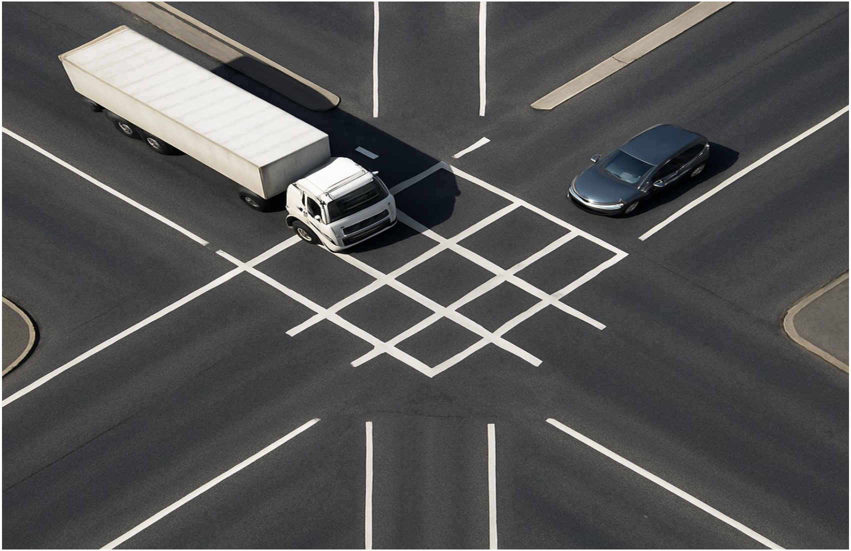

Car crash

Linear Momentum

The impact depends on three parameters

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To combine all these parameter, we define the momentum or linear momentum by

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Example
To put a billiard ball in the hole we have to choose the appropriate direction and velocity (by kicking the ball with the stick: apply a Force).

Momentum Conservation

Can be added:when two or more bodies that interact.

System	m_1	m_2	$(m_1 + m_2)$
Momentum	$\vec{p}_1$	$\vec{p}_2$	$\vec{p}_T = \vec{p}_1 + \vec{p}_2$

There are two important situations:

- Before collision
- After collision

Conservation

For an isolated system the total momentum is constant $\vec{p} = \overrightarrow{const}$

For two bodies (particles) collision

$$\underbrace{\vec{p}_1 + \vec{p}_2}_{Before} = \underbrace{\vec{p}_1^{\,\prime} + \vec{p}_2^{\,\prime}}_{After}$$

Example: Car-Truck

Before: A Truck is of mass $M = 2\ t$ and driver claims $V = 80\ km/h$ and the Car of mass $m = 1000\ kg$, claims $v = 80\ km/h$. After the shock: the truck and the car remain stick moving with $\frac{\pi}{4}$. The truth?

Apply momentum conservation

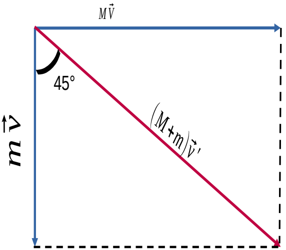
Before the shock: System momentum (Car+ Truck) is $m\vec{v} + M\vec{V}$.

After

mass is of (Lorry+ car) with $(m + M)\,\vec{v}'$ of an angle $\frac{\pi}{4}$ with respect to $M\vec{V}$. As the system is isolated then, $m\vec{v} + M\vec{V} = (m + M)\,\vec{v}'$.

From the figure we can show, $\frac{mv}{MV} = tg\,(\alpha) = 1 \Rightarrow v = \frac{MV}{m} = \frac{2000\times 80}{1000} = 160\ km/h$.

The car driver is a liar.



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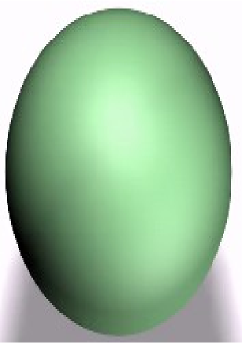

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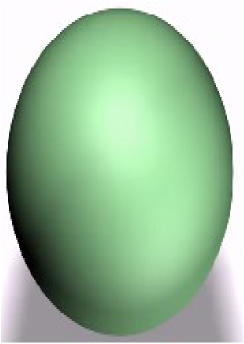

$$m_1\vec{v}_1 + m_2\vec{v}_2 = m_1\vec{v}_1{}' + m_2\vec{v}_2'$$

After the shock two unknowns v_1' and v_2'.

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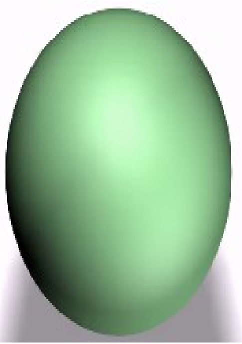


$$m_1 \vec{v}_1 + m_2 \vec{v}_2 = m_1 \vec{v}_1{}' + m_2 \vec{v}_2'$$

After the shock two unknowns v_1' and v_2'. Additional equation is needed

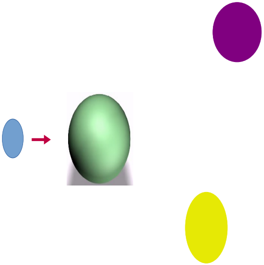
Elastic collisions

For an elastic collision kinetic energy is conserved

$$\frac{mv_1^2}{2}+\frac{mv_2^2}{2}=\frac{mv_3^2}{2}+\frac{mv_4^2}{2}$$

Solving the set of equation gives the velocities after collision.

However, for an inelastic collision



https://www.youtube.com/watch?v=2W-GEE6YU4M

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Maximum Energy Loss (Perfectly Inelastic Case; objects stick together):
The common velocity is:

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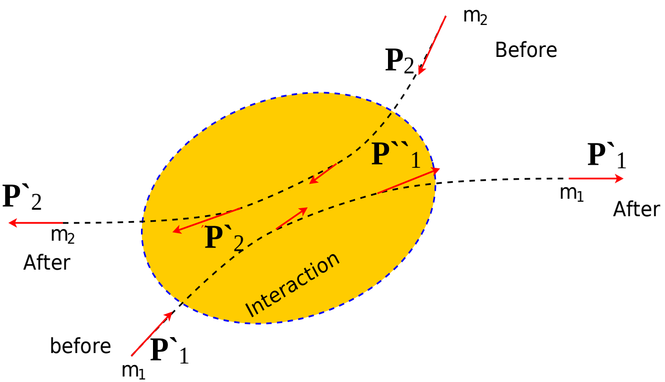
The lost kinetic energy can be found as

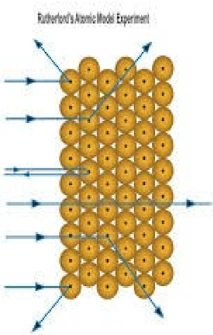
- Deformation Energy (a car crumpling in a crash).
- Heat (Thermal Energy)
- Sound Energy
- Internal Energy (Molecular Excitation)

Interaction



Phase / Interaction	before	during	after
Isolated system	m_1 , m_2	$(m_1 + m_2)$	m_1 , m_2
Momentum m_1	$\vec{p}_1 = \vec{const}$	$\vec{p}_1^{\,\prime\prime} = variable$	$\vec{p}_1^{\,\prime} = \vec{const}$
Momentum m_2	$\vec{p}_2 = \vec{const}$	$\vec{p}_2^{\,\prime\prime} = variable$	$\vec{p}_2^{\,\prime} = \vec{const}$
Momentum $(m_1 + m_2)$	$\vec{p}_T = \vec{p}_1 + \vec{p}_2 = \vec{p}_1^{\,\prime\prime} + \vec{p}_2^{\,\prime\prime} = \vec{p}_1^{\,\prime} + \vec{p}_2^{\,\prime} = \vec{const}$		

As in Rutherford experiment



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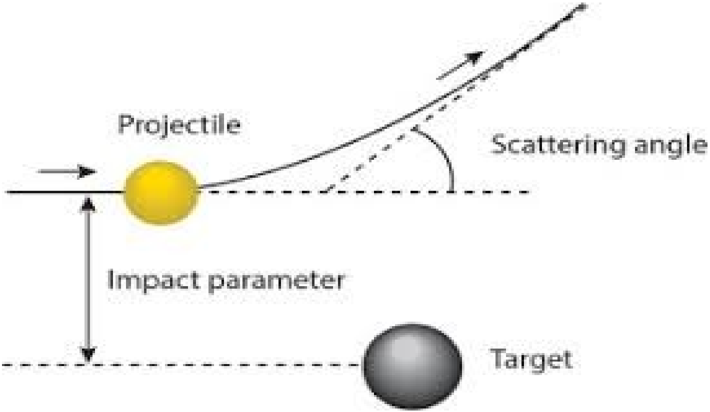
A Coulomb field force between charged particles.

Collision between charge particles



Two key parameters: Impact parameter and Scattering angle

Binary collision

To find the impact parameter and the scattering angle assume

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$$E = \frac{1}{2}mv_0^2 = \frac{1}{2}mv^2 + \frac{kq_1q_2}{r}$$

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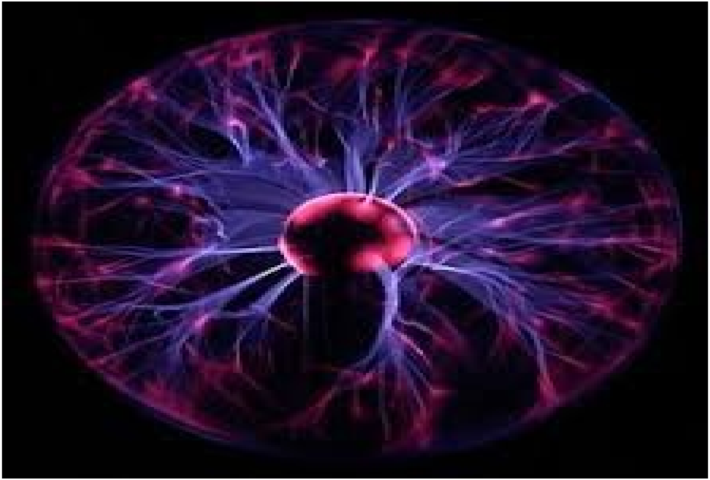
for small angle approximation $\theta \ll 1$:

$\theta \approx \dfrac{2kq_1 q_2}{mv_0^2 b}$ and the impact parameter is : $b = \dfrac{kq_1 q_2}{mv_0^2} \cot\left(\dfrac{\theta}{2}\right)$

Applications

The scattering theory is on the basic of many fields as

- Nuclear and Particle Physics:(Rutherford Scattering, particle physics (CERN).
- Plasma Diagnostics (measure ion/electron densities and temperatures in fusion plasmas)
- Astrophysics and Space Physics (Cosmic Ray Interactions)
- Atomic and Molecular Physics: atomic excitation/ionization cross-sections (critical for plasma physics).
- Medical Physics: Radiation Therapy
- Quantum Technologies: Controls electron-electron scattering for nanoscale electronics.
- Plasma Physics and Fusion Energy, Coulomb Collisions, Debye Shielding



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