# Collisional Processes in Ionospheric Plasmas: I. Basic Concepts

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# Abstract

Collisions in Earth's ionosphere are fundamental to the dynamics of ionized gases and to electromagnetic-wave propagation. These interactions, primarily between charged particles (electrons and ions) and neutral atmospheric species, depend strongly on altitude and control key ionospheric properties such as plasma conductivity, energy dissipation, and radio-wave absorption. In the lower ionosphere (D and E regions) the high frequency of electron–neutral collisions strongly limits electron mobility, thereby reducing plasma conductivity and attenuating low-frequency radio signals. At the same time, ion–neutral and electron–neutral collisions mediate energy and momentum transfer between the ionized and neutral components, driving important processes such as Joule heating and the formation of ionospheric currents.

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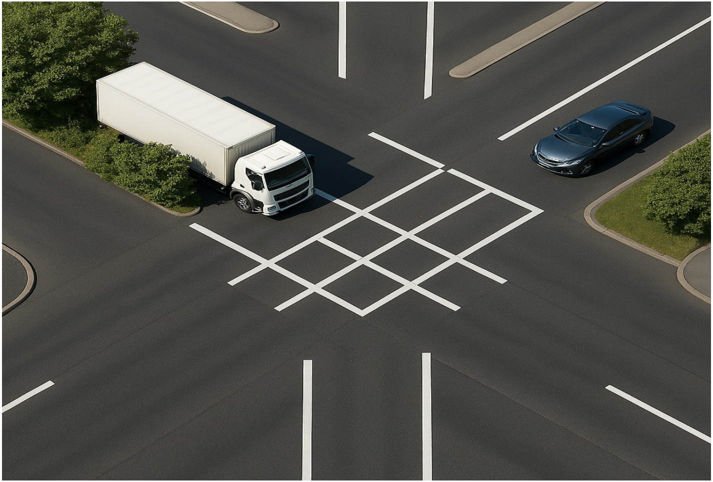
# Car crash



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$$\vec{p} = m\vec{v}, \quad \vec{p} \parallel \vec{v},$$

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**Example: Billiard ball**

To put a billiard ball into a hole, we must choose an appropriate direction and speed. This is achieved by striking the ball with the cue stick, which applies a force and thus changes the ball's linear momentum.

# Momentum Conservation

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

| System | $m_1$ | $m_2$ | $(m_1 + m_2)$ |
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## Conservation

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

For two bodies (particles) collision

$$\underbrace{\vec{p}_1 + \vec{p}_2}_{Before} = \underbrace{\vec{p}_1' + \vec{p}_2'}_{After}$$

# 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**

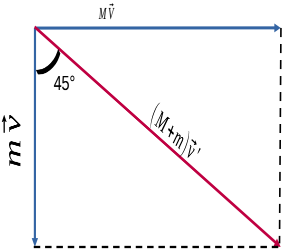
Before the shock: System momentum (Car+ Truck) is $m\vec{v} + M\vec{V}$.

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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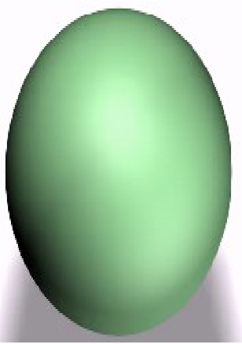

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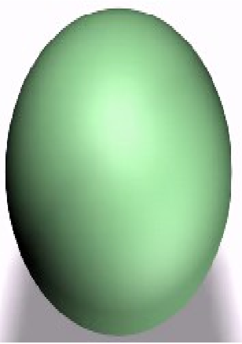

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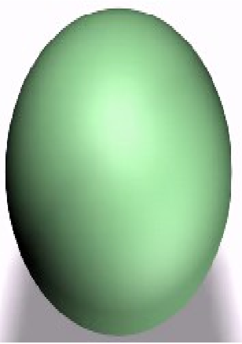

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After the shock two unknowns $v_1'$ and $v_2'$. Additional equation is needed

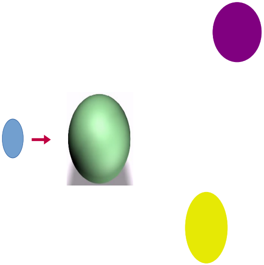
# Elastic collisions

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



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# Inelastic collisions

- **Linear momentum is conserved:**
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**Perfectly inelastic collision** (maximum energy loss; objects stick together): The common final velocity is:

$$v_f = \frac{m_1 v_{1i} + m_2 v_{2i}}{m_1 + m_2}.$$

The kinetic energy lost is: $\Delta K = K_i - K_f,$

where $K_i = \frac{1}{2} m_1 v_{1i}^2 + \frac{1}{2} m_2 v_{2i}^2$ and $K_f = \frac{1}{2}(m_1 + m_2) v_f^2$.
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- Heat (thermal energy).
- Sound energy.
- Internal energy (molecular excitation, vibration, rotation).

# Including angular momentum

When colliding objects are **extended bodies** (e.g., rods, disks, rigid bars) or when the impact is **off-center**, we must also consider **angular momentum** and the associated rotational motion.

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**Practical rule:**

- For point-mass or head-on collisions along the line of motion, linear momentum is usually sufficient.
- For off-center impacts, rotating bodies, or pivoted systems, **angular momentum** must be treated on equal footing with linear momentum.

# Angular momentum: Example

**Ball hitting a pivoted rod (horizontal plane, no friction):**

- A ball of mass $m$ with speed $v$ strikes a uniform rod of mass $M$ and length $L$, pivoted at one end.

- **Linear momentum is not conserved** because the pivot exerts an external horizontal force.
- **Angular momentum is conserved** about the pivot (net external torque $\tau_{\text{ext}} = 0$):

$$L_i = mvr = L_f = I_{\text{rod}}\omega_f + mv_{\text{ball},f}\,r.$$

For a light ball we can approximate $L_f \approx I_{\text{rod}}\omega_f$, where $I_{\text{rod}} = \frac{1}{3}ML^2$.

**When?**

For off-center impacts on pivoted or extended bodies, use *conservation of angular momentum*, not linear momentum.

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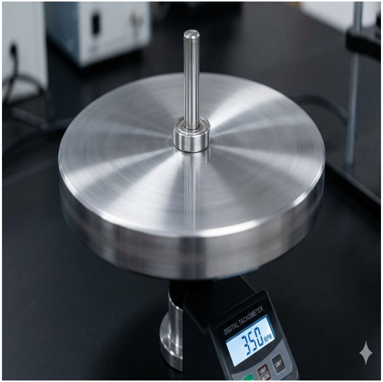
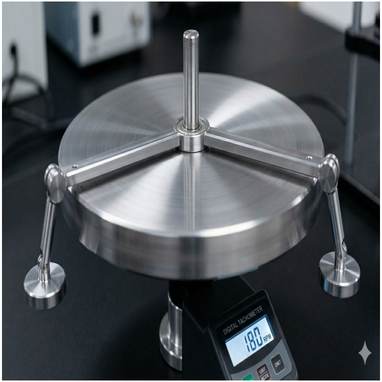
# Moment of inertia




https://www.youtube.com/watch?v=iUr4S1LQTNE&t=61s

A precision engineering model featuring a 30cm polished steel disk. It is spinning rapidly on a low-friction spindle. The motion is indicated by the blurred reflections and the high reading ('350 RPM') on the nearby tachometer. This image represents a low moment of inertia but high angular velocity $I_{low}, \ \omega_{high}$

# Moment of inertia

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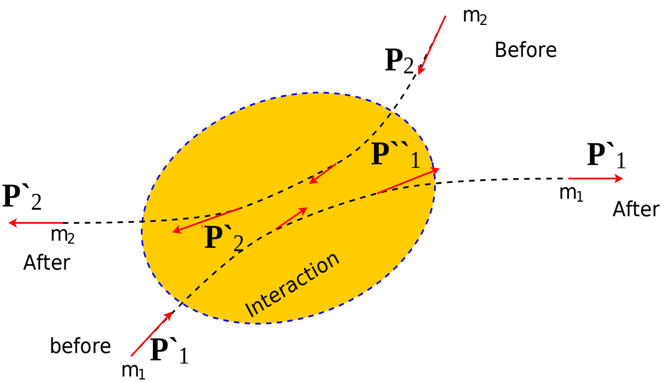
two identical auxiliary masses ("legs") have been symmetrically extended. As a result of this increased moment of inertia, the entire assembly now rotates at a visibly slower angular velocity.

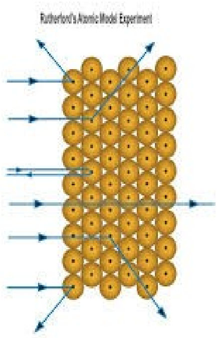
# Interaction




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

# Atomic scale

As in Rutherford experiment

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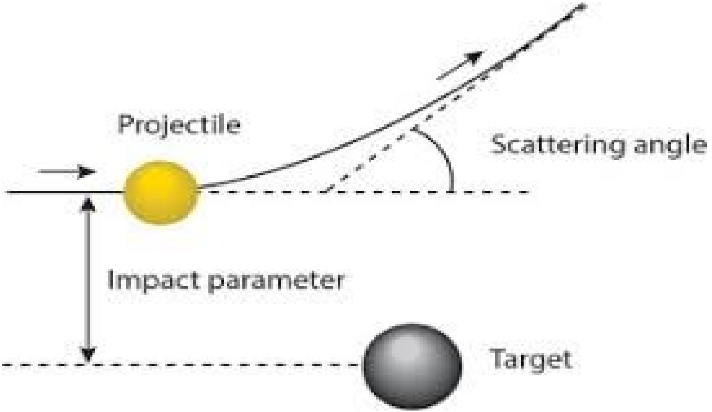
A field force Coulomb between charged particles.

# Collision between charge particles



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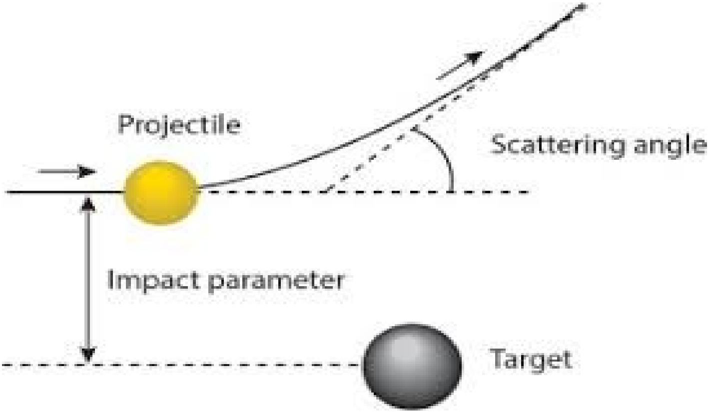


Two key parameters: Impact parameter and Scattering angle

# Binary collision

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

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

# Applications

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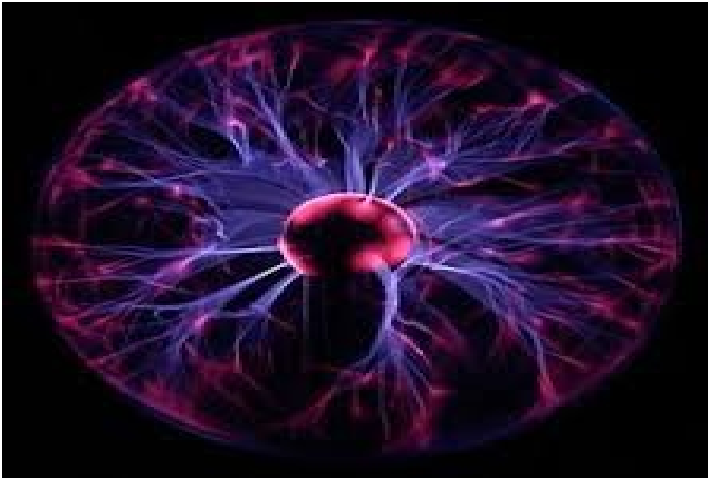
- Plasma Physics and Fusion Energy, Coulomb Collisions, Debye Shielding



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