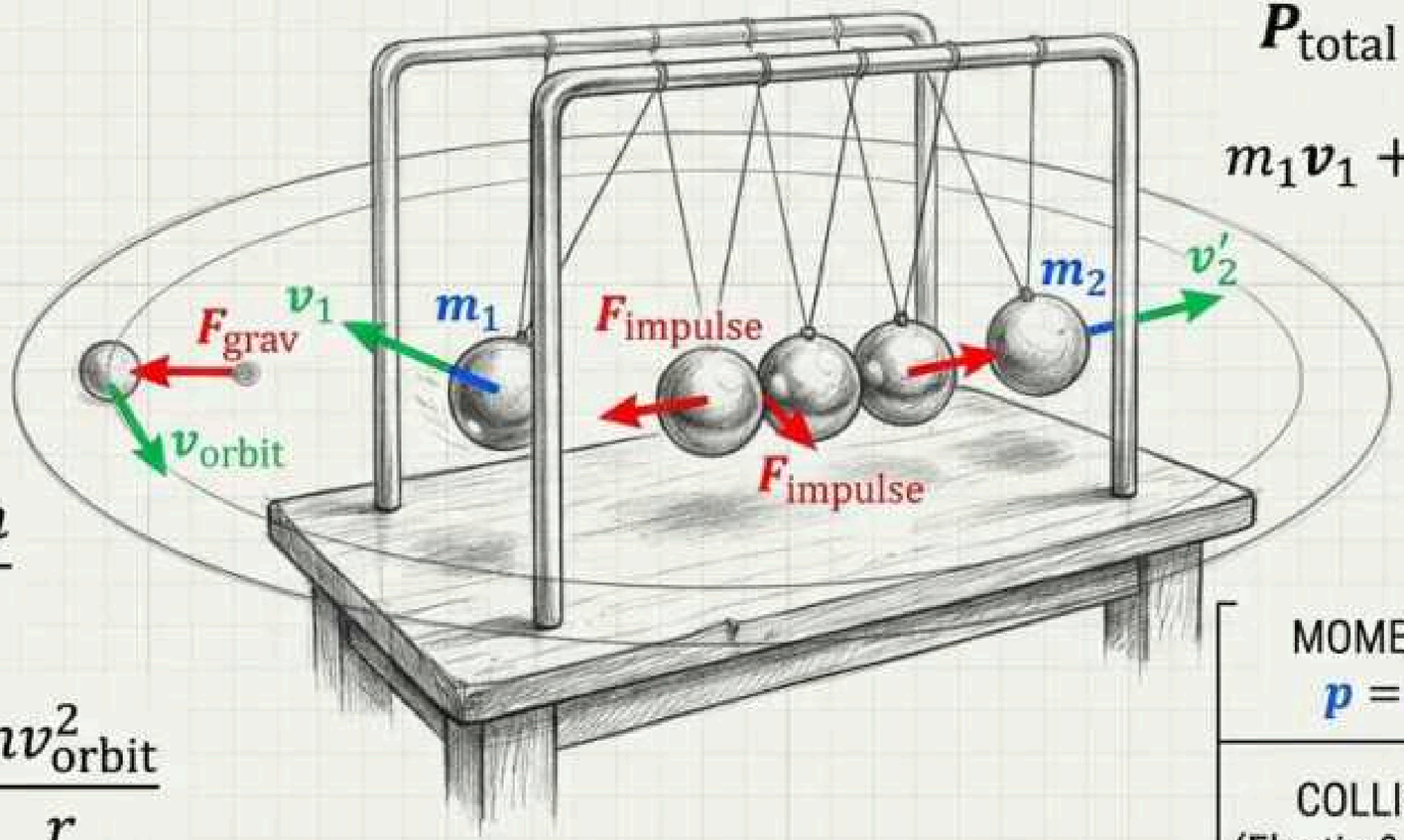
PHYS 101 B: Lecture 6 – Momentum, Collisions, and Circular Motion

¶ 6.1

At a glance: Momentum, impulse, collisions, and orbits.

$$\boldsymbol{P}_{\text{total}} = \sum \boldsymbol{p}_i = \text{constant}$$

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



$$\boldsymbol{F}_{\text{grav}} = G\frac{Mm}{r^2}$$

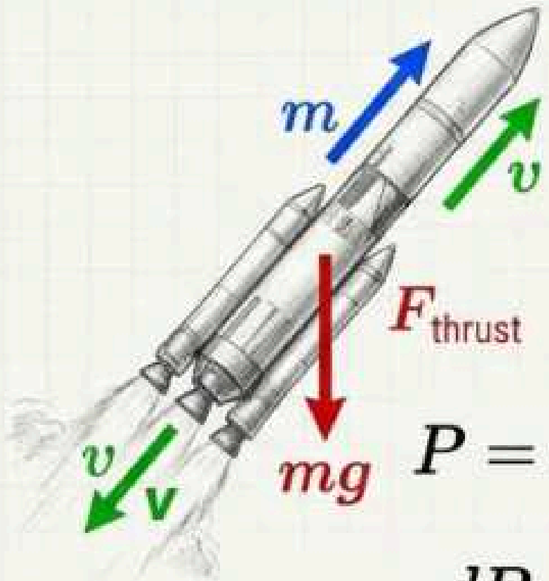
$$\boldsymbol{F}_{\text{net}} = \boldsymbol{F}_{\text{c}} = \frac{mv_{\text{orbit}}^2}{r}$$

MOMENTUM	IMPULSE
$\boldsymbol{p} = m\boldsymbol{v}$	$\boldsymbol{J} = \boldsymbol{F}\Delta t = \Delta\boldsymbol{p}$
COLLISIONS (Elastic & Inelastic)	CIRCULAR MOTION $\boldsymbol{F}_c = \frac{mv^2}{r}$

¶ 6.2

The Foundations of Mechanics

Momentum & Conservation

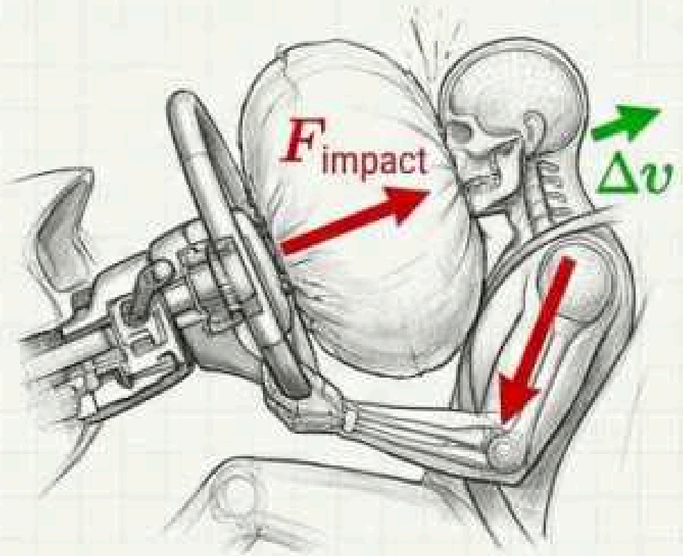


$$P = mv$$

$$\sum F_{\text{ext}} = \frac{dP}{dt}$$

Explains collisions and rockets.

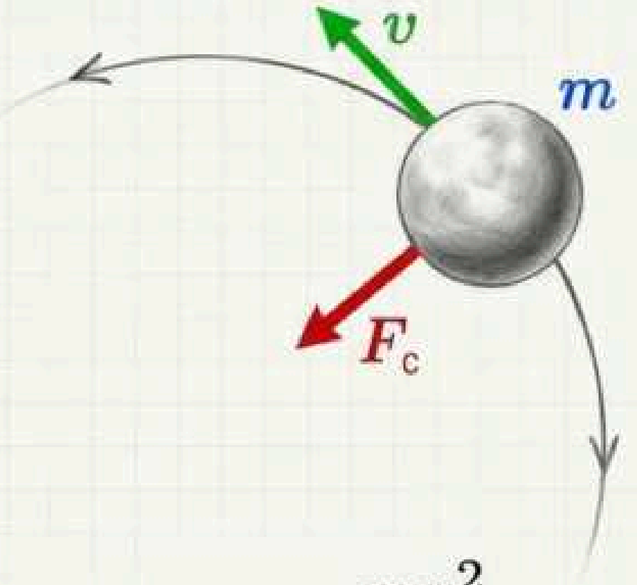
Impulse



$$J = \int F\,dt = \Delta P$$

Explains safety design and crashes.

Circular Motion



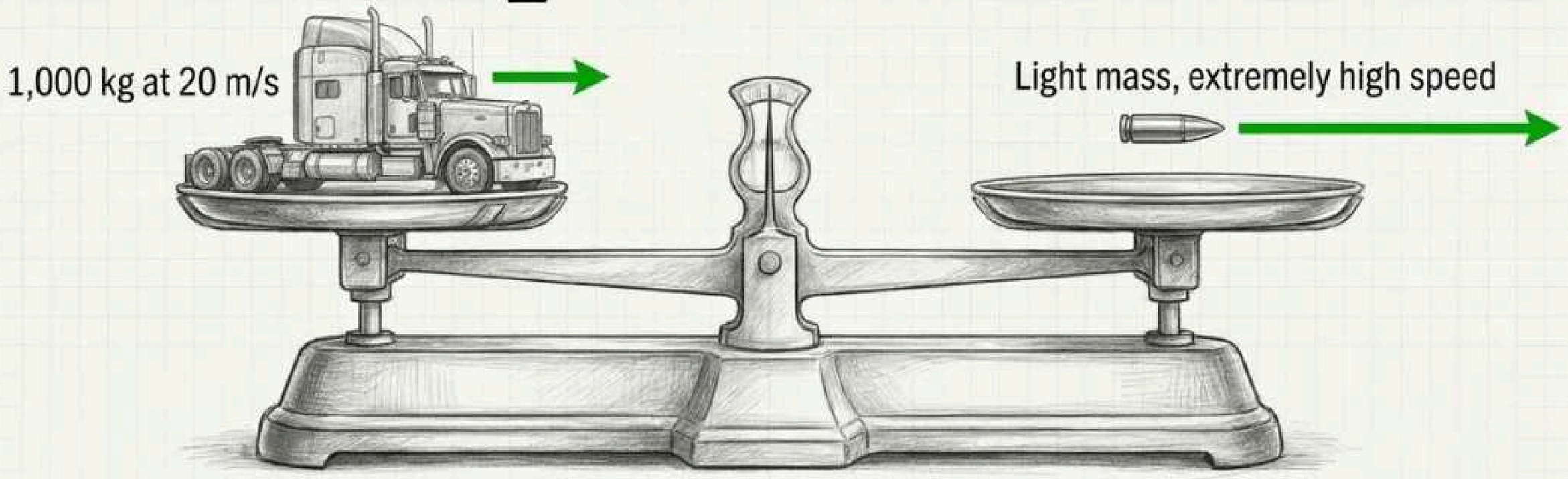
$$F_c = \frac{mv^2}{r}$$

Explains turning cars and planetary orbits.

Momentum: Mass in Motion

¶ 6.3

$$\vec{p} = m\vec{v}$$



Momentum is a vector pointing in the direction of motion. 1,000 kg at 20 m/s = 20,000 kg·m/s.

A **heavy slow truck** and a **light fast bullet** can have the **exact same momentum**. Both are equally hard to stop.

Newton's 2nd Law Reimagined

¶ 6.4

$$F_{net} = \frac{\Delta p}{\Delta t}$$

Net force equals the rate of change of momentum.

Multiply both sides by time (Δt)

$$F\Delta t = \Delta p$$

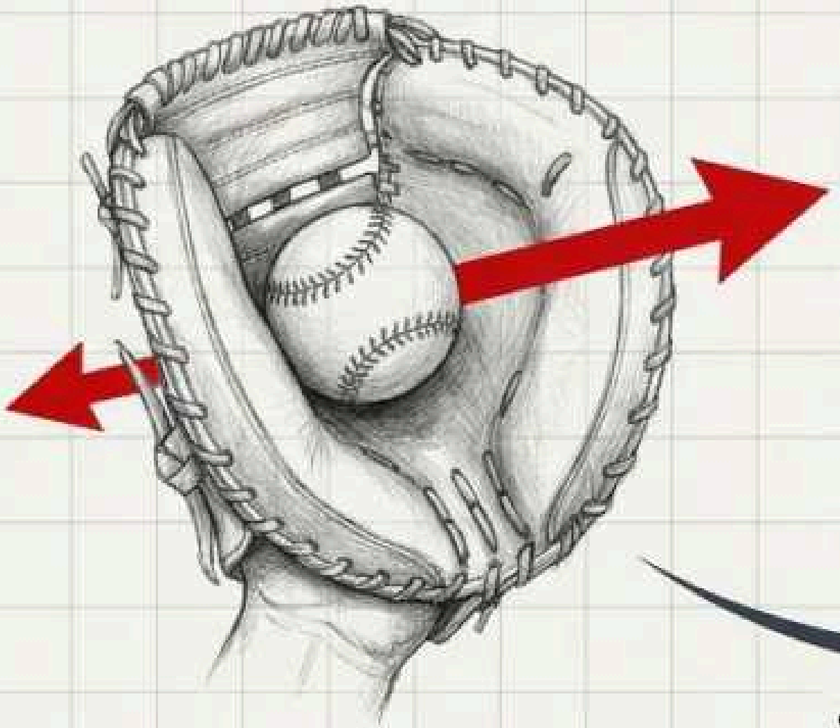
Impulse = Force × Time

To change momentum, apply a force over a duration of time.

The Math of Catching

¶ 6.5

t = 0.01 seconds

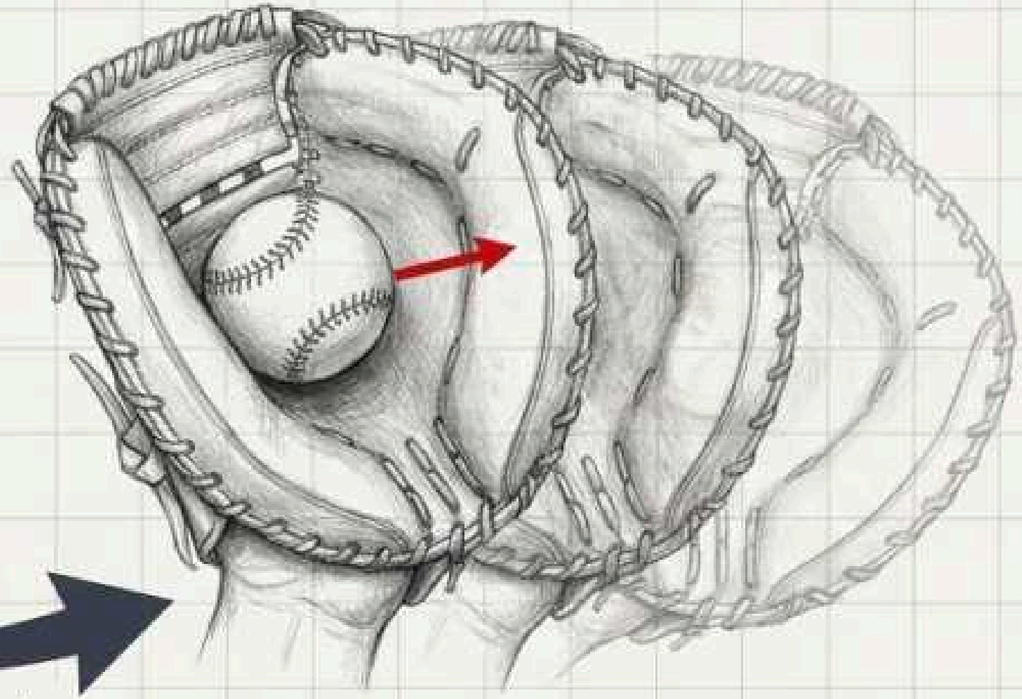


Change in momentum = 5.8

Average Force = **580 Newtons**

5x drop in force due to extended time.

t = 0.05 seconds

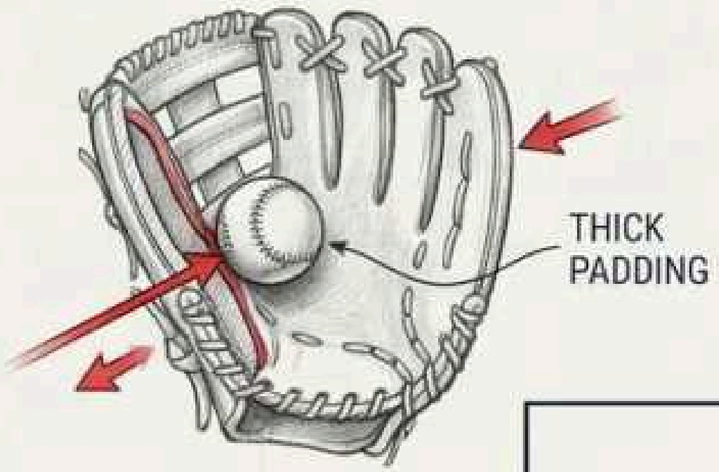


Change in momentum = 5.8

Average Force = **116 Newtons**

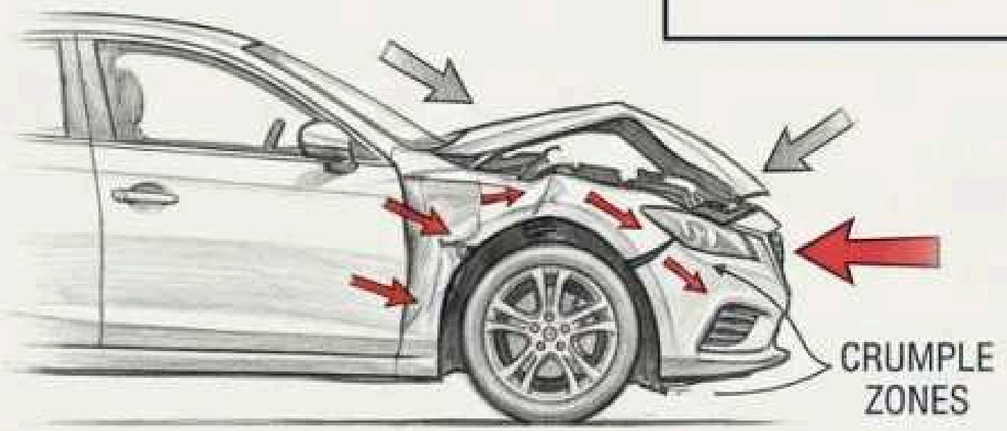
Time Is On Your Side

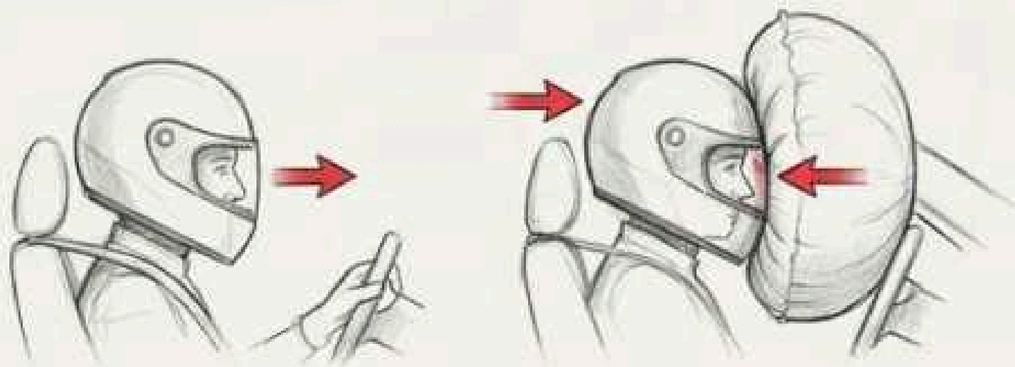
¶ 6.6





$$F_{average} = \frac{\text{Fixed } \Delta p}{\text{Maximized } \Delta t}$$

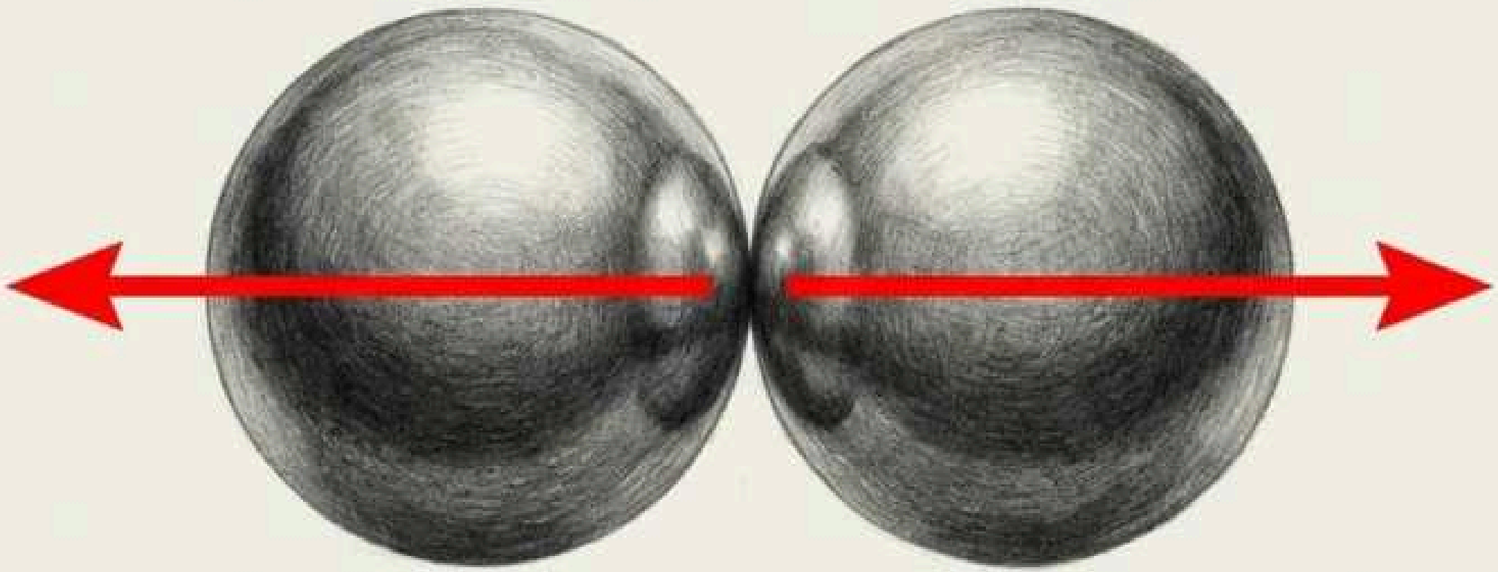




The change in momentum (Δp) is fixed by the crash. Spreading that change over a longer time (Δt) mathematically makes the average force smaller. Smaller force = less injury.

The Central Law: Conservation of Momentum

¶ 6.7



Why? Newton's 3rd Law.

The objects push on each other with equal and opposite forces, for the exact same time. One gains exactly the momentum the other loses.

Rule: If no net external force acts on a system, its total momentum stays constant.

Example 1: Inelastic Car Crash

¶ 6.8

Before



After



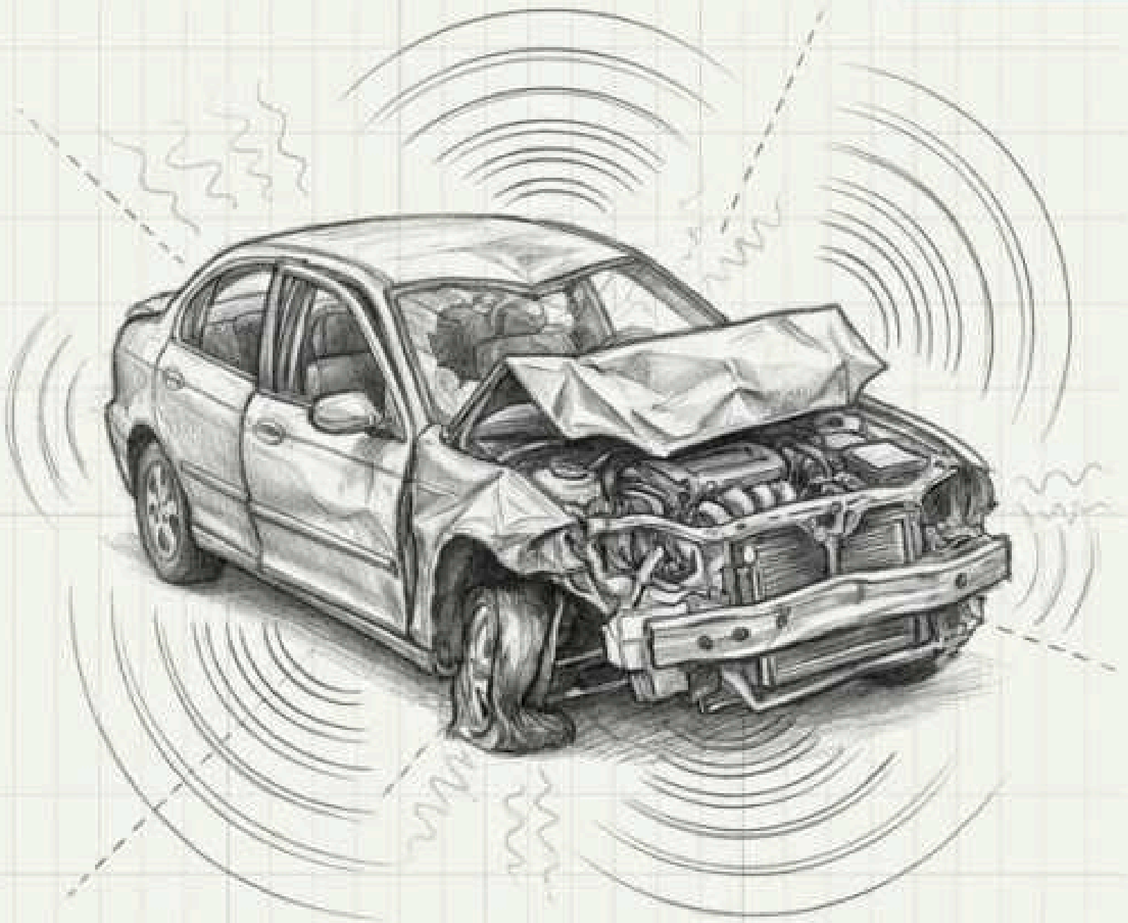
2,000 kg must maintain the 10,000 momentum.

$$\text{Speed} = 10{,}000 \div 2{,}000 = 5\ \text{m/s}$$

Checking the Energy Ledger

¶ 6.9

1	Kinetic Energy Before $(1/2 \times 1{,}000 \times 100)$	$50{,}000$ Joules
2	Kinetic Energy After $(1/2 \times 2{,}000 \times 25)$	$25{,}000$ Joules
3	Deficit	$-25{,}000$ Joules missing



Momentum was conserved, but Kinetic Energy was NOT.
Half the energy vanished into sound, heat, and bent metal.

The Types of Collisions

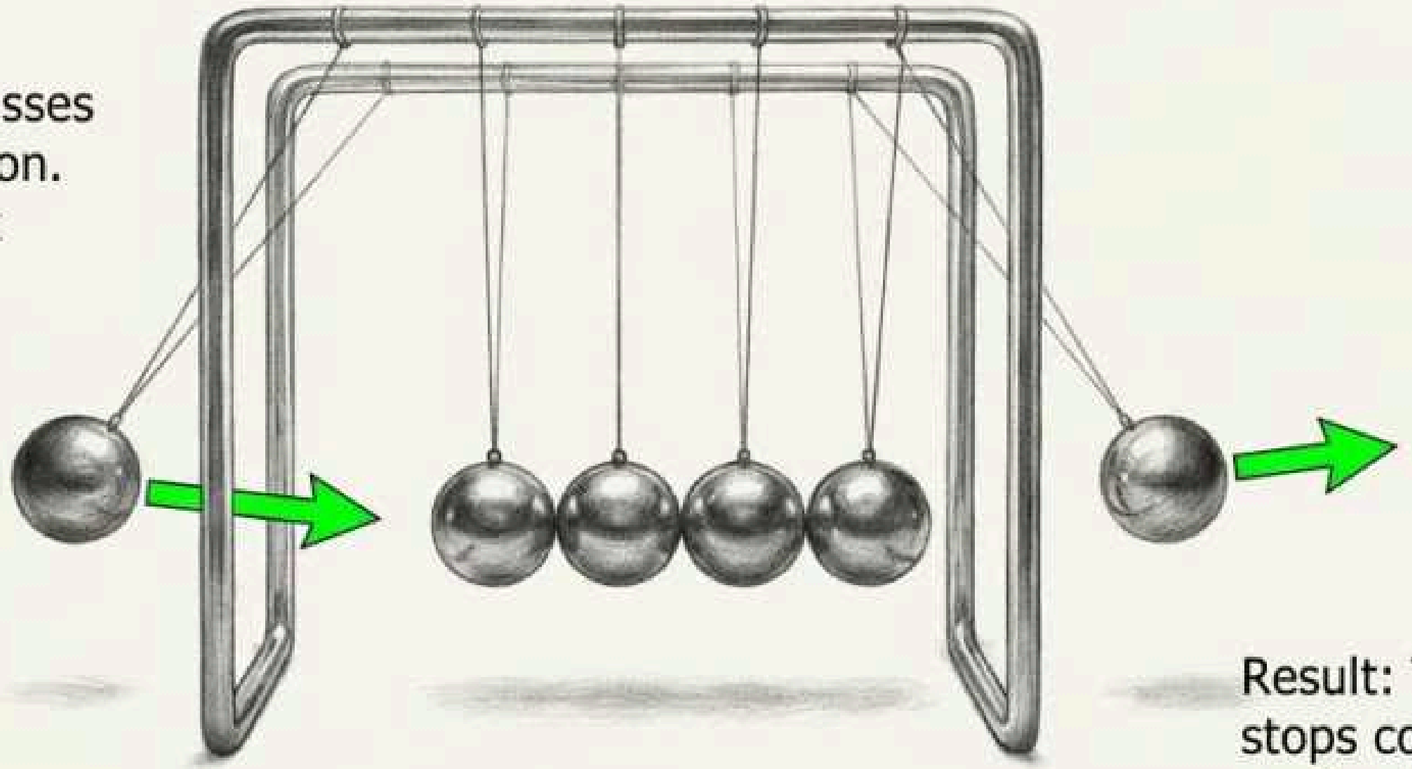
¶ 6.10

Collision Diagnostic Matrix		
Collision Type	Energy & Momentum	Characteristics / Example
Inelastic	KE Lost ✗ | Momentum Conserved ✓	Example: Standard car crash.
Perfectly Inelastic	KE Lost ✗ | Momentum Conserved ✓	Note: Objects stick together entirely into one mass.
Elastic	KE Conserved ✓ | Momentum Conserved ✓	Example: Billiard balls, atoms in a gas.

A Neat Special Case

¶ 6.11

Scenario: Two equal masses collide elastically head-on. One is moving, one is at rest.



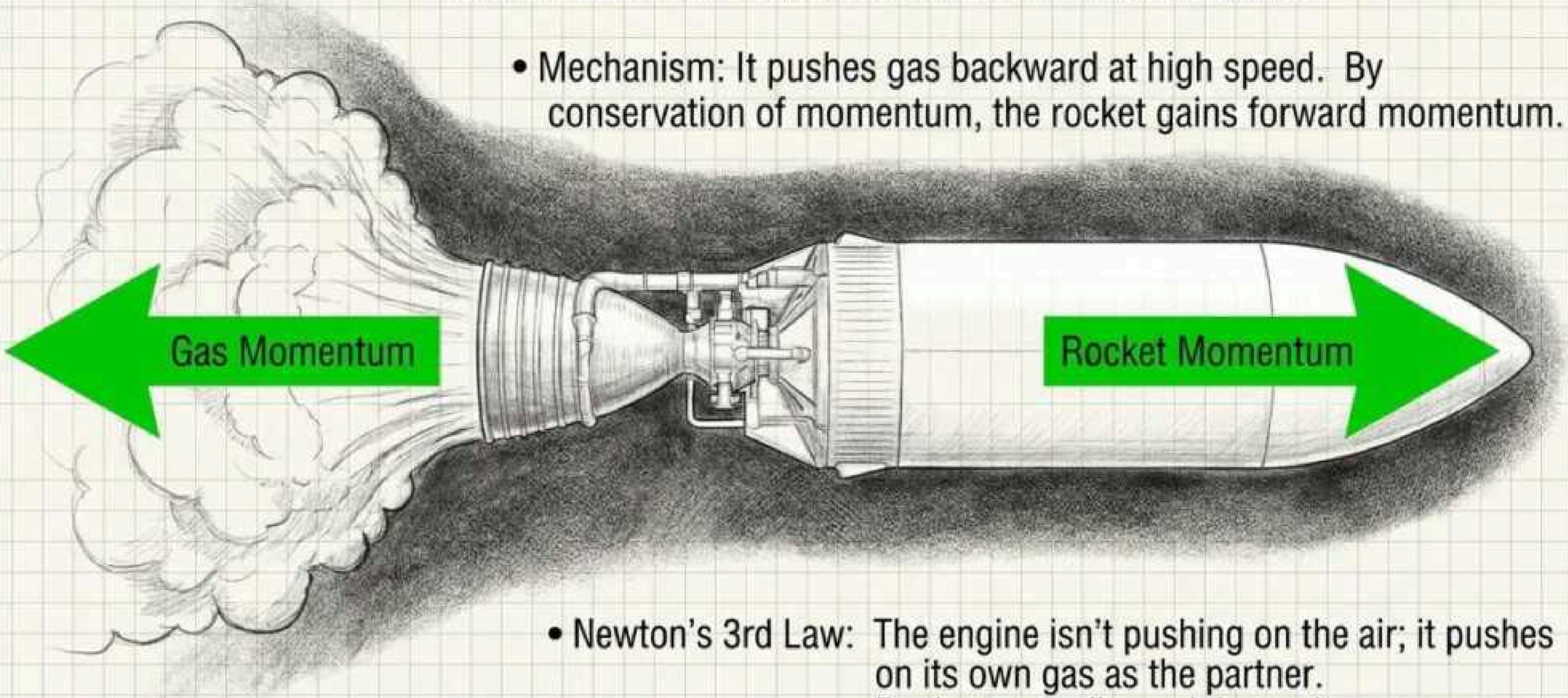
Result: The moving ball stops completely. The resting ball inherits its exact speed.

It looks like magic, but it is just two conservation laws working together.

Propulsion in a Vacuum

¶ 6.12

- Fact: A rocket in empty space has no air to push against.
- Mechanism: It pushes gas backward at high speed. By conservation of momentum, the rocket gains forward momentum.

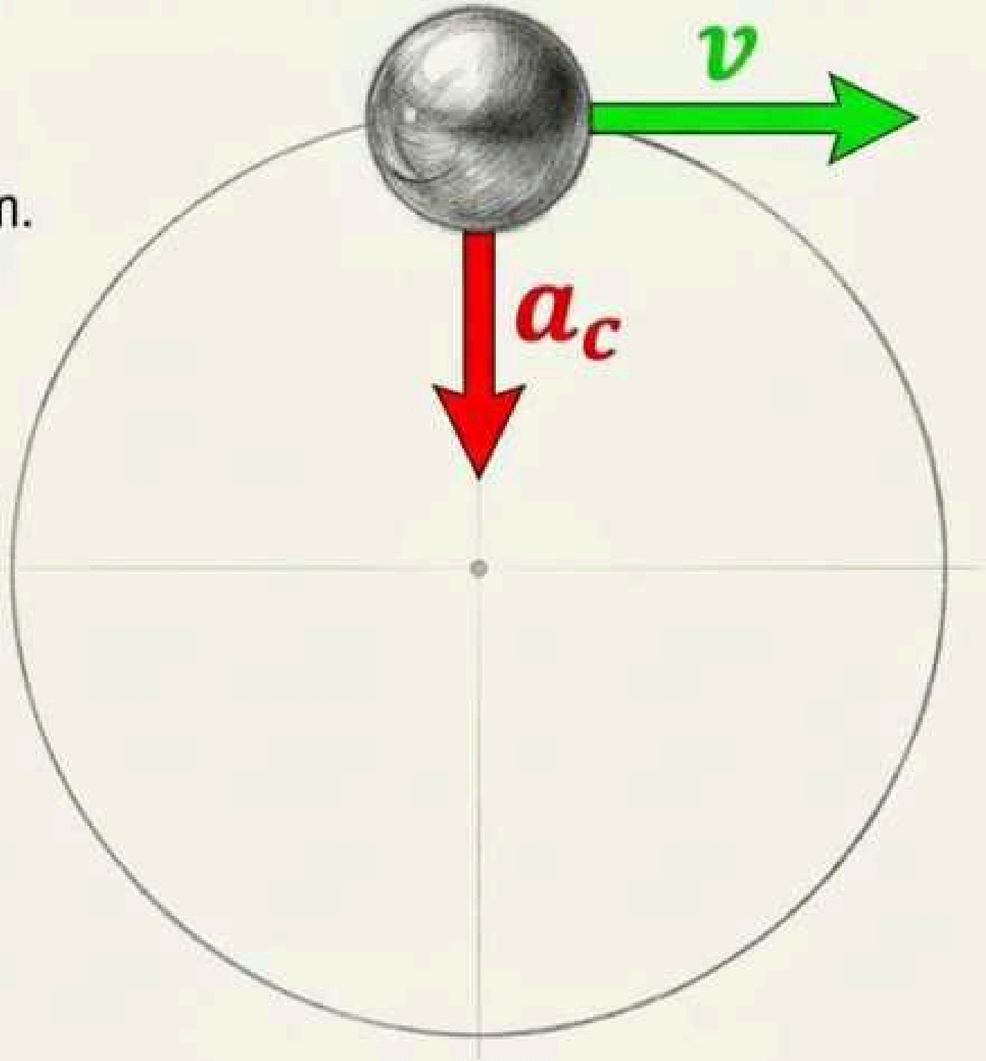


- Newton's 3rd Law: The engine isn't pushing on the air; it pushes on its own gas as the partner. Rockets actually work better in a vacuum.

Circular Motion & Centripetal Acceleration

¶ 6.13

Core Concept: Constant speed does not mean zero acceleration. Because the velocity's direction keeps changing, the object is accelerating.

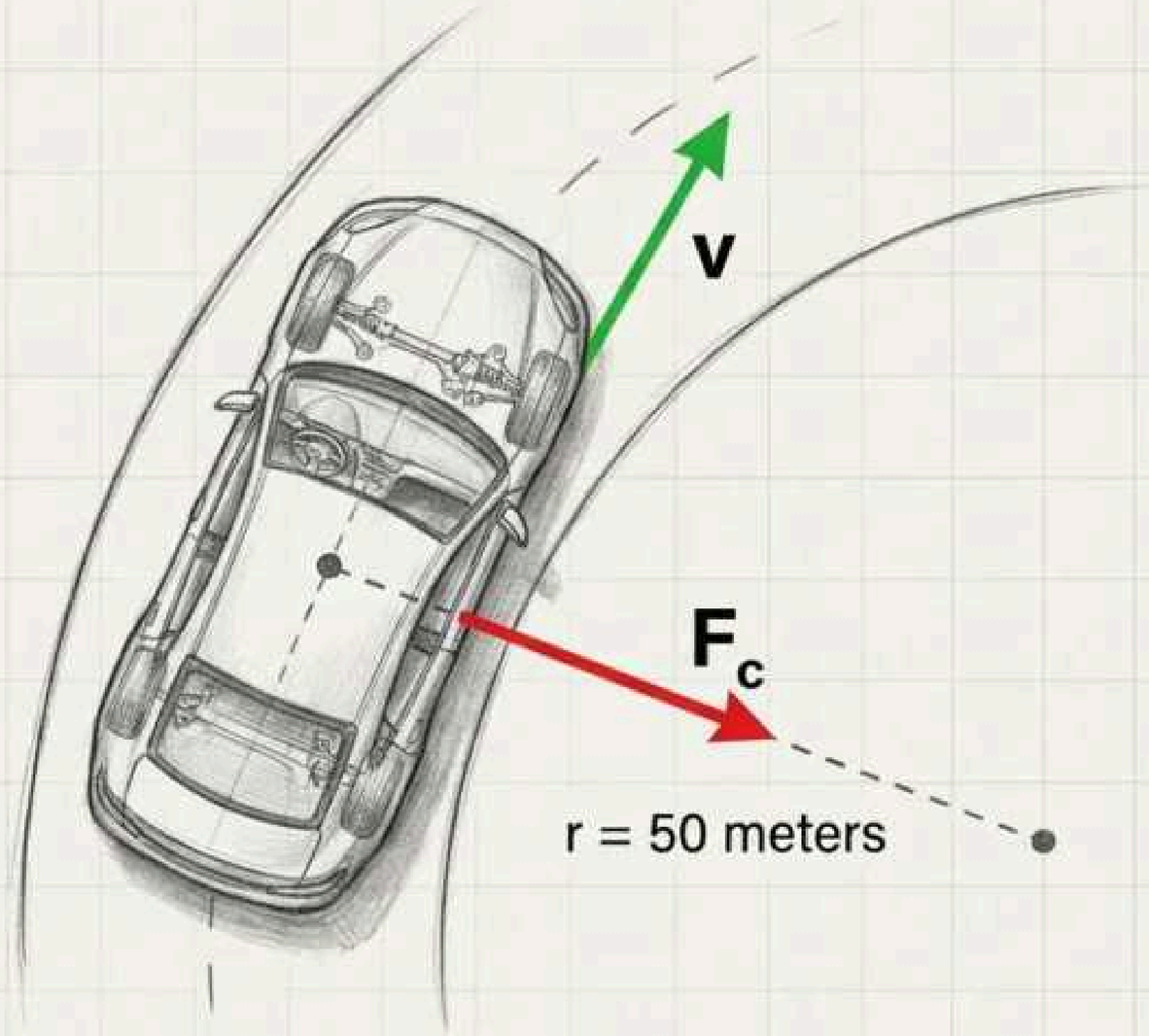


$$a_c = \frac{v^2}{r}$$

Centripetal means "center-seeking".

Example 2: The Curve

¶ 6.14



Given: Car speed = 15 m/s.
Curve radius = 50 meters.
Car Mass = 1,200 kg.

Math Step 1: Centripetal Acceleration (a_c)

$$15^2 \div 50 = \mathbf{4.5}\ \mathrm{m/s^2}$$

Math Step 2: Required Inward Force (F=ma)

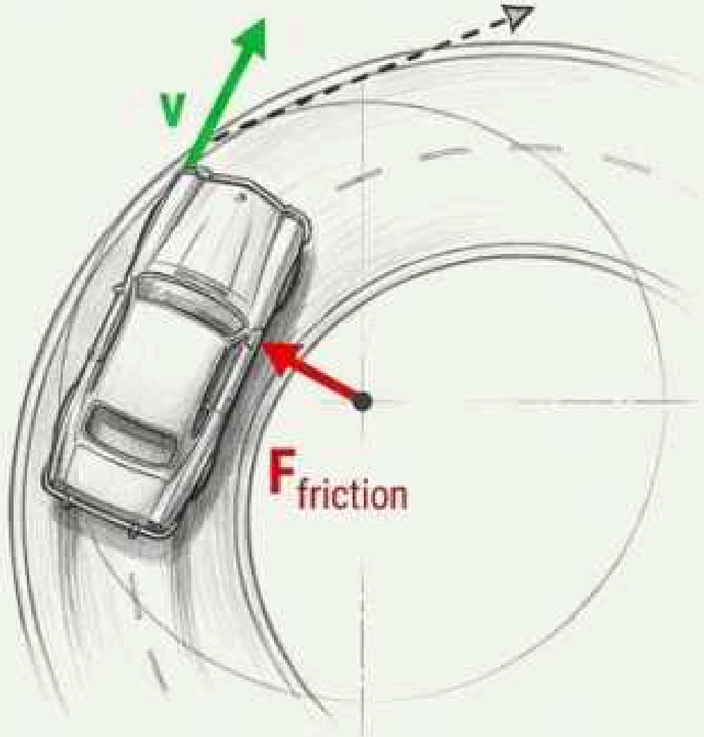
$$1{,}200 \times 4.5 = \mathbf{5{,}400}\ \text{Newtons}$$

This inward force must be supplied by the friction from the road.

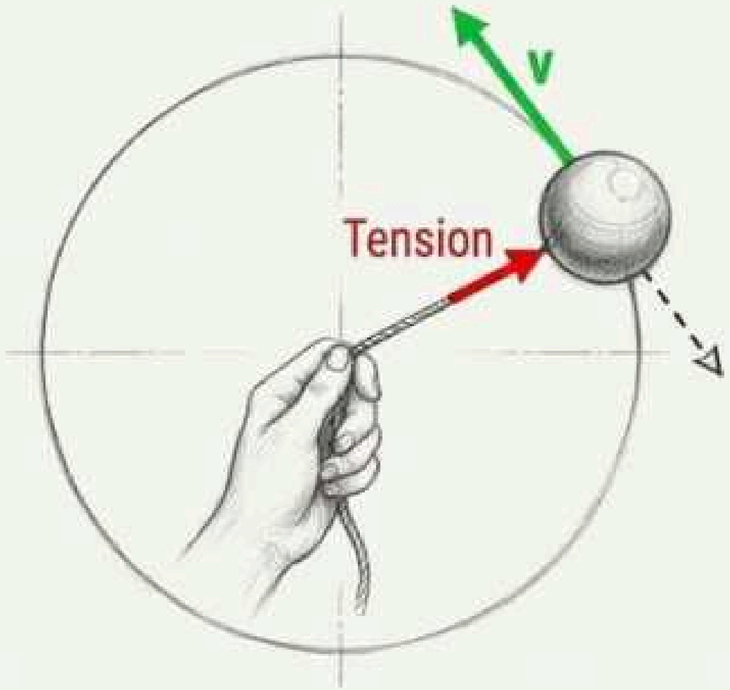
Centripetal Force is a Role, Not a Force

¶ 6.15

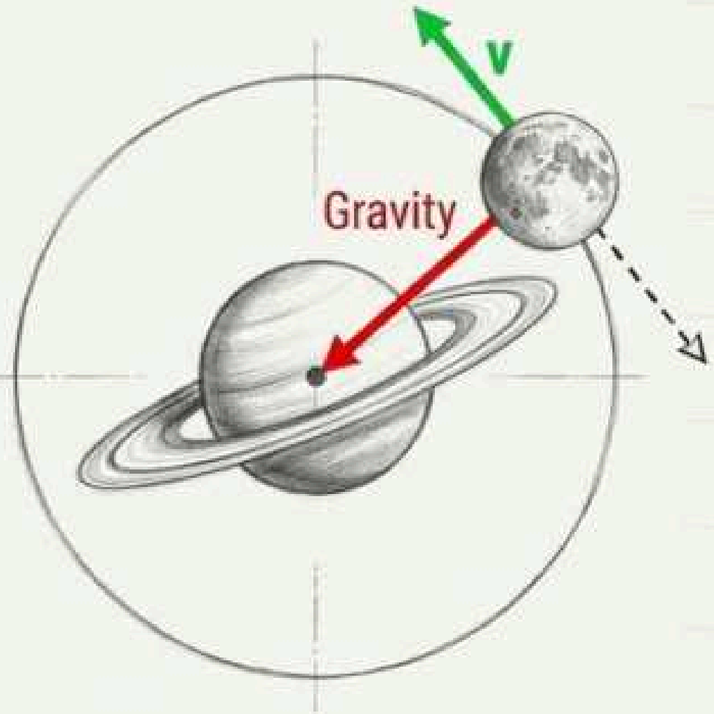
Centripetal force is simply the name for whatever existing force points toward the center.



Car = Friction



Ball = Tension



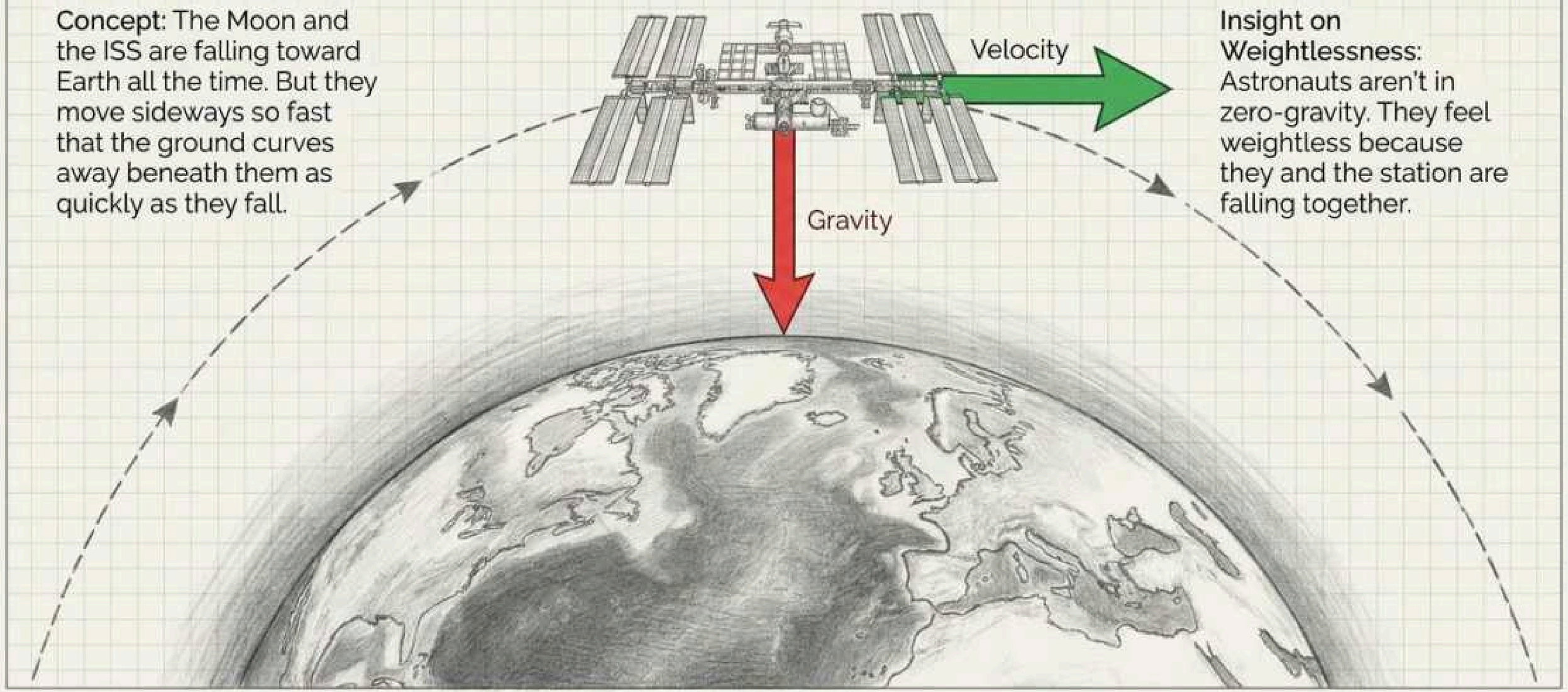
Planet = Gravity

Rule: If the force vanishes, the object flies off in a straight line (Newton's 1st Law). There is no outward force pushing it away.

Orbits: Falling Sideways

¶ 6.16

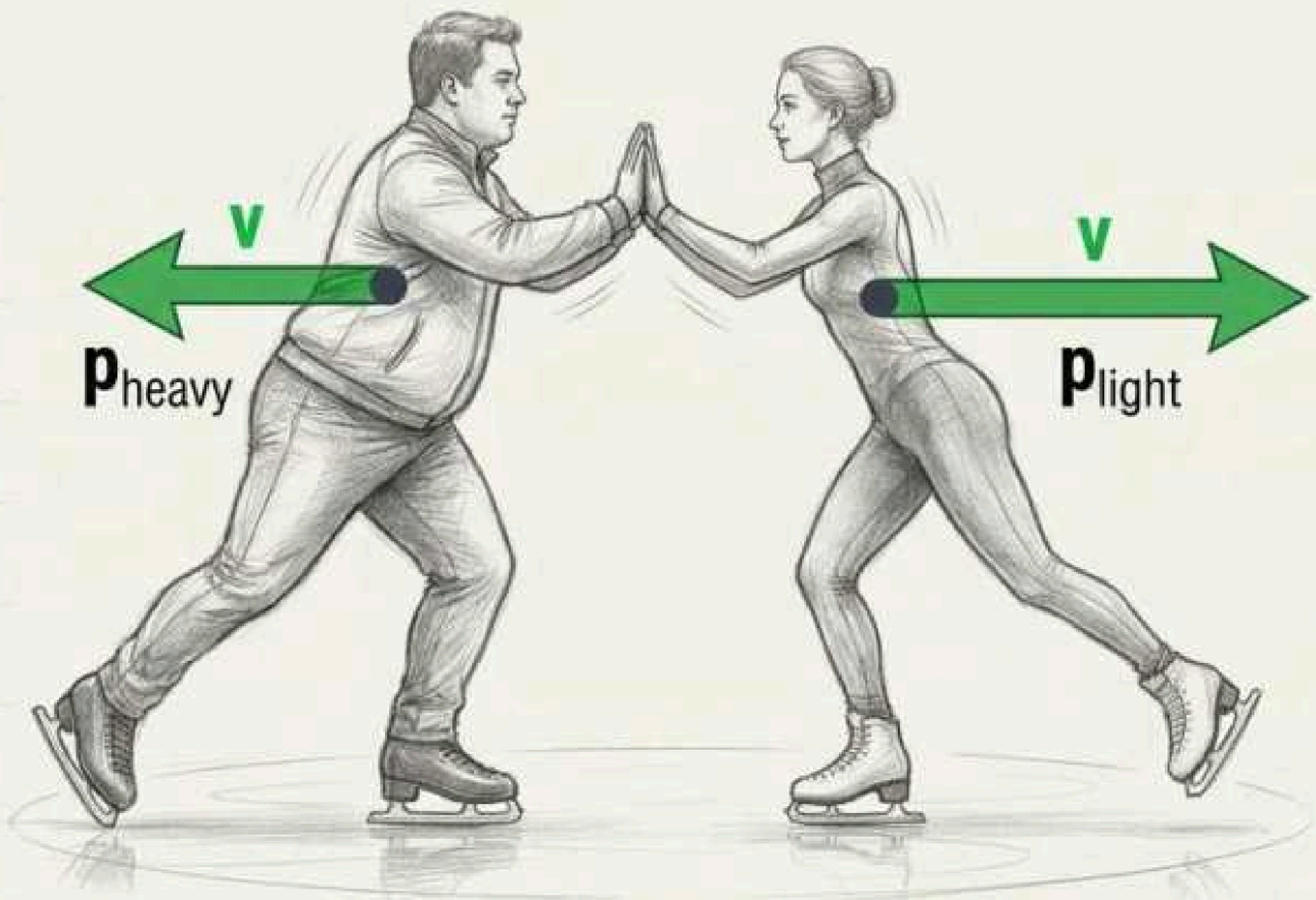
Concept: The Moon and the ISS are falling toward Earth all the time. But they move sideways so fast that the ground curves away beneath them as quickly as they fall.



Insight on Weightlessness: Astronauts aren't in zero-gravity. They feel weightless because they and the station are falling together.

Example 3: Skater Push-Off

¶ 6.17



Initial State: Skaters at rest. Total momentum = 0.

Event: **70 kg** skater and **50 kg** skater push apart. Total momentum must stay 0.

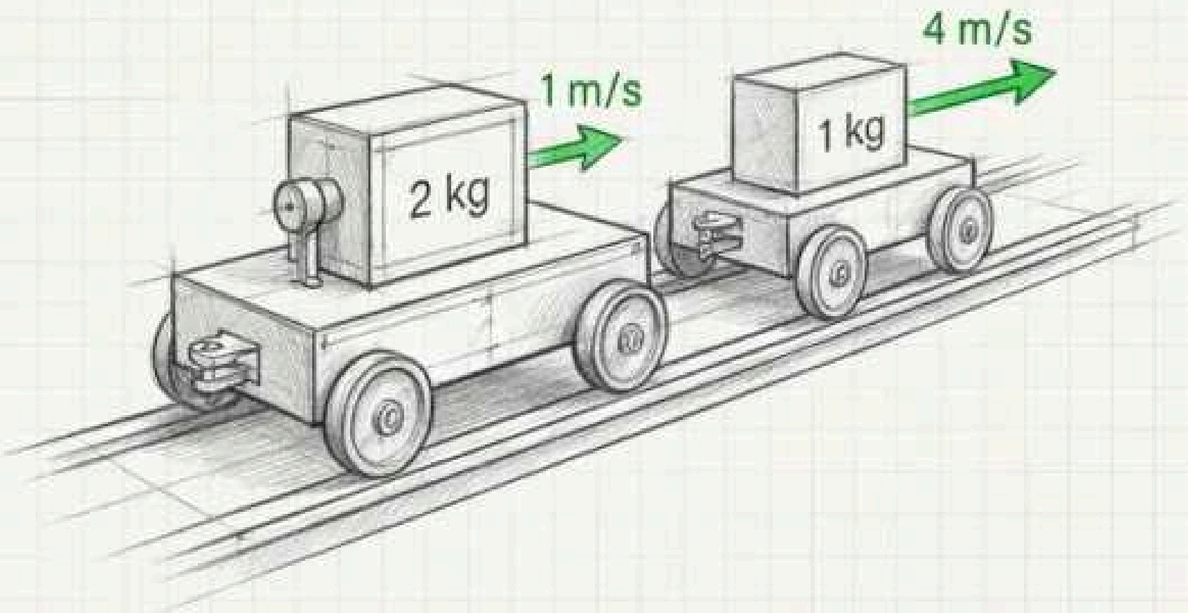
Heavier skater moves at **2 m/s** (**p** = 140).

Lighter skater must move the opposite way with equal momentum.

Speed = 140 ÷ 50 = **2.8 m/s**

Example 4: Elastic Math

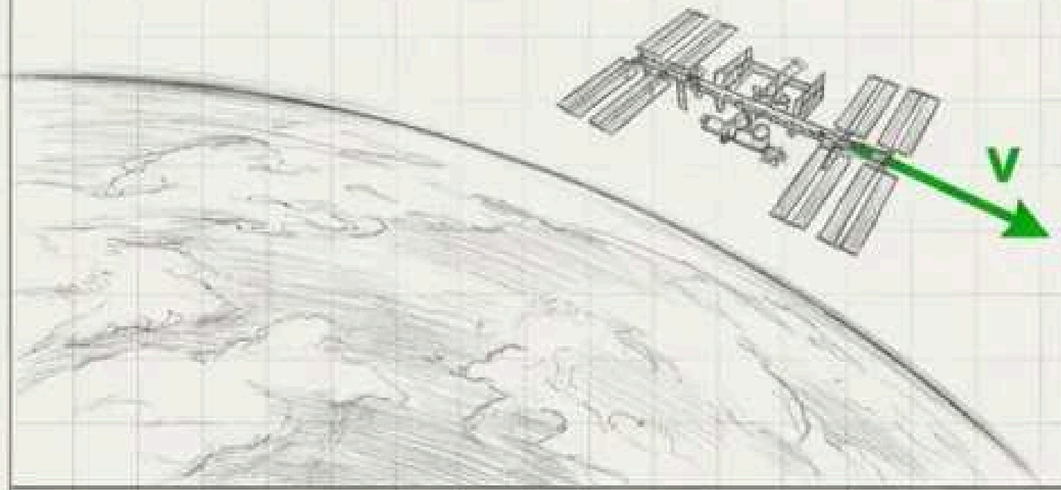
Scenario: A 2 kg cart at 3 m/s hits a 1 kg cart at rest. After perfectly elastic impact, the 2 kg cart moves at 1 m/s, the 1 kg cart at 4 m/s.



Momentum Ledger	Kinetic Energy Ledger
$Before = 6$	$Before = 9$ Joules
$After = (2 \times 1) + (1 \times 4) = 6$	$After = 1 + 8 = 9$ Joules
✓ (Conserved)	✓ (Conserved)

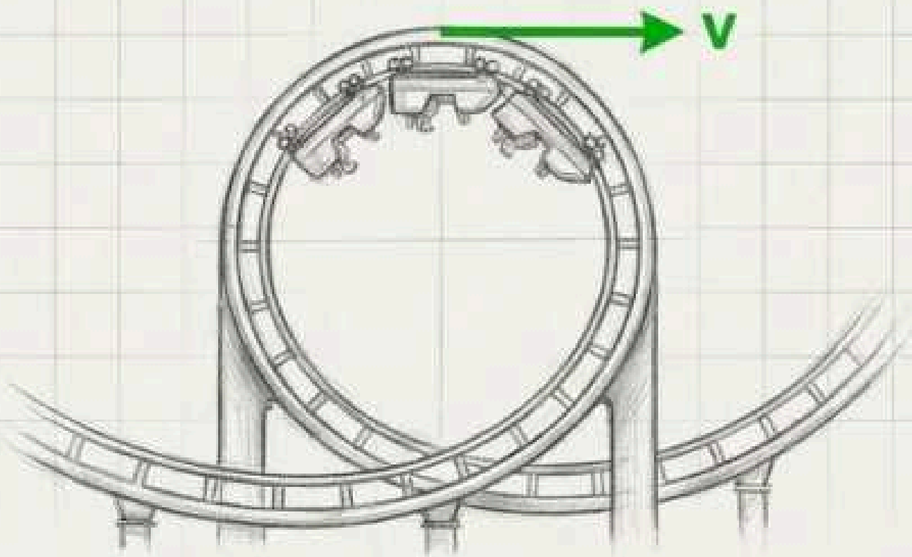
Circular Motion at Any Scale

¶ 6.19



ISS: Orbits 400 km up at **7.7 km/s**. Circles the Earth every 92 minutes.

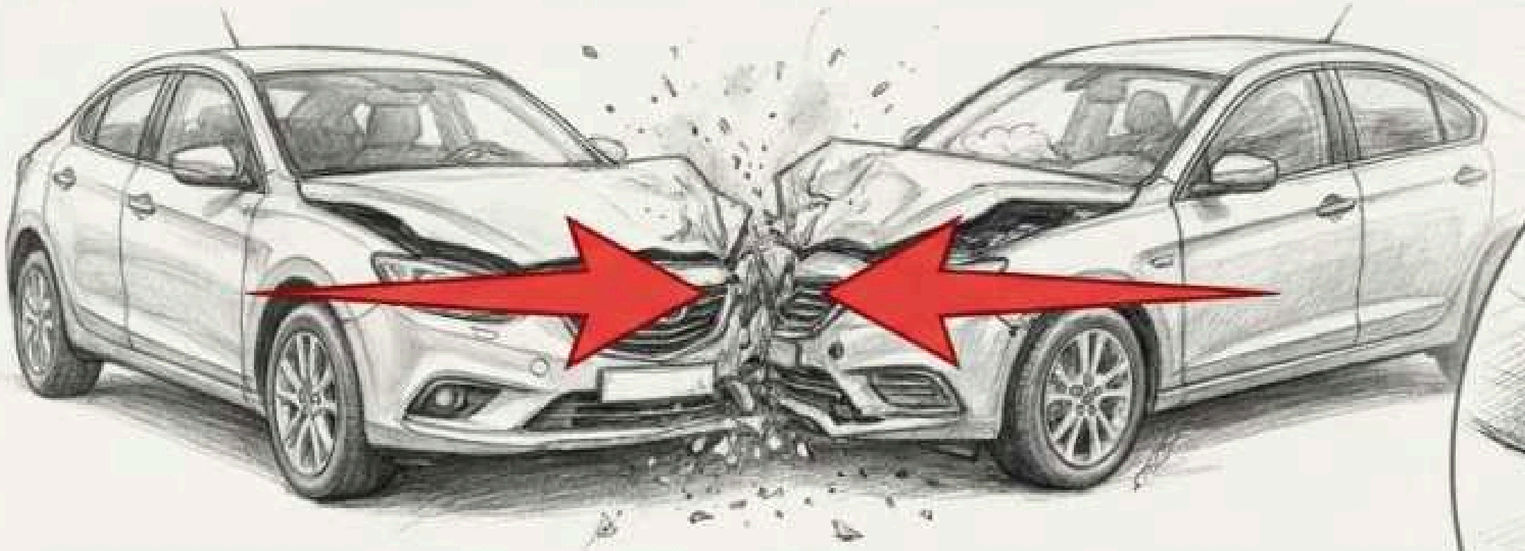
Rollercoaster: A 5 m radius loop. At the top, the car needs at least **7 m/s** to stay on the track.

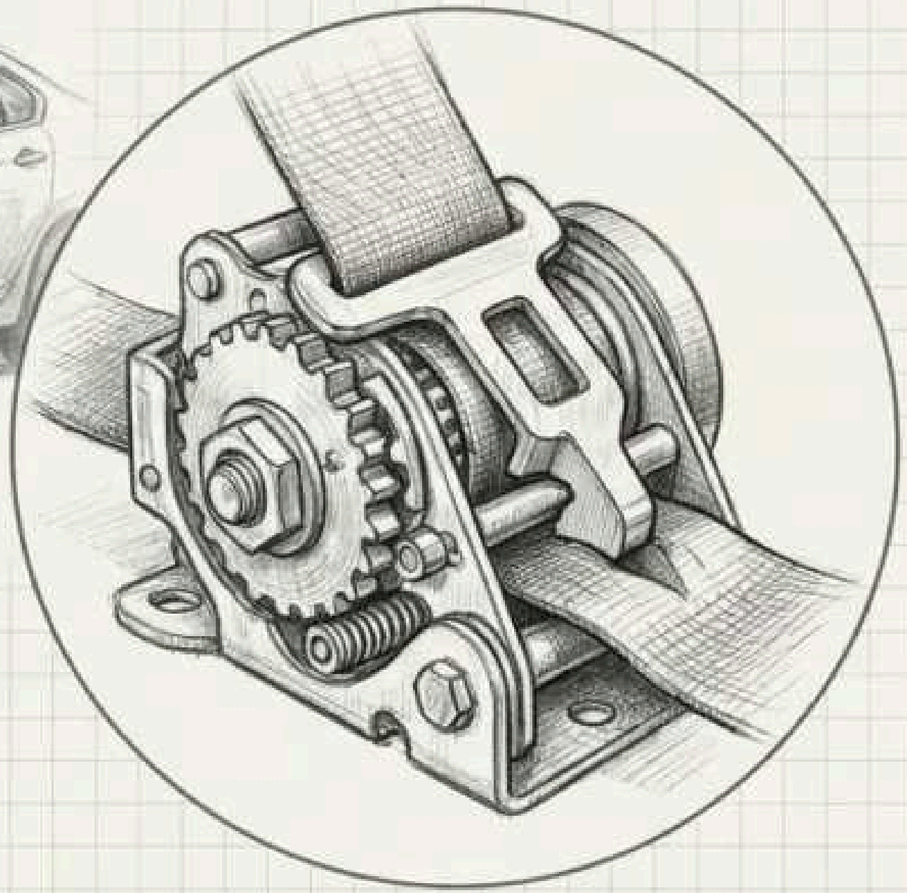


Synthesis: The exact same principles govern the physics in both scenarios.

Lecture Challenge

¶ 6.20





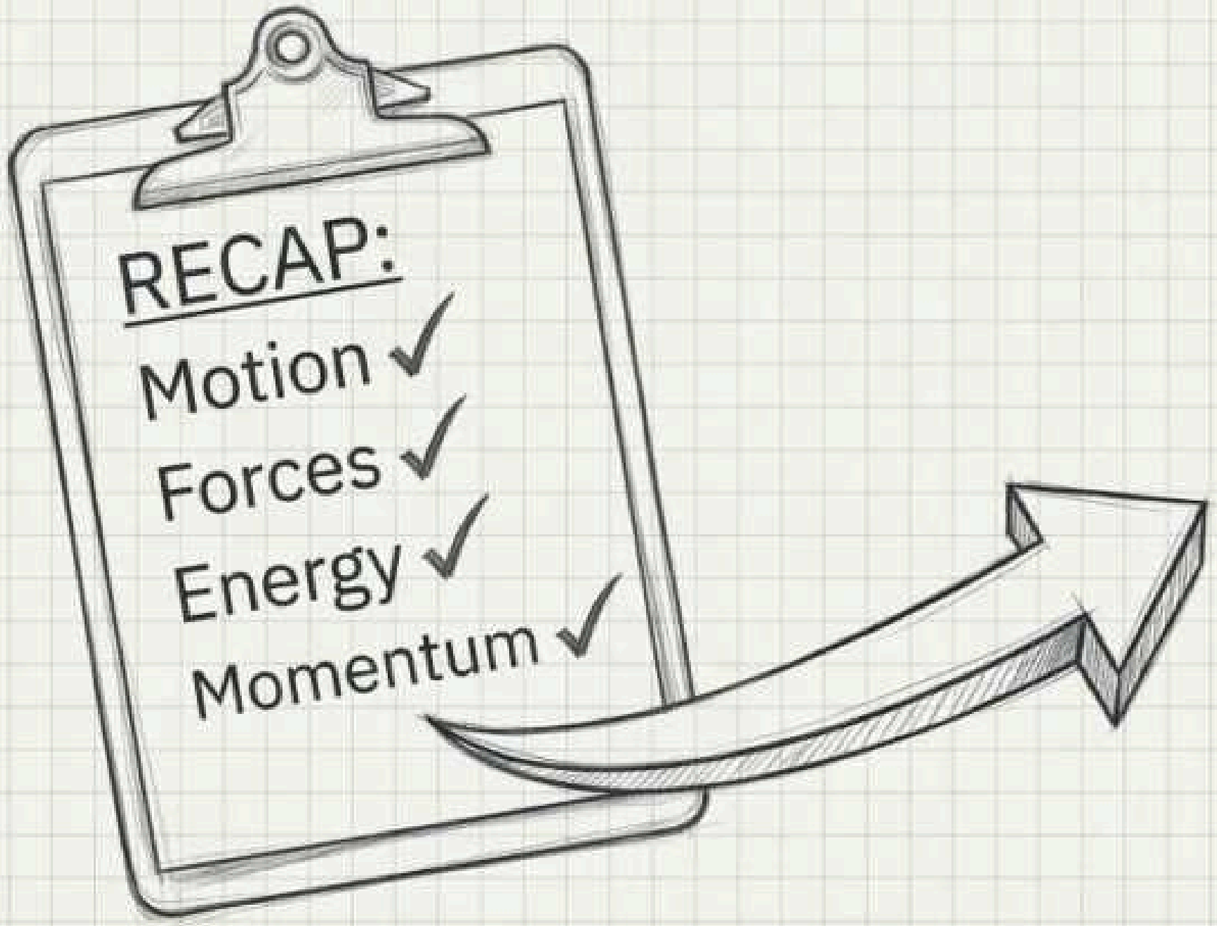
Prompt: Two cars of equal mass collide head-on at equal speeds and stop completely.

Questions to consider:

1. Which conservation laws have been obeyed?
2. What has happened to the kinetic energy?
3. Why does wearing a seat belt matter in terms of impulse ($\Delta p / \Delta t$)?

Physics 101 B: Complete

¶ 6.21



Rotation, Waves, Thermodynamics, Electricity.

Keep practicing the examples.

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