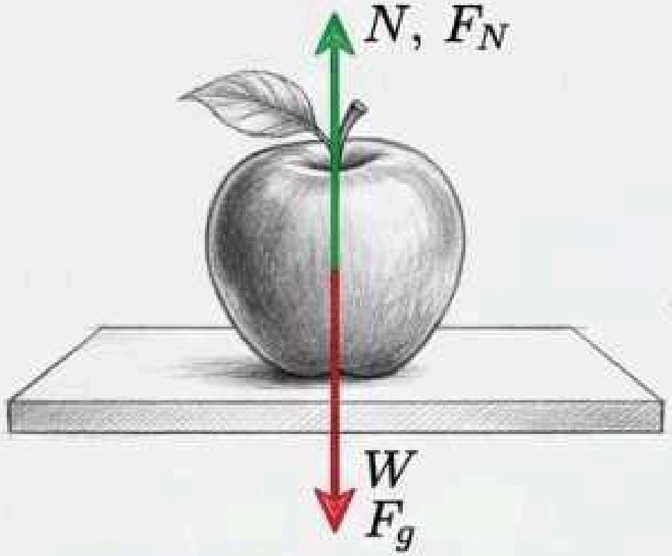
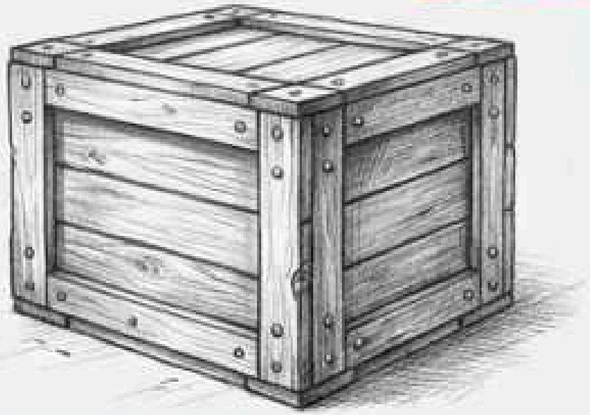
¶ 4.1

Newton's Laws and Forces

Lecture 4: What Causes Motion?



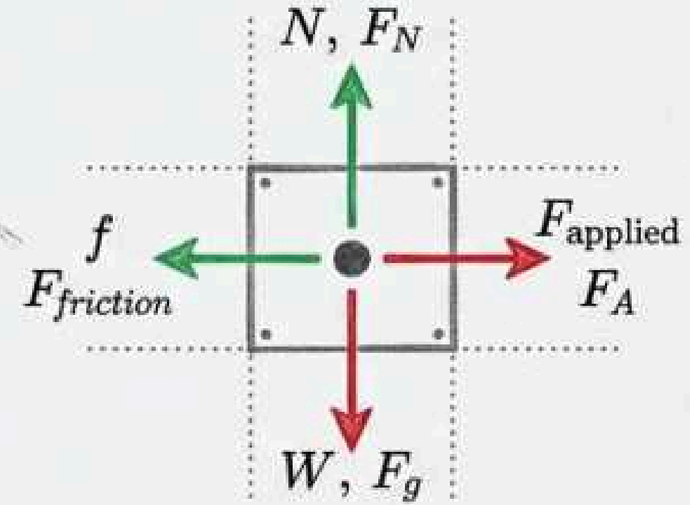
Weight & Normal Force



Newton's 3 Laws

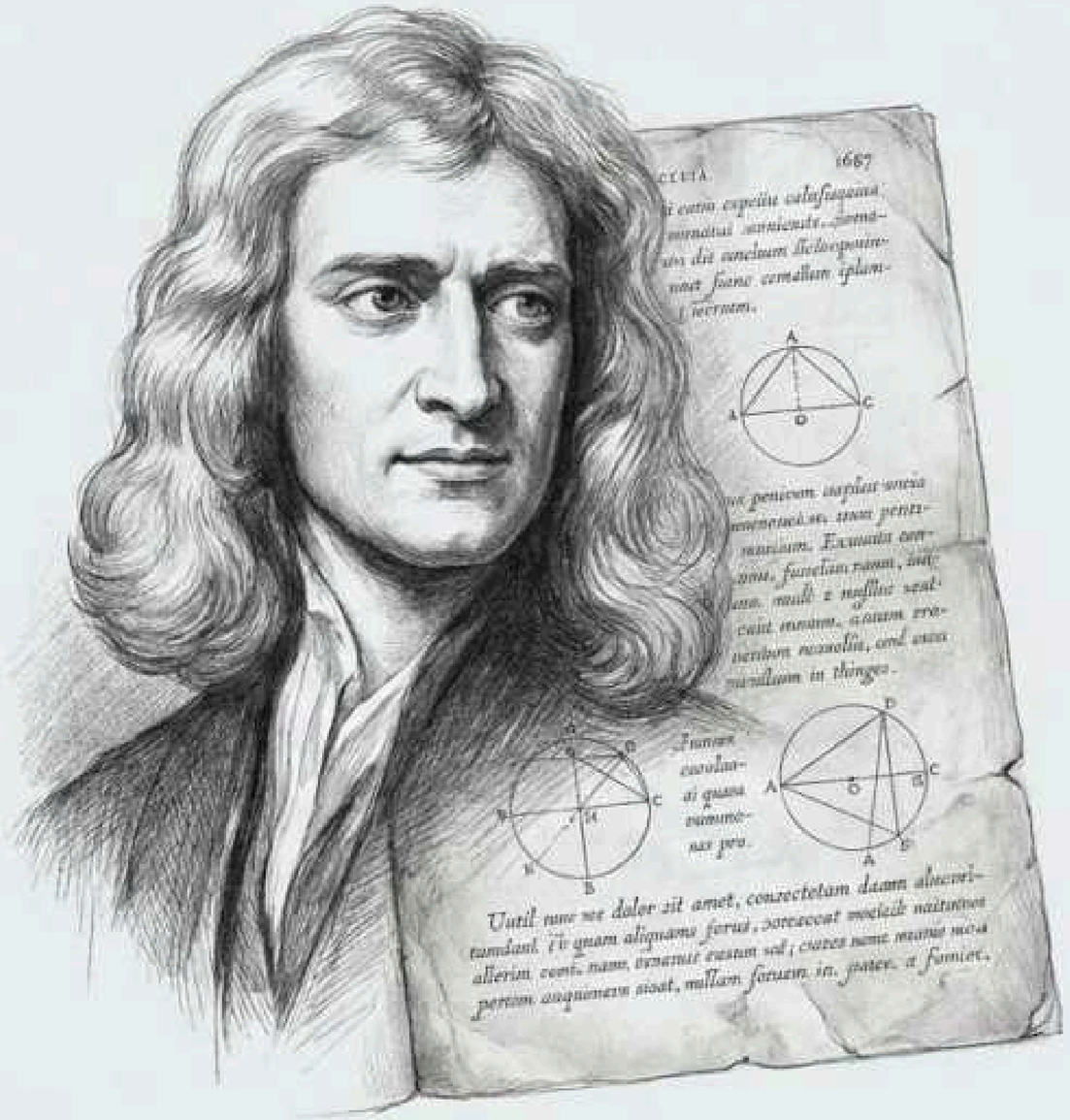


Friction



Free-Body Diagrams

¶ 4.2



The Core Question: What Causes Motion?

Until now, we described motion. In 1687, Isaac Newton published the Principia, explaining WHY things move.

His Three Laws of Motion form the absolute heart of classical mechanics.

¶ 4.3

Defining Force

- A push or a pull.

- It is a Vector:
  It has both size and direction.

$$\vec{F}$$



$$\sum \vec{F} = \vec{F}_{net}$$

(Add multiple forces as vectors to find the net force).



The Newton (N)

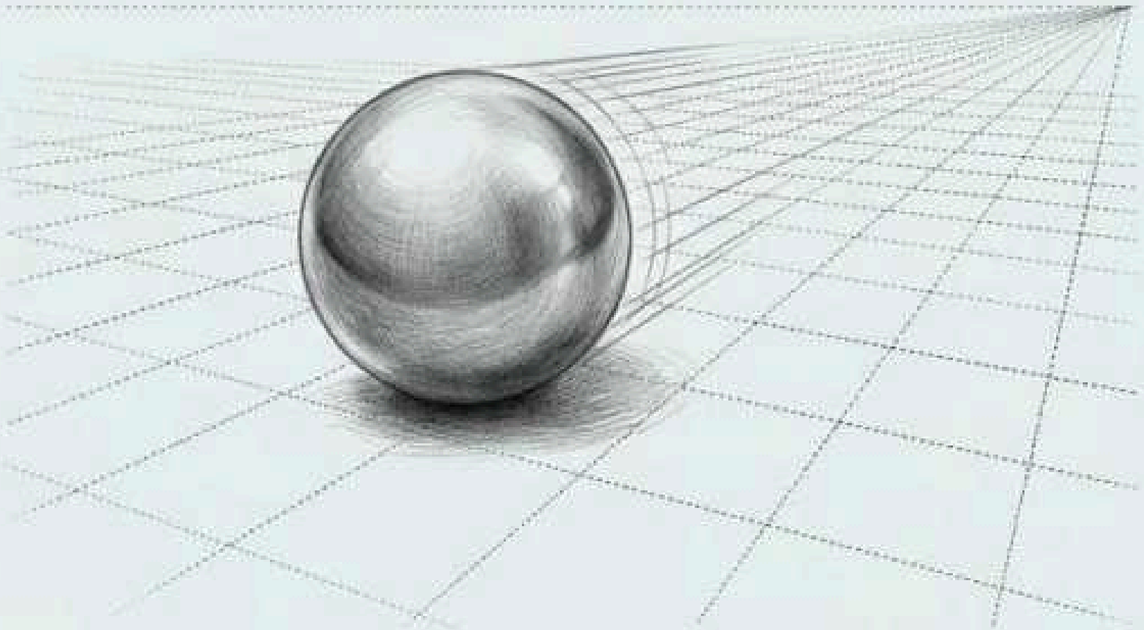
1 Newton ≈ the weight of a small apple.

Newton's First Law (Inertia)

¶ 4.4



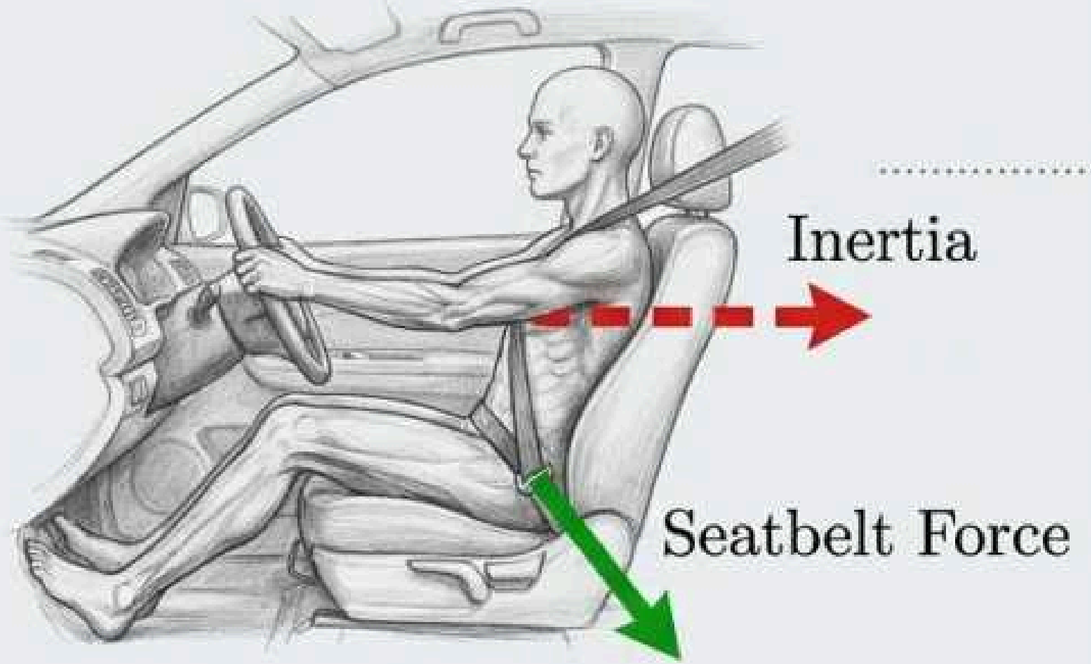
Aristotle believed motion requires a constant push. (Wrong).



Inertia: An object keeps doing what it is doing unless a net force acts upon it.

Formulaic Rule:

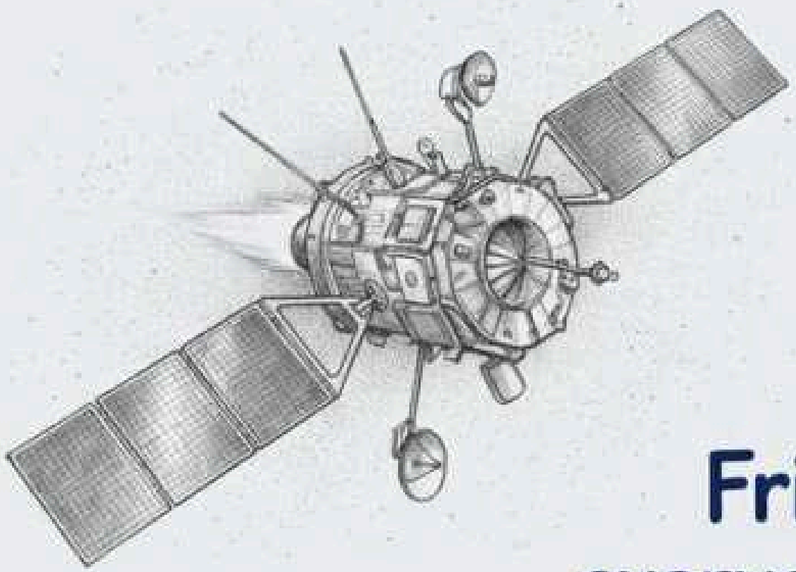
- At rest → Stays at rest.
- Moving → Constant speed, straight line.



Hard Braking:

Your body keeps moving forward.

The seatbelt supplies the net force to change your motion.



Spacecraft:

Coasts forever with engines off.

Friction is the invisible force that makes everyday objects seem to need a constant push.

Newton's Second Law: The Workhorse of Mechanics

¶ 4.6

$$F_{net} = ma$$

[Large Force] → [Large Acceleration]

[Large Mass] → [Small Acceleration]

(for the same force)

Mass = A measure of how strongly an object resists changes to its motion.

Example 1: Car Acceleration

¶ 4.7



Calculation:

Given: Mass $(m) = 1200\,\text{kg}$, Net Forward Force $(F_{net}) = 3000\,\text{N}$.

Calculation: $a = \dfrac{F_{net}}{m} = \dfrac{3000}{1200} = 2.5\,m/s^2$

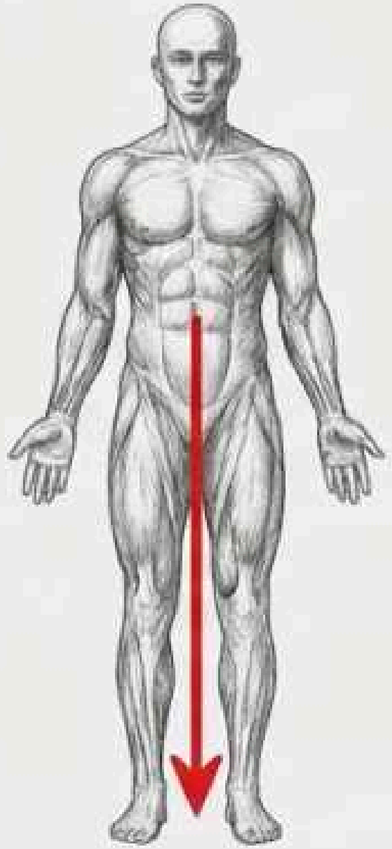
Proportionality Check (The Rule of Rules):

- Double the force $(2F) \rightarrow$ Double the acceleration $(2a)$.
- Double the mass $(2m) \rightarrow$ Halve the acceleration $(0.5a)$.

¶ 4.8

Mass vs. Weight

1	Mass = Amount of matter	Weight = Downward force of gravity $(W = mg)$
2	Mass = Never changes	Weight = Depends on location

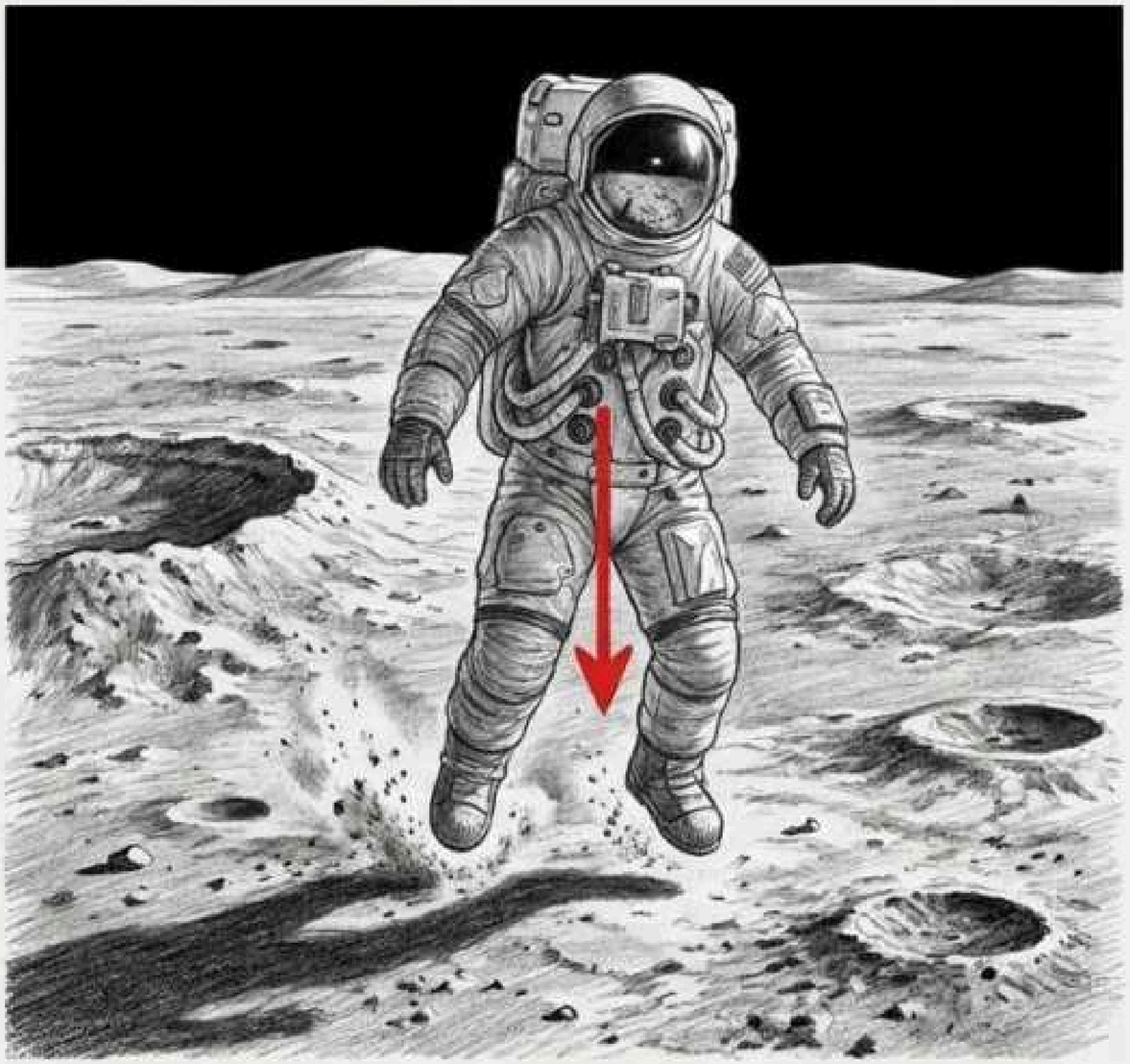


A 70 kg person.

- Mass $= 70\,\text{kg}$.
- Weight $= 70\,\text{kg} \cdot 9.8\,\frac{m}{s^2} = 686\,\text{N}$.

Gravity on the Moon ($\approx 1/6$ Earth Gravity)

¶ 4.9



The Data:

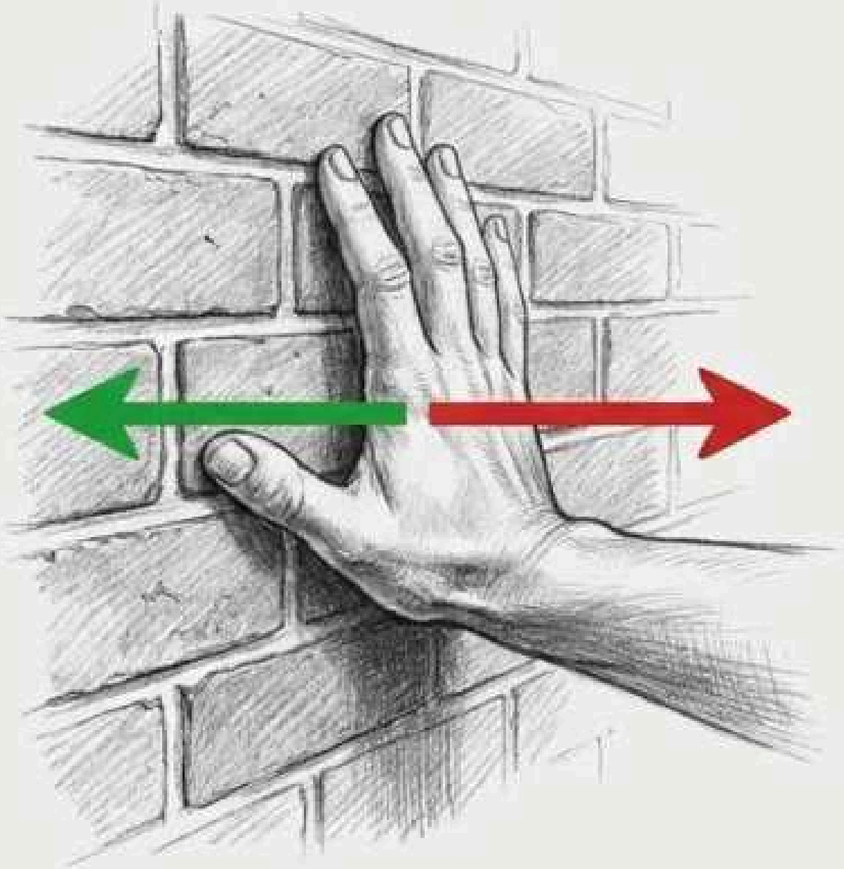
- Mass $= 70\ \mathrm{kg}$
  (Inertia is completely unchanged).
- Weight $= \approx 113\ \mathrm{N}$
  (Downward pull is much smaller).

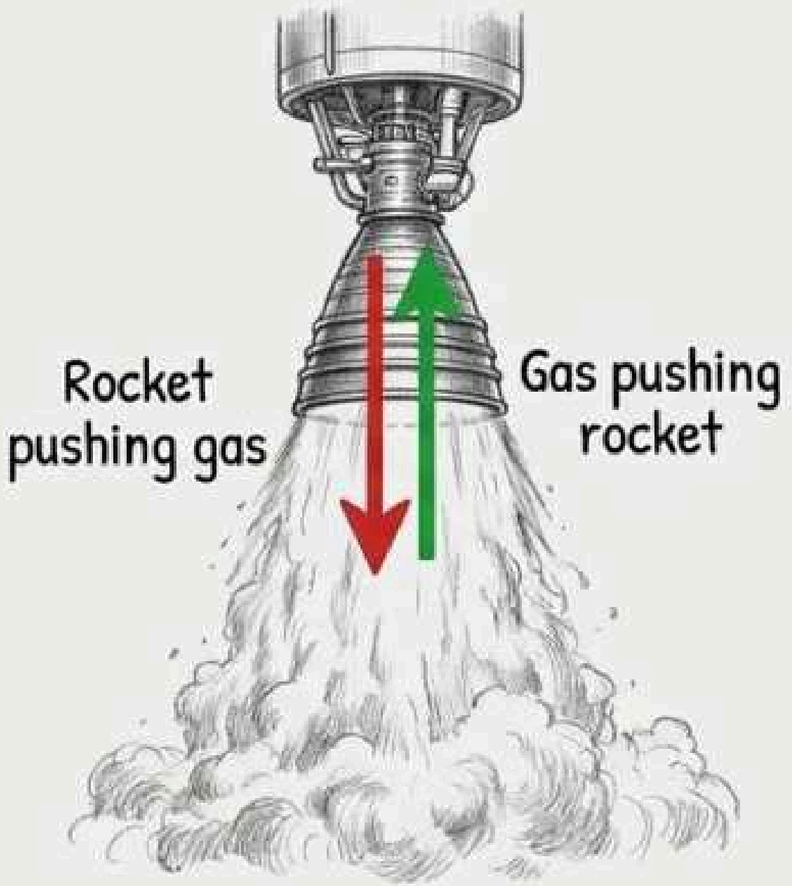
Insight: This is why astronauts bounce easily but still require effort to stop moving forward.

Warning: Be careful! Don't say "weight" in the kitchen when you actually mean "mass".

Newton's Third Law (Force Pairs)

¶ 4.10



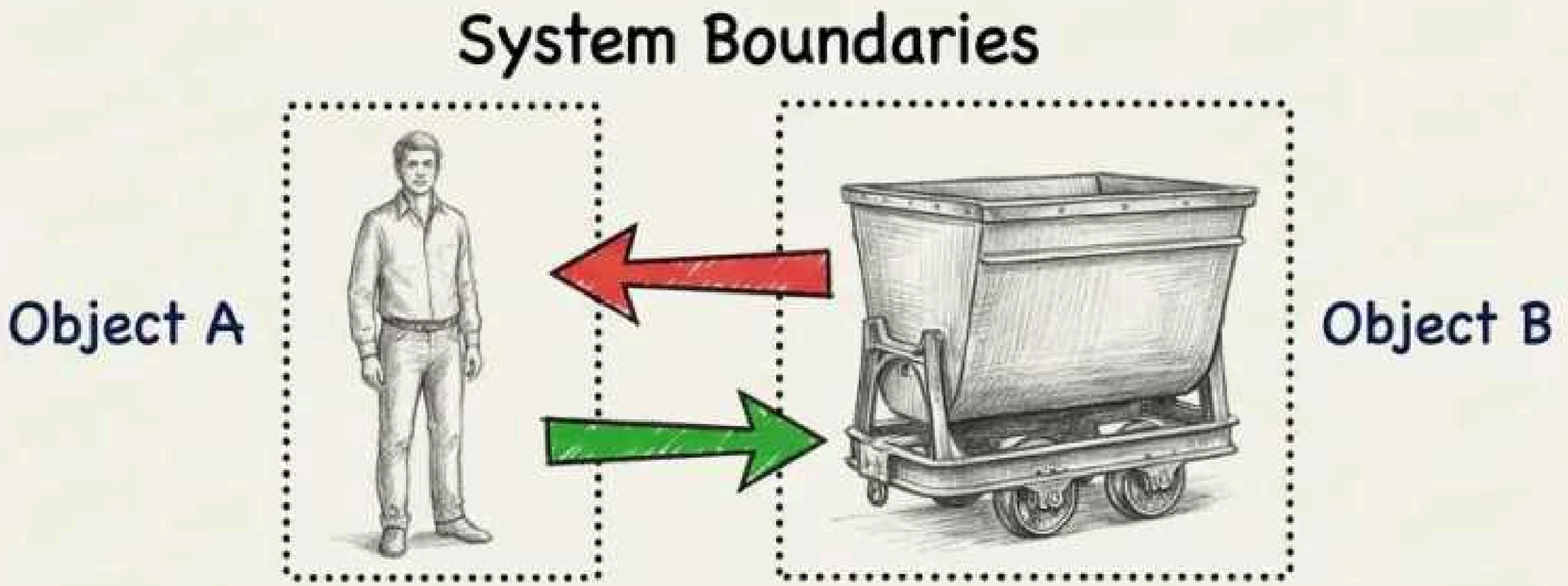


Rule: Forces always come in pairs. If A pushes B, then B pushes A.

Properties: Equally hard, opposite direction, and crucially: They act on different objects.

The Cancellation Paradox

¶ 4.11



Question: If forces are always equal and opposite, why does anything move?

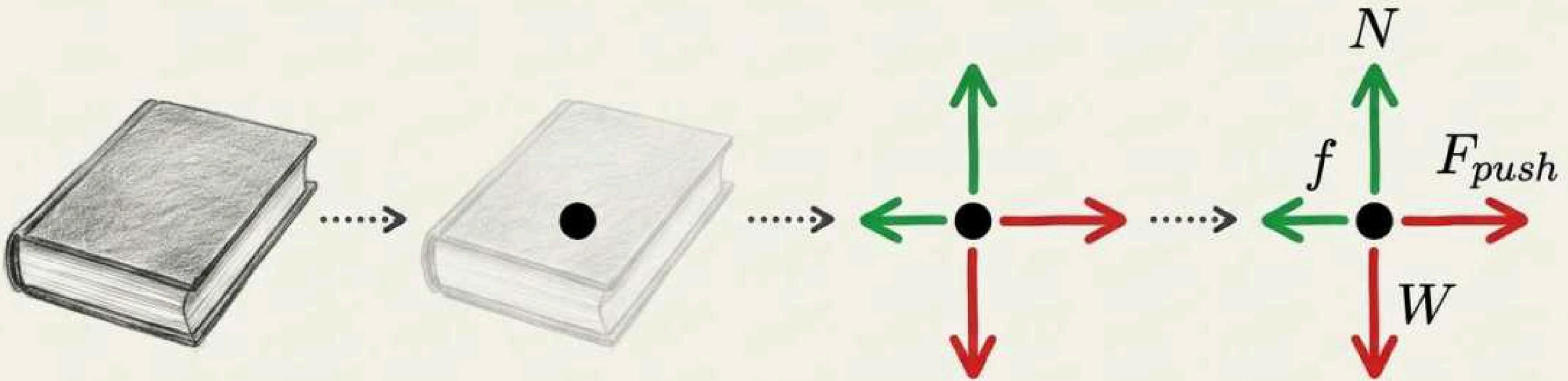
Answer: Because the paired forces act on DIFFERENT objects.
They never cancel each other out.

Conclusion: Motion depends only on the net force on one specific object.
We must draw diagrams for each object separately.

The Free-Body Diagram (FBD)

¶ 4.12

The single habit that solves most mechanics problems.



1. Draw object as single dot.

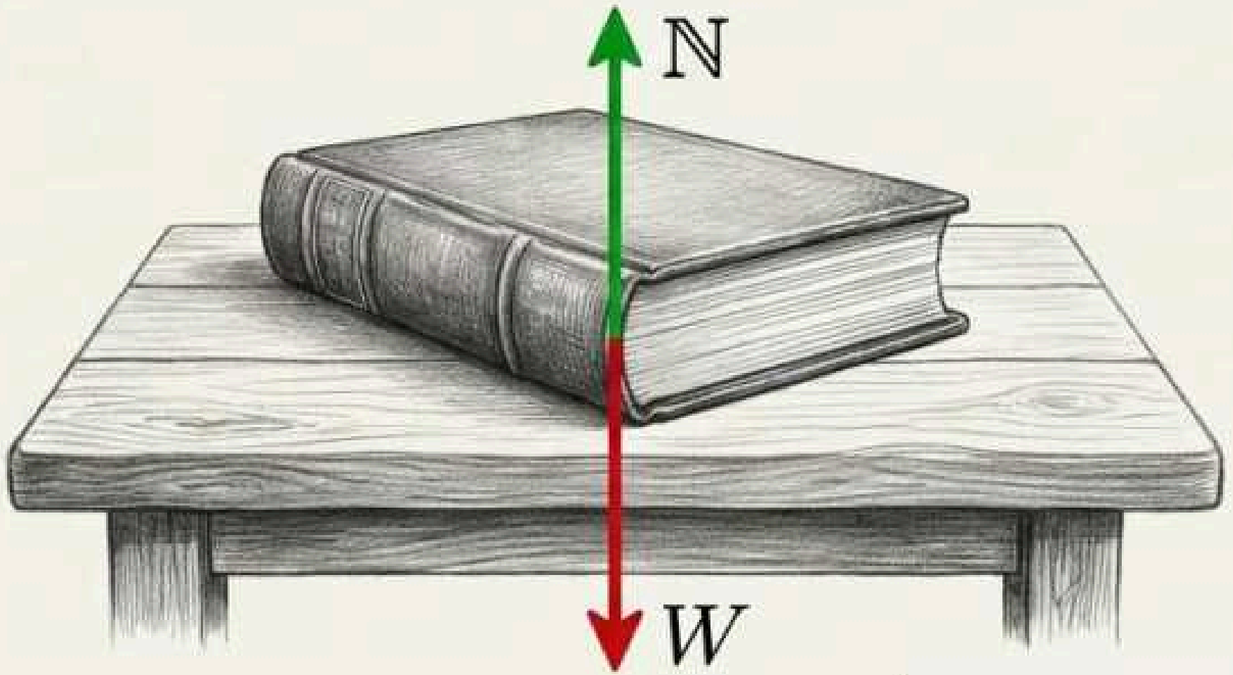
2. Draw arrows for forces.

3. Label every arrow.
4. Add vectors to find F_{net}.

The Normal Force ($\mathbb{N}$)

¶ 4.13

The push of a surface against an object.



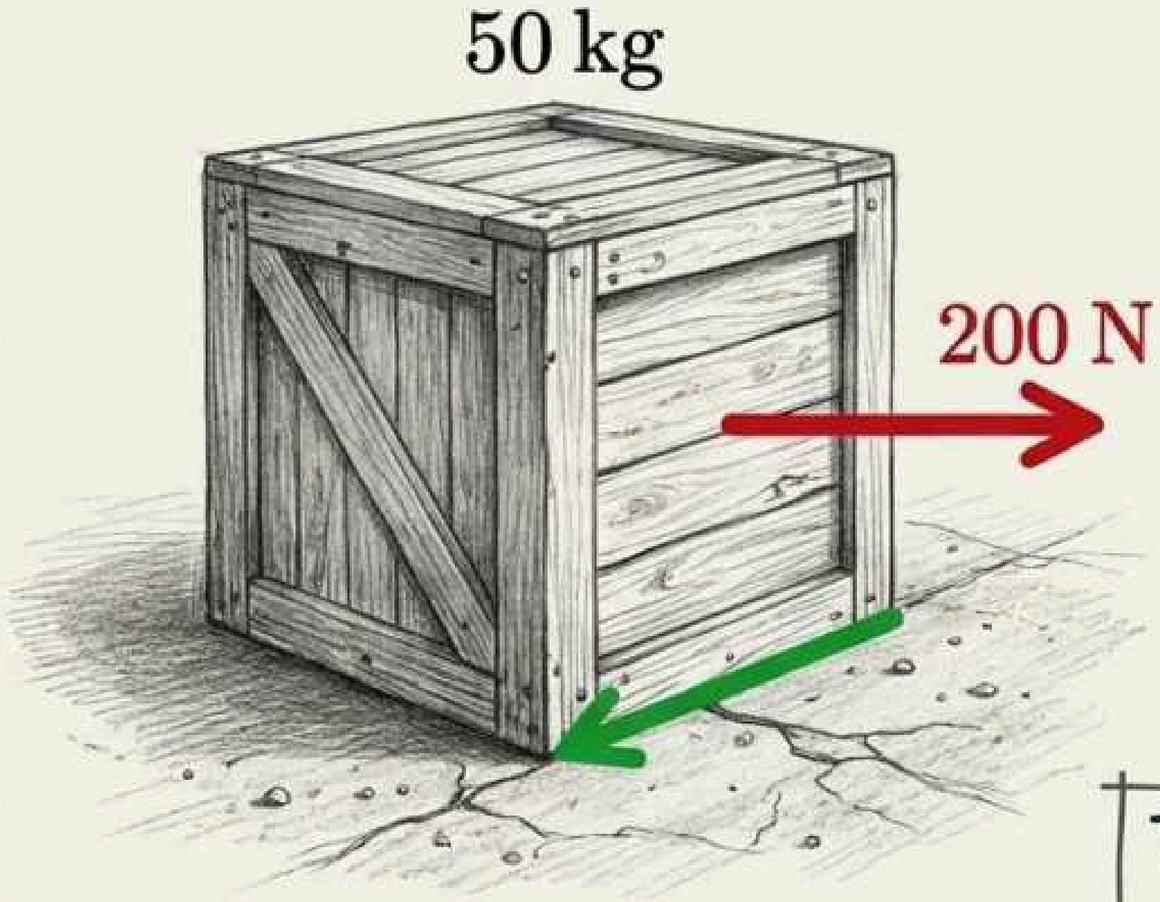
Equilibrium: Gravity presses the book down.
The table pushes up equally.

$\mathbb{F}_{net} = 0$, so the book stays still.

Preview Insight: $\mathbb{N}$ is not fixed. If you stand in an upward-accelerating elevator, the floor pushes harder → you feel heavier.

Friction Mechanics: Opposing Sliding

¶ 4.14



Formula:

$$f = \mu N$$

(Coefficient x Normal Force)

The Math (50 kg crate, $\mu = 0.3$):

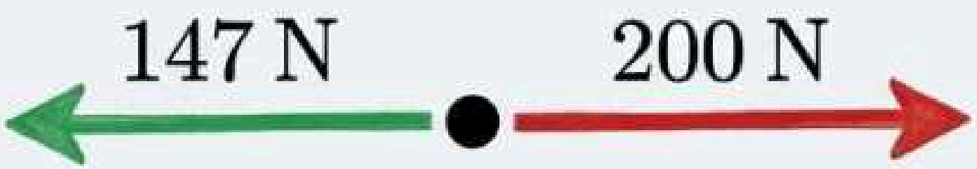
→ Normal Force $(N) = 50 * 9.8$
$= 490\ \text{N}.$

→ Friction $(f) = 0.3 * 490 = 147\ \text{N}.$

The Result: Push with $200\ \mathbb{N}$ forward.
Friction pulls $147\ \text{N}$ backward.
$F_{net} = 53\ \mathbb{N}$ forward.

¶ 4.15

Acceleration

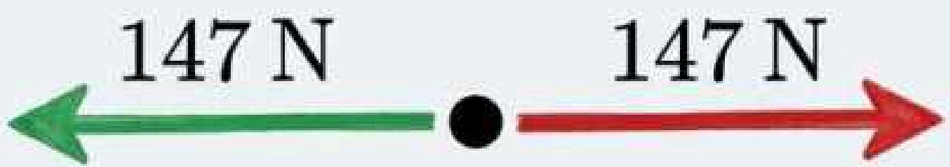


$F_{net} = 53\,\text{N}, m = 50\,\text{kg}$

$\rightarrow a \approx 1.06\,\text{m/s}^2$

(Velocity is increasing).

Constant Velocity



If push matches friction (147 N),

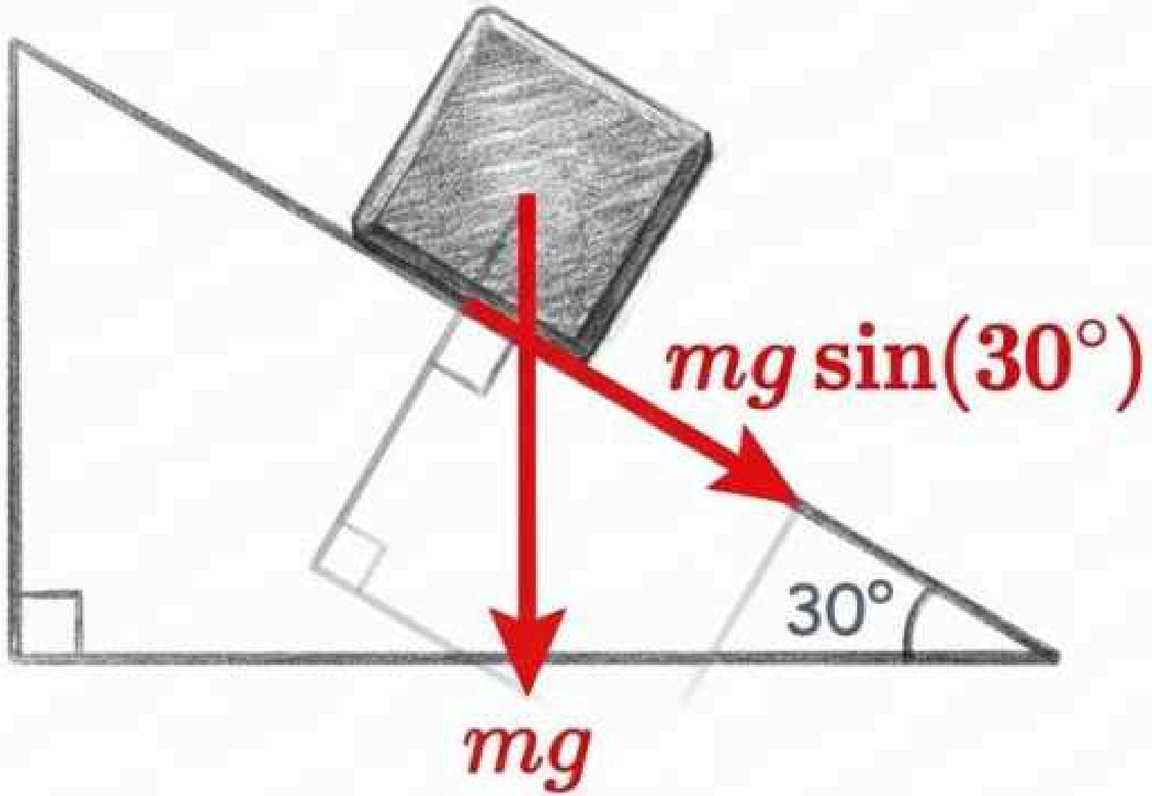
$F_{net} = 0\,\text{N}.$

Crate moves at a steady speed.

Core Rule: Do not confuse constant velocity with a lack of force. Constant velocity means zero net force.

Ramp Physics: Gravity on a Tilt

¶ 4.16



Scenario: Frictionless slope tilted at 30°.

The Math:

- Force down slope = $mg\sin(30°)$.
- Acceleration (a) = $9.8 \cdot 0.5 = 4.9\,\frac{m}{s^2}$.

Insight: A steeper slope yields a larger sine value (larger acceleration). A flat surface (0°) yields zero acceleration.

Example 2: Tension & Prediction

¶ 4.17

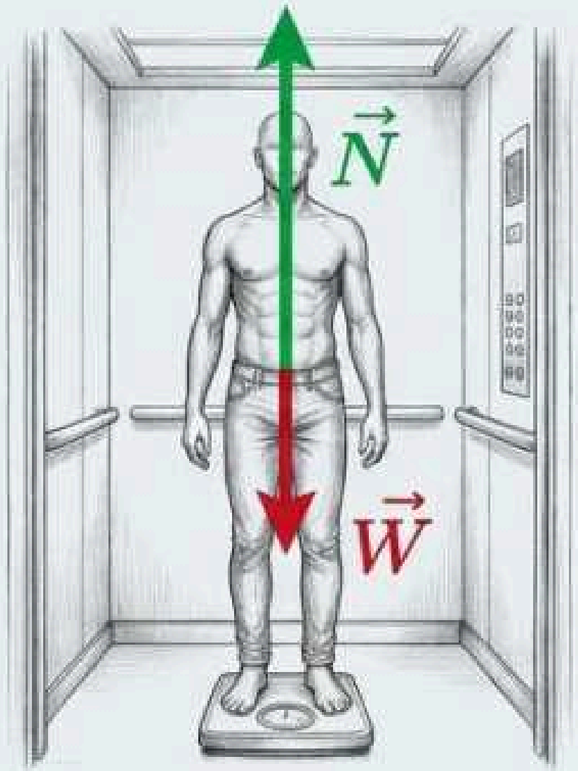


- Scenario: 10 kg ice block, 30 N rope pull, zero friction. $F_{net} = 30$ N.
- Acceleration: $a = \dfrac{30\ \text{N}}{10\ \text{kg}} = 3\ \text{m/s}^2$.
- Prediction (at $t = 4$ s): Velocity = 12 m/s.

Key Takeaway: Newton's Second Law is a time machine—it lets us perfectly predict future motion.

The Elevator Experience (Apparent Weight)

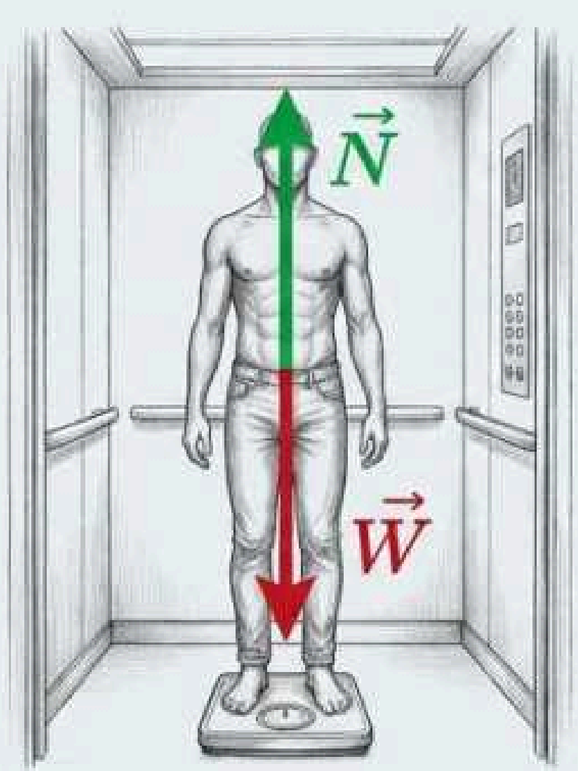
¶ 4.18



Upward $a = 2\ \text{m/s}^2$

N must overcome W.
Floor pushes up with
$70 \cdot 11.8 = 826$ N.

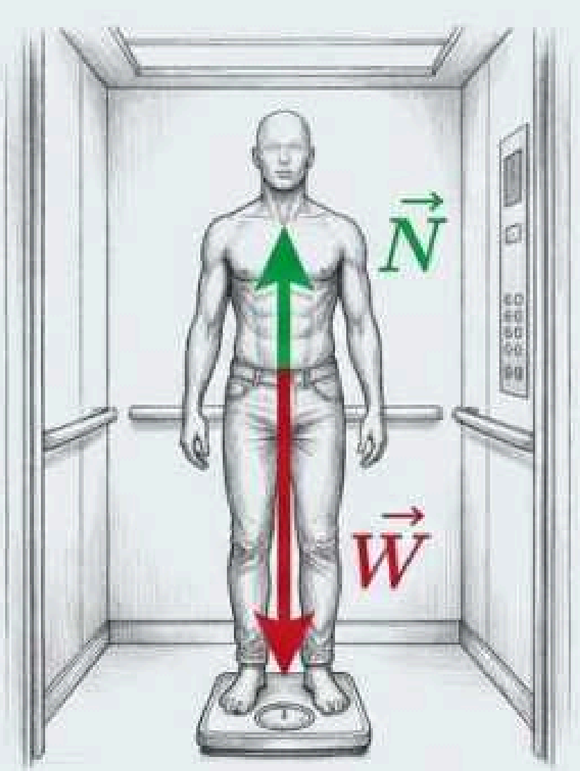
You feel heavier.



No Accel ($a = 0$)

N perfectly balances W.
Floor pushes up with 686 N.

You feel normal.



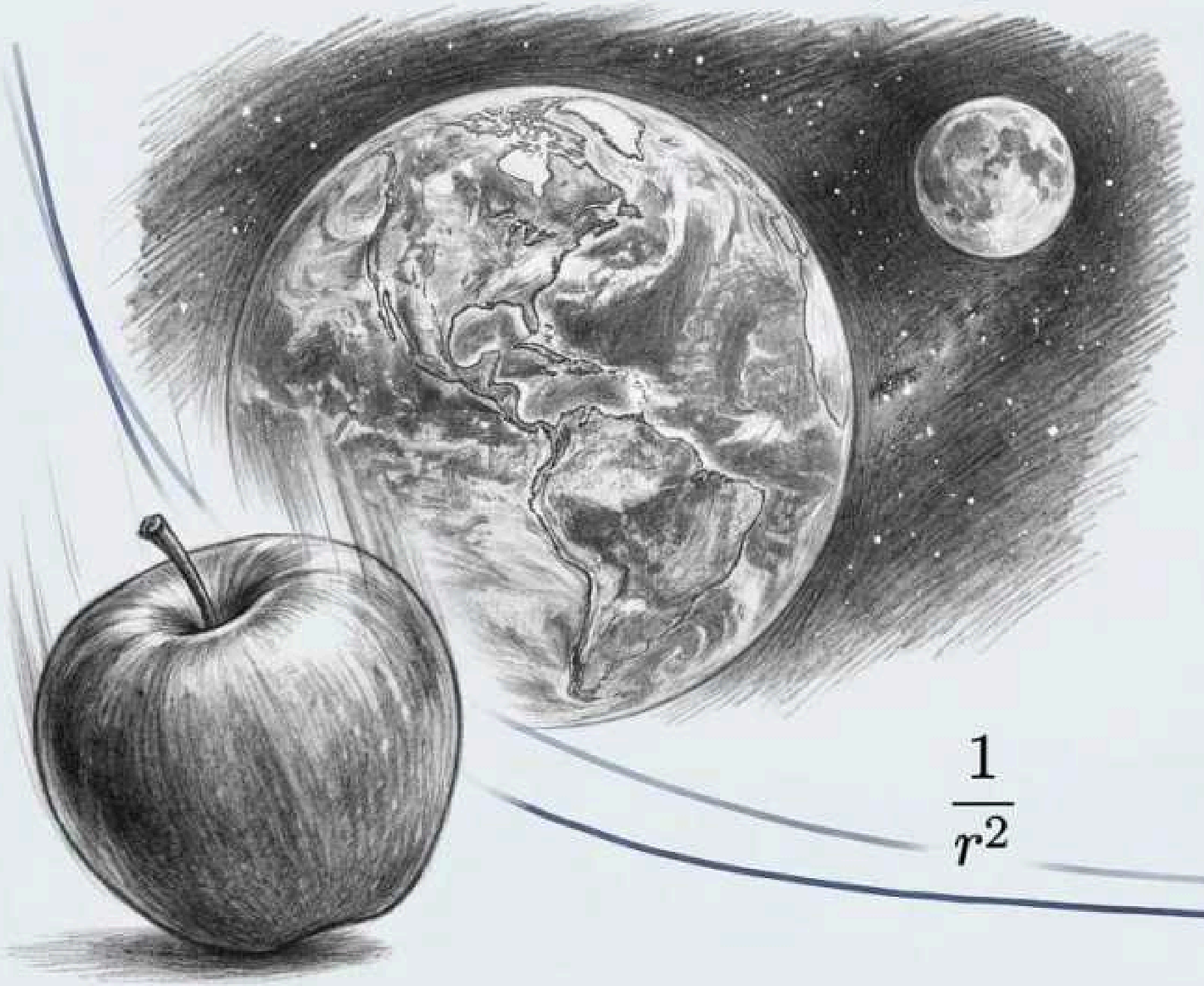
Downward $a = 2\ \text{m/s}^2$

N drops. Floor pushes up
with $70 \cdot 7.8 = 546$ N.

You feel lighter.

Universal Gravitation: Unifying Heaven & Earth

¶ 4.19



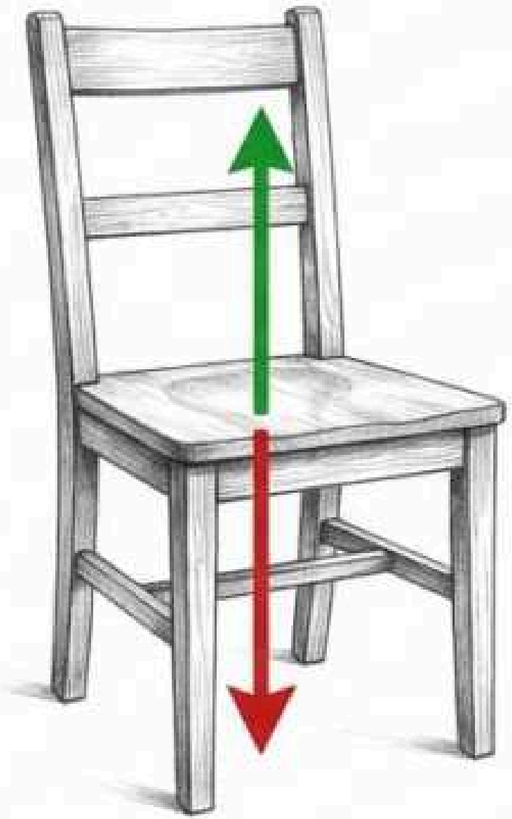
$$\frac{1}{r^2}$$

- The Concept: The exact same force that makes the apple fall keeps the Moon in orbit.
- The Law: Every mass attracts every other mass.
- The Math Rule: The force drops off rapidly with the square of the distance between them.

Lecture Question: A Thought Experiment

¶ 4.20

The Scenario:
You sit on this chair.
Gravity pulls you down,
the chair pushes you up.

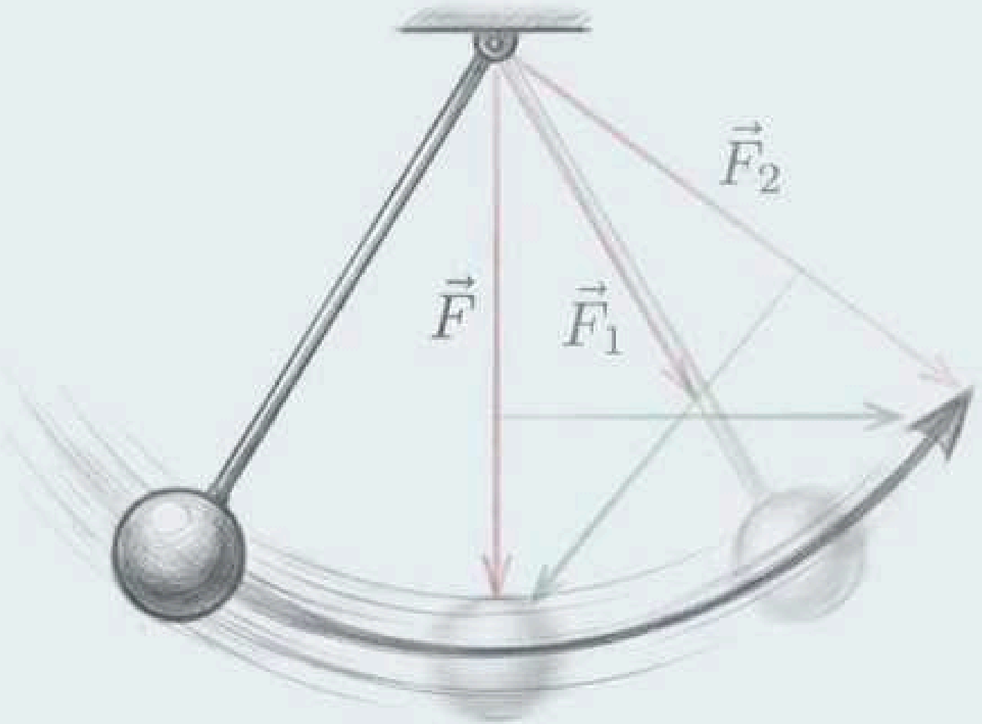


The Puzzle:
Are these two forces
a Third-Law pair?

The Hint: Review the rules. Think carefully about which objects each force acts on. What is the true partner of your weight?
(Hint: What is pulling you down?)

Looking Ahead: Lecture 5

¶ 4.21



We will move from the language of Forces to the language of Energy.

Takeaway: Energy provides a different, and often much easier, framework for solving complex problems in physics.