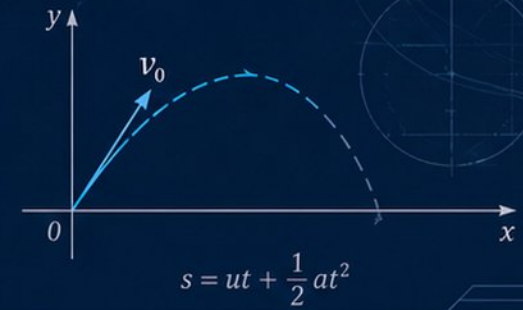


Forces and Motion: An Introduction to Physics



“Physics explains how the world works, starting with motion”



“Everyday motion: walking, driving, throwing a ball”



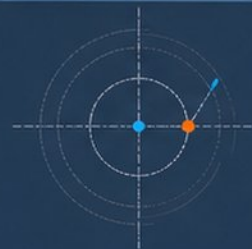
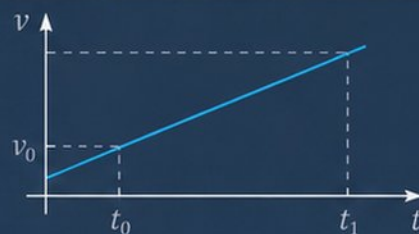
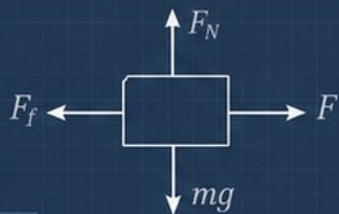
“Big idea: Motion is change in position over time”



“Big idea: Forces cause changes in motion”



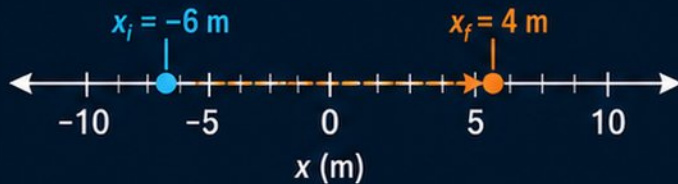
“Course roadmap: Kinematics → Dynamics → Applications”



Position, Distance, and Displacement

- Reference frames: where you stand changes what you measure
- Position is a coordinate in space relative to an origin
- Distance: total path traveled (scalar, no direction)
- Displacement: change in position (vector, has direction)
- Visualize on a number line or 2D coordinate grid

NUMBER LINE EXAMPLE



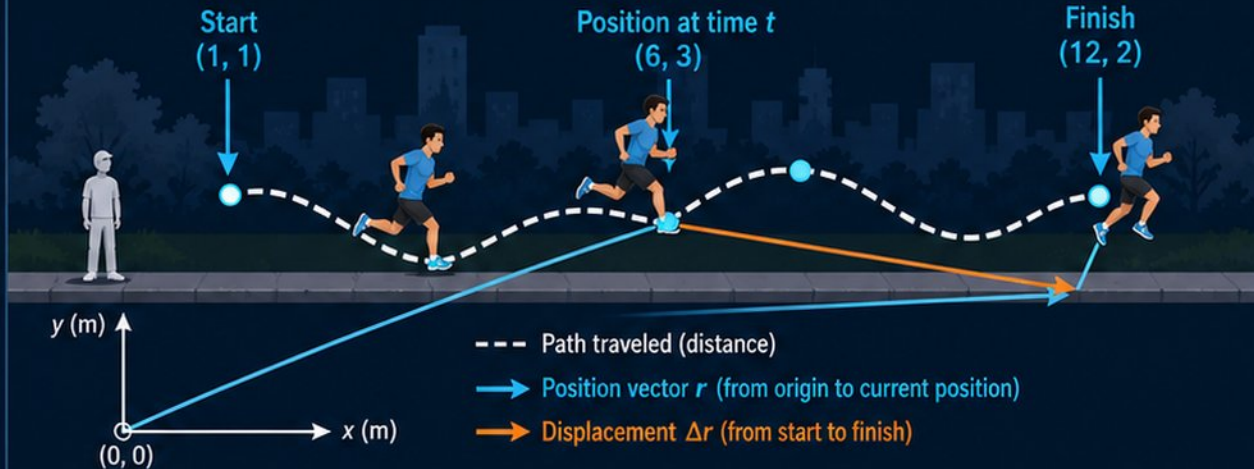
Displacement: $\Delta x = x_f - x_i = 10$ m (to the right)

Distance: 10 m



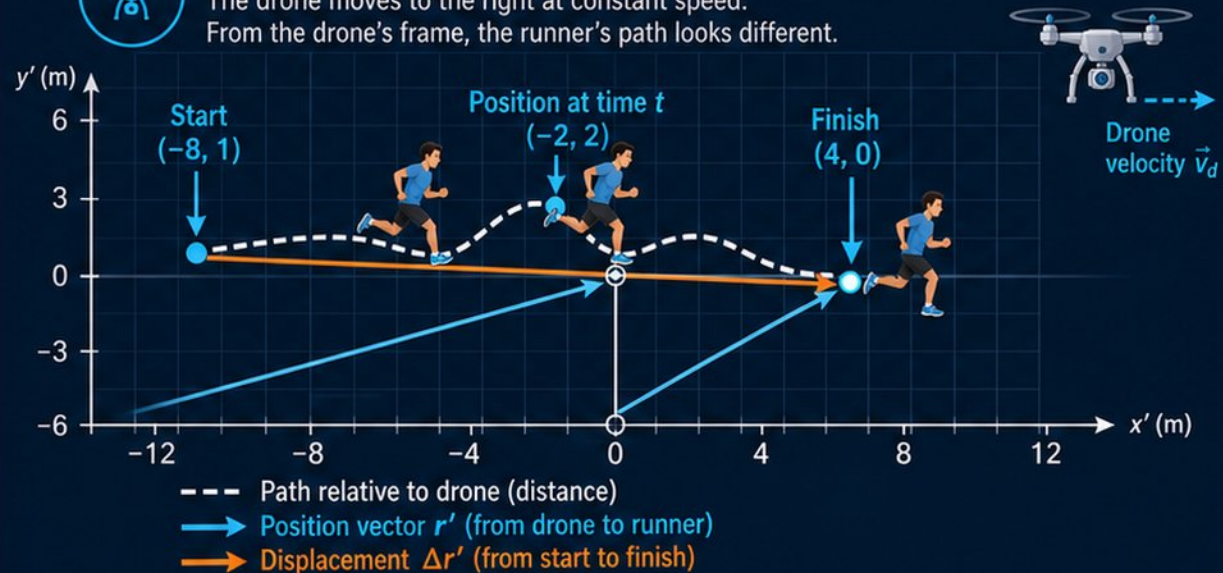
VIEW FROM SIDEWALK (STATIC OBSERVER)

You are standing on the sidewalk.
The runner moves along the path.



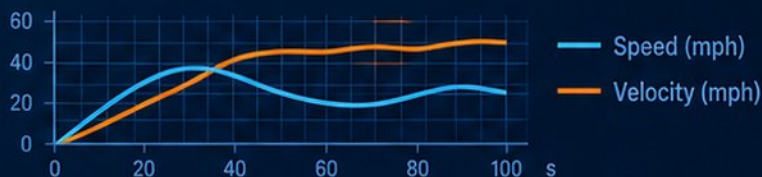
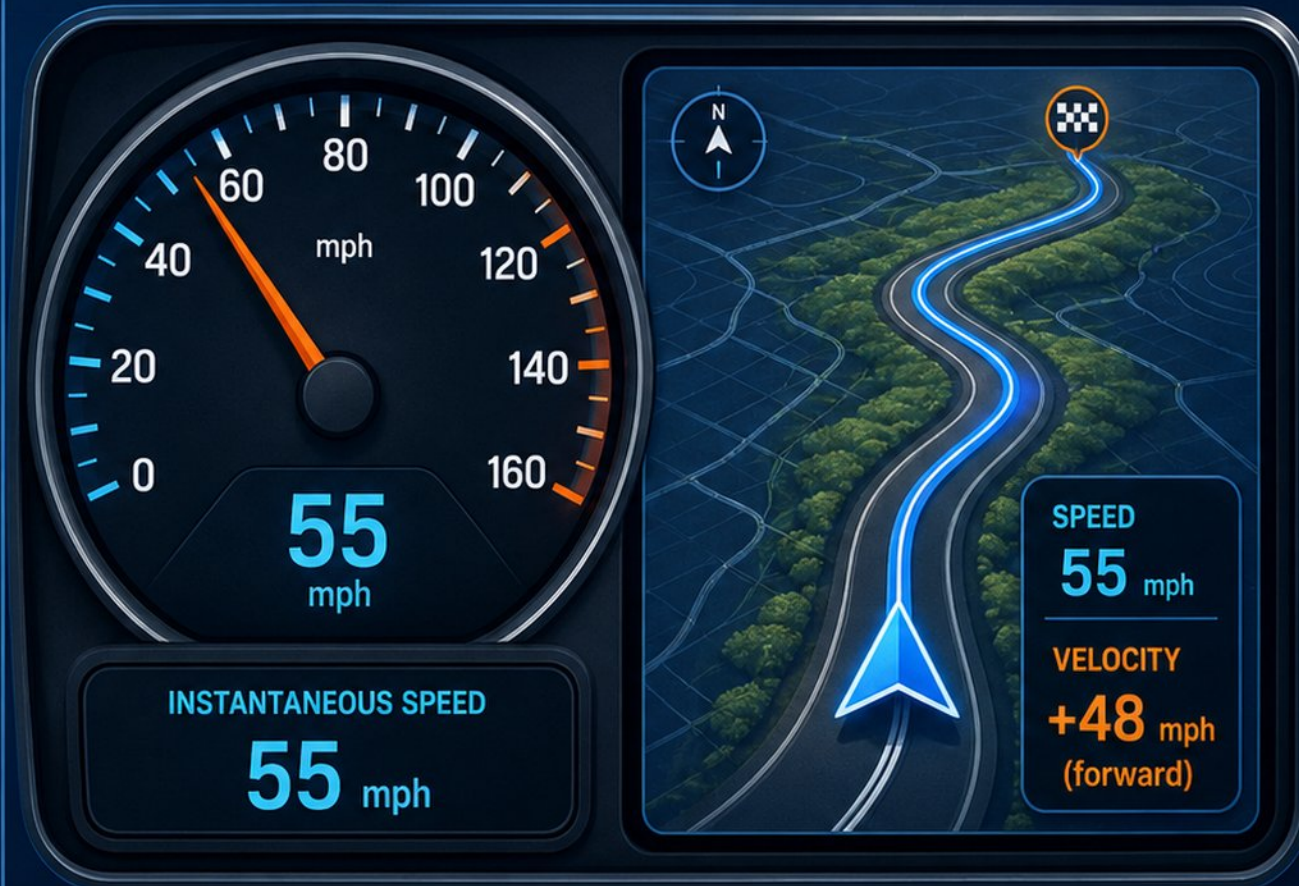
VIEW FROM DRONE (MOVING REFERENCE FRAME)

The drone moves to the right at constant speed.
From the drone's frame, the runner's path looks different.



Speed and Velocity

- Average speed: total distance traveled divided by time
- Average velocity: net displacement divided by time
- Instantaneous speed: what your speedometer shows right now
- Velocity includes direction; sign indicates forward or backward



Acceleration

- Acceleration is the rate of change of velocity over time
- Speeding up, slowing down, or changing direction all count
- Uniform acceleration is constant; non-uniform changes over time
- Free fall: objects accelerate downward at $g = 9.8 \text{ m/s}^2$



1



SPEEDING UP

Velocity increases on flat ground.

2



SLOWING DOWN

Velocity decreases while moving uphill.

3



CHANGING DIRECTION

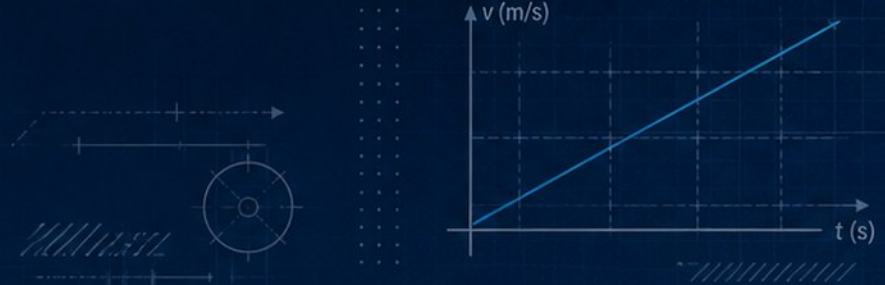
Velocity direction changes in the bowl.

Acceleration Calculations and Real-World Examples



Formula:

$$a = \frac{(v_f - v_i)}{t}$$



1 Car accelerating from rest

$v_i = 0 \text{ m/s}$

$v_f = 20 \text{ m/s}$



$t = 5 \text{ s}$

Car accelerating from rest:
0 to 20 m/s in 5 s $\rightarrow 4 \text{ m/s}^2$

2 Bicycle speeding up

$v_i = 4 \text{ m/s}$

$v_f = 10 \text{ m/s}$



$t = 3 \text{ s}$

Bicycle speeding up:
4 to 10 m/s in 3 s $\rightarrow 2 \text{ m/s}^2$

3 Car braking

$v_i = 25 \text{ m/s}$

$v_f = 5 \text{ m/s}$



$t = 4 \text{ s}$

Car braking:
25 to 5 m/s in 4 s $\rightarrow -5 \text{ m/s}^2$



Sign of acceleration: negative means direction opposite to velocity

What Is a Force?

- Force is a push or pull on an object
- Forces have magnitude and direction (vectors)
- Contact forces: friction, tension, normal
- Field forces: gravity, magnetic
- Net force determines how motion changes



CONTACT FORCE

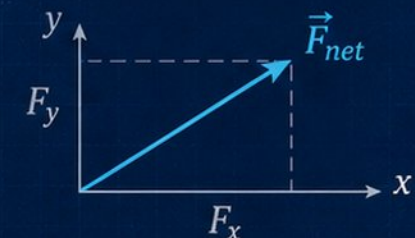
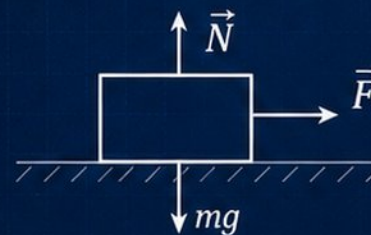


FIELD FORCE



EVERYDAY OBJECT, PHYSICS SYSTEM

The box and paperclip are systems.
Forces act on them and change their motion.



| Newton's First Law: Inertia

- An object at rest stays at rest; in motion stays in motion
- Inertia is the resistance to change in motion
- Inertia depends directly on the object's mass
- Balanced forces produce no change in velocity
- Examples: seatbelts, tablecloth trick, coffee in a car



Newton's Second Law: $F = ma$



- Acceleration is proportional to net force and inversely proportional to mass



- Equation: $F_{net} = m \times a$



- Units: Newtons (N), kilograms (kg), meters per second squared (m/s^2)

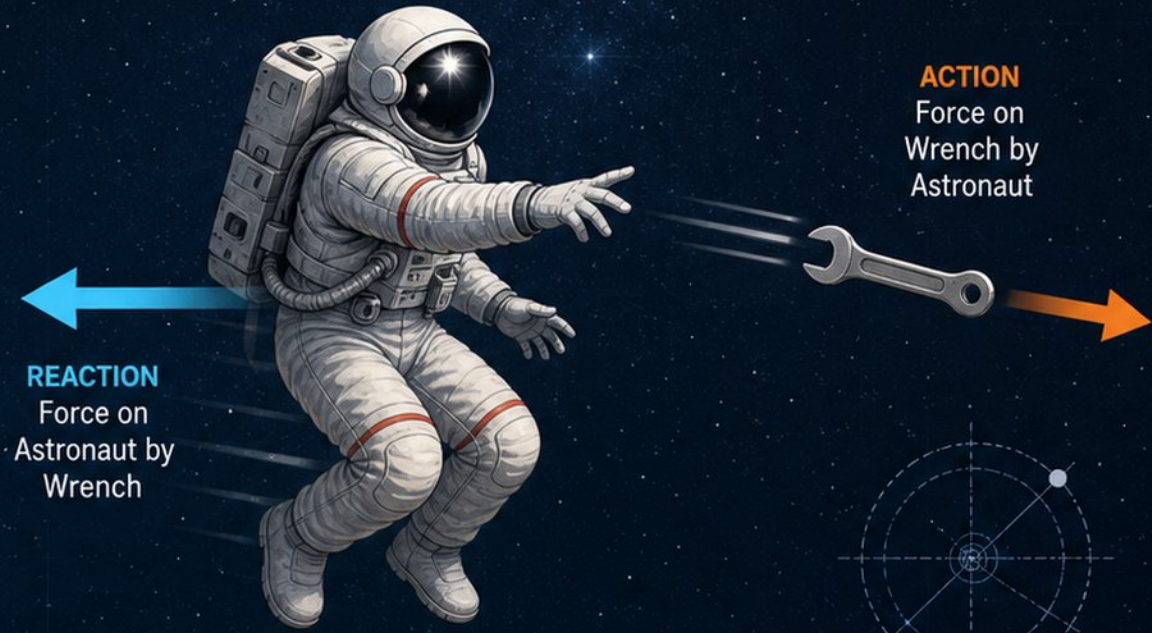


- Worked example: calculate the force needed to accelerate a bicycle



Newton's Third Law: Action and Reaction

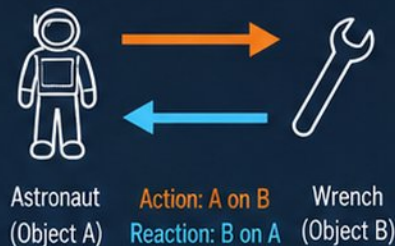
- For every action, there is an equal and opposite reaction
- Forces always come in pairs acting on different objects
- Walking, swimming, and rocket propulsion demonstrate this law
- Action-reaction pairs do not cancel—they act on different bodies



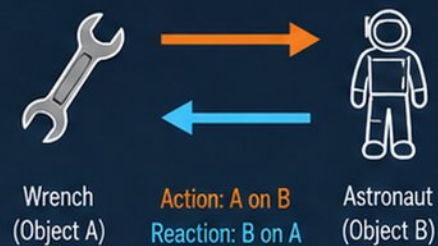
FORCE PAIR DIAGRAMS

- Action Force
(Exerted by object A on object B)
- ← Reaction Force
(Exerted by object B on object A)

ASTRONAUT ON WRENCH



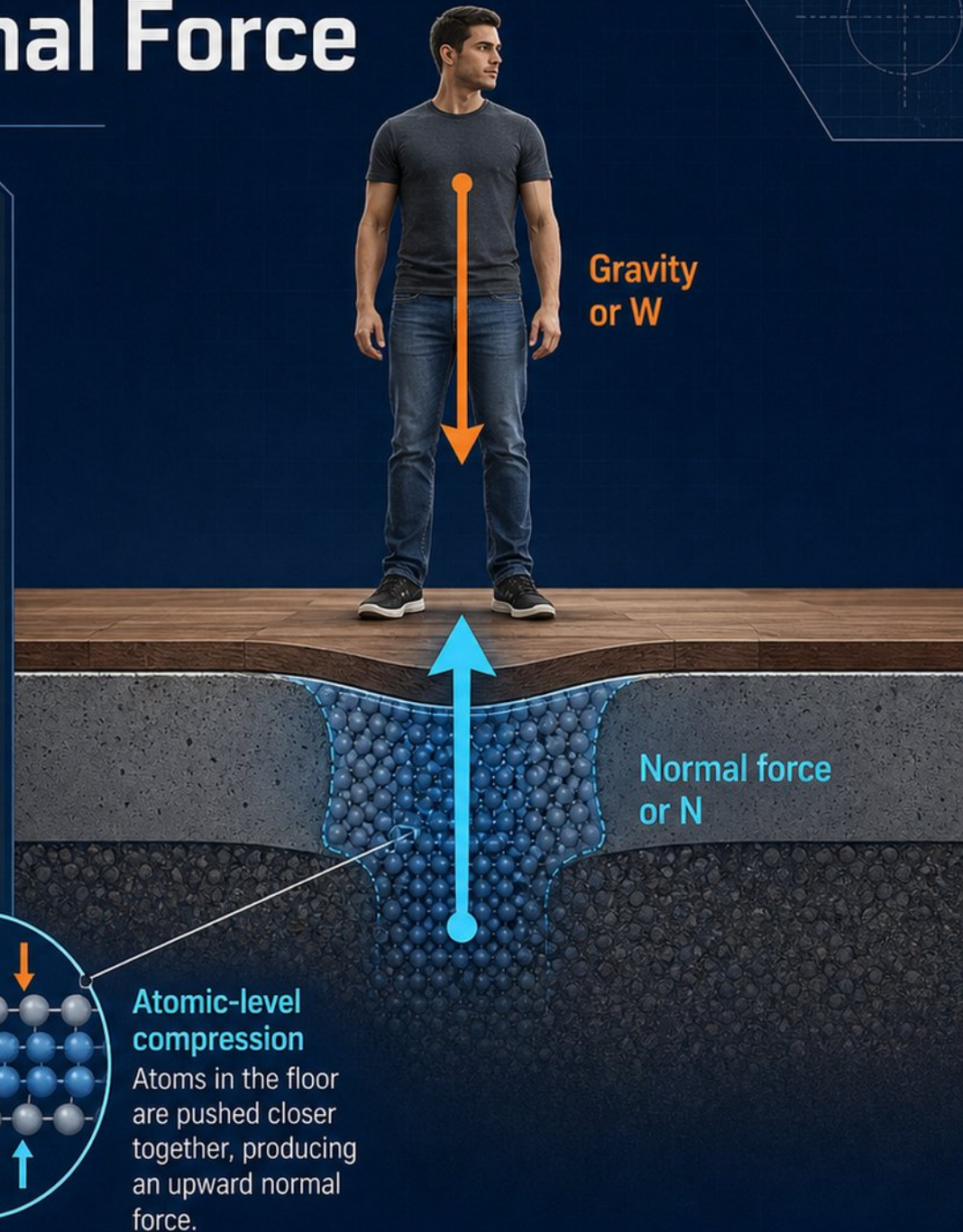
WRENCH ON ASTRONAUT



Equal in magnitude,
opposite in direction,
acting on different
objects.

Gravity and Normal Force

- Gravity: attraction between any two masses
- Weight is the force of gravity on an object: $W = mg$
- Normal force: support from a surface, perpendicular to it
- Normal force balances weight to keep you from falling through



Friction: Static and Kinetic

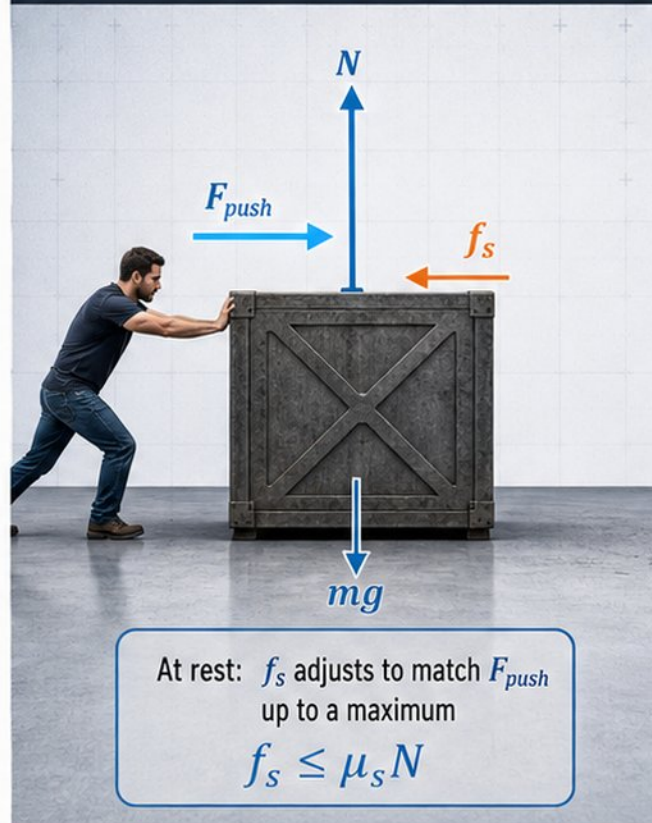
- Static friction prevents motion; adjusts up to a maximum:

$$f_s \leq \mu_s N$$
- Kinetic friction opposes sliding at a constant value:

$$f_k = \mu_k N$$
- μ_s is always greater than μ_k — starting is harder than sliding
- Pushing a heavy box, walking, and braking all rely on static friction
- Once sliding begins, kinetic friction takes over with less force

STATIC FRICTION

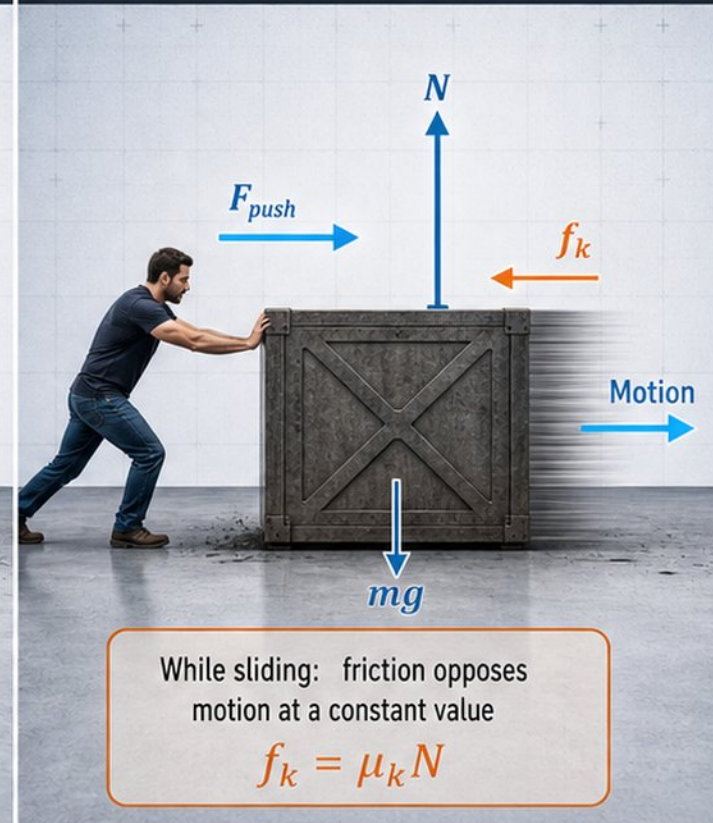
Box remains at rest



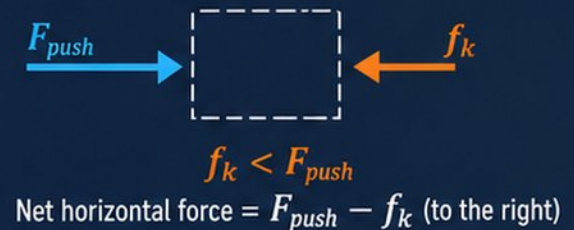
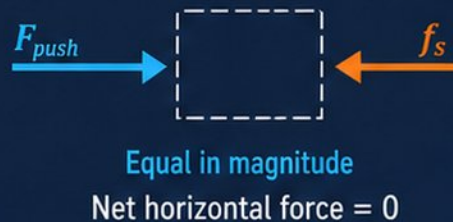
VS.

KINETIC FRICTION

Box is sliding



FORCE PAIR DIAGRAMS (Top View)



Friction in Everyday Systems



EVERYDAY OBJECT as PHYSICS SYSTEM



- Friction on an incline: gravity pulls down, friction resists up the slope



- Rolling friction: wheels replace sliding, reducing resistance 20–100×



- Air and water drag: fluid friction depends on speed and shape



- Brakes and ABS: controlled kinetic friction; ABS avoids locked-wheel skidding



- Friction can propel: static friction pushes you forward when walking or driving



Friction is not just a force that slows things down—it's a versatile interaction that enables **motion**, **control**, and **safety** in everyday life.

Tension and Spring Force (Hooke's Law)

- Tension: a pulling force transmitted through a rope or cable
- Tension is constant throughout an ideal, massless rope
- Spring force: $F = -kx$, opposing displacement from equilibrium
- Tug-of-war, elevators, and retractable pens all rely on these forces



Free-Body Diagrams

1

Simplify a physical situation by isolating a single object

2

Represent the object as a point or simple shape

3

Draw all force vectors acting on the object

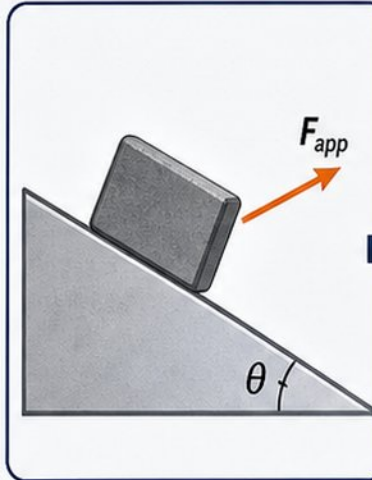
4

Choose a consistent coordinate system (x-y axes)

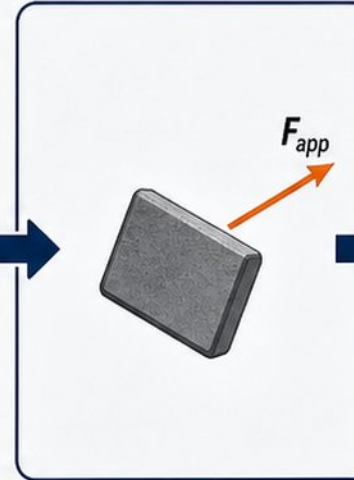
5

The essential first step for solving any dynamics problem

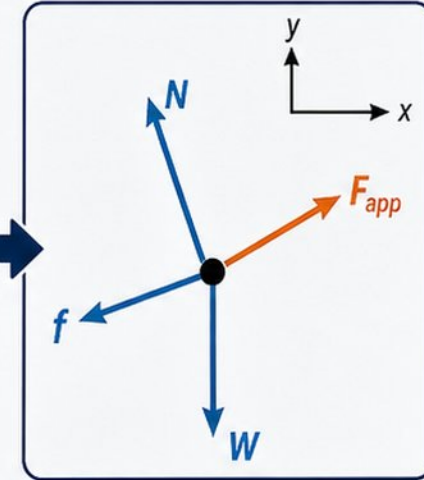
1 PHYSICAL SITUATION



2 ISOLATE THE OBJECT



3 FREE-BODY DIAGRAM



W Weight (mg)
 N Normal force (perpendicular to surface)
 f Friction force (along surface, opposing motion)
 F_{app} Applied force (along surface, up the incline)

y
 x
x: along horizontal
y: vertical



A FREE-BODY DIAGRAM SHOWS ALL **EXTERNAL FORCES** ACTING ON THE ISOLATED OBJECT.

Putting It Together: Analyzing a Car's Motion



- Identify forces: engine, friction, air resistance, gravity, normal



- Calculate net horizontal force and acceleration



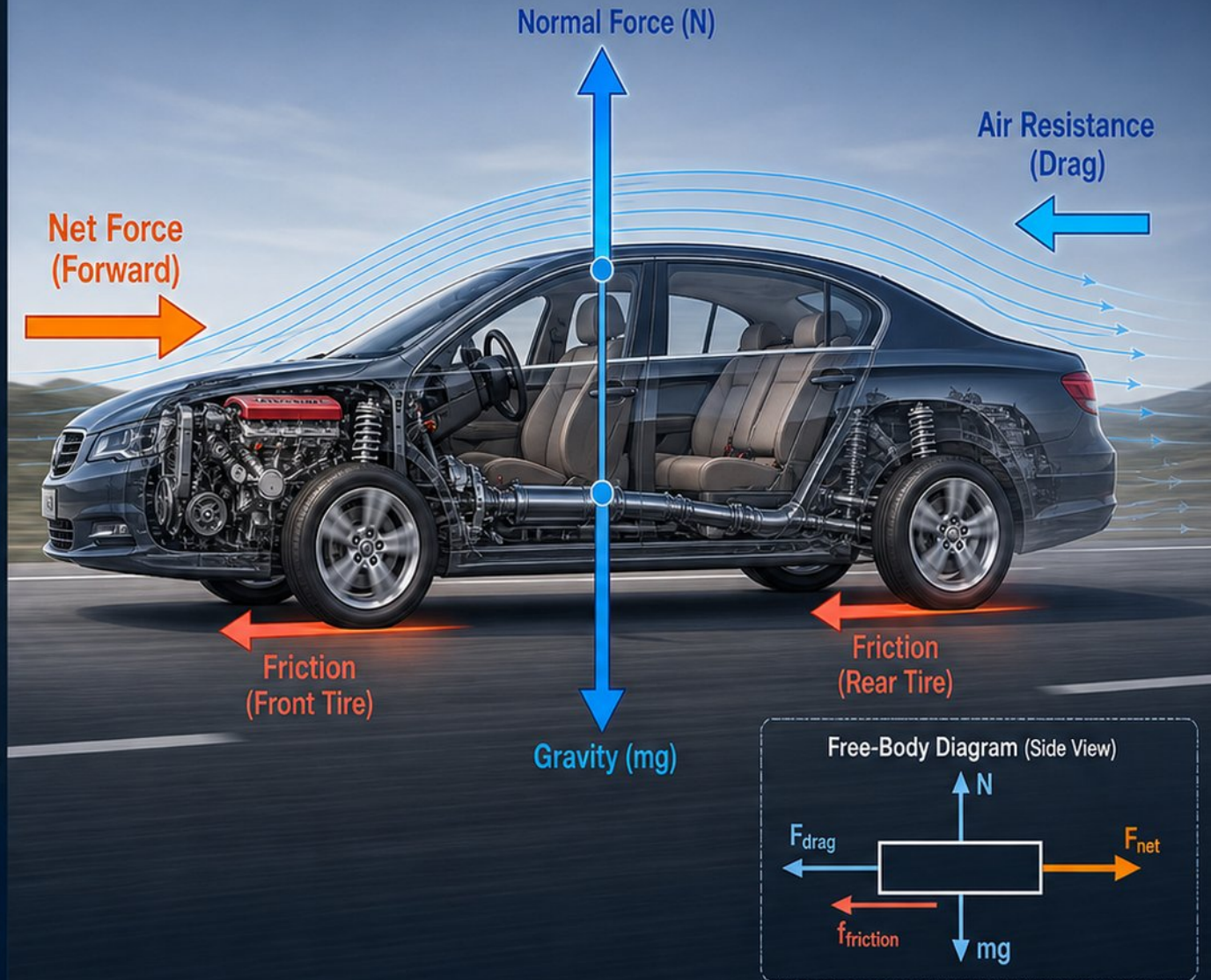
- Apply Newton's Second Law to real-world driving



- Use free-body diagrams to clarify force directions

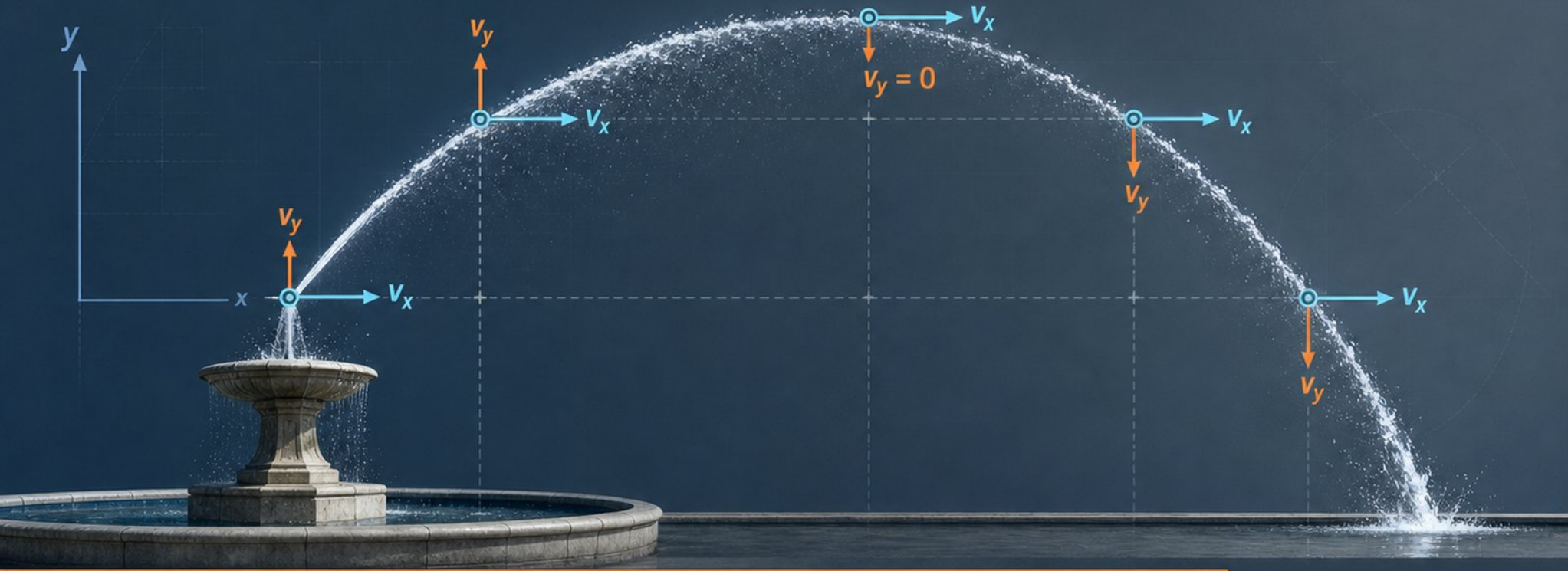


EVERYDAY OBJECT
as Physics System



By identifying and analyzing forces, we can predict and understand a car's motion.

Projectile Motion



- Motion under constant gravity with a parabolic path
- Horizontal and vertical components are independent
- Horizontal velocity is constant; vertical accelerates downward
- A thrown ball, a stream of water, a long jump



Circular Motion and Centripetal Force

- Uniform circular motion: constant speed, continuously changing velocity direction
- Centripetal acceleration points toward the circle's center
- Centripetal force is a requirement, not a new type of force
- Tension, gravity, or friction can provide the centripetal force
- Examples: car turning, ball on a string, roller coaster loop

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

a_c = centripetal acceleration

v = speed

r = radius



Key Takeaways and Next Steps in Physics



- Kinematics describes motion; dynamics explains its causes



- Newton's three laws are the foundation of classical mechanics



- Forces are everywhere, and we can model them mathematically



- Next: explore energy, momentum, and rotational motion



- Physics is a way of thinking to understand the world



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