Dynamics: Forces, Energy, & Momentum

A comprehensive overview of the fundamental principles governing motion and interaction in our physical world.

PART 1

Forces & Newton's Laws

Newton's Three Laws of Motion

1. Inertia

An object at rest stays at rest, and an object in motion stays in motion unless acted upon by a net external force.

2. Acceleration

Force equals mass times acceleration. The acceleration is directly proportional to force and inversely proportional to mass.

$$F = ma$$

3. Interaction

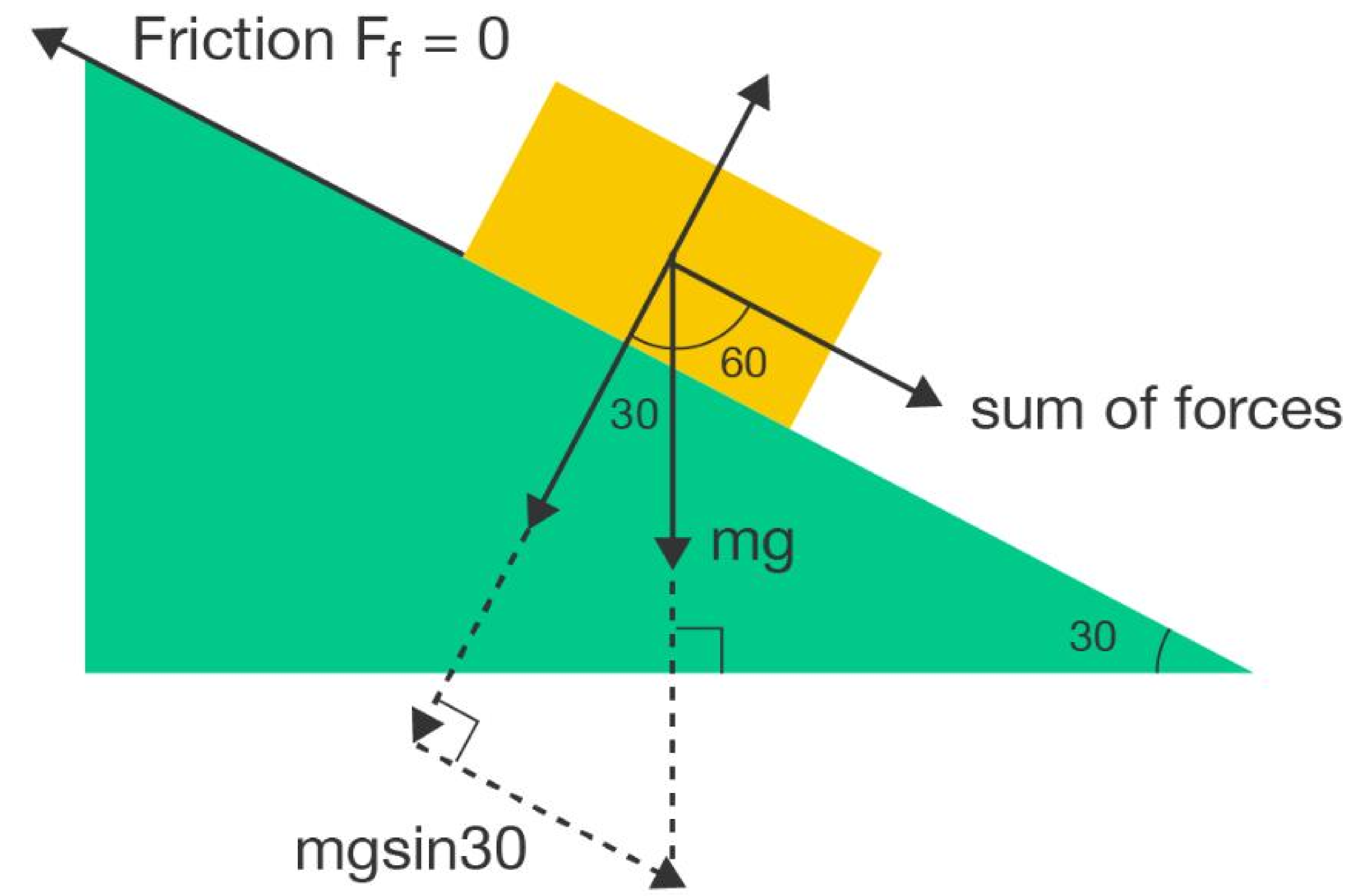
For every action, there is an equal and opposite reaction. Forces always occur in pairs.

Visualizing Forces: Free Body Diagrams

The Key to Problem Solving

A Free Body Diagram (FBD) is a simplified sketch used to show all the forces acting on a specific object.

- Isolate the object of interest.
- Represent the object as a dot or box.
- Draw vectors (arrows) for each force (Gravity, Normal, Friction, Tension).
- Label each vector clearly.



PART 2

Conservation of Energy

Forms of Mechanical Energy

Kinetic Energy (KE)

The energy of motion. Any object with mass that is moving possesses kinetic energy.

$$KE = \frac{1}{2}mv^2$$

Gravitational Potential Energy (PE)

Stored energy based on an object's position relative to a reference height.

$$PE = mgh$$

Principle: Total Mechanical Energy (KE + PE) remains constant in an isolated system.

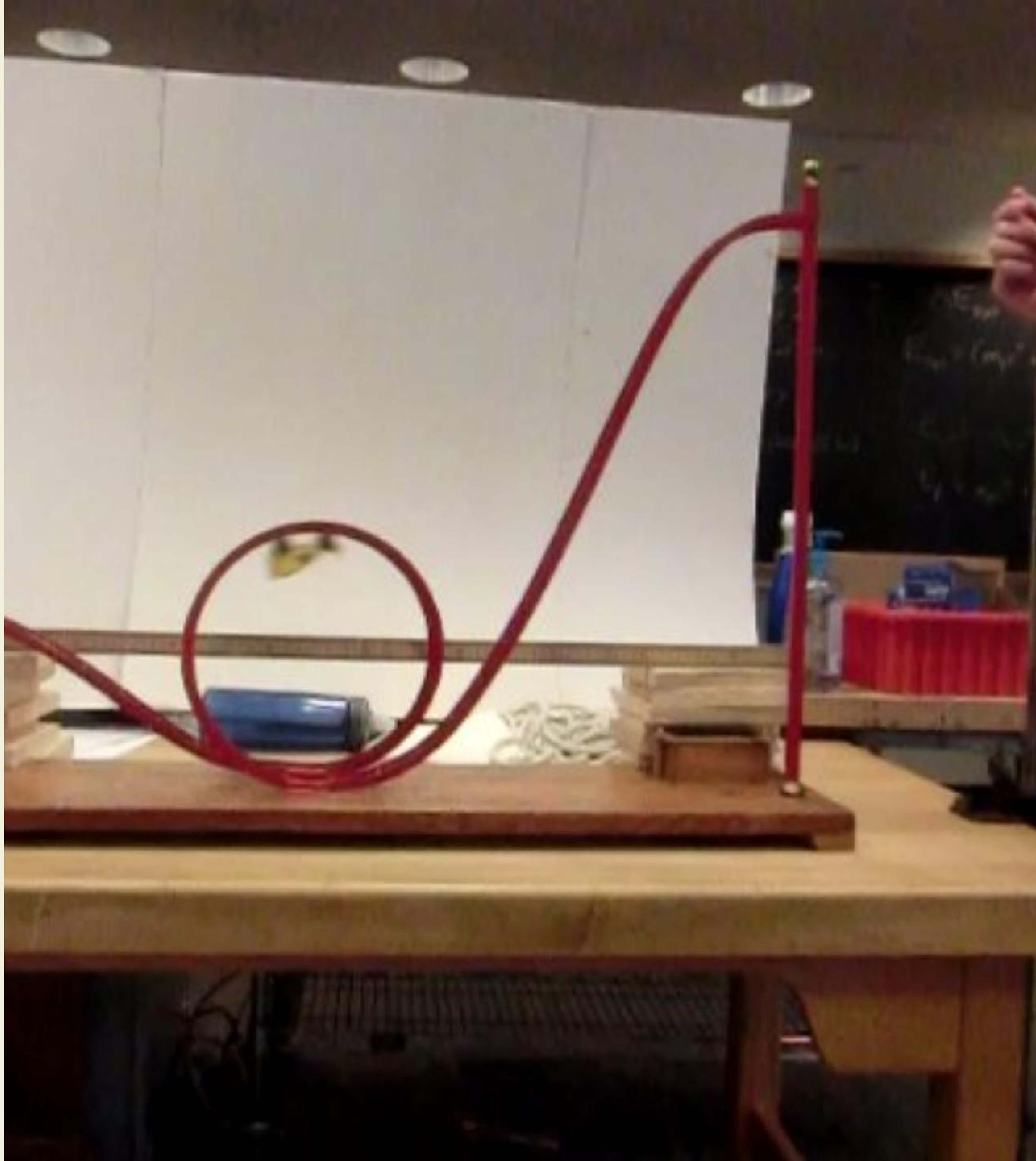
Example: The Roller Coaster

A roller coaster is the classic example of energy conservation in action.

Top of the Hill: Potential energy is at its maximum, while kinetic energy is nearly zero.

Bottom of the Drop: Potential energy converts to kinetic energy, resulting in maximum speed.

The Loop: A mix of KE and PE keeps the car moving safely through the inversion.



PART 3

Conservation of Momentum

Understanding Momentum

"Mass in Motion"

Momentum (p) is a vector quantity defined as the product of an object's mass and velocity.

$$p = mv$$

Conservation Principle

In a closed system with no external forces, the total momentum before an event equals the total momentum after the event.

$$p_{initial} = p_{final}$$

Why it matters:

- Explains recoil in cannons/rockets.
- Critical for analyzing car accidents.
- Used in sports (pool, bowling).
- Fundamental to particle physics.

Types of Collisions

Elastic vs. Inelastic

Elastic Collision: Both momentum and Kinetic Energy are conserved. Objects bounce off each other perfectly (e.g., ideal gas molecules, billiard balls approx).

Inelastic Collision: Only momentum is conserved. Kinetic Energy is lost to heat, sound, or deformation. Objects may stick together (e.g., car crash, clay hitting floor).

Note: In the real world, perfectly elastic collisions are rare.

Summary: Key Formulas & Units

Concept	Formula	SI Unit	Vector/Scalar
Force	$F = ma$	Newton (N)	Vector
Kinetic Energy	$KE = \frac{1}{2}mv^2$	Joule (J)	Scalar
Potential Energy	$PE = mgh$	Joule (J)	Scalar
Momentum	$p = mv$	kg·m/s	Vector
Impulse	$J = F\Delta t$	N·s	Vector

Practice Problems

Simple

Newton's Second Law

A 10 kg block is pushed across a frictionless surface with a net force of 50 N.

Calculate the acceleration of the block.

Intermediate

Conservation of Energy

A 2 kg rock falls from a cliff that is 20 m high. Assume air resistance is negligible.

Use energy conservation to find its speed just before impact. (g = 10 m/s^2)

Hard

Inelastic Collision

A 2000 kg truck moving at 10 m/s collides with a stationary 1000 kg car. They lock bumpers and move together.

What is their final combined velocity?

Solutions

Simple

Given: m = 10 kg, F = 50 N

Formula: $F = ma$ implies $a = \frac{F}{m}$

Calculation:

$$a = \frac{50}{10} = 5 \ \ m / s^2$$

Intermediate

Given: m=2, h=20, g=10. Start v=0.

Concept: $PE_{top} = KE_{bottom}$

$$mgh = \frac{1}{2}mv^2$$
$$10 (20) = 0.5v^2$$

$200 = 0.5v^2 \rightarrow v^2 = 400$

v = 20 m/s

Hard

Given: m1=2000, v1=10; m2=1000, v2=0.

Formula: $p_i = p_f$

$$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v_f$$
$$2000 (10) + 0 = 3000v_f$$

20,000 = 3000 vf

vf ≈ 6.67 m/s

PART 4

Interactive Learning

Group Activity: The Egg Drop Challenge

The Mission

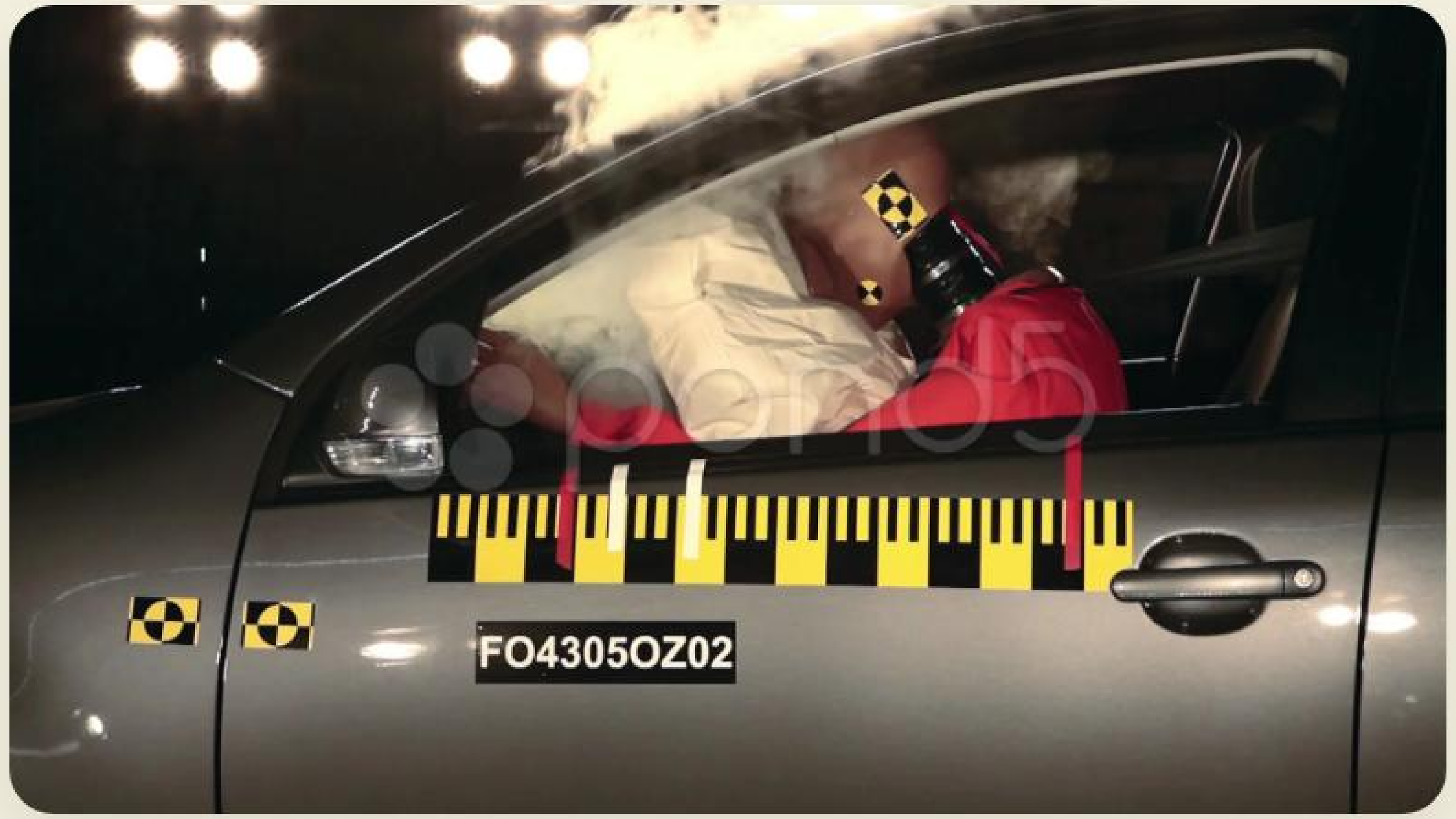
Design a container that can protect a raw egg from a fall of 3 meters.

Physics at Play:

- **Impulse:** Increasing the time of impact to reduce force ($F = \frac{\Delta p}{\Delta t}$).
- **Air Resistance:** Using parachutes to reach terminal velocity.
- **Energy Absorption:** Crumple zones to dissipate kinetic energy.

Physics in the Real World

Rocket Propulsion (Momentum)



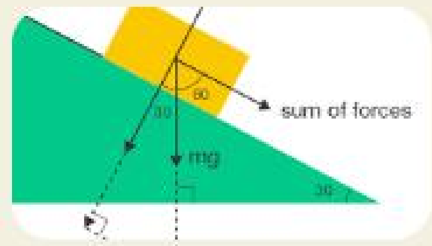
Safety Engineering (Impulse)

Sports Dynamics (Energy Transfer)

Questions?

Thank you for exploring dynamics with us.

Image Sources



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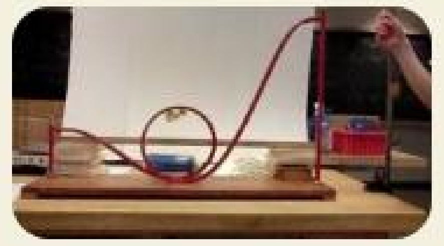

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