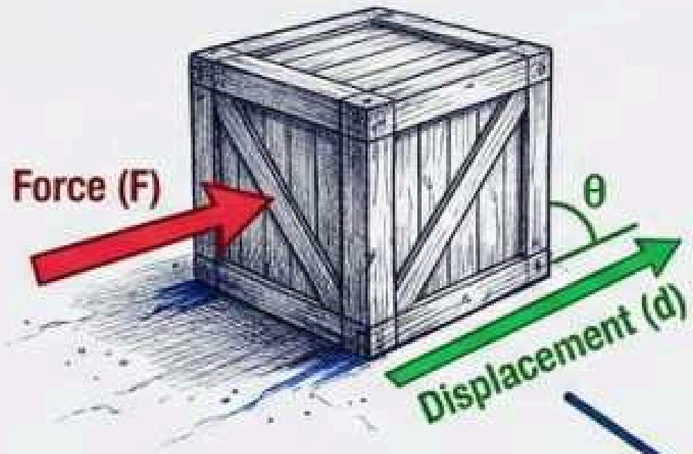
Work, Energy, and Power

Welcome to Lecture 5.

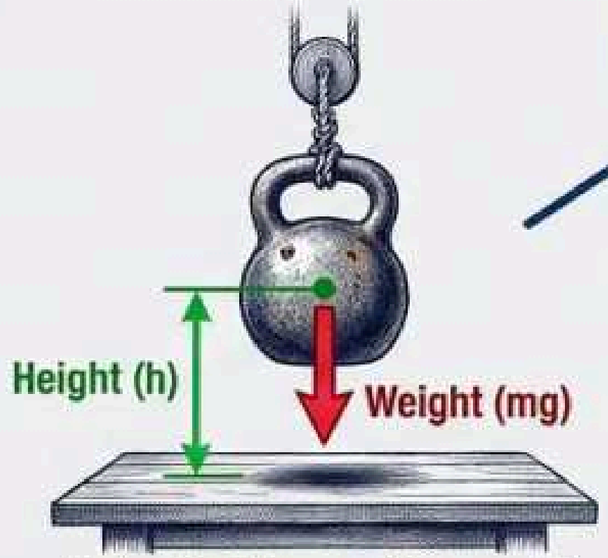


Work ($W = F \cdot d \cdot \cos\theta$)

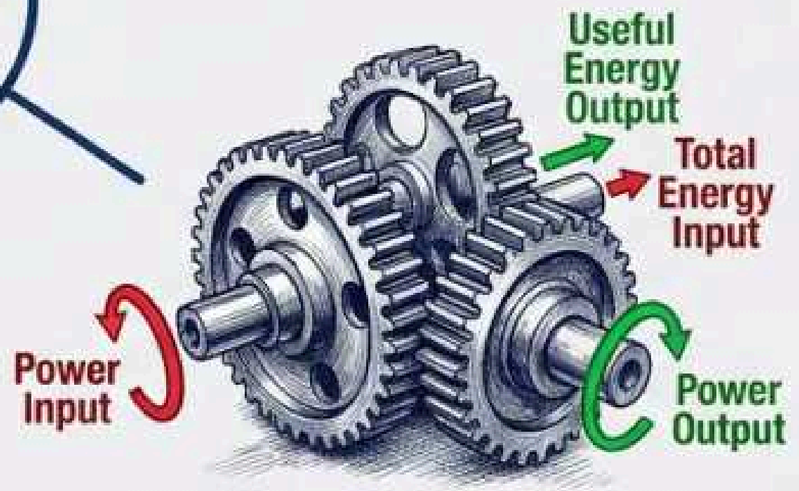


Kinetic Energy ($KE = \frac{1}{2} mv^2$)

Lecture 5



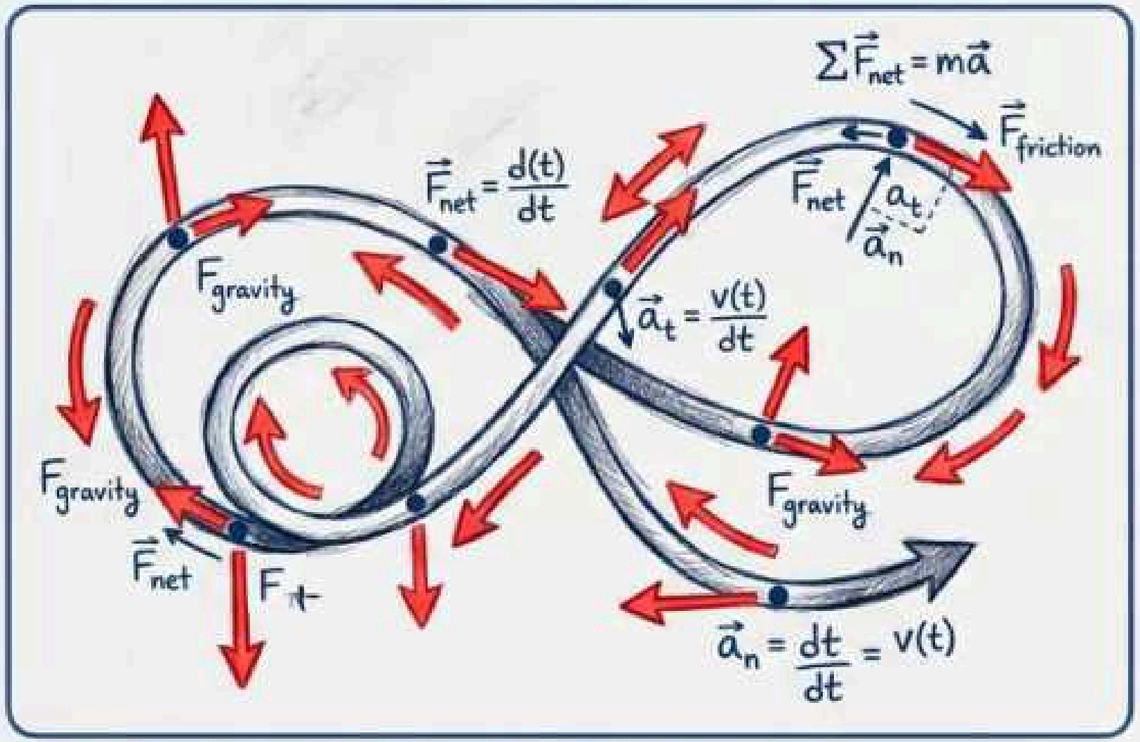
Potential Energy ($PE = mgh$)



Power ($P = W/t$) & Efficiency (η)

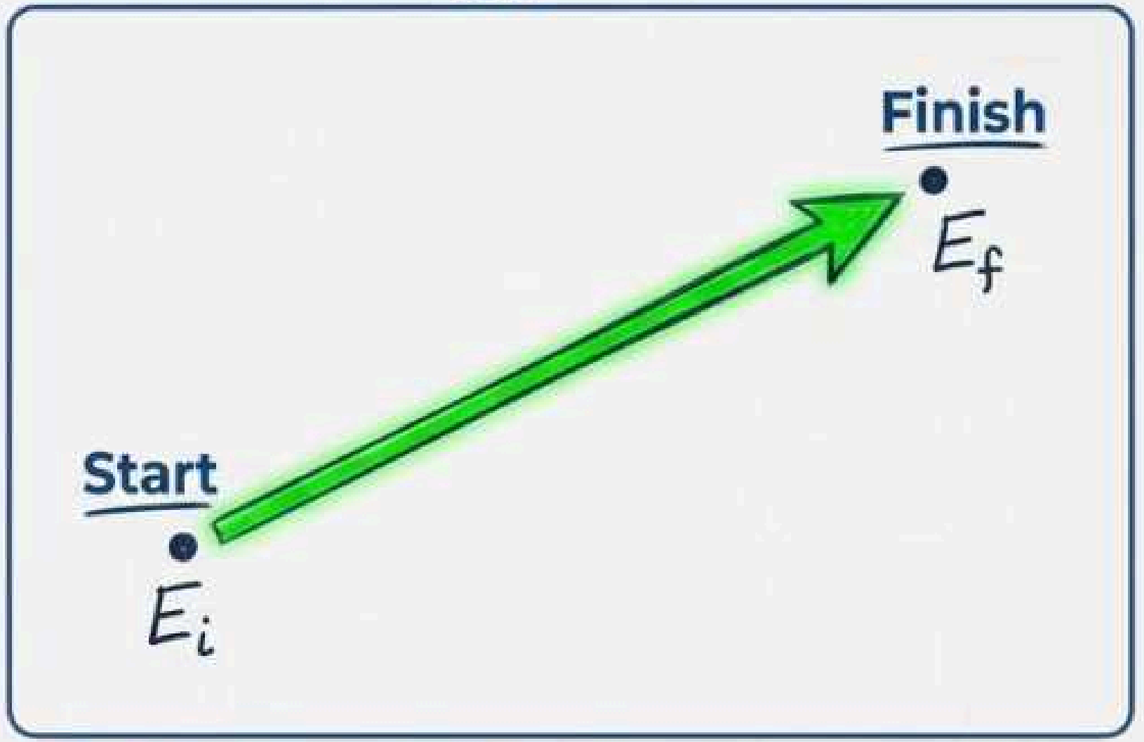
At a Glance: Work | Kinetic & Potential Energy | Conservation of Energy | Power | Efficiency

Newton's Laws



The Problem with Mechanics: Newton's laws can solve any problem, but tracking motion moment by moment is a long, tedious process.

Energy Method



The Energy Shortcut: Energy compares only the start and the finish, skipping the details of the motion in between.

The Great Law: This lecture introduces work, kinetic energy, potential energy, and power—and the great law that ties them together.

¶ 5.3

The Physics Definition: Work is done when a force moves an object through a distance.

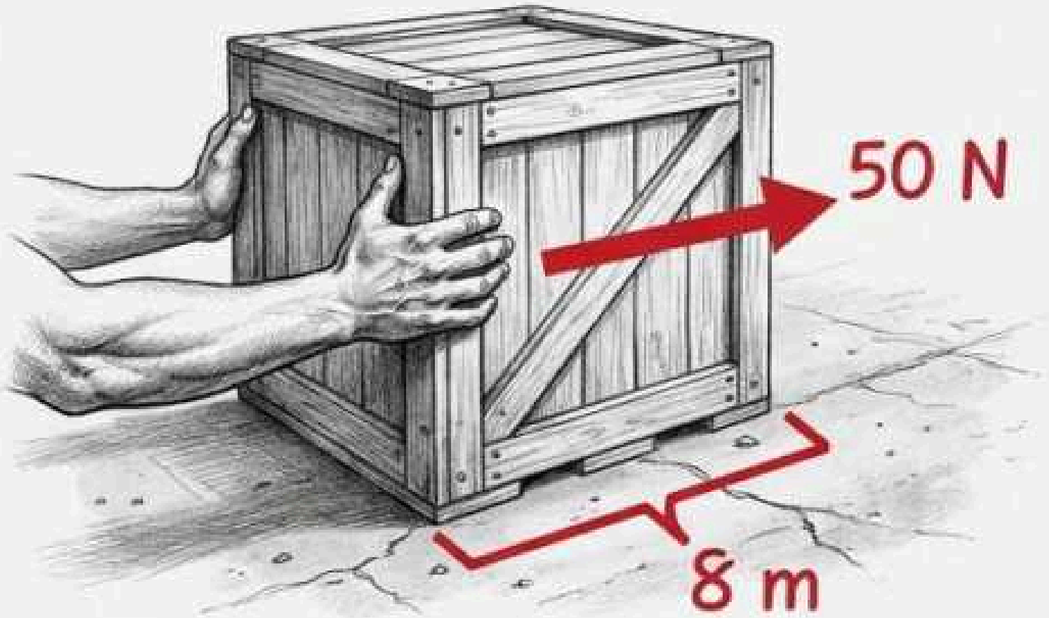
F = Force (Measured in Newtons)

$$W = F \times d$$

W = Work
(Measured in Joules)

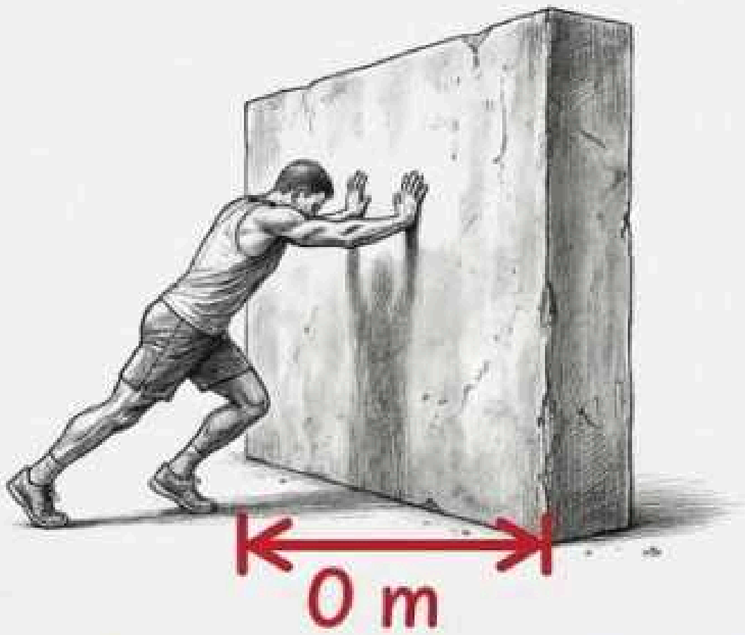
d = Distance
(Measured in Meters)

The Joule: One joule is the work done by a force of one newton over one meter.



Example 1: Motion = Work

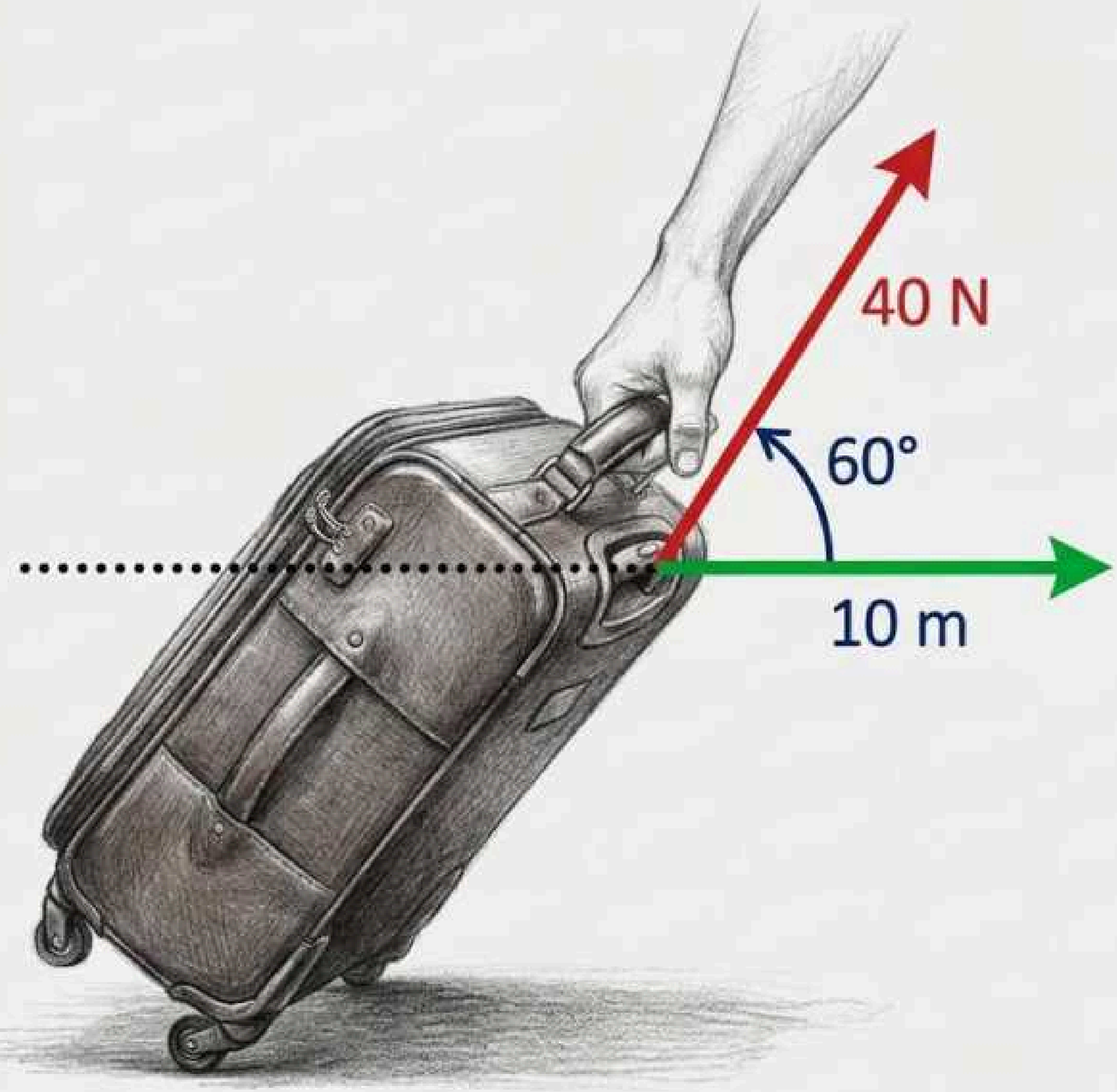
50 newtons × 8 meters = 400 joules



Example 2: No Displacement = No Work

Pushing an unmoving wall = 0 joules.

Note: In physics, you do no work if the object does not move, no matter how tired you feel.



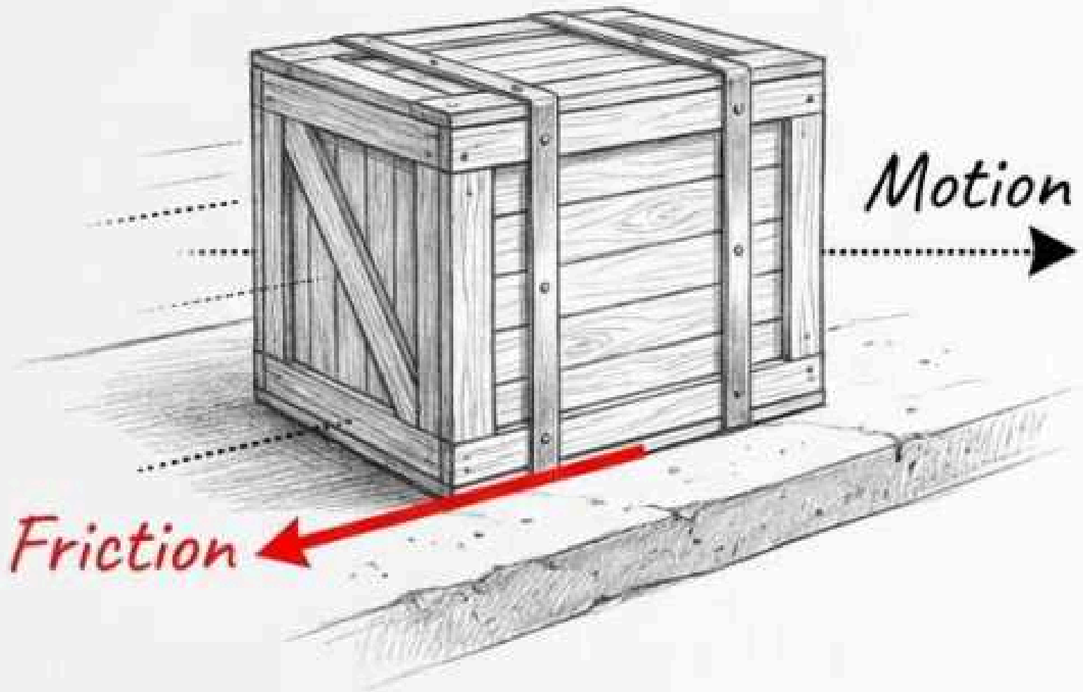
Angled Forces: Only the part of the force along the direction of motion counts.

Formula: $W = \vec{F} \cdot \vec{d} \cdot \cos(\theta)$

Calculation: Pulling a suitcase at 60° with 40 N over 10 m.

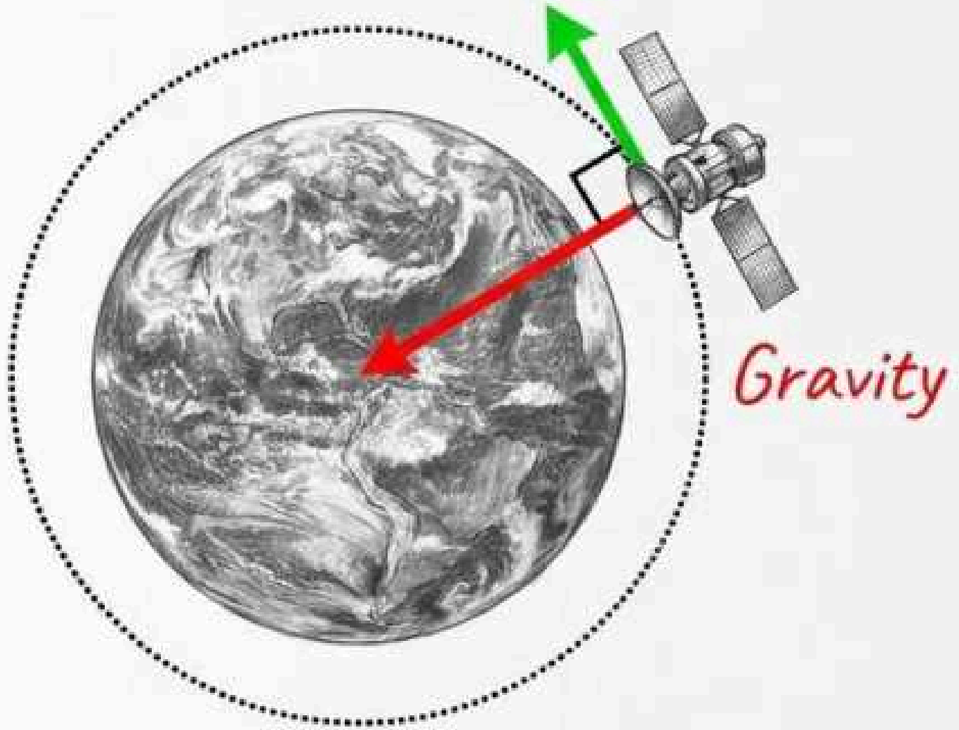
$40\,\text{N} \times 10\,\text{m} \times 0.5 = 200$ joules

Negative Work



Negative Work: Force points opposite to the motion (e.g., friction). This takes energy out of the object.

Zero Work



Zero Work: Force is at right angles to the motion. This is why Earth's gravity does no work on a satellite moving in a perfect circle.

¶ 5.7

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



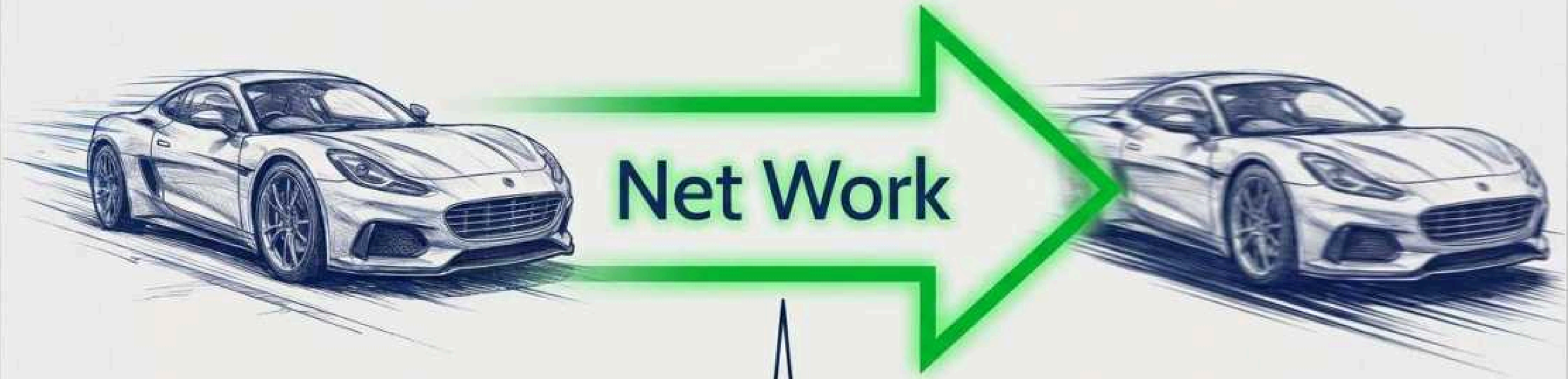
Kinetic Energy: The energy of motion.

Like stopping distance, it grows with the square of speed.

Example: A 1,000 kg car moving at 20 meters per second.

$KE = \frac{1}{2} \times 1{,}000 \times 400 = 200{,}000$ joules.

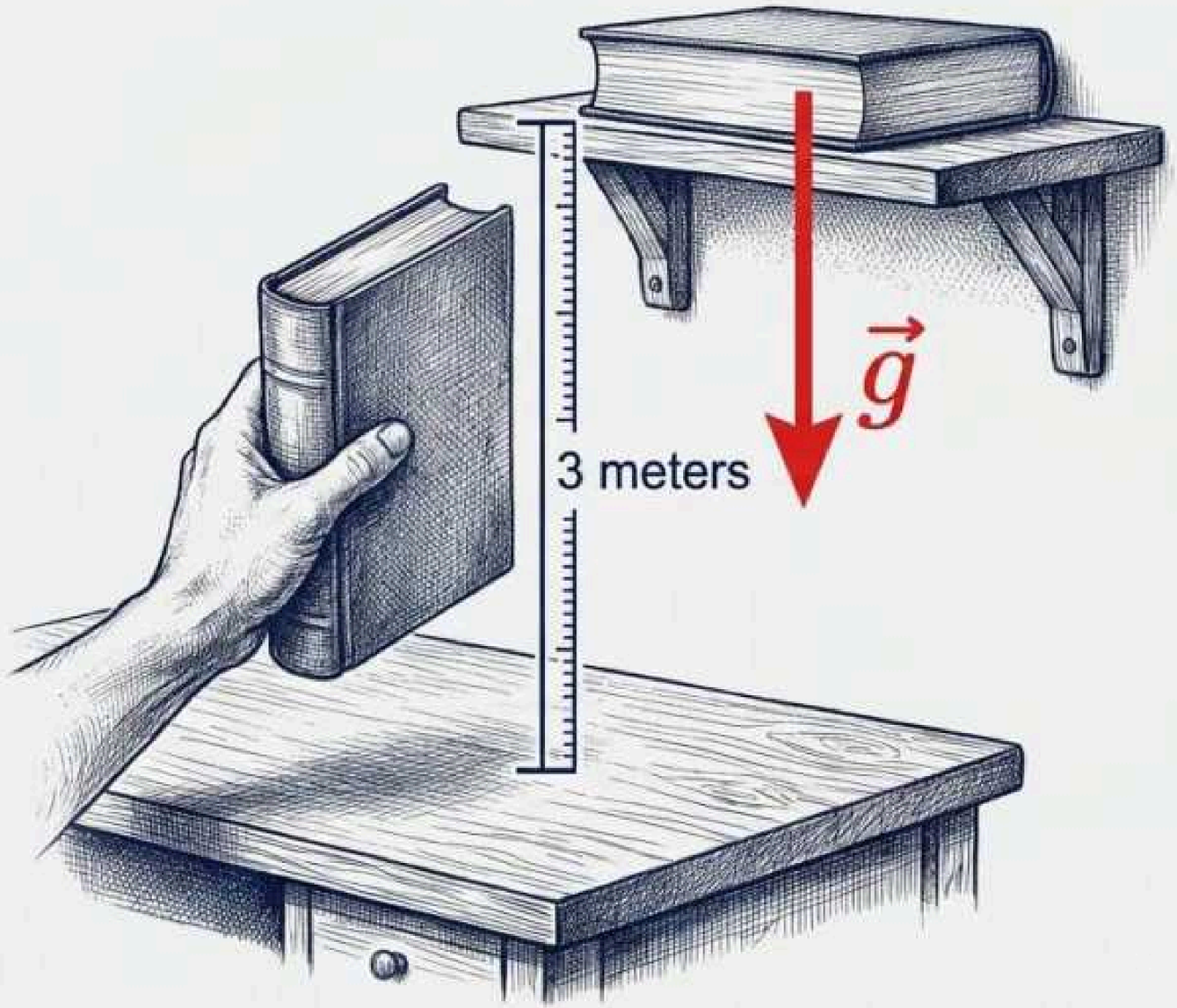
The Work-Energy Theorem: The net work done on an object equals its change in kinetic energy.



Starting KE: 200,000 J (at 20 m/s)

Ending KE: 450,000 J (at 30 m/s)

The Result: The engine and road did 250,000 joules of net work to speed the car up.



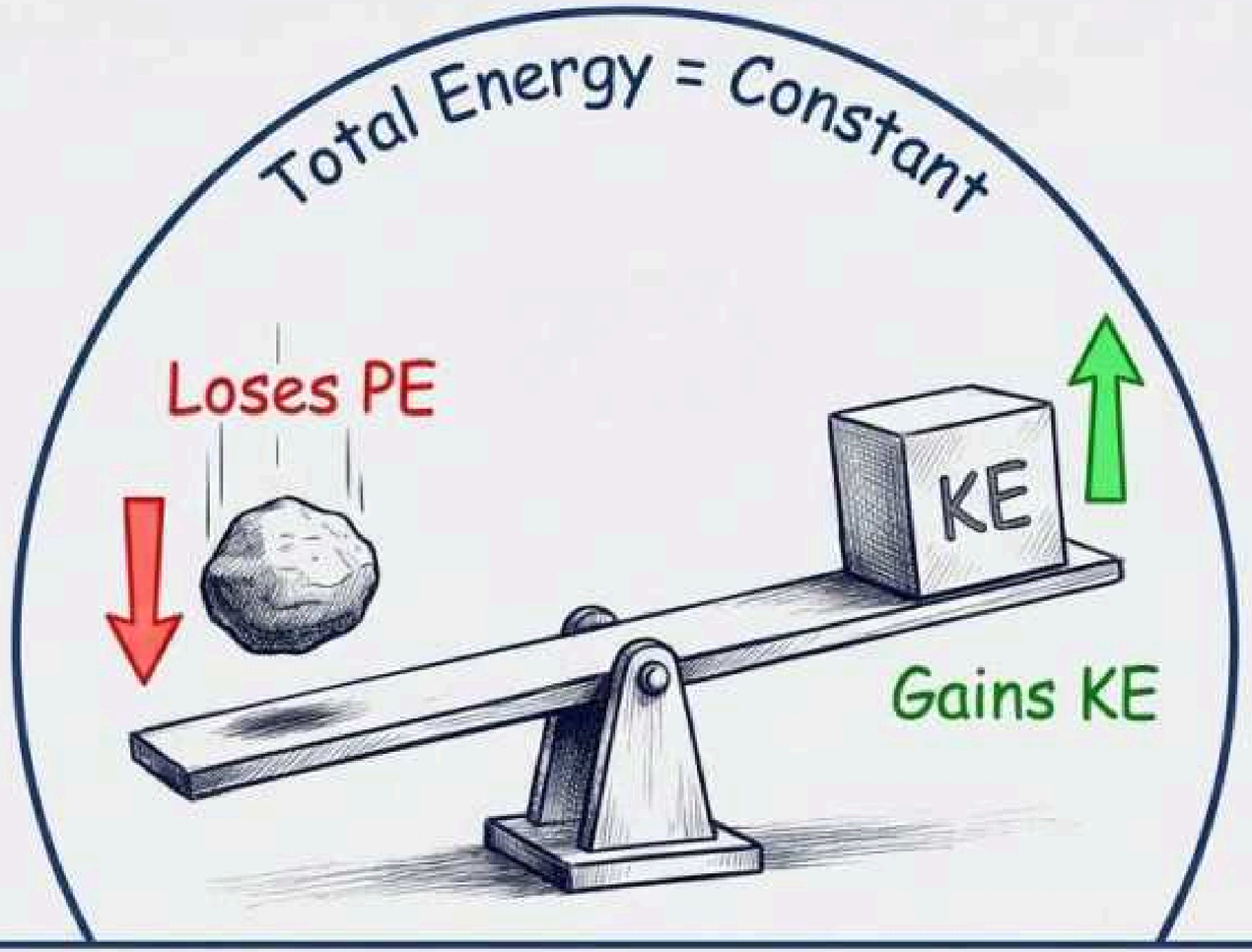
Potential Energy: Stored energy. Gravitational potential energy depends on height.

Formula: $PE = m \cdot g \cdot h$

Example: Lifting a 2 kg book by 3 meters.

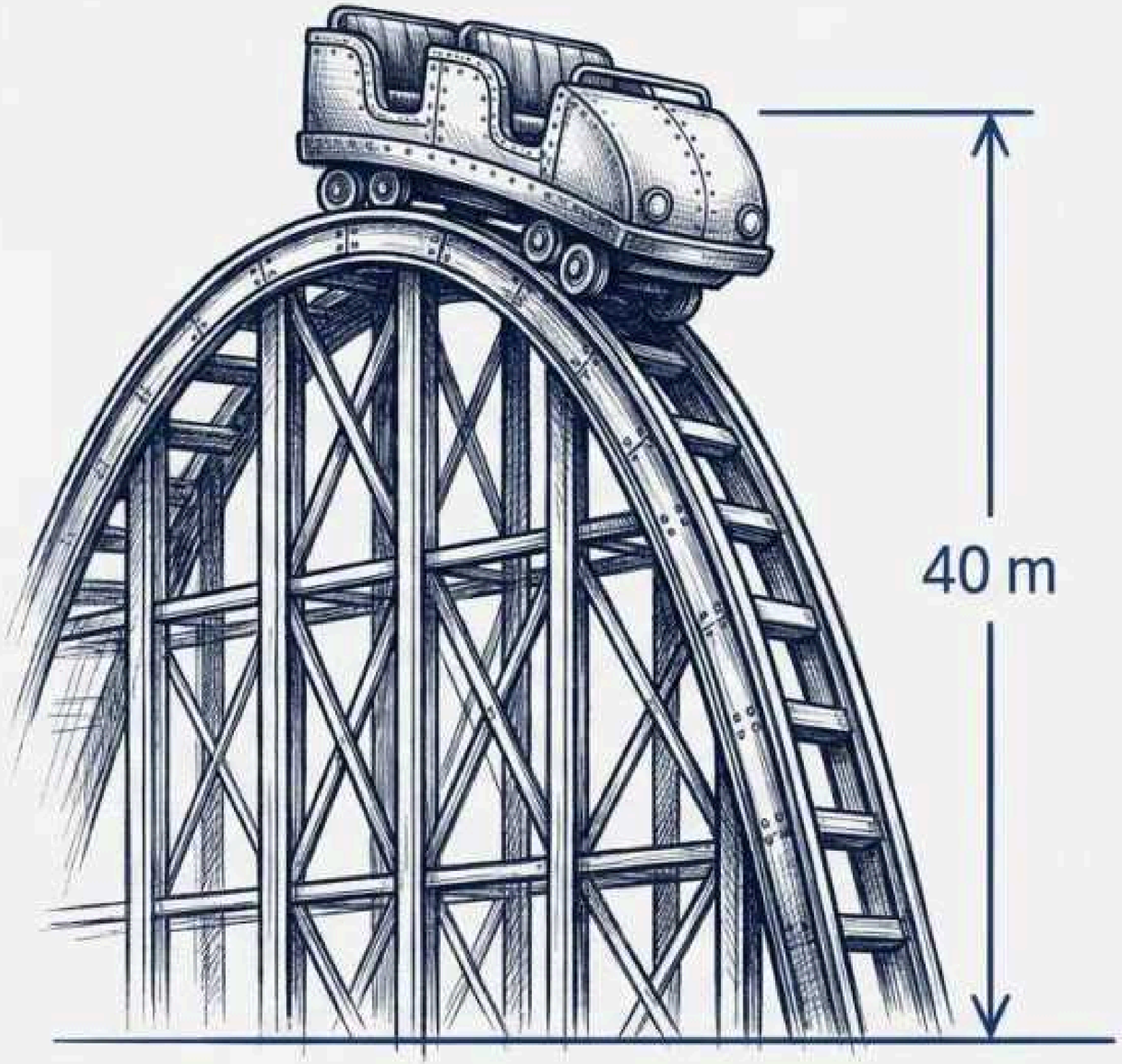
$$2\,\text{kg} \times 9.8\,\frac{\text{m}}{\text{s}^2} \times 3\,\text{m} = 58.8\,\text{joules}$$

Note: Energy is stored in the system of the book and the Earth, ready to be released by letting go.



The Great Principle: Conservation of Energy

In a system with no friction or losses, the sum of kinetic and potential energy stays constant.
Energy changes form, but is never created or destroyed.
A falling stone loses potential energy and gains an exactly equal amount of kinetic energy. The total is fixed.



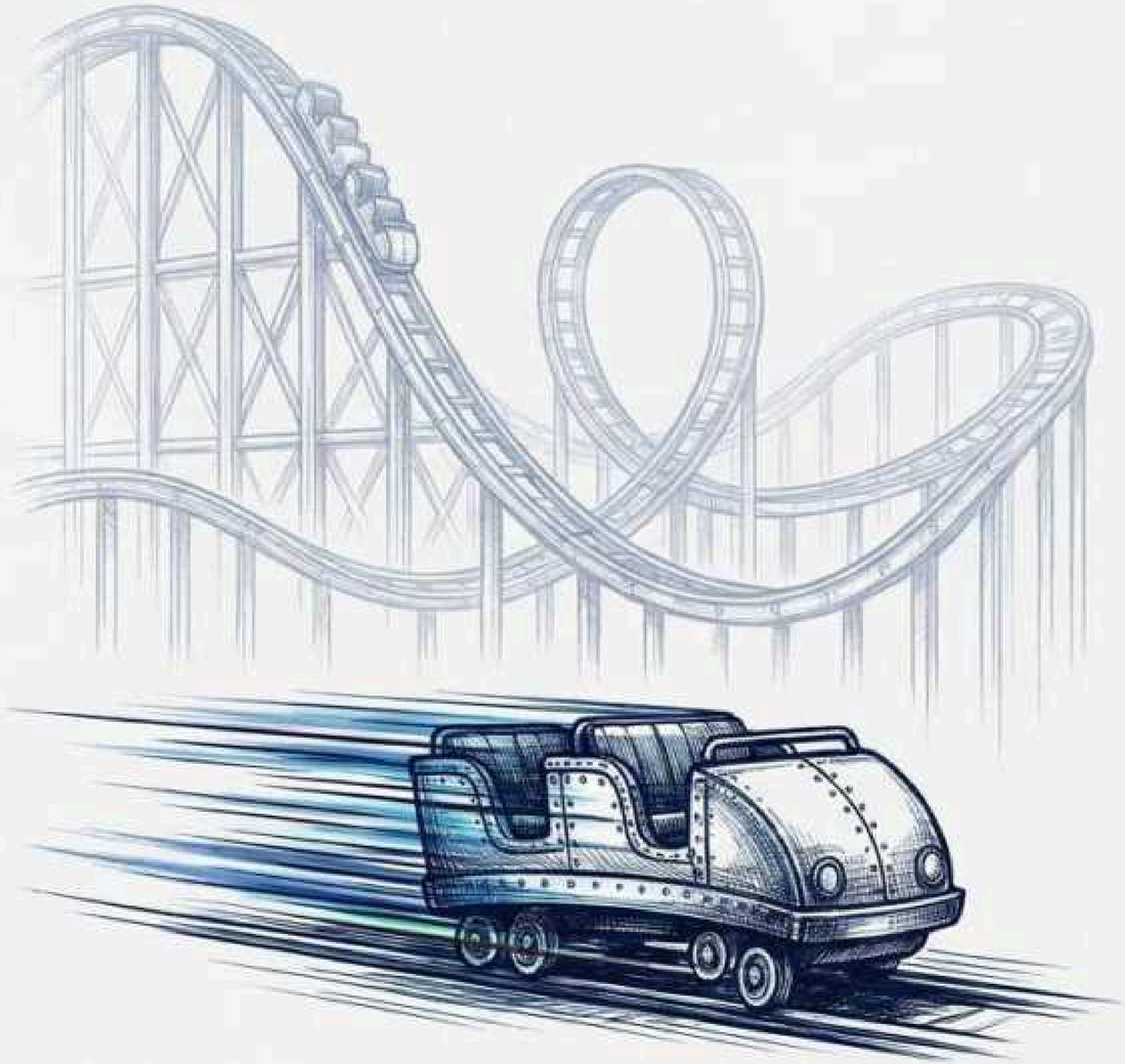
Example 2: The Roller Coaster (State A)

A car starts nearly at rest at the top of a 40 m hill. (Friction ignored).

Potential Energy per kilogram:

$$9.8 \times 40 = 392 \text{ joules}$$

At the top, all energy is Potential.



Example 2: The Roller Coaster (State B)

At the bottom, all Potential Energy becomes Kinetic Energy.

$$\frac{1}{2}v^2 = 392$$

$$v = \sqrt{784} = 28 \text{ meters per second}$$

(about 100 km/h).

The Power of Conservation Laws:
We skipped the messy middle. The energy method only needs the height. We never needed the track shape or the mass of the car.

Scenario: Dropping a stone from 45 meters.

Method 1 (Lecture 2 Free Fall)

Using kinematics

speed of about $29.7 \frac{\text{m}}{\text{s}}$

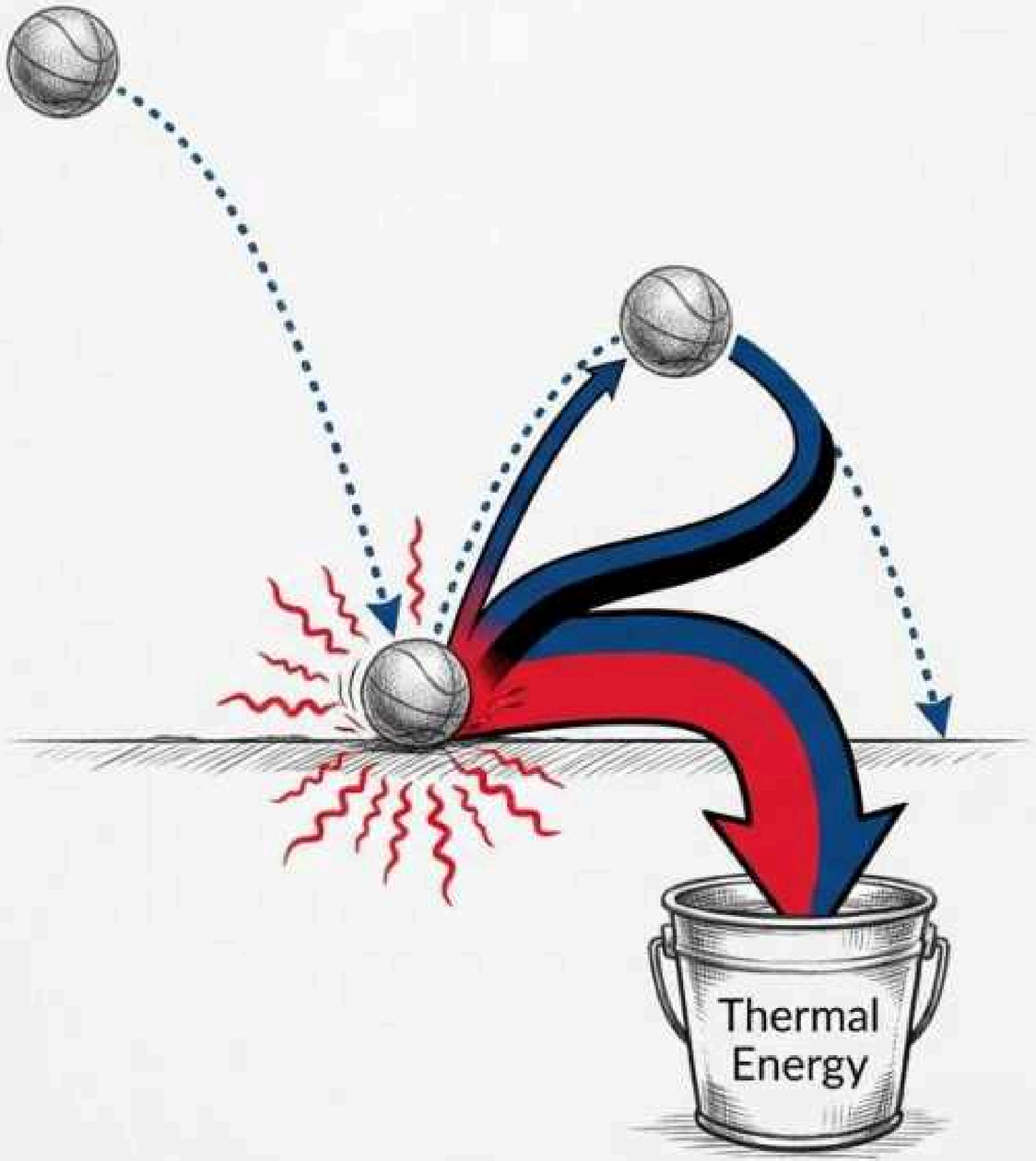


Method 2 (Energy)

$$v = \sqrt{2 \times 9.8 \times 45}$$

speed of about $29.7 \frac{\text{m}}{\text{s}}$

Conclusion: Two different methods agree perfectly. Reassuring and a useful check!



Real Systems Lose Energy

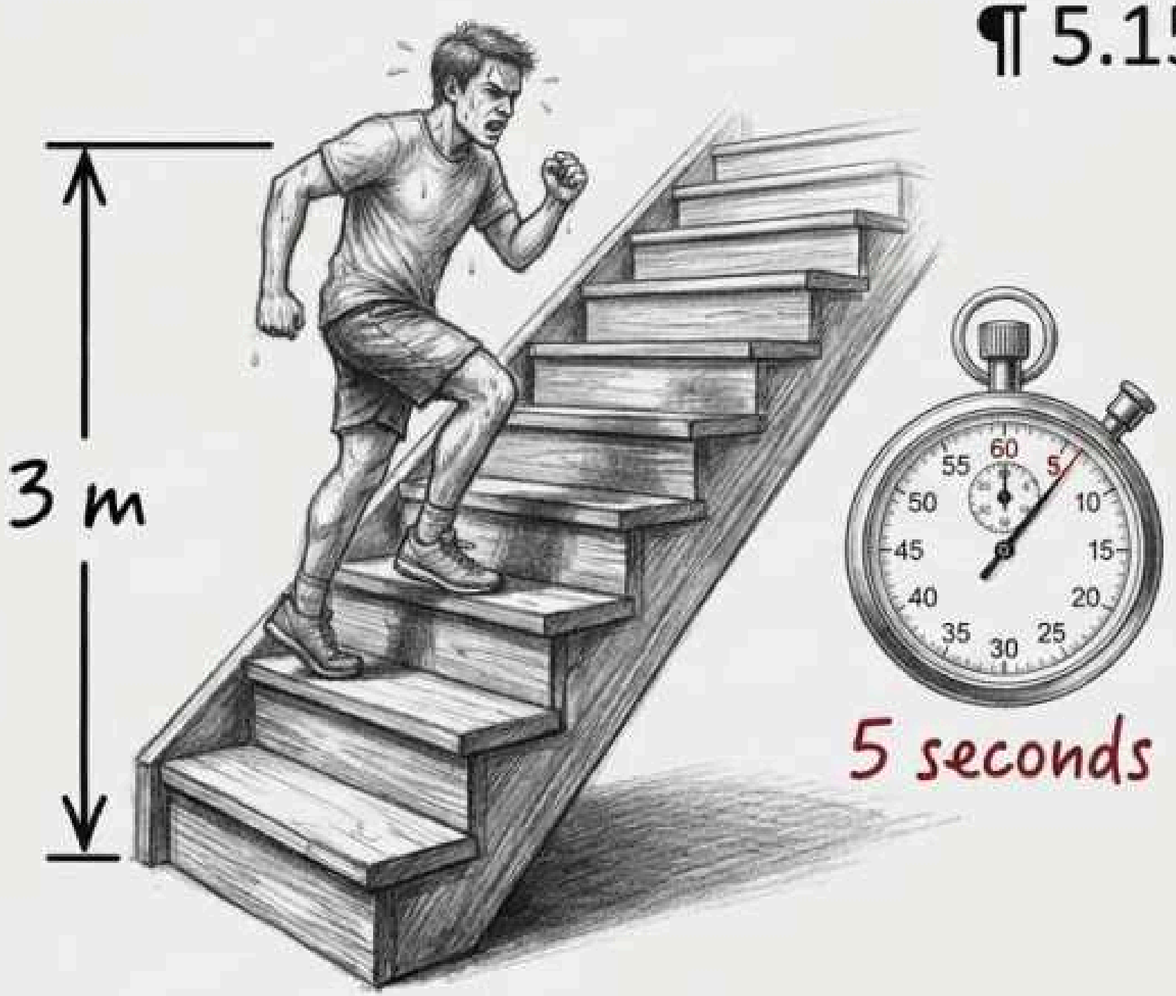
A bouncing ball does not return to its starting height because friction turns kinetic energy into heat.

Total energy is still conserved, but it becomes scattered thermal energy in the surroundings.

It cannot easily be turned back into motion—leading into thermodynamics.

Power: $P = \frac{W}{t}$

Units: Measured in Watts
(1 Watt = 1 Joule per second).



Example: A 60 kg person climbing 3 m stairs in 5 s.

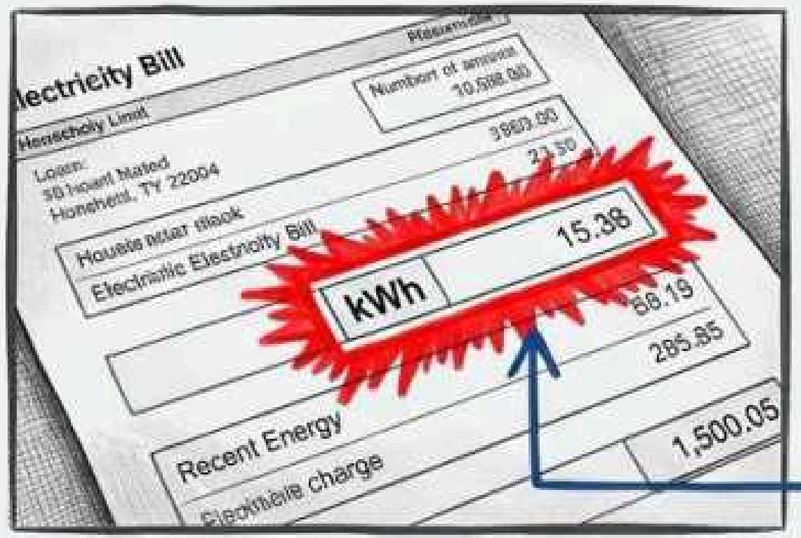
Work = $60 \times 9.8 \times 3 = 1{,}764$ J Power = $\frac{1{,}764}{5} = 353$ Watts.





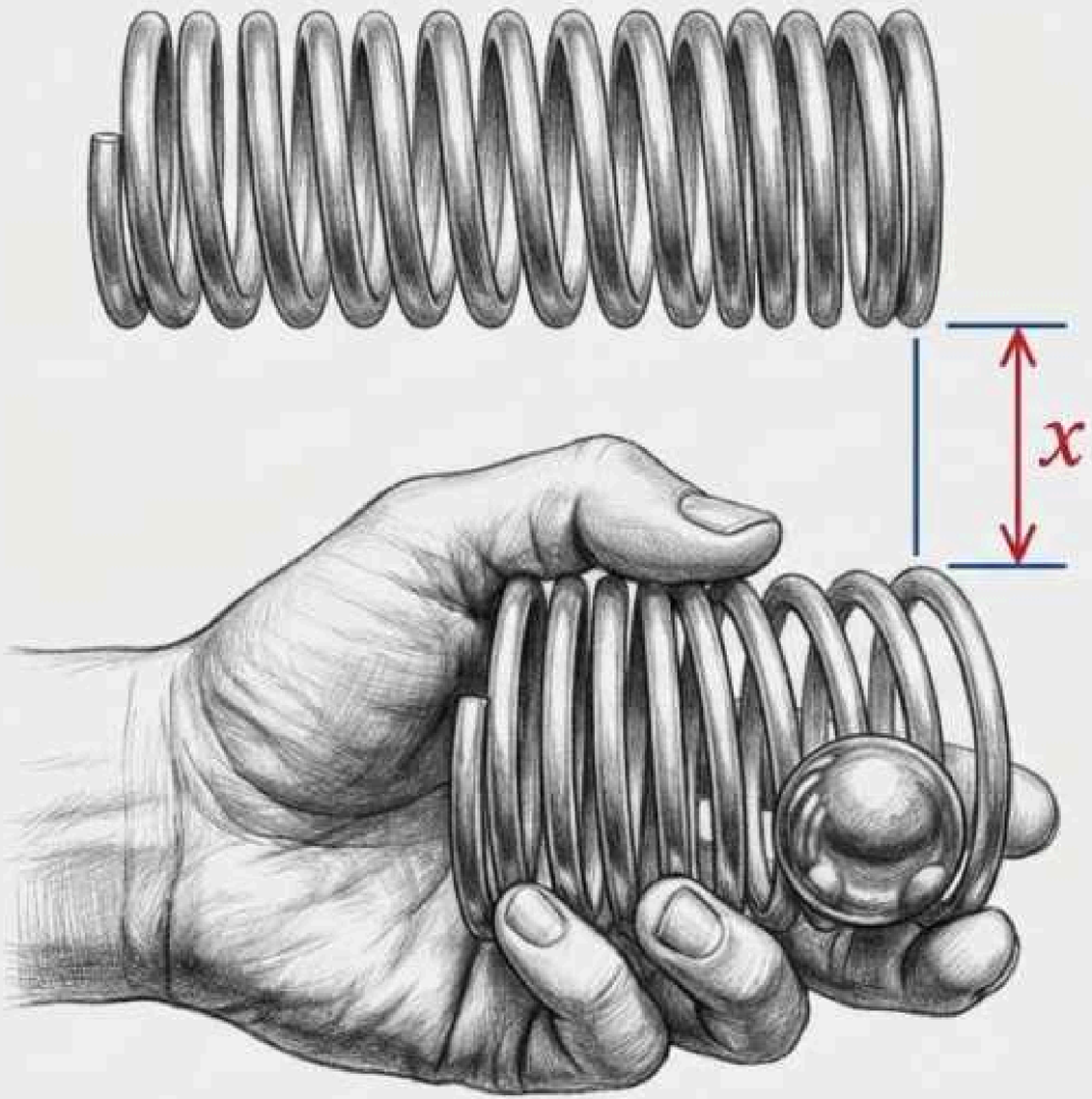
Strong Cyclist: ~ 200 - 300 Watts
(sustained for an hour)

Hair Dryer: ~ 1,500 Watts



Reading Your Bill: The **kilowatt-hour (kWh)** is power times time. It is a unit of energy, not power.

1 kilowatt-hour = 3,600,000 *Joules.*



Springs Store Energy: Force grows as the stretch grows.

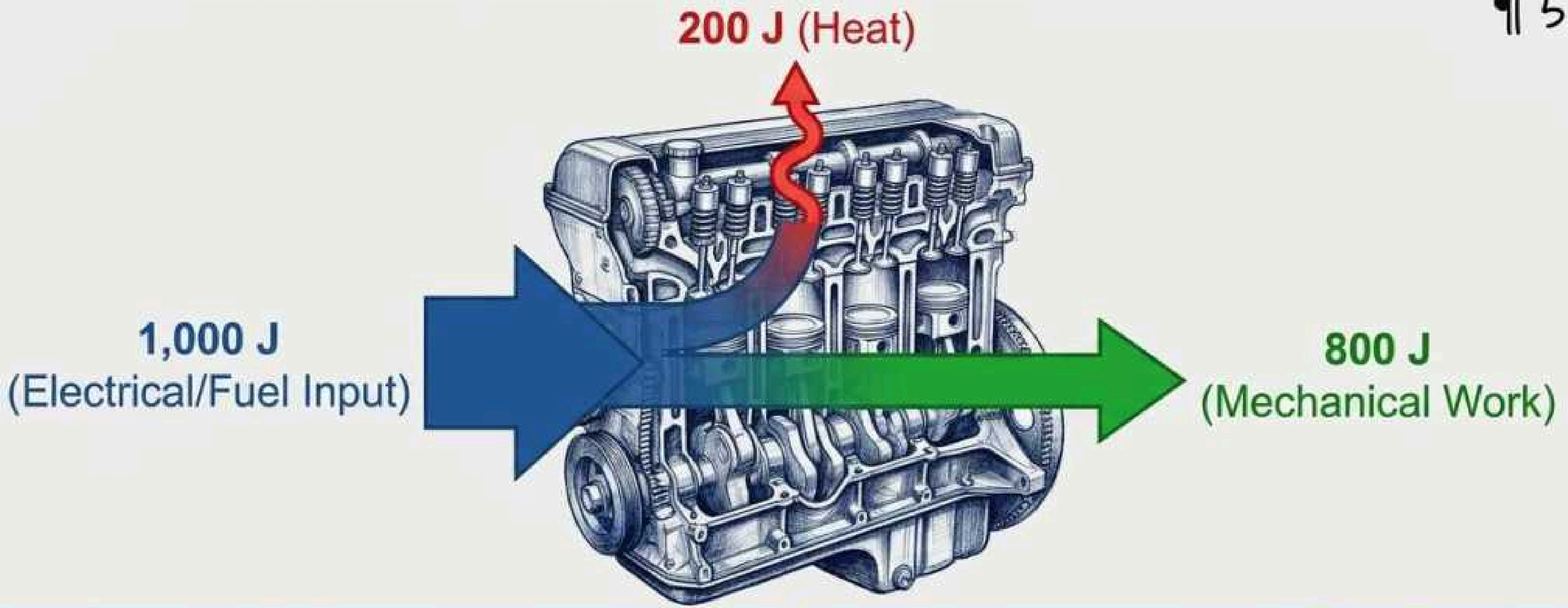
$$PE = \frac{1}{2} k x^2$$ (k = spring constant, x = stretch).

Example: A spring with constant 200 N/m, stretched by 0.3 m.

$$\text{Energy} = \frac{1}{2} \times 200 \times 0.09 = 9 \text{ joules}.$$

When released, this stored energy can launch a small ball.

¶ 5.18



Efficiency: Useful Output ÷ Input.
No machine is perfectly efficient.

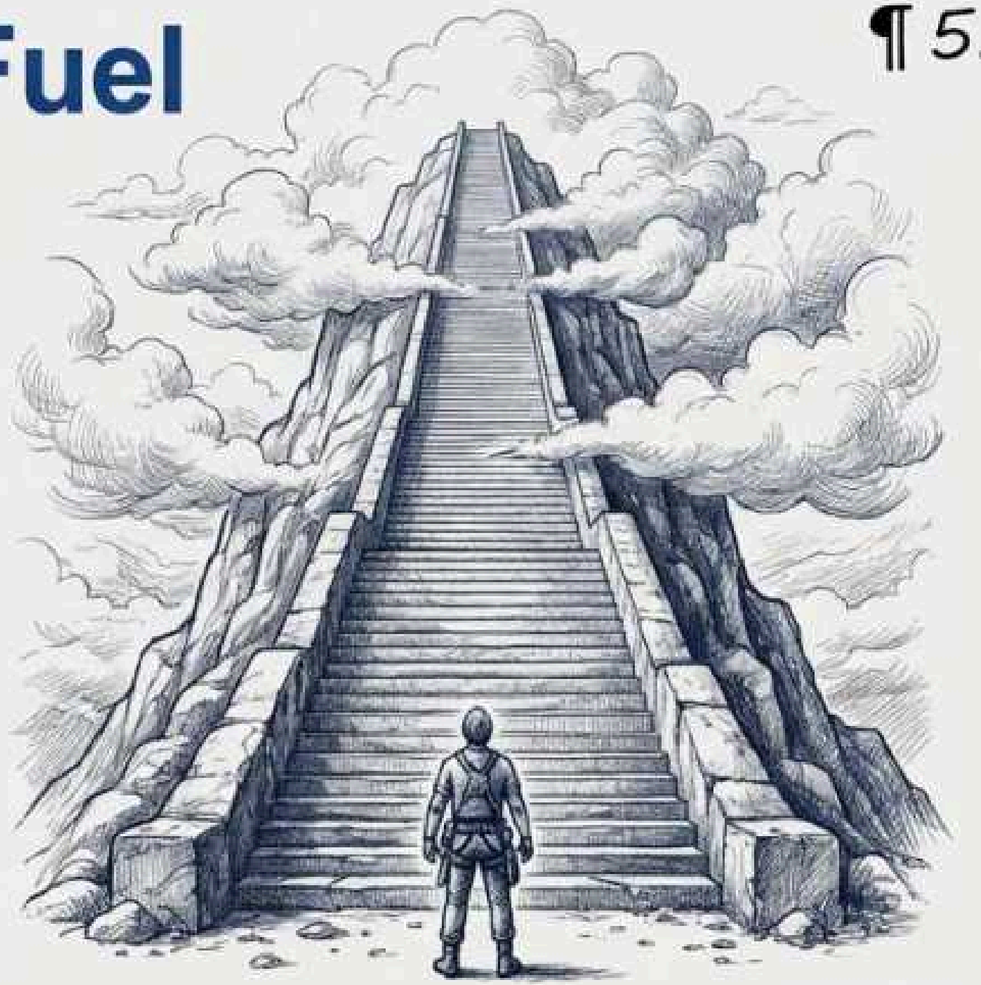
Example: $\frac{800\text{ J work}}{1{,}000\text{ J input}} = 80\%$ Efficient.
(The missing 200 J appear as heat).

Real World: A typical car engine turns only about 25% of the fuel's energy into motion. The rest is wasted as heat.

Food is Fuel

¶ 5.19

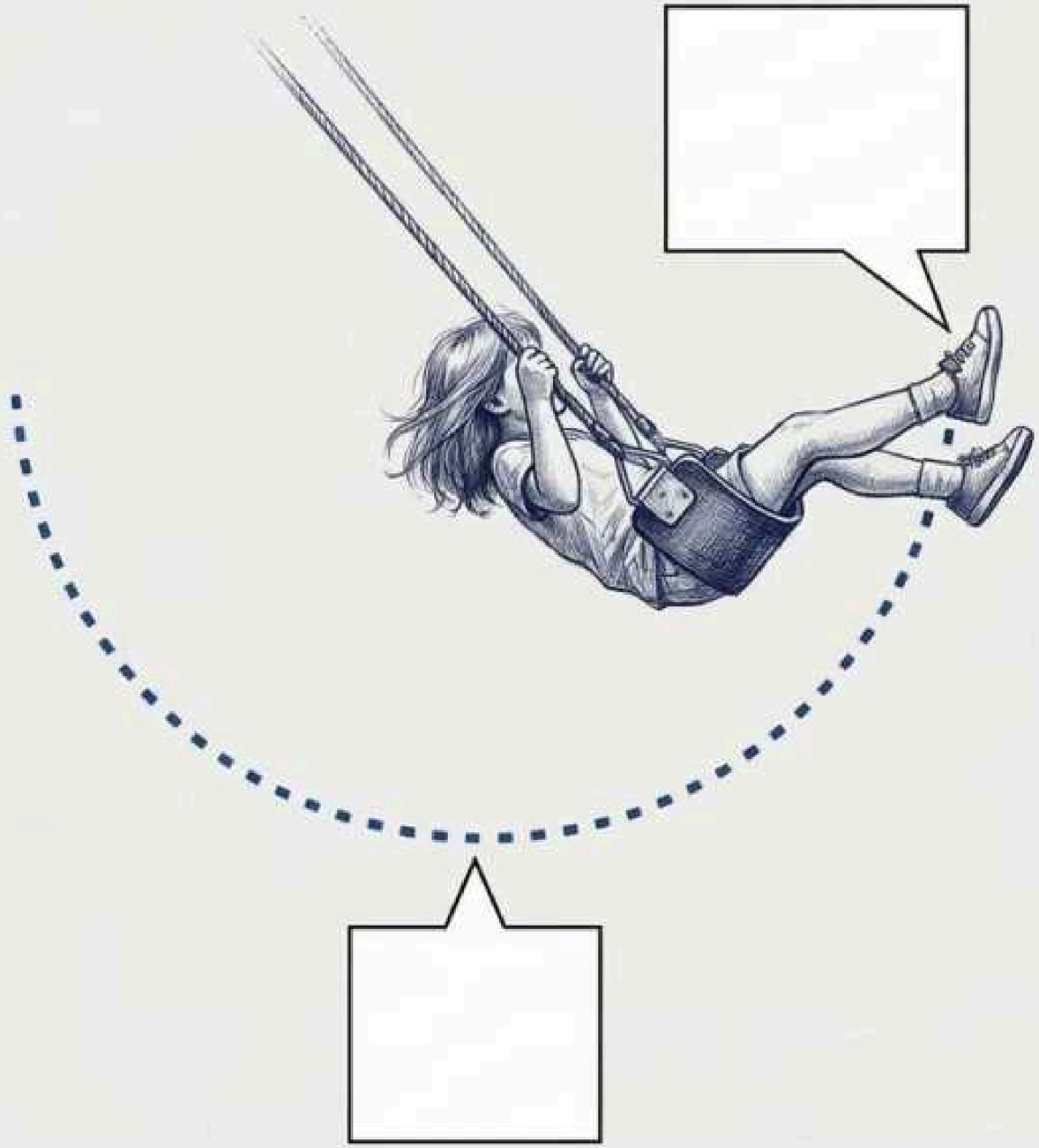




A 250 Calorie snack holds ~ 1,046,000 Joules.
(1 Food Calorie = 4,184 Joules.)

To burn this working against gravity alone, a 60 kg person must climb nearly 1,800 meters.

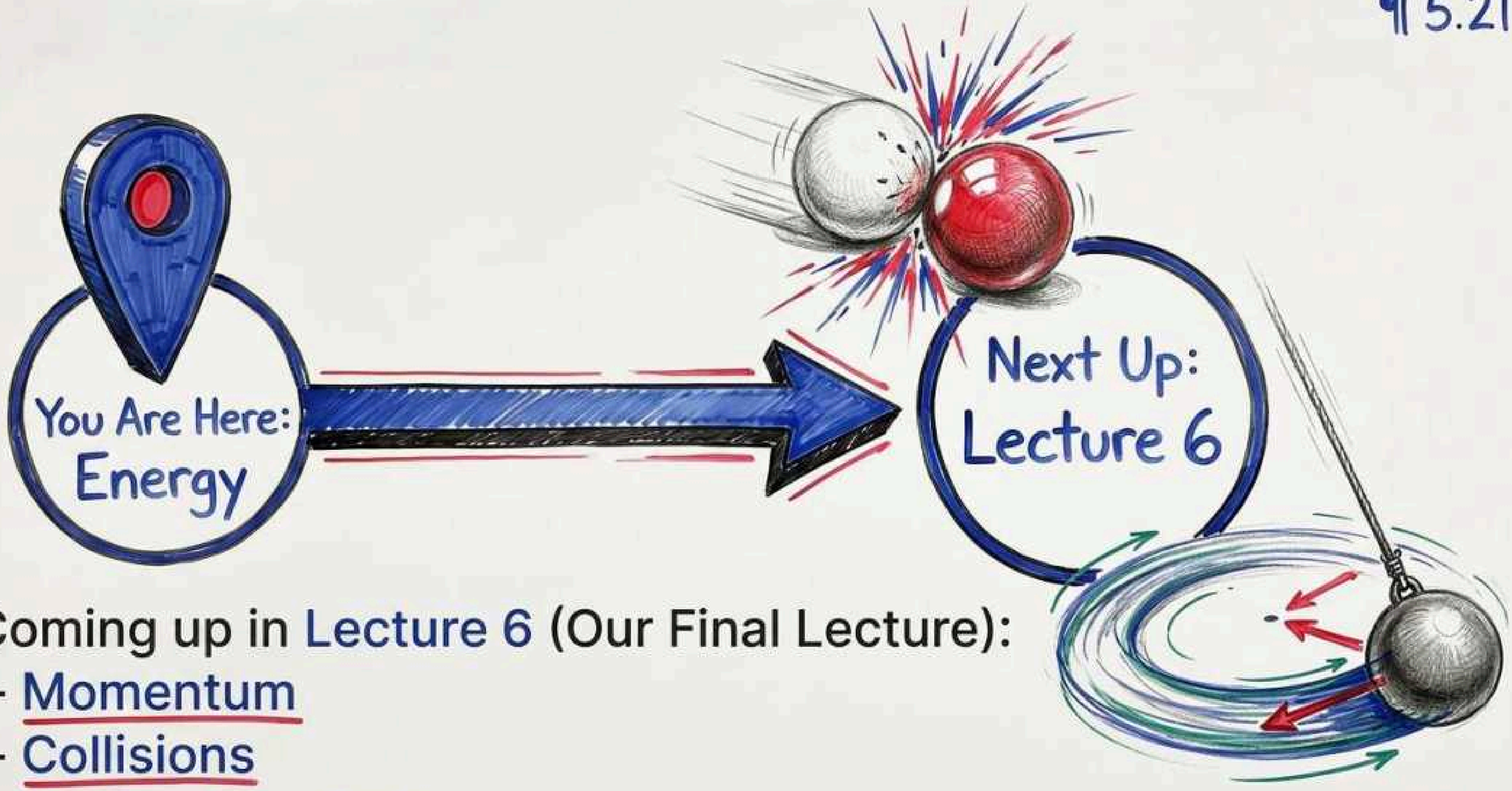
Climbing stairs alone is a slow way to burn off a snack!



Question for Review:

A child on a swing reaches the same height on each side, then slowly comes to rest if nobody pushes.

Describe, in terms of kinetic energy, potential energy, and friction, what is happening during one swing, and over many swings.



Coming up in Lecture 6 (Our Final Lecture):

- Momentum
- Collisions
- Motion in a circle