

PHYS12 CH:9.3 How Ancient Humans Moved Mountains

The Six Tools That Built Civilization

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December 2025

Outline

- 1 Introduction
- 2 Simple Machines and Mechanical Advantage
- 3 The Six Simple Machines
- 4 Efficiency and Real Machines
- 5 Problem Solving
- 6 Summary

How did ancient humans move
20-ton stone blocks
without engines or electricity?

The Mystery

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They discovered six simple machines that multiply force.

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Same tools built the pyramids and launch rockets today.

Learning Objectives

By the end of this lesson, you will be able to:

- **9.3:** Describe simple and complex machines

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- **9.3:** Calculate efficiency of simple and complex machines

9.3 The Conservation Trade-Off

Nature's Accounting System

In closed systems, total energy is conserved.
Machines cannot create energy.

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- Reduce force required
- Increase distance over which force acts
- Product $f \times d$ stays constant

The Illusion

Machines make work "easier" but don't reduce total work.

9.3 The Trade-Off Equation

Universal Law of Simple Machines

$$W_i = W_o$$

Work input equals work output (in ideal case)

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Expanding this:

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The Mental Model

If effort force F_e is less than resistance force F_r ,
then effort distance d_e must be greater than resistance distance d_r .

9.3 The Lever: Humanity's First Force Multiplier



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Components:

- Fulcrum: the pivot point
- Effort arm L_e : distance from fulcrum to effort force
- Resistance arm L_r : distance from fulcrum to load

9.3 Mechanical Advantage

Definition: Ideal Mechanical Advantage (IMA)

The number of times a machine multiplies the effort force.

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The Mental Model

IMA of 4 means you lift 400 N with only 100 N effort.

The catch: you pull 4 times the distance.

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Three classes based on fulcrum position:

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Examples: wheelbarrow, bottle opener, nutcracker

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The Paradox

Class 3 levers have IMA less than 1. They reduce force but increase speed!

9.3 Wheel and Axle



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IMA formula:

$$IMA = \frac{r_{wheel}}{r_{axle}}$$

9.3 Wheel and Axle



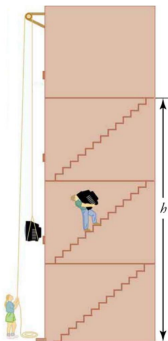
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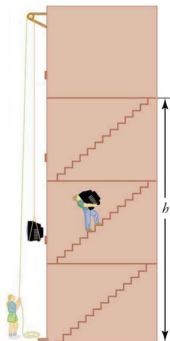
Real-World Examples

Steering wheel, door knob, windlass, screwdriver handle

9.3 Inclined Plane



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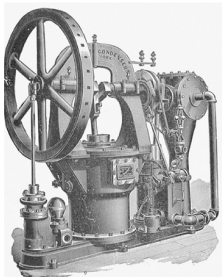


IMA formula:

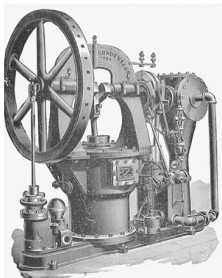
$$IMA = \frac{L}{h}$$

where L is length of ramp and h is height

9.3 The Wedge

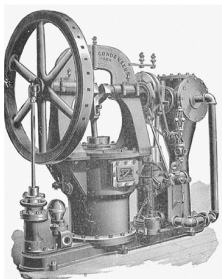


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What it is: Two inclined planes back to back

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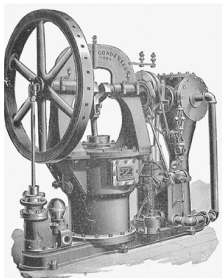


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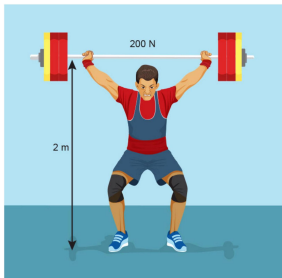
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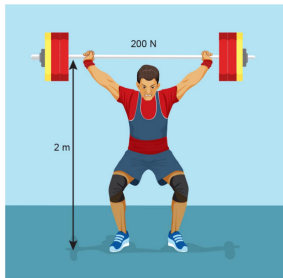
Real-World Examples

Knife, axe, chisel, nail, zipper teeth

9.3 The Screw

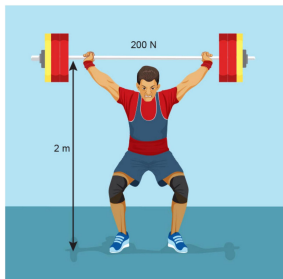


9.3 The Screw



What it is: An inclined plane wrapped around a cylinder

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IMA formula:

$$IMA = \frac{2\pi L}{P}$$

where L is handle length and P is pitch (distance between threads)

9.3 The Pulley



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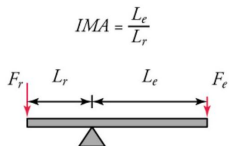


IMA formula (easiest!):

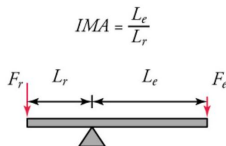
$$IMA = N$$

where N is number of ropes supporting the load

9.3 Complex Machines



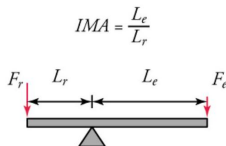
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Definition: Complex Machine

A combination of two or more simple machines

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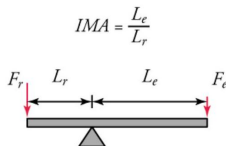
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More Examples

Bicycle: wheel and axle, levers, screws, pulleys

Car: hundreds of simple machines combined

9.3 The Reality of Friction

Civilian View vs. Reality

Ideal machine: $W_i = W_o$ (100% efficiency)

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- Air resistance

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- Air resistance
- Heat generation
- Deformation of materials

Energy is conserved, but some becomes unavailable heat.

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Since $W = F \times d$:

$$\text{Efficiency} = \frac{F_o \times d_o}{F_i \times d_i} \times 100\%$$

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Ranking by Efficiency (typical)

- 1 Pulleys (95-98%)
- 2 Wheel and axle (90-95%)
- 3 Levers (90-95%)
- 4 Inclined plane (60-90%)
- 5 Wedge (50-80%)
- 6 Screw (30-70%)

Attempt: Lever Efficiency

The Challenge (3 min, silent)

An input force of 11 N acting on the effort arm of a lever moves 0.4 m. This lifts a 40 N weight on the resistance arm a distance of 0.1 m.

Given:

- $F_i = 11 \text{ N}$, $d_i = 0.4 \text{ m}$
- $F_o = 40 \text{ N}$, $d_o = 0.1 \text{ m}$

Find: Efficiency of the lever

Can you calculate how much work is lost to friction?

Compare: Efficiency Strategy

Turn and talk (2 min):

- 1 What equation did you use for efficiency?
- 2 Did you calculate W_i and W_o separately?
- 3 What units should efficiency have?

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Name wheel: One pair share your approach (not your answer).

Reveal: Lever Efficiency Solution

Self-correct in a different color:

Step 1: Calculate input work

$$W_i = F_i \times d_i = 11 \times 0.4 = 4.4 \text{ J}$$

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Step 3: Calculate efficiency

$$\text{Efficiency} = \frac{W_o}{W_i} \times 100\% = \frac{4.0}{4.4} \times 100\% = \boxed{91\%}$$

Reveal: Lever Efficiency Solution

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Step 3: Calculate efficiency

$$\text{Efficiency} = \frac{W_o}{W_i} \times 100\% = \frac{4.0}{4.4} \times 100\% = \boxed{91\%}$$

Check: 0.4 J lost to friction out of 4.4 J input - reasonable!

Attempt: Inclined Plane IMA

The Challenge (3 min, silent)

An inclined plane is 5.0 m long and 2.0 m high.

Given:

- Length $L = 5.0$ m
- Height $h = 2.0$ m

Find: Ideal mechanical advantage (IMA)

How much does this ramp multiply your force?

Compare: IMA Formula

Turn and talk (2 min):

- 1 What is the formula for IMA of an inclined plane?
- 2 Which value goes in numerator and which in denominator?
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Name wheel: One pair share your reasoning.

Reveal: Inclined Plane IMA Solution

Self-correct in a different color:

Formula for inclined plane:

$$IMA = \frac{L}{h}$$

Reveal: Inclined Plane IMA Solution

Self-correct in a different color:

Formula for inclined plane:

$$IMA = \frac{L}{h}$$

Substitute values:

$$IMA = \frac{5.0 \text{ m}}{2.0 \text{ m}} = \boxed{2.5}$$

Reveal: Inclined Plane IMA Solution

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Formula for inclined plane:

$$IMA = \frac{L}{h}$$

Substitute values:

$$IMA = \frac{5.0 \text{ m}}{2.0 \text{ m}} = \boxed{2.5}$$

Interpretation: This ramp multiplies your force by 2.5.
You can push a 250 N load with only 100 N effort.
The trade-off: you push 2.5 times the distance.

Attempt: Pulley System

The Challenge (3 min, silent)

A pulley system lifts a 200 N load with an effort force of 52 N.
The system has an efficiency of almost 100%.

Given:

- $F_r = 200 \text{ N}$ (load)
- $F_e = 52 \text{ N}$ (effort)
- Efficiency $\approx 100\%$

Find: Number of ropes supporting the load

How many ropes does this system need?

Compare: Pulley Logic

Turn and talk (2 min):

- 1 What is mechanical advantage for pulleys?
- 2 How do you find actual MA from given forces?
- 3 For pulleys, what does IMA equal?

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Name wheel: One pair share your reasoning.

Reveal: Pulley System Solution

Self-correct in a different color:

Step 1: Calculate actual mechanical advantage

$$MA = \frac{F_r}{F_e} = \frac{200 \text{ N}}{52 \text{ N}} = 3.85$$

Reveal: Pulley System Solution

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Step 3: Since efficiency $\approx 100\%$, actual $MA \approx IMA$

$$N \approx 3.85 \approx \boxed{4 \text{ ropes}}$$

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$$N \approx 3.85 \approx \boxed{4 \text{ ropes}}$$

Check: 4 ropes supporting load makes sense.

Each rope carries roughly $200/4 = 50 \text{ N}$.

The Six Force Multipliers

Simple Machines Summary

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- 5 **Screw:** $IMA = \frac{2\pi L}{P}$
- 6 **Pulley:** $IMA = N$ (number of ropes)

Key Equations

$$IMA = \frac{F_r}{F_e} = \frac{d_e}{d_r} \quad (1)$$

$$W_i = W_o \quad (\text{ideal machine}) \quad (2)$$

$$F_e \times d_e = F_r \times d_r \quad (3)$$

$$\text{Efficiency} = \frac{W_o}{W_i} \times 100\% \quad (4)$$

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- 2 Machines cannot create energy - conservation rules
- 3 Six types: lever, wheel-axle, incline, wedge, screw, pulley
- 4 IMA tells you how much force is multiplied
- 5 Efficiency measures work lost to friction
- 6 Complex machines combine simple machines

Complete the assigned problems
posted on the LMS