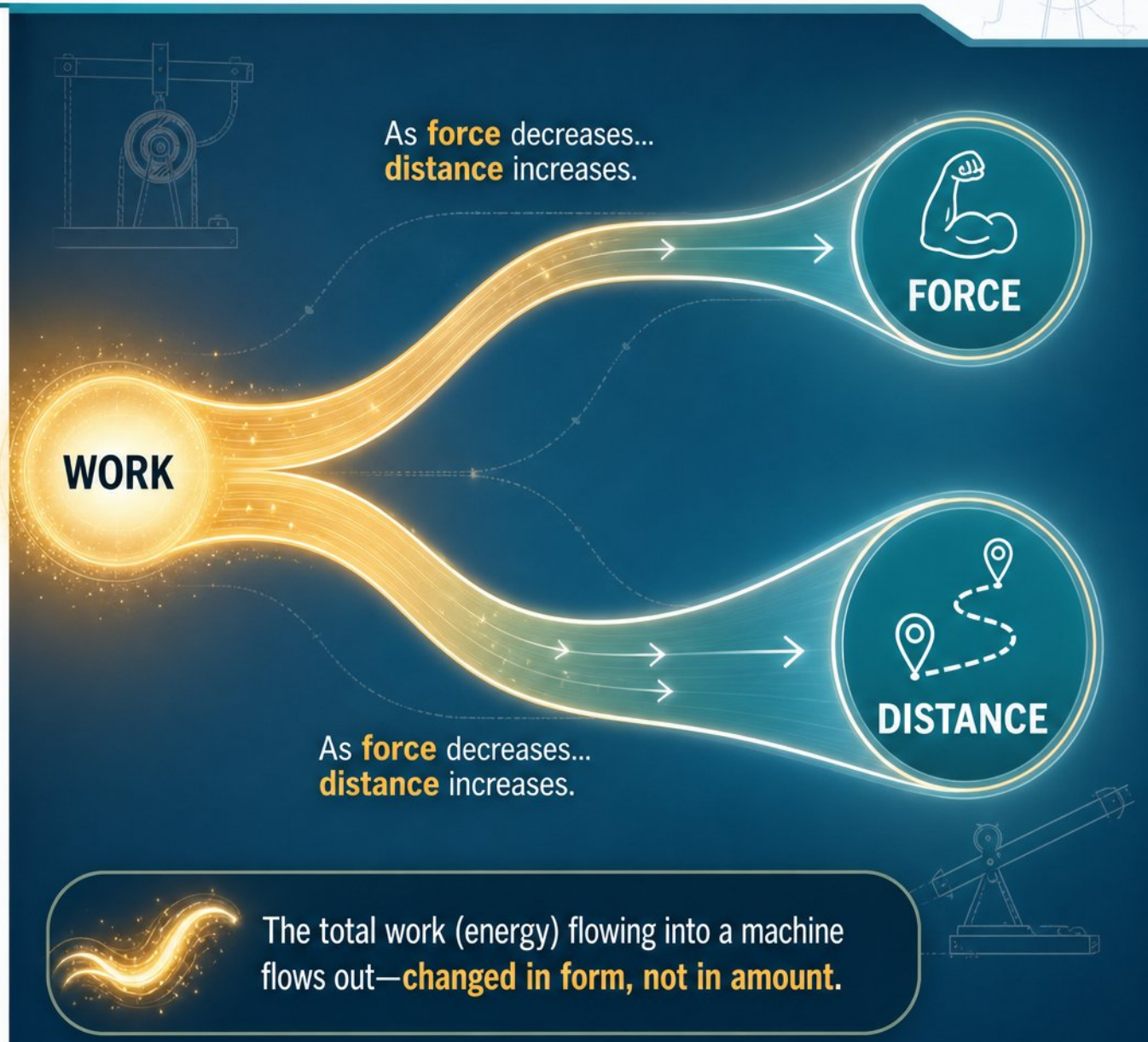
Simple Machines:
Force, Distance, and Mechanical Advantage

- - A simple machine changes the magnitude or direction of a force
- - Fundamental trade-off: multiplying force reduces required distance
- - Work remains constant; no machine can reduce total work
- - Six classical simple machines: lever, wheel & axle, pulley, inclined plane, wedge, screw

Core Concepts: Work, Force, and Distance

- Work = Force × Distance in the direction of force (W = Fd)
- In ideal machines, total work is conserved: Win = Wout
- Reducing input force means increasing input distance
- Simple machines never reduce total work required



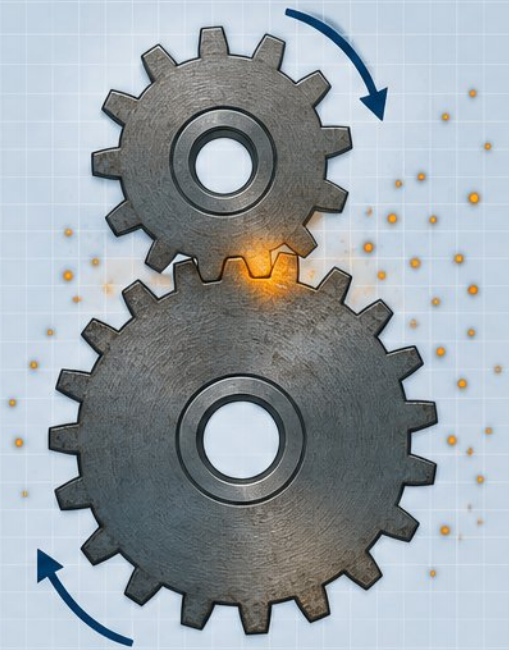
Mechanical Advantage: Definition and Calculation

- **Mechanical Advantage (MA)** is the ratio of output force to input force **(MA = Fr / Fe)**
- **Ideal MA (IMA)** is theoretical, based on geometry: **IMA = de / dr**
- **Actual MA (AMA)** is measured from real forces, always reduced by friction
- **Efficiency (%) = (AMA / IMA) × 100,** always less than 100% in real machines
- **IMA** tells what a machine could do; **AMA** tells what it does

IDEAL (FRICTIONLESS)

No friction losses. Maximum possible mechanical advantage.

REAL (WITH FRICTION)

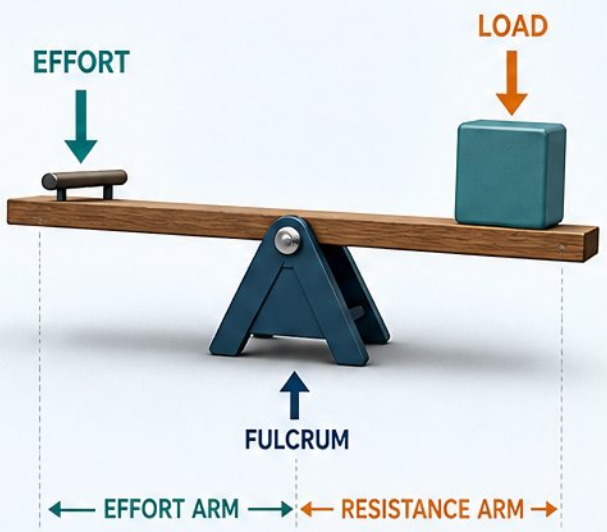


Friction causes heat and wear. Reduces actual performance.

Levers: Force Multiplication Through a Fulcrum

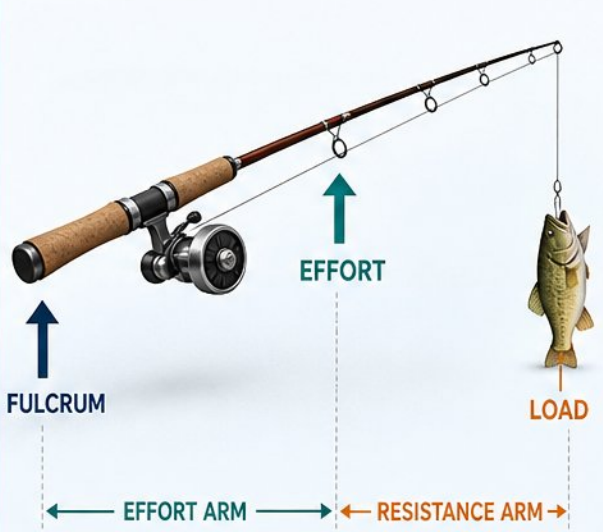
- A lever has three parts: fulcrum, effort arm, and resistance arm
- Class 1: Fulcrum in middle (seesaw); Class 2: Load in middle (wheelbarrow)
- Class 3: Effort in middle (fishing rod); trades force for speed
- IMA = effort arm length / resistance arm length
- Torque balance: Fi × di = Fo × do; work remains constant

CLASS 1: FULCRUM IN MIDDLE (SEESAW)



CLASS 2: LOAD IN MIDDLE (WHEELBARROW)

CLASS 3: EFFORT IN MIDDLE (FISHING ROD)



Inclined Planes:

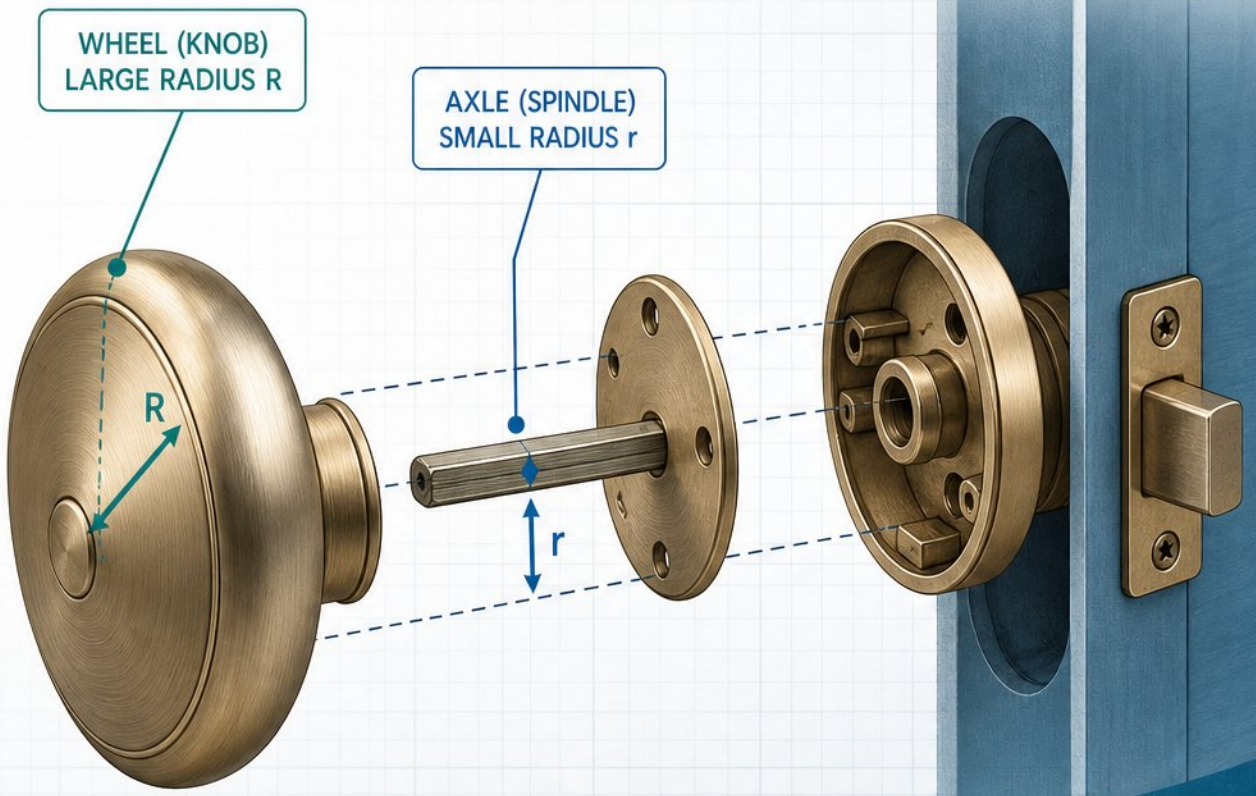
Reducing Effort by Increasing Distance

- A sloped surface reduces lifting force by increasing the distance moved
- Work remains constant: less force is applied over a longer path
- Ideal Mechanical Advantage (IMA) = Length of slope (L) ÷ Height (H)
- Gentler slopes yield higher MA but require longer travel distance
- Common examples: loading ramps, staircases, switchback mountain roads

Wheels and Axles:

Turning Rotary Motion into Advantage

- A rotating lever: large wheel rigidly fixed to a smaller axle
- IMA = Wheel Radius / Axle Radius (R/r)
- Torque conserved: Input force × R = Output force × r
- Doorknob (force multiplication) vs. Ferris wheel (speed multiplication)



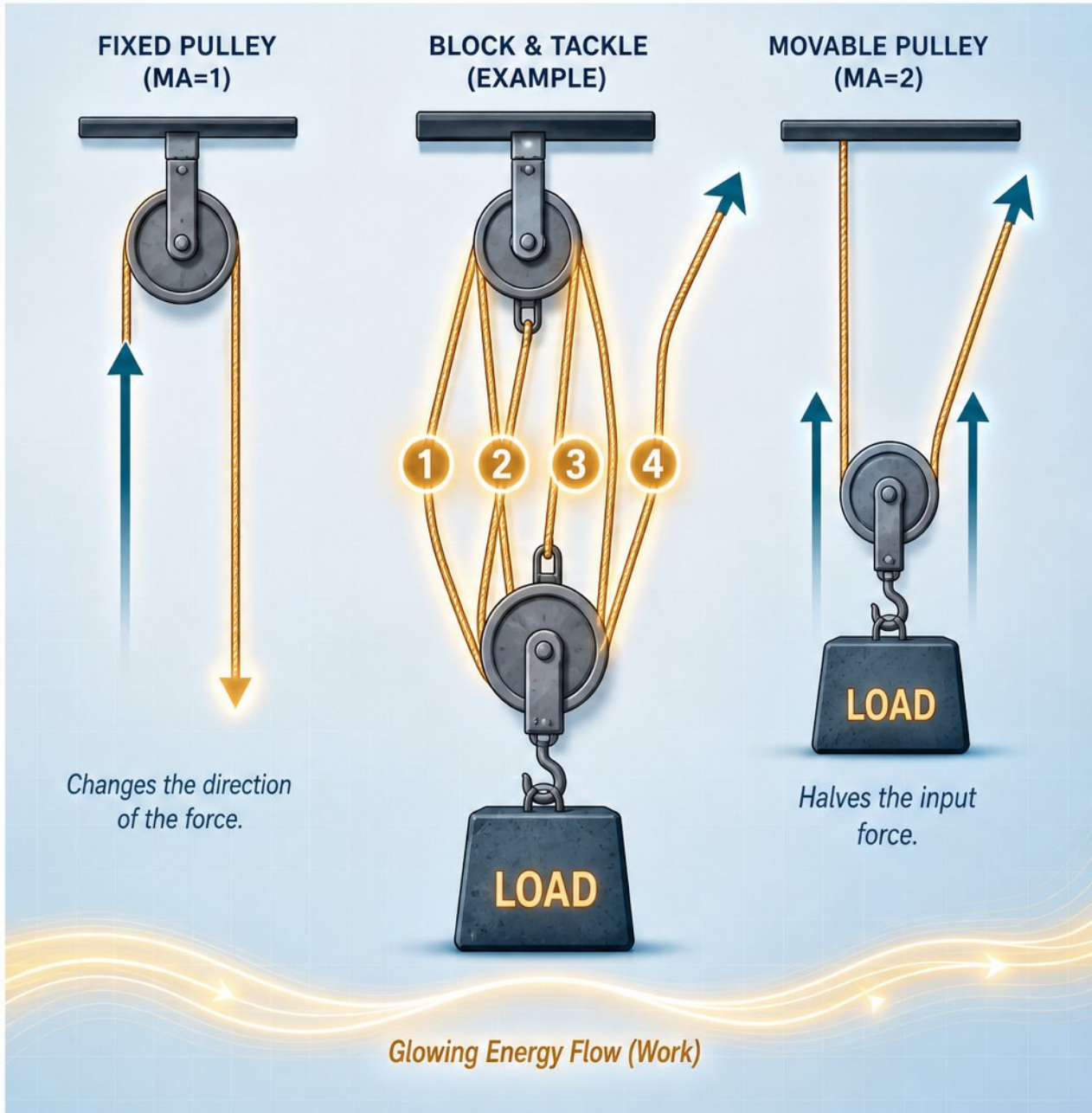
Pulleys: Redirecting Force and Gaining Advantage

- **Fixed pulley (MA=1):** changes force direction, does not reduce effort, used for flagpoles and blinds.

- **Movable pulley (MA=2):** load attached to pulley, supported by two rope segments, halves input force.

- **Block & tackle** combines fixed and movable pulleys; IMA equals number of rope segments supporting the load.

- **Trade-off:** multiplying force requires pulling proportionally more rope distance.



Wedges and Screws:
Special Applications of Inclined Planes

- A wedge is a movable inclined plane, often two back-to-back, for splitting or lifting
- A screw is an inclined plane wrapped around a cylinder
- Screw IMA = handle circumference divided by thread pitch (IMA = $2\pi r$ / pitch)
- Examples: axes and knives (wedges), jackscrews and bolts (screws)
- Finer threads (smaller pitch) or larger handles yield higher mechanical advantage

Compound Machines: Combining Simple Machines

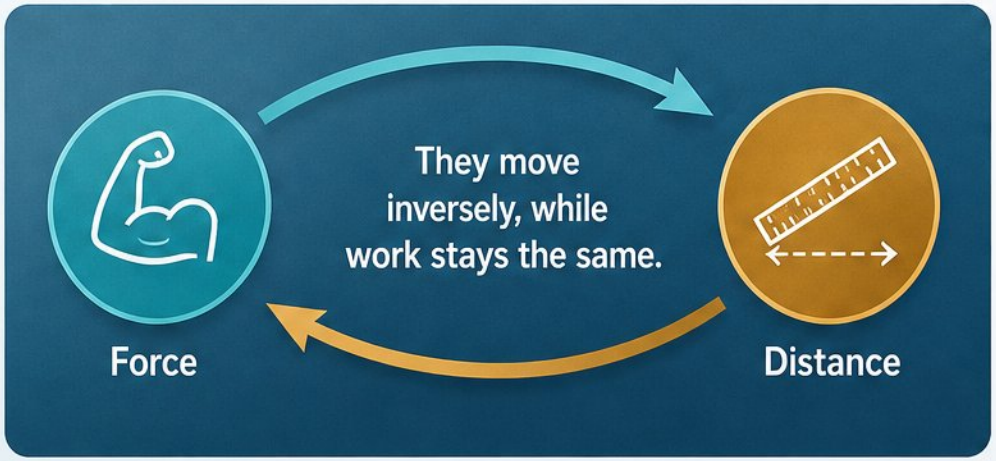
- A **compound** machine is two or more simple machines working in sequence.
- Total MA = product of the individual MAs:

$$MA_{total} = MA_1 \times MA_2 \times \dots$$

- **Example:** Bicycle uses levers (pedals), wheels & axles, and pulleys (chain).
- **Efficiency losses multiply:** low efficiency in one part drags down the whole system.

MA_1 Levers (Pedals) × MA_2 Wheels & Axles × MA_3 Pulleys (Chain) × ... = $MA_{total} = MA_1 \times MA_2 \times \dots$

The Universal Trade-Off: Force vs. Distance



- **Work** is conserved: input work always equals output work ($F_i \times d_i = F_o \times d_o$)

- Force and distance are inversely proportional; a gain in one means a loss in the other

- A machine that halves required force doubles the distance you must apply it

- **Lever:** pressing a long effort arm saves force but moves a greater arc

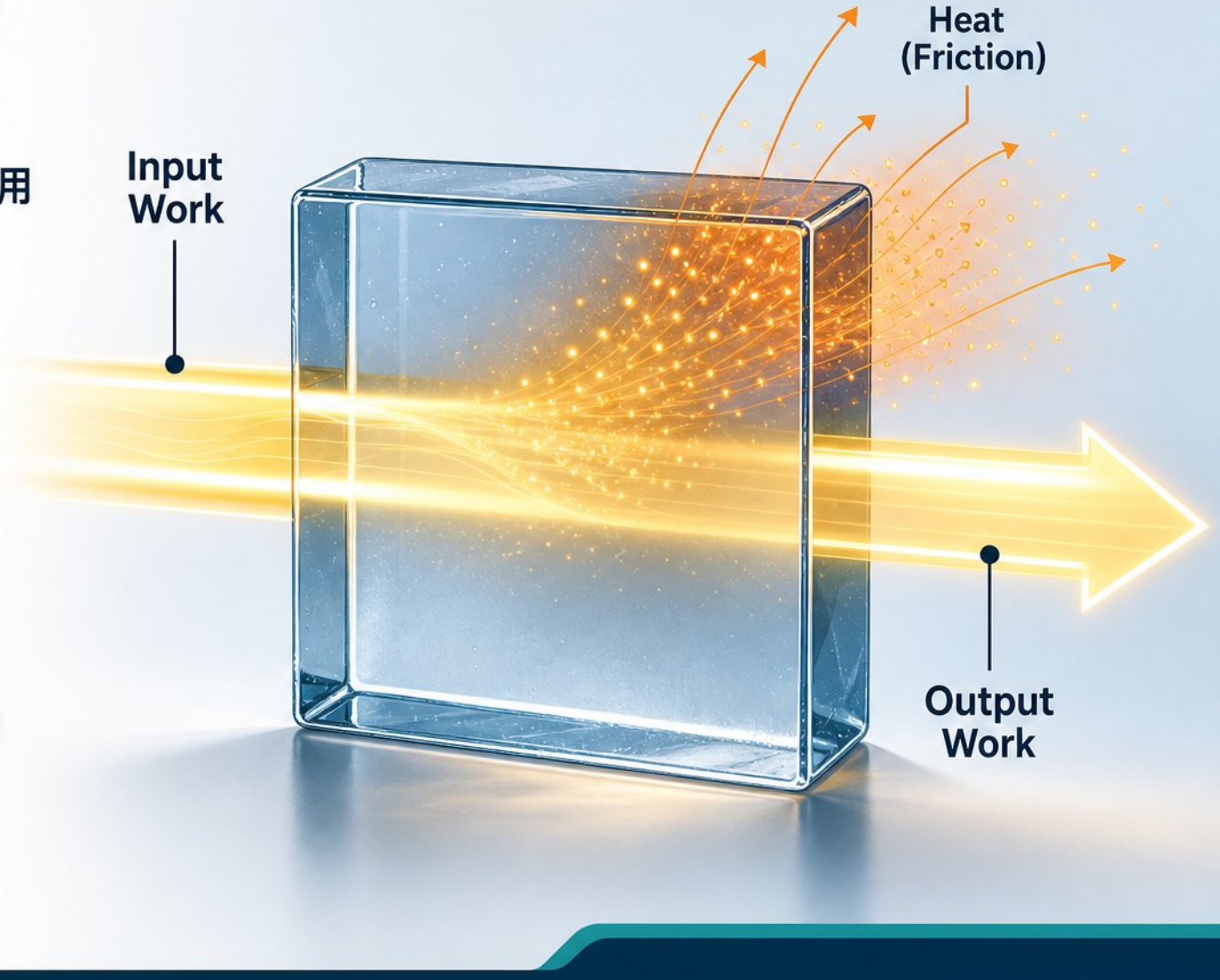
- **Inclined plane:** a gentler slope requires less force but a longer push

- **Pulley:** lifting with 4 ropes multiplies force by 4, pulling 4× more rope

- **Wheel & axle:** turning a large wheel applies a small force over a long circular path

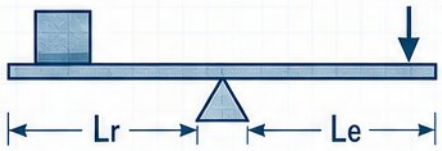
Efficiency and Friction in Real Machines

- - 理想机械优势（IMA）由几何形状决定，忽略摩擦
- - 实际机械优势（AMA）使用测量的力计算，由于摩擦，AMA 总是小于 IMA
- - 效率 (%) = (AMA ÷ IMA) × 100%，始终低于 100%
- - 示例：IMA=5 的杠杆如果效率为 80%（AMA=4），则会因摩擦而损失 20% 的功



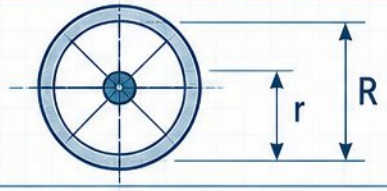
Calculating Mechanical Advantage for Each Machine

Lever



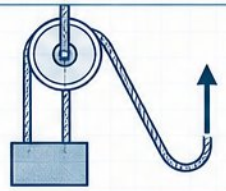
- **Lever: IMA** = Effort Arm Length / Resistance Arm Length (Le / Lr)

Wheel & Axle

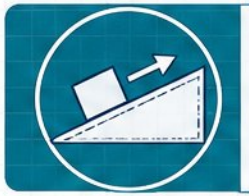


- **Wheel & Axle:** IMA = Wheel Radius / Axle Radius (R / r)

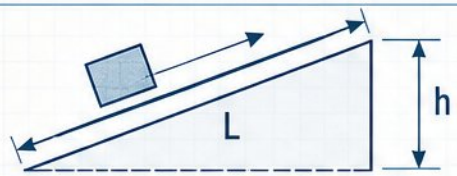
Pulley



- **Pulley:** IMA = Number of supporting rope segments (n)



Inclined Plane

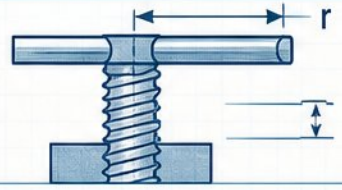


- **Inclined Plane:** IMA = Slope Length / Height (L / h)

Wedge

- **Wedge:** IMA = Slope Length / Thickness (L / t)

Screw

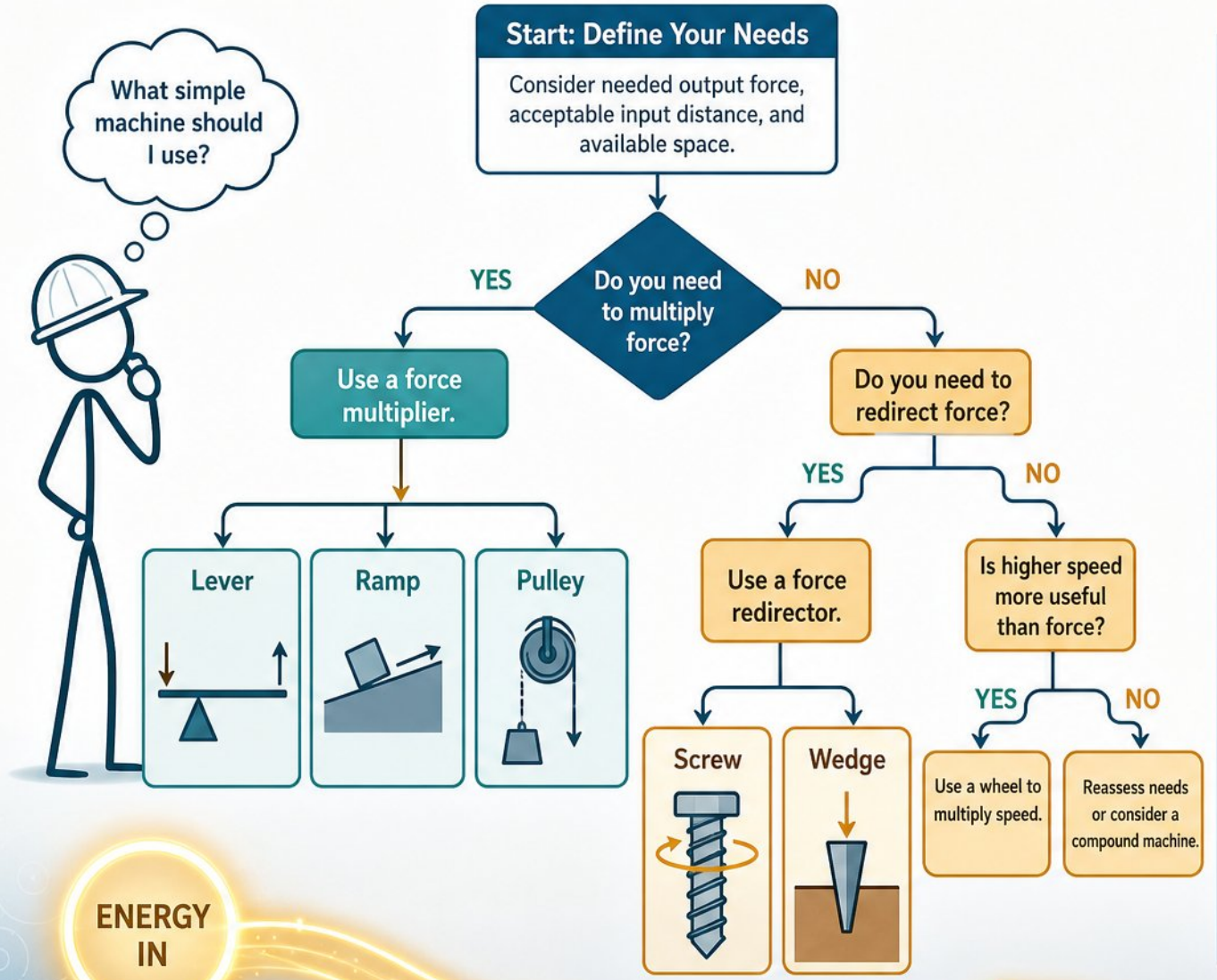


- **Screw:** IMA = 2π × Handle Radius / Pitch (2πr / p)

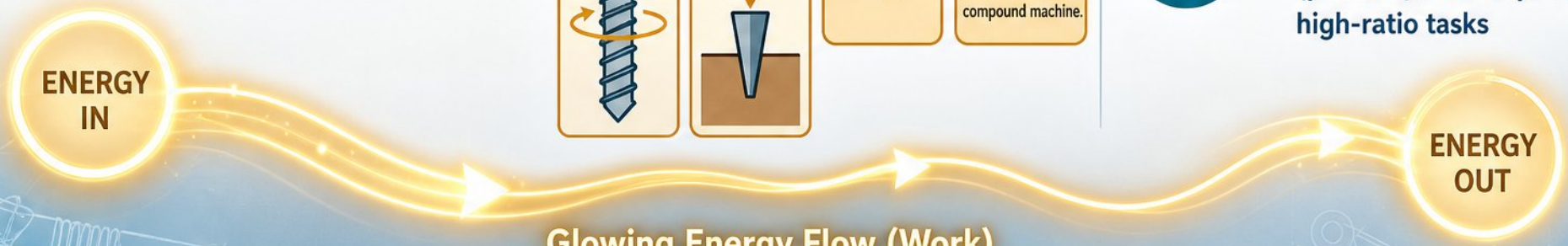
Identifying Simple Machines in Everyday Life

- Scissors use two levers and two wedges to cut with amplified force.
- A ramp is an inclined plane; longer ramps yield higher mechanical advantage.
- A doorknob is a wheel and axle trading torque for force.
- A screw-top jar lid uses screw threads to convert rotation into tight sealing force.
- Hunt for levers, planes, wheels, and screws in your room right now.

Summary and Real-World Selection Guide



- Lever, ramp, pulley: multiply force; screw, wedge: redirect force; wheel may multiply speed
- Choose machine by needed output force, acceptable input distance, and space
- Simple machines make work easier but never reduce total work
- Compound machines chain advantages (product) for complex, high-ratio tasks



PersonWise.

PersonWise • AI digital-human course platform

Scan the code or click anywhere to watch this course live, with voice Q&A

personwise.ai/t/e7915fd2/public