

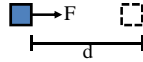
# Work, Power, and Mechanical Advantage

## Work

**Work** – The energy that is transferred by a force that moves an object a certain distance

work = force × distance moved

$$W = F \cdot d$$



If a force is applied but an object does not move, then no work was done!!

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## Unit – Work is measured in joules (J)

$$W = \text{Force (N)} \times \text{distance (m)} = \text{N} \cdot \text{m}$$

These units together are called a joule (J)

$$\text{N} \cdot \text{m} = \text{J}$$

The joule is a derived unit:

$$1 \text{ J} = 1 \text{ N} \cdot \text{m} = 1 \frac{\text{kg} \cdot \text{m}^2}{\text{s}^2}$$

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## Work Problem Example:

If a man moves a boulder a distance of 10 meters and uses a force of 100 N, how much work has been done?

$$d = 10 \text{ m} \quad F = 100 \text{ N} \quad W = ?$$

$$W = F \times d$$

$$W = (100\text{N})(10\text{m}) = 1000 \text{ N} \cdot \text{m} = 1000 \text{ J}$$

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## Power

**Power** – the rate of work performed over time

$$\text{Power} = \frac{\text{Work}}{\text{Time}} \quad P = \frac{W}{t}$$

The faster work is done, the harder it is to do.  
Power is the speed that work is performed

Another formula is:

$$P = \frac{F \cdot d}{t}$$

## Unit – Power is measured in watts (W)

$$P = \frac{\text{Work(J)}}{\text{time(s)}} \quad \text{so} \quad P = \frac{\text{J}}{\text{s}}$$

These units together are called a watt (W)

$$\frac{\text{Joule}}{\text{sec}} = \text{W}$$

The watt is a derived unit:

$$1 \text{ W} = 1 \frac{\text{J}}{\text{s}} = 1 \frac{\text{N} \cdot \text{m}}{\text{s}} = 1 \frac{\text{kg} \cdot \text{m}^2}{\text{s}^3}$$

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## Power Problem Example:

It takes 100 J of work to lift a bowling ball over your head. If this is done in 20s, what is the power output of your arms during this process?

$$W = 100 \text{ J} \quad t = 20 \text{ s} \quad P = ?$$

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

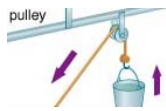
$$P = \frac{100 \text{ J}}{20 \text{ s}} = \frac{5 \text{ J}}{\text{s}} = 5 \text{ W}$$

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## Machines and Mechanical Advantage

Machines can give two types of advantage:

- They can change the direction of an input force
- They can multiply the input force.



Changing Direction



Multiplying Force

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## How Force Multiplication Happens

Machines can change an input force by changing the distance the force is applied

Increasing the distance the input force is applied will increase the output force



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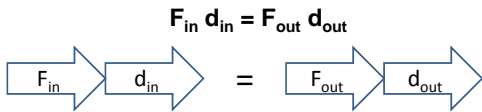
## How Force Multiplication Happens

Work that goes into a system is equal to the work that comes out when there is no friction.

**work in = work out**

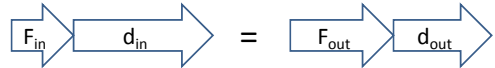
Since  $W = F \cdot d$  (Work = force  $\times$  distance) :

force in  $\times$  distance in = force out  $\times$  distance out

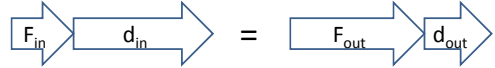


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- Using a larger input distance with a smaller input force can do the same work output.



- If you reduce the output distance then your output force will increase.



- This means we can have a small input force create a large output force.

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## Force Multiplication Example:

A 225 N force is needed to lift a box 1 m high. How much force is needed if a 3 m ramp is used?

$$F_{in} = 225 \text{ N} \quad F_{out} = ?$$

$$d_{in} = 1 \text{ m} \quad d_{out} = 3 \text{ m}$$

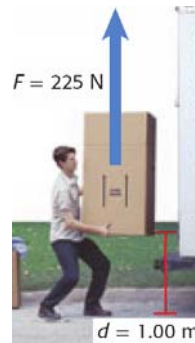
$$F_{in} d_{in} = F_{out} d_{out} = W$$

$$(225 \text{ N})(1 \text{ m}) = F_{out} (3 \text{ m}) = 225 \text{ N}\cdot\text{m or J}$$

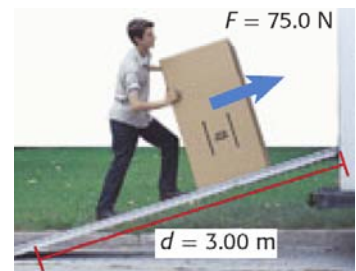
$$F_{out} = \frac{225 \text{ N}\cdot\text{m}}{3 \text{ m}} = 75 \text{ N}$$

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## Mechanical Advantage in Action



Using a 3 m ramp made the job three times easier!



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## Mechanical Advantage

Mechanical Advantage (MA) is a quantity that measures how much a machine multiplies the force or distance.

Formulas:

$$M.A. = \frac{F_{out}}{F_{in}} = \frac{d_{in}}{d_{out}}$$

There is no unit for M.A.!!

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## What the MA Values Mean

### If MA is greater than 1: Force advantage

The machine increases the force but requires you to move a larger distance.

Ex. A car jack helps by having a large MA

### If MA is less than 1: Distance advantage

The machine increases the distance and speed but reduces the force.

Ex. Your bicep muscle contracts a little to move your whole forearm

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## Mechanical Advantage Examples

What is mechanical advantage of using a ramp that is 10m long and 2m high?

$$d_{in} = 10m$$
$$d_{out} = 2m$$

$$MA = \frac{d_{in}}{d_{out}} = \frac{10m}{2m} = 5$$

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## Mechanical Advantage Examples

If you push down on a car jack with 2N of force and lift a car that is 1000N in weight, what is the mechanical advantage?

$$F_{in} = 2N$$
$$F_{out} = 1000N$$

$$MA = \frac{F_{out}}{F_{in}} = \frac{1000N}{2N} = 500$$

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## Mechanical Efficiency

Friction and other energy losses will cause machines to have less than the expected output

$$e = \frac{W_{out}}{W_{in}} \times 100\%$$

This is a percentage, so multiply by 100%

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## Mechanical Efficiency Example

A pulley is used to lift a rock to perform 1000 J of work. The amount of energy used to perform the work was 1200 J.

$$W_{out} = 1000 \text{ J}$$
$$W_{in} = 1200 \text{ J}$$
$$e = \frac{W_{out}}{W_{in}} \times 100\%$$

$$\frac{1000J}{1200J} \times 100\% = 83.3\%$$

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### Simple Machines

Six simple machines are divided into two families:

#### Lever family:



#### Inclined plane family:



### 3 Classes of Simple Levers

All levers use a fulcrum. This is a pivot point.

A **first-class lever** has a fulcrum located between the points of application of the input and output forces.

In a **second-class lever**, the fulcrum is at one end of the arm, and the input force is applied to the other end. The wheel of a wheelbarrow is a fulcrum.

**Third-class levers** multiply distance rather than force. As a result, they have a mechanical advantage of less than one. The human body contains many third-class levers.

### Pulleys

The pulley itself acts as a fulcrum  
 More turns of rope = More mechanical advantage

**The Mechanical Advantage of Pulleys**

<p>When a 150 N weight is lifted by using a single, fixed pulley, the weight must be fully supported by the rope on each side of the pulley. This kind of pulley has a mechanical advantage of one.</p>	<p>When a moving pulley is used, the load is shared by two sections of rope pulling upward. The input force supports only half of the weight. This pulley system has a mechanical advantage of two.</p>	<p>In this arrangement of multiple pulleys, all of the sections of rope are pulling up against the downward force of the weight. This arrangement gives an even higher mechanical advantage of two.</p>

### Wheel and Axle

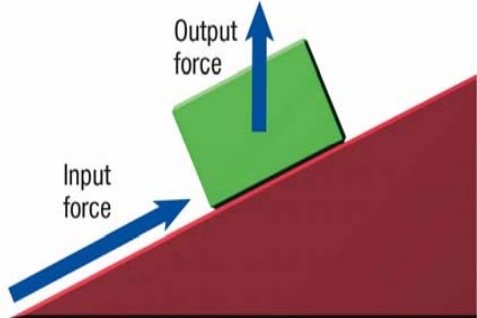
The center of the steering is the axle. The very center acts as the fulcrum

Larger Wheel = More mechanical advantage

### Inclined Plane (Ramp)

This reduces the force needed to lift an object by sharing it over a longer distance.

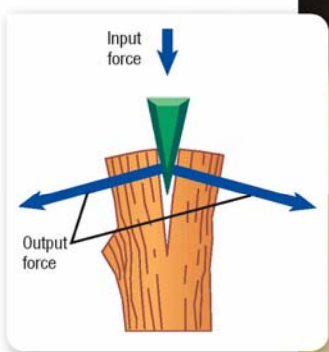
Longer Ramp = More mechanical advantage



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### Wedge

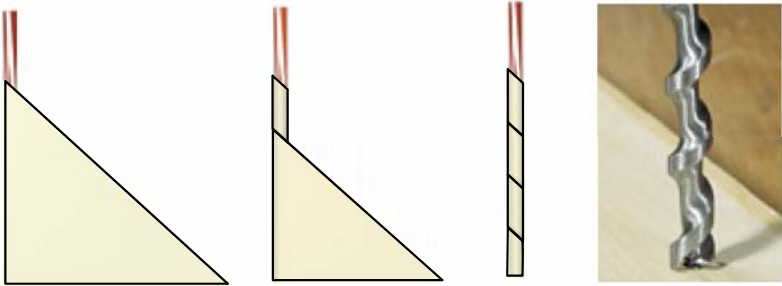
This is an incline plane that pushes into an object  
Thinner Wedge = More mechanical advantage



### Screw

This is an incline plane that is wrapped around a cylinder. The distance is spread out over each turn.

More turns = More mechanical advantage



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### Compound Machines

**Compound Machine:** a machine made of more than one simple machine



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