Machines and Mechanical Advantage

Machines can give two types of advantage:

a. They can change the direction of an input force

b. They can multiply the input force.

Changing Direction

Multiplying Force

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

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 · d (Work = force × distance) :

force in × distance in = force out × distance out

$$\mathbf{F_{in}\, d_{in} = F_{out}\, d_{out}}$$

F_{in} d_{in} = F_{out} d_{out}

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

F_{in} d_{in} = F_{out} d_{out}

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

F_{in} d_{in} = F_{out} d_{out}

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

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?

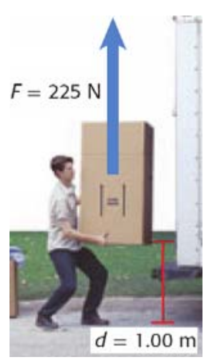
F_{in} = 225 N　　F_{out} = ?
d_{in} = 1 m　　d_{out} = 3 m

$$\mathbf{F_{in}\, d_{in} = F_{out}\, d_{out} = W}$$

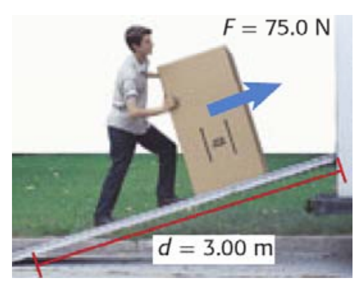
$(225\text{ N})(1\text{ m}) = F_{out}(3\text{ m}) = 225\text{ N·m or J}$

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

Mechanical Advantage in Action



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



Mechanical Advantage

a. Mechanical Advantage (MA) = how much a machine multiplies the force.

b. Ideal Mechanical Advantage (IMA) = perfect MA based on the ratio of d_{in} to d_{out}.

$$MA = \frac{F_{out}}{F_{in}} \qquad IMA = \frac{d_{in}}{d_{out}}$$

There is no unit for MA or IMA!!

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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

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

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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

$$e = \frac{W_{out}}{W_{in}} = \frac{MA}{IMA}$$

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 N
W_{in} = 1200 N

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

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

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Compound Machines

- **Compound Machine:** a machine made of more than one simple machine. The MA and IMA becomes the product of all of the combined machines.

- A pair of scissors uses two first-class levers joined at a common fulcrum; each lever arm has a wedge that cuts into the paper.

$$MA = MA_1 \times MA_2 \times MA...$$

$$IMA = IMA_1 \times IMA_2 \times IMA...$$

Simple Machines

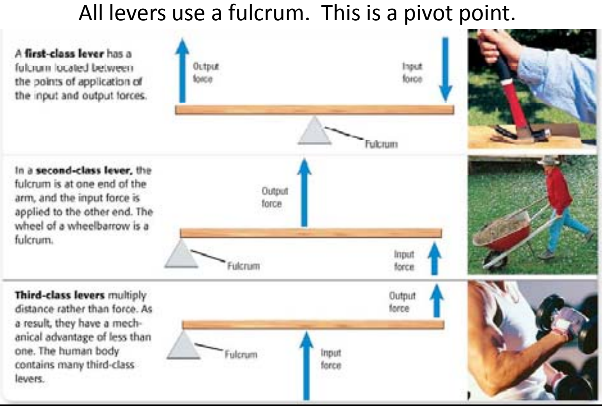
Six simple machines are divided into two families:

Lever family:

Inclined plane family:

3 Classes of Simple Levers

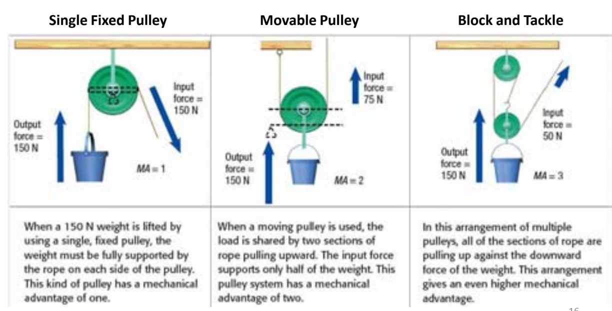
All levers use a fulcrum. This is a pivot point.



Pulleys

The pulley itself acts as a fulcrum

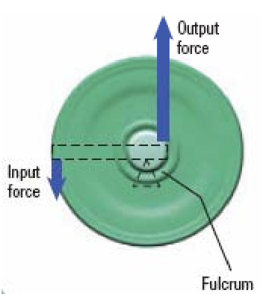
IMA = number of ropes pulling upward



Wheel and Axle

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

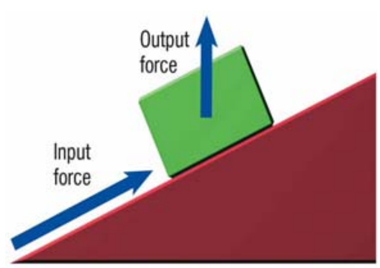
$IMA = r_i / r_o$



Inclined Plane (Ramp)

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

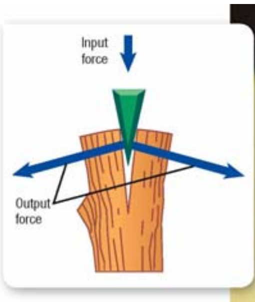
Longer Ramp = More mechanical advantage



Wedge

This is an incline plane that pushes into an object

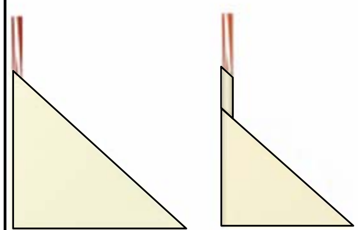
Thinner Wedge = More mechanical advantage



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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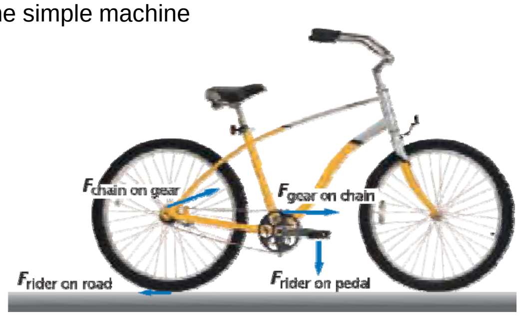
Compound Machines

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



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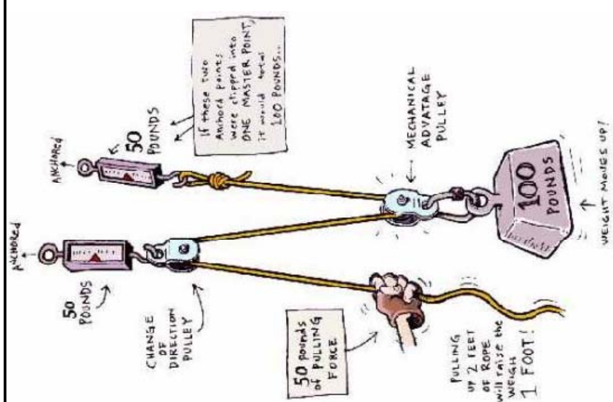

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