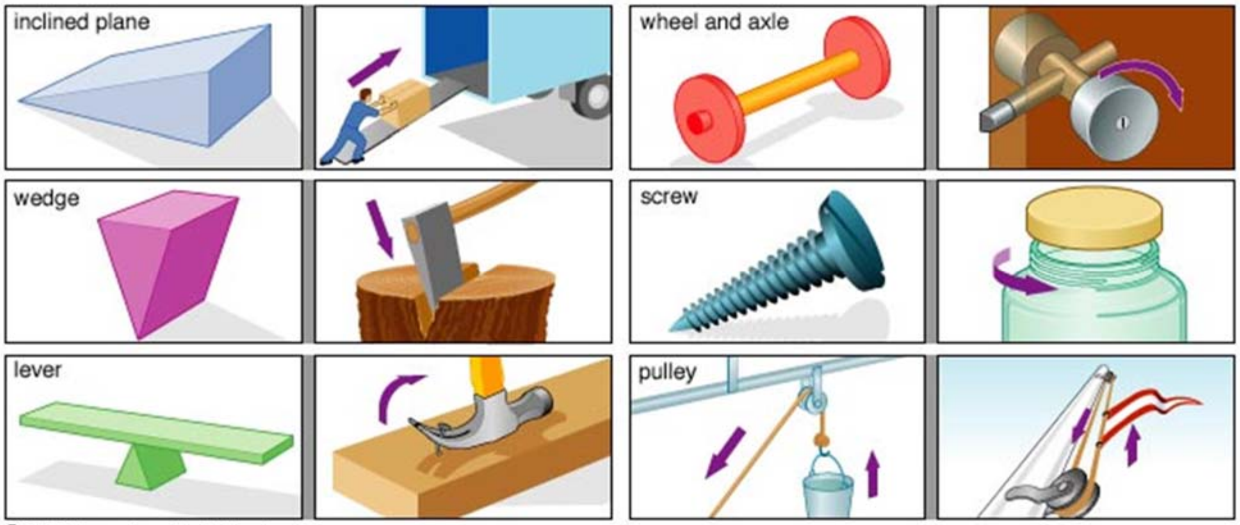
Simple Machines

Simple machines are tools employed in most machines we see around us. There are six of these devices.



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- The two purposes of a simple machine are to:
  1. Redirect force, so that it acts in a more useful direction.
  2. Mechanical advantage: to amplify a force.

- Energy is <u>not stored</u> in a simple machine, so at each moment the energy in the system is constant.

$$W_{in} = W_{out}$$

- The work put into the machine is equal to the work that the machine does. $W = \vec{F} \times d$, therefore:

$$\vec{F}_{in} \times d_{in} = \vec{F}_{out} \times d_{out}$$

<u>Mechanical Advantage</u>

Simple machines allow you to multiply a force.

- **The ratio of the force out of the machine divided by the force into the machine is called its <u>mechanical advantage</u>.**

- This formula explains how a simple machine can magnify force, and the relationship between mechanical advantage and the distances traveled on the input and output sides of the machine.

$$MA = \frac{\vec{F}_{out}}{\vec{F}_{in}} = \frac{d_{in}}{d_{out}}$$ where MA is mechanical advantage, $\vec{F}$ is force and d is distance.

- <u>Ex.</u> 1

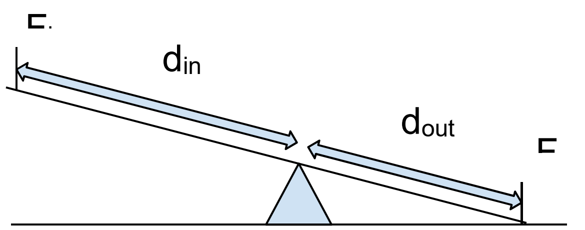
  An ideal simple machine has a mechanical advantage of 4.0. If the input force is $+8.0\ N$, what is the output force?

- Ex. 2
  An ideal simple machine has a mechanical advantage of 4.0. If the distance traveled on the input side is $1.0\ m$, what is the distance traveled on the output side?

- Ex. 3
  An ideal simple machine has a mechanical advantage of 4.0. If $24\ J$ of energy is put into the machine, what would be its energy output?

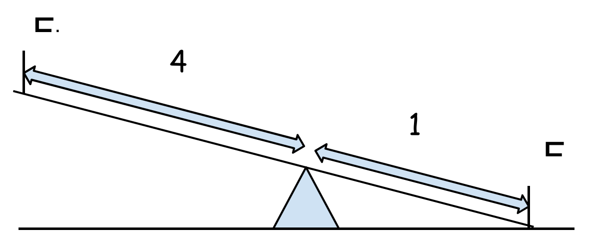
The Lever

- In general, the force provided by a lever will be $\times$ *times* the force supplied to the lever where $\times$ is the ratio of the lengths on either side of the fulcrum. The input force is call the "effort" force and the output is called the "load" force.



$$MA = \frac{\vec{F}_{out}}{\vec{F}_{in}} = \frac{d_{in}}{d_{out}}$$

- Ex. 1
  A $16\ N$ effort force is applied to this lever, what output force is generated?



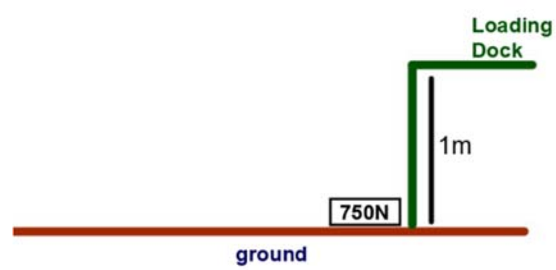
- Ex. 2
  A lever is $1.0\ m$ long, with $0.60\ m$ on the effort side of the fulcrum. About how much effort force would need to be exerted to lift a $120\ N$ weight using this lever?

- <u>Ex.</u> 3
  A lever is $6.0\ m$ long and has a mechanical advantage of 2. How long is the load side of the lever?

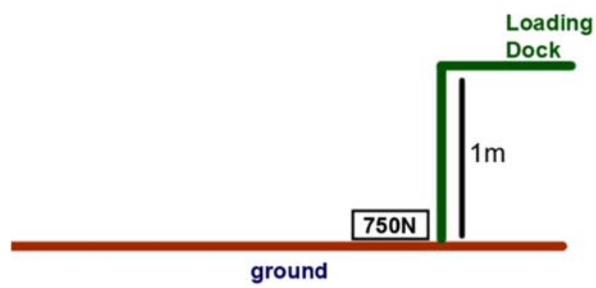
- <u>Ex.</u> 4
  A lever has a mechanical advantage of 5.0. The work done to the effort side of the lever is $45\ J$. How much work is done on the load side of the lever?

<u>Inclined Plane</u>

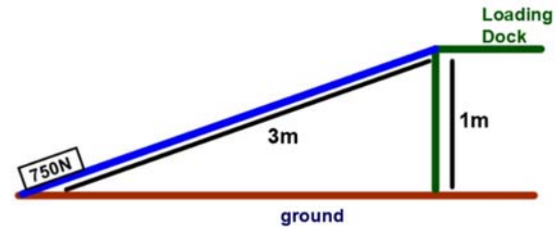
- Let's say you have a $750\ N$ box you need to lift from the ground onto a loading dock which is $1.0\ m$ above the ground. How much force would be required to lift the $750\ N$ box straight up and onto the dock? And how much work is done lifting the box up onto the loading dock?



- Let’s say you could only supply a force of $+250\ N$, how could you move this $750\ N$ box onto the loading dock by yourself?



- What is the distance the box will travel to get onto the loading dock using the inclined plane? And how much work is done by the $250\ N$ force in sliding the box up and onto the loading dock using this frictionless inclined plane?



$$MA_{ramp} = \frac{length}{height}$$

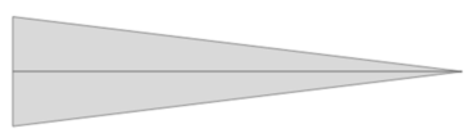
- Ex. 1
  An ideal inclined plane is $2.4\ m$ long and goes from the ground to a loading dock which is $0.50\ m$ above the ground. How much force would be needed to push a $20.\ N$ mass up the ramp?

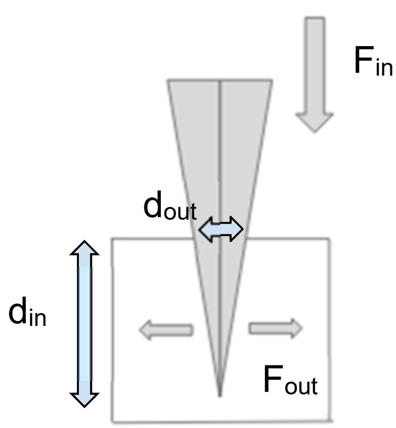
- Ex. 2
  The maximum force supplied by an electric wheelchair is $200.\ N$. What minimum ramp length would enable it to carry a combined mass of $1000.\ N$ (passenger plus chair) up a height of $0.20\ m$?

- Ex. 3
  The maximum force supplied by an electric wheelchair is $+200.\ N$. What mechanical advantage would enable it to carry a combined mass of $1000.\ N$ (passenger plus chair) up a height of $0.20\ m$?

The Wedge

- The wedge is a moveable inclined plane. In some cases a wedge acts like a single inclined plane and in others it acts like two back to back inclined planes.





- Let's call $\vec{F}_{in}$ the force that drives the wedge into the log and $\vec{F}_{out}$ the sideways force that splits the log.

- Ex. 1
  A wedge is $8.0\ cm$ long and $1.0\ cm$ wide. What is its mechanical advantage?

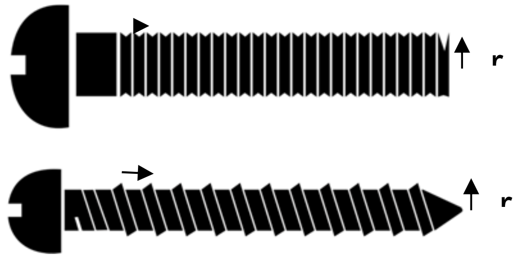
- Ex. 2
  A force of $1000.\ N$ is exerted on a wedge which is $8.0\ cm$ long and $1.0\ cm$ wide. What is the resulting splitting force on the log?

- Ex. 3
  A door stop is $10.\ cm$ long and $2.0\ cm$ high. What is its mechanical advantage?

- Ex. 4
  A door stop is $10.\ cm$ long and $2.0\ cm$ high. What upward force does it exert on a door, if the door is pushed against it with a force of $200.\ N$?

The Screw

- The screw is an inclined plane wrapped around a cylinder. Every full turn of the screw results in the outside edge of its threads moving a distance l given by $2\pi r$.



$$MA = \frac{\vec{F}_{out}}{\vec{F}_{in}} = \frac{2\pi r}{l}$$

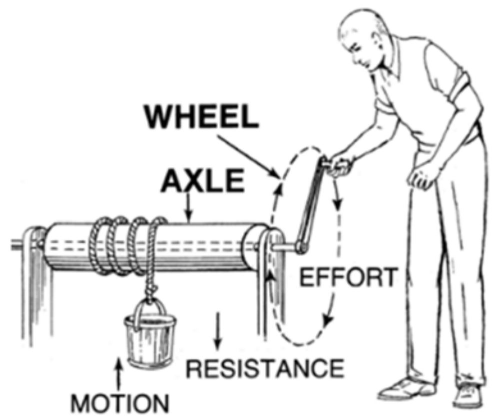
- Ex. 1

The threads of a screw are $0.25\ mm$ apart and have a circumference of $1.25\ mm$. If the turning force of the screw is $+20.\ N$, what is the force driving the screw into the wood?

Wheel and Axle

- You should see that the man's hand travels a distance of $2\pi r_w$ while the rope is pulled up a distance $2\pi r_A$.

$$F_{out} = F_{in}\frac{d_{in}}{d_{out}}$$
$$F_{out} = F_{in}\frac{2\pi r_w}{2\pi r_A}$$
$$F_{out} = F_{in}\frac{r_w}{r_A}$$
$$MA = \frac{r_w}{r_A} = \frac{r_{in}}{r_{out}}$$



- Ex. 1

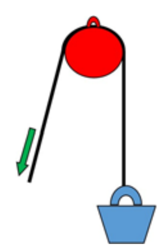
  A screwdriver with a mechanical advantage of 12 is used to drive a screw into a piece of wood. The MA for the screw is 9.0. What is the total MA?

- Ex. 2

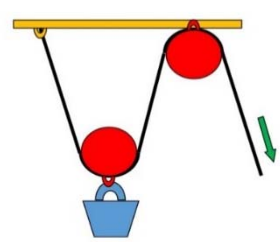
  A screwdriver with a mechanical advantage of 12 is used to drive a screw into a piece of wood. The MA for the screw is 9.0. If $+20.\ N$ of force is turning the screwdriver, what is the force pushing the screw into the wood.

The Pulley

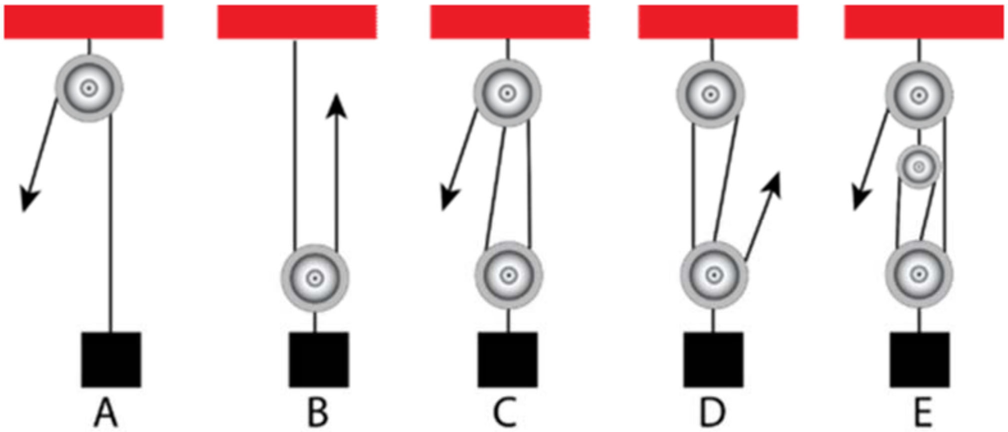
- A simple pulley has no mechanical advantage. The distance traveled on the input and output side is the same, so the $MA = 1.0$.



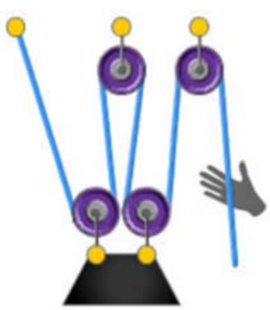
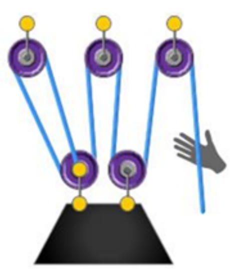
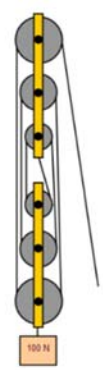
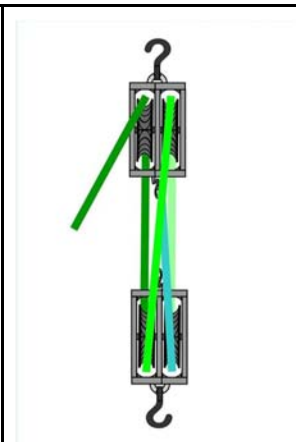
- However, two pulleys arranged like this do have a mechanical advantage. If the distance the bucket moves up is half the distance that the rope is pulled down, what is the mechanical advantage of the system?



- The MA of a pulley system can be found by counting the number of supporting strands on moveable pulleys. In example A the effort strand (rope with the arrow) is not supporting any mass therefore system A has a $MA\ of\ 1.0$.
- In example B, the effort strand is supporting half of the weight therefore system B has a $MA\ of\ 2.0$.



- Ex. 1
  What is the mechanical advantage of the following systems?

- Ex. 5
  If you need to lift a mass that weighs $1000.N$, but can only supply a force of $220.N$, how many pulleys will you need?

Efficiency

- Ex. 1
  $50.J$ of energy is put into a simple machine which does $40.J$ of work. What is its efficiency?

- Ex. 2

  A force of $+20.\,N$ is used to push a $100.\,N$ mass up a $2.0\ m$ long ramp. The mass is raised $0.20\ m$ in the process. What is the efficiency of the ramp?

- Ex. 3

  A force of $+250.\,N$ is used to pull a $20.\,m$ length of rope through a pulley system. In so doing a $1500.\,N$ mass is raised $2.0\ m$. What is the efficiency of the pulley system?

Mechanical Advantage Summary Table

Lever	**Inclined Plane**
$MA = \dfrac{length\ to\ effort\ (LE)}{length\ to\ load\ (LR)}$	$MA = \dfrac{length\ of\ plane\ (L)}{height\ of\ plane\ (H)}$
Wheel and Axle	**Pulley**
$MA = \dfrac{radius\ of\ effort\ (LE)}{radius\ of\ load\ (LR)}$	$MA = number\ of\ ropes\ that\ support\ a\ moveable\ pulley$
Wedge	**Screw**
$MA = \dfrac{length\ of\ slope\ (L)}{thickness\ of\ wedge\ (H)}$	$MA = \dfrac{circumference\ (C)}{pitch\ (p)}$