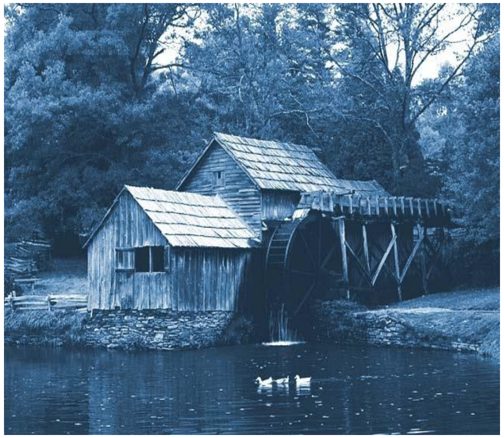
Arizona Science Lab:

WORKING WITH WATERWHEELS



Harnessing the Energy of Water

Institute Of Electrical And Electronic Engineers, Phoenix Section

Teacher In Service Program / Engineers In The Classroom (TISP/EIC)

"Helping Students Transfer What Is Learned In The Classroom To The World Beyond"

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Information Sources

- For more information on renewable energy, waterwheels, simple machines, and related topics:
  - www.Wikipedia.com
  - *www.mi**kids**.com/S**machines**.htm*
  - www.waterhistory.org
  - www.youtube.com

Norias of Hama, Syria
Orontes river ~ 400AD

The Science and Engineering of Waterwheels & Watermills

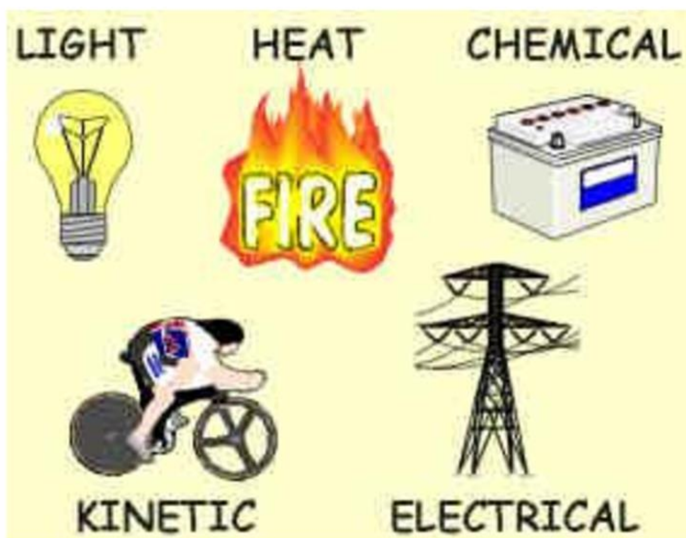
- History – Watermills date back to 400 AD!
- Energy – Rivers: Kinetic and Potential Energy
- Simple Machines – The Power of Leverage
- Build a Waterwheel!
- Today: Capturing the River – Hydroelectric Power

ENERGY
What is it?

Energy is the ability to do work.

Can you name some common forms of energy?

TYPES OF ENERGY



What is Energy?

Energy is the ability to do <u>work</u>

The food we eat contains energy. We use that energy to work and play.

Energy can be found in many forms:

- Chemical energy
- Electrical energy
- Thermal (heat) energy

Mechanical Energy

Mechanical Energy has two forms:

Potential Energy (P.E.) – Stored Energy
Energy of Position

(gravitational)

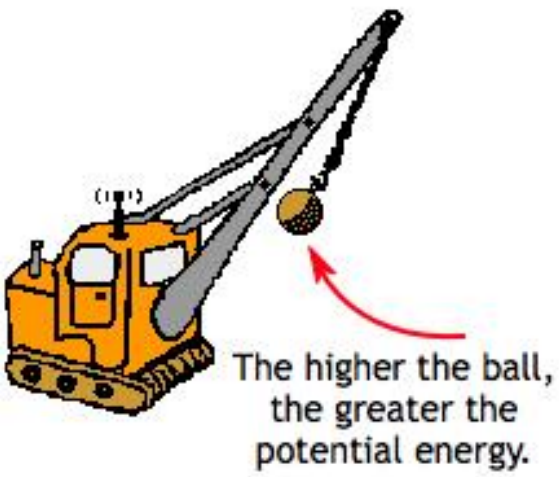
Kinetic Energy (K.E.) – The Energy of Motion

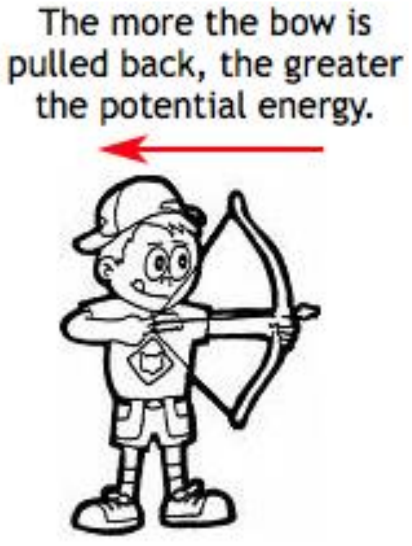
(motion of waves, electrons, atoms, molecules, and substances).

Potential Energy – P.E.

P.E. = mass • force of gravity • height

Unit of Energy - Joule

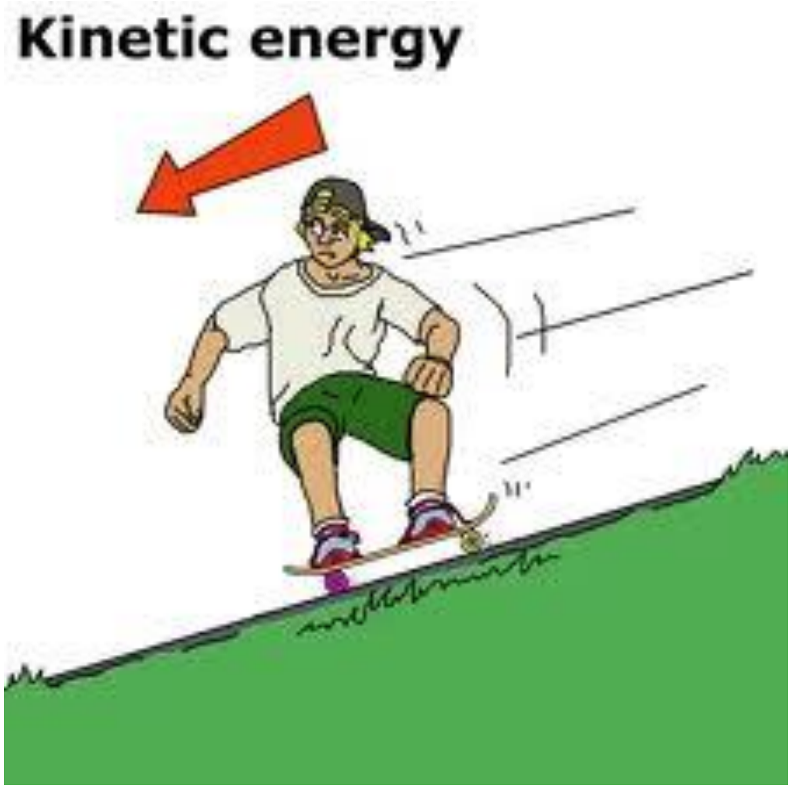




Kinetic Energy – K.E.

K.E. = ½ • mass • velocity^2

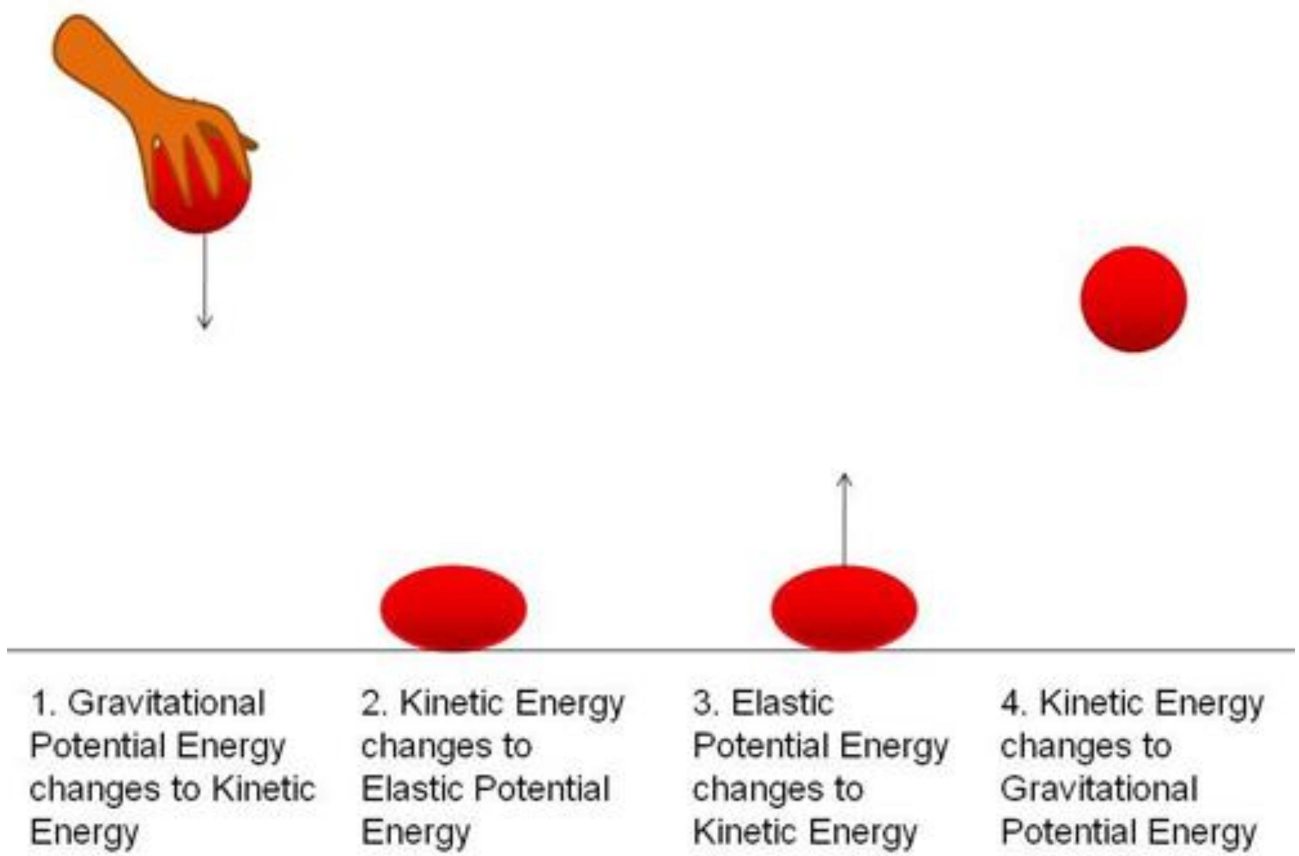
Unit of Energy - Joule

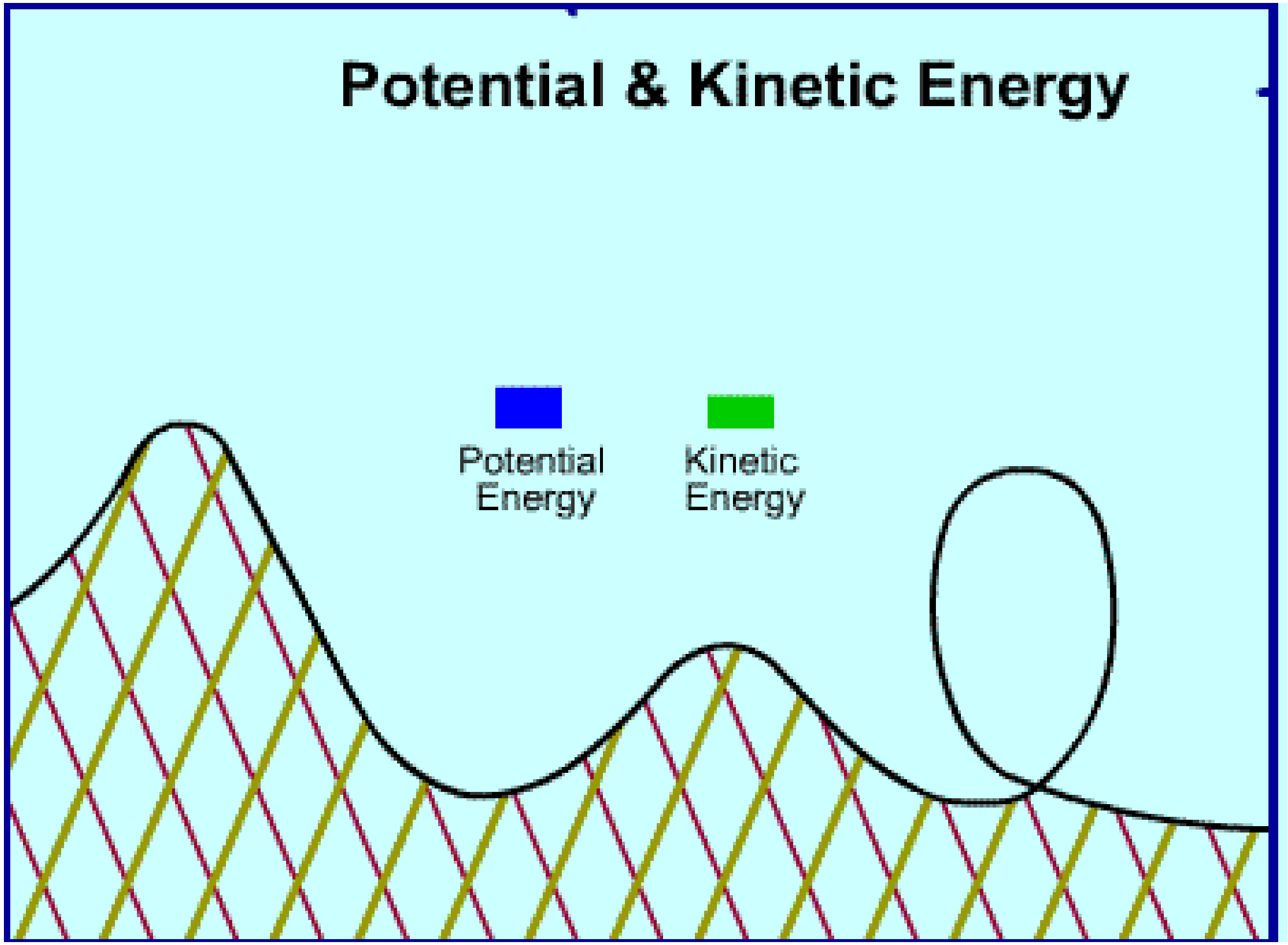


Energy Conversion

The Law of the Conservation of Energy

Energy can be <u>neither</u> created nor destroyed, but can change form.




Potential & Kinetic Energy
Potential Energy
Kinetic Energy

Does the lake contain Energy?

What is work?

What is work?

Work is a Force applied over a Distance

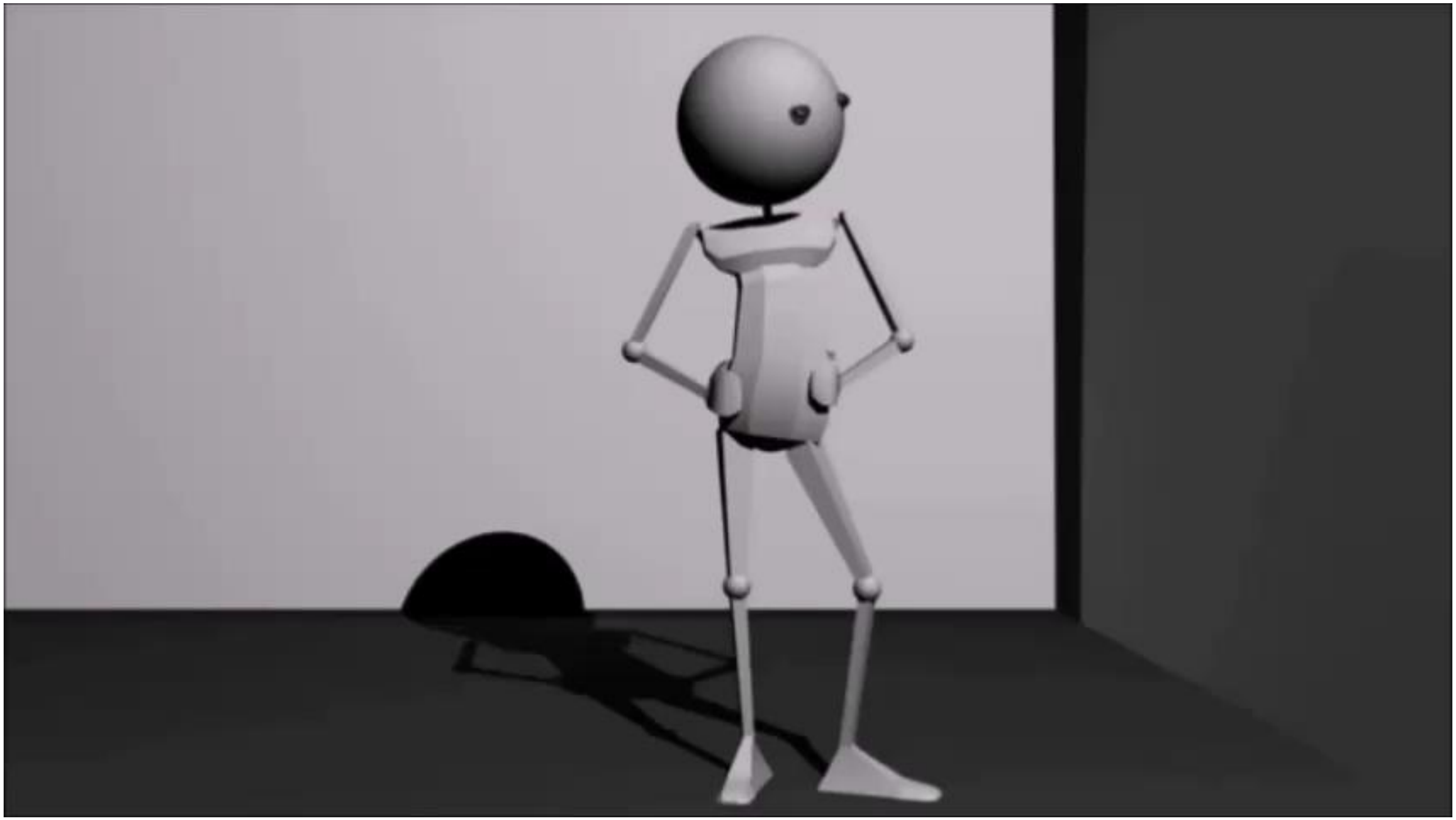
It takes energy to do work:

Work = Force * Distance

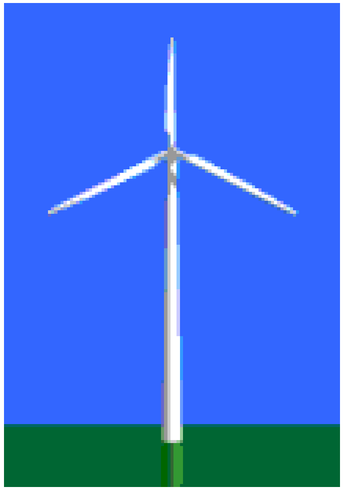
Work is moving something!

What is a Force?

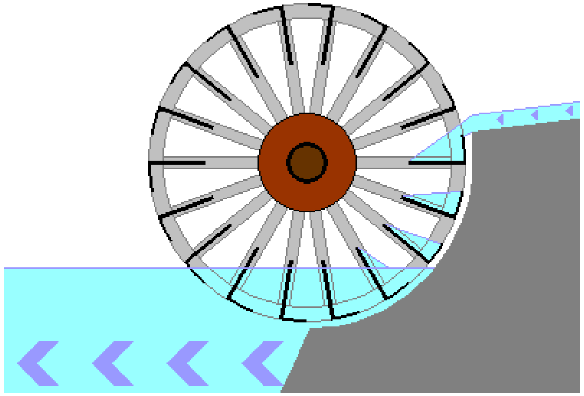
A **Force** is a push or a pull that changes the motion of an object.



Two Natural Forces



Windmill
A windmill has a wheel that rotates by the **force** of the wind.



Waterwheel
A waterwheel has a wheel that rotates by the **force** of the water.

How do Waterwheels work?

- Waterwheels capture the energy of the flowing water
- The water exerts a force on the buckets at the rim of the water wheel.
- The size of the force is multiplied at the axle.
- The axle force is converted and used to do work.

Watermills

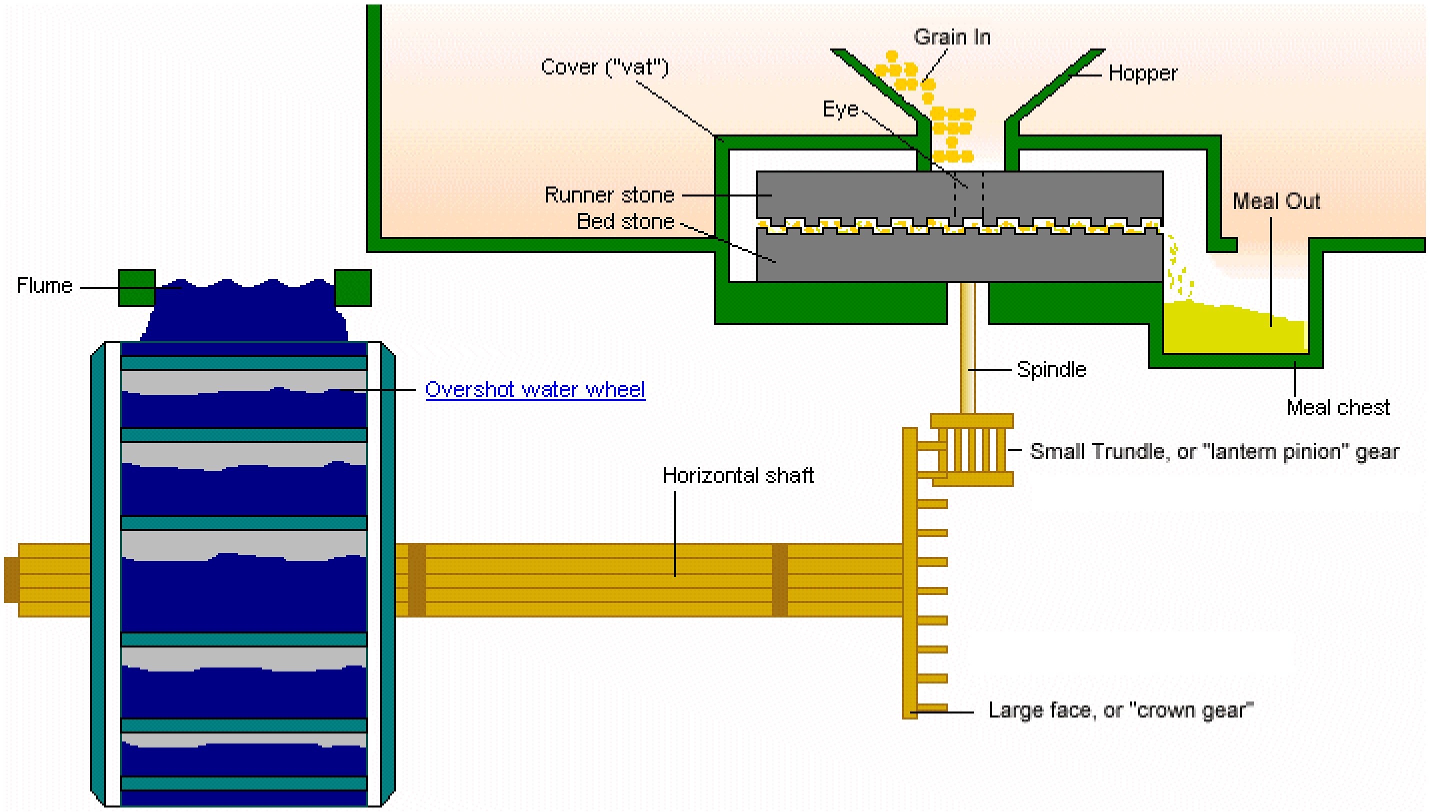
- A watermill uses a waterwheel, a wheel with blades or buckets around the outer edge, to capture the energy of the river.
- The rotary energy then drives a mechanical process:
- Many years ago that was: grinding flour or sawing lumber.

Watermills Were Used In Many Applications

- Gristmills, or *corn mills*, grind grains into flour. These were the most common kind of mill.
- Sawmills cut timber into lumber.
- Other devices operated by mechanical power.

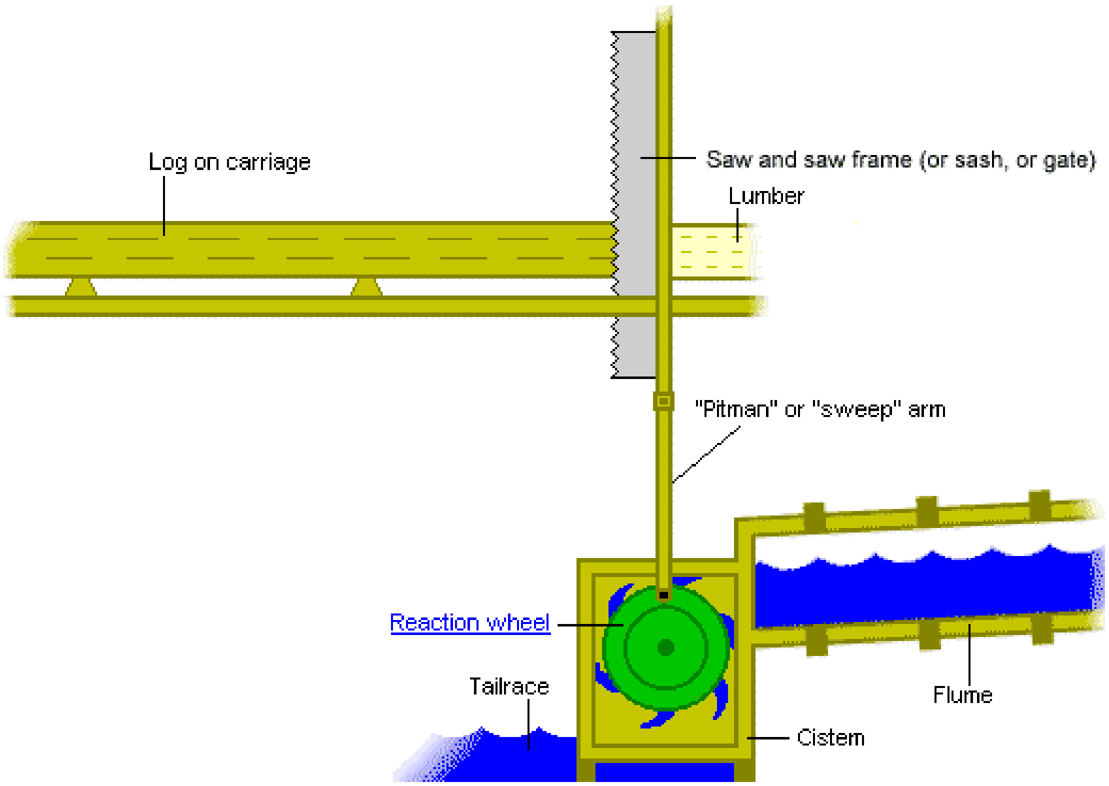
Gristmill (Or Corn Mill)

- A grist mill grinds grain into flour:



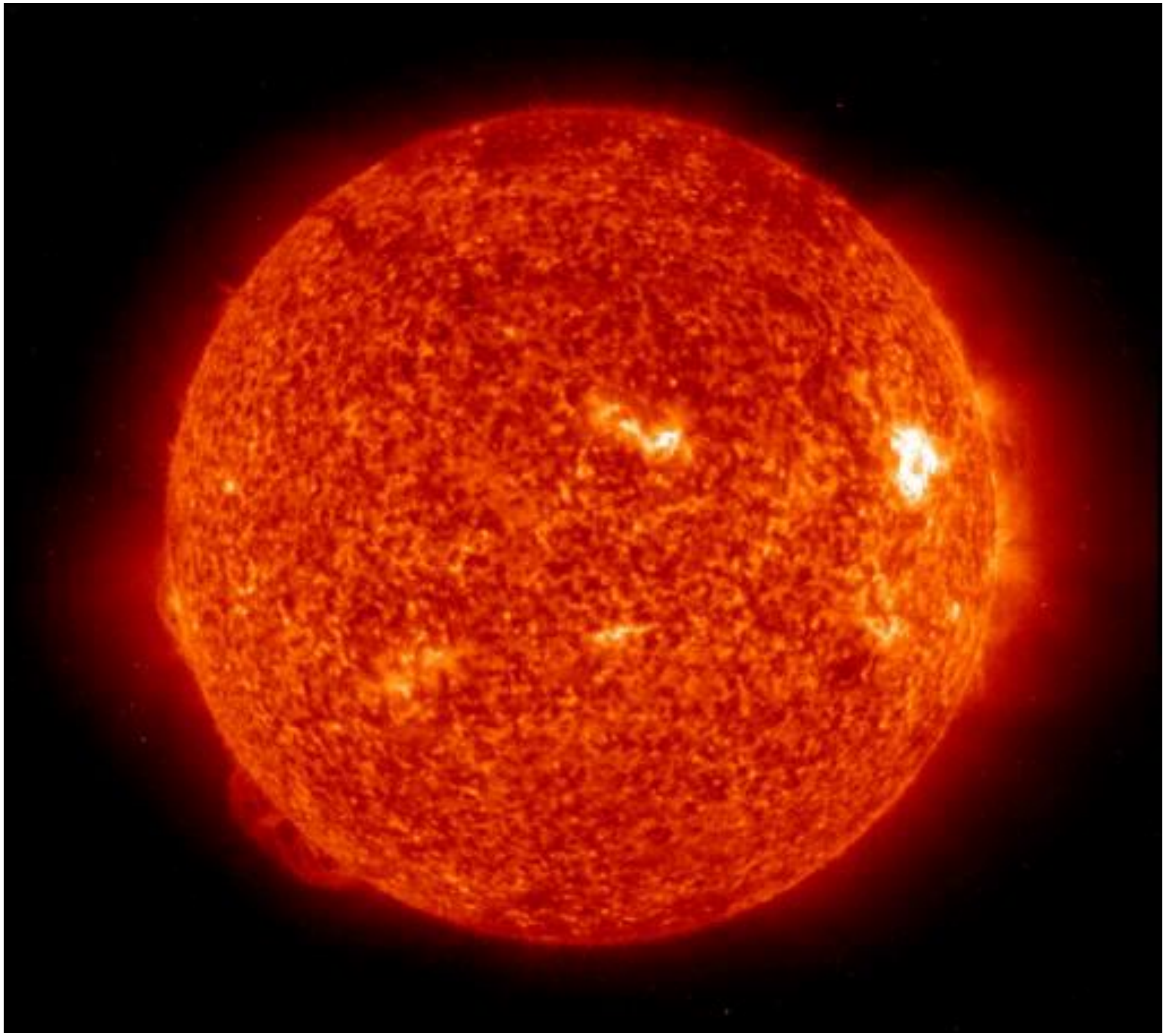
A Sawmill

- A sawmill cuts tree trunks into lumber:

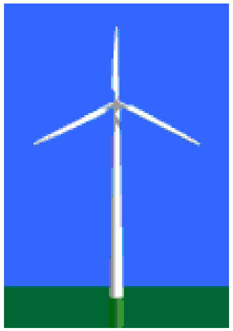


Waterwheel Driven Saw Mill

Renewable Energy



Renewable Energy Sources



River energy can be diverted, and Stored

- Wind energy can be used when available, but not always reliable.

y also can be used ble.

Hoover Dam:
Colorado River
Lake Mead

Water Flows Downhill

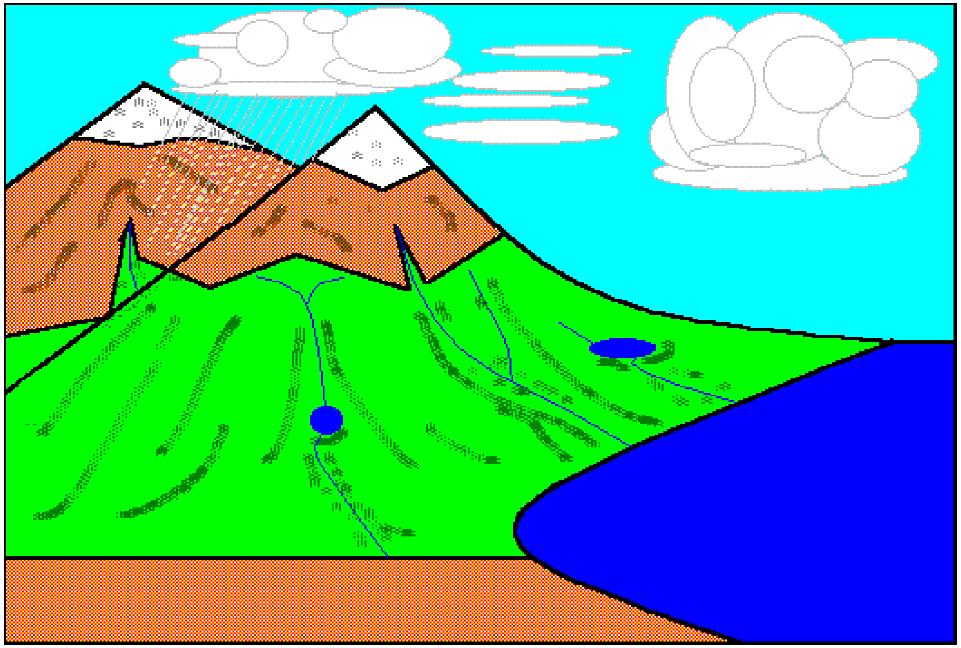
- Rivers start high in mountains and flow down to the oceans.
- Gravity pulls the water down so it flows.
- This flowing water has a lot of energy!

The Energy of Flowing Rivers

But –

How does the water get to the top of the mountains?

Hydrological or Water Cycle



This is Renewable Energy!

Energy from Water

- The flowing river: Kinetic Energy or energy of motion
- A high lake: Potential Energy or energy of position
- Water has potential energy due to its height (position).
- As gravity pulls the water down to a lower position the potential energy is converted into kinetic energy.
- So, water has both kinetic energy (flow) and potential energy (height).

Rivers, Energy, and Force

- Some rivers have mostly just kinetic energy – a slow flowing river.
- OR some rivers have both potential and kinetic energy – a lake and a waterfall.
- Waterwheels capture both forms of energy: potential (height) and kinetic (flow)

Characteristics Of Water Wheels

- A large diameter wheel.
- Buckets spaced around the edge.
- An axle that connects to whatever the wheel is driving.
- A water supply to turn the wheel.

What Have We Learned So Far?

- Waterwheels capture the energy of the river.
- Watermills transfer that energy to do work.
- Where does the energy come from?
- Energy can be potential or kinetic.

What Makes Waterwheels Work So Well?

- We take the energy of the flowing river and multiply it so we can do work.
- The force of the water is multiplied by the large size of the waterwheel.
- This is done using leverage.
- The waterwheel is a rotating lever:
  one of the simple machines!

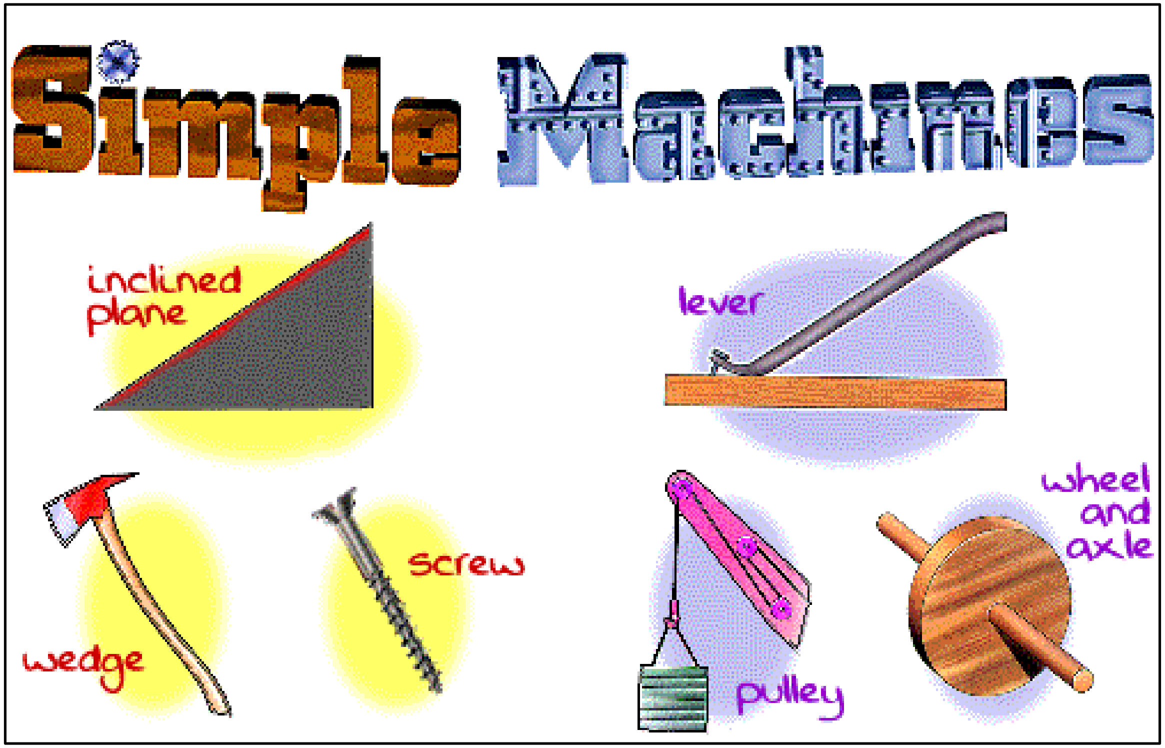
Simple Machines

- A simple machine is a mechanical device that changes the direction and/or magnitude of a force.
- They use mechanical advantage (also called leverage) to multiply force. Simple machines make work easier!
- The six classical simple machines:

Lever	Inclined plane
Wheel and axle	Wedge
Pulley	Screw

- **We are most interested in the lever and the wheel and axle machines for the watermill.**

The Six Simple Machines



Using these simple machines we apply a:

small force over a large distance

to get a:

large force over a small distance.

Some Everyday Examples of Simple Machines

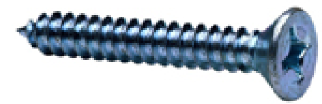
hammer

bottle opener

lid

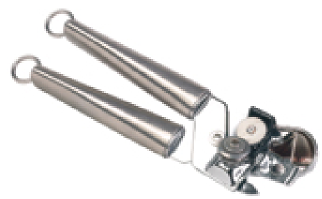
axe

wheel barrow

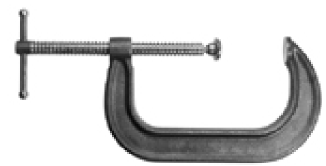


screw

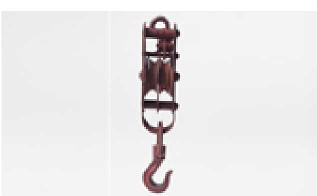
Loading ramp



can opener



clamp



pulley

knife

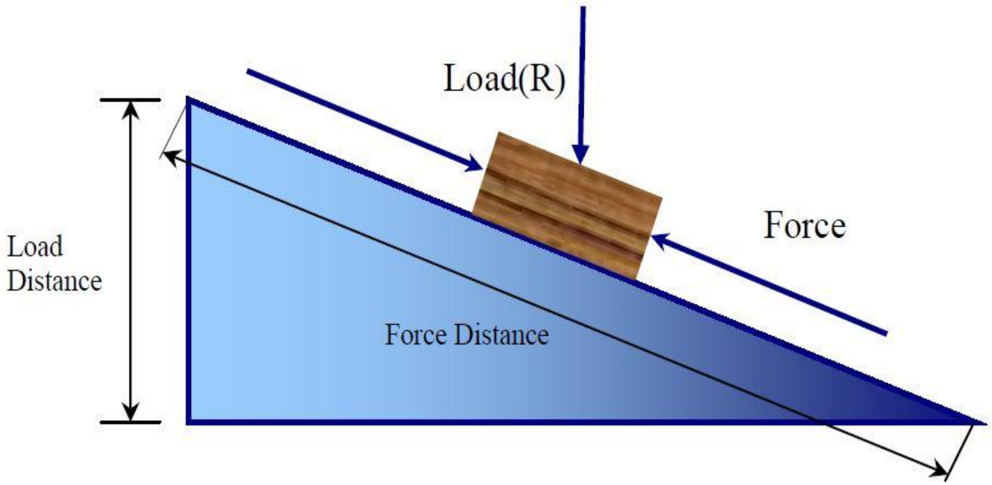
shopping cart

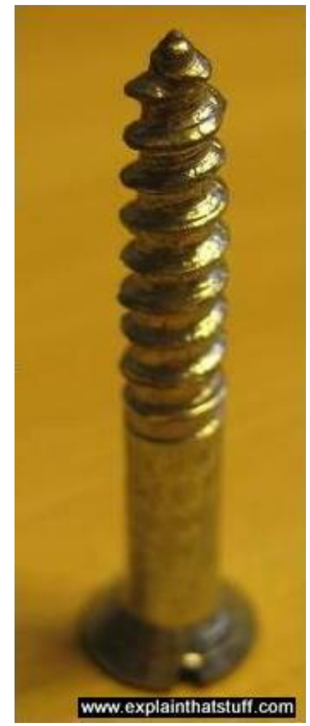
crowbar

scissors

wheel chair

Simple Machines





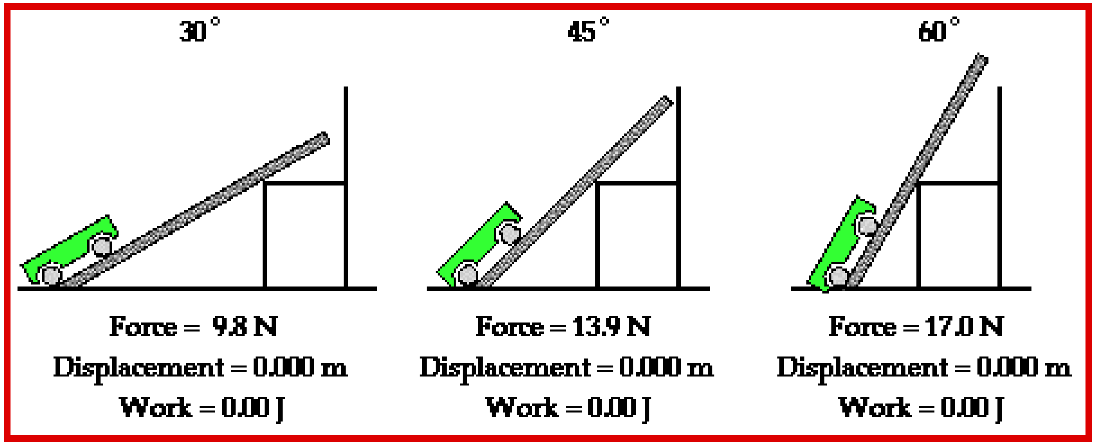
Inclined Plane:

Force distance = Ramp
Load Distance = Height
M.A. = L (ramp) / L (height)

Screw:
a circular inclined plane

How can we multiply Force?

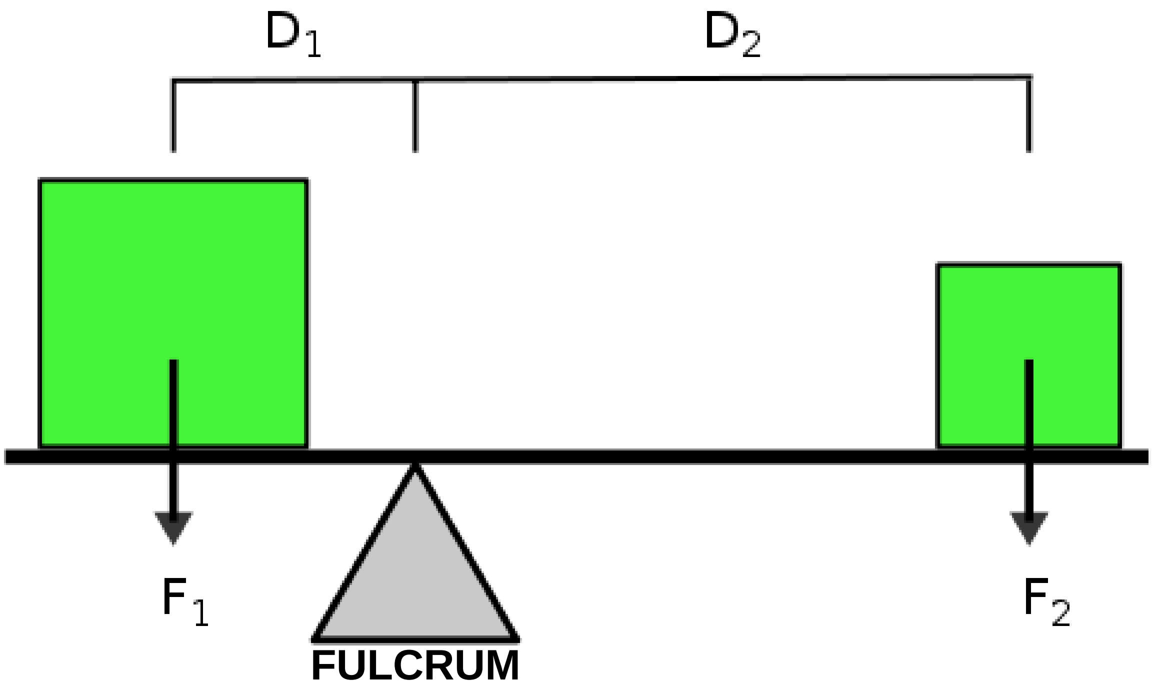
- **Work = Force * Distance**
- Simple machines change the distance over which the force is applied –



The Lever: A Simple Machine

- The lever is the oldest simple machine:
  - Ancient Egyptians used them to move the stone blocks for the pyramids
  - The original Native Americans used them to move rocks
  - The American pioneers used them to remove trees and rocks, lift logs onto cabin walls, and to jack up a wagon to change a broken wheel!

Law Of The Lever And Mechanical Advantage



Trade Force for Distance

Law Of The Lever And Mechanical Advantage

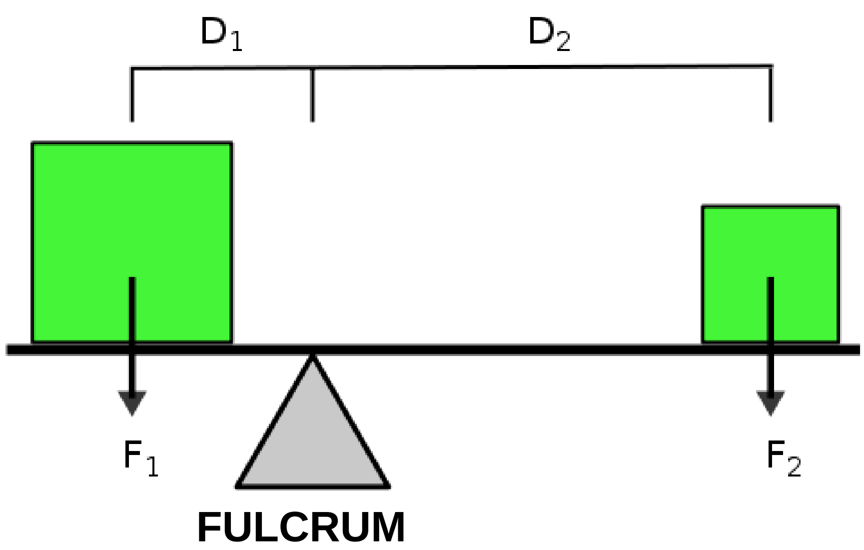
The Law of the Lever is:

Load arm X load force = effort arm X effort force

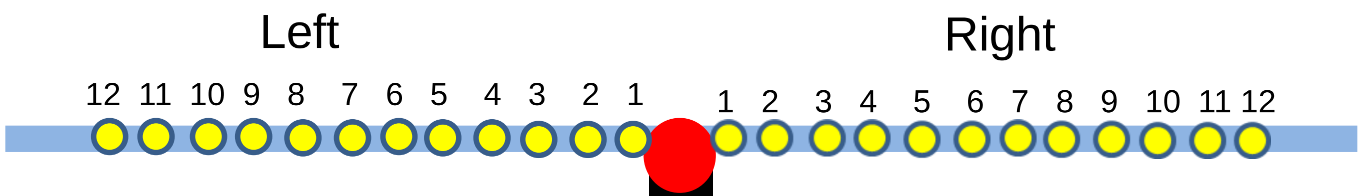
D1 x F1 = D2 x F2 = Work done!

The Mechanical Advantage (MA) of the lever is defined as:

Effort arm / Load arm = D2 / D1

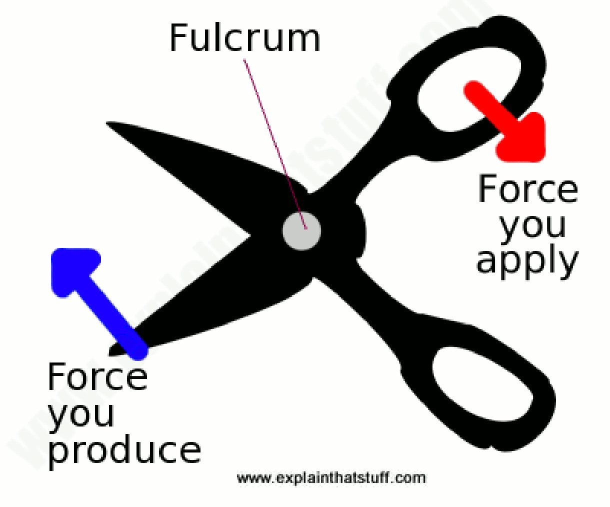


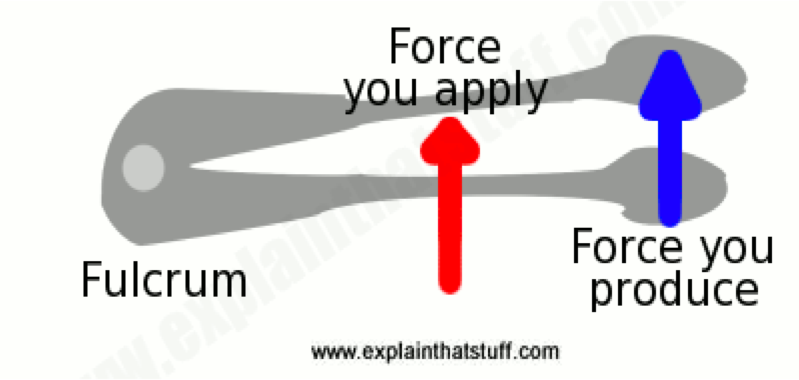
Balance and Leverage



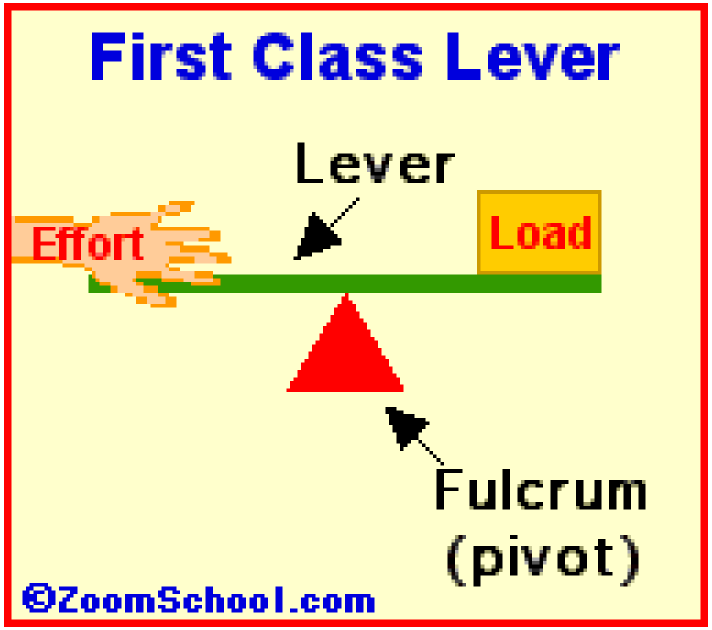
	Left	Right
Prob. 1.)	2 weights on 6	3 weights on ☐
Prob. 2.)	4 weights on 2	☐ weights on 8
Prob. 3.)	3 weights on 11	☐ weights on 3 + ☐ weights on ☐
Prob. 4.)	☐ weights on ☐	☐ weights on ☐ + ☐ weights on ☐

Examples of Levers



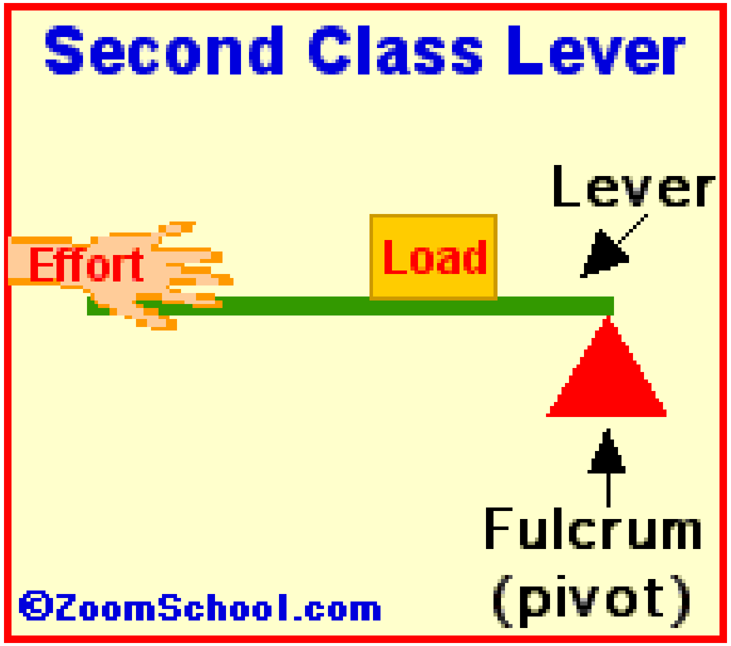


First Class Lever



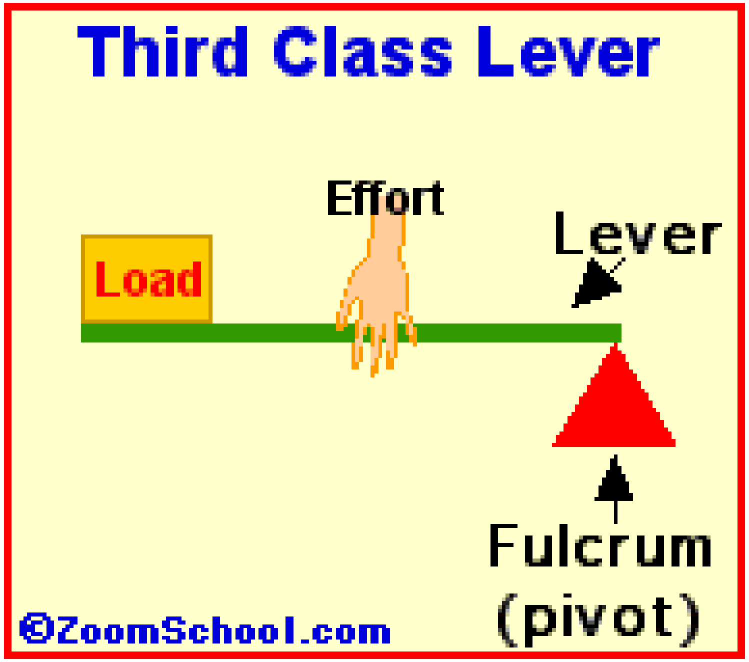
- The fulcrum is located between the effort force and the load force
- Use this type of lever to change the direction and size of a force
- Example of a First Class Lever:
  - A crowbar or pry bar pulling a nail
  - A tire iron removing a car tire

Second Class Lever



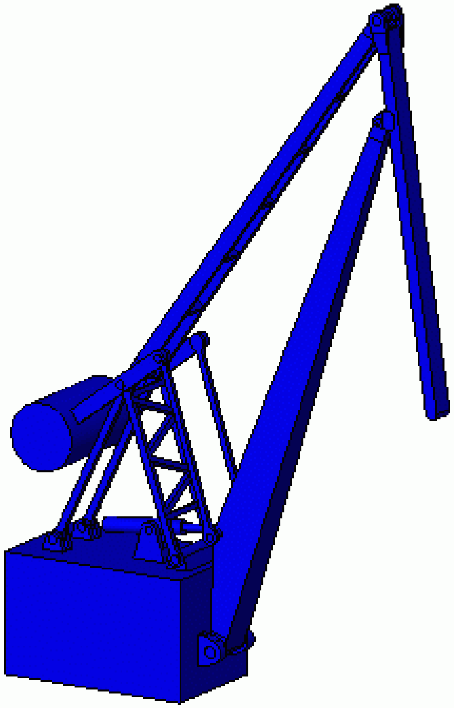
- The load force is located between the effort force and the fulcrum
- Use this type of lever if you need a greater load force in the same direction as the effort force
- Example of a Second Class Lever:
  - A wheel barrow

Third Class Lever



- The effort force is located between the load force and the fulcrum
- Use this type of lever to reduce the distance over which you apply the effort force or to increase the speed of the end of the lever
- Example of a Third Class Lever:
  - A hammer driving a nail
  - A baseball bat hitting the ball

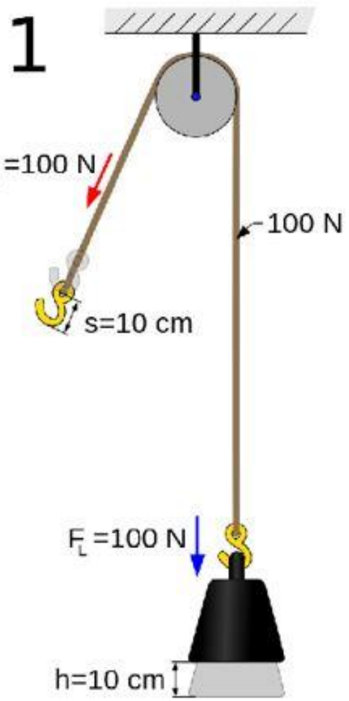
Double Crane



- Compound levers are used for more mechanical advantage
- How many levers in this crane?
- Examples of Compound Levers:
  - A bolt cutter is an example of a common tool that uses compound levers to increase the mechanical advantage

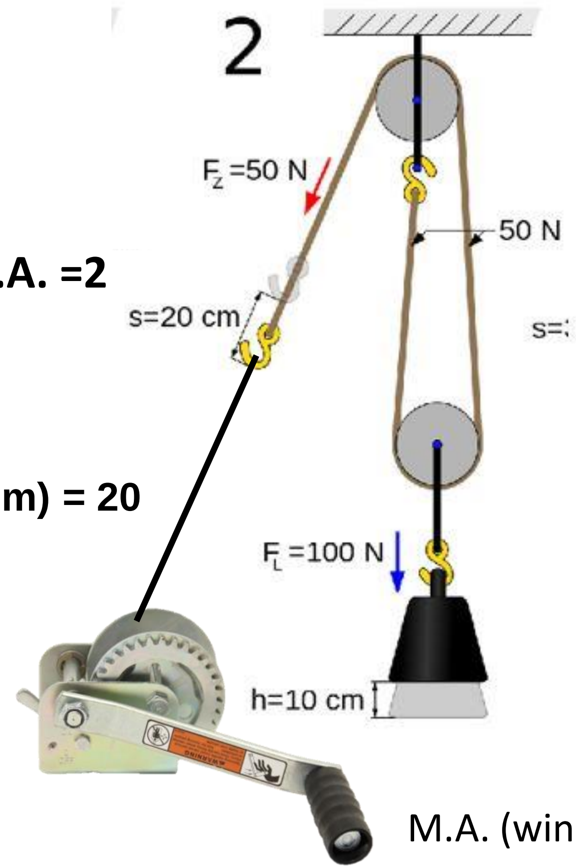
Mechanical Advantage of Pulleys and Winches

M.A. = 1



M.A. =2

M.A. (system) = 20



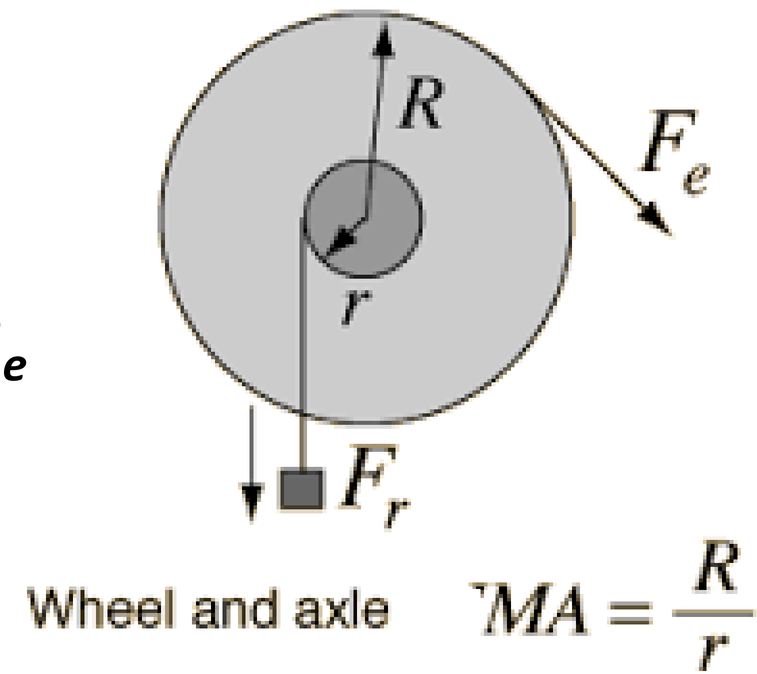
M.A. (winch) = 10

Wheel and Axle

- The wheel and axle is a simple machine—a rotating lever!
- The larger wheel (or outside) rotates around the smaller wheel (axle)
- Bicycle wheels, waterwheels, windmills and gears are all examples of a wheel and axle

F_e = Effort Force
F_r = Resistance Force
R = Radius of wheel
r = Radius of Axle
MA = Mechanical Advantage = F_r/F_e

$$F_e = Fr * \frac{r}{R}$$



The Water Wheel Is A "Wheel and Axle" Simple Machine

- R = Radius of wheel
- A = Radius of Axle
- The mechanical advantage is: R/A

Demonstration wheel:

R = 30 cms

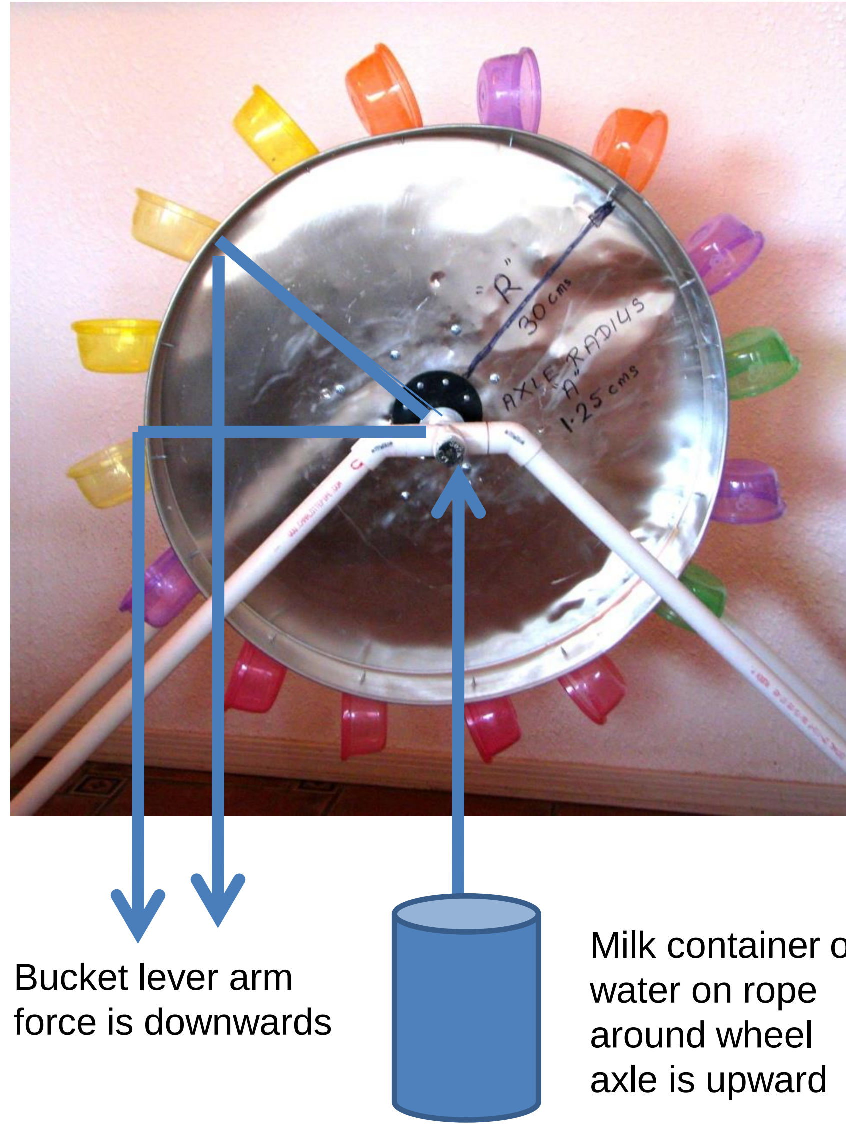
A = 1.25 cms

Mechanical Advantage =

30/1.25 = 24

The Water Wheel Is A "Continuous Lever"

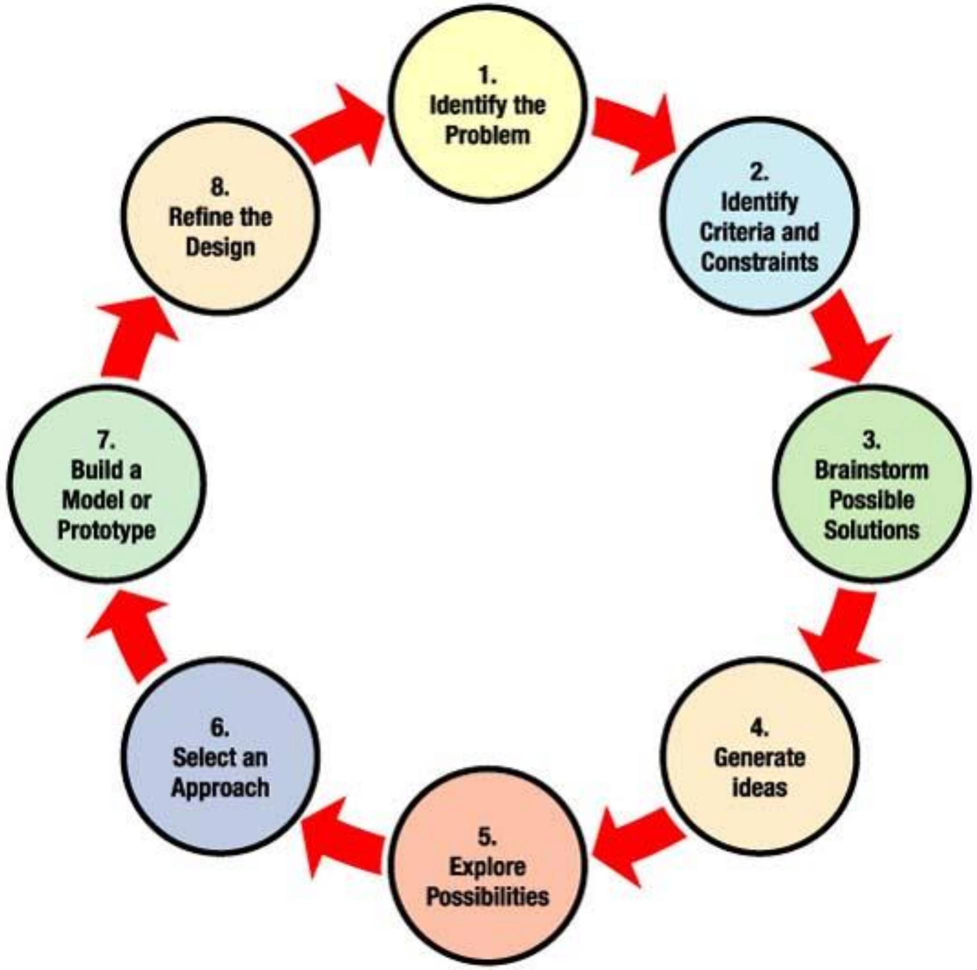
- One bucket=236 ml of water
- Weight of the water is 0.236 kg (1 liter of water weighs 1 kg!)
- Mechanical Advantage of the wheel is 24:
- 0.236 kg can balance a milk container weight of 24 x 0.236 kg = 5.664 kg at the axle!
- Now multiply that load weight / force for one bucket by the number of full and partially full buckets!
- **Hence the power of a watermill!**



Designing a Water Wheel

- Constraints and Variables -
- Make Engineering Tradeoffs:
  - Size of axle – fixed
  - Size of hub – fixed
  - Size of cups/paddles – variable
  - Number of cups/paddles – variable
  - Distance of cups/paddles from center (size of the wheel) – variable
  - Shape of the cups/paddles - variable

The Engineering Process: How We Work



What Is Most Important?

- Engineer (design) initial watermill, build prototype, test, observe
- Reengineer (improve) watermill, build, test, observe
- Reengineer (refine) watermill, build, test, observe, ……….
- Through this process you can build the best watermill possible!

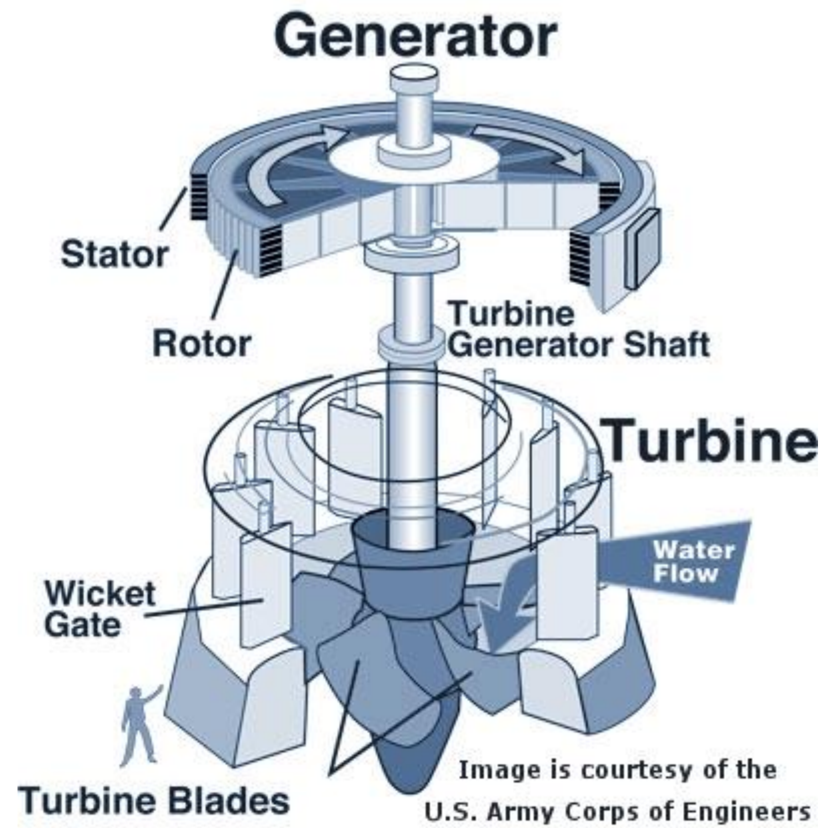
The Rules!

- You will work in teams of two.
- You can use any of the materials laid out on the tables in the lab.
- Keep in mind that all your parts will be exposed to water.
- <u>Your design has to operate in a water stream for three minutes without falling apart.</u>
- <u>It has to lift a load of steel washers by winding up a string on the axle.</u>
- Be sure to watch the tests of the other teams and observe how their different designs worked.
- After testing your first design, see if you can improve the design to overcome the deficiencies you noted.
- Make and test as many different wheel designs as you have time for!

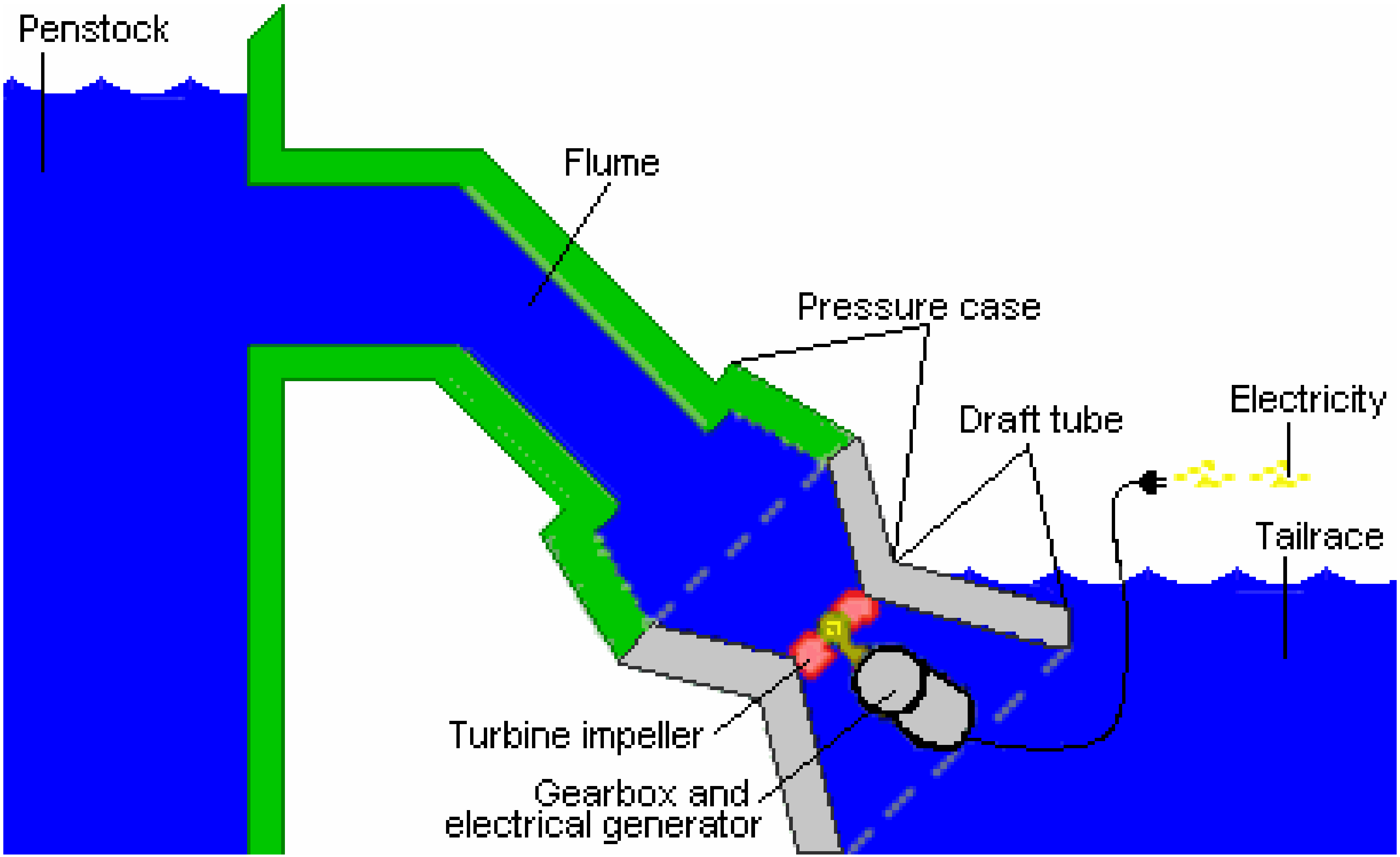
Let’s Build A Waterwheel!

A Modern Waterwheel: Hydroelectric Power

- Hydroelectric power plants harness the power of water.
- A hydroelectric plant uses the power of passing water to turn a propeller or turbine — the turbine in turn rotates a shaft in an electric generator to produce electricity.
- The turbine is a modern, more efficient form of the ancient waterwheel.



Hydroelectric Power



Hoover Dam

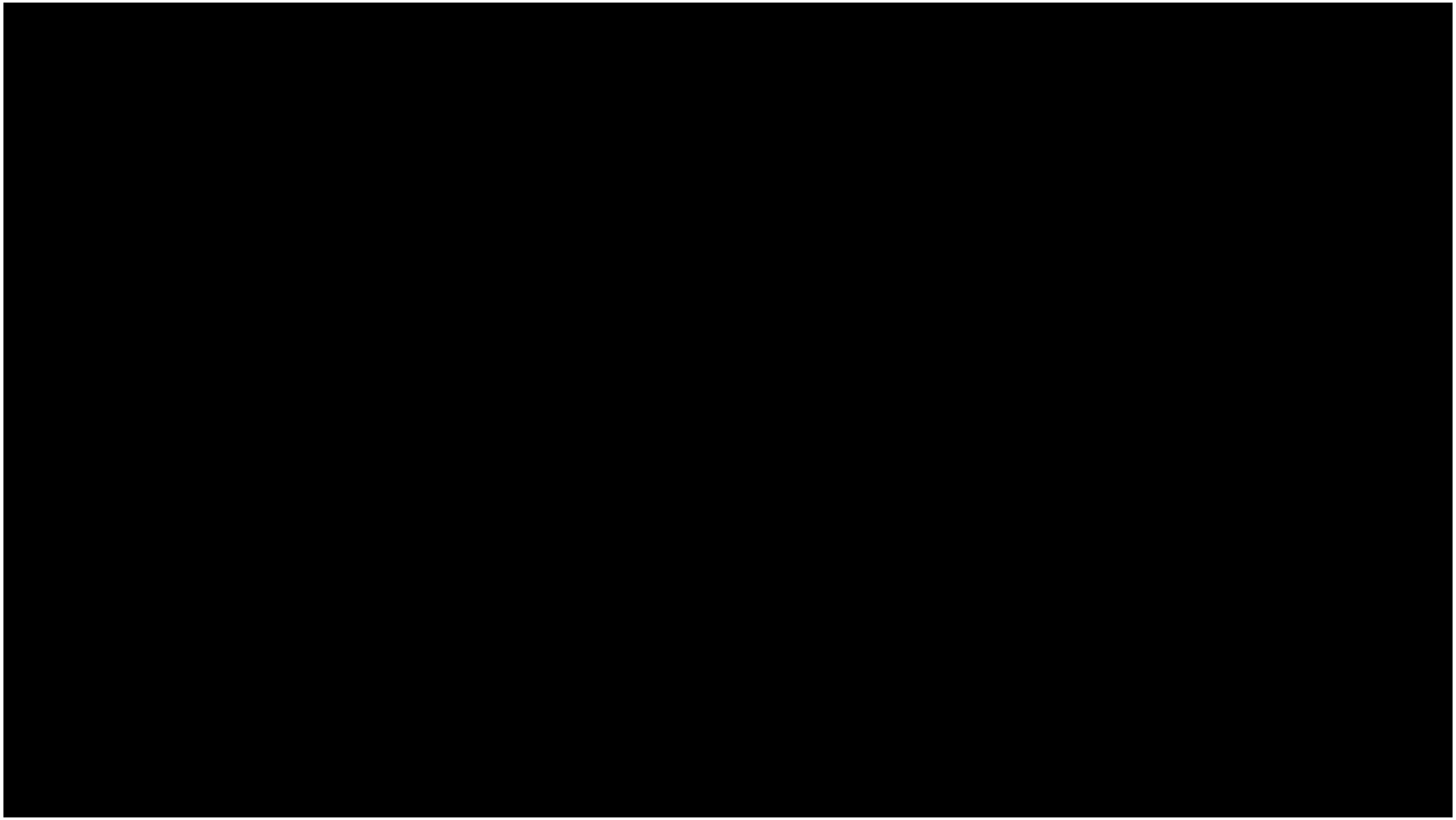
Wrap up

- What have we learned?
  - Energy of the river – where does it come from?
  - Potential and kinetic energy – what is the difference?
  - Simple machines – what do they do?
  - Engineering a waterwheel/watermill – what is best?

Science & Engineering

- Is science and engineering fun?
- You must each find your passion/interest.
- There are many great careers in science & engineering!
- Do what you really enjoy and earn a great living!

Careers in STEM

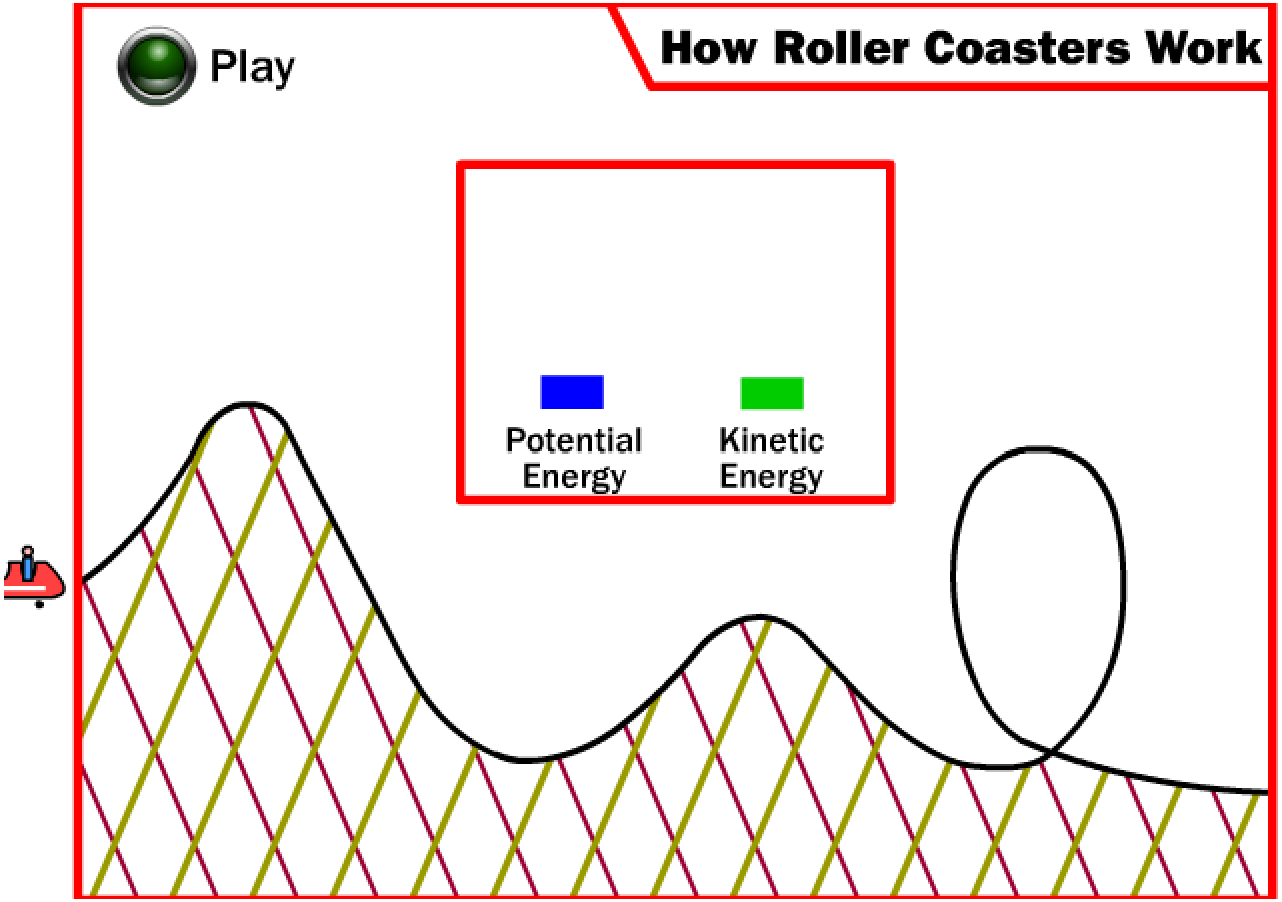


Have Fun Today?

Check out our website: www.azsciencelab.org
click on the "For Students" tab!

Thanks for coming and exploring with us the world of energy, simple machines, and waterwheels!

Roller Coaster - Example



Demos, Hands-on, Experiments

- Bowling Ball Pendulum demo: P-K Energy
- Show Simple Machines: tools, etc.
- See-saw Demo with kids: leverage
- Experiment with Lever-balance and weights
- Nail pulling: lever
- Nail cutting: compound lever
- Pulleys Demo: mechanical advantage
- Large Waterwheel demo w/water jugs: mechanical advantage