This is the contents of a binder for Simple Machines that I used for part of the 2015 season.

The first two pages are general notes about simple machines and their types.

The next page is a formula sheet. All the formulas are given using the “triangle” method. (see this video for an explanation of the triangle method: https://youtu.be/J_9klCxjhiA?t=180)

The final page is specific notes about torque.

It is highly recommended when creating a binder that you create your own notes rather than printing out and putting entire documents from the internet into your binder.

Use the information and topics mentioned in here as a jumping off point. This binder is by no means complete.

Simple Machine-A mechanical device that changes the direction or magnitude of a force; the simplest mechanisms that use mechanical advantage to multiply force.

- **Force**-any action that has the ability to change motion
  - **Newton**-A unit of force equal to the amount required to accelerate one kilogram at one meter per second per second
- **Work**-Force applied over a distance
  - **Joule**-A unit of energy and work equal to one newton of force times one meter of distance
- **Energy**-A measure of ability to change or create change; energy is required to make a force do work
  - **Law of conservation of energy**-Energy cannot be created or destroyed, although it can be changed from one form to another
- **Power**-The rate at which work is done; rate at which energy flows; equal to work÷time or energy÷time; measured in watts
  - **Watt**-One joule per second

General **history** of simple machines:

- **Greeks**
  - The **concept of simple machines** first originated with the philosopher **Archimedes**, who studied the Archimedean simple machines: levers, pulleys, and screws
  - **Archimedes** was also the first to identify the principle of **mechanical advantage**, which he did with the lever
  - Later, philosophers defined 5 simple machines and roughly calculated their mechanical advantage
  - For example, in his work *Mechanics*, **Heron of Alexandria** lists five mechanisms and their fabrication and uses: lever, pulley, wedge, screw, and windlass
  - Greek knowledge was limited to the statics of forces (e.g., input and output forces) and did not include dynamics of forces (e.g., work)
- **Renaissance**
  - Dynamics of simple machines (e.g., work) were defined
  - **Simon Stevin** defined the mechanical advantage of inclined planes
  - **Galilei** defined the complete dynamic theory of simple machines and showed the underlying mathematical similarity of the machines in *Le Meccaniche* (On Mechanics). He was the first to understand that simple machines do not create energy, only transform it

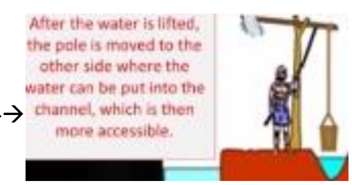
6 classical simple machines:

- **Lever**-A machine consisting of a rigid beam pivoted at a fulcrum. There are 3 different types characterized by the location of the fulcrum, resistance, and effort.
  - **Class 1**-Fulcrum in the middle: the effort is applied on one side of the fulcrum and the resistance on the other side (e.g., scissors, crowbar, etc.). Mechanical advantage may be greater or less than 1.
  - **Class 2**-Resistance in the middle: the effort is applied on one side of the resistance and the fulcrum is located on the other side (e.g., a wheelbarrow, a nutcracker, a bottle opener, brake pedal of a car, etc.). Mechanical advantage is always greater than 1.
  - **Class 3**-Effort in the middle: the resistance is on one side of the effort and the fulcrum is located on the other side (e.g., a pair of tweezers, a human elbow, etc.). Mechanical advantage is always less than 1.
- **Inclined Plane**-A flat supporting surface tilted at an angle, with one end higher than the other. Moving an object up an inclined plane requires less force than lifting it straight up, at a cost of an increase in the distance moved.
- **Wedge**-A compound inclined plane that can be used to separate two objects or portions of an object, lift up an object, or hold an object in place. Functions by converting a force applied to its blunt end into forces perpendicular to its inclined surfaces.
- **Pulley**-A wheel on an axle that is designed to support movement and change of direction of a cable or belt along its circumference. Useful for changing the direction of a force.
  - **Fixed Pulley**-a pulley that doesn't move with the load; can be thought of as a 1st class lever: 

  - **Movable Pulley**-a pulley that moves with the load; can be thought of as a 2nd class lever: 

- **Wheel and Axle**-A wheel attached to an axle so that these two parts rotate together in which a force is transferred from one to the other. In this configuration a hinge, or bearing, supports the rotation of the axle.
- **Screw**-A mechanism that converts rotational motion to linear motion, and a torque (rotational force) to a linear force. The most common form consists of a cylindrical shaft with helical grooves.

History of **individual simple machines**:

- **Lever**-Used since prehistoric times
  - Used to assist in the construction of a wide variety of ancient structures
  - As early as 5000 B.C.E., a simple balance scale employing a lever was used to weigh gold and other items.
    - Greek device called a steelyard improved on these simple scales by adding a sliding weight to enhance precision.
  - Around 1500 B.C.E., the shaduf appeared in Egypt and India--→ 

    - Appears on a Sargonid seal of c.2000 BC
  - The earliest remaining writings regarding levers date from the 3rd century BC and were provided by Archimedes
    - *"Give me a place to stand, and I shall move the Earth with it"*
    - Archimedes' Law of the Lever: *"Magnitudes are in equilibrium at distances reciprocally proportional to their weights"*
  - Chinese credited with invention of the wheelbarrow (2nd class lever, fulcrum being the wheel) around 100 C.E.
- **Inclined Plane**-
- **Wedge**-
- **Pulley**-
- **Wheel and Axle**-
- **Screw**-

Mechanical Advantage-A measure of the force amplification achieved by using a tool, mechanical device, or machine system. Is calculated as $MA = \frac{F_{out}}{F_{in}}$

- **Ideal Mechanical Advantage**-The mechanical advantage of a device with the assumption that its components do not flex, there is no friction, and there is no degradation of the device. It is calculated using the physical dimensions of the device and defines the maximum performance the device can achieve.

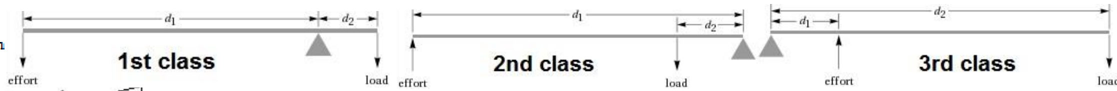
- **Actual Mechanical Advantage**-The mechanical advantage determined by physical measurement of the input and output forces; takes into account energy loss due to deflection, friction, and wear. It is calculated as the ratio of the measured force output to the measured force input.

Efficiency-The ratio of power out to power in is the efficiency (η) of the machine, and is a **measure of the energy losses**; also stated as the ratio of the experimentally determined actual mechanical advantage to the ideal mechanical advantage.

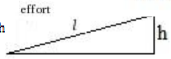
- Occurs due to the loss of energy through friction, deformation, and wear, which is dissipated as heat
- It is always less than 1 (or 100%) in reality, but theoretically can equal 1 (the AMA of the device would be the same as the IMA)

IMA of simple machines:

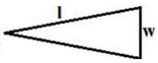
- **Lever-** $\text{IMA} = \frac{d_1}{d_2}$ d_1 = effort arm, d_2 = load arm



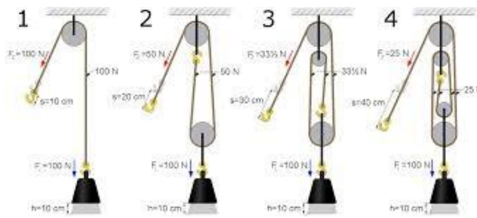
- **Inclined Plane-** $\text{IMA} = \frac{l}{h}$ l = slope length, h = height



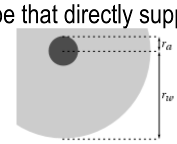
- **Wedge-** $\text{IMA} = \frac{l}{w}$



- **Pulley**-count the number of strands of rope that directly support the load.



- **Wheel and Axle-** $\text{IMA} = \frac{r_w}{r_a}$ r_w = wheel radius, r_a = axle radius

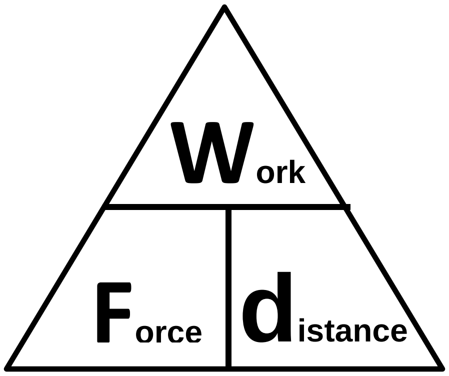


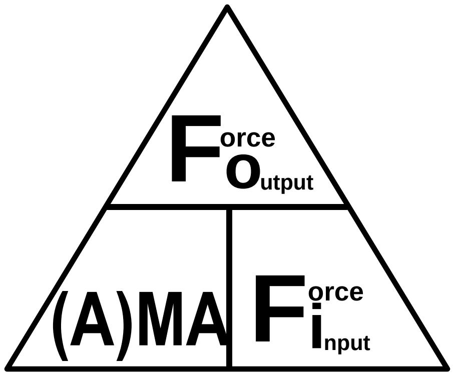
Friction-the force resisting the relative motion of solid surfaces, fluid layers, and material elements sliding against each other

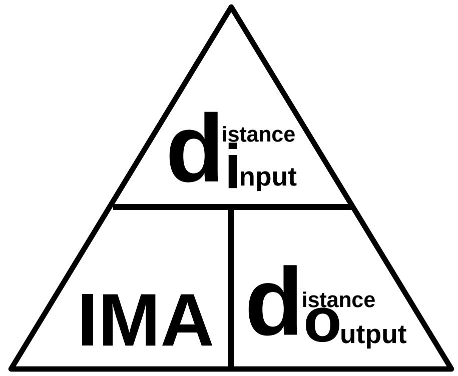
- History:
  - Classic rules of sliding friction were discovered by **Leonardo da Vinci**, but remained unpublished in his notebooks
  - Rediscovered by **Guillaume Amontons**, who presented the nature of friction in terms of surface irregularities and the force required to raise the weight pressing the surfaces together
  - **Leonhard Euler** derived the angle of repose of a weight on an inclined plane and first distinguished between static and kinetic friction
  - **Arthur Morrin** developed the concept of sliding versus rolling friction
  - **Osborne Reynolds** derived the equation of viscous flow
- **Laws of dry friction**: three empirical laws of kinetic friction developed between the 15th and 18th centuries:
  - **Amontons' First Law**: The force of friction is directly proportional to the applied load.
  - **Amontons' Second Law**: The force of friction is independent of the apparent area of contact.
  - **Coulomb's Law of Friction**: Kinetic friction is independent of the sliding velocity.

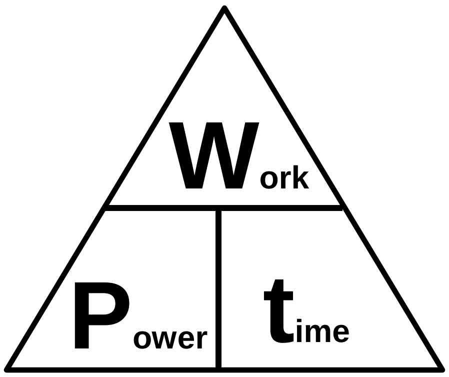
Examples of types of levers:

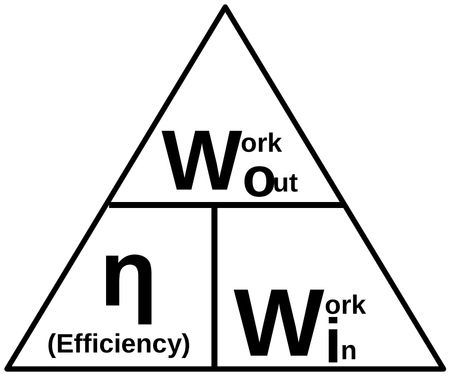
- Class 1:
  - Seesaw/teeter-totter, pliers (two working in conjunction), scissors (two working in conjunction), certain trebuchets, can and bottle openers, bicycle hand brakes, hammer, when pulling a nail with the hammer's claw, tweezers that are shaped like scissors work as double levers (such as test tube holders), shoehorn
- Class 2:
  - Nutcracker, door, stapler, diving board, wrench, wheelbarrow, the handle of a pair of nail clippers
- Class 3:
  - Human arm, tweezers (forceps), certain slings, trebuchets, and fishing rods, hoe, scythe, the main body of a pair of nail clippers, in which the handle exerts the effort force shovel, broom, staple remover, hockey stick, human mandible (jaw), baseball bat, mousetrap

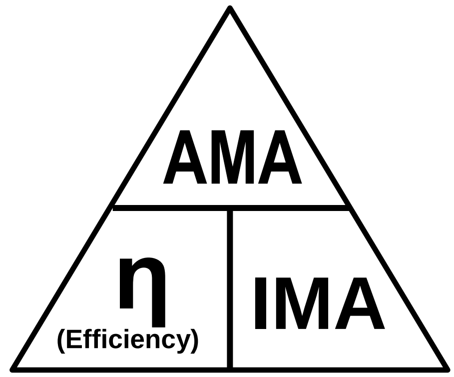

Work
Force
distance


Force output
(A)MA
Force input


distance input
IMA
distance output


Work
Power
time


Work Out
η
(Efficiency)
Work in

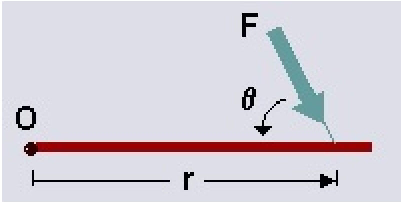

AMA
η
(Efficiency)
IMA

Torque

Torque is the tendency of a force to rotate an object about an axis, fulcrum, or pivot. It is a measure of how much a force acting on an object causes that object to rotate. Torque can be thought of as a twist to an object. Torque is usually denoted by the Greek letter tau (τ).

To find the direction of a torque vector, use the right hand rule; put fingers in the direction of r (see below paragraph), and curl them to the direction of F, then the thumb points in the direction of the torque vector.

Three quantities are utilized when determining torque: the force applied (F), the length of the lever arm connecting the axis to the point of force application (r), and the angle between the force vector and the lever arm (θ). Torque is represented in several formulas:

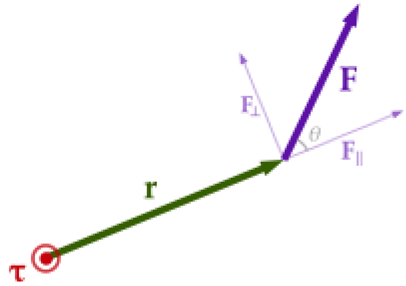


Torque on a particle: $\tau = r \times F$

Magnitude of Torque: 1: $\tau = r \bullet F \bullet \sin(\theta)$ (See top diagram)

2: $\tau = r \bullet F_{\perp}$ (See bottom diagram)

$F_{\perp}$ = force perpendicular to r



The SI **unit of torque is a Newton-meter**, which is also a way of expressing a Joule (the unit for energy). However, torque is not energy. So, to avoid confusion, we will use the units N•m, and not J. The distinction arises because energy is a scalar quantity, whereas torque is a vector.

The concept of torque, also called moment or couple, originated with the studies of **Archimedes** on levers. The rotational analogues of force, mass, and acceleration are torque, moment of inertia and angular acceleration, respectively.