7.2.3 MACHINES AND MOMENTS[M22]

7.2.3.1 Machines

Machines are **energy converters** that enable energy to be used more efficiently. Six types of simple machines are illustrated in Figure 7.2.3.1. Each one can be used to multiply force. Other machines are either modifications of these simple machines or combinations of two or more of them. (The six machines shown are actually variations of two basic types: the pulley and the wheel and axle are forms of **levers**, and the wedge and screw are modified **inclined planes**).

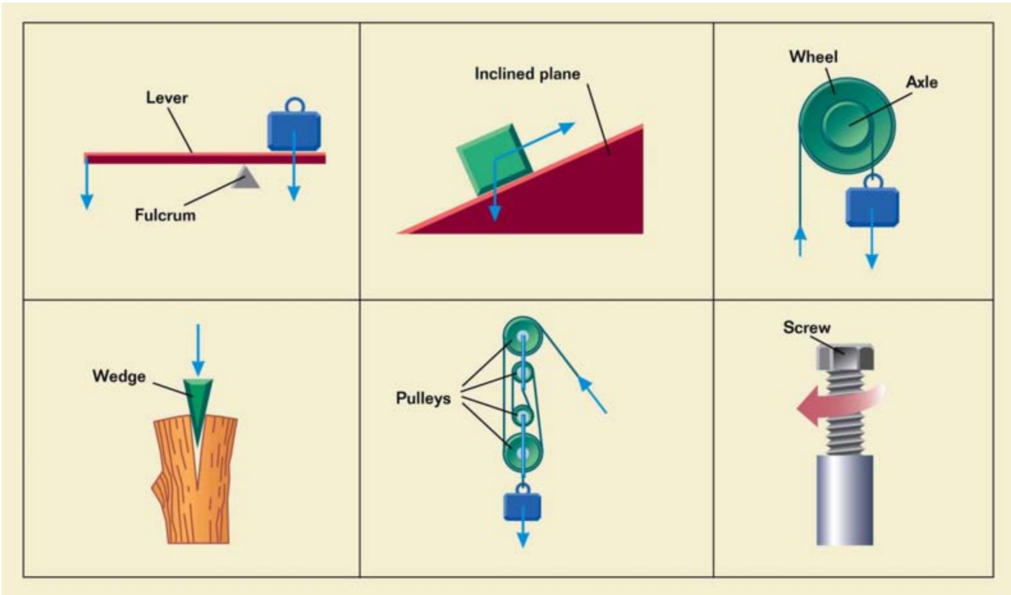


Figure 7.2.3.1 Simple machines. Each machine multiplies force at the expense of distance.

Although a machine can be used to multiply force, it cannot multiply work. The work output of a machine cannot exceed the work input. In a frictionless machine, work output and work input would be exactly equal. In a machine that multiplies force, this equality means that the distance over which the input force moves is always greater than the distance over which the load moves (*i.e.* the load moves more slowly). Thus, an **increase in force** is gained through a **loss of speed**. Conversely, an **increase in speed** can only be accomplished by a **loss in force**.

The ratio of the useful work output of a machine to total work input is called the efficiency:

$$\textbf{Efficiency} = \frac{W_{output}}{W_{input}}$$

Thus in using a machine to lift an object, the efficiency equation becomes:

$$\textbf{Efficiency} = \frac{F_w h}{F_a d}$$

where F_w is the lifting force;
h is the height to which the object is lifted;
F_a is the applied force; and
d is the distance through which the applied force moves.

As well as increasing force, machines can be used to change the direction of a force (*e.g.* gears, pulleys) or to change speed (*e.g.* gears).

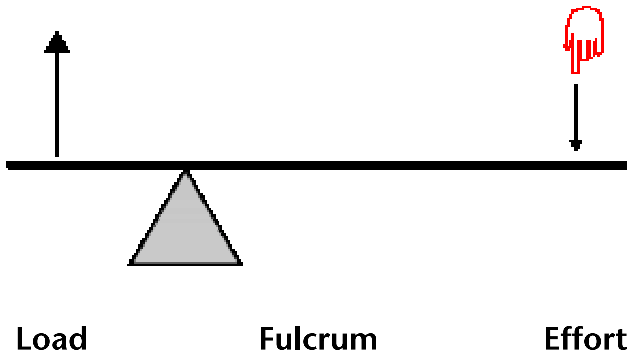
The efficiency of all machines is less than 100% because the work output is always less than the work input due to frictional losses.

7.2.3.2 Lever Systems[1]

There are three classes of levers representing variations in the location of the fulcrum and the input (effort) and output (load) forces.

7.2.3.2.1 First Order Levers

A First Order lever is a lever in which the fulcrum is located in between the input (effort) force and the output (load) force. In operation, a force is applied (by pulling or pushing) to a section of the bar, which causes the lever to swing about the fulcrum, overcoming the resistance force on the opposite side.

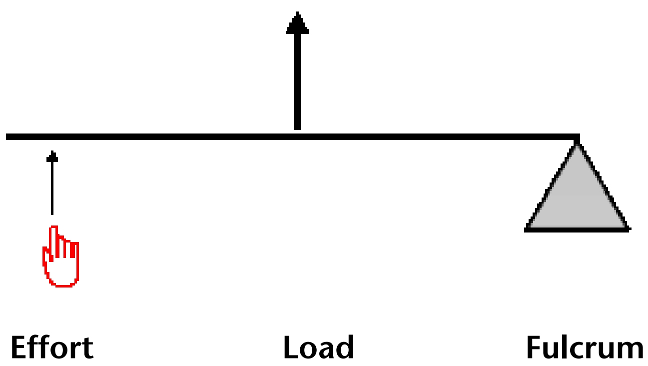


Examples:

- Seesaw
- Crowbar
- Pliers
- Scissors

7.2.3.2.2 Second Order Levers

In a Second Order lever, the fulcrum is located at one end of the bar, the load is in the middle and the effort is applied at the end opposite the fulcrum.



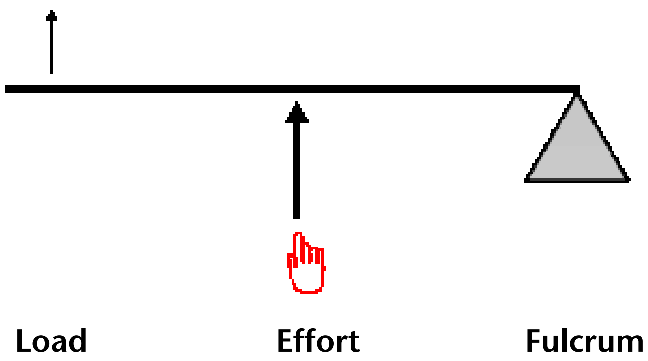
[1] http://en.wikipedia.org/wiki/lever

Examples:

- Wheelbarrow
- Nutcracker
- Door
- Oars, when used for rowing, steering, or sculling

7.2.3.2.3 Third Order Levers

In a Third Order lever, the fulcrum is again located at one end of the bar, but the load is located at the other end and the effort is applied between the two. It should be noted that in this case, the input effort is greater than the output load, in contrast to the First and Second Order levers. Note, however, that the effort moves through a shorter distance than the load.



Examples:

- Human arm
- Tweezers
- Fishing rod
- Shovel
- Broom

7.2.3.2.4 Lever Order Mnemonic

A mnemonic to help remember the three orders of levers is the word **flex**, where the letters **f-l-e** represent the *fulcrum*, the *load*, and the *effort* as being between the other two, in First, Second, and Third order levers respectively.

7.2.3.2.5 Levers and Force

The forces applied to a lever are inversely proportional to the ratio of the length of the lever arm measured between the fulcrum and application points of the respective forces:

$$\frac{Effort}{Load} = \frac{Load\ Arm\ Length}{Effort\ Arm\ Length}$$

or:

$$Effort \times Effort\ Arm\ Length = Load \times Load\ Arm\ Length$$

7.2.3.3 Moments

The moment of a force, sometimes called **torque**, is a measure of its turning effect. It is the product of the force and the distance from the turning point: (fulcrum):

$$\boldsymbol{\Gamma} = \mathbf{Fs}$$

where $\boldsymbol{\Gamma}$ (the upper case Greek letter Gamma) is the moment;
F is the applied force; and
s is the distance between the line of action of the force **F** and the turning point (fulcrum)

The SI unit for a moment is the Newton metre (N·m).

7.2.3.3.1 The Principle of Moments

When a lever is balanced, the sum of the clockwise moments equals the sum of the anti-clockwise moments.

$$\sum_{clockwise} \boldsymbol{\Gamma} = \sum_{anticlockwise} \boldsymbol{\Gamma}$$

When the forces acting on an object, such as a lever, are such that they balance each other out in this way, the object is said to be in *equilibrium*.

Carry out Experiments 22.4, 22.5 & 22.7

7.2.3.4 Inclined Planes

The inclined plane is a machine in that it allows a mass to be raised more easily than if it was to be lifted straight up. As noted earlier, the same amount of work is done in either case, but on an inclined plane a smaller force acts over a greater distance. The steeper the incline, however, the greater the force required.

Carry out Experiment 22.2

Common examples of machines employing inclined planes include the axe or log splitter, and the door wedge.

7.2.3.4.1 The Screw Thread

Although it may not be immediately obvious, a screw is a particularly useful example of a machine based on an inclined plane.

Carry out Experiment 22.3

Note that the pitch of a screw thread, like the slope of an inclined plane, dictates how much effort must be expended to tighten the screw. The finer the thread, the less the effort that is required to tighten a screw or bolt, but the more times the screw or bolt must be turned to clamp down an object. For example, bolts that have to be fastened very tightly will usually have fine threads, whereas screws that need to be fastened quickly have coarse threads.

7.2.3.5 Centre of Gravity

The idea that an object is in equilibrium only when the net force acting on it is zero, and that in this state the net torque must also be zero, leads to the definition of what is called the centre of gravity, or **centre of mass**, of a body.

> *The centre of mass of any abject is that point at which the whole weight force of the body may be supposed to act.*

Carry out Experiment 22.9

The centre of mass of a body does not always coincide with its intuitive geometric centre. Engineers try to make a sports or racing car as light as possible, then add weight to the bottom of or low down in the car so that the centre of mass is as close as possible to the road surface. This reduces the tendency of the car to roll when accelerating—including braking and cornering—and improves its handling. When high jumpers perform a *Fosbury Flop* they bend their body in such a way that it is possible for the jumper to clear the bar while their centre of mass passes under it.

7.2.3.6 Mechanical Advantage

The advantage gained from using a machine is determined by dividing the size of the load moved by the size of the effort required to move the load:

$$Mechanical\ Advantage = \frac{Load}{Effort} = \frac{Distance\ of\ Effort\ from\ Turning\ Point}{Distance\ of\ Load\ from\ Turning\ Point}$$

7.2.3.7 Velocity Ratio

The *Velocity Ratio*, the ratio of the distances moved by the effort and the load in the same time, is a measure of the loss in speed associated with the increase in force provided by a machine:

$$Velocity\ Ratio = \frac{Distance\ Travelled\ by\ Effort}{Distance\ Travelled\ by\ Load}$$

Carry out Experiment 22.? on pulley systems