WORK AND MACHINES

Chapter 14

14A Making Work Easier

Work: Force and Position

In physics, work must meet two conditions:

1. **A force must be applied.**
2. **An object must move.**

Force must be in the direction of motion.

Work does NOT depend on the path.

W = force • distance

Sample problem: If you take a force of 100 N (about 22 lbs.) and use it to move an object 7 meters, how much work has been done?

Work = (100 N)(7 meters)
= 700 N-meters (A N-meter is the same as a joule.)
= 700 J

Work and Motion

Work can also change the motion of an object from still to moving or from one speed to another speed.

Because an object increases in energy as work is done on it, it can do more work on other objects.

Simple Machines

Examples include:

Levers
Wheels and axles
Pulleys
Inclined planes
Wedges
Screws

These help in several ways:

They increase the amount of force.
They change the direction of force.
They change the speed at which a force acts.

They cannot increase the amount of work done or energy needed.

Levers

A lever is a rigid bar which turns about a fixed point.

The fixed point is called a fulcrum.

Law of Moments

(Force)(distance) = (force)(distance)

$$(w_1)(d_1) = (w_2)(d_2)$$

Sample Problem: If a 600-N girl sits on one end of a seesaw (3 m from the fulcrum), where should a 450-N girl sit in order to balance the seesaw?

$$(600\text{ N})(3\text{ m}) = (450\text{ N})(d_2)$$
$$1800\text{ Nm} = (450)(d_2)$$
$$4\text{ m} = d_2$$

<u>Law of Moments</u>: "If the lever is to stay still, the turning forces must be equal on each side."

That turning force is called torque.

First-Class Levers

The fulcrum is in the middle, the push (effort) is at one end, and the weight (resistance) is at the other end.

Example: Seesaw

The side on which the push occurs is called the effort arm.

The side on which the weight is found is called the resistance arm.

The law of moments allows us to solve problems involving levers.

Sample problem: If a 980-N stone is 40 cm from the fulcrum, how much force should be applied at 160 cm on the other side of the fulcrum to balance the lever?

$$(\text{Force})(\text{distance}) = (\text{force})(\text{distance})$$
$$(980\ \text{N})(40\ \text{M}) = (\text{force})(160\ \text{cm})$$
$$39{,}200\ \text{Nm} = (\text{force})(160\ \text{cm})$$
$$245\ \text{N} = \text{force}$$

Mechanical advantage

How can 245 N lift 980 N?

Did it magically gain effort? No, to gain effort, you lose distance. The effort arm moves four times as far as the resistance arm.

To gain effort, you lose distance.

$$\text{M.A.} = \frac{\text{Resistance}}{\text{Effort}} = \frac{\text{Length of effort arm}}{\text{Length of resistance arm}} = \frac{\text{Distance effort arm moves}}{\text{Distance resistance arm moves}}$$
$$= \frac{980\ \text{N}}{245\ \text{N}} = \frac{160\ \text{cm}}{40\ \text{cm}} = \frac{40\ \text{cm}}{10\ \text{cm}}$$
$$= 4 = 4 = 4$$

The price you pay to gain effort is in the distance over which you must move the effort.

This is mechanical advantage (M.A.) or "force-multiplying ability" of a machine.

Second-Class Levers

The resistance is in the middle.

Examples: wheelbarrow, door hinge

M.A. will always be greater than 1 because the effort arm is longer.

Sample problem: If a 500-N force sits in a wheelbarrow 0.5 m from the fulcrum and a boy lifts the wheelbarrow 1.2 m from the fulcrum, what is the M.A.?

$$\text{M.A.} = \frac{\text{effort arm}}{\text{resistance arm}} = \frac{1.2\ \text{m}}{0.5\ \text{m}} = 2.4$$

Third-Class Levers

The effort is applied between the fulcrum and the resistance.

Since this makes the effort arm shorter, the M.A. is always less than 1.

Sample problem: If a person's biceps contract with 90 N of force in order to lift a 70-N weight, what is the M.A.?

$$\text{M.A.} = \frac{\text{resistance}}{\text{effort}} = \frac{70\ \text{N}}{90\ \text{N}} = 0.77$$

14B Other Simple Machines and the Distance Principle

Wheels and Axles

The fulcrum is the center of the axle.
Both the effort arm and the resistance arm rotate around the fulcrum.
M.A. is calculated in the same manner as it is for levers.

Pulleys

This pulley does not move up or down, so it is called a fixed pulley.
The length of the effort arm = resistance arm length, so M.A. must be 1.
This pulley is moveable. Each moveable pulley increases the M.A. by 2, since distance is lost.

Block and Tackle

To calculate the M.A. of this arrangement of fixed and moveable pulleys (called a block and tackle), remember that a fixed pulley does not change the M.A.
There are 4 rope sections not involved with the fixed pulley, so the M.A. is 4.

Inclined Planes

No, not an airplane taking off or landing, but a ramp.
How can this be a machine? It is a machine because it increases force by sacrificing distance, just like a lever.
Since W = F • d, if an object requires 400 N of force to push it up an inclined plane 30 m long, the work is (400 N)(30 m) = 12,000 N•m = 12,000 J.
Why push an object up an inclined plane when it is further than just lifting the object?
Since distance is sacrificed, something must be gained, and it is force.
To calculate the M.A., divide the force to lift the object by the force to roll it up the inclined plane.
Another way to calculate the M.A. of an inclined plane is to divide the distances.
Divide the length of the inclined plane by its height (the distance the object would be lifted straight up) to find the M.A.

Wedge

A wedge is two inclined planes back to back.
They concentrate the force on the tip of the wedge.
Once again, distance is sacrificed to gain force.

Screw

A screw is an inclined plane wrapped around a cylinder (machine screw or bolt) or a cone (wood screw).
Think of a road that winds around a mountain; distance is sacrificed to gain force.
Could the car go straight up the mountain?
A thread is an individual ridge on a screw.
The pitch of a screw refers to the distance between two adjacent threads on the screw.
More threads/inch equals more distance sacrificed, so more force is gained.

Efficiency

Efficiency is the measure of the amount of the work put into a machine which produces useful output.

The rest must overcome friction.

Work and Power

Power is the rate of doing work, the speed at which the energy is released.

$$\text{Power} = \frac{\text{Work}}{\text{Time}}$$

The unit of power is the watt.

Sample problem: If you weigh 550 N and run up the Empire State building (300 m) in 1650 seconds, what would the power usage be?

$$\text{Power} = \frac{\text{Work}}{\text{Time}} = \frac{(500\ \text{N})(300\ \text{m})}{1650\ \text{seconds}} = 100\ \text{watts}$$

Rate of using power

Appliances in our houses use a certain number of watts as long as they are in use.

If a 1000-W appliance runs for an hour, it has used 1 kilowatt-hour of energy (1 kWh).

This costs about 10 to 20 cents.

Your family uses about 1000 kWh each month!!