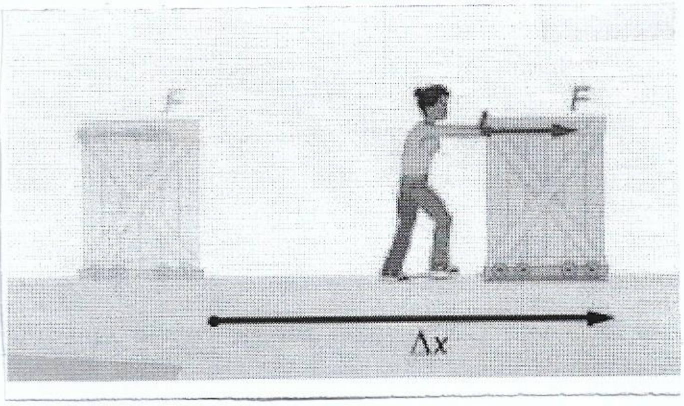
Work: The product of displacement and the force in the direction of displacement.

- When the force on an object is in the same direction as the displacement, the magnitude of the force and the object's displacement can be multiplied together to calculate the work done by the force.

$$W = F \cdot \Delta X$$



where

W: work

F: force

ΔX: displacement

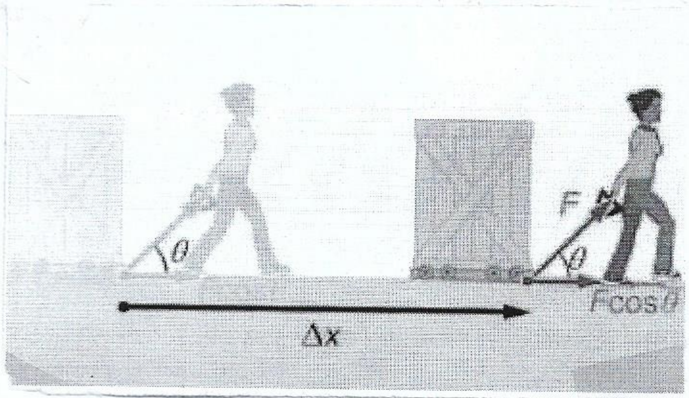
units: joule (J)

Note: If the force at angle to displacement as shown in the below figures, only force component along displacement contributes to work.

$$W = (F\cos\theta)\,\Delta X$$

where

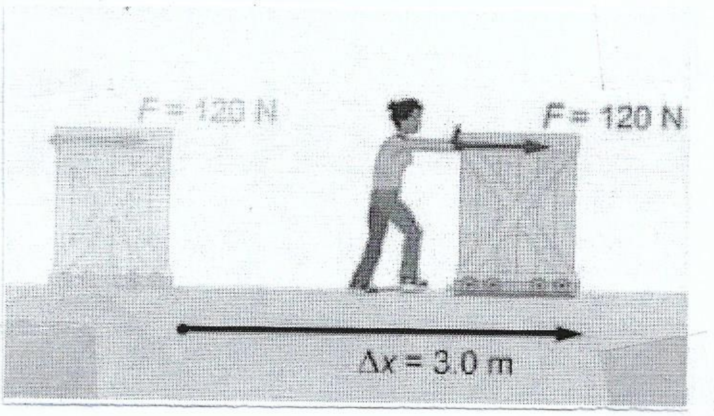
θ: angle between force and displacement



Example: How much work does the woman do on the crate as shown below?

Solution:

$$W = F \cdot \Delta X$$
$$= 120 \times 3 = 360 \text{ J}$$



Example: Now the woman is pulling the crate at an angle. If she does the same amount of work as before ($W = 360\ J$), how much force must the woman exert?

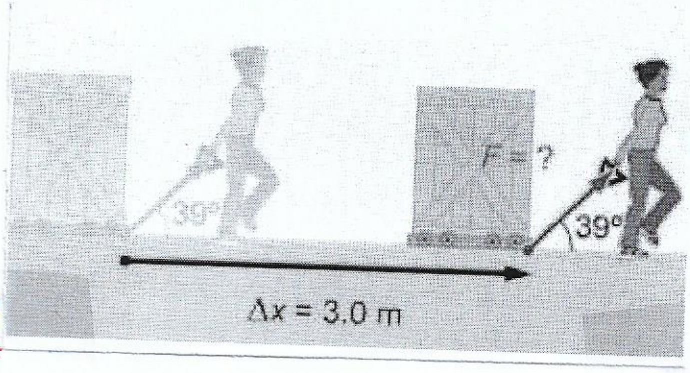
Solution:

$$W = (F\cos\theta)\,\Delta X$$

$$W = F\cos 39^\circ * 3$$

$$360 = 3F\cos 39^\circ$$

$$F = \frac{360}{3\cos 39^\circ} \Rightarrow \underline{F = 154.4\ N}$$



Energy: In physics, energy is the quantitative property that must transferred to an object in order to perform work on, or to heat, the object. Energy is a conserved quantity; the law of conservation of energy states that energy can be converted in form, but not created or destroyed.

- Many forms of energy exist: electric, atomic, chemical, kinetic, potential, and so on.

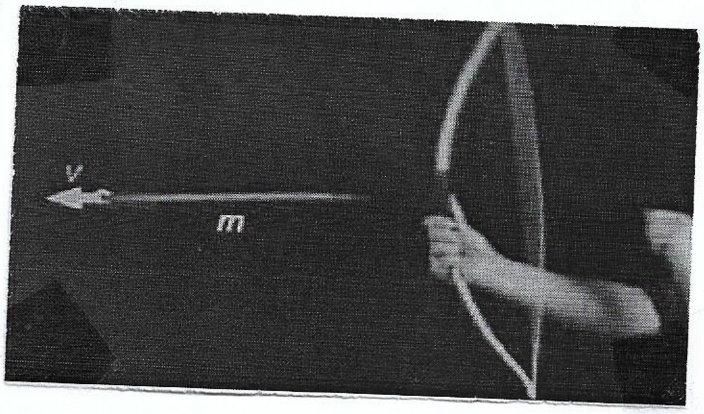
- There is a relationship between work and energy. For instance, if you do work by kicking a stationary soccer ball, you increase a form of its energy called kinetic energy, the energy of motion.

- Energy can transfer between objects. When a cue ball in the game of pool strikes another ball, the cue ball slows or stops, and the other ball begins to roll. The cue ball's loss of energy is the other ball's gain.

- Energy is a scalar. Objects can have more or less energy, and some forms of energy can be positive or negative, but energy does not have a direction, only a value. The joule is the unit for energy, just as it is for work. The fact that work and energy share the same unit is another indication that a fundamental relationship exists between them.

Kinetic energy (KE): The energy of motion

- Physicists describe the energy of objects in motion using the concept of kinetic energy (KE)



$$KE = \frac{1}{2} m v^2$$

KE: kinetic energy

m: mass

v: speed

unit: Joule (J)

- kinetic energy is proportional to mass and square of speed.
- The kinetic energy of an object increases with mass and the square of speed.
- objects never have negative kinetic energy, only zero or positive kinetic energy.

Example: What is the kinetic energy of the arrow for the below figure?

Solution:

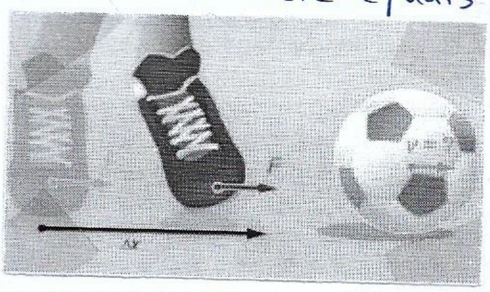
$$KE = \frac{1}{2} m v^2$$

$$KE = \frac{1}{2} (0.015)(5)^2$$

$$KE = 0.19 \text{ J}$$

Work - Kinetic energy theorem.

Work - kinetic energy theorem: The net work done on a particle equals its change in kinetic energy.



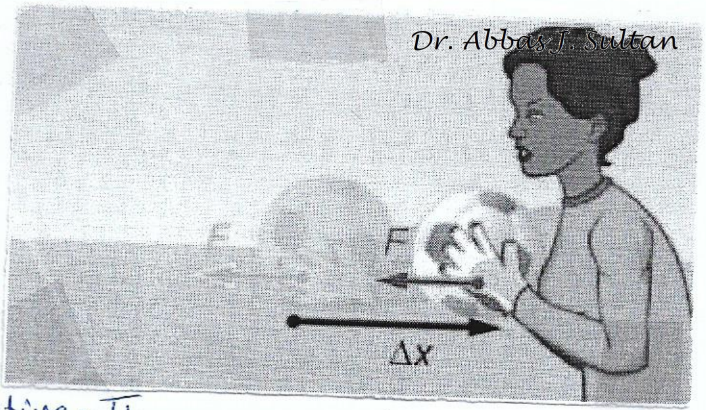
$$W = \Delta KE$$

where

W: net work

KE: kinetic energy

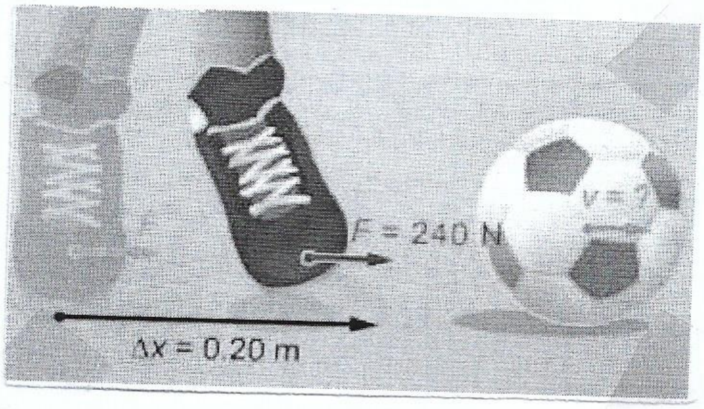
According to this figure, the ball is stationary. It has zero kinetic energy because it has zero speed. The foot applies a force to the ball as it moves through a short displacement. This force accelerates the ball. The ball now has a speed greater than zero, which means it has kinetic energy. The work-kinetic energy theorem states that the work done by the foot on the ball equals the change in the ball's kinetic energy. In this example, the work is positive (the force is in the direction of the displacement) so the work increases the kinetic energy of the ball.



According to right figure, a goalie catches a ball kicked directly at her. The goalie's hand apply a force to the ball, slowing it. The force on the ball is opposite the ball's displacement, which means the work is negative. The negative work done on the ball slows and then stops it, reducing its kinetic energy to zero. Again, the work equals the change in energy; in this case, negative work on the ball decreases it energy.

Example: What is the soccer ball's speed immediately after being kicked? Its mass is 0.42 kg.

Solution:



$$W = F \cdot \Delta x$$

$$W = (240)(0.2) = 48 \text{ J}$$

$$W = \Delta KE = 48 \text{ J}$$

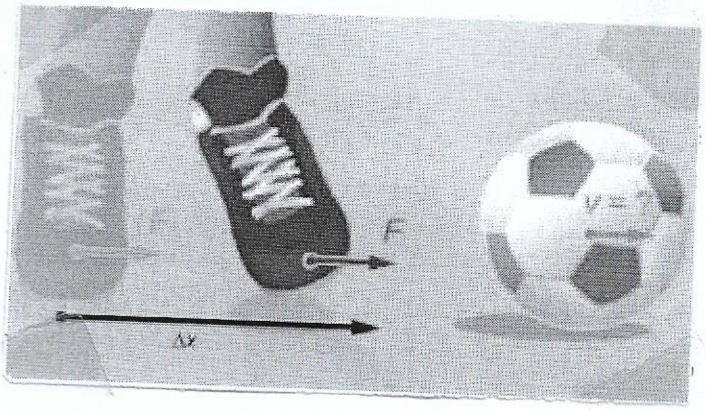
$$KE = \frac{1}{2} m v^2$$

$$48 = \frac{1}{2}(0.42)\, v^2 \Rightarrow v = 14.45 \text{ m/s}$$

Derivation: work-kinetic energy theorem

In this section, we show that the net work done on an object and its change in kinetic energy are equal by using the definition of work and Newton's second law.

We will again use the illustration of a soccer ball being kicked and model the ball as particle. The ball starts at rest and we assume the force applied by the foot equals the net force on the ball, and that the ball moves without rotating.



Since

$$W = F\,\Delta x \quad \text{—— } ①$$

&

$$\sum F_x = m \cdot a \Rightarrow F = m \cdot a$$ sub. into Eq. ①, Newton's second law

$$W = (m \cdot a)\,\Delta x \quad \text{—— } ②$$

$$W = m\,a\Delta X \quad \text{—— (2)}$$

Since

$$v^2 = v_i^2 + 2a\,\Delta X$$, linear motion equation.

Since $v_i = 0$, because the ball was at rest, therefore, the above equations becomes

$$v^2 = 2a\,\Delta X$$

$$a\Delta X = \frac{1}{2} v^2 \quad \text{—— (3)}$$ sub. into Eq. (2)

$$W = m * \frac{1}{2} v^2$$

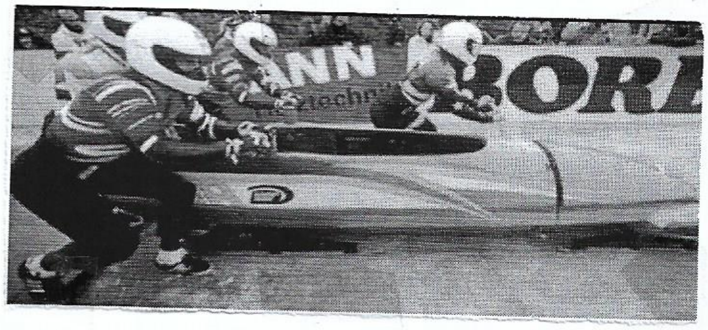
$$W = \frac{1}{2} m v^2$$

Hence

$$W = \frac{1}{2} m v^2 = KE$$

Example: Four bobsledders push their 235 kg sled with a constant force, moving it from rest to a speed of 10.0 m/s along a flat, 50-meter-long icy trak. Ignoring friction and air resistance, what force does the team exert on the sled?

Solution:



Assumptions:

- we assume here that all the work done by the athletes goes to increasing the kinetic energy of the sled.

$$\Delta KE = KE_f - KE_i$$

$$\Delta KE = \frac{1}{2} m v_f^2 - \frac{1}{2} m v_i^2$$, Since $v_i = 0$.

$$\Delta KE = \frac{1}{2} m v_f^2 \Rightarrow \Delta KE = \frac{1}{2}(235)(10)^2$$

$$\Delta KE = 11750 \text{ J}$$

Since

$$W = \Delta KE$$ (work-kinetic energy theorem)

$$F\Delta X = \Delta KE$$

$$F \times 50 = 11750 \Rightarrow F = 235 \text{ N}$$

Power: work divided by time; the rate of energy ouput or consumption.

$$\bar{P} = \frac{W}{\Delta t}$$

where

$\bar{P}$: average power

W: work

Δt: time

units: watts (W)

- The unit of power is the watt (W), which equals one joule per second (J/s).
- It is a scalar unit.
- Power can also expressed as the rate of change of energy. For instance, a 100 megawatt power plant supplies 100 million joules of energy to the electric grid every second.

Example: Applying a force of 2.0×10^5 N, the tugboat moves the log boom 1.0 kilometer in 15 minutes. What is the tugboat's average power?

Solution:

$$W = F \Delta X$$

$$W = 2.0 * 10^5 * (1 * 10^3\ m) =$$

$$W = 2 * 10^8\ J$$

$$\bar{P} = \frac{W}{\Delta t} = \frac{2 * 10^8\ J}{900\ S}$$

$$\underline{\bar{P} = 2.2 * 10^5\ W}$$

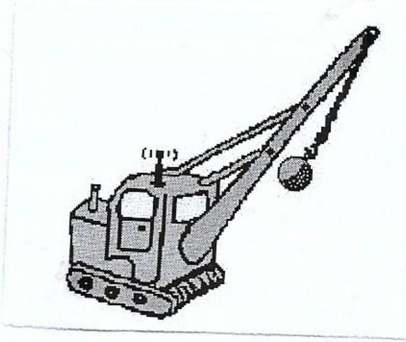
$$1\ \cancel{km} * \frac{1000\ m}{1\ \cancel{km}} = 1000\ m = 10^3\ m$$

$$15\ \cancel{min} * \frac{60\ S}{1\ \cancel{min}} = 900\ S$$

Potential energy: An object can store energy as the result of its position. For example, the heavy ball of a demolition machine is storing energy when it is held at an elevated position. This stored energy of position is referred to as potential energy.

- Gravitational potential energy is the energy stored in an object as the results of its vertical position or height.

The energy is stored as the result of gravitational attraction of earth for object.



$\Delta PE = mg\Delta h$, change in gravitational potential energy

where

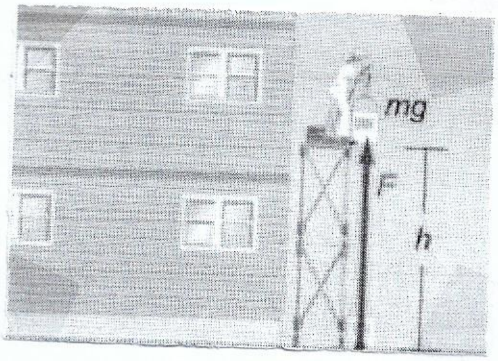
PE: potential energy,

mg: object's weight.

Δh: vertical displacement.

- A change in (PE) can be positive or negative. The magnitude of weight is a positive value, but change in height can be positive (when the bucket moves up) or negative (when it moves down).

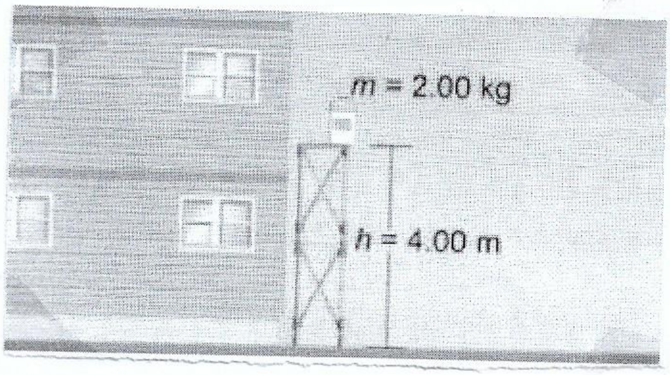
According to the figure to the right, it is convenient to say the system has zero (PE) when the bucket is on the Earth's surface. This convention means its PE equals its weight times its height above the ground, mgh. Only the bucket's distance above the Earth, h, matters here; if the bucket moves left or right, its (PE) does not change.



$PE = mgh$

$PE = 0$ when $h = 0$

Example: What is the bucket's gravitational potential energy for the below figure?



Solution:

$$PE = mgh$$

$$PE = (2)(9.8)(4)$$

$$PE = 78.4\ J$$