Physics 102

Work and Energy

PHYS 102

- **7. Energy and Energy Transfer**
  - Work Done by a Constant Force.
  - Work Done by a Spring.
  - Kinetic Energy and the Work--Kinetic Energy Theorem.
  - The Non-Isolated System — Conservation of Energy.
- **8. Potential Energy**
  - Potential Energy of a System.
  - Elastic Potential Energy

Energy

- Energy is the ability to do work.
- There are many forms of energy.
- Whenever you do work you transfer energy from one form to another.
- It can only be observed when it is transferred.
- Is a scalar quantity.
- Measured in :
  - Joule (J) , in SI system.
  - Erg , in CGS system. (1 erg = 10^{-7} J)

WORK

Work is the force necessary to move an object a distance.

Not Work

Work

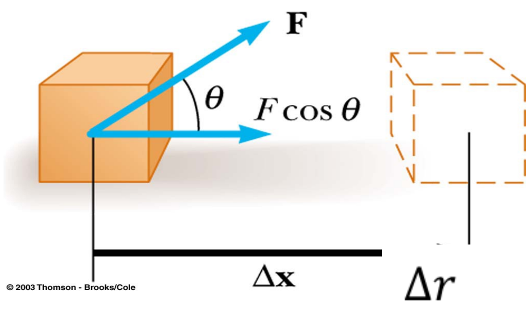
1. Work Done by a Constant Force

- If the constant force F is in the same direction as the displacement, the work W *done on an* object is:

$$W = F\Delta r$$

- If the constant force F makes an angle θ with the direction of the displacement, the work W *done on an* object by this force is:

$$W \equiv F\Delta r \cos\theta$$



WORK

- Work is a scalar quantity.
- Its units are force's unit multiplied by length's unit

($N \times m$).

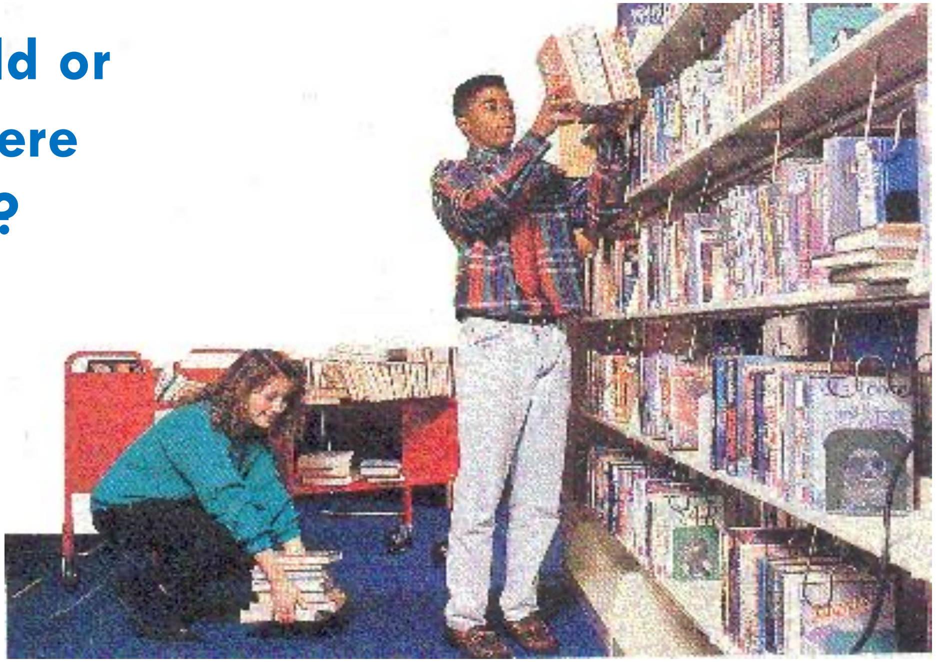
Therefore, the SI unit of work is Joule = ……..

the CGS unit of work is erg = ……..

Is there any work done ?

- When the book are being lifted, is there any work done on it ?

- when they are being held or carried horizontally, is there any work done on them ?

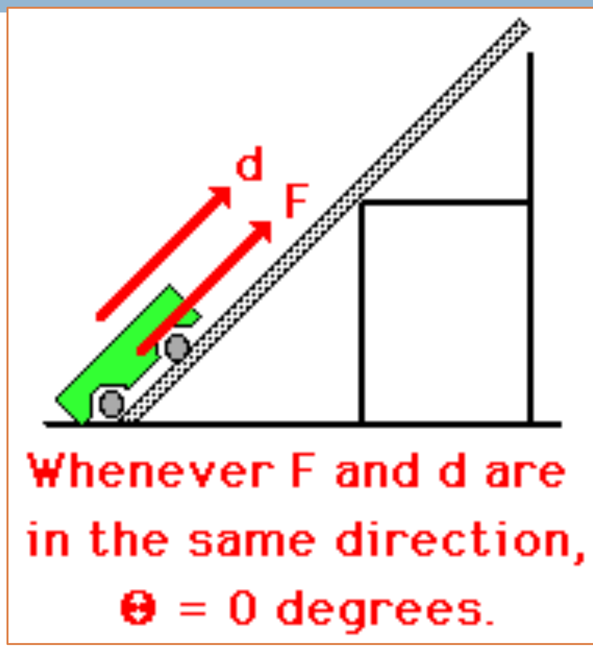


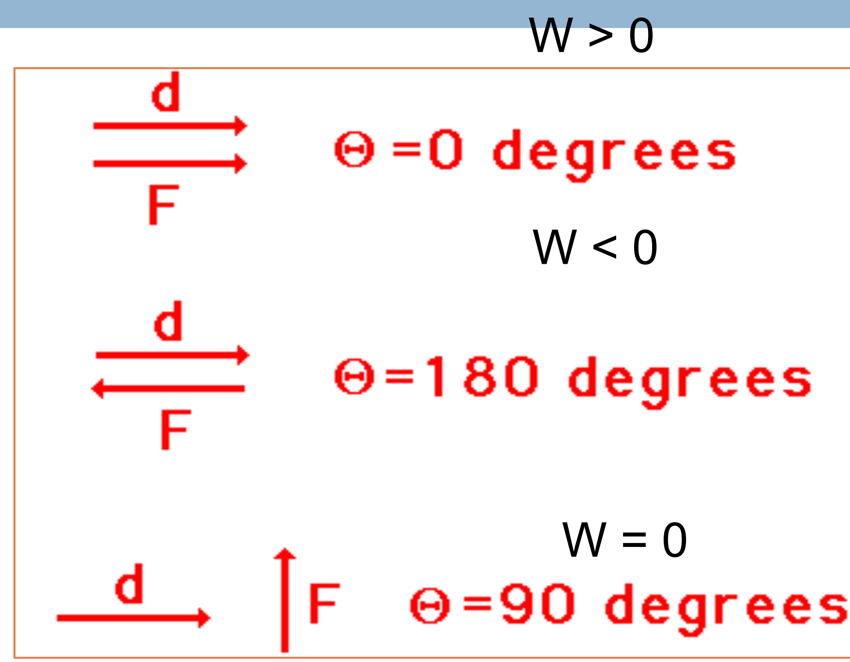
Is there any work done ?

- Work is done on the books when they are being lifted, (F // Δx)

- But no work is done on them when they are being held or carried horizontally. ($\Delta x = 0$)

- The work done may be positive, zero, or negative, depending on the angle between the force and the displacement:





$$W = Fd(\cos \theta)$$

. . . so when the applied force is perpendicular to the distance, you end up with zero work!

The sign of the work

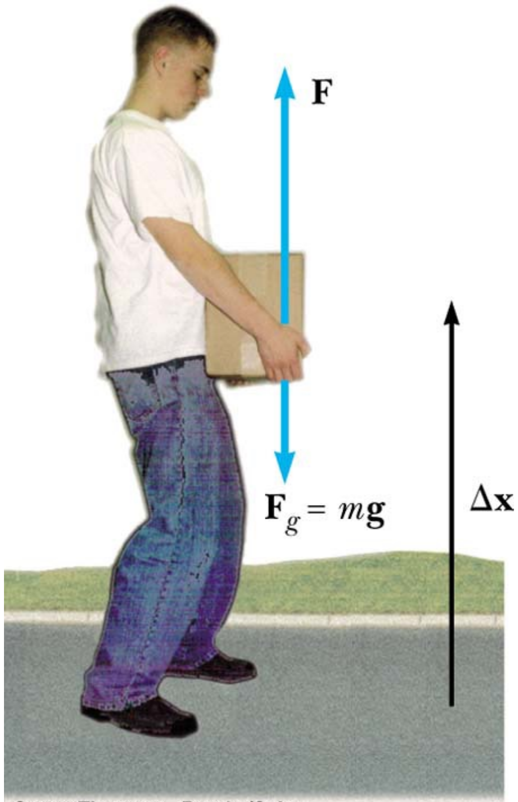
The sign of the work depends on the direction of F relative to Δr.

If F and Δr in the same direction the work done is positive $W > 0$

If F and Δr in the opposite direction the work done is negative $W < 0$

The sign of the work

- Man does positive work lifting box ,because applied force is in same direction as the displacement.
- Man does negative work lowering box.
- Gravity does positive work when box lowers.
- Gravity does negative work when box is raised.



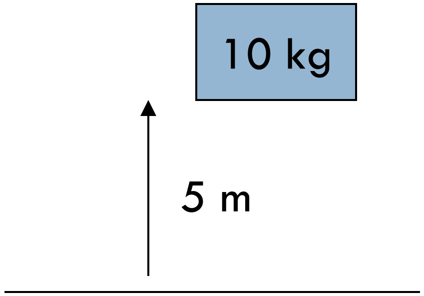
Example

Ex.1: How much work is necessary to lift 10 kg 5m in the air?

Ans.:

1) 10 N 2) 50 J

3) 490 J 4) 4900 J

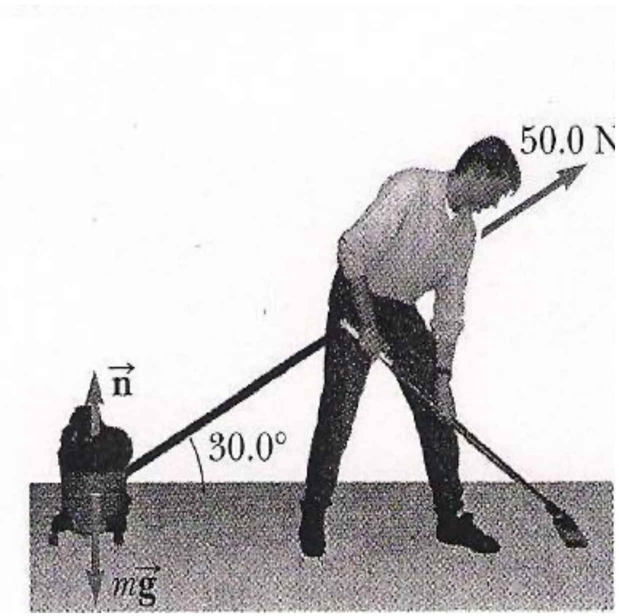


The answer is: $$W = F\Delta r$$

$$F = mg = 10kg \times 9.8\frac{m}{s^2} = 98\ N \rightarrow W = 98N \times 5m = 490\ J$$

Example 3 : Mr. Clean

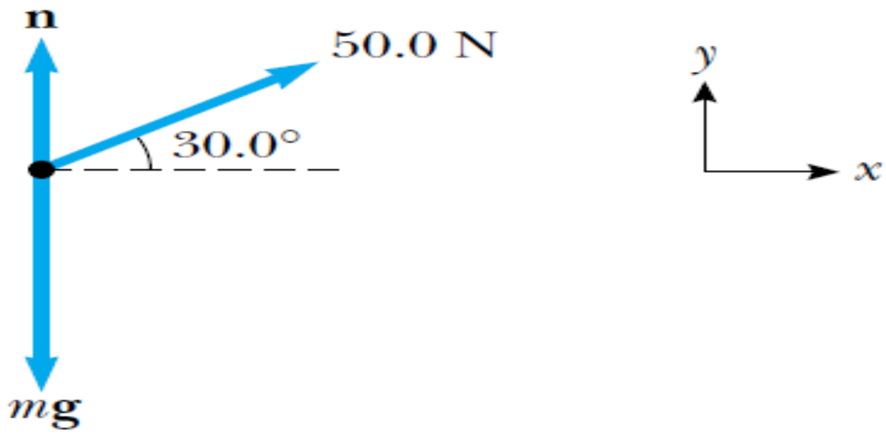
A man cleaning a floor pulls a vacuum cleaner with a force of magnitude F= 50.0 N at an angle of 30.0° with the horizontal. Calculate the work done by the force on the vacuum cleaner as the vacuum cleaner is displaced 3.00 m to the right.



Example 3 :   Mr. Clean

$$W = F\,\Delta r \cos\theta = (50.0\text{ N})(3.00\text{ m})(\cos 30.0°)$$

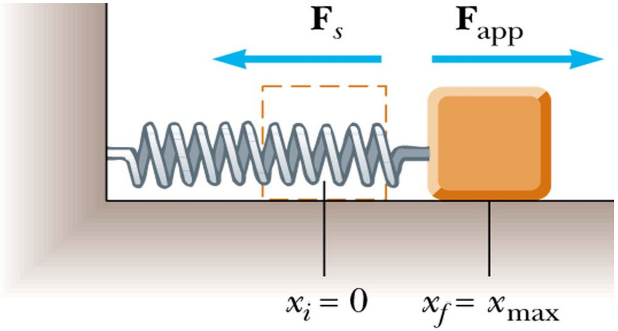
$$= 130\text{ N}\cdot\text{m} = 130\text{ J}$$



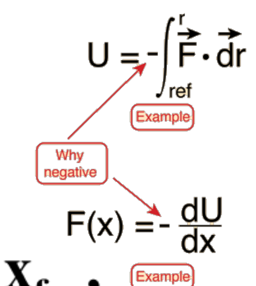
2. Work done by a spring

If the spring is either stretched or compressed a small distance from its un-stretched (equilibrium) configuration, it exerts on the block a force that can be expressed as:

$$F_s = -kx$$

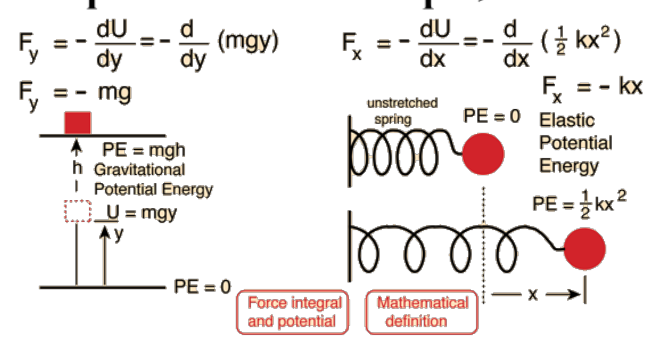


where *x is the position of the block relative to its equilibrium position (x = 0), and k is* a positive constant called the force constant or the spring constant of the spring.



If the block undergoes a displacement from $x = x_i$ to $x = x_f$, the work done by the spring on the block is:

$$W_s = -\frac{1}{2} K (x_f^2 - x_i^2)$$



Mechanical Energy

PHYS 102

Mechanical Energy = Kinetic Energy +Potential Energy

Potential Energy (Stored energy)

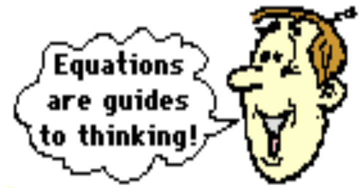
The capacity to do work by virtue of position or configuration

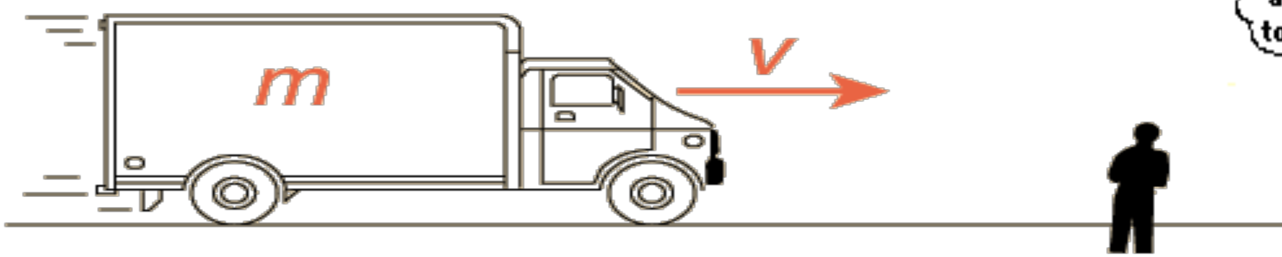
Kinetic Energy (Energy of motion)

Energy which a body possesses because of its motion, which occurs anywhere from an atomic level to that of a whole organism

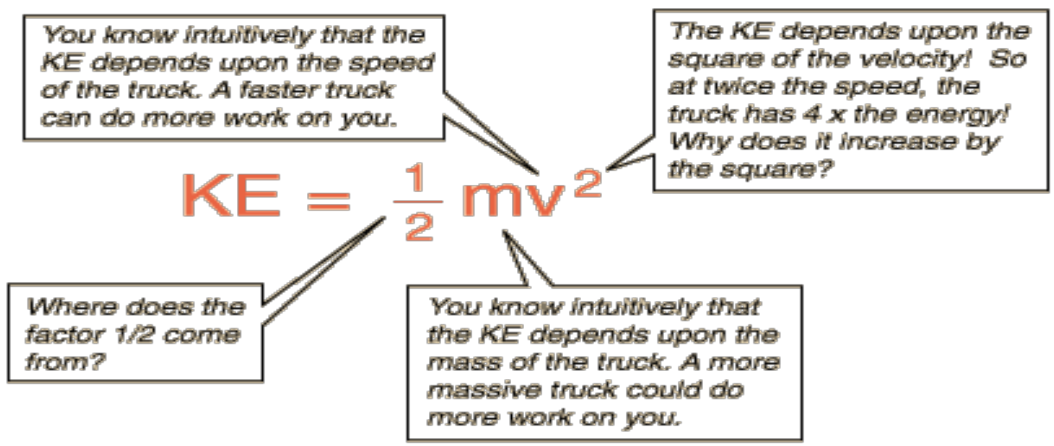
Kinetic Energy Concept :

Energy which a body possesses because of its motion.





You know it's not a good idea to step out into the road right now because of the truck's kinetic energy. It can do work on you as a result of this "motion energy".



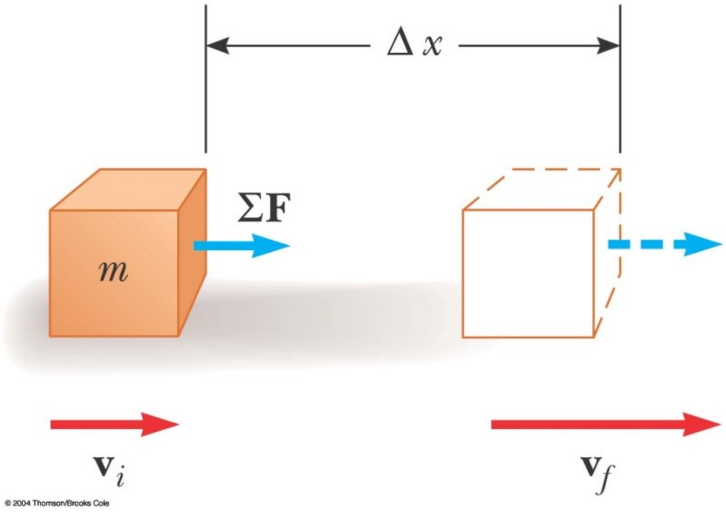
** Kinetic energy is a scalar quantity and has the same units as work.

Work – Kinetic Energy Theorem

$$W = \int_{x_i}^{x_f} \sum F\, dx = \int_{x_i}^{x_f} ma\, dx$$

$$W = \int_{v_i}^{v_f} mv\, dv$$

$$\sum W = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$



The total work done on an object is equal to its final kinetic energy minus the initial kinetic energy

The Work – Kinetic Energy Theorem

$$\sum W = \Delta K$$

$$\sum W = K_f - K_i$$

$$\sum W = \frac{1}{2} m v^2{}_f - \frac{1}{2} m v^2{}_i$$

"In the case in which work is done on a system and the only change in the system is in its speed, the work done by the net force equals the change in kinetic energy of the system."

The total work done on an object is equal to its final kinetic energy minus the initial kinetic energy

Potential Energy

Potential Energy of a System

- **Potential energy** exists whenever an object which has mass has a position within a force field (gravitational, magnetic, electrical).
- Is stored energy.
- is a scalar quantity
- has the same units as kinetic energy and work .
- We will focus primarily on
  - gravitational potential energy (energy an object has because of its height above the Earth) ,
  - and elastic potential energy (energy stored in a spring)

1. Gravitational Potential Energy

- is the potential energy associated with gravitational force
- $PE_g = m \times g \times y$
  - m is mass in kilograms
  - g is acceleration caused by gravity
  - y is vertical distance it can fall in meters.
- Depends on mass and height.
- Remember (mg) is weight in N , so (mgy) is force times distance.
- Potential energy, like work and kinetic energy, is a scalar quantity & measured in the same unit (joule).

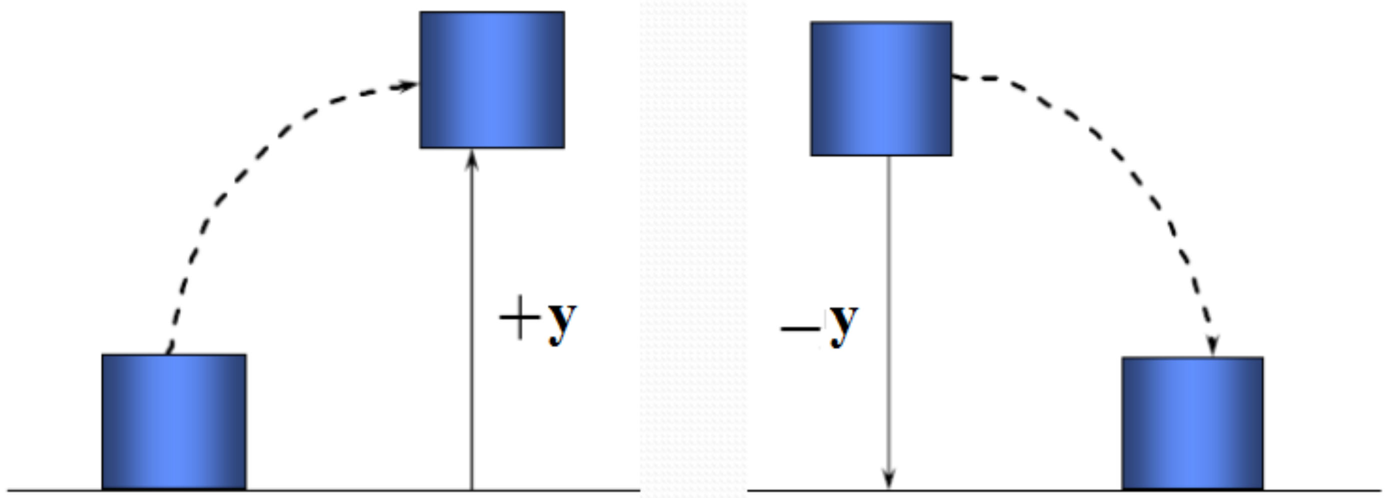
Potential Energy (P.E.)

$\Delta PE = +mg\mathbf{y}$

$\Delta PE > 0$

$\Delta PE = -mg\mathbf{y}$

$\Delta PE < 0$



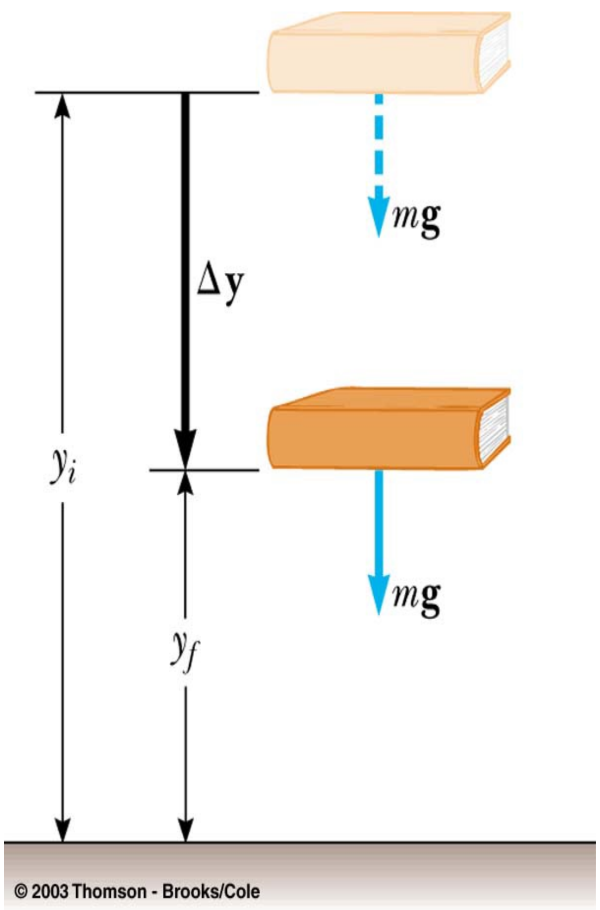
energy due to the **change of position** in gravitational field

gravitational work & gravitational potential energy

- The work done by the external force on the system (object and Earth) as the object undergoes downward displacement is given as :

$$W_g = -(PE_f - PE_i) = -\Delta PE_g$$

- Explanation: If an object falls from one point to another inside a gravitational field, the force of gravity will do positive work on the object and the gravitational potential energy will decrease by the same amount.



ELASTIC POTENTIAL ENERGY

- When you compress a spring:
  - If there is no friction, spring moves back
  - Kinetic energy has been "stored" in the ***elastic*** deformation of the spring

- Rubber-band slingshot: the same principle
  - Work is done on the rubber band by the force that stretches it
  - That work is ***stored*** in the rubber band until you let it go
  - You let it go, the rubber gives kinetic energy to the projectile

- ***Elastic*** body: if it returns to its ***original*** shape and size ***after*** being ***deformed.***

2. Elastic potential energy

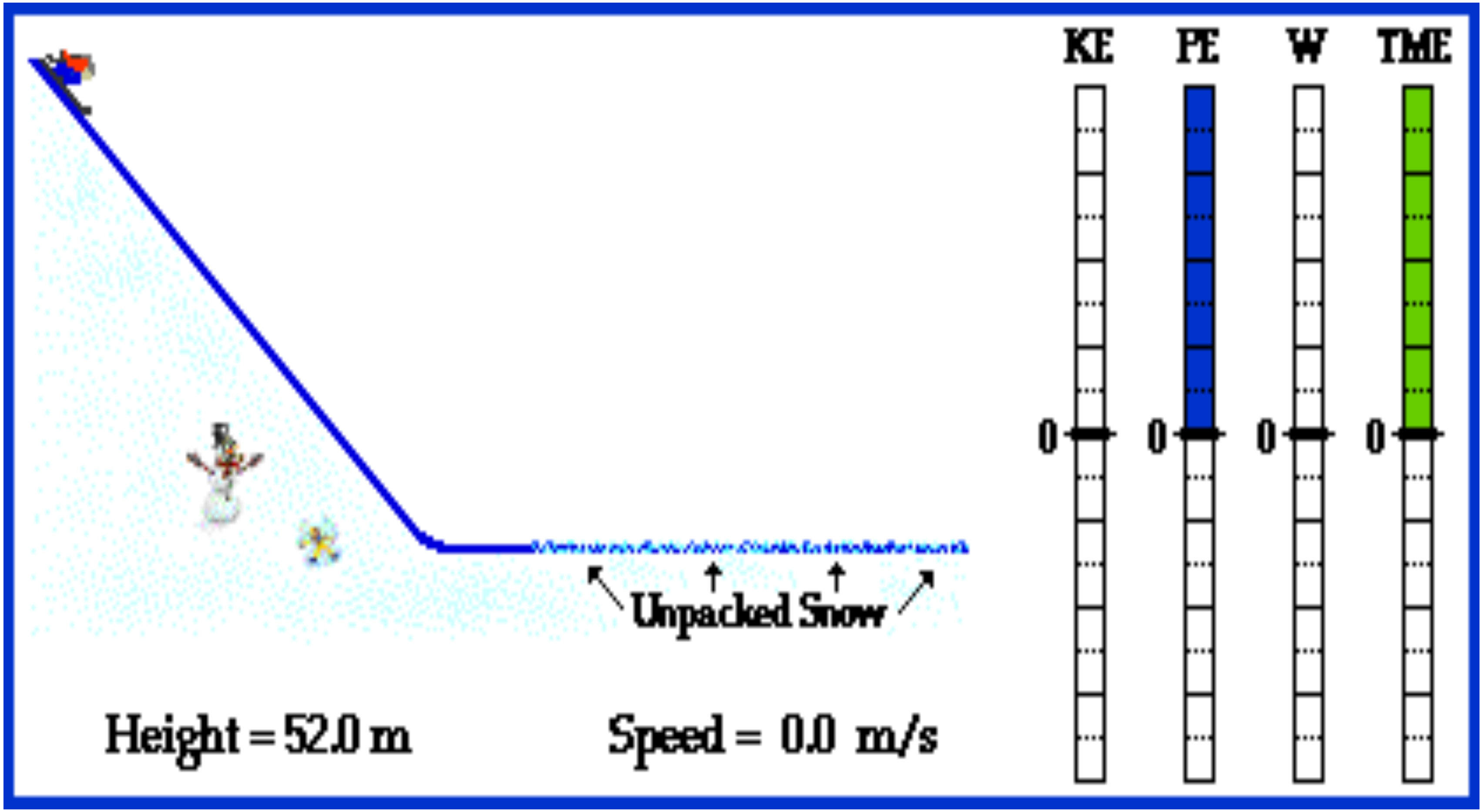
- we learned that the work done by a *spring is given by:*

$$W_s = -\tfrac{1}{2}\, k\,(X_f^2 - X_i^2)$$

- The Elastic potential energy stored in a spring is defined by:

$$PE_s = \tfrac{1}{2}\, k\, X^2$$

The relationship between KE , PE & W & Total Mechanical Energy



Total Mechanical energy is due to its vertical position above the ground gravitational potential energy (TME = KE + PE)

The Non isolated System – Conservation of Energy

- Conservative forces: (closed loop net force = 0)

  Ex. : Gravity, electrical….

  E_t (total energy)= KE + PE = constant

- Non-conservative forces: (net force ≠ 0)

  Ex. Friction, air resistance…

  E_t = KE + PE ≠ constant

- Non-conservative forces still conserve energy !!

  Energy just transfers to thermal energy.

The Law of Conservation of Energy

Energy in a system may take on various forms

(e.g. kinetic, potential, heat, light).

law of conservation of energy states that:

energy may neither be created nor destroyed.

Therefore , the sum of all the energies in the system is a constant.

$$KE_i + PE_i = KE_f + PE_f$$

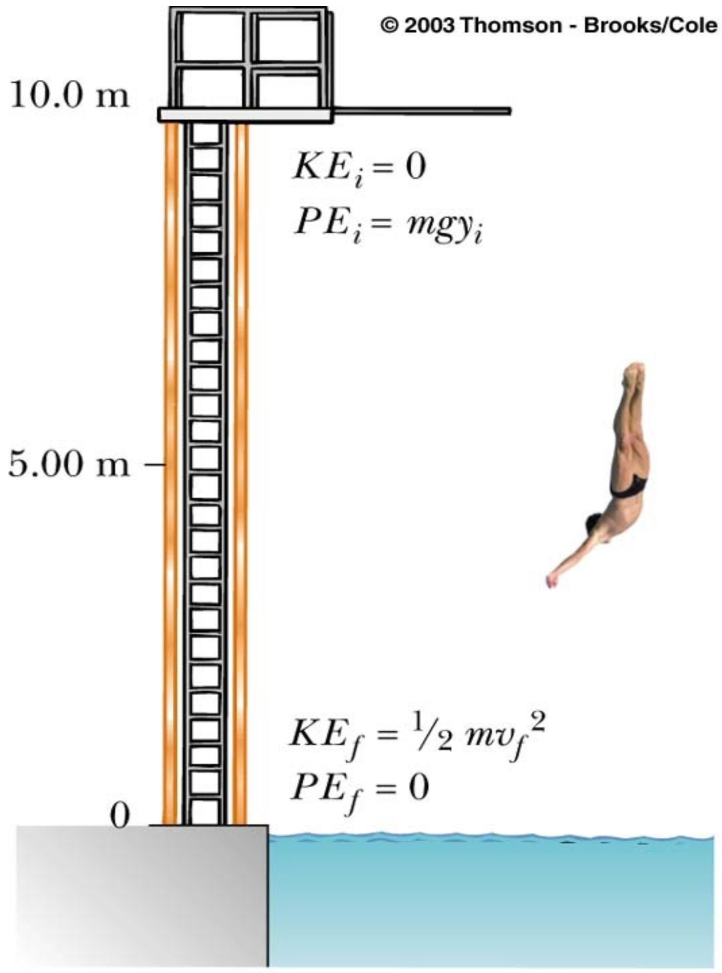
$$\frac{1}{2}mv_i^2 + mgy_i = \frac{1}{2}mv_f^2 + mgy_f$$

Example

A diver of mass *m* drops from a board 10.0 m above the water surface, as in the Figure.

a) **Find his speed 5.00 m above the water surface. Neglect air resistance.**

a) **Find his speed when he hits the water.**



Example

Ans.:

$KE_i + PE_i = KE_f + PE_f$

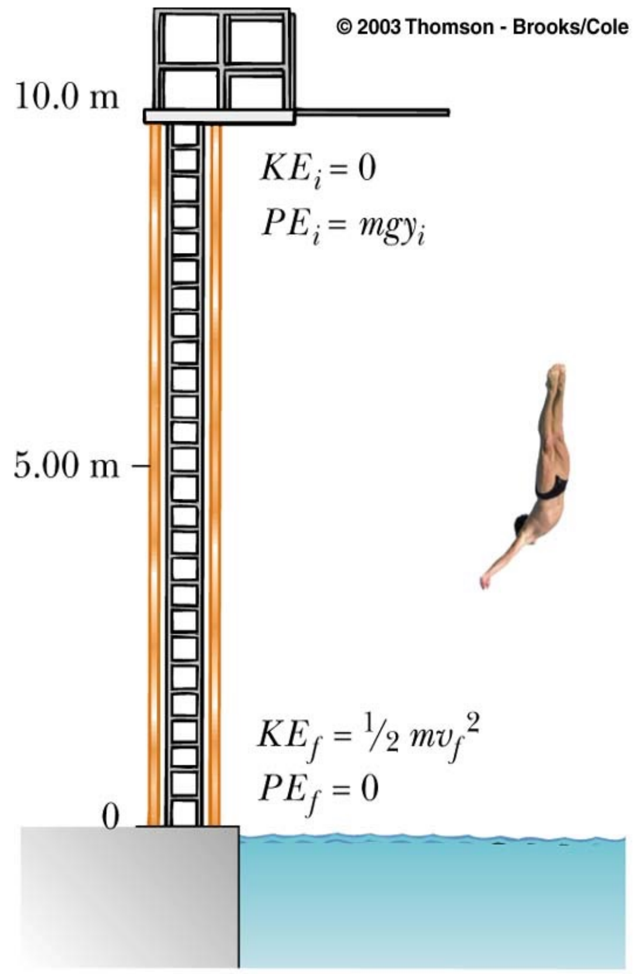
$$\frac{1}{2}mv_i^2 + mgy_i = \frac{1}{2}mv_f^2 + mgy_f$$

$$0 + gy_i = \frac{1}{2}v_f^2 + gy_f$$

$$v_f = \sqrt{2g(y_i - y_f)}$$

$$= \sqrt{2(9.80m/s^2)(10.0m - 5.0m} = 9.90m/s$$

his speed 5.00 m above the water surface = 9.9 m/s



Example

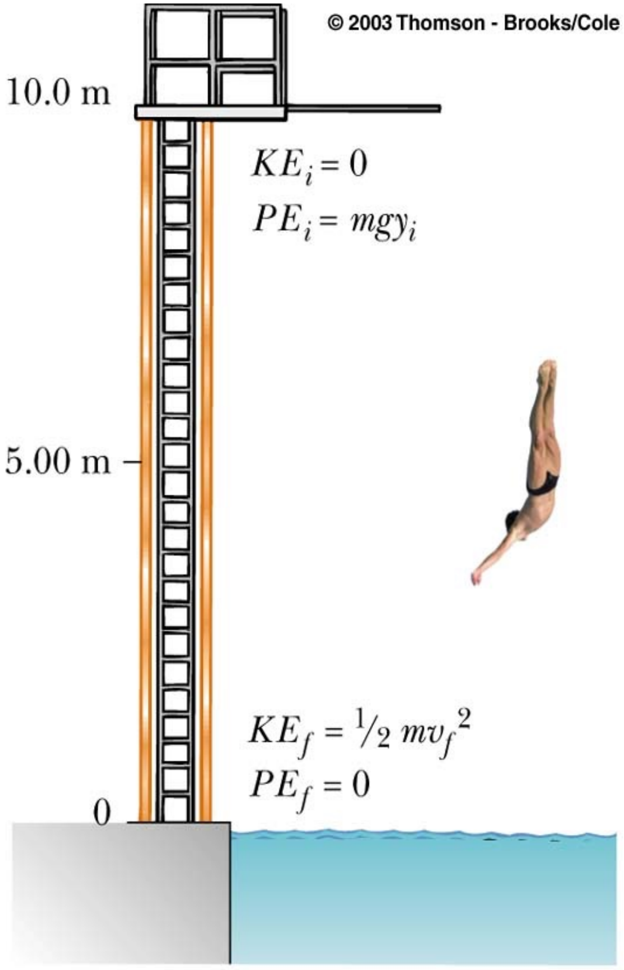
Ans.:

(b) Find his speed as he hits the water.

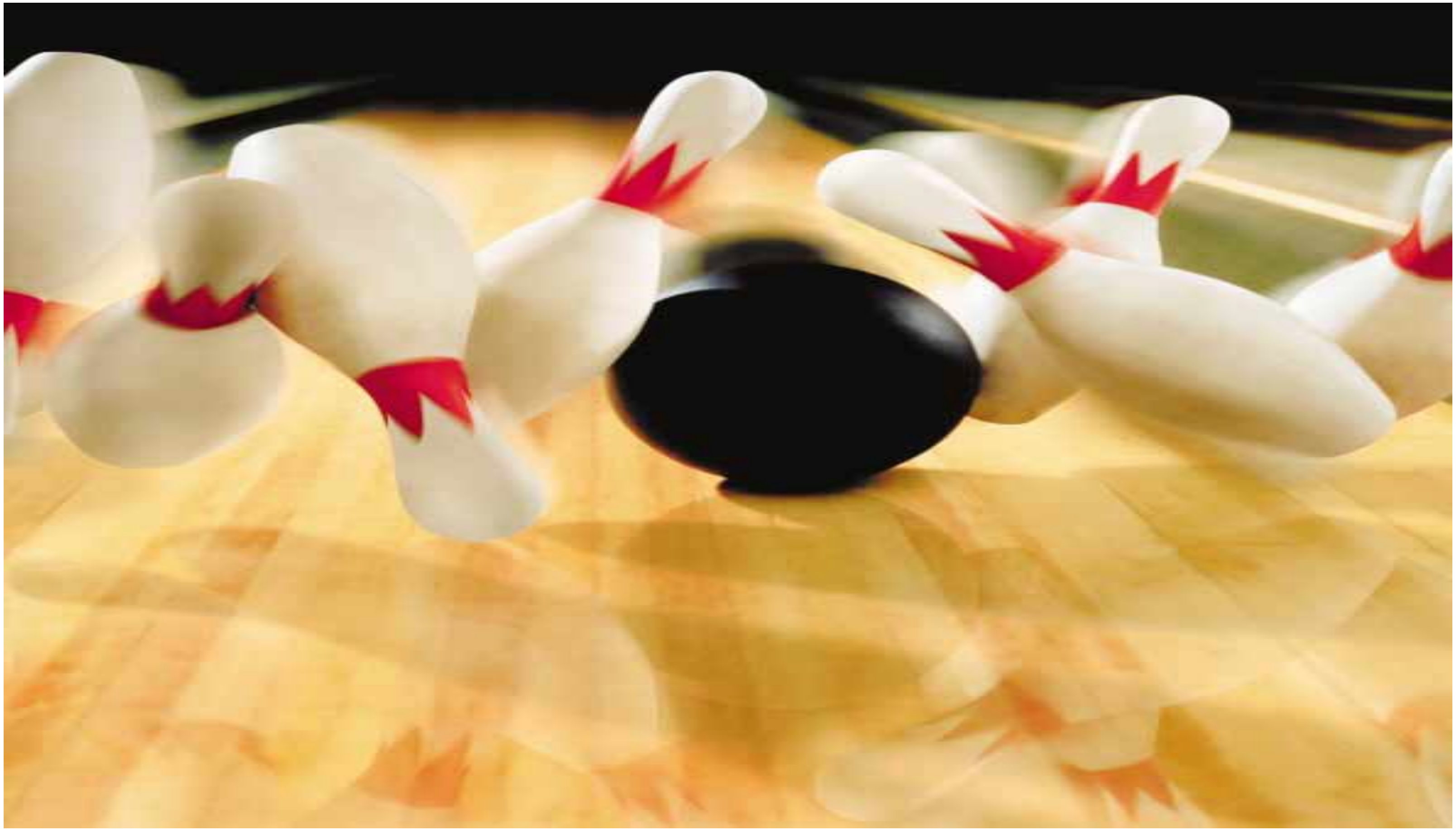
$$\frac{1}{2}mv_i^2 + mgy_i = \frac{1}{2}mv_f^2 + mgy_f$$

$$0 + mgy_i = \frac{1}{2}mv_f^2 + 0$$

$$v_f = \sqrt{2gy_i} = \sqrt{2(9.80m/s)^2(10.0m)} = 14.0m/s$$



Linear Momentum



Linear Momentum

- **Is defined to be equal to the mass of an object times its velocity.**

$$\vec{p} = m\vec{v}$$

- Momentum is a vector quantity.

- The vector for linear momentum points in the same direction as the velocity.

- S.I unit of momentum : Kg . m/s

Linear Momentum

The relationship between m & v

- Huge ship moving at a small velocity

$$P = Mv$$

- High velocity bullet

$$P = {}_{m}V$$

Linear Momentum

The relationship between m & v

Example :

- A 10,000 kg truck moving at 2 m/s has a linear momentum of 20,000 kg.m/s ,while a 80 kg bicyclist moving at 2 m/s has a linear momentum of 160 kg m/s.
- The truck has a much larger linear momentum even though both are moving at the same velocity.
- It is easier to bring the bicyclist to a stop than it is to bring the truck to a stop.
- Similarly, it is easier to stop a bicyclist moving at 2 m/s than a bicyclist moving at 5 m/s.

Impulse

Using Newton's Second Law

$$\Sigma F = ma$$
$$= m(\Delta v/\Delta t)$$
$$= (\Delta mv)/(\Delta t)$$
$$= (\Delta p/ \Delta t)$$

Rearranging,

$$\text{Impulse} = \Delta p = F\Delta t$$

How hard is it to stop a moving object?

To stop an object, we have to apply a force over a period of time.

This is called **Impulse**

$$\text{Impulse} = \vec{F}\Delta t \qquad \text{Units: N·s}$$

F = force (N)

Δt = time elapsed (s)

Homework

1- A student lifts a 50 pound (lb) ball 4 feet (ft) in 5 seconds (s). How many joules of work has the student completed?

2- what is the kinetic energy of a jogger with a mass of 65 kg traveling with a speed of 2.5 m/s?

3- find the potential energy of a street light that has mass of 13 kg and is 4.8 meters above the ground.

4. What distance is a book from the floor if the book contains 196 joules of potential energy and has a mass of 5 kilograms?