WE02 POTENTIAL ENERGY & CONSERVATION OF ENERGY

SPH4U

EQUATIONS

- Gravitational Potential Energy

$$\Delta E_P = mg\Delta y$$

- Thermal Energy

$$E_{th} = F_K \Delta d$$

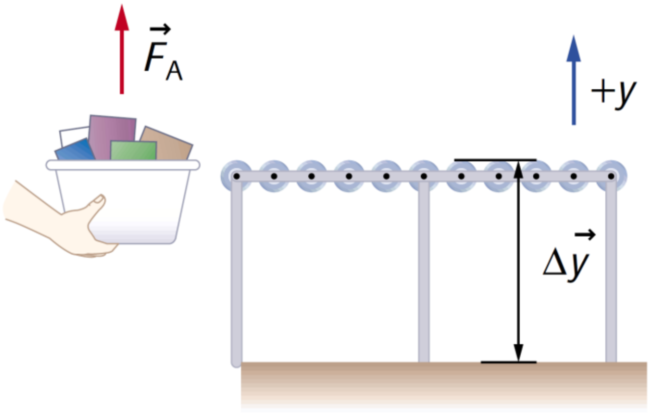
GRAVITATIONAL POTENTIAL ENERGY

- **Gravitational Potential Energy (E_g) [J]:** the energy due to elevation above Earth's surface

$$E_g = mgy \qquad\qquad W = \Delta E_g = mg\Delta y$$

  - m – mass of the object [kg]
  - g – gravitational field strength at the surface [m/s^2]
  - $y/\Delta y$ – vertical position relative to surface/ displacement [m]

NOTE: $W = \Delta E_g$ when there is <u>only</u> a change in gravitational potential energy

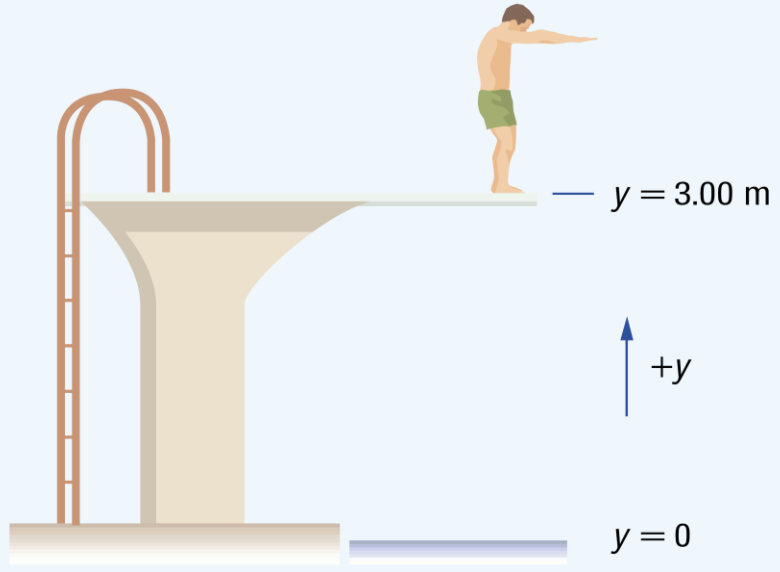


POINTS TO CONSIDER

- The equation determines the change in gravitational potential energy and does *not* determine an absolute value of gravitational potential energy. In practical problems involving the equation, Earth's surface is often used as a reference level of zero gravitational potential energy, although any other convenient arbitrary level may be chosen.
- The value of y is the vertical displacement of the object. This means that the horizontal path an object follows in changing its vertical height is not significant.
- The equation may only be used when y is small enough that g does not vary appreciably over y.
- Values of y (and E_g) are positive if the displacement is upward, and negative if the displacement is downward.

PROBLEM 1

A diver, of mass 57.8 kg, climbs up a diving-board ladder and then walks to the edge of the board. He then steps off the board and falls vertically from rest to the water 3.00 m below. The situation is shown in **Figure 3**. Determine the diver's gravitational potential energy at the edge of the diving board, relative to the water.



PROBLEM 1 – SOLUTIONS

The $+y$ direction is upward. The reference position ($y = 0$) is the level of the water.

$m = 57.8$ kg

$g = 9.80$ m/s^2

$\Delta y = 3.00$ m

$\Delta E_g = ?$

$$\Delta E_g = mg\Delta y$$
$$= (57.8 \text{ kg})(9.80 \text{ m/s}^2)(3.00 \text{ m})$$
$$\Delta E_g = 1.70 \times 10^3 \text{ J}$$

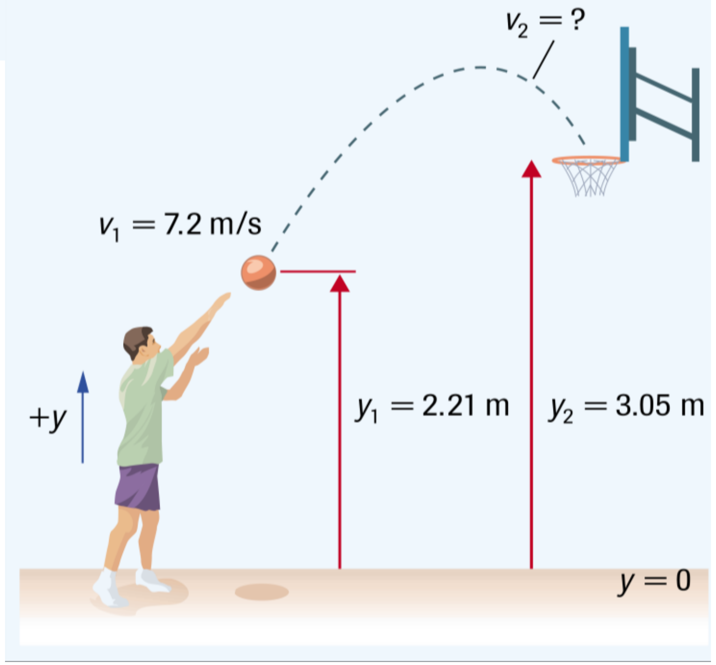
The diver's gravitational potential energy relative to the water is 1.70×10^3 J.

THE LAW OF CONSERVATION OF ENERGY

- **Law of Conservation of Energy:** for an isolated system, energy can be converted into different forms, but cannot be created or destroyed.
  - NOT the same as Energy Conservation!
- **Isolated System:** a system of particles that is completely isolated from outside influences

PROBLEM 2

A basketball player makes a free-throw shot at the basket. The basketball leaves the player's hand at a speed of 7.2 m/s from a height of 2.21 m above the floor. Determine the speed of the basketball as it goes through the hoop, 3.05 m above the floor. **Figure 1** shows the situation.



PROBLEM 2 – SOLUTIONS

According to the law of conservation of energy, the total energy of the basketball is constant as it travels through the air. Using the subscript 1 for the release position and 2 for the position where the basketball goes through the hoop, and taking the heights y_1 and y_2 relative to the floor,

$v_1 = 7.2\text{ m/s}$ $\quad$ $g = 9.80\text{ m/s}^2$

$y_1 = 2.21\text{ m}$ $\quad$ $v_2 = ?$

$y_2 = 3.05\text{ m}$

Applying the law of conservation of energy:

$$E_{T1} = E_{T2}$$

$$\frac{1}{2}mv_1^2 + mgy_1 = \frac{1}{2}mv_2^2 + mgy_2$$

$$mv_1^2 + 2mgy_1 = mv_2^2 + 2mgy_2$$

$$v_1^2 + 2gy_1 = v_2^2 + 2gy_2$$

$$v_2^2 = v_1^2 + 2gy_1 - 2gy_2$$

$$v_2^2 = v_1^2 + 2g(y_1 - y_2)$$

$$v_2 = \pm\sqrt{v_1^2 + 2g(y_1 - y_2)}$$

$$= \pm\sqrt{(7.2\text{ m/s})^2 + 2(9.80\text{ m/s}^2)(2.21\text{ m} - 3.05\text{ m})}$$

$$v_2 = \pm 5.9\text{ m/s}$$

Only the positive square root applies since speed is always greater than zero. The speed of the basketball through the hoop is therefore 5.9 m/s. It is logical that this speed is less than the release speed because the ball is at a higher level; the gravitational potential energy of the ball is greater while its kinetic energy (and thus its speed) must be less.

OTHER FORMS OF ENERGY

- **Thermal Energy (E_{th}) [j]:** internal energy associated with the motion of atoms and molecules

$$E_{th} = F_K \Delta d$$

  - F_K – force of kinetic friction [N]
  - Δd – displacement [m]

- Equation comes from energy being converted to thermal energy by kinetic friction, through work being done to slow down an object

PROBLEM 3

After leaving a player's hand, a 19.9-kg curling rock slides in a straight line for 28.8 m, experiencing friction with a coefficient of kinetic friction of 0.105. The situation is shown in **Figure 5**.

(a) How much thermal energy is produced during the slide?

(b) Determine, using energy conservation, the rock's speed just as it left the player's hand.

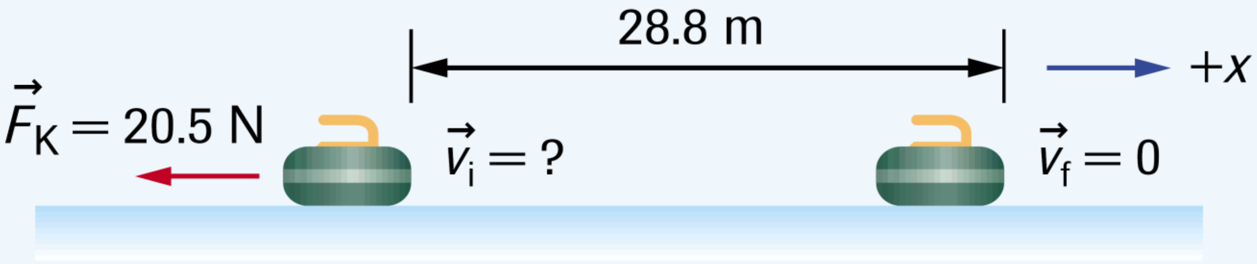


Figure 5
Using components to illustrate the rock's motion

PROBLEM 3 – SOLUTIONS

(a) $\mu_K = 0.105$ $\quad F_K = \mu_K F_N$

$m = 19.9 \text{ kg}$ $\quad F_N = mg$

$\Delta d = 28.8 \text{ m}$ $\quad E_{th} = ?$

$$E_{th} = F_K \Delta d$$
$$= \mu_K F_N \Delta d$$
$$= \mu_K mg \Delta d$$
$$= (0.105)(19.9 \text{ kg})(9.80 \text{ N/kg})(28.8 \text{ m})$$
$$E_{th} = 5.90 \times 10^2 \text{ J}$$

The thermal energy produced is 5.90×10^2 J.

PROBLEM 3 – SOLUTIONS CONT.

(b) According to the law of conservation of energy, the initial kinetic energy of the rock must equal the thermal energy produced during the slide, because there is no kinetic energy remaining at the end of the slide. (Gravitational potential energy is not considered because the ice surface is level.)

$E_{th} = 5.90 \times 10^2 \text{ J}$

$v_i = ?$

$$E_{Ki} = E_{th}$$

$$\frac{mv_i^2}{2} = E_{th}$$

$$v_i^2 = \frac{2E_{th}}{m}$$

$$v_i = \pm\sqrt{\frac{2(5.90 \times 10^2 \text{ J})}{19.9 \text{ kg}}}$$

$$v_i = \pm 7.70 \text{ m/s}$$

We choose the positive root because speed is always positive. Thus, the rock's initial speed is 7.70 m/s.

OTHER FORMS OF ENERGY – CONT.

Form of Energy	Comment
electromagnetic	• carried by travelling oscillations called electromagnetic waves • includes light energy, radio waves, microwaves, infrared waves, ultraviolet waves, X rays, and gamma rays • travels in a vacuum at 3.00×10^8 m/s, the speed of light
electrical	• results from the passage of electrons, for example, along wires in appliances in your home
electric potential	• associated with electric force • changes as charges are moved

OTHER FORMS OF ENERGY – CONT.

Form of Energy	Comment
gravitational potential	• associated with the gravitational force • changes as masses are moved relative to each other
chemical potential	• stored in the chemical bonds that hold the atoms of molecules together
nuclear potential	• the stored energy in the nucleus of an atom • converts into other forms by rearranging the particles inside a nucleus, by fusing nuclei together (fusion), or by breaking nuclei apart (fission)
sound	• carried by longitudinal waves from molecule to molecule

OTHER FORMS OF ENERGY – CONT.

Form of Energy	Comment
elastic potential	• stored in objects that are stretched or compressed
thermal	• associated with the motion of atoms and molecules • for a monatomic gas such as helium, it is the total kinetic energy of all the atoms • for more complicated molecules and for atoms in solids, it is partly kinetic energy and partly electric potential energy • differs from heat, which is the transfer of energy due to a difference in temperatures

SUMMARY – GRAVITATIONAL POTENTIAL ENERGY AT EARTH'S SURFACE

- Gravitational potential energy is the energy possessed by an object due to its elevation above Earth's surface. It is a scalar quantity measured in joules (J).
- Gravitational potential energy is always stated relative to a reference level.
- The gravitational potential energy of an object depends on its mass, the gravitational field in which the object is located, and the object's height above a reference level.

SUMMARY – THE LAW OF CONSERVATION OF ENERGY

- The law of conservation of energy states that for an isolated system, energy can be converted into different forms, but cannot be created or destroyed.
- The work done on a moving object by kinetic friction results in the conversion of kinetic energy into thermal energy.
- The law of conservation of energy can be applied to solve a great variety of physics problems.

PRACTICE

Readings

- Section 4.3, pg 189
- Section 4.4, pg 195

Questions

- pg 194 #1-5
- pg 201 #1,3,5,7,9