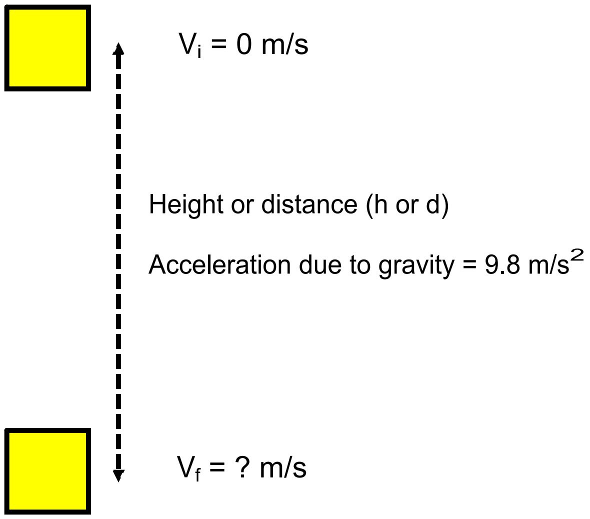
Sec. 4.3 - 4.4 - Gravitational Potential Energy (near the surface) & Conservation of Energy

Learning Goal: By the end of today, I will be able to determine the gravitational potential energy in a closed system, and use the conservation of energy concept to determine unknowns in a closed system.

Gravitational Potential Energy: A Stored Type of Energy

An object suspended in the air has the Potential Energy.
(starts moving, thus it has speed, and therefore kinetic energy)



$E_{Potential} = ?$

$$E_K = \frac{mv^2}{2}$$

Let's work the problem backwards, from the bottom up.

$$E_K = \frac{m{v_f}^2}{2}$$

The kinetic energy at the bottom is base on V_f, but V_f is related to V_i , acceleration, and height, by the following kinematic equation.

$$V_f^2 = V_i^2 + 2a \cdot \Delta d$$

$$E = \frac{m(v_i^2 + 2ad)}{2}$$

If we replaced the V_f in the Kinetic energy equation...

$$E = \frac{m(0 + 2ah)}{2}$$

and replaced the V_i with Zero since we are starting from rest,

$$E = \frac{m(2gh)}{2}$$

and replaced the "d" with an "h" for height

and replaced the "a" with a "g" for acceleration due to gravity, simplified, we would come up with...

$$E_g = mgh$$

$$\Delta E_g = mg\Delta y$$

change in energy change in height

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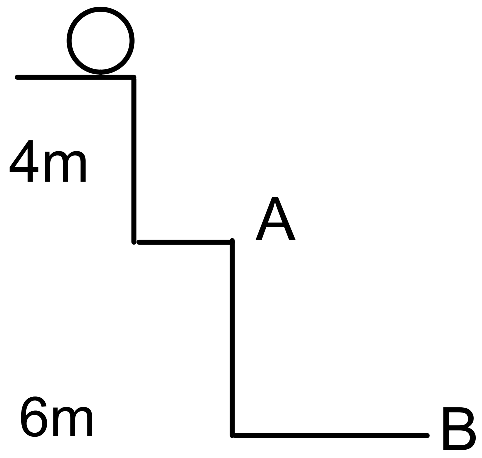
What is the potential energy for the 10 kg mass given the following conditions:



(a) relative to A

(b) relative to B

Law of Conservation of Energy

The total amount of energy in the universe is conserved. There is a certain total amount of energy in the universe, and this total never changes. New energy cannot be created out of nothing, and existing energy cannot disappear; the energy that exists can only be changed from one form into another. When an energy transformation occurs, no energy is lost.

$$E_m = E_k + E_g$$

or

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

(Ideal system)

A 65 kg diver is about to jump from the 10m high diving board.

Calculate his potential and kinetic energy before, half way, and at the end of his jump.

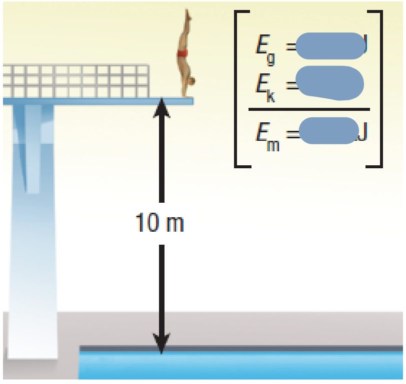


Figure 3 Phase 1: before the dive

Potential $E_g = mgd$ Kinetic $E_k = 0.5mv^2$

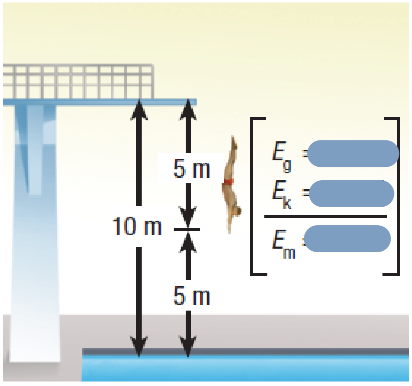


Figure 4 Phase 2: at the halfway point

Potential $E_g = mgd$ Kinetic $E_k = 0.5mv^2$

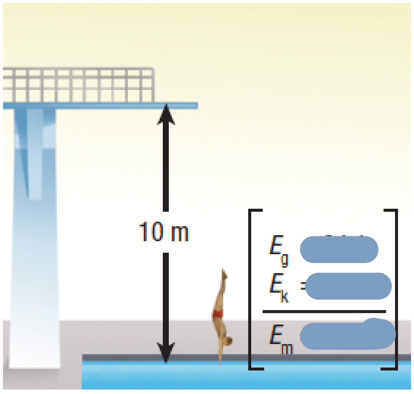


Figure 5 Phase 3: at the water's surface

Potential $E_g = mgd$ Kinetic $E_k = 0.5mv^2$

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.

Energy is a scalar, so directions are not important.

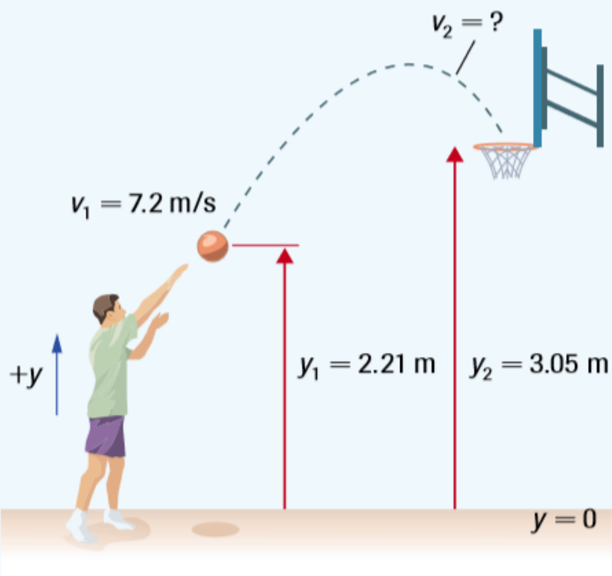


Figure 1

Solution

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,

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

$y_1 = 2.21$ m $\quad v_2 = ?$

$y_2 = 3.05$ m

Applying the law of conservation of energy:

$$E_{T1} = E_{T2}$$
$$\frac{1}{2}mv_1^2 + mgy_1 = \frac{1}{2}mv_2^2 + mgy_2$$
$$mv_1^2 + 2mgy_1 = mv_2^2 + 2mgy_2$$
$$v_1^2 + 2gy_1 = v_2^2 + 2gy_2$$
$$v_2^2 = v_1^2 + 2gy_1 - 2gy_2$$
$$v_2^2 = v_1^2 + 2g(y_1 - y_2)$$
$$v_2 = \pm\sqrt{v_1^2 + 2g(y_1 - y_2)}$$
$$= \pm\sqrt{(7.2 \text{ m/s})^2 + 2(9.80 \text{ m/s}^2)(2.21 \text{ m} - 3.05 \text{ m})}$$
$$v_2 = \pm 5.9 \text{ m/s}$$

Conservation of Energy

Other forms of energy

$$E_{k1} + E_{g1} + E_{other1} = E_{k2} + E_{g2} + E_{other2}$$

Table 2 Common Forms of Energy

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
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
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

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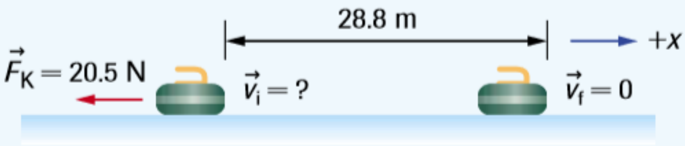
After leaving a player's hand, a 19.9-kg curling rock slides in a straight line for 28.8 m, experiencing friction with a coefficient of kinetic friction of 0.105. The situation is shown in **Figure 5**. Draw a picture and FBD please - what types of energy are present.

(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.



$E_{k1} + E_{g1} = E_{k2} + E_{g2} + E_{other2}$

Figure 5
Using components to illustrate the rock's motion

Solution

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

$m = 19.9$ kg $\quad F_N = mg$

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

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

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

(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.)

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

$v_i = ?$

$$\begin{aligned} E_{Ki} &= E_{th} \\ \frac{mv_i^2}{2} &= E_{th} \\ v_i^2 &= \frac{2E_{th}}{m} \\ v_i &= \pm\sqrt{\frac{2(5.90 \times 10^2 \text{ J})}{19.9 \text{ kg}}} \\ v_i &= \pm 7.70 \text{ m/s} \end{aligned}$$

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

Efficiency

Efficiency is the ratio of the amount of useful energy produced (energy output, or E_{out}) to the amount of energy used (energy input, or E_{in}), expressed as a percentage. Efficiency is calculated as follows:

$$\text{efficiency} = \frac{E_{out}}{E_{in}} \times 100\ \%$$

An 80kg person climbs a stairwell with a vertical change in height of 5m. If it required 4300J of chemical energy to accomplish the task, how efficient is their body at converting energy?

Physicists use the word power (P) to describe the rate at which energy is transformed, or the rate at which work is done. Your body produces more power when you run up a set of stairs than when you climb up slowly. We may describe power mathematically as follows:

$$P = \frac{\Delta E}{\Delta t} \quad \text{or} \quad P = \frac{W_{net}}{\Delta t}$$

delta Δ = "change in"

Energy, work, and time are scalar quantities, so power is also a scalar quantity (it has no direction associated with it). Since energy and work are measured in joules and time is measured in seconds, power is measured in joules per second (J/s). In the SI system, the unit for power is called the watt (W) in honour of James Watt, a Scottish engineer who invented the first practical steam engine. One watt is equal to 1 J/s.

A small tweak to the power relationship

$$P = \frac{\Delta E}{\Delta t}$$

$$P = \frac{Work}{\Delta t} \qquad P = \frac{F \cdot \Delta d}{\Delta t} \qquad P = F\frac{\Delta d}{\Delta t}$$

$$P = F \cdot v$$

J/s N m/s

A constant force of 300N is required to keep a car moving at 25m/s. What is the power usage of the car?

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.

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Homework

4.3

Read 189 - 194

4.4

Read 195 - 201

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