

# Applications of Energy and Momentum

by Zack Ridgway and Jeffrey Wan

# KINETIC ENERGY

Kinetic energy- energy of an object that it possesses due to its motion.

## Common examples

- A baseball thrown by a pitcher, although having a small mass, can have a large amount of kinetic energy due to its fast velocity.
- A downhill skier traveling down a hill has a large amount of kinetic energy because of their mass and high velocity.
- An asteroid falling to earth at incredible speeds has an enormous amount of kinetic energy.

# KINETIC ENERGY PROBLEM

Suppose a 30kg package on a conveyor belt system is moving at .500m/s. What is its kinetic energy?

$$KE = \frac{1}{2}mv^2$$

$$KE = \frac{1}{2}(30\text{kg})(.500\text{m/s})^2$$

$$KE = 3.75\text{J}$$

# POTENTIAL ENERGY

Potential energy- is the energy that an object has due to its position in a force field or that a system has due to the configuration of its parts.

## Examples

- A coiled spring
- A child at the top of the slide
- A Ferris wheel before it starts moving

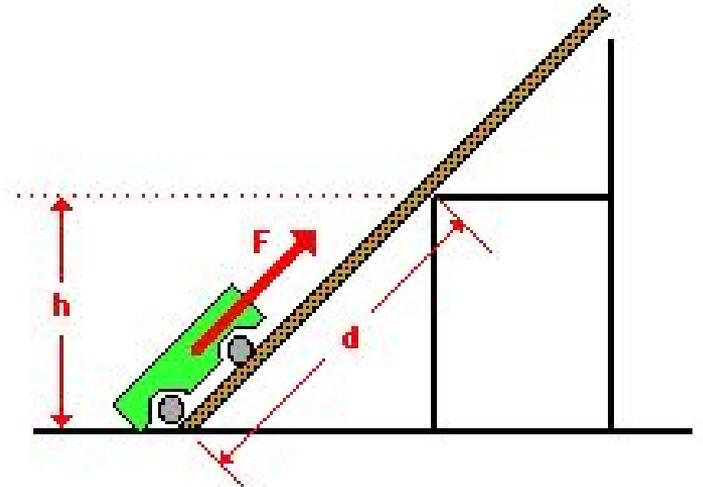
# POTENTIAL ENERGY PROBLEM

1. A cart is loaded with a brick and pulled at constant speed along an inclined plane to the height of a seat-top. If the mass of the loaded cart is 3.0 kg and the height of the seat top is 0.45 meters, then what is the potential energy of the loaded cart at the height of the seat-top?

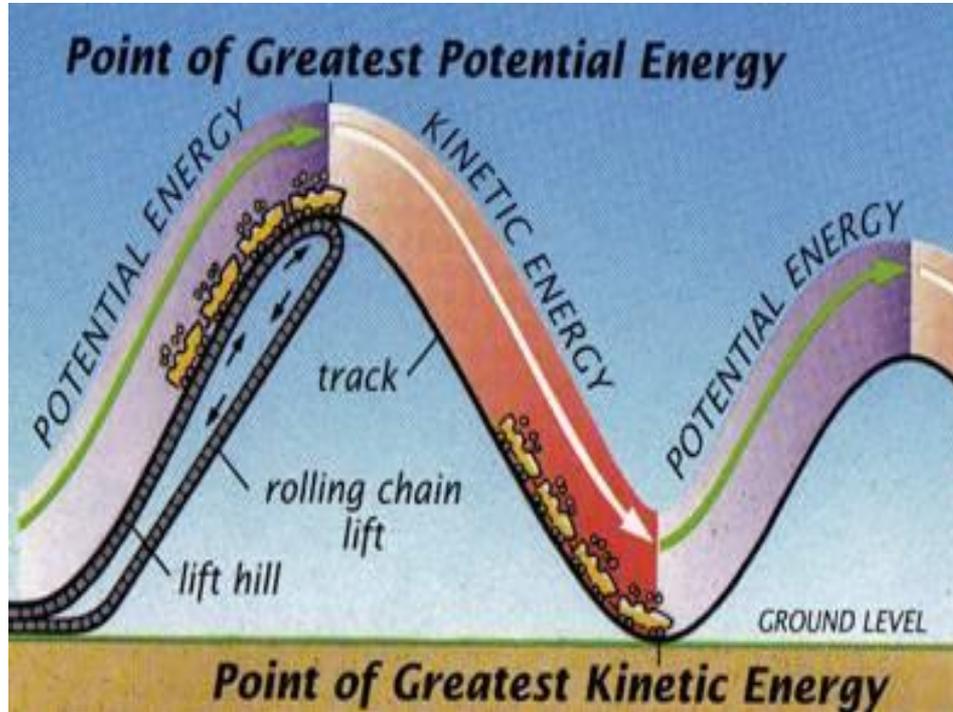
$$PE = m \times g \times h$$

$$PE = (3\text{kg}) (9.8\text{m/s}) (0.45\text{m})$$

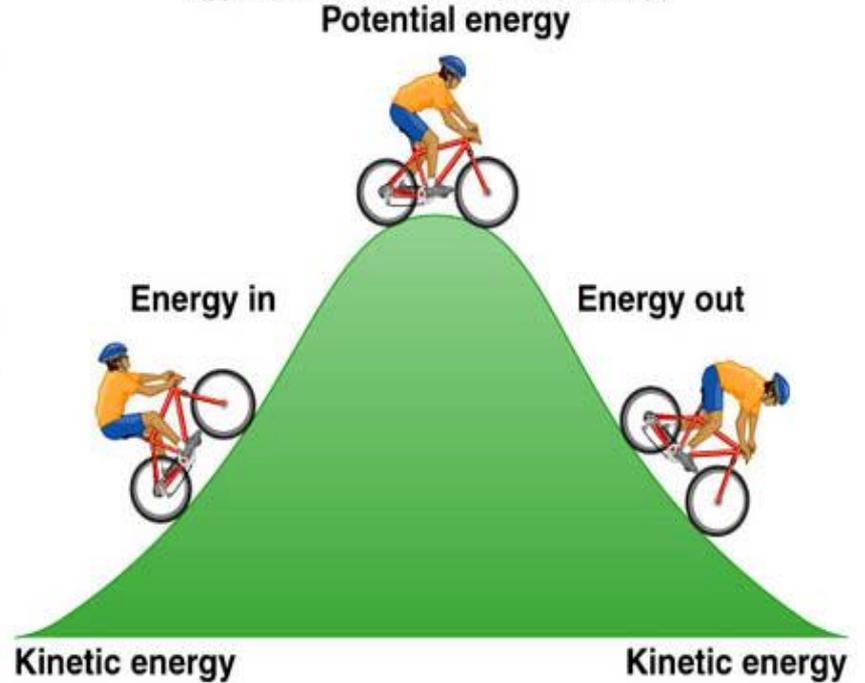
$$PE = 13.2\text{J}$$



# COMPARISONS



Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.



# GRAVITATIONAL POTENTIAL ENERGY

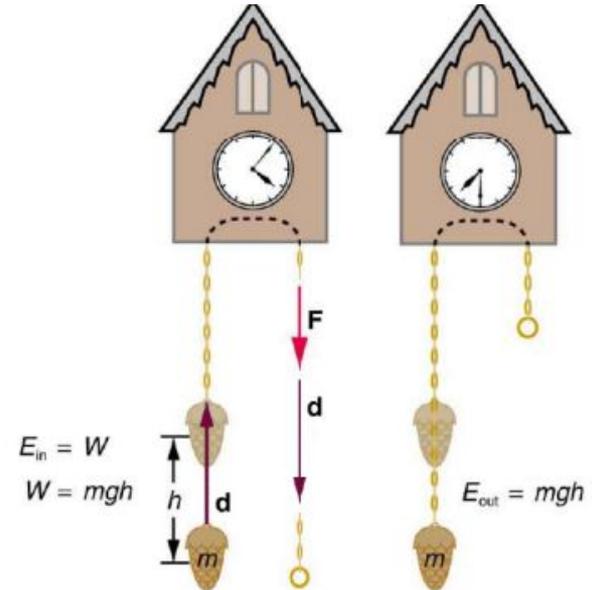
## Converting Between Potential Energy and Kinetic Energy

Gravitational potential energy may be converted to other forms of energy, such as kinetic energy. If we release the mass, gravitational force will do an amount of work equal to  $mgh$  on it, thereby increasing its kinetic energy by that same amount (by the work-energy theorem). We will find it more useful to consider just the conversion of  $PE_g$  to  $KE$  without explicitly considering the intermediate step of work. (See **Example 7.7.**) This shortcut makes it easier to solve problems using energy (if possible) rather than explicitly using forces.

$$\Delta PE_g = mgh, \quad (7.27)$$

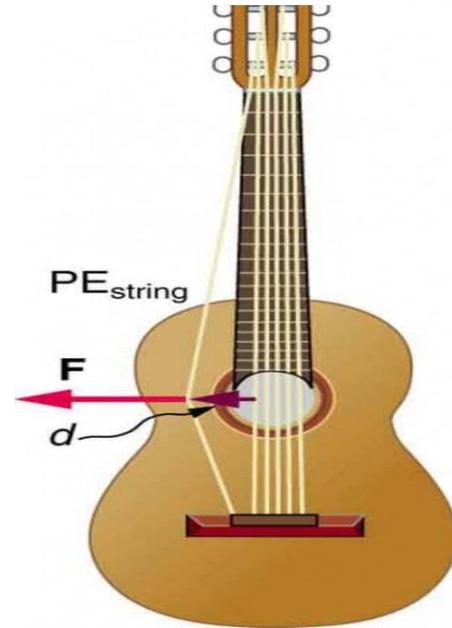
where, for simplicity, we denote the change in height by  $h$  rather than the usual  $\Delta h$ . Note that  $h$  is positive when the final height is greater than the initial height, and vice versa. For example, if a 0.500-kg mass hung from a cuckoo clock is raised 1.00 m, then its change in gravitational potential energy is

$$\begin{aligned} mgh &= (0.500 \text{ kg})(9.80 \text{ m/s}^2)(1.00 \text{ m}) \\ &= 4.90 \text{ kg} \cdot \text{m}^2/\text{s}^2 = 4.90 \text{ J}. \end{aligned} \quad (7.28)$$



# CONSERVATION FORCES AND POTENTIAL ENERGY

The equation  $PE_s = \frac{1}{2}kx^2$  has general validity beyond the special case for which it was derived. Potential energy can be stored in any elastic medium by deforming it. Indeed, the general definition of **potential energy** is energy due to position, shape, or configuration. For shape or position deformations, stored energy is  $PE_s = \frac{1}{2}kx^2$ , where  $k$  is the force constant of the particular system and  $x$  is its deformation. Another example is seen in **Figure 7.11** for a guitar string.



# WORK

Work is done when a force that is applied to an object moves that object.

$$W = Fd \cos \theta$$

W = Work

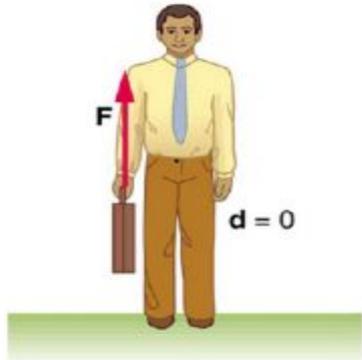
F = Force

d = displacement of system

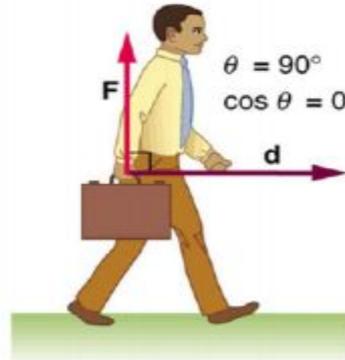
$\theta$  = the angle between force vector (f) and displacement vector(d)

# WORK APPLICATIONS

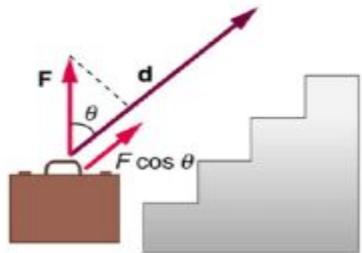
(a)



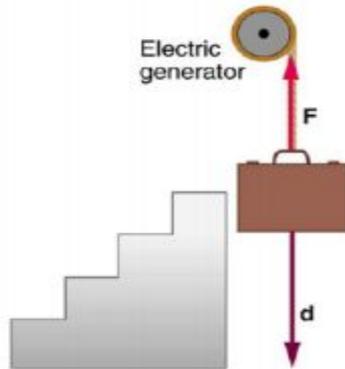
(b)



(c)



(d)



(e)



# POWER

$$P=W/T$$

$$P= \text{Power}$$

$$W= \text{Work}$$

$$T = \text{Time}$$

Table 7.3 Power Output or Consumption

Object or Phenomenon	Power in Watts
Supernova (at peak)	$5 \times 10^{37}$
Milky Way galaxy	$10^{37}$
Crab Nebula pulsar	$10^{28}$
The Sun	$4 \times 10^{26}$
Volcanic eruption (maximum)	$4 \times 10^{15}$
Lightning bolt	$2 \times 10^{12}$
Nuclear power plant (total electric and heat transfer)	$3 \times 10^9$
Aircraft carrier (total useful and heat transfer)	$10^8$
Dragster (total useful and heat transfer)	$2 \times 10^6$
Car (total useful and heat transfer)	$8 \times 10^4$
Football player (total useful and heat transfer)	$5 \times 10^3$
Clothes dryer	$4 \times 10^3$
Person at rest (all heat transfer)	100
Typical incandescent light bulb (total useful and heat transfer)	60
Heart, person at rest (total useful and heat transfer)	8
Electric clock	3
Pocket calculator	$10^{-3}$

Table 7.4 Basal Metabolic Rates (BMR)

Organ	Power consumed at rest (W)	Oxygen consumption (mL/min)	Percent of BMR
Liver & spleen	23	67	27
Brain	16	47	19
Skeletal muscle	15	45	18
Kidney	9	26	10
Heart	6	17	7
Other	16	48	10
<b>Totals</b>	<b>85 W</b>	<b>250 mL/min</b>	<b>100%</b>

# MOMENTUM

Momentum is directly proportional to the object's mass and also its velocity.

Applications:

Linear Momentum

Momentum and Newton's Second Law

Conservation of Momentum

Impulse

# LINEAR MOMENTUM

**linear momentum** is defined as the product of a system's mass multiplied by its velocity

$$p=mv$$

p= momentum

m=mass

v=velocity

The greater the mass or velocity the greater the momentum will be.

# LINEAR MOMENTUM PROBLEM

- a) Calculate the momentum of a 110- kg football player running at 8.0 m/s
- b) Compare the player's momentum of a hard thrown 0.410kg football that has a speed of 25m/s

To determine the momentum of the player, substitute the known values for the player's momentum and speed into the equation  $p=mv$

$$P(\text{player}) = (110\text{kg})(8\text{m/s}) = 880\text{kgxm/s}$$

To determine the momentum of the ball, substitute the known values for the ball's mass and speed into the equation  $p=mv$

$$P_{\text{ball}} = (.410\text{kg})(25\text{m/s}) = 10.3\text{kgxm/s}$$

# NEWTON'S SECOND LAW OF MOTION

- Newton's second law in terms of momentum states that the net external force equals the change in momentum divided by the time over which it changes.

$$F_{\text{net}} = \Delta p / \Delta t$$

$F_{\text{net}}$  is the external force

$\Delta p$  is the change in momentum

$\Delta t$  is the change in time

# NEWTON'S SECOND LAW OF MOTION PROBLEM

During the 2007 French Open, Venus Williams hit the fastest recorded serve in a premier women's match, reaching a speed of 58 m/s (209 km/h). What is the average force exerted on the 0.057-kg tennis ball by Venus Williams' racquet, assuming that the ball's speed just after impact is 58 m/s, that the initial horizontal component of the velocity before impact is negligible, and that the ball remained in contact with the racquet for 5.0 ms (milliseconds)?

## Solution

To determine the change in momentum, substitute the values for the initial and final velocities into the equation above.

$$\begin{aligned}\Delta p &= m(v_f - v_i) && (8.15) \\ &= (0.057 \text{ kg})(58 \text{ m/s} - 0 \text{ m/s}) \\ &= 3.306 \text{ kg} \cdot \text{m/s} \approx 3.3 \text{ kg} \cdot \text{m/s}\end{aligned}$$

Now the magnitude of the net external force can be determined by using  $F_{\text{net}} = \frac{\Delta p}{\Delta t}$ :

$$\begin{aligned}F_{\text{net}} &= \frac{\Delta p}{\Delta t} = \frac{3.306 \text{ kg} \cdot \text{m/s}}{5.0 \times 10^{-3} \text{ s}} && (8.16) \\ &= 661 \text{ N} \approx 660 \text{ N}.\end{aligned}$$

# IMPULSE

$$F_{\text{net}} = \Delta P / \Delta T$$

Quantity  $F_{\text{net}}\Delta T$  is given the name impulse

Two identical billiard balls strike a rigid wall with the same speed, and are reflected without any change of speed. The first ball strikes perpendicular to the wall. The second ball strikes the wall at an angle of  $30^\circ$  from the perpendicular, and bounces off at an angle of  $30^\circ$  from perpendicular to the wall.

(a) Determine the direction of the force on the wall due to each ball.

In order to determine the force on the wall, consider the force on the ball due to the wall using Newton's second law and then apply Newton's third law to determine the direction. Assume the  $x$ -axis to be normal to the wall and to be positive in the initial direction of motion. Choose the  $y$ -axis to be along the wall in the plane of the second ball's motion. The momentum direction and the velocity direction are the same.

# APPLICATION WITH CONSERVATION OF MOMENTUM

If a football player runs into a goal post at the end of the endzone then, there will be a force that sends him backwards. The Earth also recoils- conserving momentum- because of the force applied to it through the goalpost. Because the Earth is many orders of magnitude more massive than the player, its recoil is immeasurably small and can be neglected in any practical sense, but is real.

# ROCKET APPLICATION

By calculating the change in momentum for the entire system over  $\Delta t$ , and equating this change to the impulse, the following expression can be shown to be a good approximation for the acceleration of the rocket.

$$a = \frac{v_e}{m} \frac{\Delta m}{\Delta t} - g \quad (8.77)$$

A Saturn V's mass at liftoff was  $2.80 \times 10^6$  kg, its fuel-burn rate was  $1.40 \times 10^4$  kg/s, and the exhaust velocity was  $2.40 \times 10^3$  m/s. Calculate its initial acceleration.

Substituting the given values into the equation for acceleration yields

$$\begin{aligned} a &= \frac{v_e}{m} \frac{\Delta m}{\Delta t} - g \\ &= \frac{2.40 \times 10^3 \text{ m/s}}{2.80 \times 10^6 \text{ kg}} (1.40 \times 10^4 \text{ kg/s}) - 9.80 \text{ m/s}^2 \\ &= 2.20 \text{ m/s}^2. \end{aligned}$$

# LAB ACTIVITY

<https://www.youtube.com/watch?v=sCmX5R7KDFM>

Answer the following question

what is the formula for:

Momentum, Kinetic Energy and Impulse

# THANKS FOR LISTENING!

By Zack Ridgway and Jeffrey Wan