AP Physics-B **Energy And Its Conservation**

Introduction: Energy is a term that most of us take for granted and use quite freely. We assume we know what we are talking about when speaking of energy. In truth, energy is probably the most complex and least understood of all physical quantities. Thus, in this unit, energy will be defined as the capacity to do work. However, this definition states what energy does, not what it is. Still, as you learn the basic concepts related to energy, we will refer to it in this way.

All forms of energy are interchangeable. When energy changes form – the total energy of a system remains the same.

Performance Objectives: Upon completion of the activities and readings of this unit, and when asked to respond either orally or on a written test, you will:

- ✓ Define work as the product of force and displacement and in terms of energy transfer.
- ✓ Define kinetic energy. Calculate the kinetic energy of a body given the mass and velocity of the body. Calculate the change in kinetic energy of a body given the force applied and the displacement.
- ✓ Define potential energy. Calculate the gravitational potential energy of a body near the surface of the earth.
- ✓ State the law of conservation of energy.
- ✓ Define elastic collision. Use the conservation of energy and momentum to solve collision problems in one dimension. Solve problems with equal mass colliding elastically at an angle.
- ✓ Define inelastic collision.
- ✓ Describe energy changes in a pendulum swing. Solve problems associated with a pendulum.

Kinetic Energy: The energy an object possesses because of its motion. Kinetic energy depends on mass and velocity. $\mathbf{K = \frac{1}{2}mv^2}$. The net work done on a body can change its kinetic energy: $\mathbf{Work_{net} = \Delta K = K_f - K_i}$

Problems and Exercises:

1.) An 8.0 kg mass moves at 30.0 m/s. What is its kinetic energy? *3600J*

2.) An electron with a mass of 9.1×10^{-31} kg moves through a vacuum with a speed of 2.5×10^{8} m/s. Find the electron's kinetic energy. *2.8×10^{-14} J*

3.) An alpha particle travels at 1.6×10^{7} m/s. The kinetic energy of the particle is 6.0×10^{-13} J. What is the mass of the alpha particle? *4.7×10^{-27} kg*

4.) A baseball that weighs 1.6 N leaves a bat with a speed of 40.0 m/s. Calculate the kinetic energy of the ball. *130 J*

5.) A 10.0 kg body has a kinetic energy of 500.0 J. What is the body's velocity? What is its momentum? 10 m/s *100 kg·m/s*

6.) A 10.0 kg body at rest on a frictionless table receives an impulse of 30.0 N·s. What is its final kinetic energy? *45 J*

7.) A constant 20.0 N force acts for 10.0 s on a 5.0 kg object that is initially at rest. a.) What is the object's final momentum? b.) What is the object's final kinetic energy? c.) How much work must be done in accelerating the body? *200 kg·m/s* *4000 J* *4000 J*

8.) A 10.0 kg mass is moving with constant speed of 10.0 m/s. a.) How much work must be done to double the speed to 20 m/s? b.) How much work must be done to reduce its speed to 5.0 m/s? *1500 J* *375 J*

9.) A car of mass 1100 kg moves at 20 m/s. A breaking force of 1200 N is needed to bring the car to a halt. a.) What is its stopping distance? b.) If the same car is moving at 40 m/s, what is its stopping distance?
183 m 732 m

10.) What is the kinetic energy of a 1600 kg car which moves at a.) 30.0 km/hr? b.) 60.0 km/hr? c.) What is the ratio of (b) to (a)? *55000 J 220000 J 4:1*

11.) How does the kinetic energy of a car change when its speed is doubles?

12.) Compare the kinetic energies of two objects, A and B, identical in every aspect except one. Assume that the singe difference is: a.) Object A has twice the velocity of B. b.) Object A moves North, B South c.) Object A moves in a circle, B in a straight line. d.) Object A is a projectile falling vertically downward, B is a projectile moving vertically upward at the same speed.

13.) Two bodies of unequal mass each have the same kinetic energy and are moving in the same direction. If the same retarding force is applied to each, how will the stopping distances of the bodies compare?

14.) A force of 30.0 N accelerates a 2.0 kg object from rest for a distance of 3.0 m along a level, frictionless surface; the force then changes to 15 N and acts for an additional 2.0 m a.) What is the final kinetic energy of the object? b.) How fast is it moving? *120 J 11 m/s*

Potential Energy: The energy an object has because of its position, configuration or state. The potential energy an object has due to its position above the surface of the earth is called its gravitational potential energy - U_G. The increase in the potential energy of any system is equal to the work done on the system.

When the distance above the earth is very small compared to the radius of the earth, we consider the gravitational field to be uniform and treat the gravitational force on a body as a constant. If the lowest position is chosen as the zero position, then the work necessary to lift an object a vertical displacement above the zero position is stored as gravitational potential energy: $U_G = -mgh$: where m is the mass in kilograms, g is the acceleration due to gravity in m/s^2 and h is the height above the zero position in meters.

Once again, the increase in the potential energy of any system is equal to the work done on the system. For example, if you lift a 5.0 kg box a distance of 2.0 meters above the ground, the work done on the box is 98 J. You are doing work on the box-earth system. The increase in the potential energy of the box-earth system is 98 J. You are actually working against gravity. The work done by gravity on the box is -98 J. The work done against gravity is stored as potential energy.

15.) A 5.0 kg bowling ball is lifted from the floor to a height of 1.5 m. What is the increase in its potential energy?
73.3 J

16.) A person weighing 630 N climbs up a ladder to a height of 5.0 m. a.) What work does the person do? b.) What is the increase in the potential energy of the earth-person system when the person is at this height?
3150 J

The Law of Conservation of Energy: The total energy of a system cannot change unless work is done on the system. Within an isolated system, energy always remains the same. Energy can never be "lost" by a system.

Work done by a conservative force conserves mechanical energy. If only conservative forces are working in a system, mechanical energy is conserved: $E = K + U$! This means that at any instant, the total mechanical energy (potential and kinetic) is a constant.

We will study two conservative forces in this unit – gravitational and elastic forces. The work done a conservative force always has these properties: 1.) It is equal to the difference between the initial and final values of a potential energy function. 2.) It is reversible. 3.) It is independent of the path of the body and depends only on the starting and ending points. 4.) When the starting and ending points are the same, that is when the body travels a closed path, the total work done by the conservative force is zero.

The conservation of energy can be used to solve problems that would be more complicated if solved directly using Newton's Laws. According to the conservation of mechanical energy: At any instant, the total mechanical energy (potential and kinetic) is a constant. The total mechanical energy at the beginning of a process is equal to the total mechanical energy at the end of the process.

$$\textbf{Work (W)} = \Delta K + -\Delta U \qquad\qquad U_i + K_i = U_f + K_f$$

17.) An 8.0 kg flowerpot falls from a window ledge 12.0 m above the sidewalk. a.) What is the potential energy of the flowerpot just before it falls? b.) What is the kinetic energy of the flowerpot just before it strikes the sidewalk? c.) Determine the speed of the pot just before it strikes the sidewalk. *940 J 940 J 15 m/s*

18.) A 15.0 kg model glider flies horizontally at 12.5 m/s. a.) Calculate its kinetic energy. b.) The plane goes into a power dive and levels off 20.4 m closer to the earth. How much potential energy did it lose during the dive? c.) How much kinetic energy did the plane gain during the dive? d.) What is its new kinetic energy? e.) Neglecting frictional effects, what is its new horizontal velocity?
1171 J 3000 J 3000 J 4171 J 23.6 m/s

19.) A 10.0 kg test rocket is fired from Kennedy Space Center. Its fuel gives it a kinetic energy of 1960 J before it leaves the ramp. How high with the rocket rise? *20 m*

20.) In an electronics factory, small cabinets slide down a 30° incline for a distance of 16 m to reach the next assembly stage. The cabinets have a mass of 10.0 kg each. a.) What kinetic energy would a cabinet attain when it gets to the bottom of the incline? b.) Calculate the speed each cabinet would acquire if the incline were frictionless. *784 J 12.5 m/s*

21.) A ping-pong ball of mass m rolls off the edge of a table that is 1.0 m high. When the ball strikes the floor its velocity is 5.0 m/s. How fast was it rolling when it left the table? *2.3 m/s*

Elastic Collisions: An elastic collision is a collision in which the total kinetic energy of the objects involved is exactly the same before and after the collision. Strictly speaking, all collisions between objects larger than individual particles of matter are inelastic. In an inelastic collision, the total kinetic energy decreases during the collision. In some collisions between large objects, very little kinetic energy is lost and we treat these collisions as elastic collisions. The collision between two billiard balls or two glass marbles moving across a smooth surface is nearly elastic.

The law of conservation of momentum holds for all collisions. Although kinetic energy decreases during an inelastic collision, there is no change in momentum.

In an elastic collision, the behavior of objects is predictable. This is done by considering the laws of conservation of energy and conservation of momentum together.

22.) Two bowling balls, each with a mass of 8.0 kg, roll together along a smooth ramp at 10.0 m/s. they collide with a row of 8.0 kg bowling balls at rest. Collisions between bowling balls are nearly elastic. a.) After the collision, can one bowling ball leave the opposite end of the row with a speed of 20.0 m/s and satisfy the law of conservation of momentum? b.) If one bowling ball did leave the opposite end of the row at 20.0 m/s, what kinetic energy would it possess? What was the total kinetic energy of the two balls before the collision? Would energy be conserved under these circumstances? c.) Two bowling balls leave the opposite ends of the row at 10.0 m/s. Is the law of conservation of momentum obeyed? Is the law of conservation of energy obeyed?
Yes, 1600 J, 800 J, No, Yes, Yes

23.) What happens if a single bowling ball with a mass of 8.0 kg moving at 10.0 m/s collides with a row of stationary bowling balls? That is, will one bowling ball move away from the opposite end of the row at 10.0 m/s? Or will two balls move away from the opposite ends of the row at 5.0 m/s each?

24.) A 10.0 kg mass moving with a velocity of 5.0 m/s right collides head-on with a stationary 10.0 kg mass. The collision is elastic. What is the final velocity of each of the masses? *zero* *5 m/s right*

25.) A 2.0 kg mass moving at a velocity of 2.0 m/s left collides elastically head-on, with a 5.0 kg mass initially at rest. Find the final velocities of both masses. *-0.857 m/s* *1.143 m/s*

26.) A 10.0 kg mass moving with a velocity of 5.0 m/s right collides elastically, with a 5.0 kg mass which is initially at rest. What is the final kinetic energy of the system? *125 J*

27.) A 20 kg mass moving at a speed of 3.0 m/s collides inelastically with a stationary 10.0 kg mass. The two stick together and move off at the same speed. A.) What is the final speed? b.) How much kinetic energy is lost? *2 m/s* *30 J*

28.) A railroad car with a mass of 5.0×10^5 kg collides with a stationary railroad car of equal mass. After the collision, the two cars lock together and move off at 4.0 m/s. a.) Before the collision, the first railroad car moved at 8.0 m/s. What was its momentum? b.) What is the total momentum of the two cars after the collision? c.) Find the kinetic energies of the two cars before and after the collision. d.) Account for the loss of total kinetic energy in the system? *4.0×10^6 N•s* *1.6×10^7 J*

29.) A railroad car with a mass of 1500 kg rolls along a level track at a speed of 10.0 m/s. It collides with a stationary car of equal mass. a.) The two cars lock together and then move off. What is the new velocity? b.) How much kinetic energy is lost during the collision?

Energy Considerations of a Pendulum: The swinging of a pendulum illustrates the way in which potential energy may be transformed into kinetic energy and then back to potential energy. When a pendulum is pulled to one side, the mass has no velocity and no kinetic energy, but it does have potential energy. When the mass is released, it swings downward, acquiring kinetic energy and losing potential energy. At the bottom of the swing, the pendulum bob has maximum kinetic energy. As it swings upward, this kinetic energy is transformed again into potential energy. A very similar transformation of energy can be traced in the case of a mass on the end of a spring also.

30.) A pendulum bob is pulled to one side until its center of gravity has been raised 10.0 cm above its equilibrium position. Find the speed of the bob as it swings through the equilibrium position. *1.4 m/s*

31.) A pendulum bob has a mass of 0.5 kg. It is suspended by a cord 2.0 m long, which is pulled back through an angle of 30°. Find its maximum potential energy relative to its lowest position and its potential energy when the cord makes an angle of 15° with the vertical. Find its maximum speed and its speed when the cord makes the angle of 15° with the vertical. *1.31 J* *0.33 J* *2.29 m/s* *1.98 m/s*

The *ballistic pendulum* is a device, which makes possible the determination of the velocity of a projectile. The projectile is fired into a block supported as a simple pendulum. The block swings up and is caught at its maximum height. Its change in potential energy is calculated. From the change in potential energy, the change in kinetic energy is known. From the change in kinetic energy, the velocity after the collision can be calculated. Then use the conservation of momentum to calculate the initial velocity of the projectile.

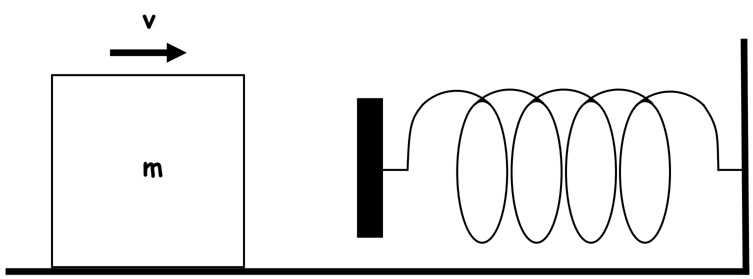
32.) A bullet of 20.0 g mass is fired into a block of 500.0 g mass supported from a 100.0 cm cord, causing it to swing through an angle of 10° with the vertical. Calculate the original velocity of the bullet. *14 m/s*

33.) A bullet fired at a ballistic pendulum lodges in the wooden block which swings over and rises to a height of 7.0 cm. The mass of the bullet is 6.0 g and the mass of the block is 4.0 kg. The pendulum string is 5.0 m long. What is the original velocity of the bullet? *782 m/s*

Potential Energy: As discussed earlier, objects that have been raised short distances above the earth have energy stored in them. This energy (due to an object's position above the earth's surface) may be used to do work on the object's surroundings should the object fall back to earth. Objects may also have the ability to do work because of their position relative to forces produced by other objects that are pushing or pulling on them. For example: the spring of a pinball machine has energy because it is compressed, or the twine (of a bow and arrow) because it has been drawn back ready to fire. This potential energy is called Elastic Potential Energy and shall be indicated as U_{elas} or simply U_e. For a spring, the amount of U_e depends directly on the spring constant and is given as:

$$U_e = \frac{1}{2} kx^2$$

34.) A 0.30 kg block sliding on a horizontal frictionless surface with a speed of 2.5 m/s strikes a light spring that has a spring constant of 3.0×10^3 N/m (see the diagram below). a.) What is the total mechanical energy of the system? b.) What is the kinetic energy of the block when the spring is compress a distance of 1.0 cm? (Assuming that no energy is lost in collision) c.) How far will the spring be compressed when the block comes to a stop? *a.) 0.94 J* *b.) 0.79 J*



35.) A 0.25 kg marble is placed on a vertical spring (spring constant – 10 N/m) which compresses the spring a little bit. The marble sitting on the spring is then compressed an additional 50 cm and then released – make sure you're out of the way! a.) How much elastic potential energy is contained in the system at full compression?
b.) Assuming no energy loss, how high does the marble rise above the spring? c.) If the marble falls back down directly onto the spring, by how much does the spring get compressed? *2.78 J* *1.13 m* *74.5 cm*