SECTION 5.2

Energy

Kinetic Energy

We often talk about how much energy we have. The physics definition of *energy* is "the ability to produce change." This is often a change in motion. An example of a change in motion is when you throw a ball or when a firework explodes.

Kinetic energy is the energy of motion. Consider an object of mass m moving at speed v.

$$\text{kinetic energy} = 0.5(\text{mass})(\text{speed})^2$$

$$KE = 0.5mv^2$$

Kinetic energy is a scalar quantity. The SI unit is joules.

KEY TERMS

- kinetic energy
- work-kinetic energy theorem
- potential energy
- gravitational potential energy
- elastic potential energy
- spring constant

READING CHECK

1. How could you increase an object's kinetic energy?

____

SAMPLE PROBLEM B

A 7.00 kg bowling ball moves at 3.00 m/s. What is its kinetic energy? How fast would a 2.45 g tennis ball need to move to have the same kinetic energy?

SOLUTION

1 ANALYZE

Determine what information is given and unknown. Use subscript b *for the bowling ball and* t *for the tennis ball. Write the mass of the table-tennis ball in kilograms.*

Given: $m_b = 7.00$ kg $v_b = 3.00$ m/s kg $m_t = 0.00245$ kg

Unknown: $KE_b = ?$ $v_t = ?$

2 SOLVE

Use the equation for kinetic energy.

$$KE_b = 0.5m_bv_b^2$$

$$KE_b = 0.5(7.00\text{ kg})(3.00\text{ m/s})^2 = \boxed{31.5\text{ J}}$$

SAMPLE PROBLEM (continued)

Use this value for KE_t and solve for v_t.

$$KE_t = 0.5 m_t v_t^2$$

$$\frac{2KE_t}{m_t} = v_t^2$$

$$v_t = \sqrt{\frac{2KE_t}{m_t}}$$

$$v_t = \sqrt{\frac{2(31.5\ \text{J})}{0.00245\ \text{kg}}} = \boxed{1.60 \times 10^2\ \text{m/s}}$$

Note that 160 m/s is an unlikely speed for a tennis ball.

PRACTICE

A. Calculate the speed of an 8.0×10^4 kg plane with a kinetic energy of 1.1×10^9 J.

Given:

Unknown:

B. A baseball has mass 0.145 kg and kinetic energy 109 J. What is its speed?

The net work done on a body equals its change in kinetic energy.

Suppose you drop a rock into soft sand. The rock has zero kinetic energy while it is in your hand. The force of gravity accelerates it downward as it falls. Its velocity increases and its kinetic energy increases. The sand slows the rock to a stop when the rock hits the sand. The velocity decreases to zero and the rock's kinetic energy decreases to zero. You can begin the cycle again by lifting the rock back to its starting position.

You do work when you raise the rock. Gravity does work when the rock falls. The sand does work when the rock slows to a stop in the sand. A change in motion indicates that work is being done. The **work-kinetic energy theorem** states that the change in an object's kinetic energy is equal to the net work done on the object.

$$\Delta KE = W_{net}$$

$$\Delta KE = F_{net} d$$

READING CHECK

2. Suppose you push against a moving box to slow it down. Would the work you did be positive or negative? Think about whether the force is with the direction of motion or against it. Would the kinetic energy of the box increase or decrease?

All the forces acting on the object must be considered. Suppose you push against a heavy box. The box doesn't move. You are exerting a force when you push on the box. The fibers in your muscles contract and expand. This does work and burns chemical energy from the food you ate. But your force causes no change in the box's motion. The box's kinetic energy is constant and no work is done on the box.

SAMPLE PROBLEM

A girl pushes a 10.0 kg sled onto a frozen pond with an initial speed of 2.2 m/s. The coefficient of kinetic friction between the sled and the ice is 0.10. How far does the sled move before it comes to a stop?

SOLUTION

1 ANALYZE

Determine what information is given and unknown.

Given: $m = 10.0\text{ kg}$ $v_i = 2.2\text{ m/s}$ $v_f = 0\text{ m/s}$ $\mu_k = 0.10$

Unknown: $d = ?$

2 PLAN

Find W_{net} with the work-kinetic energy theorem.

$$W_{net} = \Delta KE = KE_f - KE_i = 0.5mv_f^2 - 0.5mv_i^2$$

$$W_{net} = 0.5(10.0\text{ kg})(2.2\text{ m/s})^2 - 0.5(10.0\text{ kg})(0\text{ m/s})^2 = 24\text{ J}$$

The work done by friction on the sled is $W = F_k d$. The force of kinetic friction on the sled is $F_k = \mu_k mg$.

3 SOLVE

$$W_{net} = F_k d$$

$$W_{net} = (\mu_k mg)d$$

$$d = \frac{W_{net}}{\mu_k mg} = \frac{24\text{ J}}{(0.10)(10.0\text{ kg})(9.81\text{ m/s}^2)} = \boxed{2.4\text{ m}}$$

Units: $1\text{ J} = 1\text{ kg}\cdot\text{m}^2/\text{s}^2$, so $\text{J} \div \text{kg}\cdot\text{m/s}^2 = \text{m}$.

4 CHECK

Because $F = W \div d = 10\text{ N}$, $a = F \div m = 1\text{ m/s}^2$. To accelerate from 2.2 m/s to 0 m/s at this rate would take about 2 s. The sled at 2.2 m/s for 2 s would travel 4.4 m without friction. 2.4 is less than 4.4 and so the answer is reasonable.

SAMPLE PROBLEM (continued)

PRACTICE

A. A girl wearing skates is pushed on a horizontal surface with a constant net force of 45 N. She starts from rest. How far must she be pushed so that her final kinetic energy is 352 J?

Given:
Unknown:

B. A man pushes a 75 kg sled along a horizontal surface. The sled moves 4.5 m. Its speed goes from 0 to 6.0 m/s. Find the net force on the sled.

Potential Energy

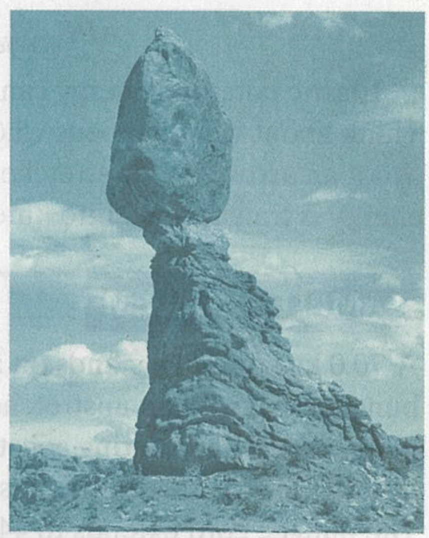
Look at the balanced rock in the photo. The rock has no kinetic energy as long as it remains balanced. The rock will gain kinetic energy if it becomes unbalanced and falls.

Potential energy is stored energy.

Potential energy is the energy associated with an object because of its potential to move. It depends on both the object and its environment.

Gravitational potential energy depends on height from a zero level.

The potential kinetic energy of the rock in the photo depends on both its mass and the velocity it might achieve as it falls. This potential velocity depends on the height of the rock above the ground. The energy associated with an object because of its position in a gravitational field is its **gravitational potential energy**. It is equal to the force of gravity times the height the object can fall.



A rock suspended above the ground has potential energy.

PE_g = (force of gravity on object) (height it can fall)

$$PE_g = (mg)h$$

Imagine you are standing on the roof of a building. You have a ball in your hand. You toss the ball upward. It can fall 0.2 m and land in your hand, 1 m and land on the roof, or 20 m and land on the ground. It doesn't matter whether your hand, the roof, or the ground is considered 0. You can choose a 0 that makes calculations easier or makes the problem easier to visualize.

Elastic potential energy depends on distance compressed or stretched.

Suppose you stretch a piece of elastic between your hands. The elastic returns to its original size and shape when you release it. **Elastic potential energy** is the energy stored in any compressed or stretched object. It depends on the distance that the object is stretched or compressed away from its resting shape. It also depends on a quality called the spring constant. The **spring constant** measures a spring's resistance to being compressed or stretched.

Here is a way to show the elastic potential energy of a spring with a spring constant k. It has been compressed or stretched a distance x.

$$PE_{elastic} = \frac{1}{2}kx^2$$

Elastic potential energy can be used to accelerate an object. Think about what happens when you jump on a trampoline or shoot an arrow from a stretched bowstring. Elastic potential energy is transformed into kinetic energy.

SAMPLE PROBLEM

A 70.0 kg stuntman stands on a bridge. He is attached to a bungee cord with an unstretched length of 15.0 m. The bungee cord has a spring constant of 71.8 N/m and is attached to the bridge at the level of his feet. He jumps off the bridge. The bungee cord extends to 44.0 m. What is the potential energy stored in the cord? How did the stuntman's gravitational potential energy change?

Critical Thinking

3. Draw Conclusions What happens to the gravitational potential energy of a rock as it falls from your hand toward the sand below?

____

____

____

Critical Thinking

4. Infer One spring has a spring constant of 18 N/m. A second spring has a spring constant of 36 N/m. Which will be harder to compress 10 cm?

____

SAMPLE PROBLEM (continued)

SOLUTION

1 ANALYZE *Determine what information is given and unknown.*

Given: $m = 70.0$ kg $\quad k = 7.81$ N/m

$x_i = 15.0$ m $\quad x_f = 44.0$ m

Unknown: $PE_{elastic} = ?$ $\quad \Delta PE_{grav} = ?$

2 PLAN *For $PE_{elastic}$ you need the spring constant k and the distance the spring stretched Δx. First calculate Δx.*

$$\Delta x = x_f - x_i = 44.0 \text{ m} - 15.0 \text{ m} = 29.0 \text{ m}$$

For PE_{grav} you need the mass m, the acceleration due to gravity g, and the change in height h. Calculate Δh, the distance from the bridge to where he stops falling.

$$\Delta h = 0 - 44.0 \text{ m} = -44.0 \text{ m}$$

3 SOLVE *Calculate $PE_{elastic}$.*

$$PE_{elastic} = 0.5kx^2 = 0.5(7.81 \text{ N/m})(29.0 \text{ m})^2 = 113 \text{ N} \cdot \text{m} = \boxed{113 \text{ J}}$$

Calculate PE_{grav}.

$$PE_{grav} = mgh = (70.0 \text{ kg})(9.81 \text{ m/s}^2)(-44.0 \text{ m}) = \boxed{-30{,}200 \text{ J}}$$

Note that the answer will be in kg•m^2/s^2, or J.

4 CHECK An order-of-magnitude estimate of PE_{grav} is $100 \text{ kg} \cdot 10 \text{ m/s}^2 \cdot 10 \text{ m} = 10^4$ J. A similar estimate of $PE_{elastic}$ is $10 \text{ N/m} \cdot (10 \text{ m})^2 = 10^3$ J.

PRACTICE

A. A vertical spring has a spring constant of 5.2 N/m and a relaxed length of 2.45 m. A mass is attached to the end of the spring. The mass stretches the spring to 3.57 m. Calculate the elastic potential energy stored in the spring.

Given:

Unknown:

B. The staples inside a stapler are kept in place by a spring with a relaxed length of 11.5 cm. The spring constant is 51.0 N/m. How much elastic potential energy is stored in the spring when its length is 8 cm?