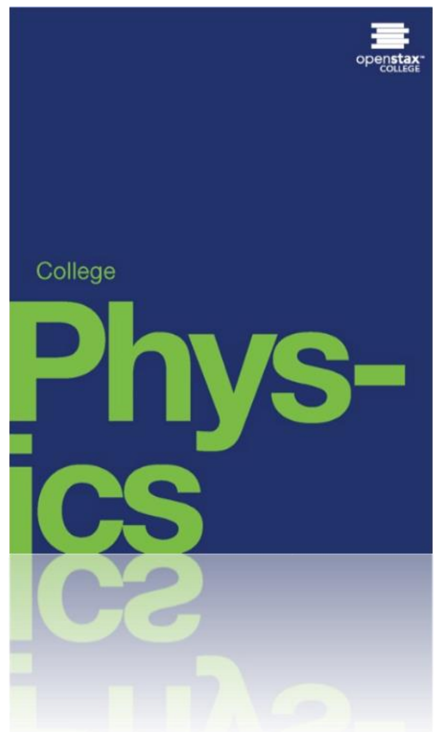
COLLEGE PHYSICS

Chapter 7 WORK, ENERGY, AND ENERGY RESOURCES

PowerPoint Image Slideshow



openstax™

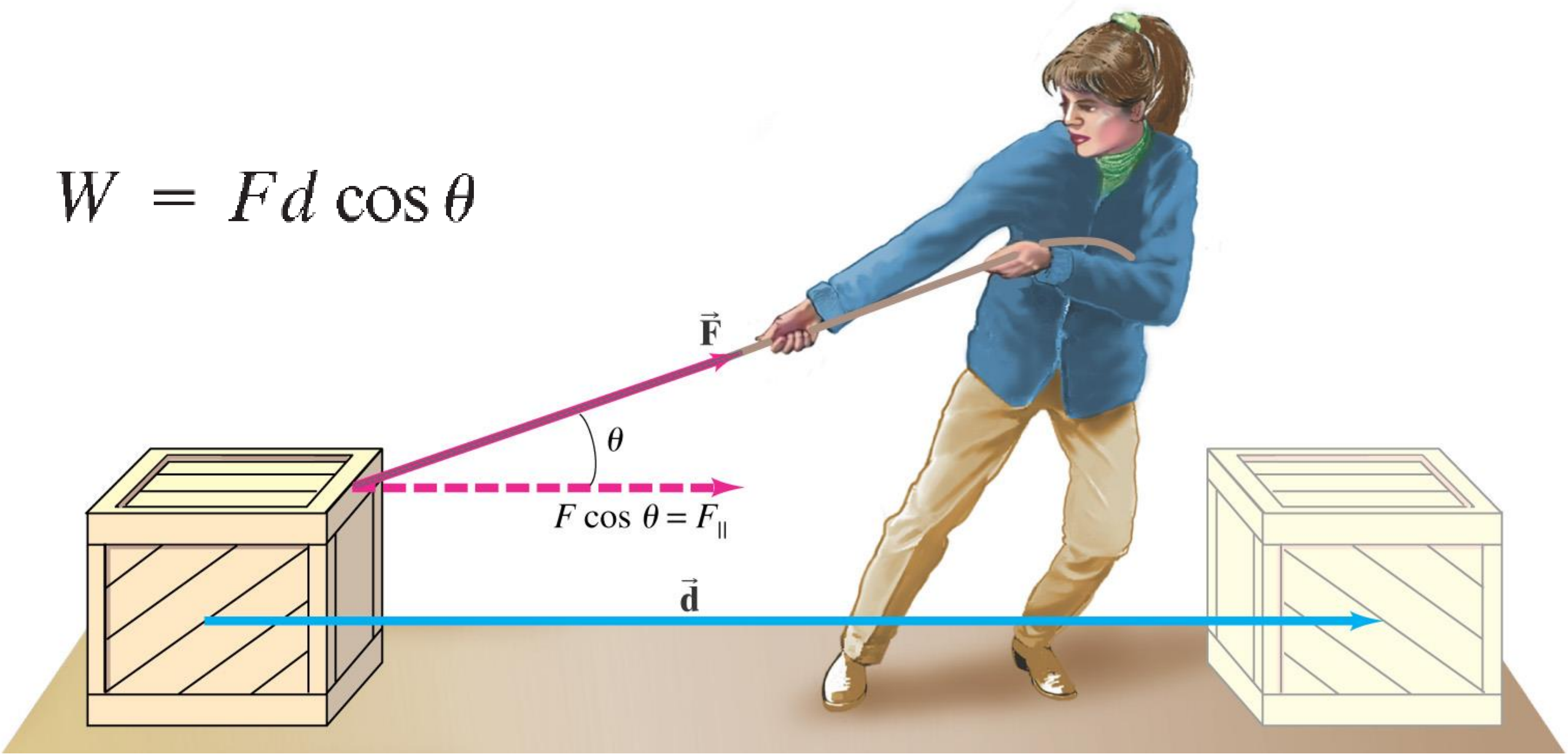
Work and Energy

- Work Done by a Constant Force
- Work Done by a Varying Force
- Kinetic Energy, and the Work-Energy Principle
- Potential Energy
- Conservative and Nonconservative Forces
- Mechanical Energy and Its Conservation
- Other Forms of Energy, Energy Transformations and Law of Conservation of Energy
- Energy Conservation with Dissipative Forces
- Power

Work Done by a Constant Force

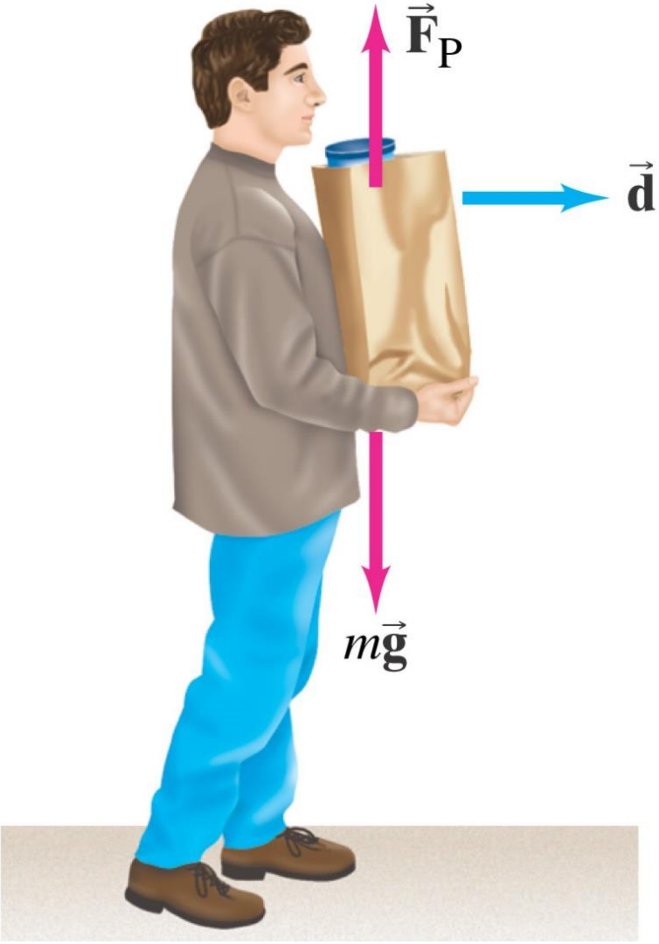
The work done by a constant force is defined as the distance moved multiplied by the component of the force in the direction of displacement:

$$W = Fd\cos\theta$$



Work Done by a Constant Force

In the SI system, the units of work are joules:



$$1\ \mathrm{J} = 1\ \mathrm{N \cdot m}$$

As long as this person does not lift or lower the bag of groceries, he is doing no work on it. The force he exerts has no component in the direction of motion.

Examples of work.

(a) The work done by the force **F** on this lawn mower is $Fd \cos \theta$. Note that $F \cos \theta$ is the component of the force in the direction of motion.

(b) A person holding a briefcase does no work on it, because there is no motion. No energy is transferred to or from the briefcase.

(c) The person moving the briefcase horizontally at a constant speed does no work on it, and transfers no energy to it.

(d) Work *is* done on the briefcase by carrying it up stairs at constant speed, because there is necessarily a component of force **F** in the direction of the motion. Energy is transferred to the briefcase and could in turn be used to do work.

(e) When the briefcase is lowered, energy is transferred out of the briefcase and into an electric generator. Here the work done on the briefcase by the generator is negative, removing energy from the briefcase, because **F** and **d** are in opposite directions.

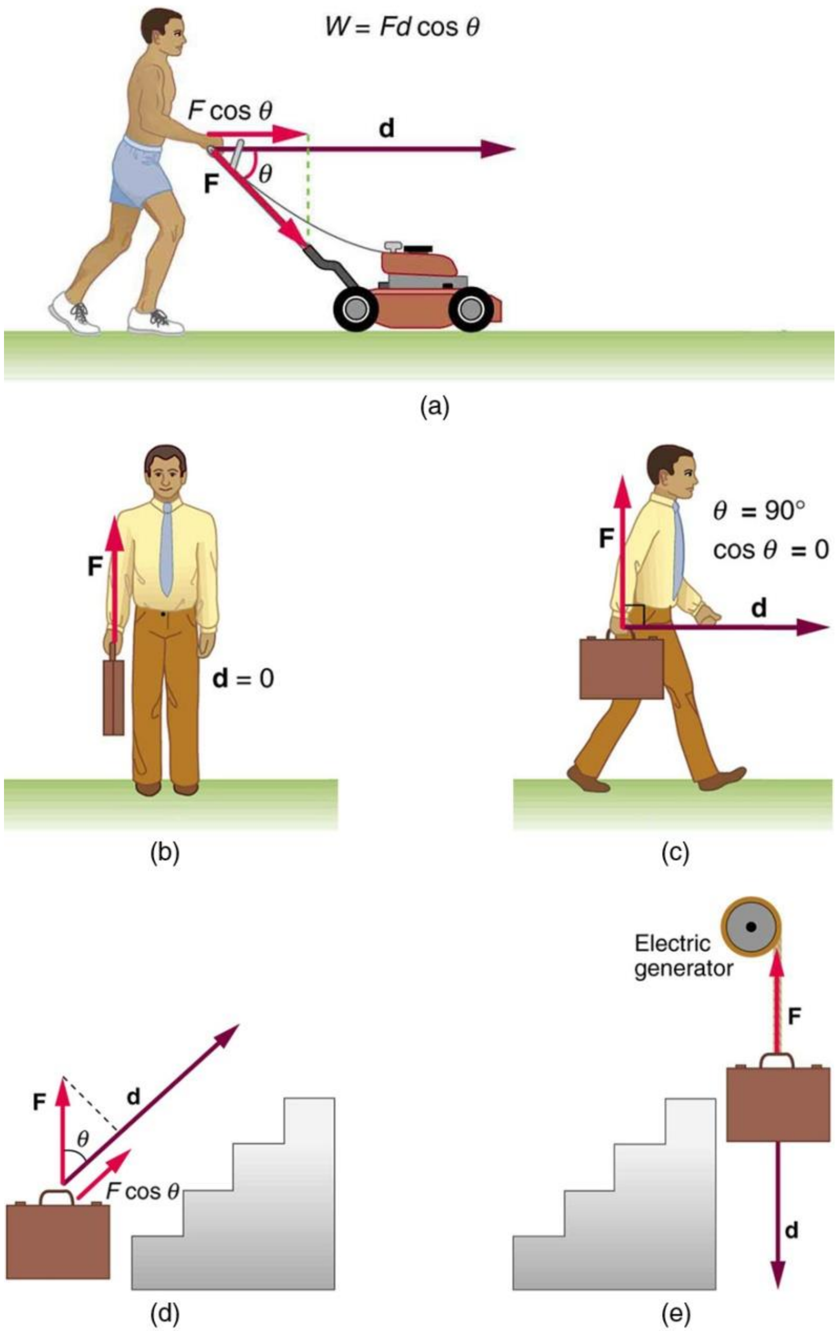
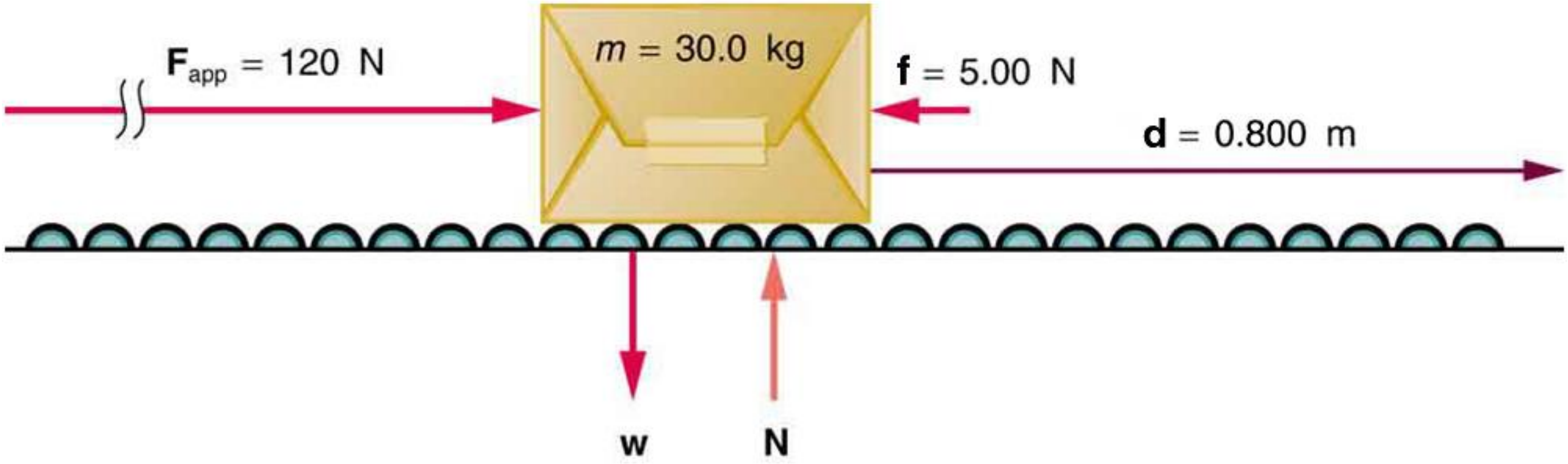


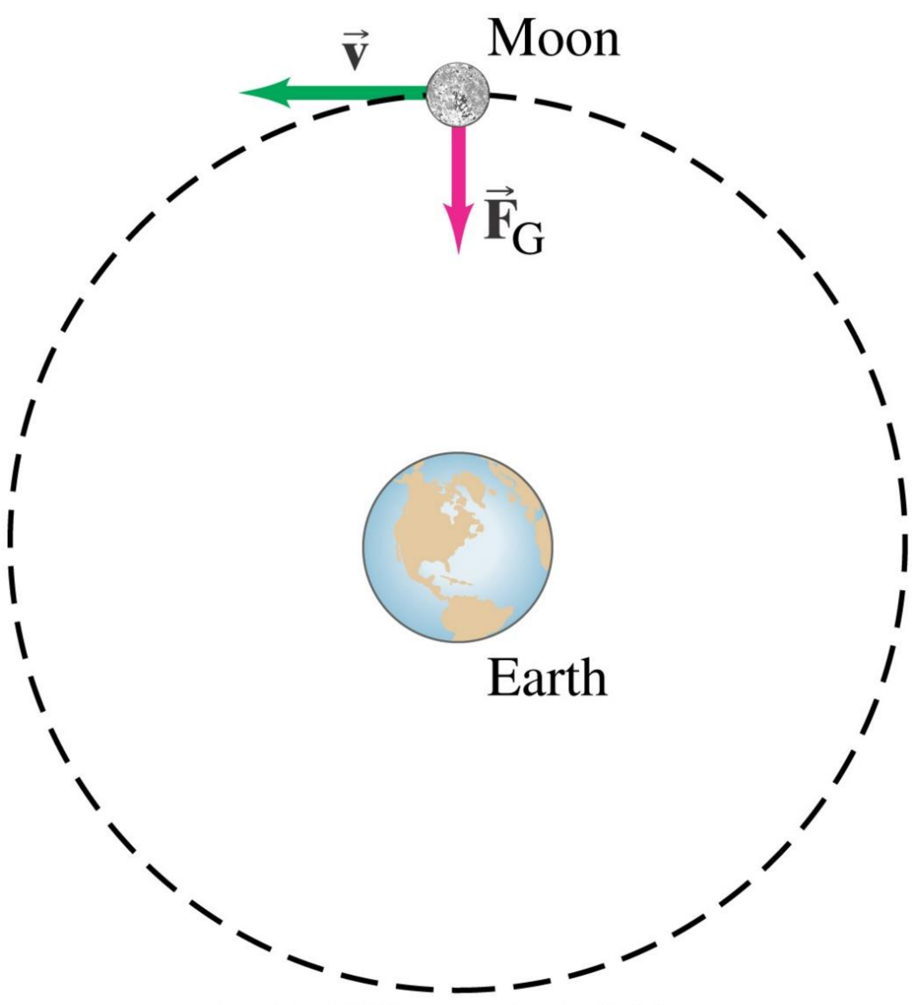
FIGURE 7.4



A package on a roller belt is pushed horizontally through a distance **d**
.

Work Done by a Constant Force

Work done by forces that oppose the direction of motion, such as friction, will be negative.



Centripetal forces do no work, as they are always perpendicular to the direction of motion.

Kinetic Energy and Work-Energy Principle

Energy was traditionally defined as the ability to do work. We now know that not all forces are able to do work; however, we are dealing with mechanical energy, which does follow this definition.

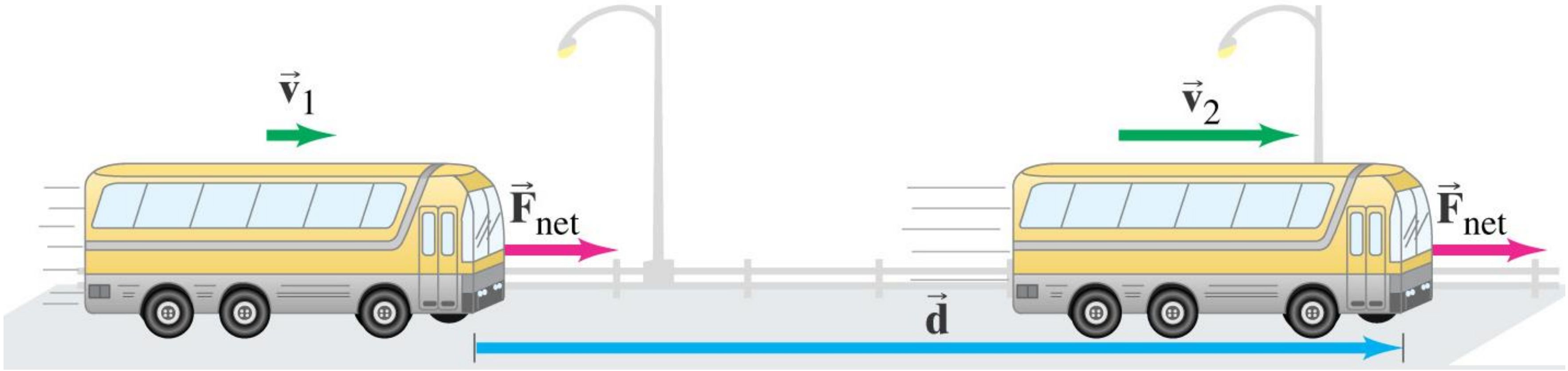
Kinetic Energy and Work-Energy Principle

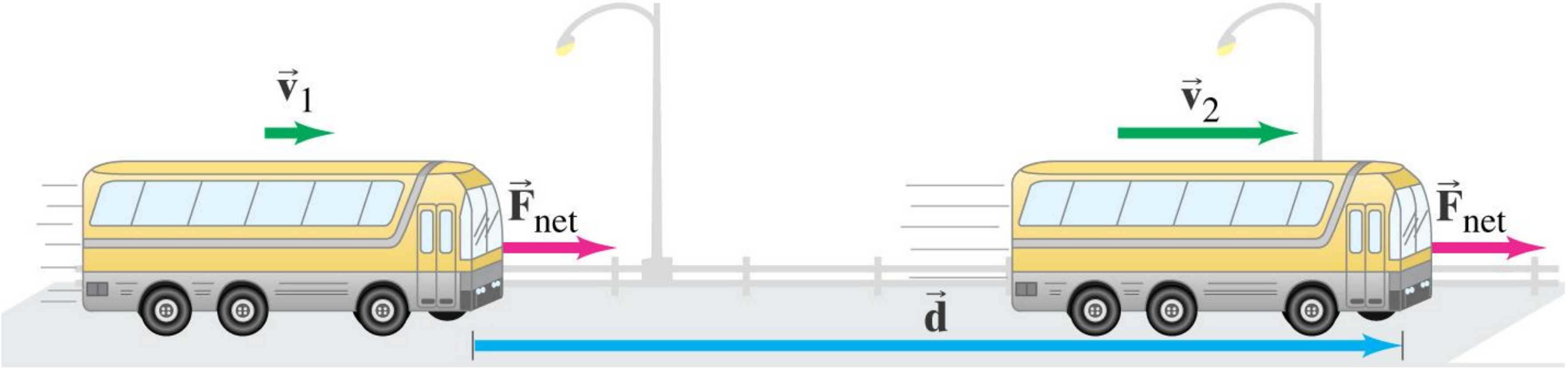
If we write the acceleration in terms of the velocity and the distance, we find that the work done here is

$$W_{\text{net}} = \tfrac{1}{2}mv_2^2 - \tfrac{1}{2}mv_1^2$$

We define the kinetic energy:

$$\text{KE} = \tfrac{1}{2}mv^2$$





x_1 x_2

$$x_2 - x_1 = d = (v_2^2 - v_1^2)/2a$$

$$a(x_2 - x_1) = ad = (v_2^2 - v_1^2)/2$$

$$mad = m(v_2^2 - v_1^2)/2 = F_{net}\,d = W_{net}$$

$$m(v_2^2 - v_1^2)/2 = KE_2 - KE_1 = \Delta KE = W_{net}$$

Kinetic Energy and Work-Energy Principle

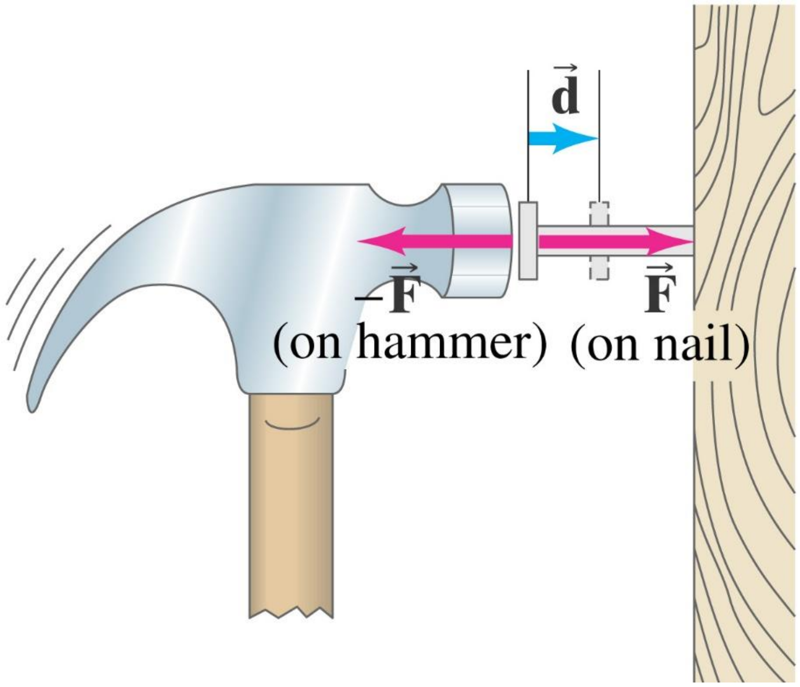
This means that the work done is equal to the change in the kinetic energy:

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

- If the net work is positive, kinetic energy increases
- If the net work is negative, kinetic energy decreases

Kinetic Energy and Work-Energy Principle

Because work and kinetic energy can be equated, they must have the same units: kinetic energy is measured in joules.



Potential Energy

An object can have potential energy by virtue of its surroundings.

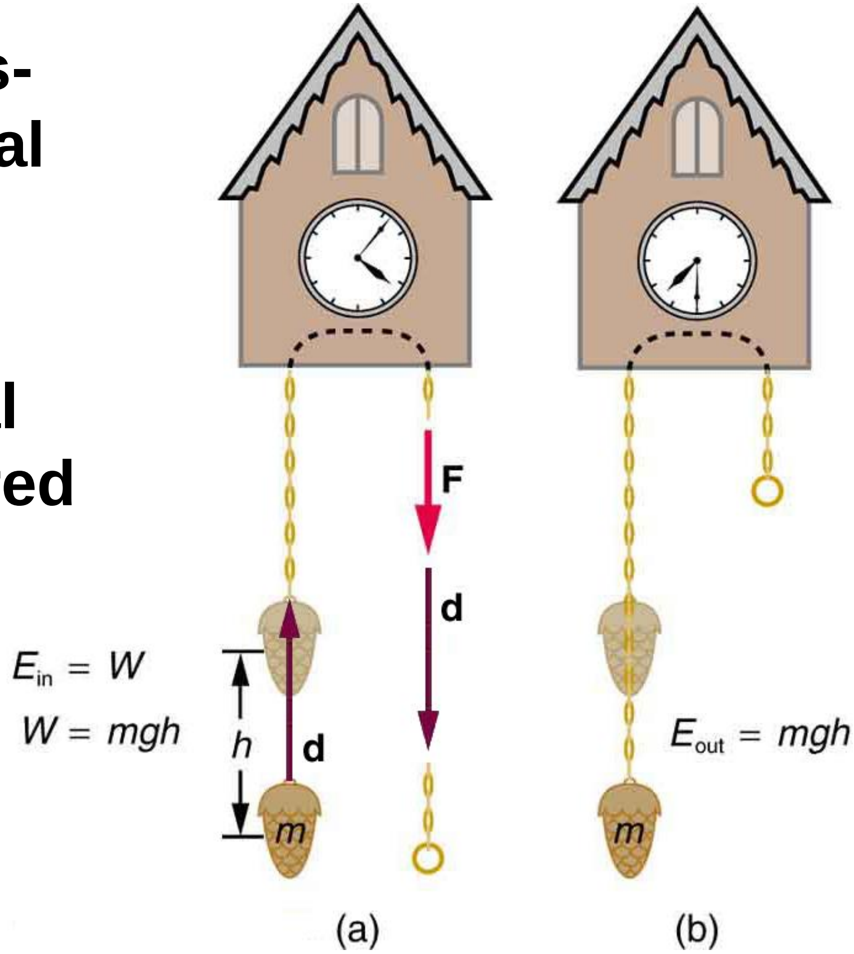
Familiar examples of potential energy:

- A wound-up spring
- A stretched elastic band
- An object at some height above the ground

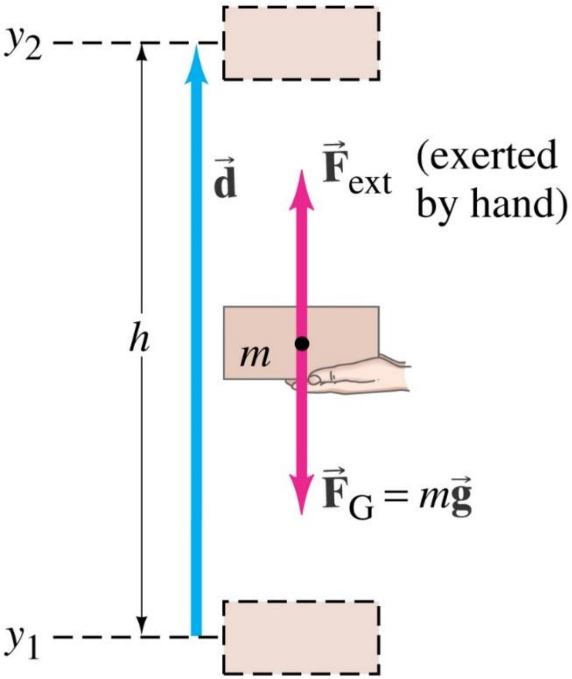
FIGURE 7.5

(a) The work done to lift the weight is stored in the mass-Earth system as gravitational potential energy.

(b) As the weight moves downward, this gravitational potential energy is transferred to the cuckoo clock.



Potential Energy



In raising a mass *m* to a height *h*, the work done by the external force is

$$W_{\text{ext}} = F_{\text{ext}}\, d \cos 0° = mgh$$
$$= mg(y_2 - y_1)$$

We therefore define the gravitational potential energy:

$$\text{PE}_{\text{grav}} = mgy$$

Potential Energy

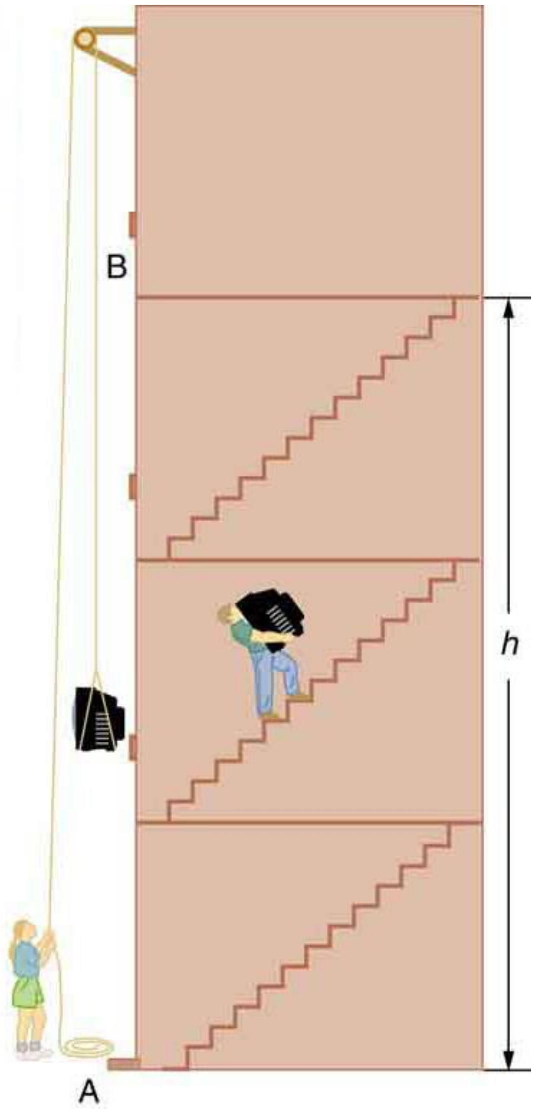
This potential energy can become kinetic energy if the object is dropped.

Potential energy is a property of a system as a whole, not just of the object (because it depends on external forces).

If $PE_{grav} = mgy$, where do we measure *y* from?

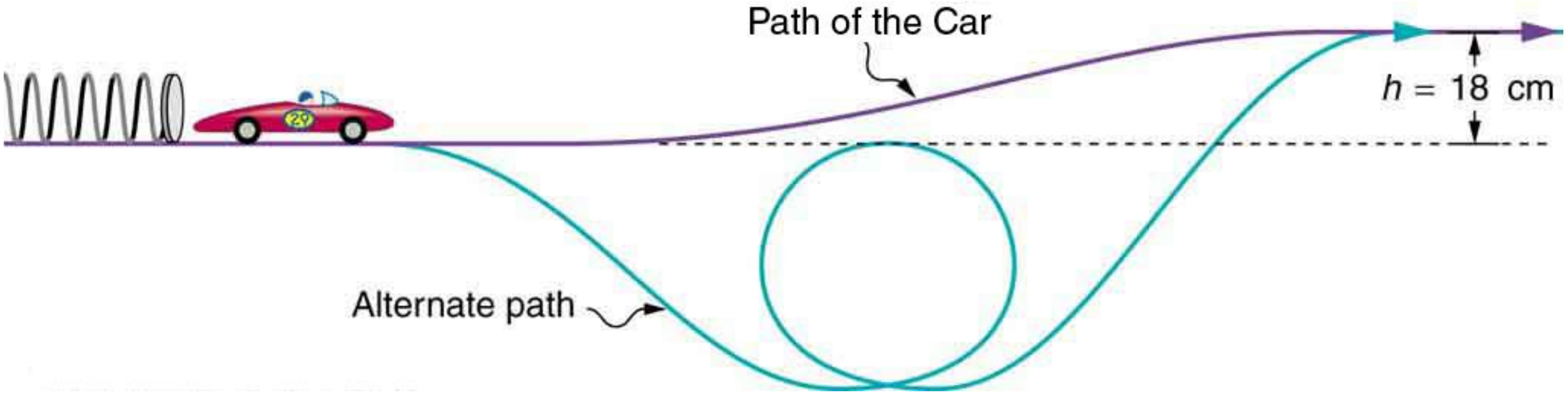
It turns out not to matter, as long as we are consistent about where we choose *y* = 0. Only changes in potential energy can be measured.

FIGURE 7.6



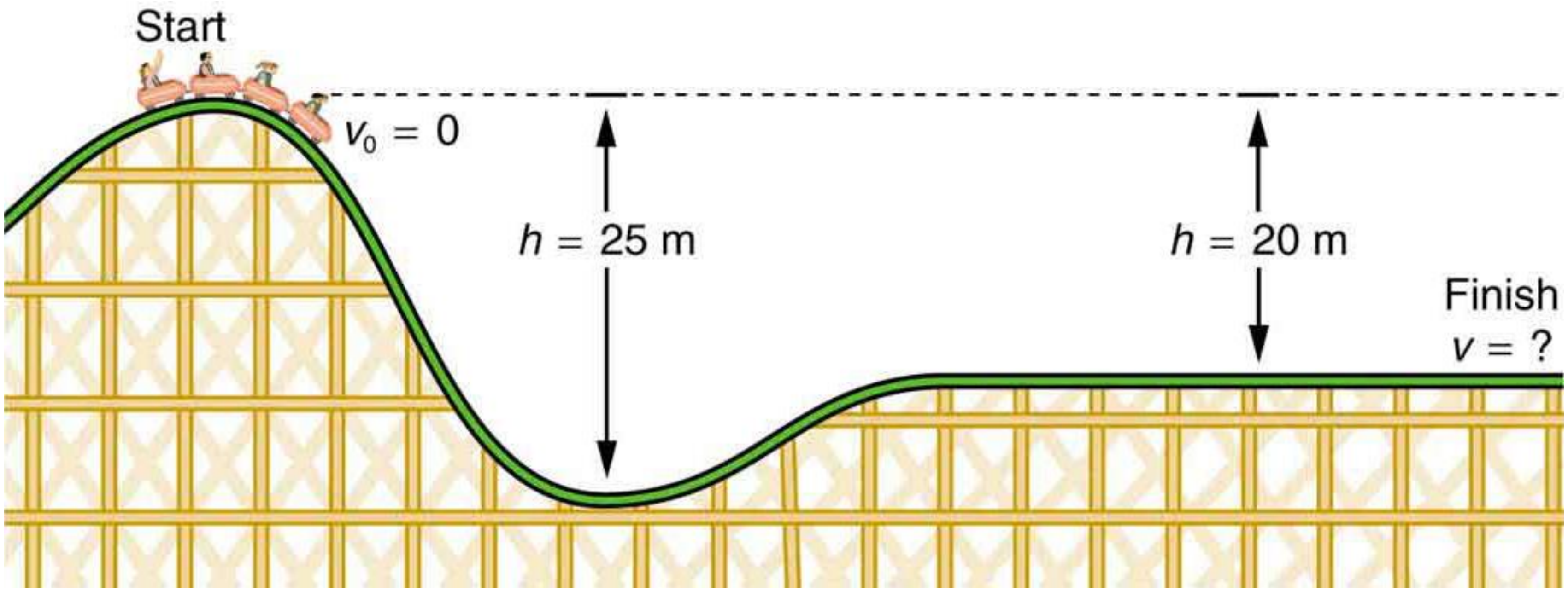
The change in gravitational potential energy (ΔPE_g) between points A and B is independent of the path. $\Delta PE_g = mgh$ for any path between the two points. Gravity is one of a small class of forces where the work done by or against the force depends only on the starting and ending points, not on the path between them.

FIGURE 7.12

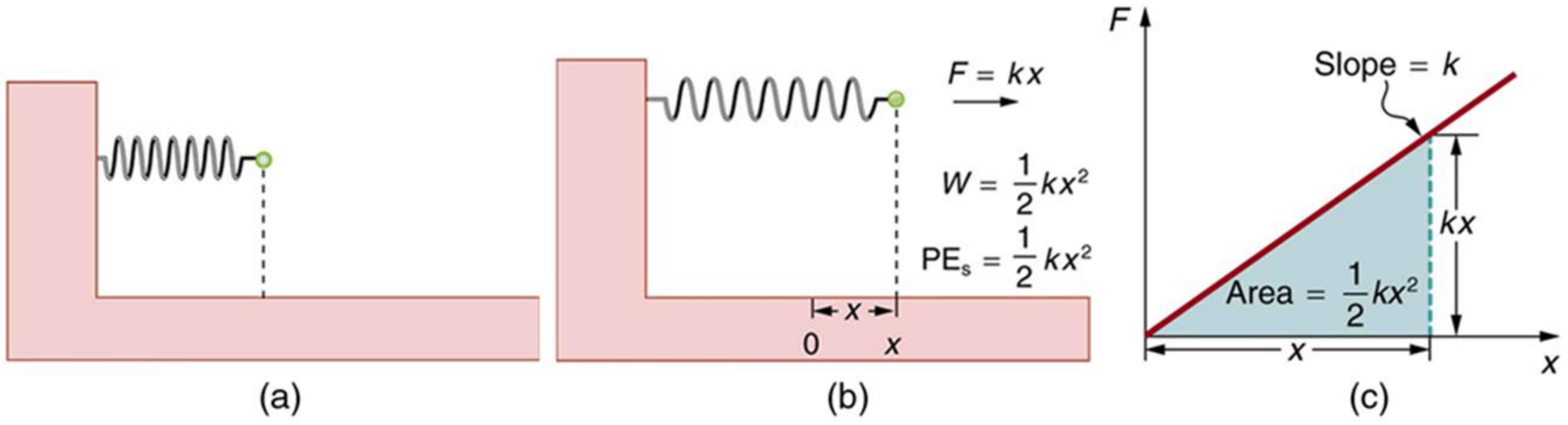


A toy car is pushed by a compressed spring and coasts up a slope. Assuming negligible friction, the potential energy in the spring is first completely converted to kinetic energy, and then to a combination of kinetic and gravitational potential energy as the car rises. The details of the path are unimportant because all forces are conservative—the car would have the same final speed if it took the alternate path shown.

FIGURE 7.8



The speed of a roller coaster increases as gravity pulls it downhill and is greatest at its lowest point. Viewed in terms of energy, the roller-coaster-Earth system's gravitational potential energy is converted to kinetic energy. If work done by friction is negligible, all ΔPE_g is converted to KE .



(a) An undeformed spring has no PEs stored in it.

(b) The force needed to stretch (or compress) the spring a distance *x* has a magnitude $F = kx$, and the work done to stretch (or compress) it is $\frac{1}{2}kx^2$

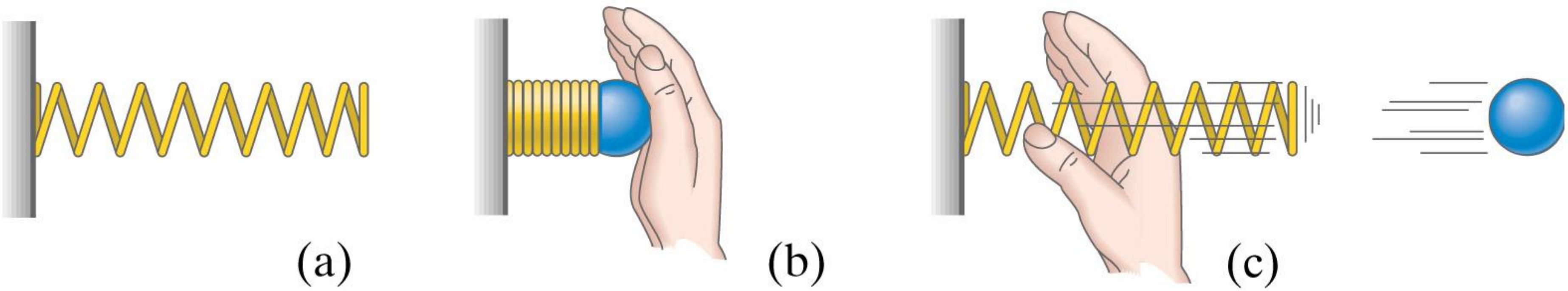
(c) Because the force is conservative, this work is stored as potential energy (PEs) in the spring, and it can be fully recovered.

(d) A graph of *F* vs. *x* has a slope of *k* , and the area under the graph is $\frac{1}{2}kx^2$

(e). Thus the work done or potential energy stored is $\frac{1}{2}kx^2$

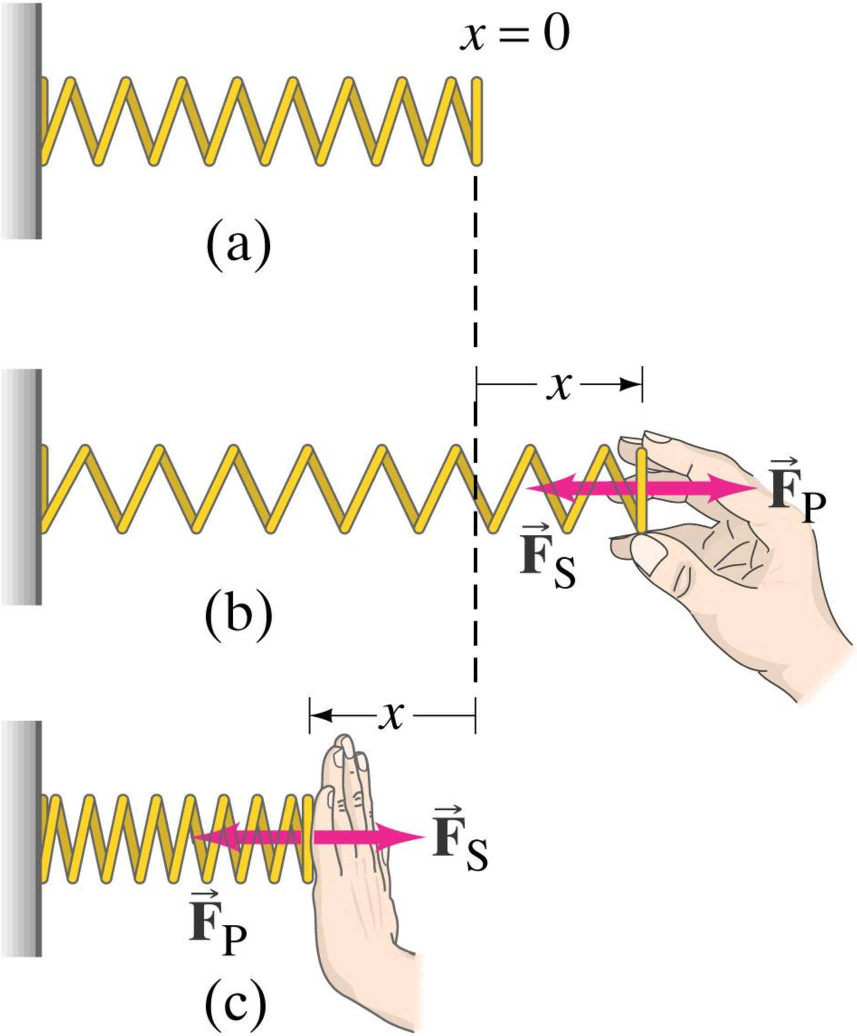
Potential Energy

Potential energy can also be stored in a spring when it is compressed; the figure below shows potential energy yielding kinetic energy.



(a) (b) (c)

Potential Energy



The force required to compress or stretch a spring is:

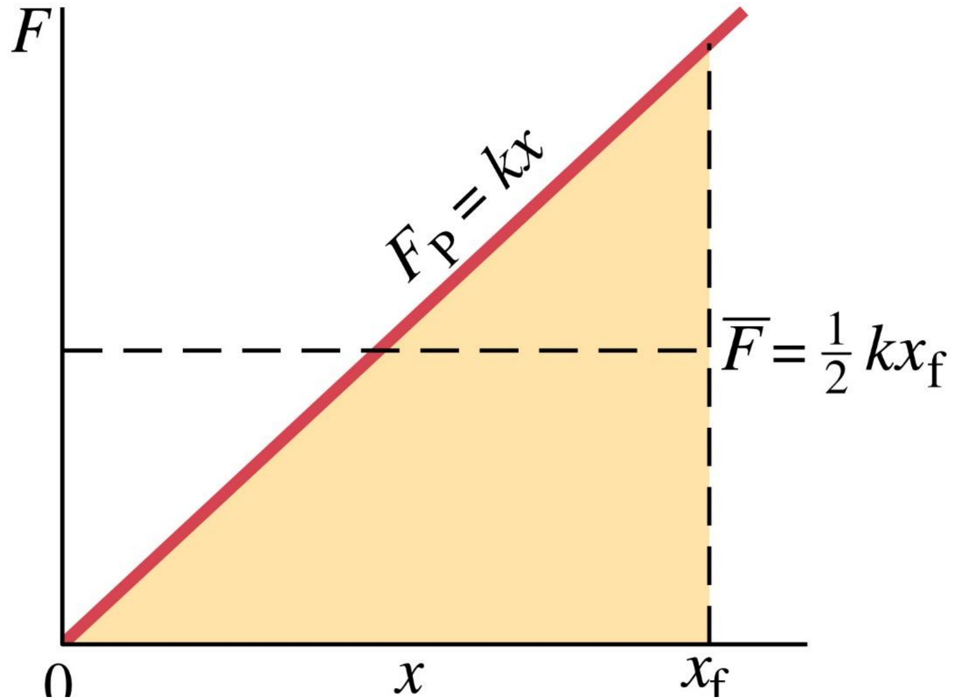
$$F_S = -kx$$

where *k* is called the spring constant, and needs to be measured for each spring.

Potential Energy

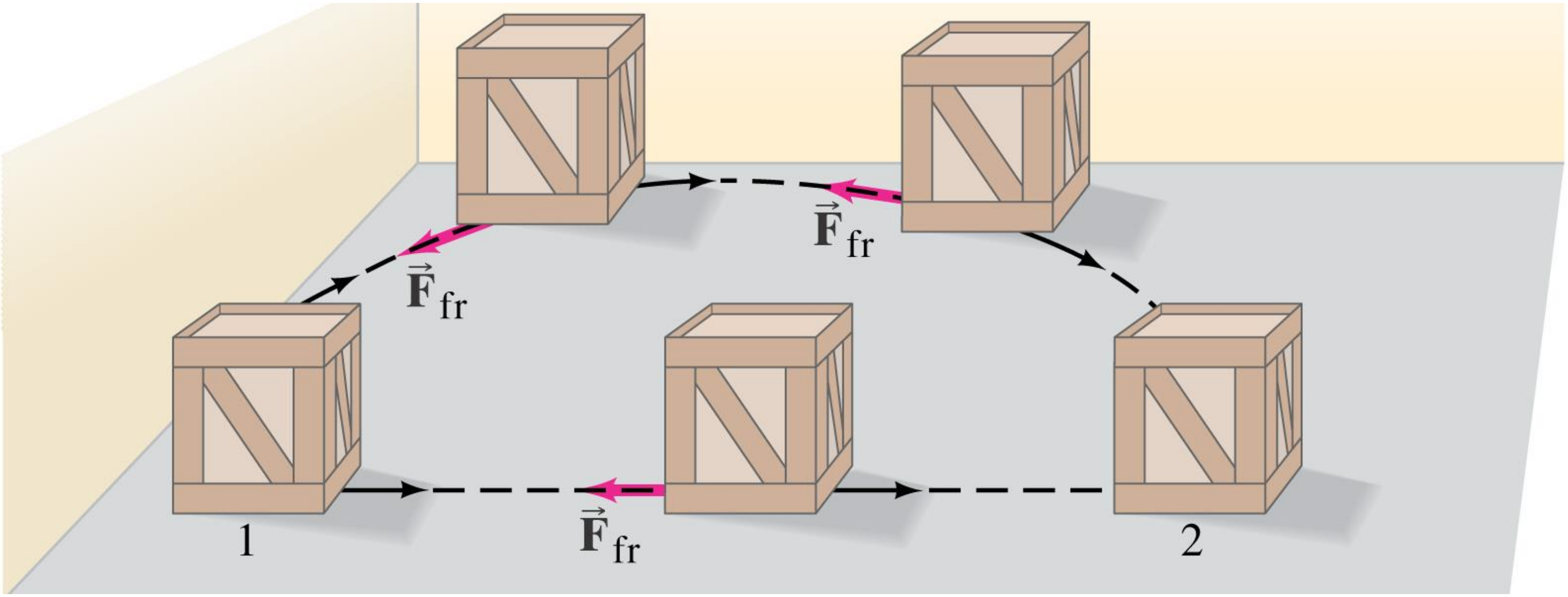
The force **increases** as the spring is stretched or compressed further. We find that the **potential energy** of the compressed or stretched spring, measured from its equilibrium position, can be written:

$$\text{elastic PE} = \frac{1}{2}kx^2$$



Conservative and Nonconservative Forces

If friction is present, the work done depends not only on the starting and ending points, but also on the path taken. Friction is called a nonconservative force.



Conservative and Nonconservative Forces

Potential energy can only be defined for conservative forces.

Conservative and Nonconservative Forces

Conservative Forces	**Nonconservative Forces**
Gravitational	Friction
Elastic	Air resistance
Electric	Tension in cord
	Motor or rocket propulsion
	Push or pull by a person

Conservative and Nonconservative Forces

Therefore, we distinguish between the work done by conservative forces and the work done by nonconservative forces.

We find that the work done by nonconservative forces is equal to the total change in kinetic and potential energies:

$$W_{NC} = \Delta KE + \Delta PE.$$

Mechanical Energy and Its Conservation

If there are no nonconservative forces, the sum of the changes in the kinetic energy and in the potential energy is zero – the kinetic and potential energy changes are equal but opposite in sign.

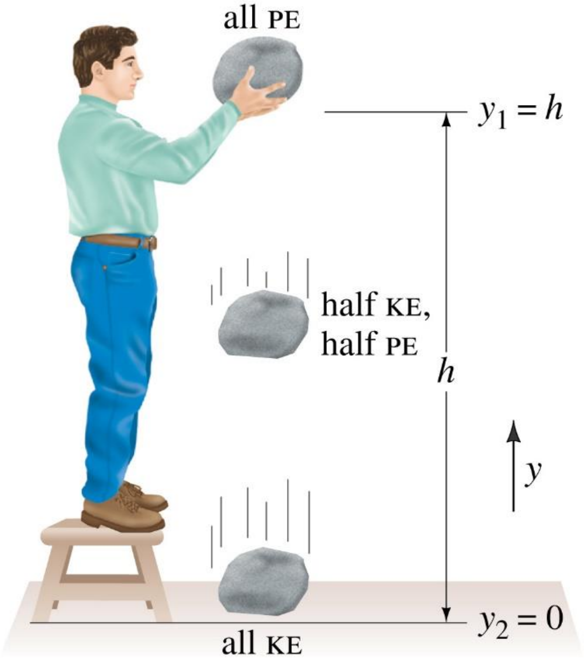
This allows us to define the total mechanical energy:

$$E = \mathrm{KE} + \mathrm{PE}$$

And its conservation:

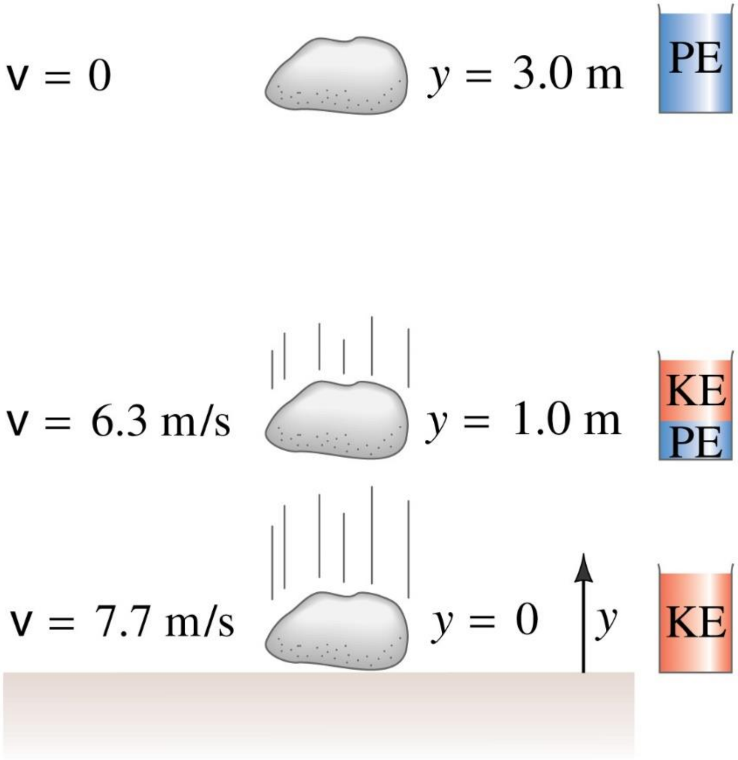
$$E_2 = E_1 = \text{constant}$$

Problem Solving Using Conservation of Mechanical Energy



In the image on the left, the total mechanical energy is:

$$E = \mathrm{KE} + \mathrm{PE} = \frac{1}{2}mv^2 + mgy$$



The **energy buckets** (right) show how the energy moves from all potential to all kinetic.

Other Forms of Energy; Energy Transformations and the Conservation of Energy

Some other forms of energy:

Electric energy, nuclear energy, thermal energy, chemical energy.

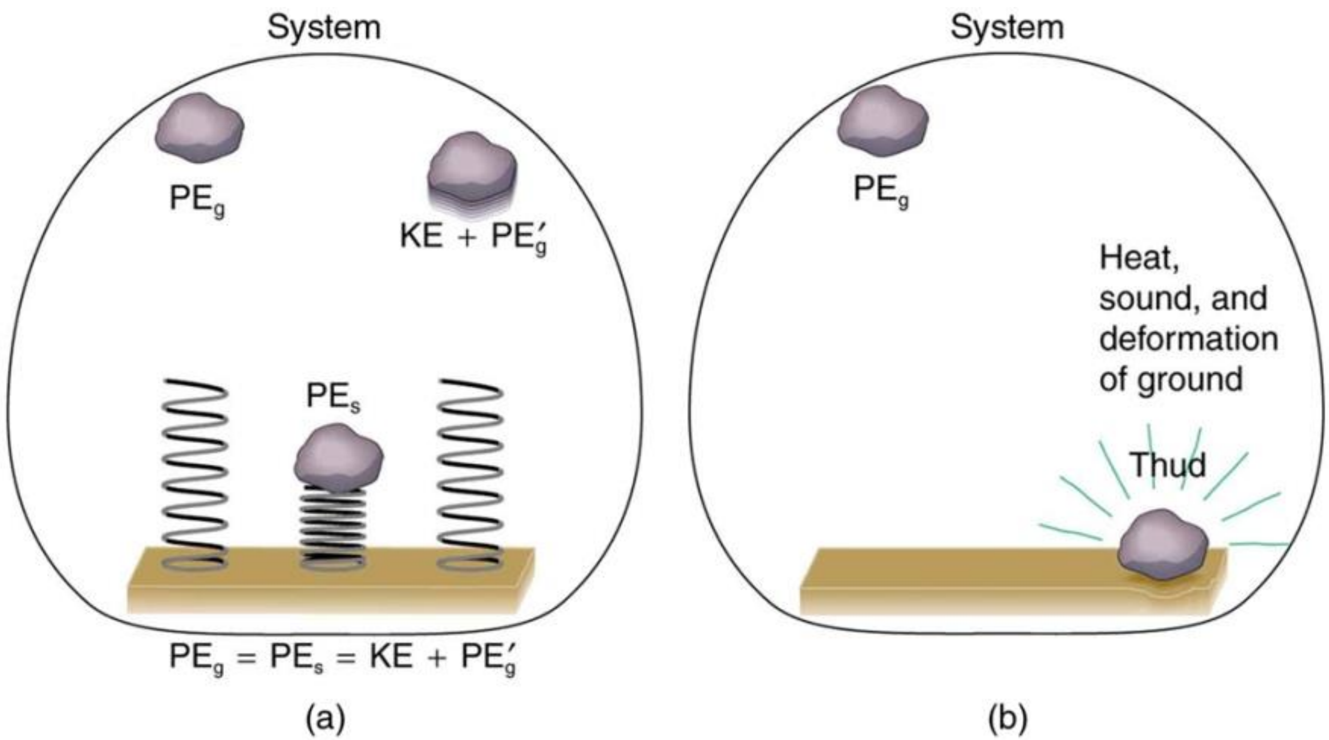
Work is done when energy is transferred from one object to another.

Accounting for all forms of energy, we find that the total energy neither increases nor decreases. Energy as a whole is conserved.

Energy Conservation with Dissipative Processes; Solving Problems

If there is a nonconservative force such as friction, where do the kinetic and potential energies go?

They become heat; the actual temperature rise of the materials involved can be calculated.

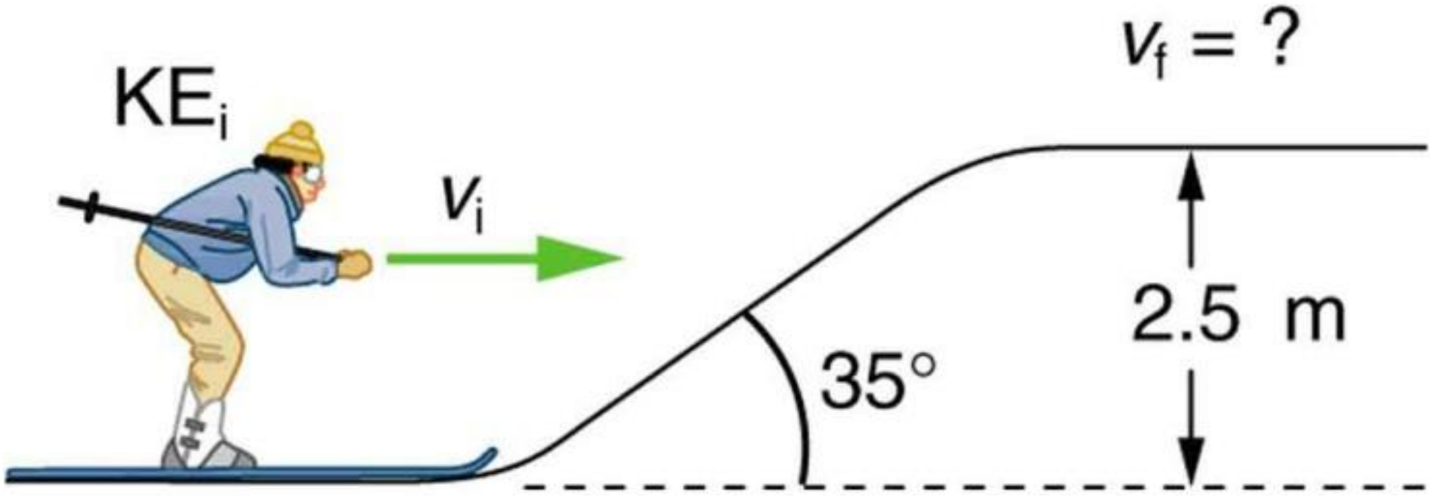


Comparison of the effects of conservative and non-conservative forces on the mechanical energy of a system.

(a) system with only conservative forces. When a rock is dropped onto a spring, its mechanical energy remains constant (neglecting air resistance) because the force in the spring is conservative. The spring can propel the rock back to its original height, where it once again has only potential energy due to gravity.

(b) A system with non-conservative forces. When the same rock is dropped onto the ground, it is stopped by non-conservative forces that dissipate its mechanical energy as thermal energy, sound, and surface distortion. The rock has lost mechanical energy.

FIGURE 7.39



The skier’s initial kinetic energy is partially used in coasting to the top of a rise.

Power

Power is the rate at which work is done –

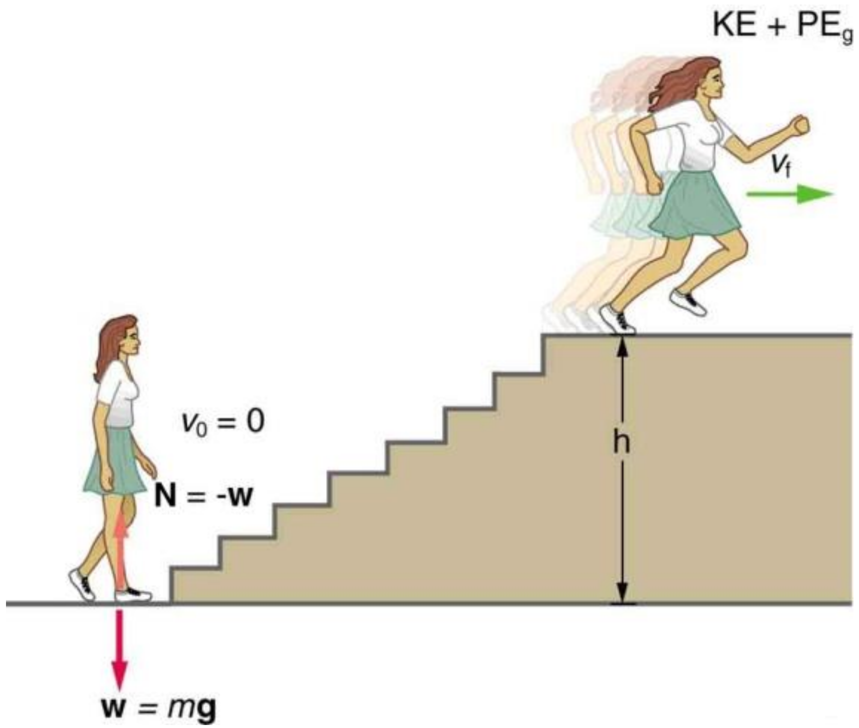
$$\overline{P} = \text{average power} = \frac{\text{work}}{\text{time}} = \frac{\text{energy transformed}}{\text{time}}$$

In the SI system, the units of power are watts:

$$1\ \text{W} = 1\ \text{J/s}$$

The difference between walking and running up these stairs is power – the change in gravitational potential energy is the same.

FIGURE 7.23



When this woman runs upstairs starting from rest, she converts the chemical energy originally from food into kinetic energy and gravitational potential energy. Her power output depends on how fast she does this.

Power

Power is also needed for acceleration and for moving against the force of gravity.

The average power can be written in terms of the force and the average velocity:

$$\overline{P} = \frac{W}{t} = \frac{Fd}{t} = F\overline{v}.$$

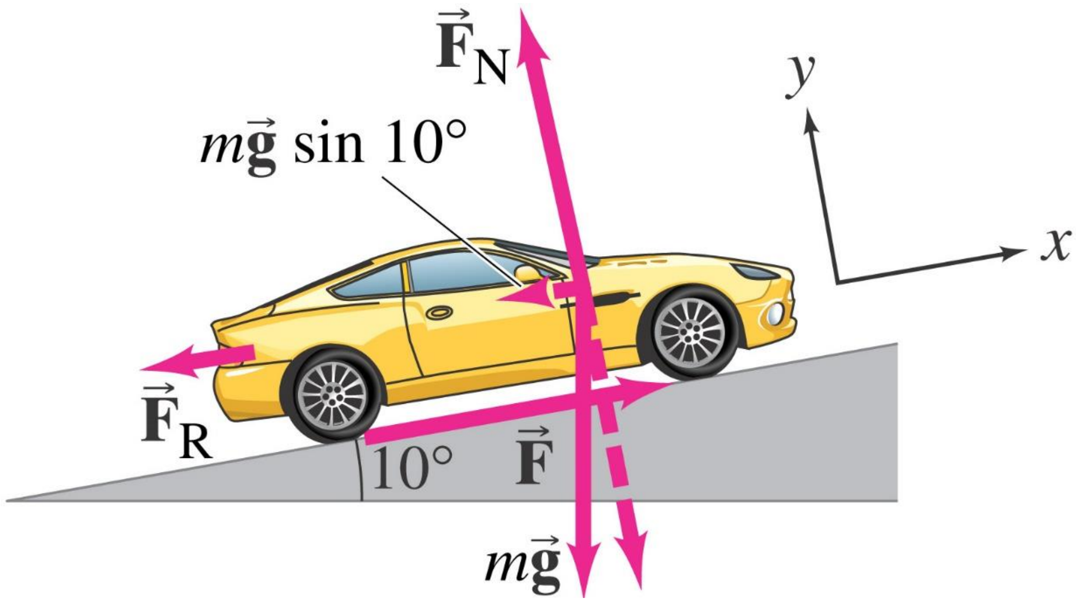
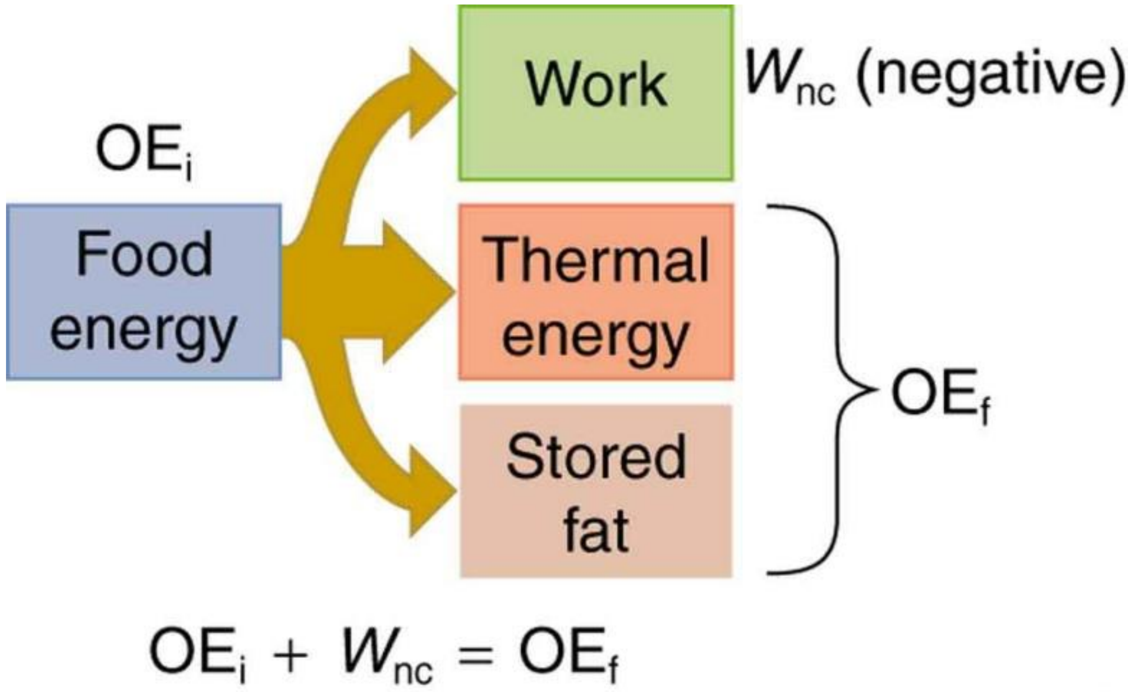


FIGURE 7.25



Energy consumed by humans is converted to work, thermal energy, and stored fat. By far the largest fraction goes to thermal energy, although the fraction varies depending on the type of physical activity.

Summary

- Work: $W = Fd\cos\theta$

- Kinetic energy is energy of motion: $\mathrm{KE} = \frac{1}{2}mv^2$

- Potential energy is energy associated with forces that depend on the position or configuration of objects.

$$\mathrm{PE}_{\mathrm{grav}} = mgy \qquad \text{elastic PE} = \tfrac{1}{2}kx^2$$

- The net work done on an object equals the change in its kinetic energy.

- If only conservative forces are acting, mechanical energy is conserved.

- Power is the rate at which work is done.