

Chapter 6

Work and Energy

Work Done by a Constant Force

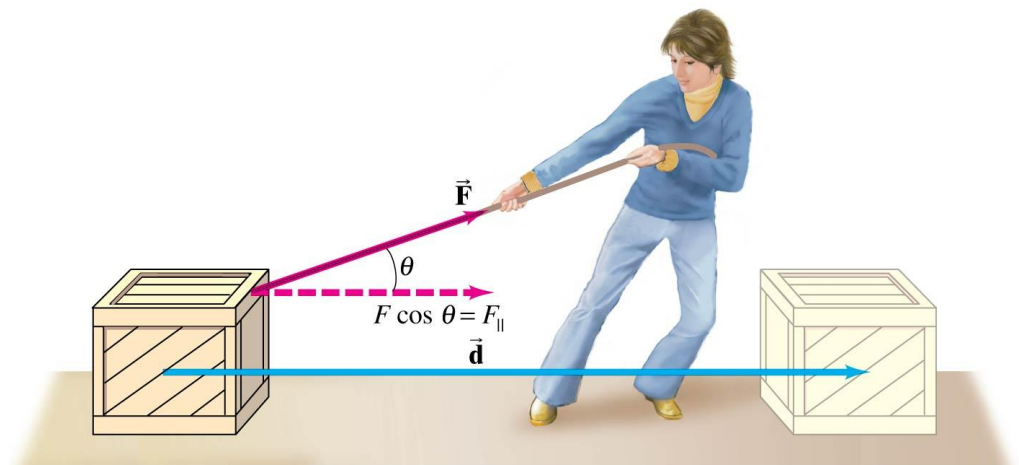
The work done by a constant force is defined as the distance moved multiplied by the component of the force in the direction of displacement:

$$W = Fd \cos \theta$$

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

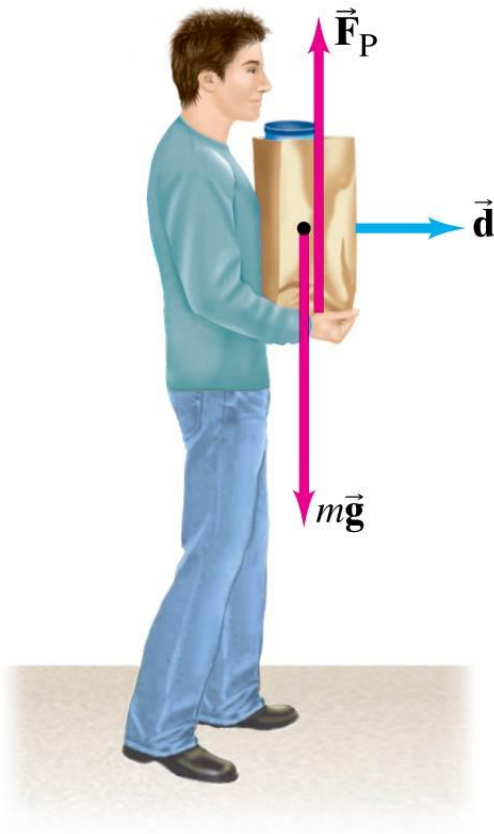
$$1 \text{ J} = 1 \text{ N} \cdot \text{m}$$

Work is a scalar quantity—it has no direction, but only magnitude, which can be positive or negative or zero



A force can be exerted on an object and yet do no work.

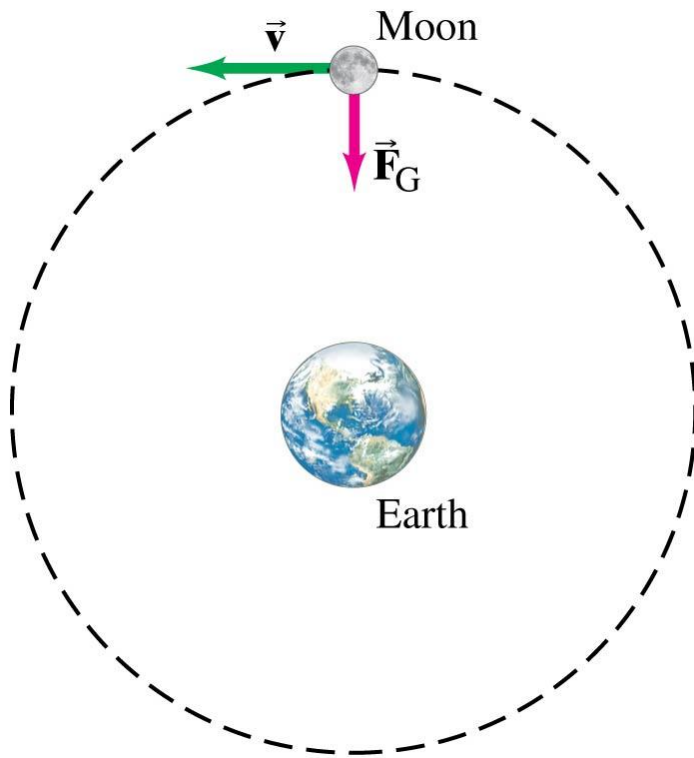
The force he exerts has no component in the direction of motion.



when a particular force is perpendicular to the displacement, no work is done by that force.

A force can be exerted on an object and yet do no work.

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



What is work and how it is related to energy?

A person pulls a 50-kg crate 40 m along a horizontal floor by a constant force $F_{app} = 100\text{ N}$ which acts at a 37° angle as shown. The floor is rough and exerts a friction force $F_f = 50\text{ N}$. Determine (a) the work done by each force acting on the crate, and (b) the net work done on the crate.

A 380-kg piano slides 2.9 m down a 25° incline and is kept from accelerating by a man who is pushing back on it parallel to the incline. Determine: (a) the force exerted by the man, (b) the work done on the piano by the man, (c) the work done on the piano by the force of gravity, and (d) the net work done on the piano. Ignore friction.



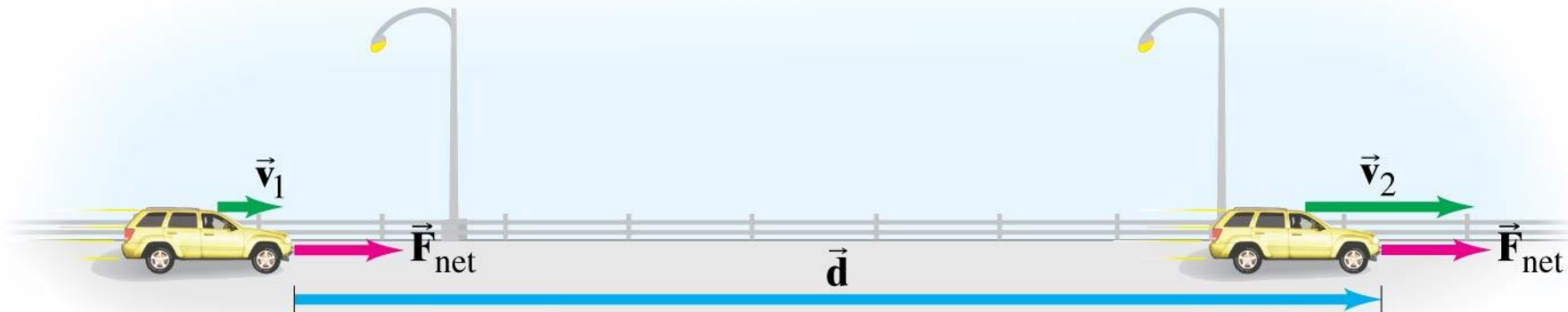
Kinetic Energy and the Work-Energy Principle

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

$$W_{\text{net}} = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2 \quad (6-2)$$

- We define the kinetic energy:

$$\text{KE} = \frac{1}{2}mv^2. \quad (6-3)$$



6-3 Kinetic Energy and the Work-Energy Principle

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

$$W_{\text{net}} = \Delta_{\text{KE}} = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2. \quad (6-4)$$

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

How much work must be done to stop a 925-kg car traveling at 95 km/h?

How much work must be done to accelerate a 1000 kg car traveling from rest to 100 km/h?

An 85-g arrow is fired from a bow whose string exerts an average force of 105 N on the arrow over a distance of 75 cm. What is the speed of the arrow as it leaves the bow?

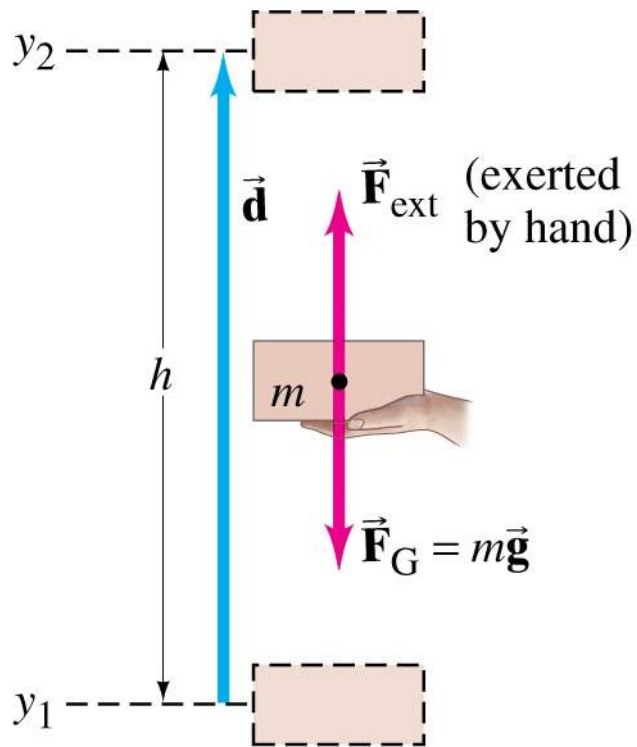
Potential Energy

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

Potential Energy Work done by external force



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

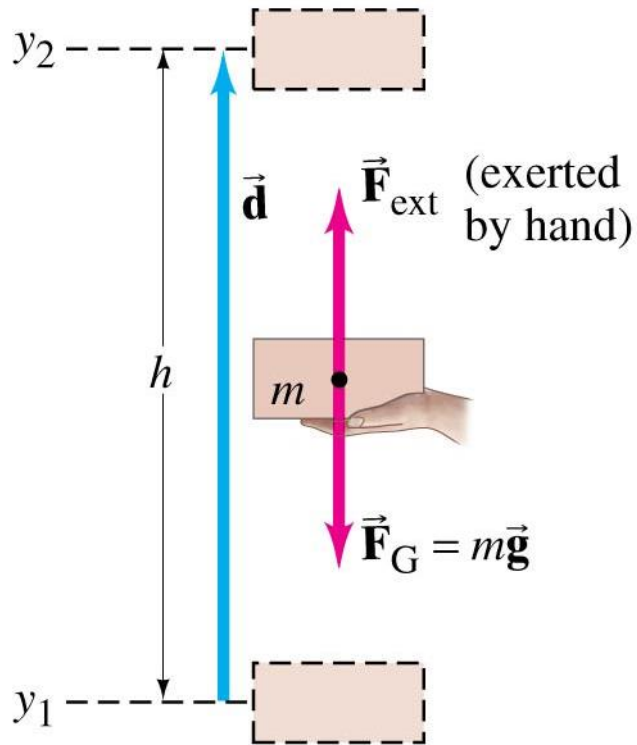
$$\begin{aligned} W_{\text{ext}} &= F_{\text{ext}} d \cos 0^\circ = mgh && (6-5a) \\ &= mg(y_2 - y_1) \end{aligned}$$

We therefore define the gravitational potential energy:

(6-6)

$$W_{\text{ext}} = PE_f - PE_i$$

Potential Energy (Work done by gravity)



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

$$\begin{aligned} W_g &= F_g d \cos 180 \\ &= -mg(y_2 - y_1) \end{aligned}$$

$$W_g = PE_i - PE_f$$

Potential Energy

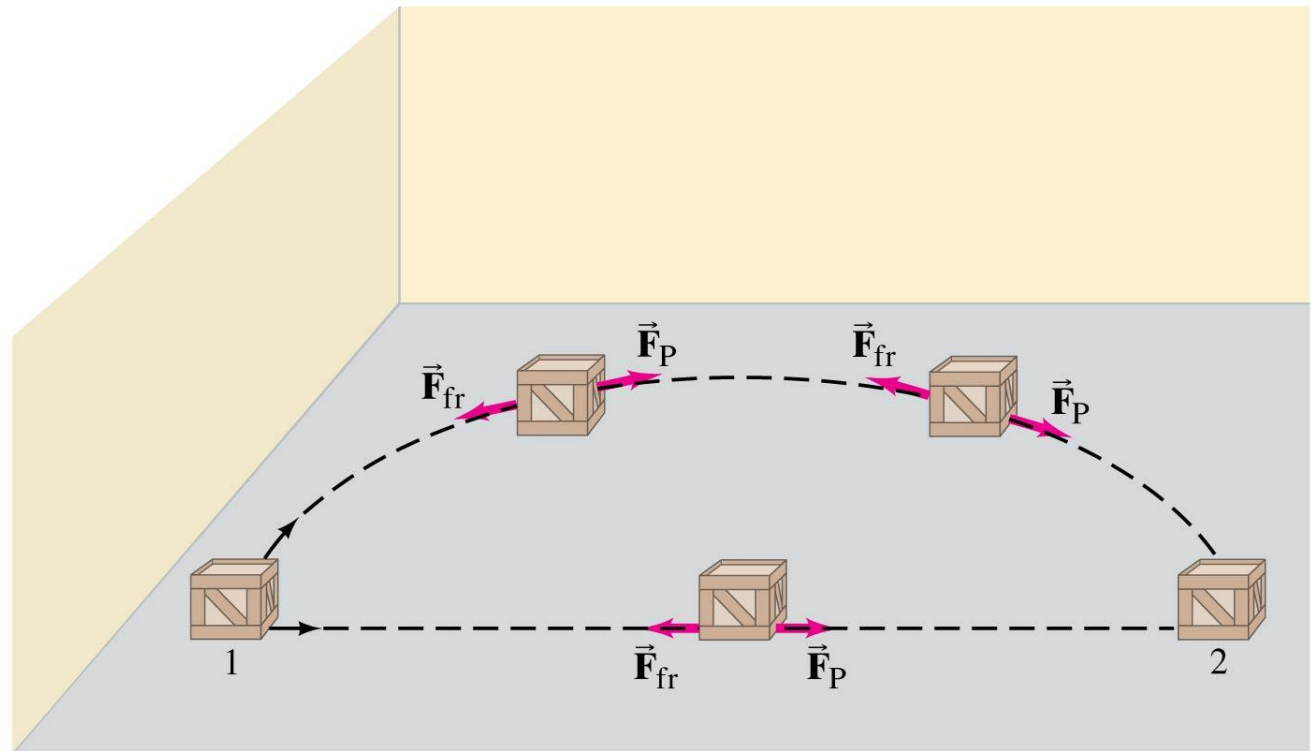
If $PE = mgy$, where do we measure y from?

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.

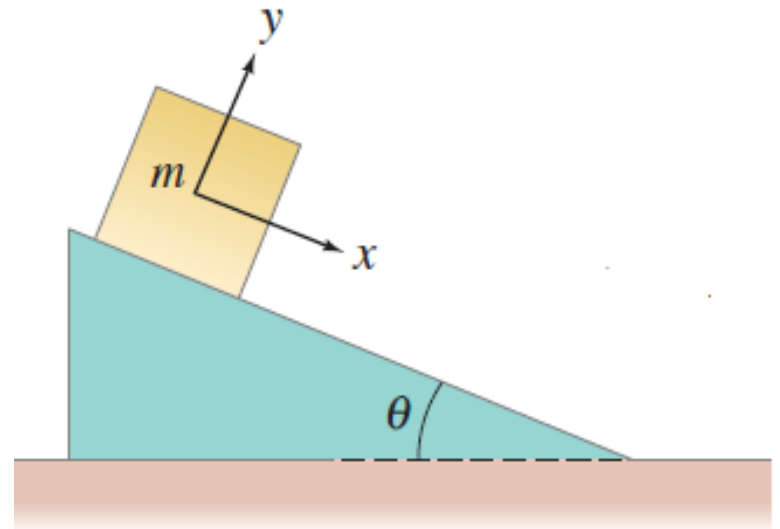
A 1.60-m-tall person lifts a 1.65-kg book off the ground so it is 2.20 m above the ground. What is the potential energy of the book relative to (a) the ground, and (b) the top of the person's head? (c) How is the work done by the person related to the answers in parts (a) and (b)?

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



6-5 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:

$$W_{\text{NC}} = \Delta\text{KE} + \Delta\text{PE} \quad (6-10)$$

6-6 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.

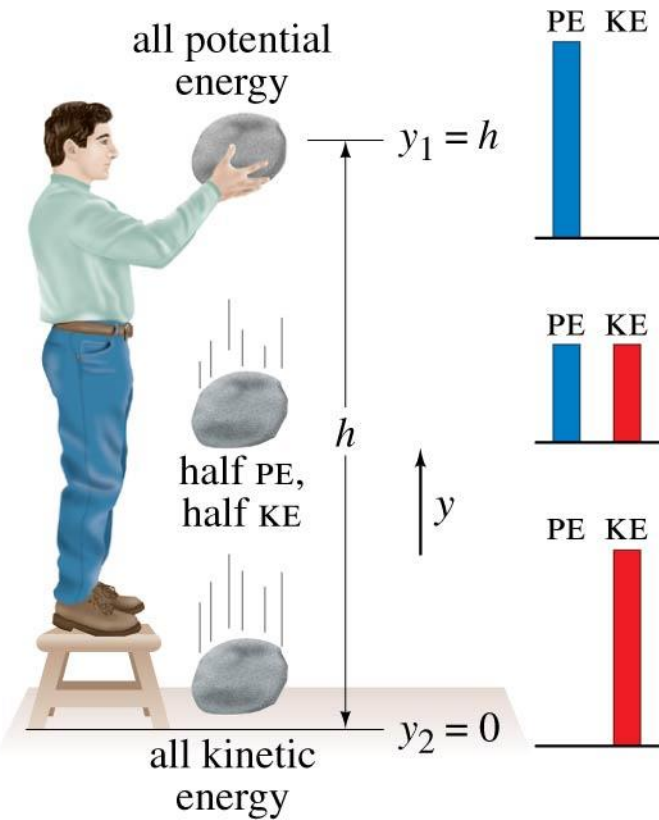
This allows us to define the total mechanical energy:

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

And its conservation:

$$E_2 = E_1 = \text{constant.} \quad (6-12b)$$

6-7 Problem Solving Using Conservation of Mechanical Energy

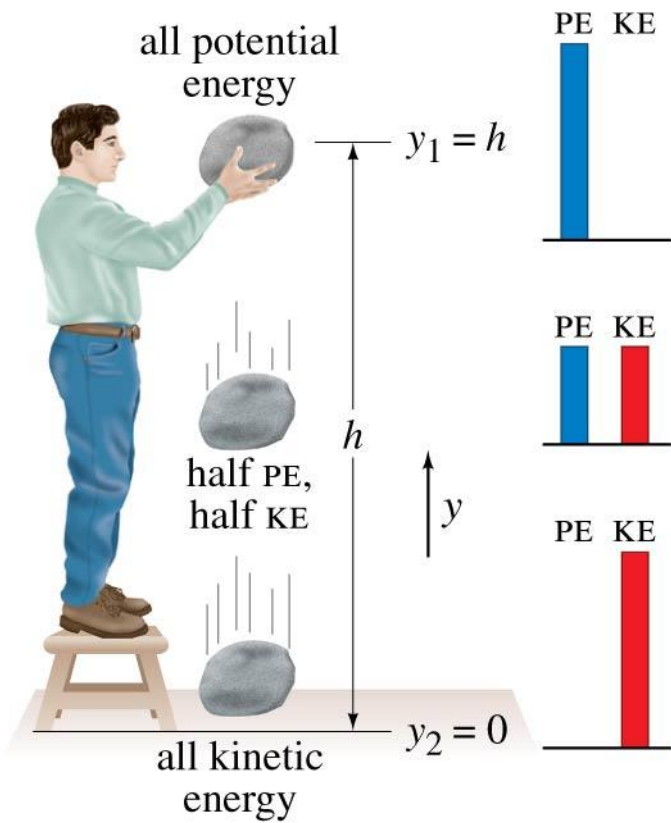


In the image on the left, the total mechanical energy is:

$$E = \text{KE} + U = \frac{1}{2}mv^2 + mgy$$

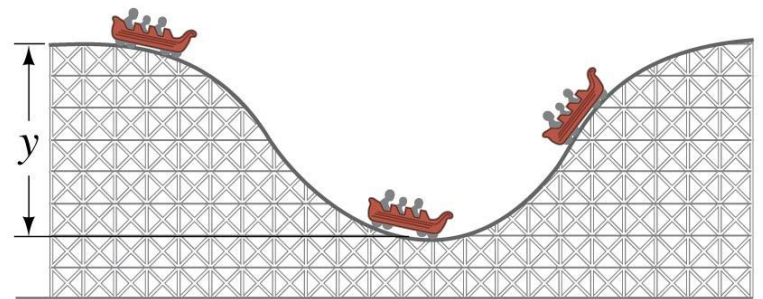
The mechanical energy is constant

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



calculate the rock's velocity when it has fallen to 1.0 m above the ground.

Assuming the height of the hill is 40 m, and the roller-coaster car starts from rest at the top, calculate (a) the speed of the roller-coaster car at the bottom of the hill, and (b) at what height it will have half this speed.



Other Forms of Energy and Energy Transformations; the Law of 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.

6-9 Energy Conservation with Dissipative Processes; Solving Problems

$$KE_1 + PE_1 + W_{NC} = KE_2 + PE_2.$$

$$\frac{1}{2}mv_1^2 + mgy_1 - F_{fr}d = \frac{1}{2}mv_2^2 + mgy_2$$

A 16.0-kg child descends a slide 2.20 m high and, starting from rest, reaches the bottom with a speed of 1.25 m/s . How much thermal energy due to friction was generated in this process?

44. (II) A skier traveling 11.0 m/s reaches the foot of a steady upward 19° incline and glides 15 m up along this slope before coming to rest. What was the average coefficient of friction?

42. (II) A ski starts from rest and slides down a 28° incline 85 m long. (a) If the coefficient of friction is 0.090, what is the ski's speed at the base of the incline? (b) If the snow is level at the foot of the incline and has the same coefficient of friction, how far will the ski travel along the level? Use energy methods.

6-10 Power

Power is the rate at which work is done—

$$\bar{P} = \text{average power} = \frac{\text{work}}{\text{time}} = \frac{\text{energy transformed}}{\text{time}} \quad (6-17)$$



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

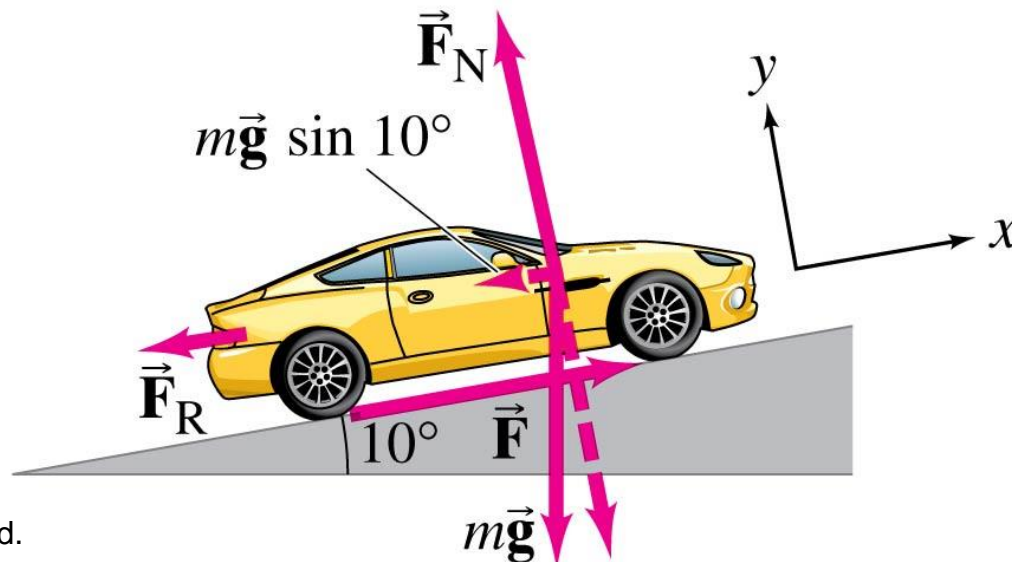
$$1\text{W} = 1\text{ J/s}$$

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

6-10 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:

$$\bar{P} = \frac{W}{t} = \frac{Fd}{t} = F\bar{v} \quad (6-18)$$


49. (I) How long will it take a 2750-W motor to lift a 385-kg piano to a sixth-story window 16.0 m above?

56. (II) A 975-kg sports car accelerates from rest to 95 km/h in 6.4 s. What is the average power delivered by the engine?

Summary of Chapter 6

- Work: $W = Fd \cos \theta$
- Kinetic energy is energy of motion: $KE = \frac{1}{2} mv^2$
- Potential energy is energy associated with forces that depend on the position or configuration of objects.
- 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.