

# *Chapter 6*

## ***Work and Energy***

**continued**

## 6.2 *The Work-Energy Theorem and Kinetic Energy*

### Chapters 1–5

Motion equations were been developed, that relate the concepts of velocity, speed, displacement, time, and with a particular emphasis on the **acceleration** of an object.

Newton discovered three laws that define the concept of a force.

The first two laws provide the relationship of forces to the **acceleration** of an object. The third law describes the nature of forces at the point of contact between two objects.

The effect of forces, including human generated forces, on the motion of an object have been solved in common situations . The forces of gravity, friction, (elastic) tension and compression, have been described.

## 6.2 The Work-Energy Theorem and Kinetic Energy

Relate these to Energy

**Work:** the effect of a force acting on an object making a displacement.

$$W = (F \cos \theta)s,$$

where  $W$  is the work done,  $F, s$  are the magnitudes of the force and displacement, and  $\theta$  is the angle between  $\vec{F}$  and  $\vec{s}$ .

The origin of the force does not affect the calculation of the work done.

Work can be done by: gravity, elastic, friction, explosion, or human forces.

**Kinetic energy:** property of a mass ( $m$ ) and the square of its speed ( $v$ ).

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

**Work-Energy Theorem:** Work changes the Kinetic Energy of an object.

$$KE_f = KE_0 + W$$

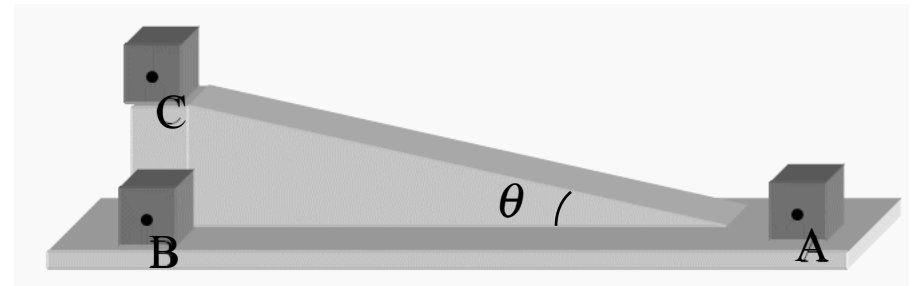
or

$$KE_f - KE_0 = W$$

## Quiz 5

1. C&J page 158 (middle), Check Your Understanding #4: “A suitcase ...”
2. An elevator descends a shaft at a **constant speed**. Only tension in the cable and the gravitational force act on the elevator. Let  $W_G$  = work by gravity, and  $W_T$  = work by tension. Pick the true statement:
  - a)  $W_T$  = zero joules.
  - b)  $W_T + W_G$  = zero joules.
  - c)  $W_G$  = zero joules
  - d)  $|W_G| > |W_T|$
  - e)  $|W_T| > |W_G|$
3. A sanding machine moves a sanding block 45 times back and forth each time moving a distance of 0.15m. The normal force is 1.8 N and the coefficient of friction is 0.92. How much work is done by the machine?
  - a) +12 J
  - b) -12 J
  - c) +24 J
  - d) -24 J
  - e) zero J

4. Determine the amount of work done in firing a 2.0-kg projectile to an initial speed of 50 m/s. Neglect any effects due to air resistance
- a) 900 J
  - b) 1600 J
  - c) 2500 J
  - d) 4900J
  - e) zero
5. On a frictionless surfaces, a box can be moved up the ramp (A to C) with gravity doing work  $W_{AC}$ , or horizontally and then up (A to B to C) with gravity doing work  $W_{ABC}$ . Compare this work on the two paths.
- a)  $W_{ABC}$  is much greater than  $W_{AC}$
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  - c)  $W_{ABC}$  is much less than  $W_{AC}$
  - d)  $W_{ABC}$  is slightly less than  $W_{AC}$
  - e) The work done by gravity is the same on both paths



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a)  $W$  is +, up,  $W$  is –, down

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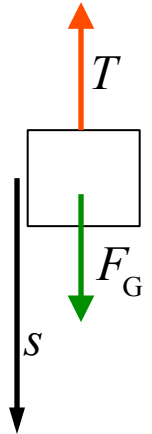
e)  $|W_T| > |W_G|$

lowered distance  $s$ ,  $T = mg$

$$W_T = (T \cos 180^\circ)s, \quad W_G = (mg \cos 0^\circ)s$$

$$W_T = -mgL, \quad W_G = +mgL$$

$$W_{\text{Net}} = W_T + W_G = 0$$



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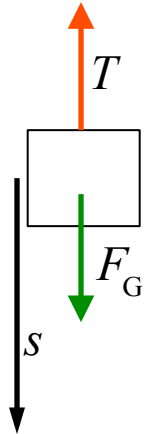
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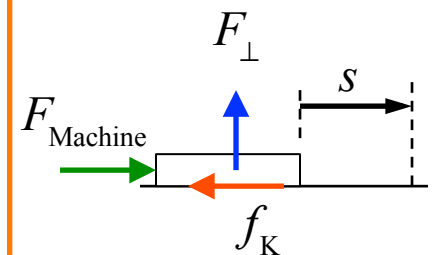
e) zero J

$$f_K = \mu_K F_\perp = 0.92 \cdot 1.8 \text{ N} = 1.7 \text{ N}$$

work each stroke:

$$w = (f_K \cos 0^\circ)s = +(1.7 \text{ N})(0.15 \text{ m}) = +0.26 \text{ J}$$

$$\text{Work for 45 times: } W = 45(+0.26 \text{ J}) = +12 \text{ J}$$





4. Determine the amount of work done in firing a 2.0-kg projectile to an initial speed of 50 m/s. Neglect any effects due to air resistance

a) 900 J

b) 1600 J

c) 2500 J

d) 4900J

e) zero

Work changes kinetic energy,  $KE_0 = 0$

$$W = KE_f - KE_0 = \frac{1}{2}mv^2 = (0.5)(2.0 \text{ kg})(50 \text{ m/s})^2 = 2500 \text{ J}$$

5. On a frictionless surfaces, a box can be moved up the ramp (A to C) with gravity doing work  $W_{AC}$ , or horizontally and then up (A to B to C) with gravity doing work  $W_{ABC}$ . Compare this work on the two paths.

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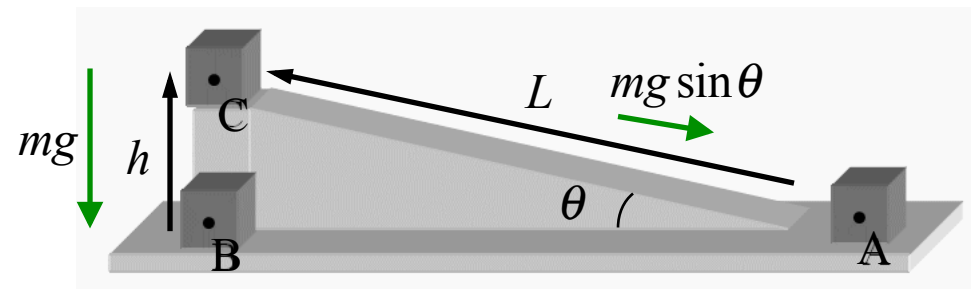
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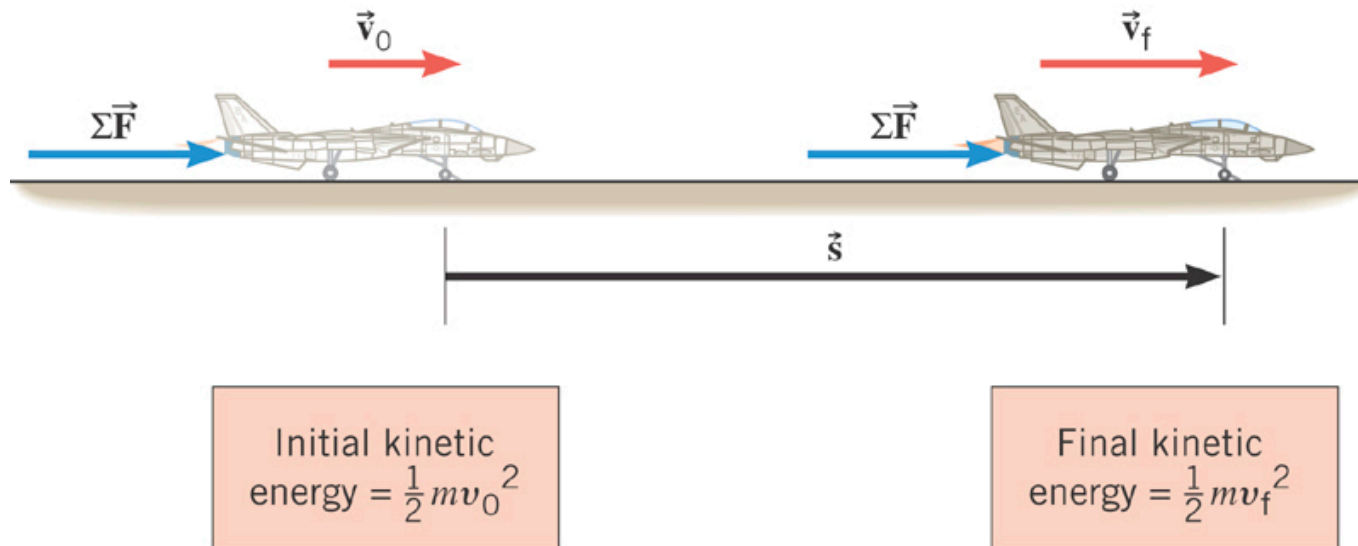
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$$W_{AC} = (F_{\parallel} \cos 180^\circ)L = -F_{\parallel}L = -(mg \sin \theta)L$$
$$W_{ABC} = (mg \cos 180^\circ)h, \quad h = L \sin \theta$$
$$= -mgL \sin \theta$$

- e) The work done by gravity is the same on both paths

## 6.2 The Work-Energy Theorem and Kinetic Energy



### THE WORK-ENERGY THEOREM

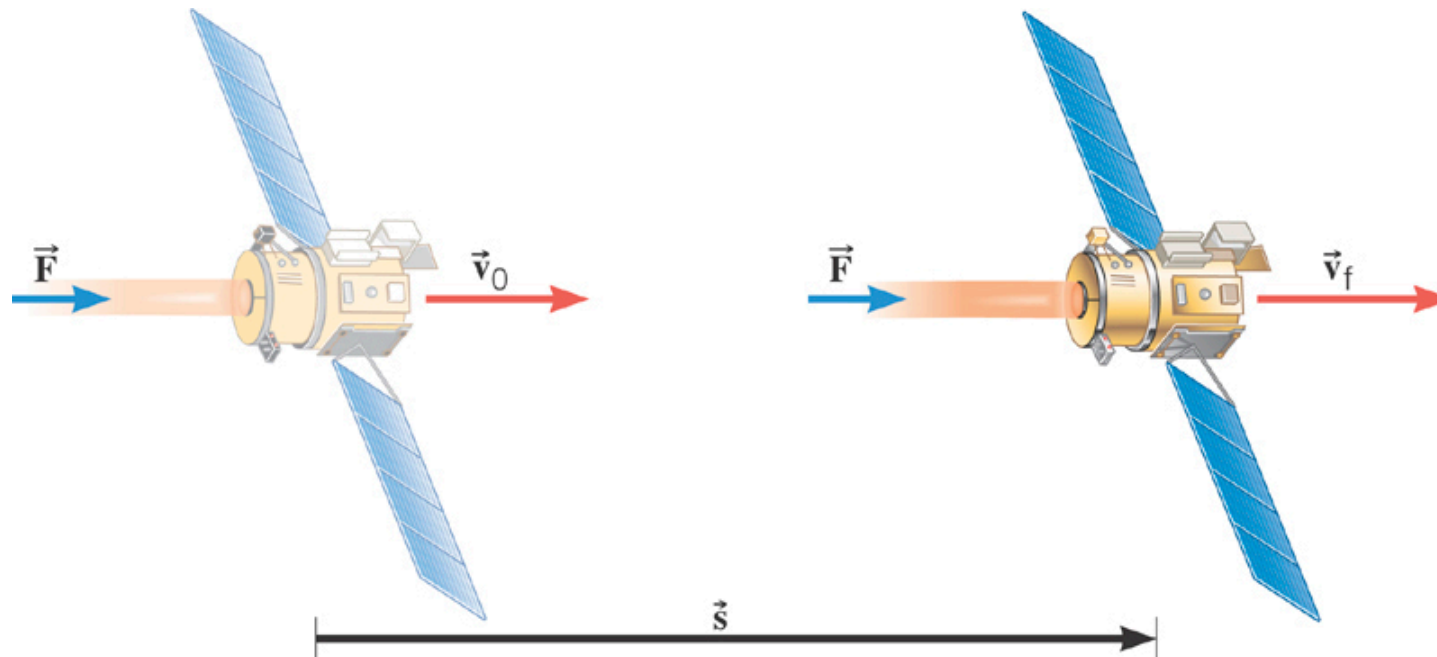
When a net external force does work on an object, the kinetic energy of the object changes according to

$$W = \text{KE}_f - \text{KE}_0 = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_0^2$$

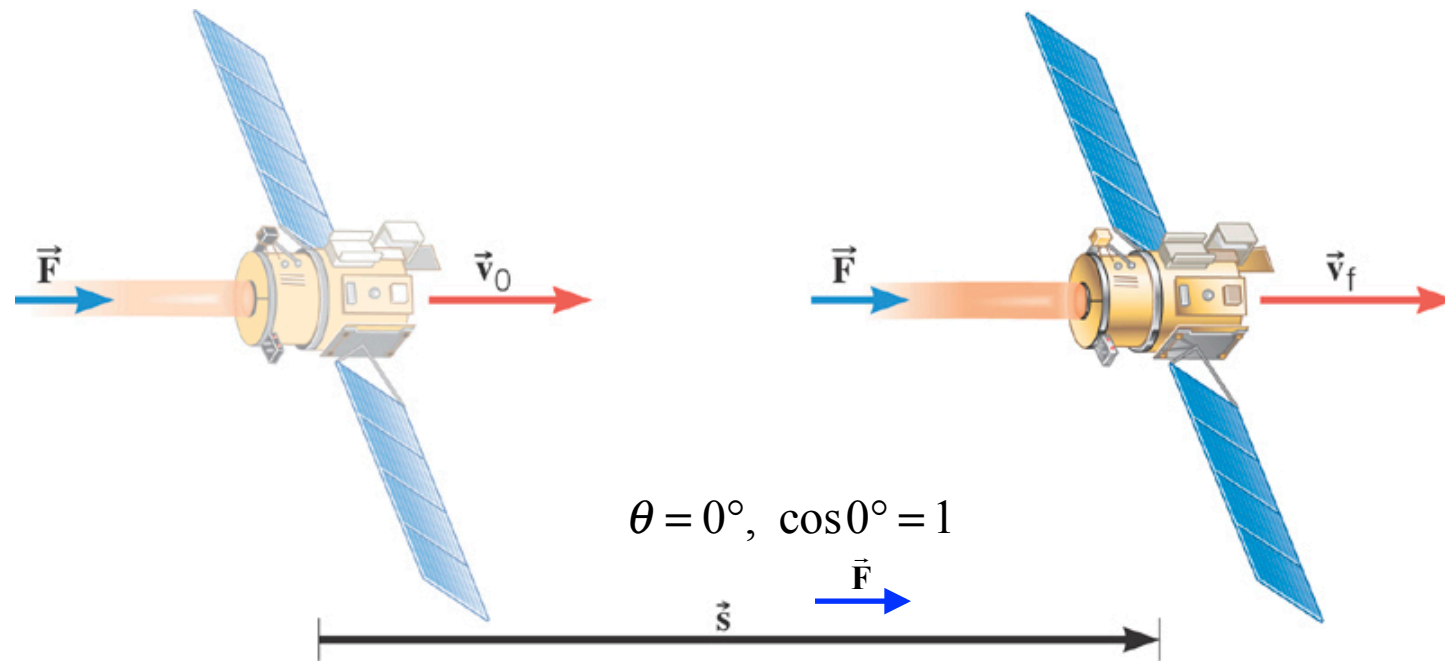
## 6.2 *The Work-Energy Theorem and Kinetic Energy*

### **Example 4 Deep Space 1**

The mass of the space probe is 474-kg and its initial velocity is 275 m/s. If the 56.0-mN force acts on the probe through a displacement of  $2.42 \times 10^9$  m, what is its final speed?



## 6.2 The Work-Energy Theorem and Kinetic Energy



$$W = [F \cos \theta] s = (5.60 \times 10^{-2} \text{ N})(2.42 \times 10^9 \text{ m}) = 1.36 \times 10^8 \text{ J}$$

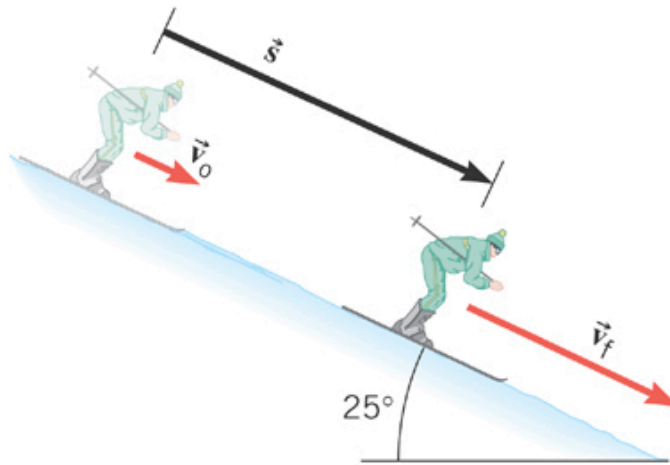
$$W = \frac{1}{2} m v_f^2 - \frac{1}{2} m v_o^2$$

$$v_f^2 = \frac{2W}{m} + v_o^2 = \frac{2.72 \times 10^8 \text{ J}}{474 \text{ kg}} + (275 \text{ m/s})^2$$

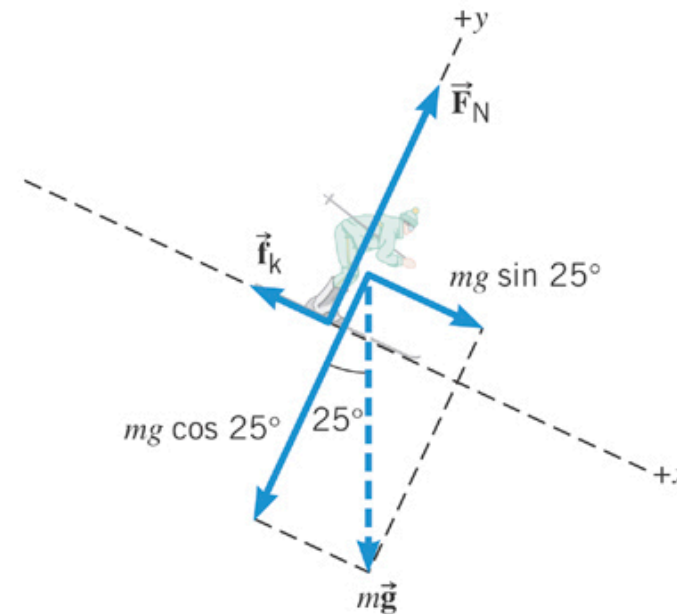
$$v_f = 806 \text{ m/s}$$

## 6.2 The Work-Energy Theorem and Kinetic Energy

Familiar decomposition of the gravitation force,  $mg$  downward



(a)



(b) Free-body diagram for the skier

Choosing downward as +  
In this case the net force is

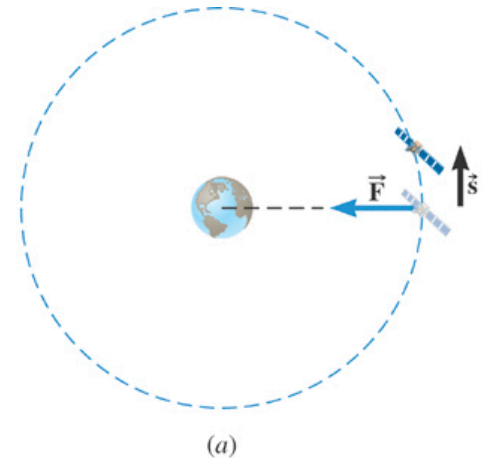
$f_k$  is given as 71 N

$$\sum F = mg \sin 25^\circ - f_k$$

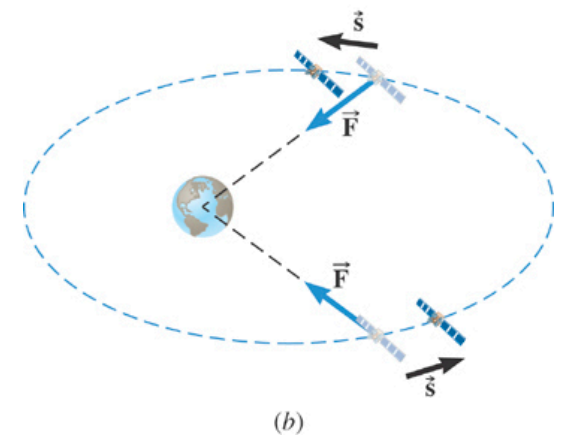
## 6.2 *The Work-Energy Theorem and Kinetic Energy*

### **Conceptual Example 6** Work and Kinetic Energy

A satellite is moving about the earth in **a circular** orbit. Does kinetic energy change during the motion?



A satellite is moving about the earth in **an elliptical** orbit. Does kinetic energy change during the motion?

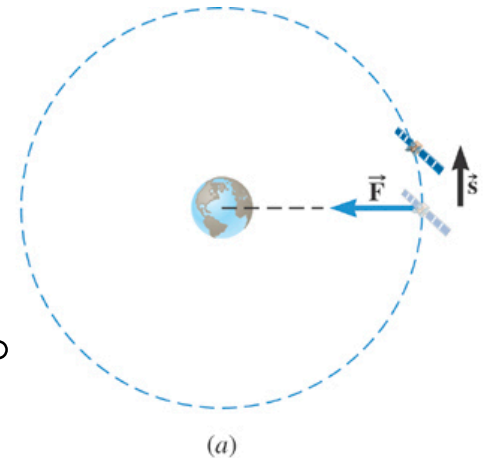


## 6.2 The Work-Energy Theorem and Kinetic Energy

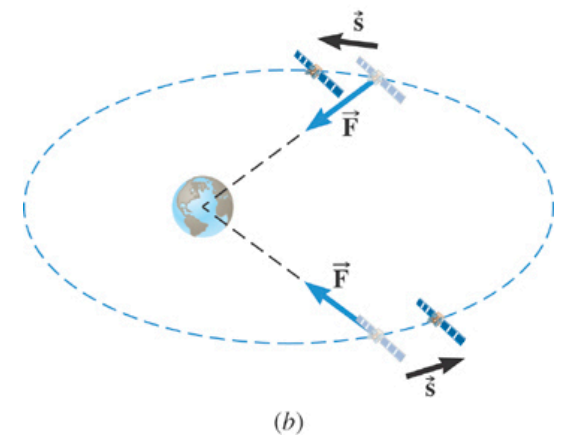
### Conceptual Example 6 Work and Kinetic Energy

A satellite is moving about the earth in **a circular** orbit. Does kinetic energy change during the motion?

$$\begin{aligned} \text{(work)} \quad W &= (F \cos \theta)s, \text{ but between } \vec{F} \text{ and } \vec{s}, \theta = 90^\circ \\ &= (F \cdot \cos 90^\circ)s = \text{ZERO} \end{aligned}$$



A satellite is moving about the earth in **an elliptical** orbit. Does kinetic energy change during the motion?





## 6.2 The Work-Energy Theorem and Kinetic Energy

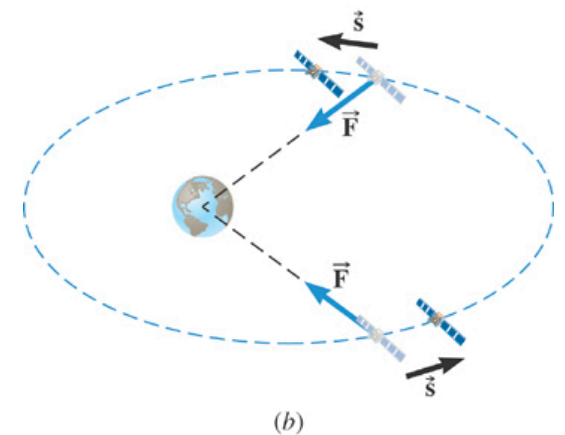
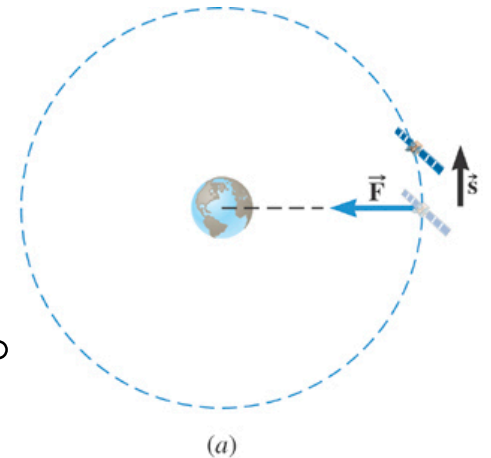
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$$\begin{aligned} KE_f - KE_o &= W \\ &= 0 \text{ (no change in kinetic energy)} \end{aligned}$$

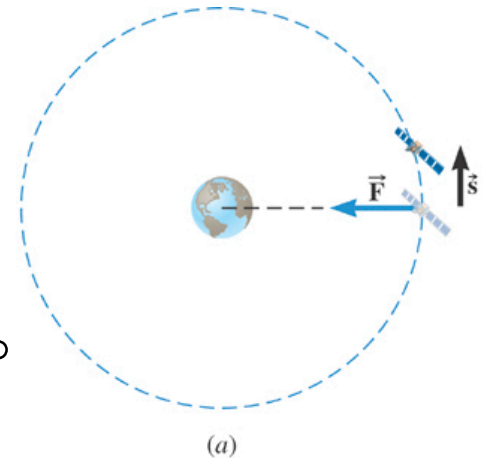
A satellite is moving about the earth in **an elliptical** orbit. Does kinetic energy change during the motion?



## 6.2 The Work-Energy Theorem and Kinetic Energy

### Conceptual Example 6 Work and Kinetic Energy

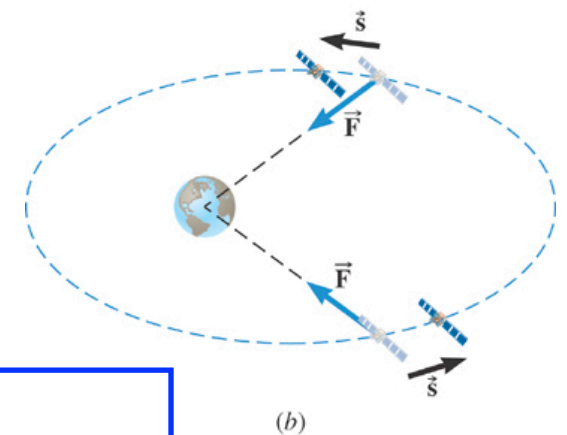
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A satellite is moving about the earth in **an elliptical** orbit. Does kinetic energy change during the motion?



$$\begin{aligned} \text{(work)} \quad W &= (F \cos \theta)s, \quad \theta \text{ not always equal to } 90^\circ \\ \text{kinetic energy increases at places and decreases at others.} \end{aligned}$$

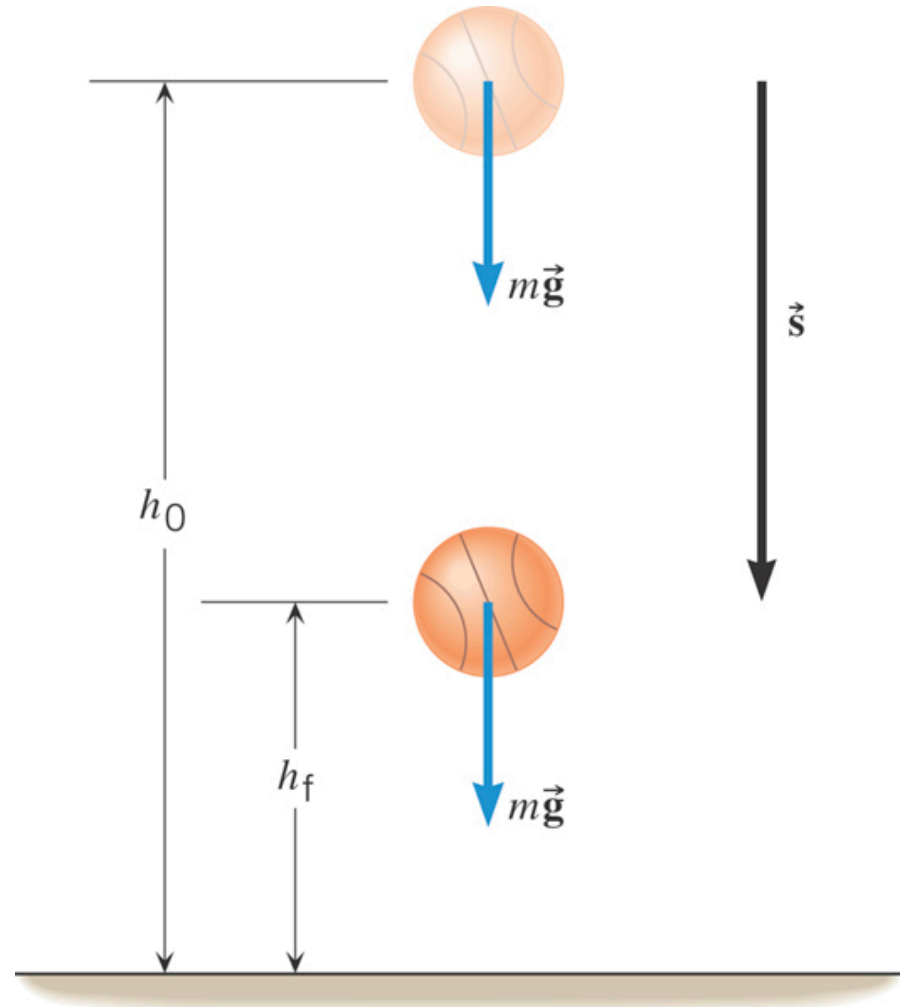
### 6.3 Gravitational Potential Energy

This  $\theta$  is the angle between  $\vec{F}$  and  $\vec{s}$ .

$$W = (F \cos \theta) s$$
$$= mgs$$

$s$  = distance of fall =  $(h_0 - h_f)$

$$W_G = mg(h_0 - h_f)$$



Why use  $(h_0 - h_f)$  instead of  $s$ ?  $\Rightarrow$  because we already have  $KE_f$  and  $KE_0$

### 6.3 Gravitational Potential Energy

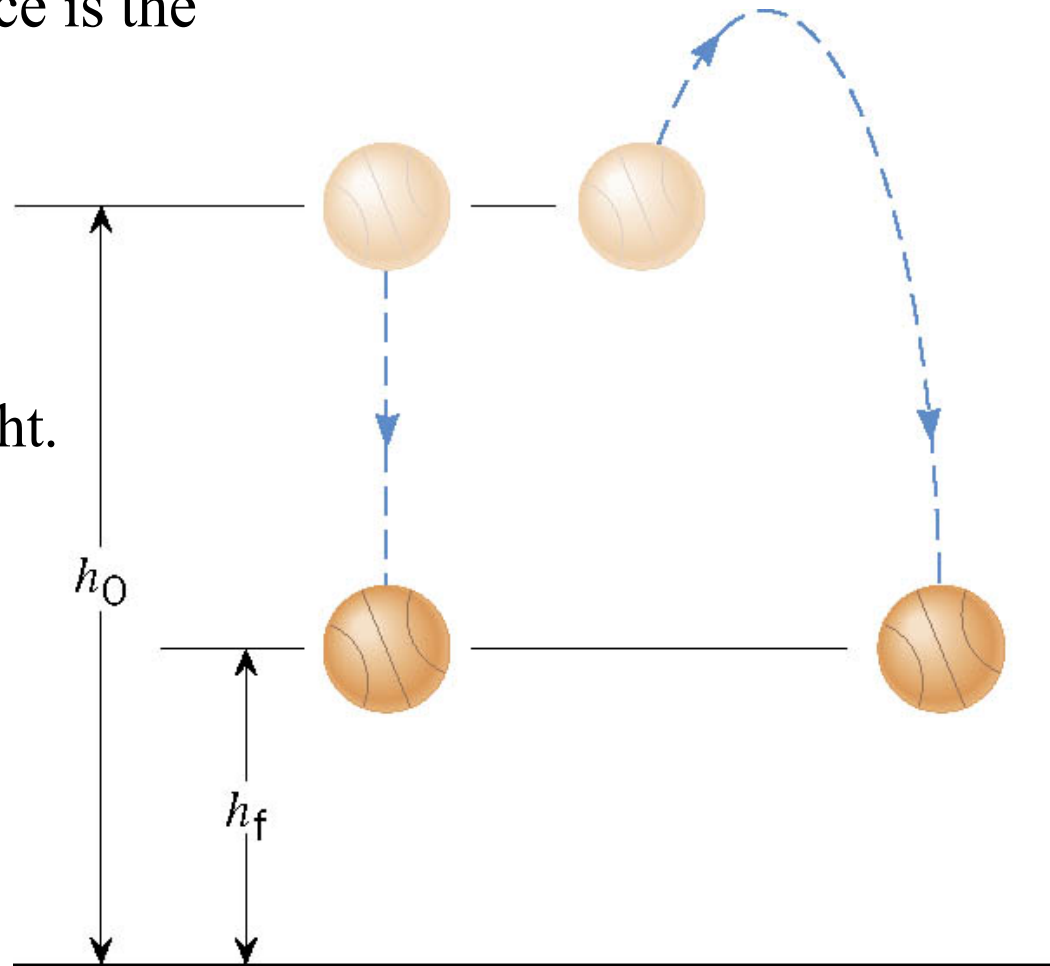
When returning to the initial height,  $h_0$ , the work done by gravity is zero. There is no displacement,  $s = 0$ .

Work by the gravitational force is the same over the two paths

$$W_G = mg(h_0 - h_f)$$

Same starting and ending height.

Gravity is unusual!  
It is a "conservative force".



## 6.4 *Conservative Versus Nonconservative Forces*

### DEFINITION OF A CONSERVATIVE FORCE

**Version 1** A force is conservative when the work it does on a moving object is independent of the path between the object's initial and final positions.

**Version 2** A force is conservative when it does no net work on an object moving around a closed path, starting and finishing at the same point.

**Also:**

**Version 3** A force is conservative when the energy absorbed from a mass by the force can be returned to the mass without loss by that force.

## 6.4 *Conservative Versus Nonconservative Forces*

**Table 6.2**   **Some Conservative  
and Nonconservative Forces**

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***Conservative Forces***

Gravitational force (Ch. 4)

Elastic spring force (Ch. 10)

Electric force (Ch. 18, 19)

***Nonconservative Forces***

Static and kinetic frictional forces

Air resistance

Muscular forces

Explosions

Jet or rocket forces

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### 6.3 *Gravitational Potential Energy*

Because gravity is a conservative force, when a mass moves upward against the gravitational force, the kinetic energy of the mass decreases, but when the mass falls to its initial height that kinetic energy returns completely to the mass.

When the kinetic energy decreases, where does it go?

#### DEFINITION OF GRAVITATIONAL POTENTIAL ENERGY

The gravitational potential energy PE is the energy that an object of mass  $m$  has by virtue of its position relative to the surface of the earth. That position is measured by the height  $h$  of the object **relative to an arbitrary zero level**:

$$\boxed{PE = mgh}$$

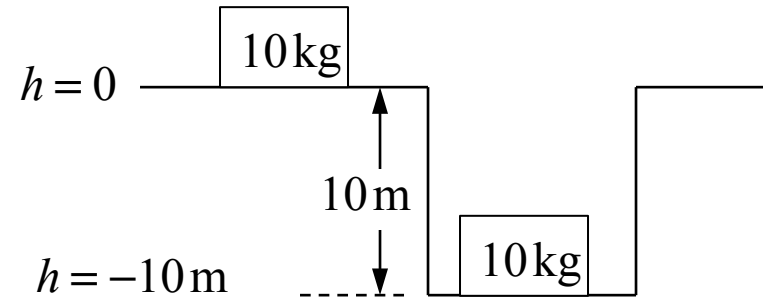
$$1 \text{ N} \cdot \text{m} = 1 \text{ joule (J)}$$

**( $h$  can be + or -)**

## Clicker Question 6.1

The potential energy ( $mgh$ ) of a 10 kg mass on the surface of the earth is zero. What is the potential energy of the mass in a 10 m deep hole?

- a) 0J
- b) 98J
- c) -98J
- d) 980J
- e) -980J

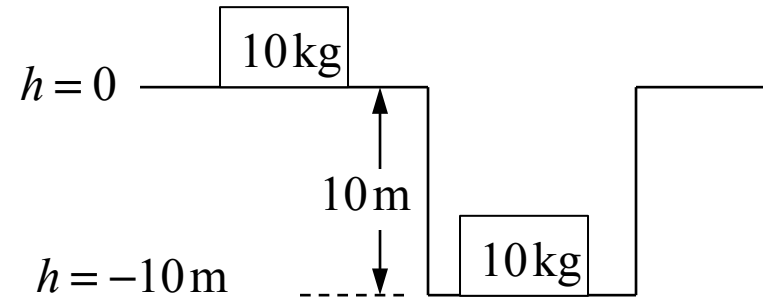




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- a) 0J
- b) 98J
- c) -98J
- d) 980J
- e) -980J**



$$\begin{aligned} PE &= mgh = (10\text{kg})(9.8\text{ m/s}^2)(-10\text{m}) \\ &= -980\text{ J} \end{aligned}$$

### 6.3 Gravitational Potential Energy

#### Moving upward

Gravitational work is negative.

$$\begin{aligned}W_G &= (F \cos 180^\circ)s \\ &= -mg(h_f - h_0)\end{aligned}$$

Gravitational Potential Energy increases.

$$\begin{aligned}\text{PE}_f - \text{PE}_0 &= mg(h_f - h_0) \\ &= -W_G\end{aligned}$$

Work-Energy Theorem becomes:

$$\begin{aligned}\text{KE}_f - \text{KE}_0 &= W_G \\ &= -(\text{PE}_f - \text{PE}_0)\end{aligned}$$

$\text{KE}_f + \text{PE}_f = \text{KE}_0 + \text{PE}_0$ Conservation of Energy
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