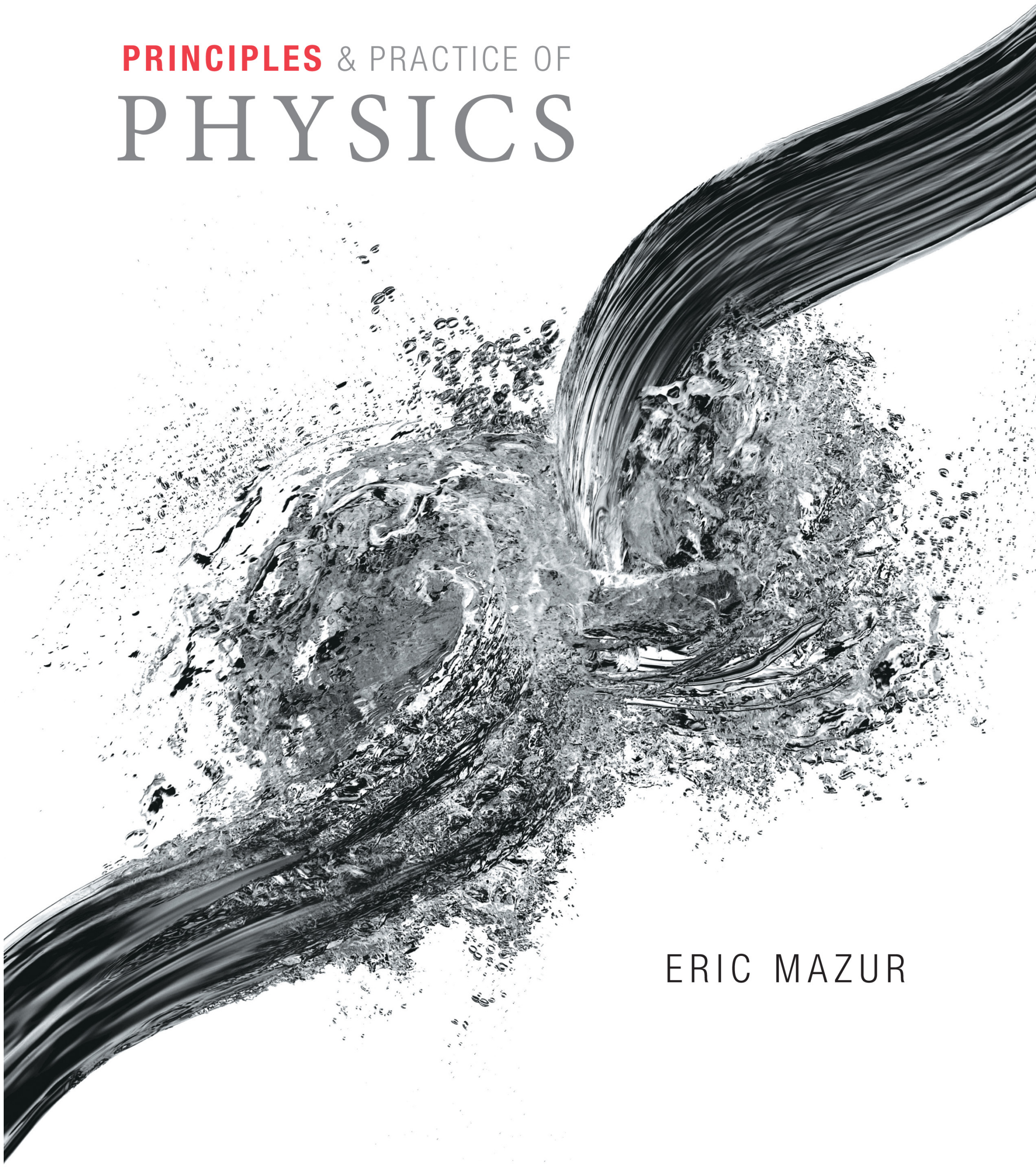
Chapter 8 summary: Force



Chapter 8: Summary

Concepts: Characteristics of forces

- When an object participates in one interaction only, the **force** exerted on the object is given by the time rate of change in the object's momentum.

- A **contact force** is a force that one object exerts on another object only when the two objects are in physical contact.

Chapter 8: Summary

Concepts: Characteristics of forces

- A **field force** is a force (such as gravity) that one object exerts on another object without the requirement that the two objects be in physical contact.

- When two objects interact, the forces they exert on each other form an **interaction pair,** and these forces have equal magnitudes but opposite directions.

Quantitative Tools: Characteristics of forces

- The SI unit of force is the **newton** (N):

$$1\ \mathrm{N} \equiv 1\ \mathrm{kg \cdot m/s^2}$$

- For an interaction pair of forces,

$$\vec{F}_{12} = -\vec{F}_{21}$$

Concepts: Some important forces

- A taut, flexible object (such as a spring, rope, or thread), when subjected to equal and opposite *tensile forces* applied at either end, experiences along its length a *stress* called **tension**. If the object is very light, the tension is the same everywhere in it.

- **Hooke's law** relates the force that a spring exerts on a load to the distance the spring is stretched (or compressed) from its relaxed position.

Chapter 8: Summary

Quantitative Tools: Some important forces

- The x component of the force of gravity exerted on an object of inertia m near Earth's surface is

$$F^G_{\text{Eo}\,x} = -mg$$

where the minus sign indicates that the force is directed downward.

- **Hooke's law:** If a spring is stretched (or compressed) by a *small* distance $x - x_0$ from its unstretched length x_0, the x component of the force it exerts on the load is

$$(F_{\text{by spring on load}})_x = -k(x - x_0)$$

where k is called the **spring constant** of the spring.

Chapter 8: Summary

Concepts: Effects of force

- The vector sum of the forces exerted on an object is equal to the time rate of change of the momentum of the object.
- The **equation of motion** for an object relates the object's acceleration to the vector sum of the forces exerted on it.
- **Newton's laws of motion** describe the effects forces have on the motion of objects.
- If an object is at rest or moving with constant velocity, it is in **translational equilibrium.** In this case, the vector sum of the forces exerted on it is equal to zero.
- A **free-body diagram** for an object is a sketch representing the object by a dot and showing all the forces exerted *on* it.

Concepts: Effects of force

- The vector sum of the forces exerted on an object is equal to the time rate of change of the momentum of the object.

- The **equation of motion** for an object relates the object's acceleration to the vector sum of the forces exerted on it.

Chapter 8: Summary

Concepts: Effects of force

- **Newton's laws of motion** describe the effects forces have on the motion of objects.
- If an object is at rest or moving with constant velocity, it is in **translational equilibrium**. In this case, the vector sum of the forces exerted on it is equal to zero.
- A **free-body diagram** for an object is a sketch representing the object by a dot and showing all the forces exerted *on* it.

Quantitative Tools: Effects of forces

- Vector sum of forces exerted on an object:

$$\Sigma\vec{F} \equiv \frac{d\vec{p}}{dt}$$

- Equation of motion:

$$\vec{a} = \frac{\Sigma\vec{F}}{m}$$

- If the inertia *m* of an object is constant, Newton's second law is usually written as

$$\Sigma\vec{F} = m\vec{a}$$

- For two interacting objects, 1 and 2, Newton's third law of motion states that

$$\vec{F}_{12} = -\vec{F}_{21}$$

Concepts: Impulse

- The **impulse** produced by forces exerted on an object is the product of the vector sum of the forces and the time interval over which the forces are exerted. The impulse delivered to the object is also equal to the change in its momentum.

Quantitative Tools: Impulse

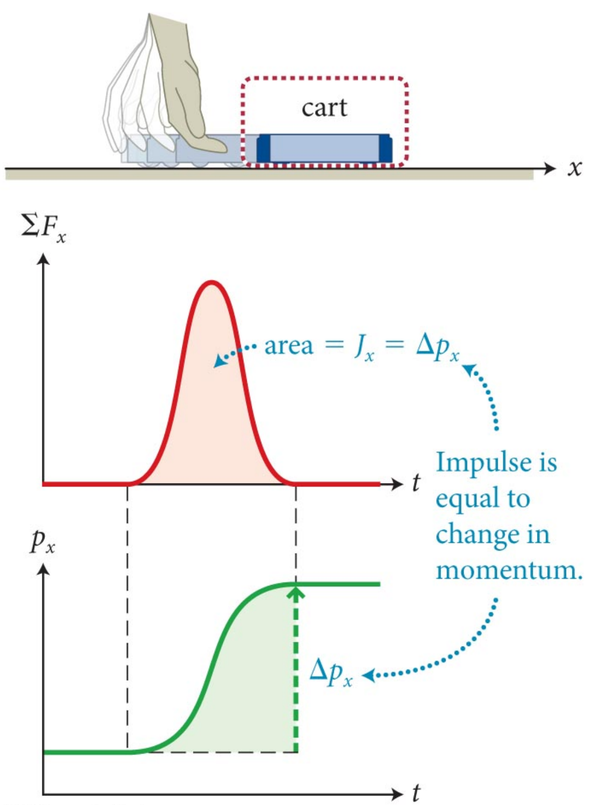
- For a constant force,

$$\Delta\vec{p} = \vec{J} = \left(\Sigma\vec{F}\right)\Delta t$$

- For a time-varying force,

$$\Delta\vec{p} = \vec{J} = \int_{t_1}^{t_\mathrm{f}} \Sigma\vec{F}(t)\,dt$$

(b) Hand shoves cart, exerting force that varies with time



Concepts: System of interacting objects

- The center of mass of a system of objects accelerates as though all the objects were located at the center of mass and the external force were applied at that location.

Quantitative Tools: System of interacting objects

- Acceleration of a system of objects:

$$\vec{a}_{\mathrm{cm}} = \frac{\Sigma \vec{F}_{\mathrm{ext}}}{m}$$

- Internal forces between interacting objects cancel out!
- ***Net*** motion is only due to external forces

Grades

- Midterm grades due tomorrow
- Grades so far on Blackboard:
    - HW 1-4
    - RQ 1-9
    - Labs 1-3
    - participation through 10/2 (expect 12 Q+A)
    - Exam 1
    - check for accuracy

PackBack

- Does not count this week (or last weekend)
- counted weeks:
  - 8/28-9/4
  - 9/4-9/11
  - 9/18-9/25
  - 9/25-10/2***
  - total: 12 through last week

- 9/11-9/18 = catch up week, counts toward total
- before 8/28 was not counted

8.90

- A – net force is (contact-weight) = 0
  - no acceleration, net force is zero
- B – net force is (contact-weight) = +ma
  - acceleration is upward, same dir as contact force
- C – net force is (contact-weight) = -ma
  - acceleration is downward

- acceleration = direction of *change in velo*city – does it act with or against velocity?

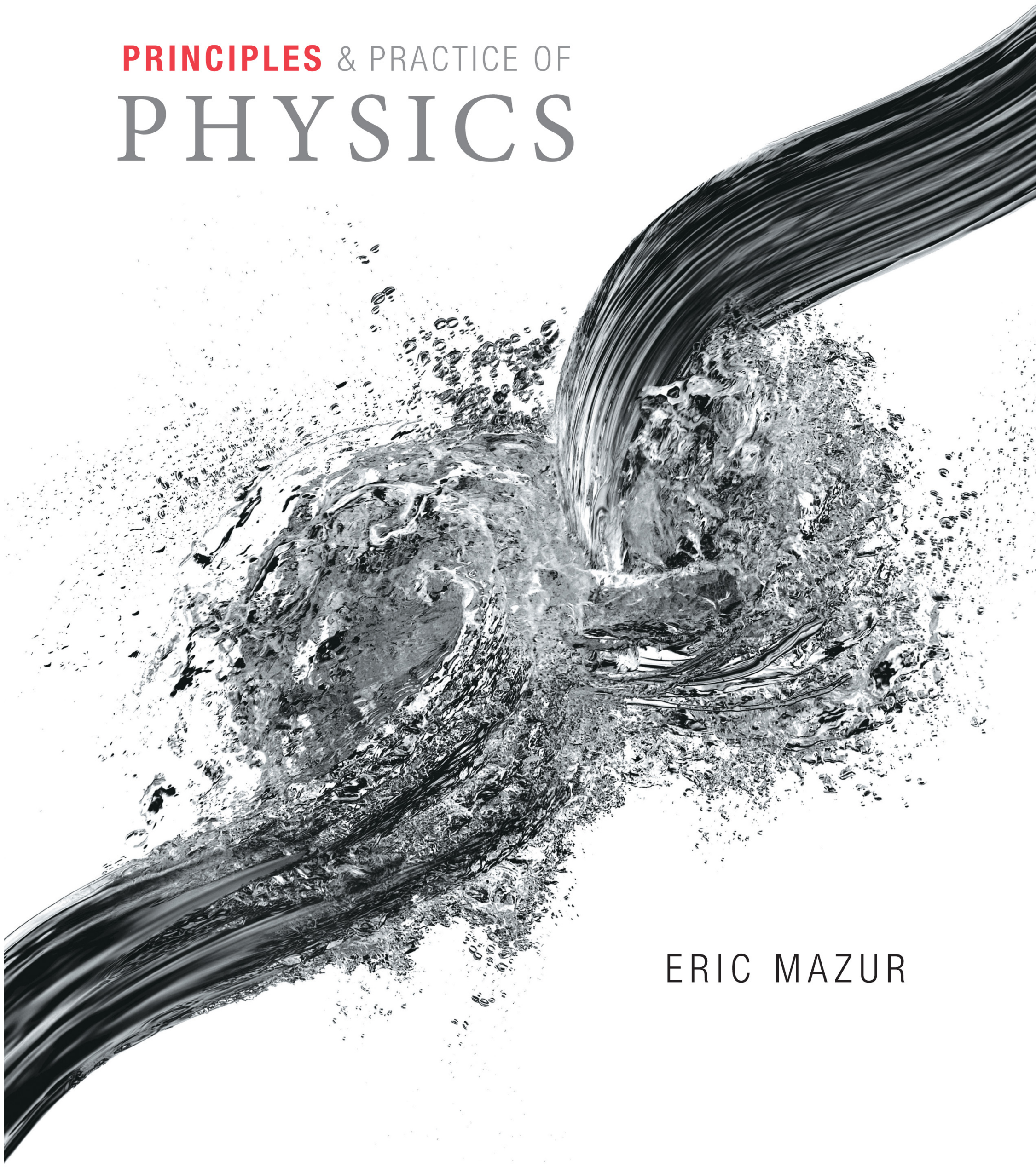
8.70

- A - impulse is m(change in v), watch sign …
- B - force is impulse/time, get time from kinematics
  - $x = \frac{1}{2}at^2$ and $v_f = v_i + at$
- should all be negative

8.62

- km/h → m/s
- watch signs – velocity must change from + to –
- watch units – ms → s

Chapter 9
Work



Reading quiz

The first one

- A person applies a 50 N force on a crate, causing it to move horizontally at a constant speed through a distance of 10 m. What is the net work done on the crate?

- read carefully: *constant speed* means zero acceleration, which means zero net force
- *net* work is zero if *net* force is zero

Chapter 9: Work

Chapter Goal: To learn how to analyze the change in energy of a system due to external influences. This type of energy change is called *work*.

Looking Ahead: Work done by a constant force

- In order for a force to do **work** on an object, the point of application of the force must undergo a **displacement**.
- Work is the ‘useful’ application of a force
- The SI unit of work is the **joule** (J).

Chapter 9: Work

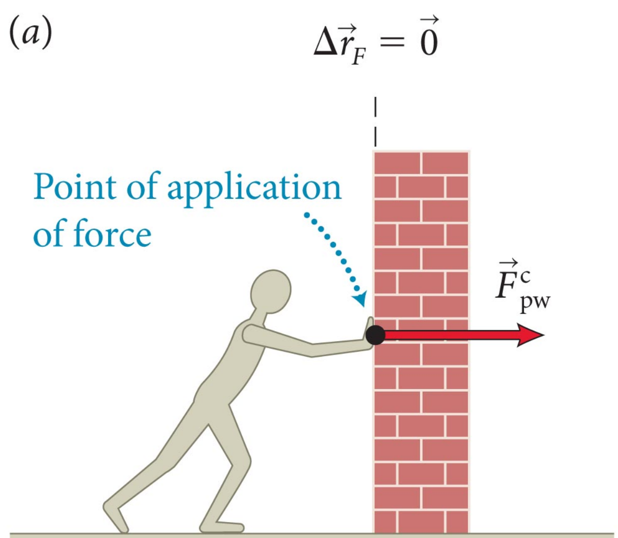
- Forces can change the physical state of an object (internal energy) as well as its state of motion (kinetic energy).
- To describe these changes in energy, physicists use the concept of **work:**
  - **Work is the change in the energy of a system due to external forces.**
- The SI unit of work is the joule (J).

Section 9.1: Force displacement

- **Work** amounts to a **mechanical transfer of energy**, either from a system to the environment or from the environment to a system.
- Do external force *always* cause a change in energy on a system?
  - To answer this question, it is helpful to consider an example

Checkpoint 9.1

9.1 Imagine pushing against a brick wall as shown in Figure 9.1*a*. (*a*) Considering **the wall as the system**, is the force you exert on it internal or external? (*b*) Does this force accelerate the wall? Change its shape? Raise its temperature? (*c*) Does the energy of the wall change as a result of the force you exert on it? (*d*) Does the force you exert on the wall do work on the wall?



Point of application does not move, so force does no work on wall.

Checkpoint 9.1

9.1 Imagine pushing against a brick wall.

(a) Considering the wall as the system, is the force you exert on it internal or external? **external**

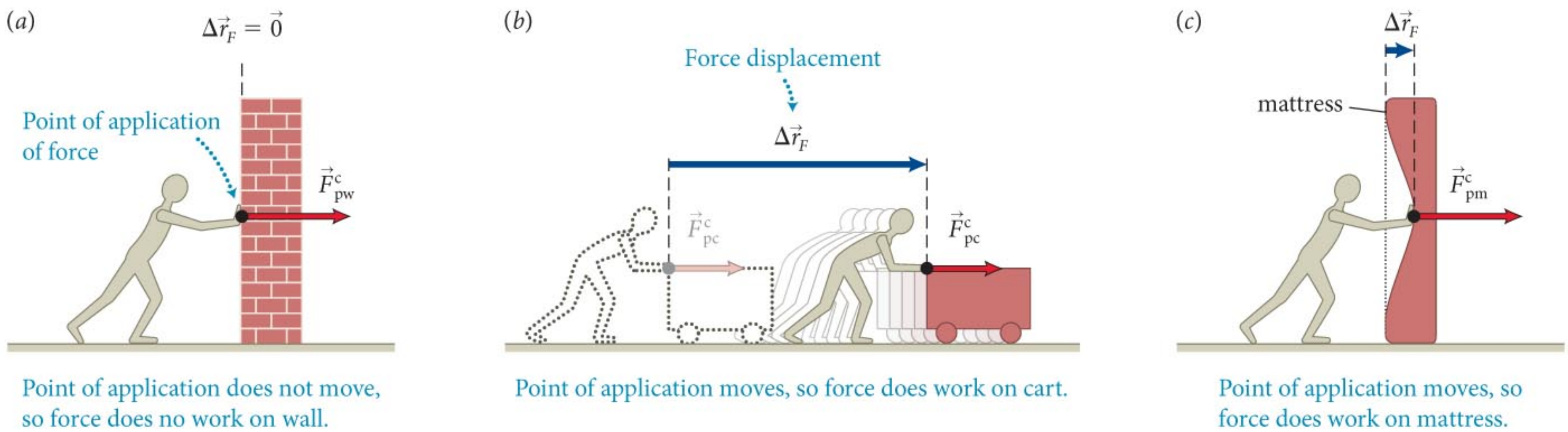
(b) Does this force accelerate the wall? Change its shape? Raise its temperature? **no, no, no**

(c) Does the energy of the wall change as a result of the force you exert on it? **no**

(d) Does the force you exert on the wall do work on the wall?

no

Section 9.1: Force displacement



- Even though the work is zero in (*a*), it is nonzero in (*b*) and (*c*).
- **In order for a force to do work, the point of application of the force must undergo a displacement.**
- The displacement of the point of application of the force is called the **force displacement**.

Exercise 9.1 Displaced forces

For which of the following forces is the force displacement nonzero:

(a) the force exerted by a hand compressing a spring

(b) the force exerted by Earth on a ball thrown upward,

(c) the force exerted by the ground on you at the instant you jump upward,

(d) the force exerted by the floor of an elevator on you as the elevator moves downward at constant speed?

Exercise 9.1 Displaced forces (cont.)

SOLUTION (*a*), (*b*), and (*d*).

(*a*) The point of application of the force is at the hand, which moves to compress the spring.

(*b*) The point of application of the force of gravity exerted by Earth on the ball is at the ball, which moves.

(*c*) The point of application is on the ground, which doesn't move.

(*d*) The point of application is on the floor of the elevator, which moves. ✔

Checkpoint 9.2

9.2 You throw a ball straight up in the air. Which of the following forces do work on the ball while you throw it? Consider the interval from the instant the ball is at rest in your hand to the instant it leaves your hand at speed v.

(a) The force of gravity exerted by Earth on the ball.

(b) The contact force exerted by your hand on the ball.

Checkpoint 9.2

9.2 You throw a ball straight up in the air. Which of the following forces do work on the ball while you throw it? Consider the interval from the instant the ball is at rest in your hand to the instant it leaves your hand at speed v. (*a*) The force of gravity exerted by Earth on the ball. (*b*) The contact force exerted by your hand on the ball.

both do work – for both, the point of application is the ball, and this point moves as you launch the ball

(your hand has to move to launch the ball)

Section 9.1
Question 1

A woman holds a bowling ball in a fixed position. The work she does on the ball

1. depends on the weight of the ball.
2. cannot be calculated without more information.
3. is equal to zero.

Section 9.1
Question 1

A woman holds a bowling ball in a fixed position. The work she does on the ball

1. depends on the weight of the ball.
2. cannot be calculated without more information.
3. is equal to zero.

Question 2

A man pushes a very heavy load across a horizontal floor. The work done by gravity on the load

1. depends on the weight of the load.
2. cannot be calculated without more information.
3. is equal to zero.

Section 9.1
Question 2

A man pushes a very heavy load across a horizontal floor. The work done by gravity on the load

1. depends on the weight of the load.
2. cannot be calculated without more information.
3. is equal to zero.

gravity acts vertically, the displacement is horizontal.
the work is against the frictional force

Section 9.2: Positive and negative work

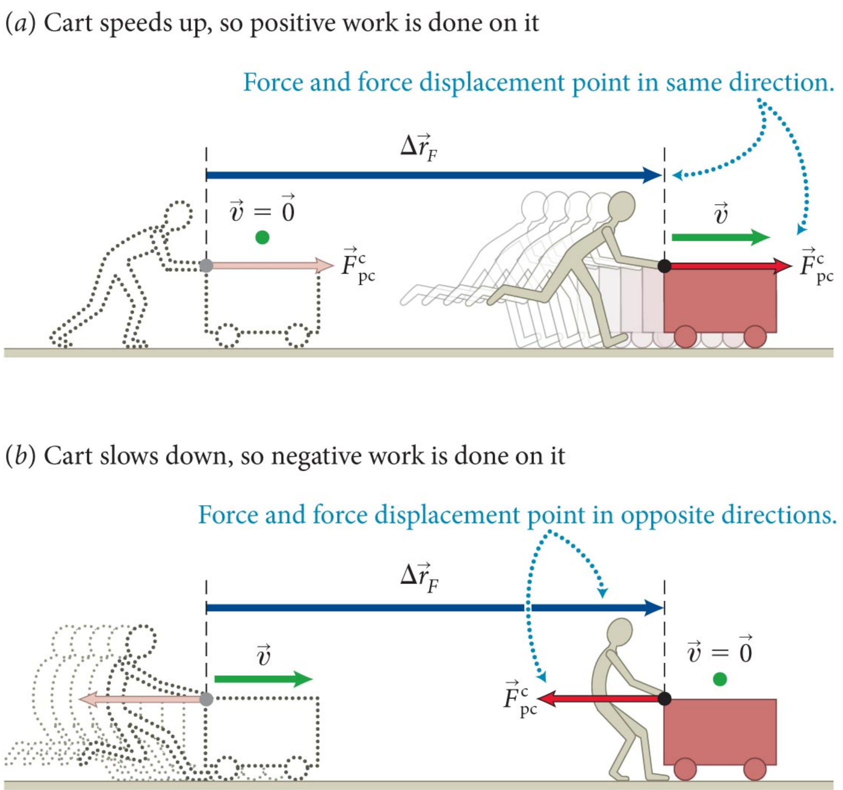
Section Goal

You will learn to

- Determine how the **sign** of the work done depends on the vector relationship between the force and the displacement.

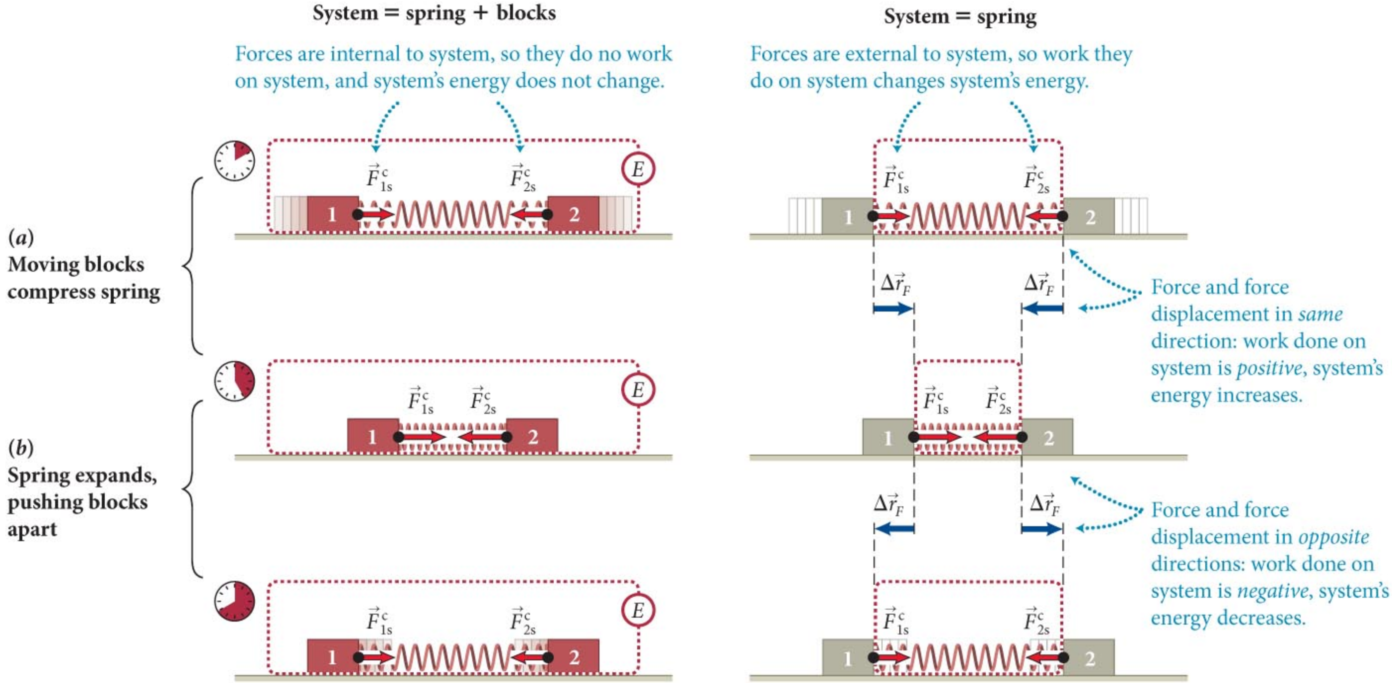
Section 9.2: Positive and negative work

- When the work done by an external force on a system is positive, the change in energy is positive, and when work is negative, the energy change is negative.
- Examples of negative and positive work are illustrated in the figure below.
- **The work done by a force on a system is positive when the force and the force displacement point in the same direction and negative when they point in opposite directions.**



Section 9.2: Positive and negative work

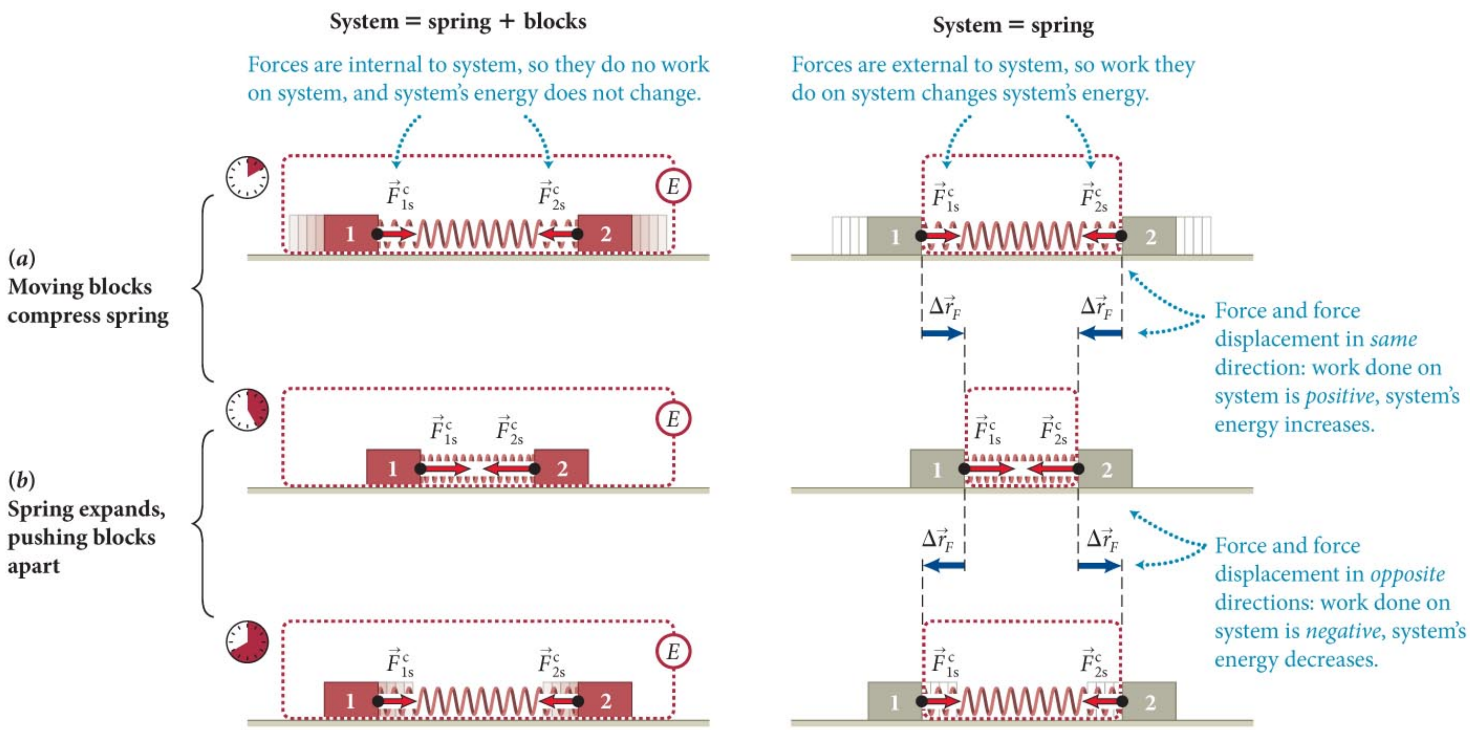
- Let us now consider a situation involving potential energy.
- In part (*a*) of the figure , we consider the **spring + blocks to be a closed system.**
- In this case the change in potential energy will manifest as a change in the kinetic energy of the blocks, keeping the total energy constant.



- Because no external forces are exerted on the system, no work is involved.

Section 9.2: Positive and negative work

- In part (*b*) of the figure, we consider the **spring by itself as the system.**
- When the compressed spring is released, the decrease in the energy of the spring implies that the work done by the block on the spring is negative.
- The force exerted on the spring by the block and the force displacement are in opposite directions, which confirms that the work is negative.



Checkpoint 9.3

9.3 A ball is thrown vertically upward.

(a) As it moves upward, it slows down under the influence of gravity. Considering the changes in energy of the ball, is the work done by Earth on the ball positive or negative?

(b) After reaching its highest position, the ball moves downward, gaining speed. Is the work done by the gravitational force exerted on the ball during this motion positive or negative?

Checkpoint 9.3

9.3 A ball is thrown vertically upward.

(a) As it moves upward, it slows down under the influence of gravity. Considering the changes in energy of the ball, is the work done by Earth on the ball positive or negative?

- As it moves upward, KE decreases, E_{int} is constant. The ball's energy ($K + E_{int}$) decreases, so work is negative (force & displacement opposite)

(b) After reaching its highest position, the ball moves downward, gaining speed. Is the work done by the gravitational force exerted on the ball during this motion positive or negative?

- Ball's energy now increases, so work is positive (force & displacement in same direction)

Exercise 9.2 Positive and negative work

Is the work done by the following forces positive, negative, or zero? In each case the **system is the object on which the force is exerted.**

(*a*) the force exerted by a hand compressing a spring,
(*b*) the force exerted by Earth on a ball thrown upward,
(*c*) the force exerted by the ground on you at the instant you jump upward

(*d*) the force exerted by the floor of an elevator on you as the elevator moves downward at constant speed.

Exercise 9.2 Positive and negative work (cont.)

SOLUTION

(*a*) Positive. To compress a spring, I must move my hand in the same direction as I push. ✔

(*b*) Negative. The force exerted by Earth points downward; the point of application moves upward. ✔

(*c*) Zero, because the point of application is on the ground, which doesn't move. ✔

(*d*) Negative. The force exerted by the elevator floor points upward; the point of application moves downward. ✔

Section 9.2
Question 3

You throw a ball up into the air and then catch it. How much work is done by gravity on the ball while it is in the air?

1. A positive amount
2. A negative amount
3. Cannot be determined from the given information
4. Zero

Section 9.2
Question 3

You throw a ball up into the air and then catch it. How much work is done by gravity on the ball while it is in the air?

1. A positive amount
2. A negative amount
3. Cannot be determined from the given information
4. Zero – comes back to where it started

Checkpoint 9.5

9.5 Suppose that instead of the two moving blocks in Figure 9.3*a*, just one block is used to compress the spring while the other end of the spring is held against a wall.

(a) Is the system comprising the block and the spring closed?

(b) When the system is defined as being only the spring, is the work done by the block on the spring positive, negative, or zero? How can you tell?

(c) Is the work done by the wall on the spring positive, negative, or zero?

Checkpoint 9.5

9.5 Suppose that instead of the two moving blocks in Figure 9.3*a*, just one block is used to compress the spring while the other end of the spring is held against a wall.

(a) Is the system comprising the block and the spring closed?

yes – no changes in motion or state in environment

(b) When the system is defined as being only the spring, is the work done by the block on the spring positive, negative, or zero? How can you tell?

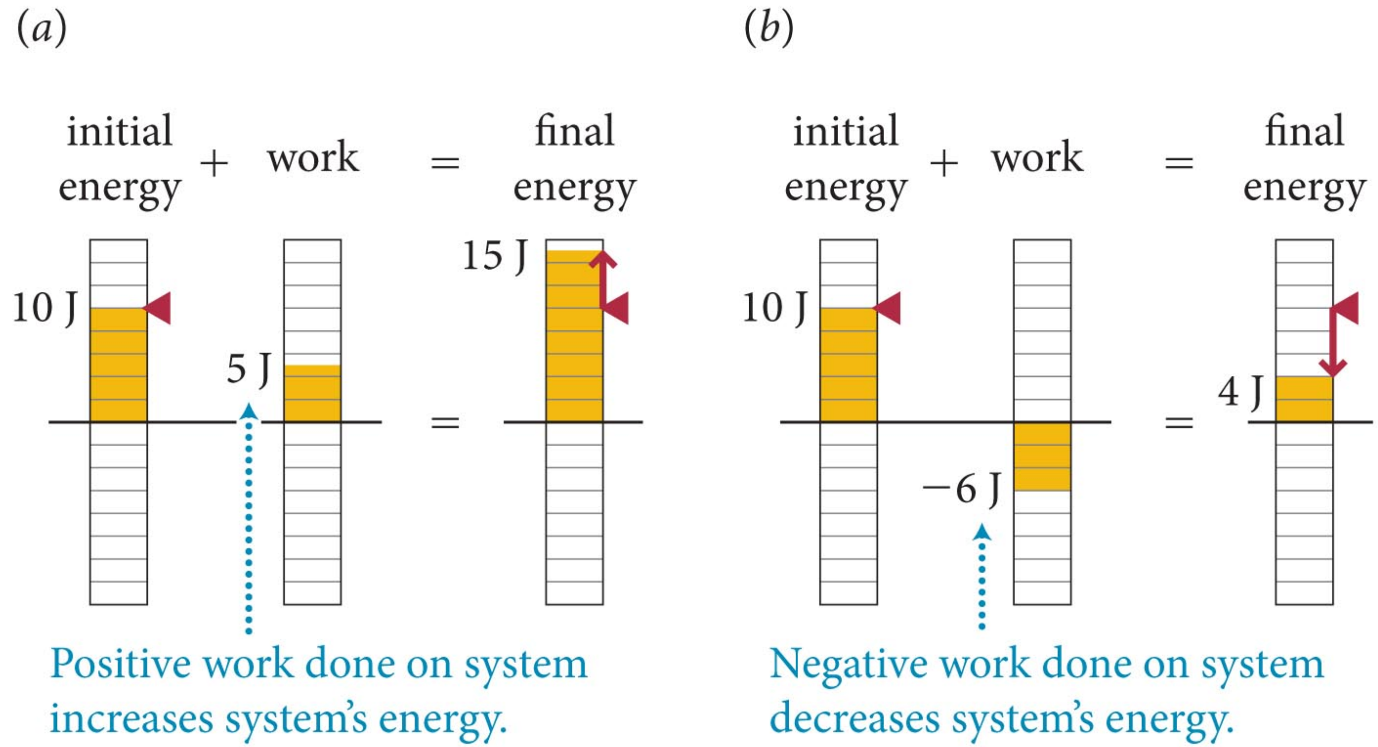
positive – force on spring is in direction of motion

(a) Is the work done by the wall on the spring positive, negative, or zero?

zero – point of contact doesn't move

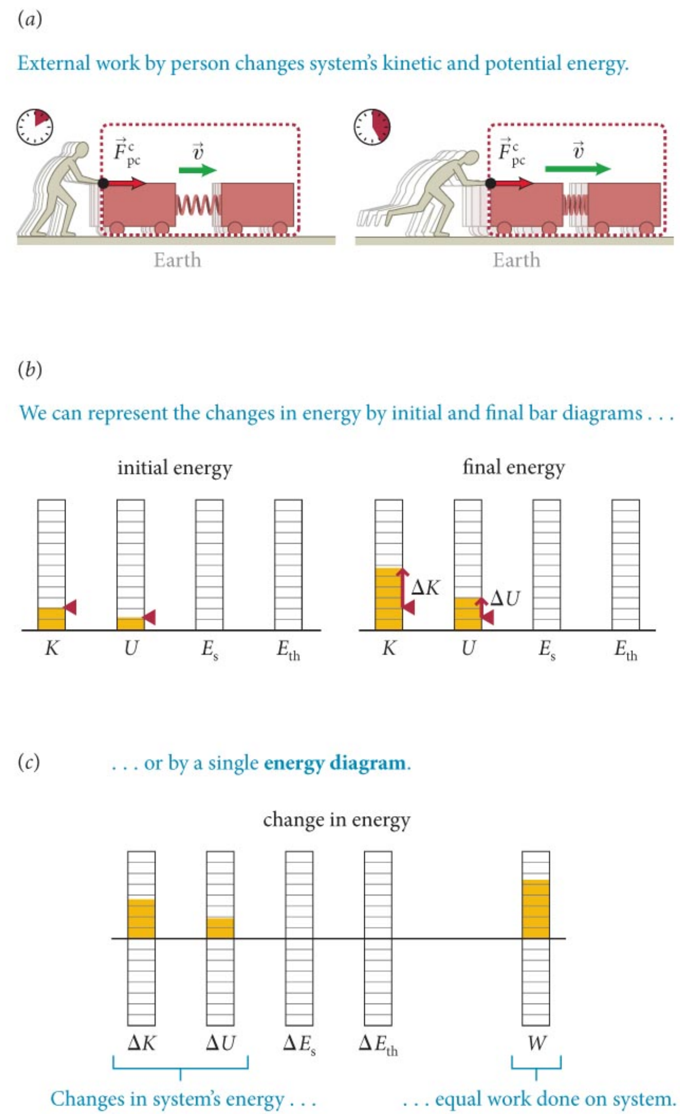
Section 9.3: Energy diagrams

- We can use energy bar charts to visually analyze situations involving work.
- This is why the sign is important



Section 9.3: Energy diagrams

- Because any of the four kinds of energy can change in a given situation, we need more details in our energy bar charts [part (*b*)].
- As shown in part (*c*), we can also draw one set of bars for change in each category of energy, and a fifth bar to represent work done by external forces.
  - These are called **energy diagrams.**

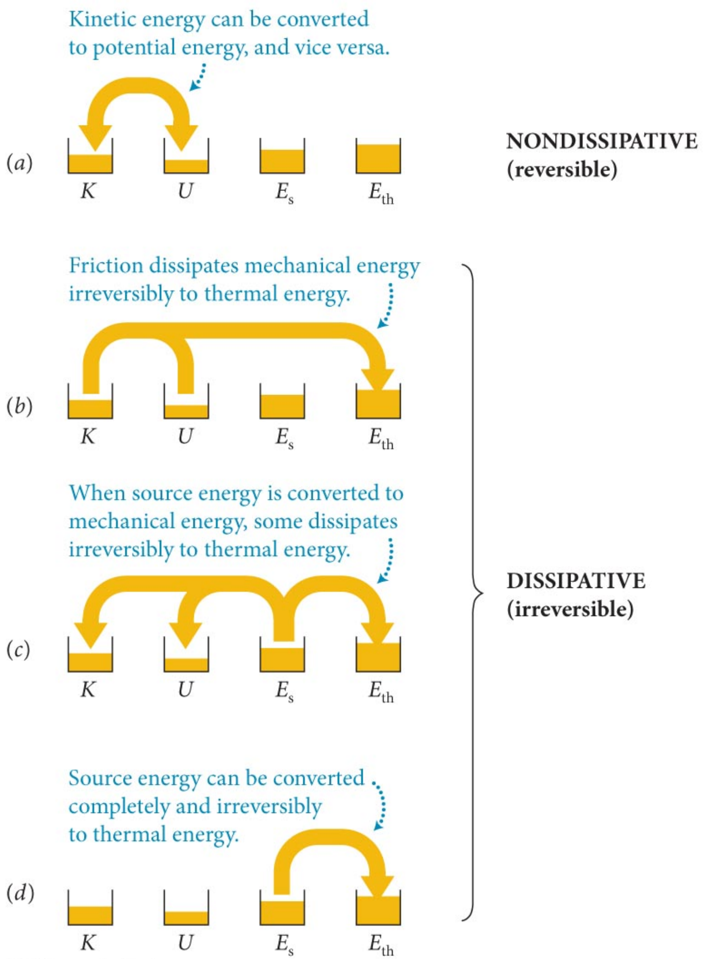


Procedure: Drawing energy diagrams

1. Specify the **system** under consideration by listing the components inside the system.
2. **Sketch** the system in its initial and final states. (The initial and final states may be defined for you by the problem, or you may have to choose the most helpful states to examine.) Include in your sketch any external forces exerted on the system that undergo a nonzero force displacement, and draw a dot at the point of application of each force.

Procedure: Drawing energy diagrams

3. Determine any nonzero **changes in energy** for each of the four categories of energy, taking into account the four basic energy-conversion processes illustrated in Figure 7.13:



Procedure: Drawing energy diagrams

a. Did the speed of any components of the system change? If so, determine whether the system's kinetic energy increased or decreased and draw a bar representing ΔK for the system. For positive ΔK, the bar extends above the baseline; for negative ΔK, it extends below the baseline.

(For some problems you may wish to draw separate ΔK bars for different objects in the system; be sure to specify clearly the system component that corresponds to each bar and verify that the entire system is represented by the sum of the components.)

Procedure: Drawing energy diagrams

b. Did the configuration of the system change in a reversible way? If so, draw a bar representing the change in potential energy ΔU for the system. If necessary, draw separate bars for the changes in different types of potential energy, such as changes in elastic and gravitational potential energy.

Procedure: Drawing energy diagrams

c. Was any source energy consumed? If so, draw a bar showing ΔE_s. Source energy usually decreases, making ΔE_s negative, and so the bar extends below the baseline. Keep in mind that conversion of source energy is always accompanied by generation of thermal energy (Figure 7.13*c* and *d*).

Procedure: Drawing energy diagrams

d. Does friction occur within the system, or is any source energy consumed? If so, draw a bar showing ΔE_{th}. In nearly all cases we consider, the amount of thermal energy increases, and so ΔE_{th} is positive.

Procedure: Drawing energy diagrams

4. Determine whether or not any **work** W is done by external forces on the system. Determine whether this work is negative or positive. Draw a bar representing this work, making the length of the bar equal to the sum of the lengths of the other bars in the diagram.

   If no work is done by external forces on the system, leave the bar for work blank, then go back and adjust the lengths of the other bars so that their sum is zero.

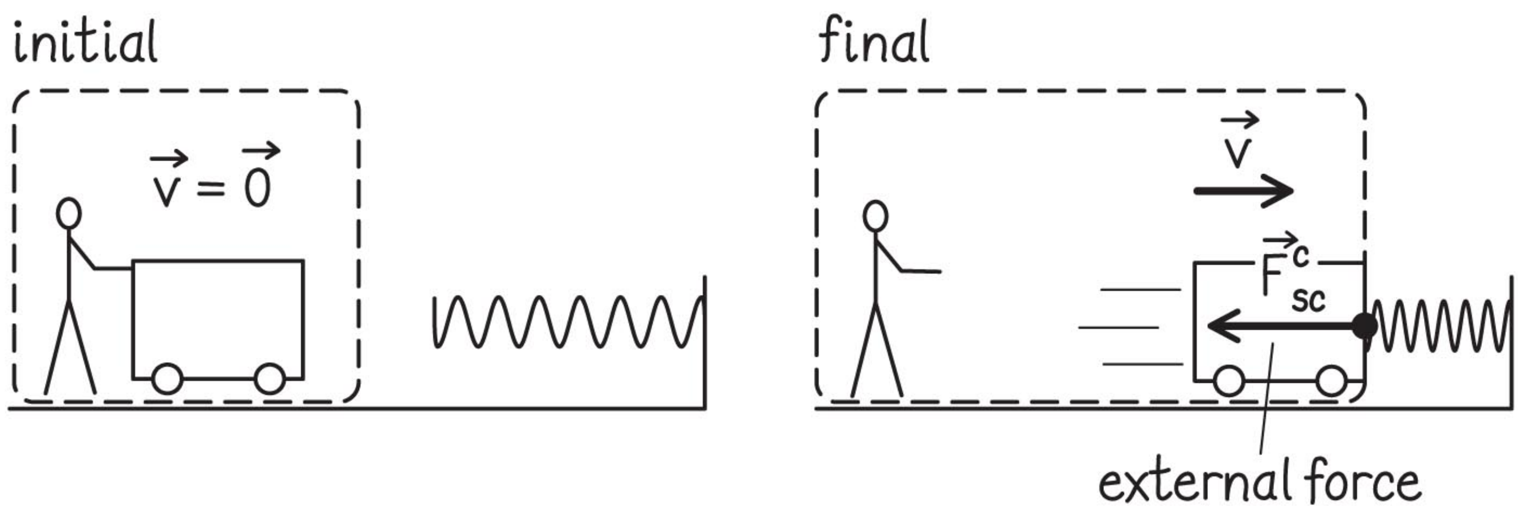
Exercise 9.3 Cart launch

A cart is at rest on a low-friction track. A person gives the cart a shove and, after moving down the track, the cart hits a spring, which slows down the cart as the spring compresses. Draw an energy diagram for the **system that comprises the person and the cart** over the time interval from the instant the cart is at rest until it has begun to slow down.

Section 9.3: Energy diagrams

Exercise 9.3 Cart launch (cont.)

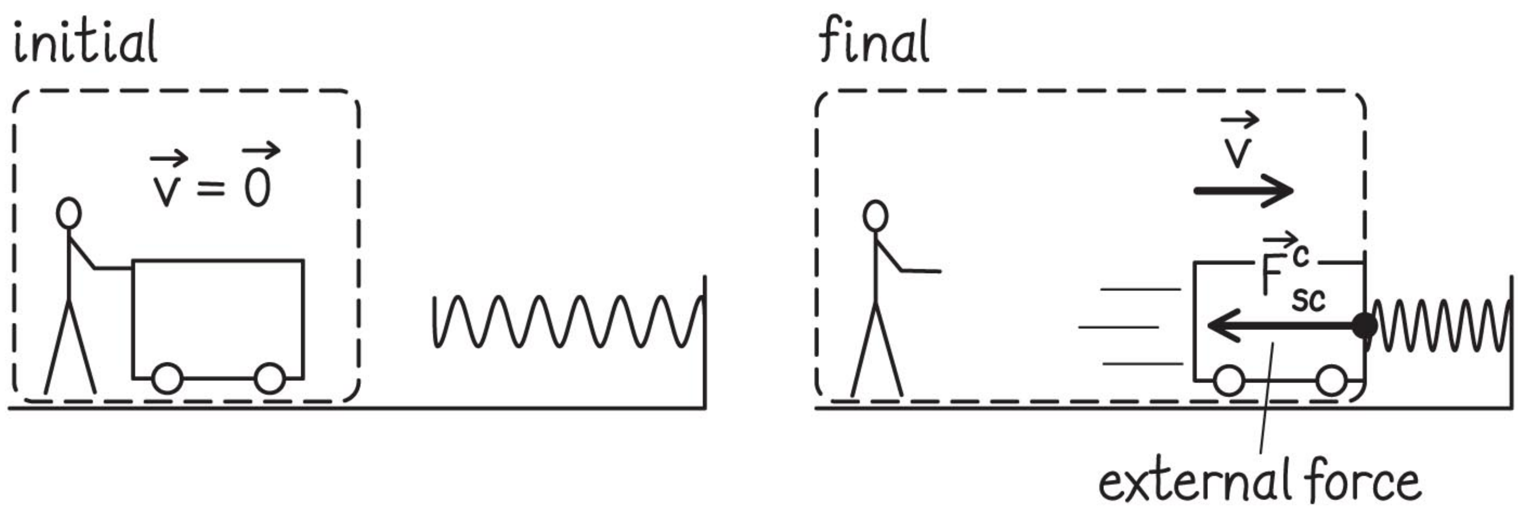
SOLUTION Following the steps in the Procedure box, I begin by listing the objects that make up the system: cart and person. Then I sketch the system in its initial and final states (Figure 9.6).



Section 9.3: Energy diagrams

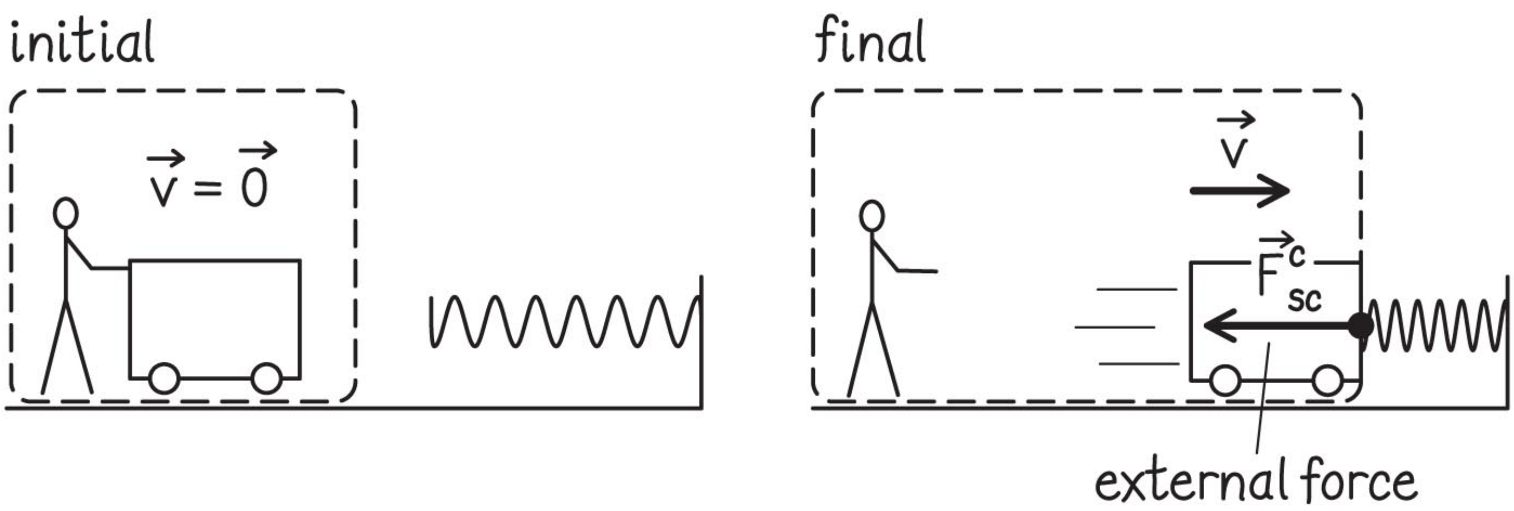
Exercise 9.3 Cart launch (cont.)

SOLUTION The external forces exerted on the system are the force of gravity on person and cart, the contact force exerted by ground on person, the contact force exerted by track on cart, and the contact force exerted by spring on cart.



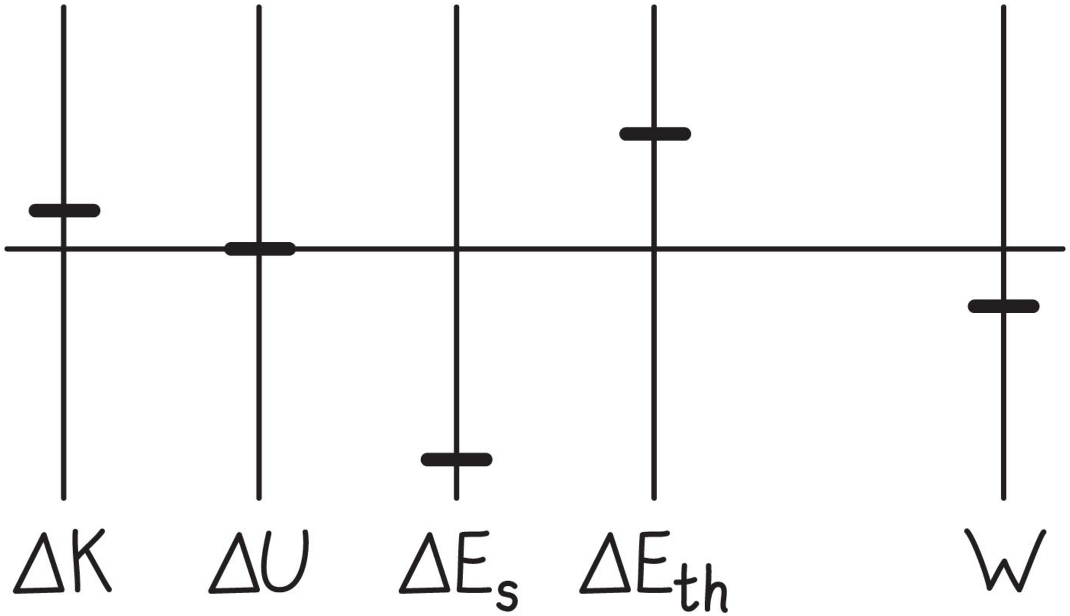
Exercise 9.3 Cart launch (cont.)

SOLUTION The vertical forces add up to zero, and so the work done by them on the system is zero. The force exerted by the spring on the cart, however, undergoes a force displacement, so I include that force in my diagram and indicate its point of application, as shown in Figure 9.6.



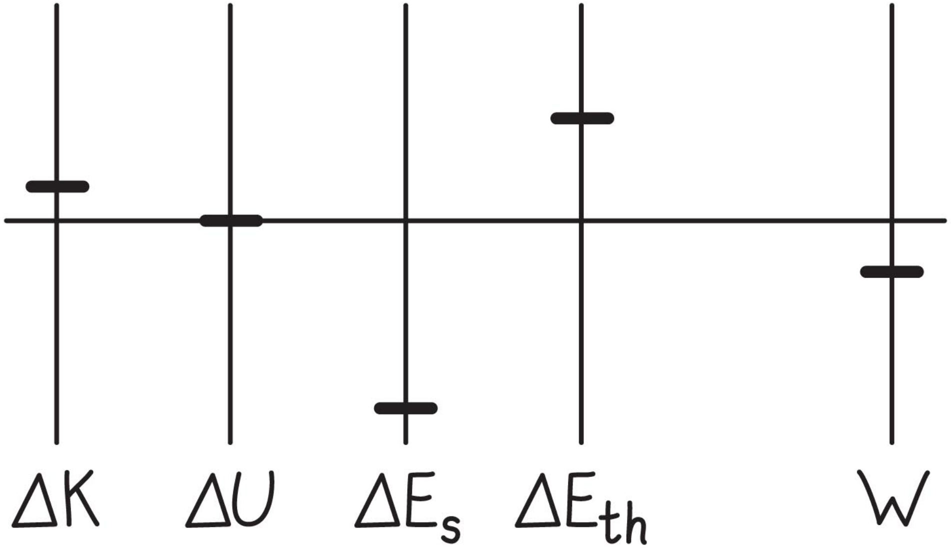
Exercise 9.3 Cart launch (cont.)

SOLUTION Next I determine whether there are any changes in energy. Kinetic energy: The cart begins at rest and ends with nonzero speed, which means a gain in kinetic energy (Figure 9.7).



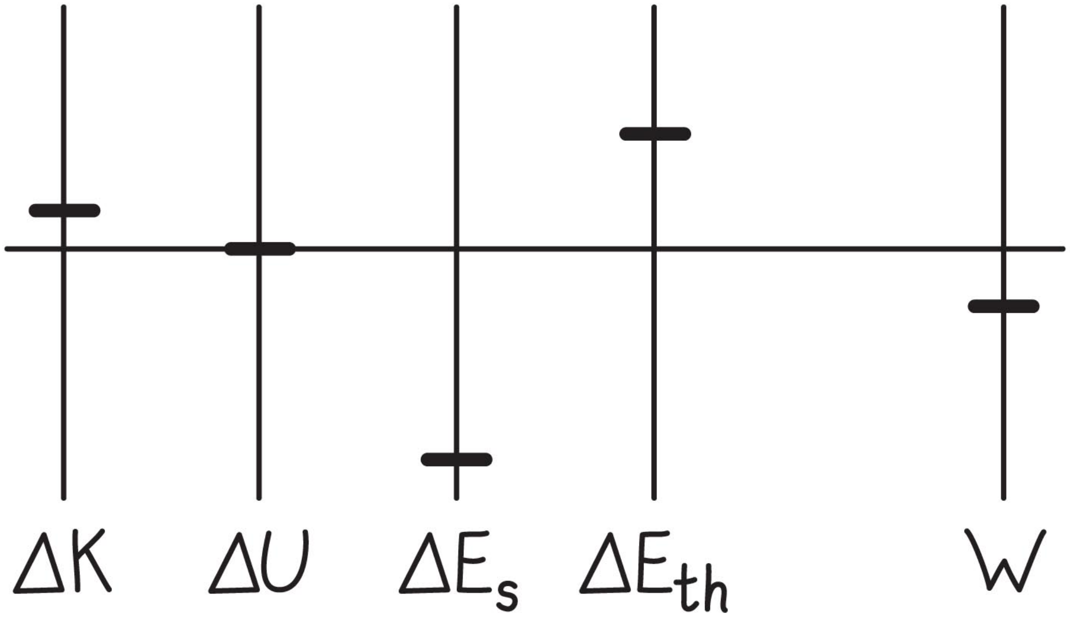
Exercise 9.3 Cart launch (cont.)

SOLUTION Potential energy: Neither the configuration of the cart nor that of the person changes in a reversible way, so the potential energy does not change. (The configuration of the spring does change in a reversible way, but the spring is not part of the system.)



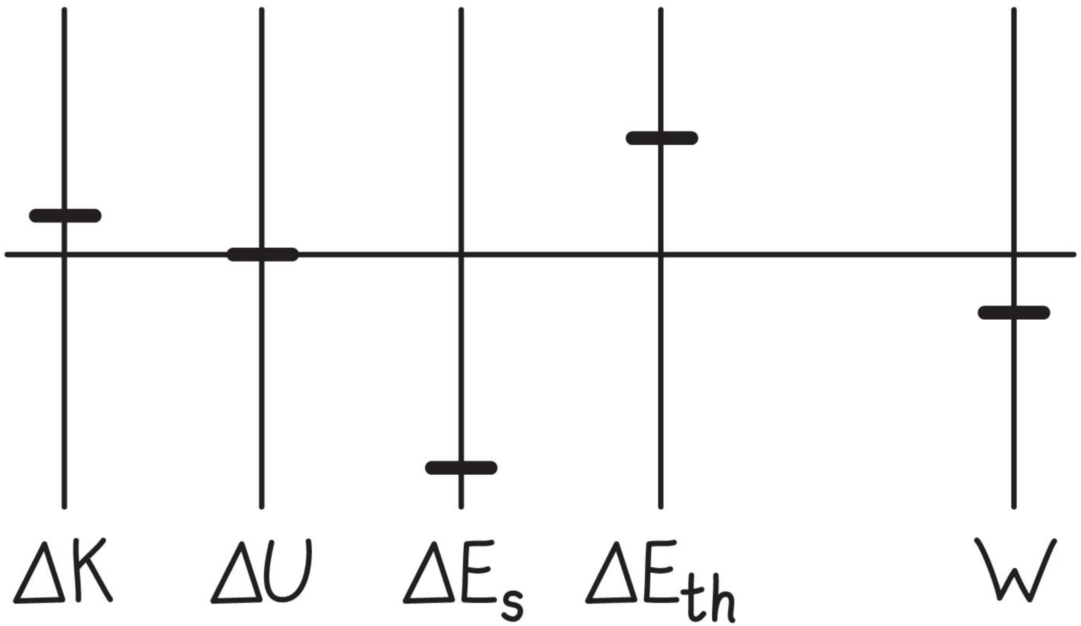
Exercise 9.3 Cart launch (cont.)

SOLUTION Source energy: The person has to exert effort to give the cart a shove, so source energy is consumed. The source energy of the system therefore decreases.



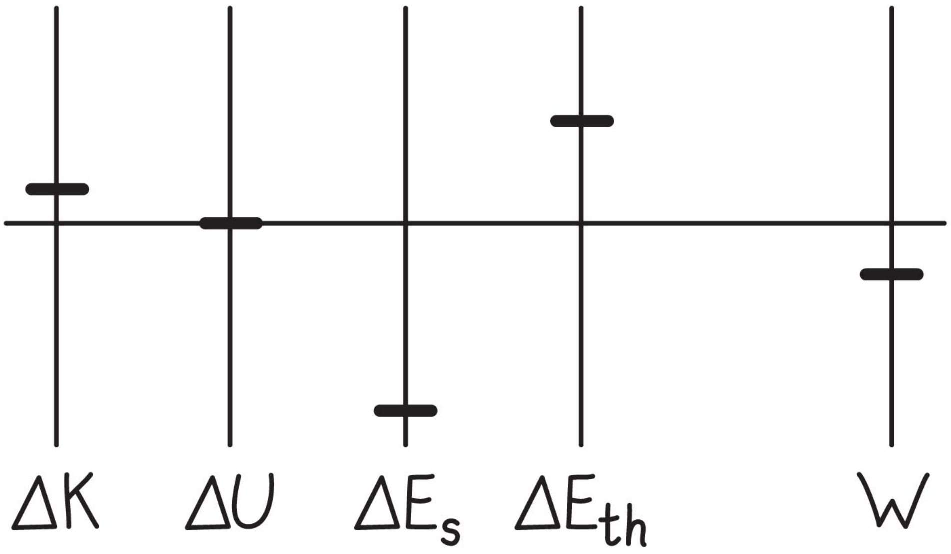
Exercise 9.3 Cart launch (cont.)

SOLUTION Thermal energy: No friction is involved, but the conversion of source energy is always accompanied by the generation of thermal energy, so the thermal energy increases. (The person's muscles heat up.)



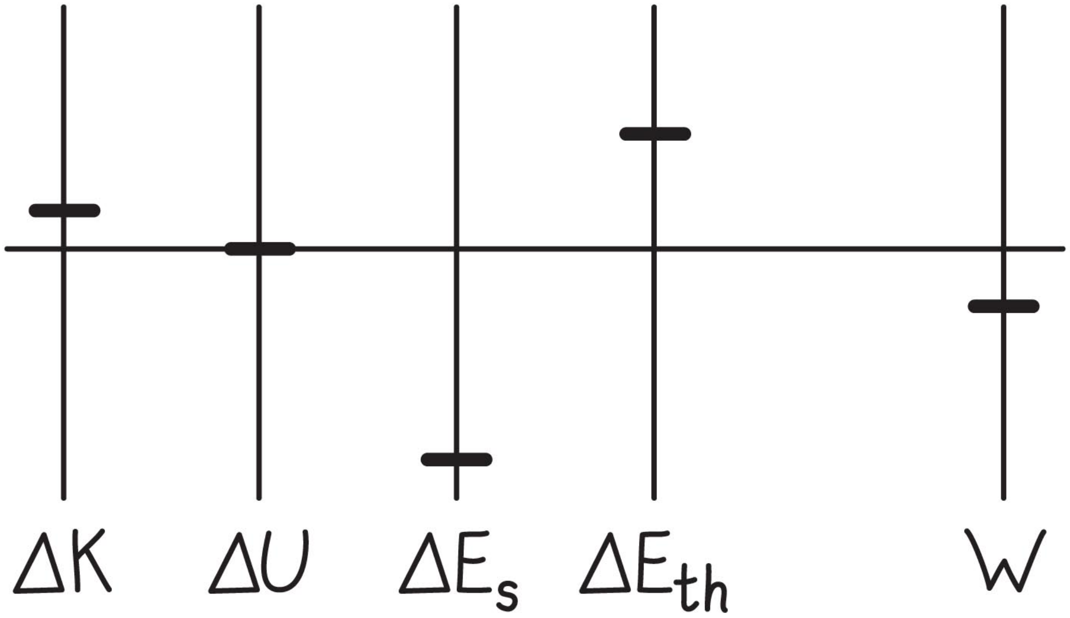
Exercise 9.3 Cart launch (cont.)

SOLUTION In Figure 9.6 the force exerted by the spring on the cart points to the left and the force displacement points to the right. This means that the work done by the spring on the cart is negative, and the W bar of my energy diagram must extend below the baseline.



Exercise 9.3 Cart launch (cont.)

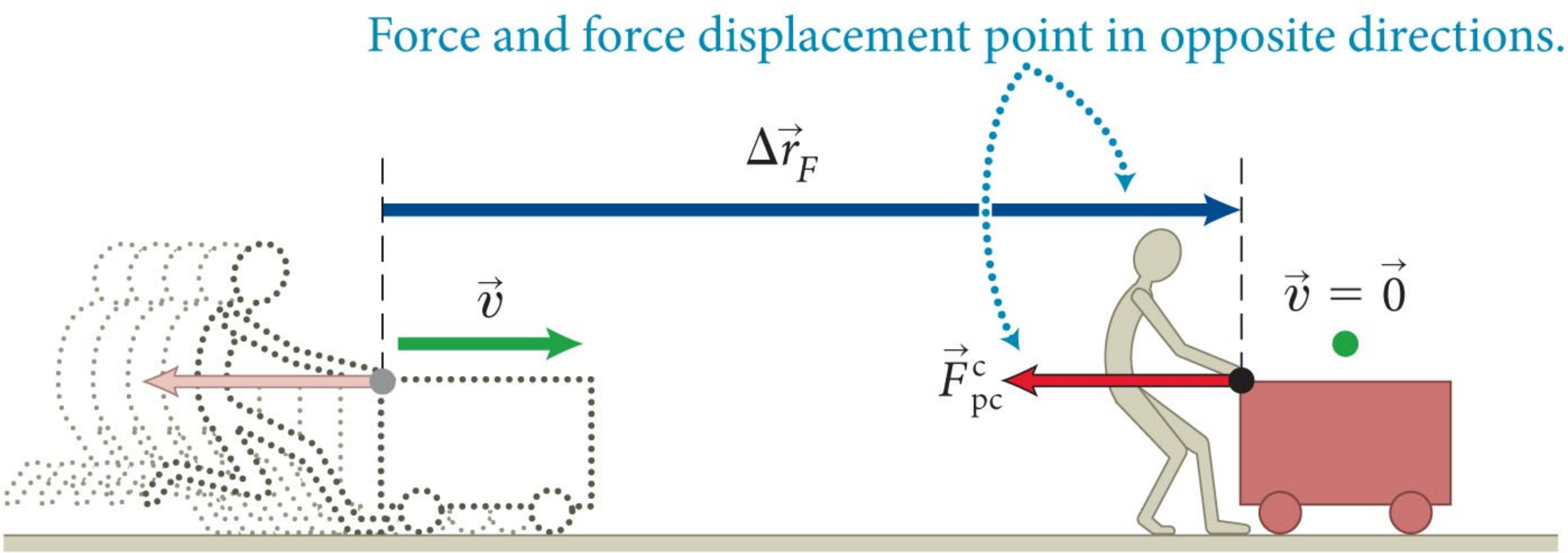
SOLUTION I adjust the lengths of the bars so that the length of the W bar is equal to the sum of the lengths of the other bars, yielding the energy diagram shown in Figure 9.7. ✔



Checkpoint 9.6

9.6 Draw an energy diagram for the cart in Figure 9.2*b*.

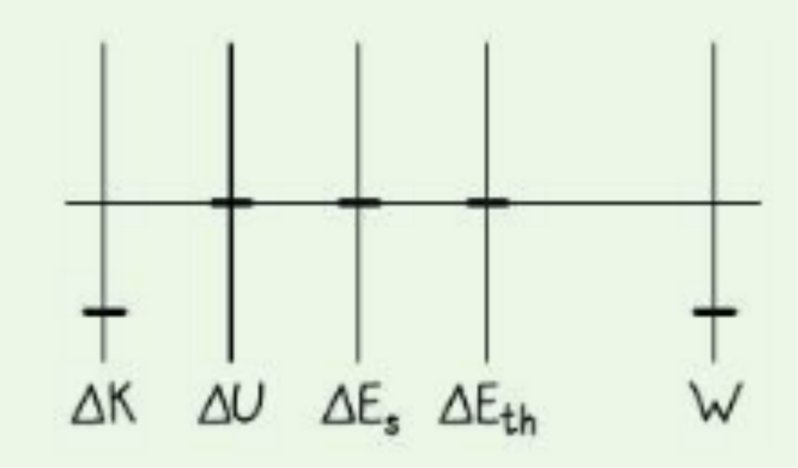
(*b*) Cart slows down, so negative work is done on it



Checkpoint 9.6

9.6

- The cart's KE decreases to zero, no changes in other forms of energy.
- Person's force is to the left, displacement to the right: work is negative.
- Change in KE should be same as W done in magnitude



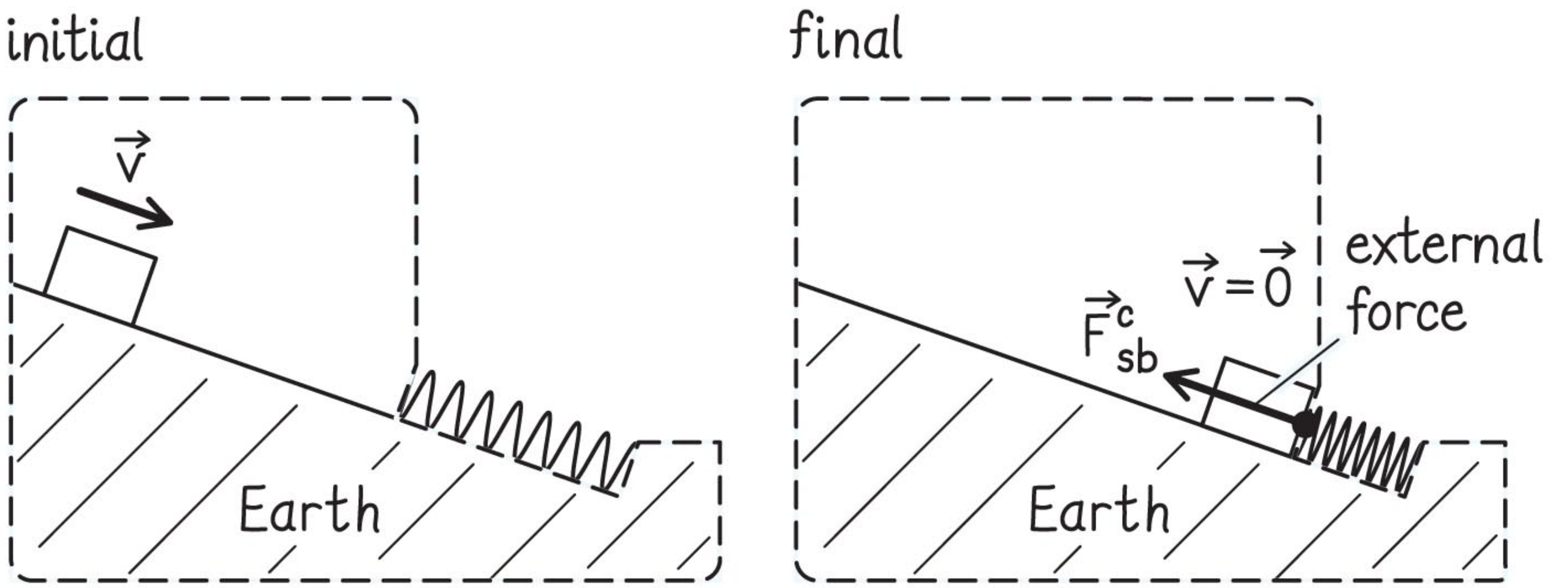
Exercise 9.4 Compressing a spring

A block initially at rest is released on an inclined surface. The block slides down, compressing a spring at the bottom of the incline; there is friction between the surface and the block.

Consider the time interval from a little after the release, when the block is moving at some initial speed v, until it comes to rest against the spring. Draw an energy diagram for the **system that comprises the block, surface, and Earth.**

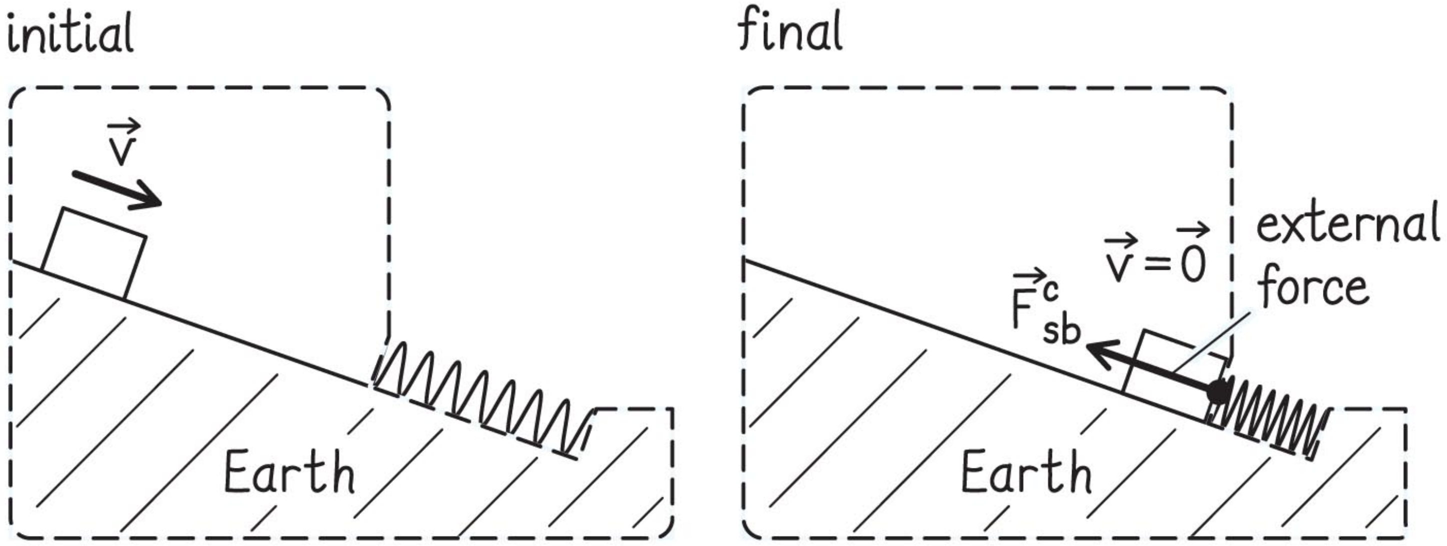
Exercise 9.4 Compressing a spring (cont.)

SOLUTION I begin by listing the objects that make up the system: block, surface, and Earth. Then I sketch the initial and final states of the system (Figure 9.8). The spring exerts external forces on the system.



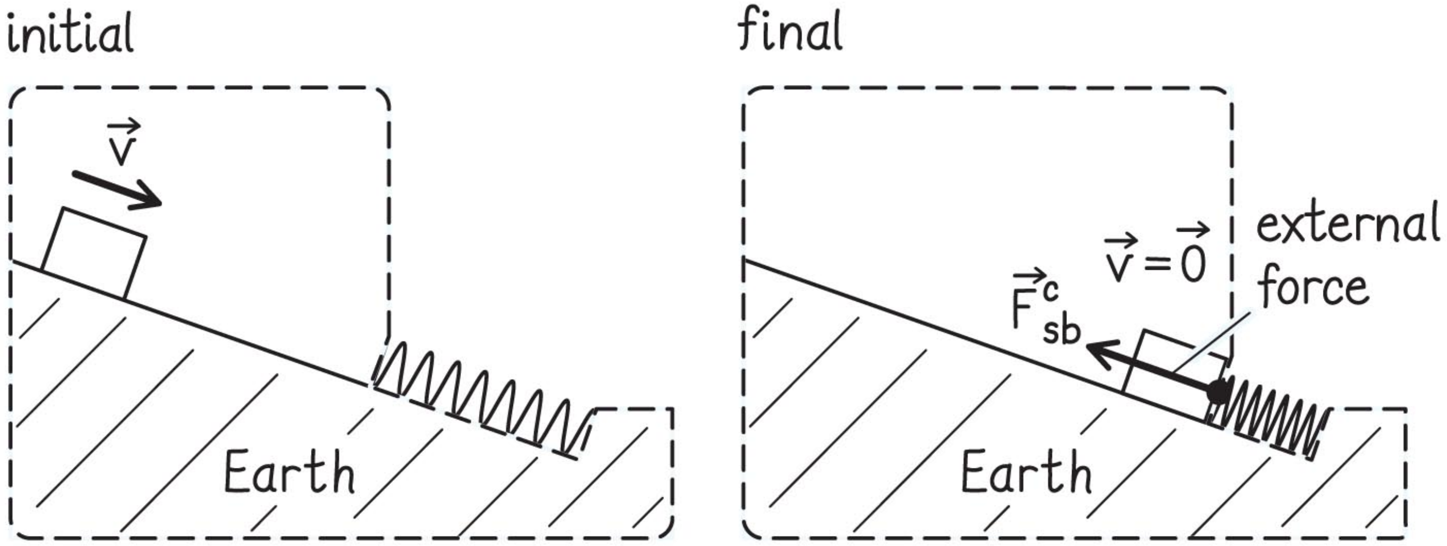
Exercise 9.4 Compressing a spring (cont.)

SOLUTION The bottom end of the spring exerts a force on the surface edge, but this force has a force displacement of zero. The top end of the spring exerts a force $\vec{F}^{c}_{sb}$ on the block. Because this force undergoes a nonzero force displacement, I include it in my diagram and show a dot at its point of application.



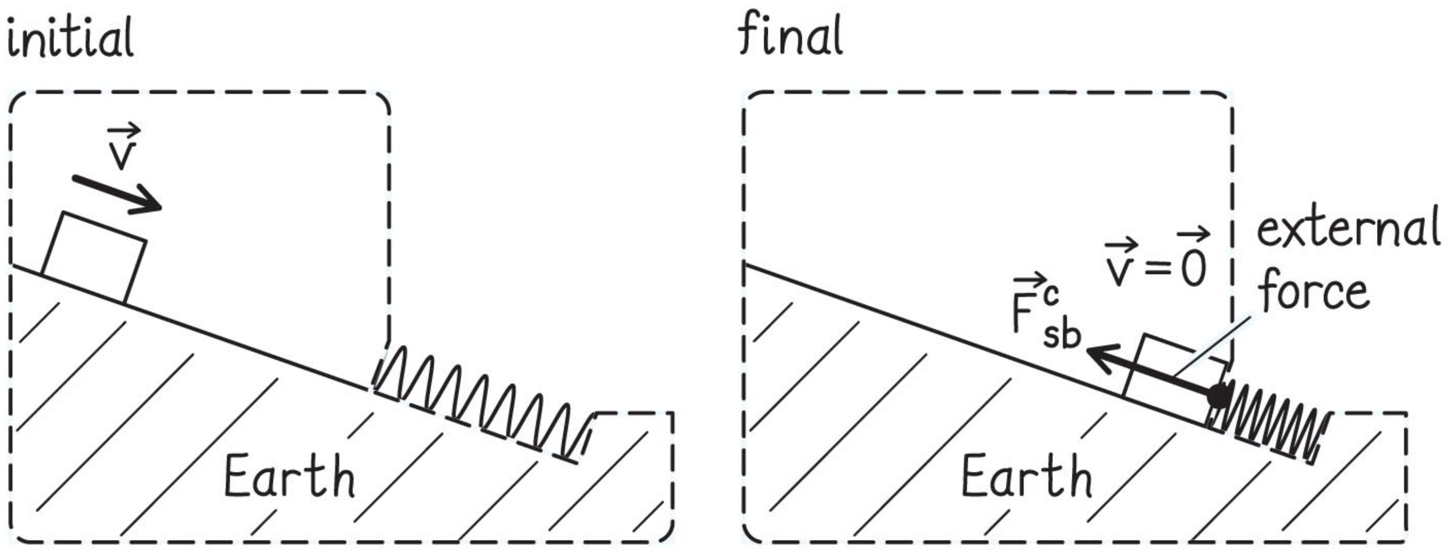
Exercise 9.4 Compressing a spring (cont.)

SOLUTION Next I determine whether there are any energy changes. Kinetic energy: The block's kinetic energy goes to zero, and the kinetic energies of the surface and Earth do not change. Thus the kinetic energy of the system decreases, and ΔK is negative.



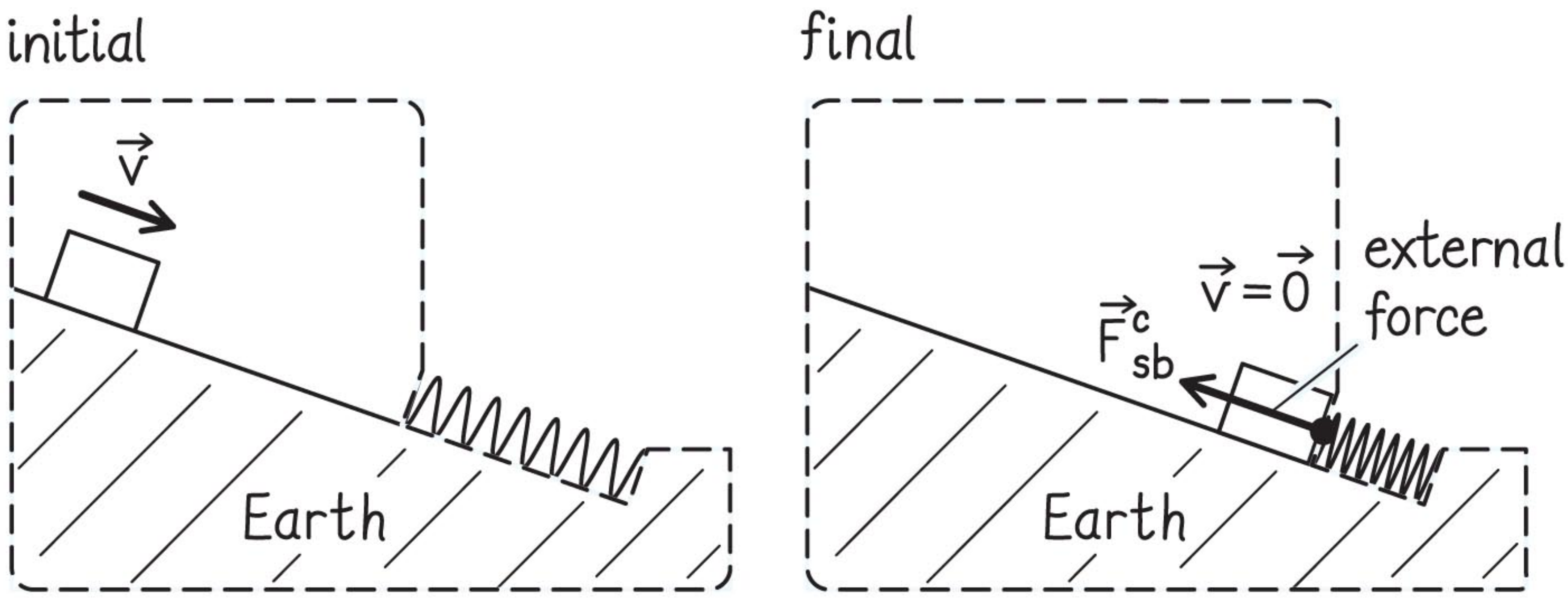
Exercise 9.4 Compressing a spring (cont.)

SOLUTION Potential energy: As the block moves downward, the gravitational potential energy of the block-Earth system decreases, and so ΔU is negative. (Because the spring gets compressed, its elastic potential energy changes, but the spring is not part of the system.)



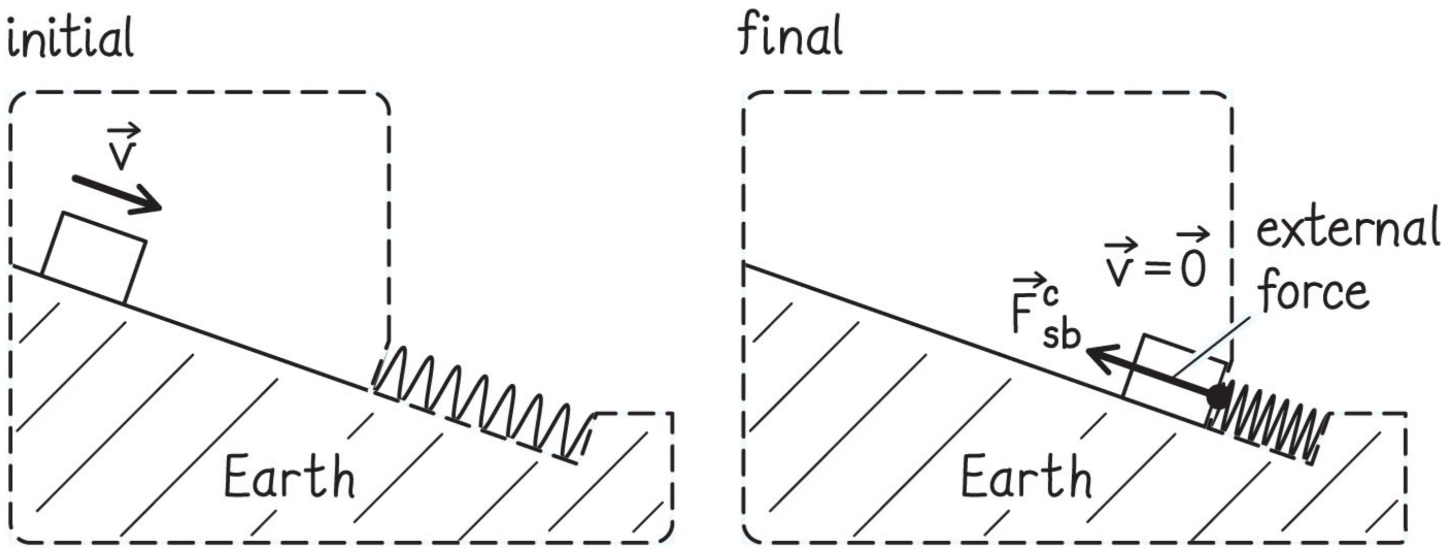
Exercise 9.4 Compressing a spring (cont.)

SOLUTION Source energy: none (no fuel, food, or other source of energy is converted in this problem). Thermal energy: As the block slides, energy is dissipated by the friction between the surface and the block, so ΔE_{th} is positive.



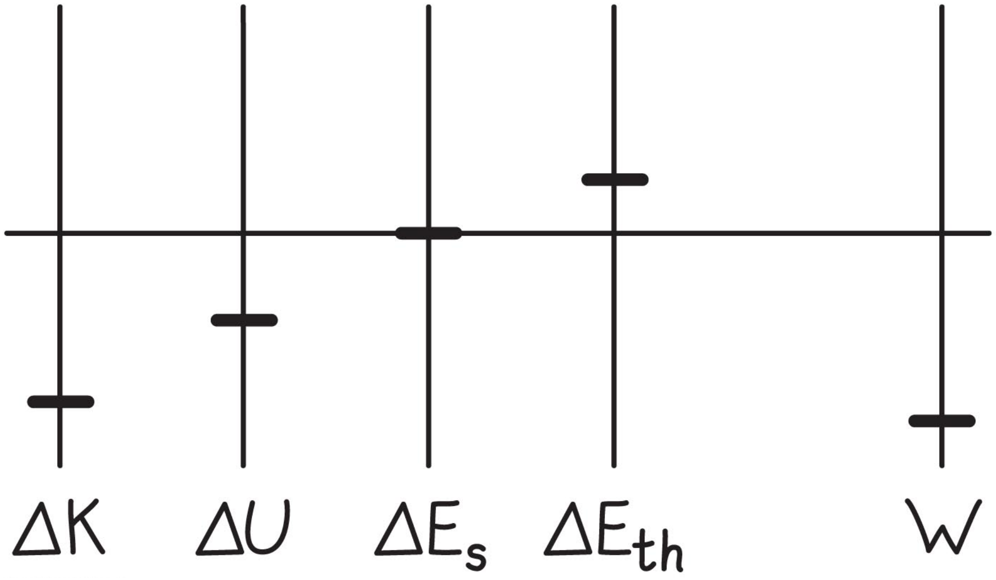
Exercise 9.4 Compressing a spring (cont.)

SOLUTION To determine the work done on the system, I look at the external forces exerted on it. The point of application of the external force $\vec{F}^{\text{c}}_{\text{sb}}$ exerted by the spring on the block undergoes a force displacement opposite the direction of the force, so that force does negative work on the system.



Exercise 9.4 Compressing a spring (cont.)

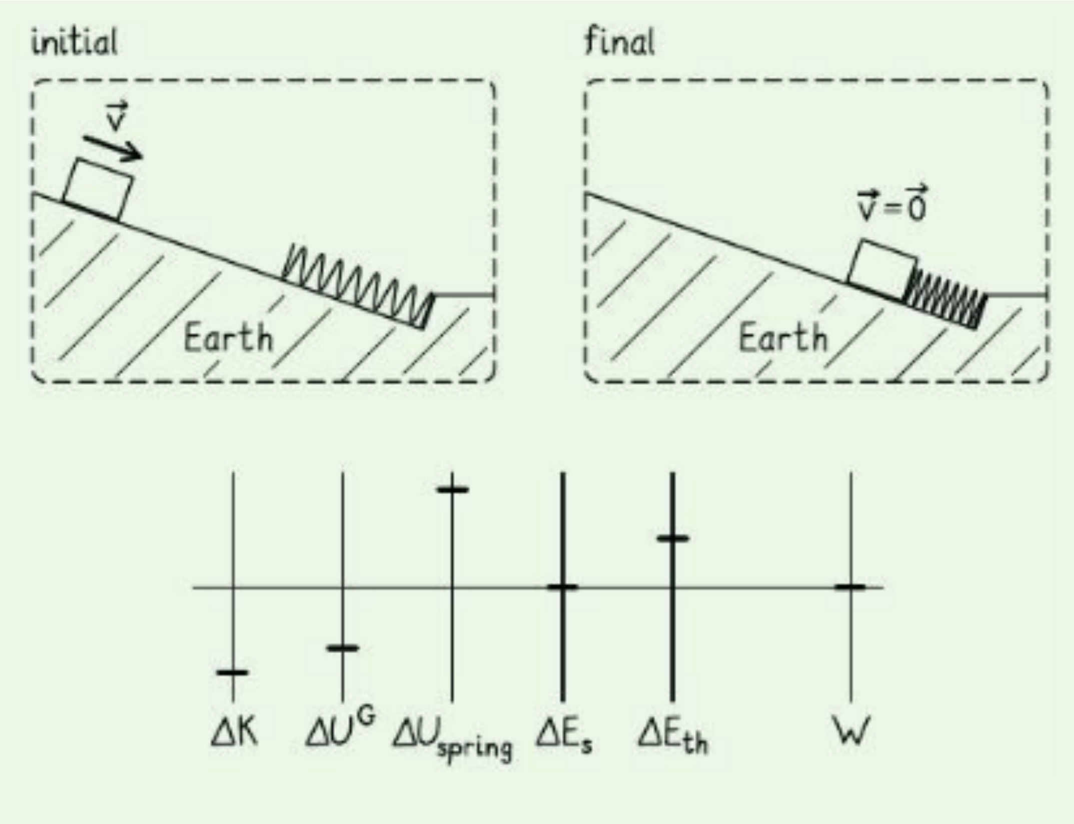
SOLUTION Thus the work done on the system by the external forces is negative, and the *W* bar extends below the baseline (Figure 9.9). I adjust the lengths of the bars so that the length of the *W* bar is equal to the sum of the lengths of the other three bars, yielding the energy diagram shown in Figure 9.9. ✔



Checkpoint 9.7

9.7 Draw an energy diagram for the situation presented in Exercise 9.4, but choose the system that comprises **block, spring, surface, and Earth. (i.e., include the spring now)**

Which changes should be equal? No external force now, no work.



Section 9.4: Choice of system

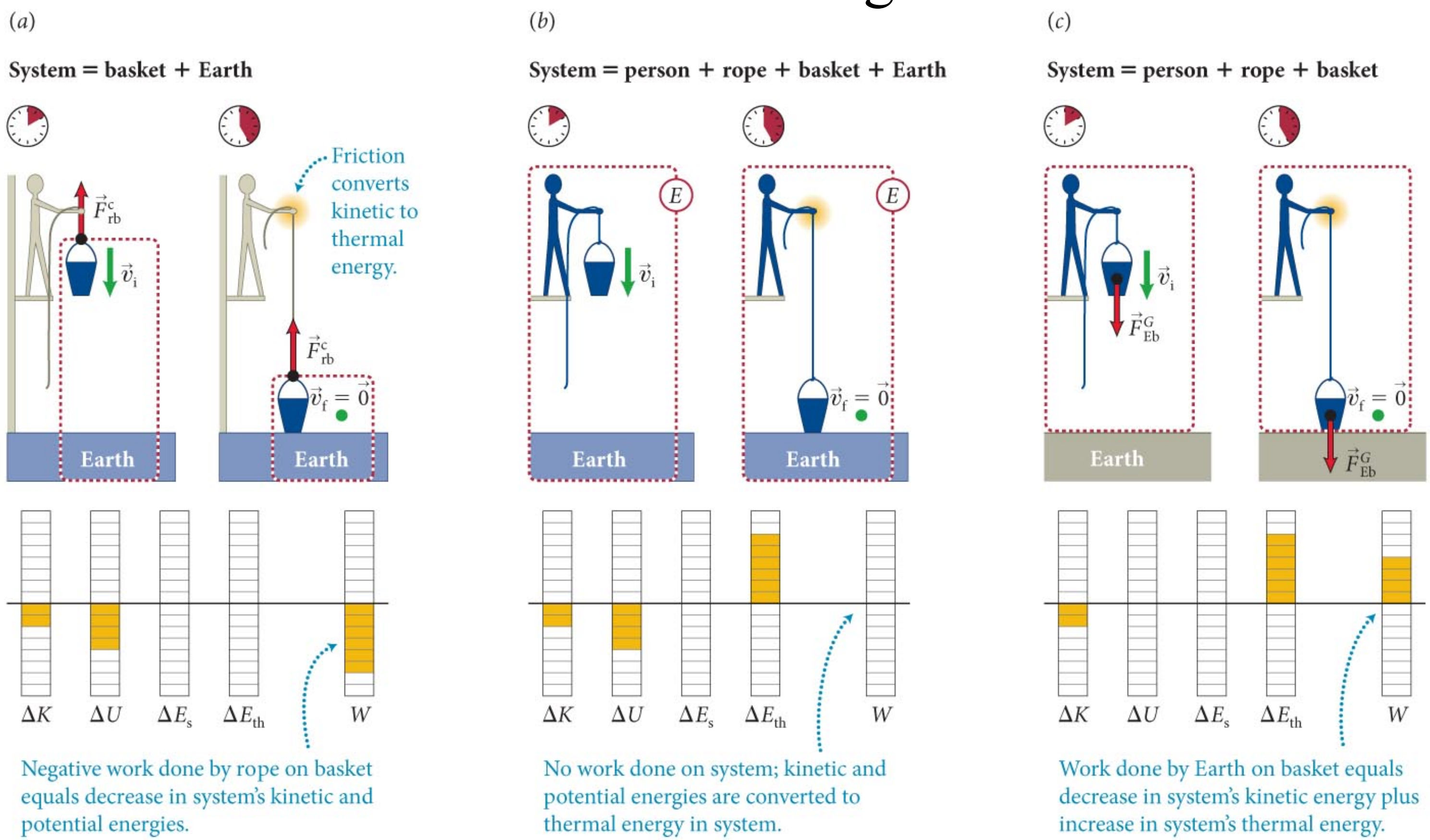
Section Goals

You will learn to

- Choose an **appropriate system** for a physical problem of interest in order to systematically account for the various energy changes.
- Recognize that a system chosen for which **friction** acts across the boundary is **difficult** to analyze. This is because in these situations thermal energy is generated in both the environment and the system, making energy accounting for the system problematic.

Section 9.4: Choice of system

- Different choices of systems lead to different energy diagrams.
- What is "work" in one context is energy conversion in another
- Work is involved when an *external* agent acts with a force

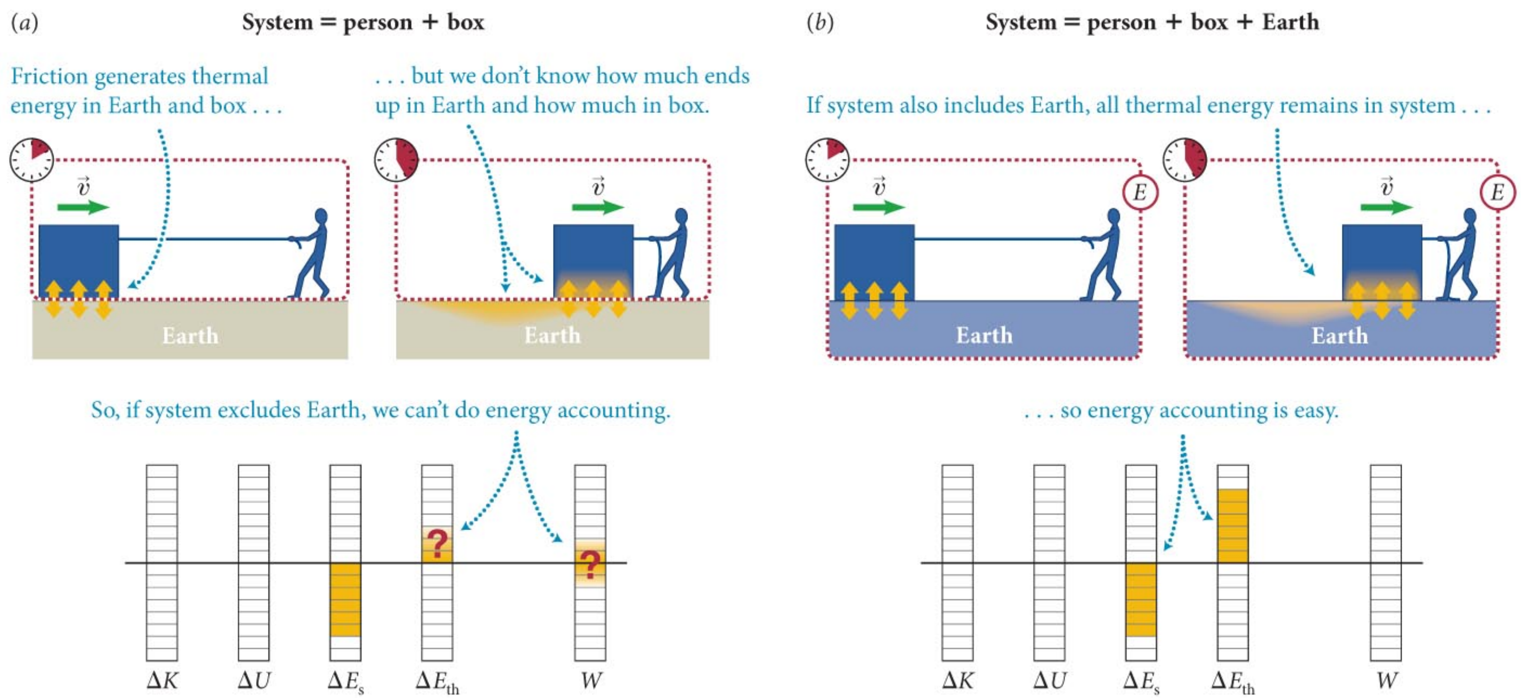


Section 9.4: Choice of system

- Need to be careful not to double count gravitational potential energy!
- It is important to remember the following point:
  - **Gravitational potential energy always refers to the relative position of various parts within a system, never to the relative positions of one component of the system and its environment.**
- In other words, depending on the choice of system, the gravitational interaction with the system can appear in energy diagrams as either a change in gravitational potential energy or work done by Earth, but not both.
- Earth outside system? Probably work (earth = external agent then)

Section 9.4: Choice of system

- As seen in the figure, the thermal energy generated (in this case due to friction) ends up on both surfaces.
- As seen in part (*a*), certain choices of systems lead to complications:
  - **When drawing an energy diagram, do not choose a system for which friction occurs at the boundary of the system.**



Section 9.4
Question 4

When computing energies, should the gravitational interaction be associated with?

1. Work
2. Potential energy
3. Neither
4. Either
5. Both

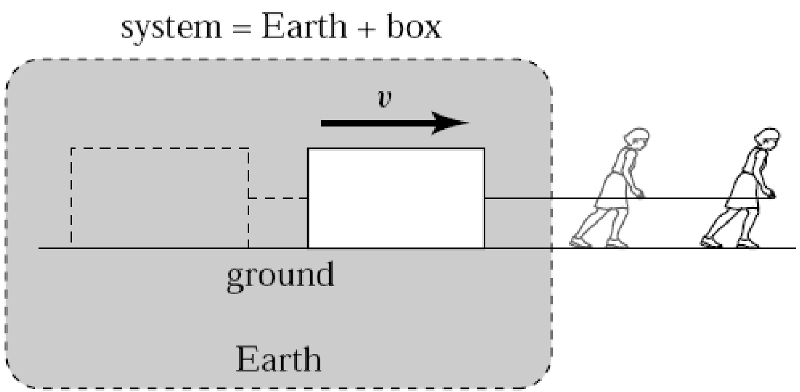
Section 9.4
Question 4

When computing energies, should the gravitational interaction be associated with?

1. Work
2. Potential energy
3. Neither
4. Either – outside of system or not?
5. Both

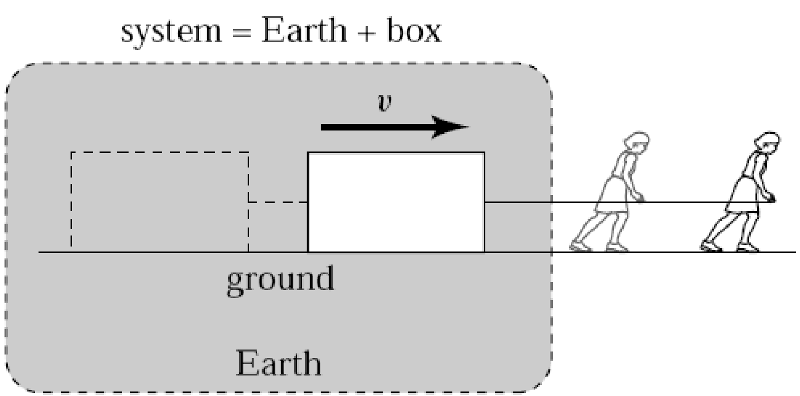
Section 9.4
Question 5

A person pulls a box along the ground at a constant speed. If we consider Earth and the box as our system, what can we say about the net external force on the system?



1. It is zero because the system is isolated.
2. It is nonzero because the system is not isolated.
3. It is zero even though the system is not isolated.
4. It is nonzero even though the system is isolated.
5. None of the above

A person pulls a box along the ground at a constant speed. If we consider Earth and the box as our system, what can we say about the net external force on the system?



1. It is zero because the system is isolated.
2. It is nonzero because the system is not isolated.
3. It is zero even though the system is not isolated.
4. It is nonzero even though the system is isolated.
5. None of the above

Chapter 9: Self-Quiz #1

A stunt performer falls from the roof of a two-story building onto a mattress on the ground. The mattress compresses, bringing the performer to rest without his getting hurt.

Is the work done by the mattress on the performer positive, negative, or zero?

Is the work done by the performer on the mattress positive, negative, or zero?

Chapter 9: Self-Quiz #1

Answer

Because the mattress brings the performer to rest, $\vec{F}^{c}_{mp}$ must point upward. The point of application of this force moves downward as the mattress compresses, meaning the work done by the mattress on the performer is negative. The work done by the performer on the mattress is positive because $\vec{F}^{c}_{pm}$ points downward and its point of application moves downward.

Chapter 9: Self-Quiz #2

Consider a weightlifter holding a barbell motionless above his head.

(*a*) Is the sum of the forces exerted on the barbell zero?

(*b*) Is the weightlifter exerting a force on the barbell?

(*c*) If the weightlifter exerts a force, does this force do any work on the barbell?

(*d*) Does the energy of the barbell change?

(*e*) Are your answers to parts (*c*) and (*d*) consistent in light of the relationship between work and energy?

Chapter 9: Self-Quiz #2

Answer

(*a*) Yes, because the barbell remains motionless.

(*b*) Yes. He exerts an upward force to counter the downward gravitational force.

(*c*) No, because the point at which the lifter exerts a force on the barbell is not displaced.

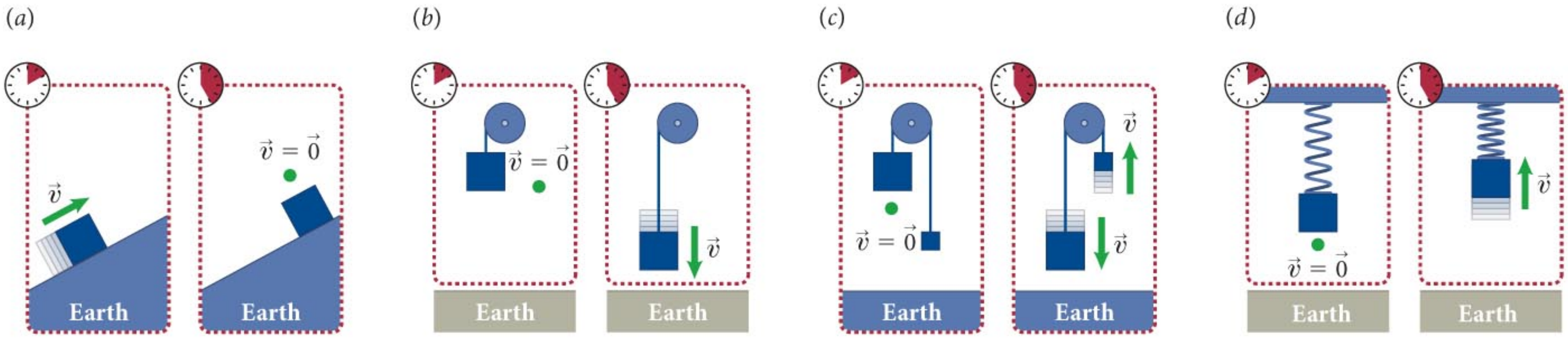
(*d*) No.

(*e*) They are consistent. If no work is done on a system, the energy of the system does not change.

Chapter 9: Self-Quiz #3

Do any of the systems in the figure undergo a change in potential energy?

If yes, is the change positive or negative? Ignore any friction.



Chapter 9: Self-Quiz #3

Answer

Yes. (*a*), (*c*), and (*d*). Because none of the situations involves friction or the conversion of source energy, the only things you need to consider are changes in the kinetic and potential energies and work done by external forces on the system.

The system in part *a* is closed, and so the decrease in kinetic energy causes an increase in gravitational potential energy: $\Delta U > 0$.

In part *b*, Earth is not included in the system, so there can be no potential energy component of the system's energy.

In part *c*, the system is closed, so the increase in kinetic energy must be due to a decrease in gravitational potential energy: $\Delta U < 0$.

In part *d*, Earth does negative work on the system, so the energy of the system must decrease. Because the kinetic energy increases, the elastic potential energy of the spring must decrease: $\Delta U < 0$.

Quantitative Tools

Section 9.5: Work done on a single particle

- When work is done by external forces on a system, the energy change in the system is given by the **energy law:**

$$\Delta E = W$$

- To determine the work done by an external force, we will consider the simple case of a **particle:**
  - *Particle* refers to any object with an inertia m and no internal structure ($\Delta E_{\text{int}} = 0$).
- Only the kinetic energy of a particle can change, so

$$\Delta E = \Delta K \text{ (particle)}$$

- The constant force acting on the particle give is it an acceleration given by

$$a_x = \frac{\Sigma F_x}{m} = \frac{F_x}{m}$$

Section 9.5: Work done on a single particle

- Consider the motion of the particle in time interval $\Delta t = t_f - t_i$. From Equations 3.4 and 3.7, we can write

$$\upsilon_{x,f} = \upsilon_{x,i} + a_x \Delta t$$

$$\Delta x = \upsilon_{x,i}\Delta t + \tfrac{1}{2}a_x(\Delta t)^2$$

- The kinetic energy change of the particle is given by

$$\Delta K = K_f - K_i = \tfrac{1}{2}m(\upsilon_f^2 - \upsilon_i^2)$$

- Combining the above equations we get,

$$\begin{aligned}
\Delta K &= \tfrac{1}{2}m\left[\left(\upsilon_{x,i} + a_x\Delta t\right)^2 - \upsilon_{x,i}^2\right] \\
&= \tfrac{1}{2}m\left[2\upsilon_{x,i}a_x\Delta t + a_x^2(\Delta t)^2\right] \\
&= ma_x\left[\upsilon_{x,i}\Delta t + \tfrac{1}{2}a_x(\Delta t)^2\right] \\
&= ma_x\Delta x_F = F_x\Delta x_F
\end{aligned}$$

where Δx_F is the force displacement.

Section 9.5: Work done on a single particle

- Since $\Delta E = W$, and for a particle $\Delta E = \Delta K$, we get

  $$W = F_x \Delta x_F \text{ (constant force exerted on particle, one dimension)}$$

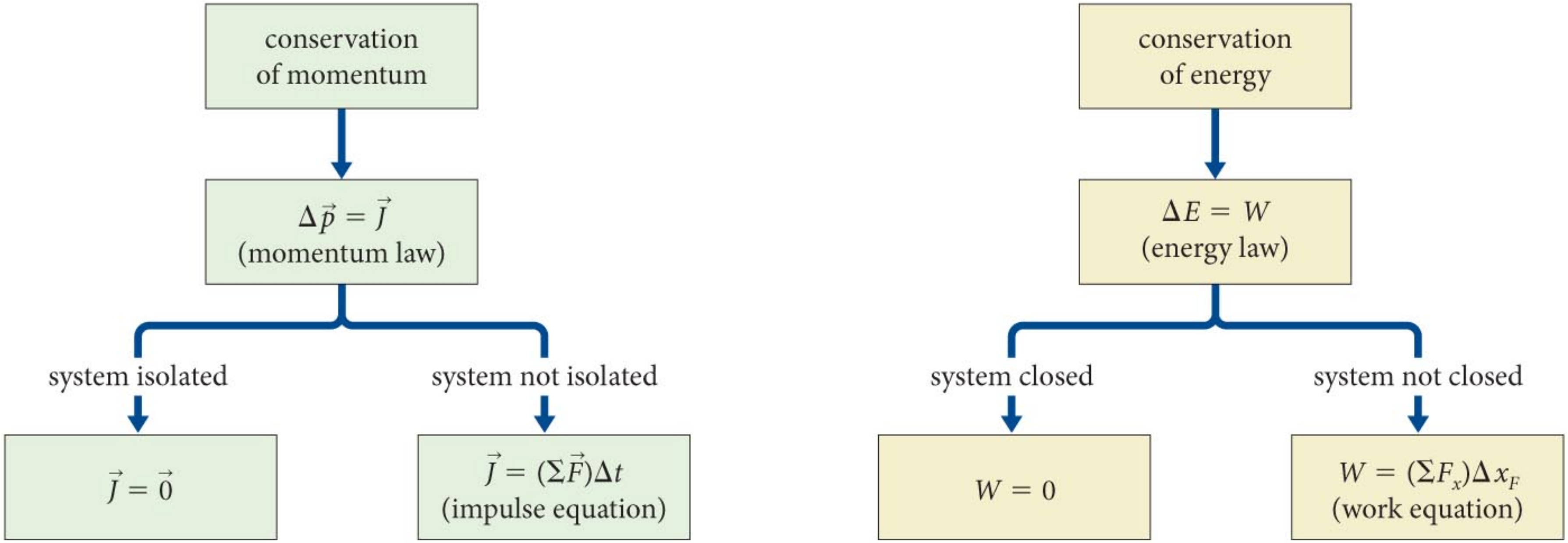
- The equation above in words:
  - **For motion in one dimension, the work done by a constant force exerted on a particle equals the product of the *x* component of the force and the force displacement.**
- If more than one force is exerted on the particle, we get

  $$W = (\Sigma F_x)\Delta x_F \text{ (constant forces exerted on particle, one dimension)}$$

- This is called the **work equation.**

Section 9.5: Work done on a single particle

- Notice the parallel between our treatment of momentum/impulse and energy/work, as illustrated in the figure.

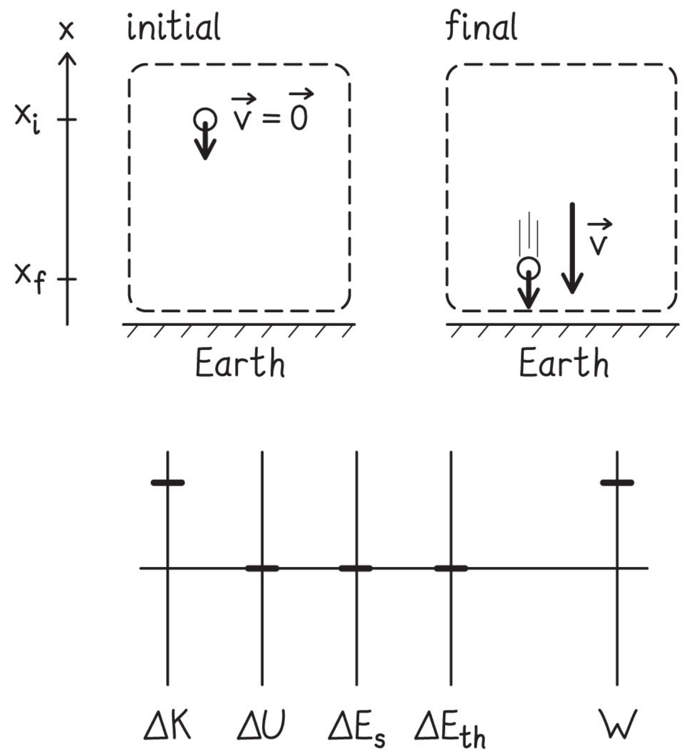


Example 9.6 Work done by gravity

A ball of inertia m_b is released from rest and falls vertically. What is the ball's final kinetic energy after a displacement $\Delta x = x_f - x_i$?

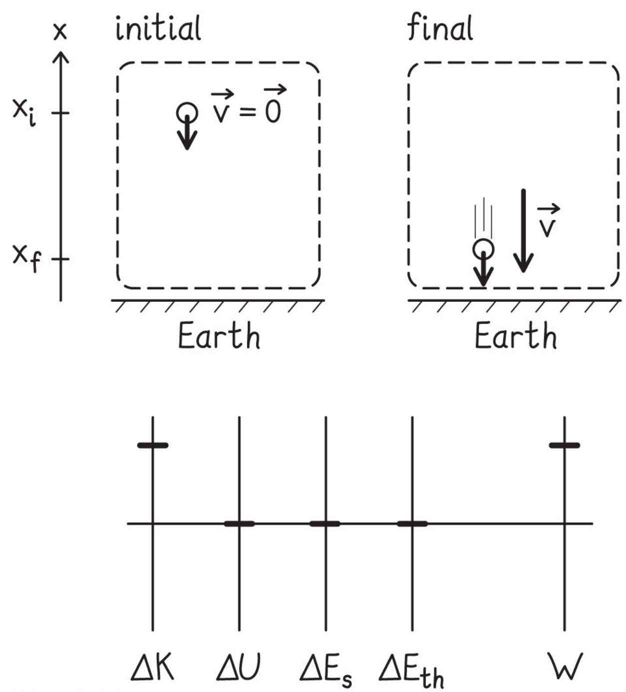
Example 9.6 Work done by gravity (cont.)

❶ GETTING STARTED I begin by making a sketch of the initial and final conditions and drawing an energy diagram for the ball (Figure 9.17). I choose an x axis pointing upward.



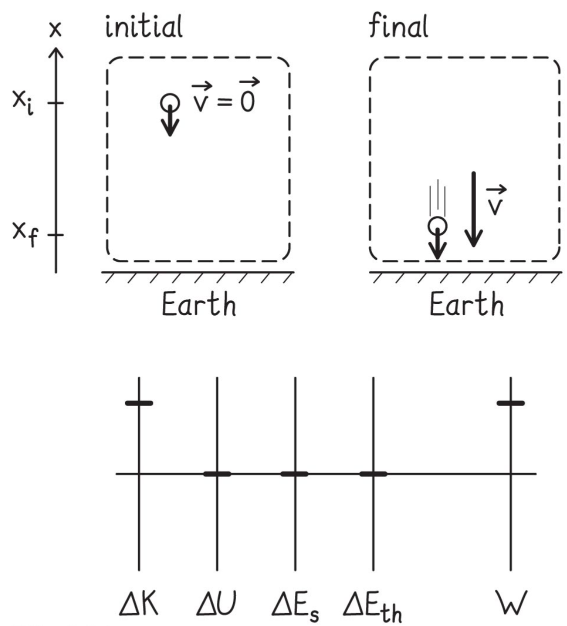
Example 9.6 Work done by gravity (cont.)

❶ GETTING STARTED Because the ball's internal energy doesn't change as it falls (its shape and temperature do not change), I can treat the ball as a particle. Therefore only its kinetic energy changes.



Example 9.6 Work done by gravity (cont.)

❶ GETTING STARTED I can also assume air resistance is small enough to be ignored, so that the only external force exerted on the ball is a constant gravitational force. This force has a nonzero force displacement and so does work on the ball. I therefore include this force in my diagram.



Example 9.6 Work done by gravity (cont.)

❷ DEVISE PLAN If I treat the ball as a particle, Eqs. 9.1 and 9.2 tell me that the change in the ball's kinetic energy is equal to the work done on it by the constant force of gravity, the x component of which is given by Eq. 8.17: $F^G_{\mathrm{Eb}\,x} = -m_\mathrm{b}g$.

(The minus sign means that the force points in the negative x direction.)

To calculate the work done by this force on the ball, I use Eq. 9.8.

Example 9.6 Work done by gravity (cont.)

❸ EXECUTE PLAN Substituting the x component of the gravitational force exerted on the ball and the force displacement $x_f - x_i$ into Eq. 9.8, I get

$$W = F^G_{\mathrm{Eb}\,x}\Delta_{x_F} = -m_\mathrm{b}g(x_\mathrm{f} - x_\mathrm{i}).$$

Example 9.6 Work done by gravity (cont.)

❸ EXECUTE PLAN Because the work is equal to the change in kinetic energy and the initial kinetic energy is zero, I have $W = \Delta K = K_f - 0 = K_f$, so

$$K_f = -m_b g(x_f - x_i). \checkmark$$

Example 9.6 Work done by gravity (cont.)

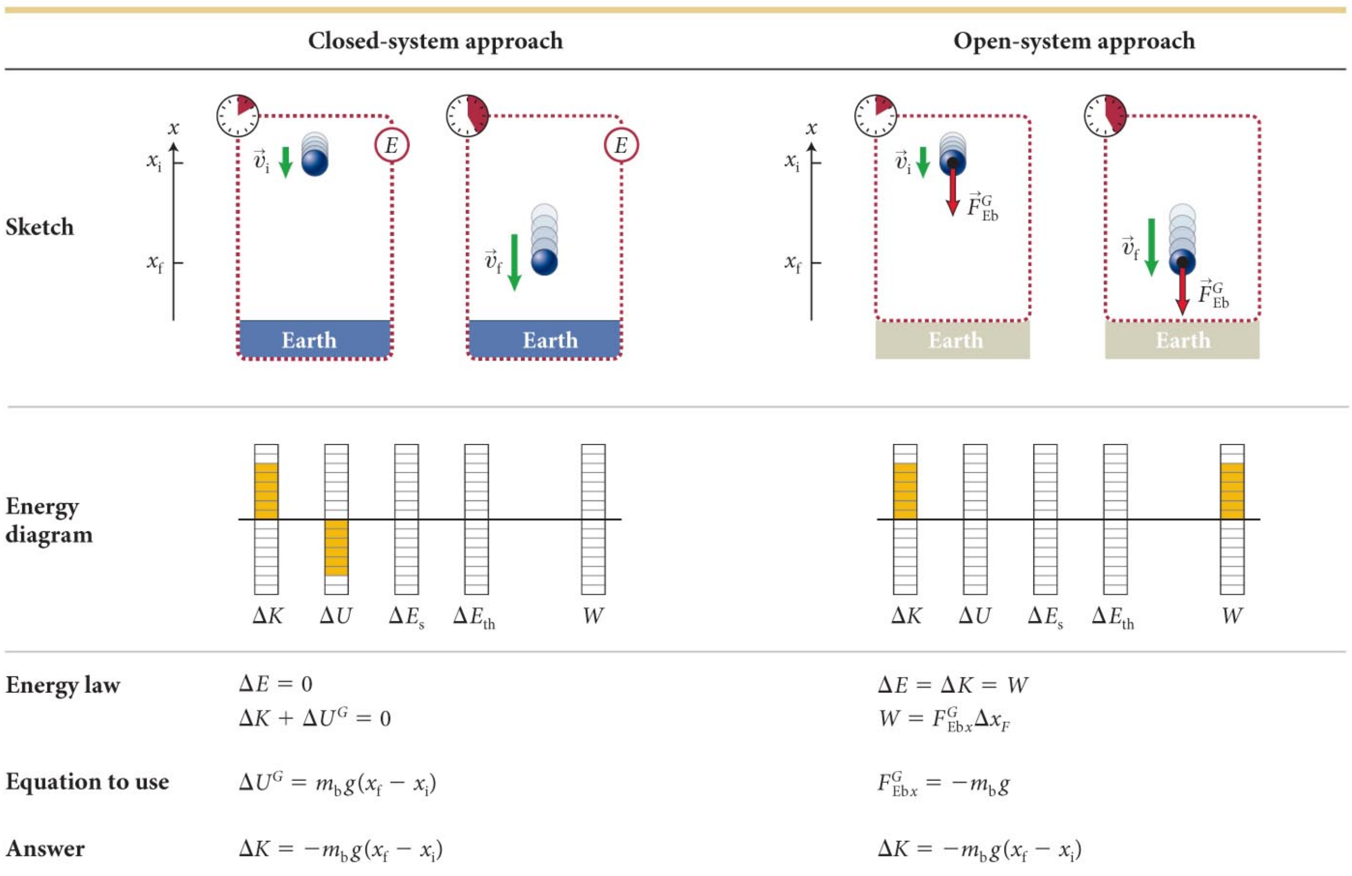
❹ EVALUATE RESULT Because the ball moves in the negative x direction, $\Delta x = x_f - x_i$ is negative and so the final kinetic energy is positive (as it should be).

Example 9.6 Work done by gravity (cont.)

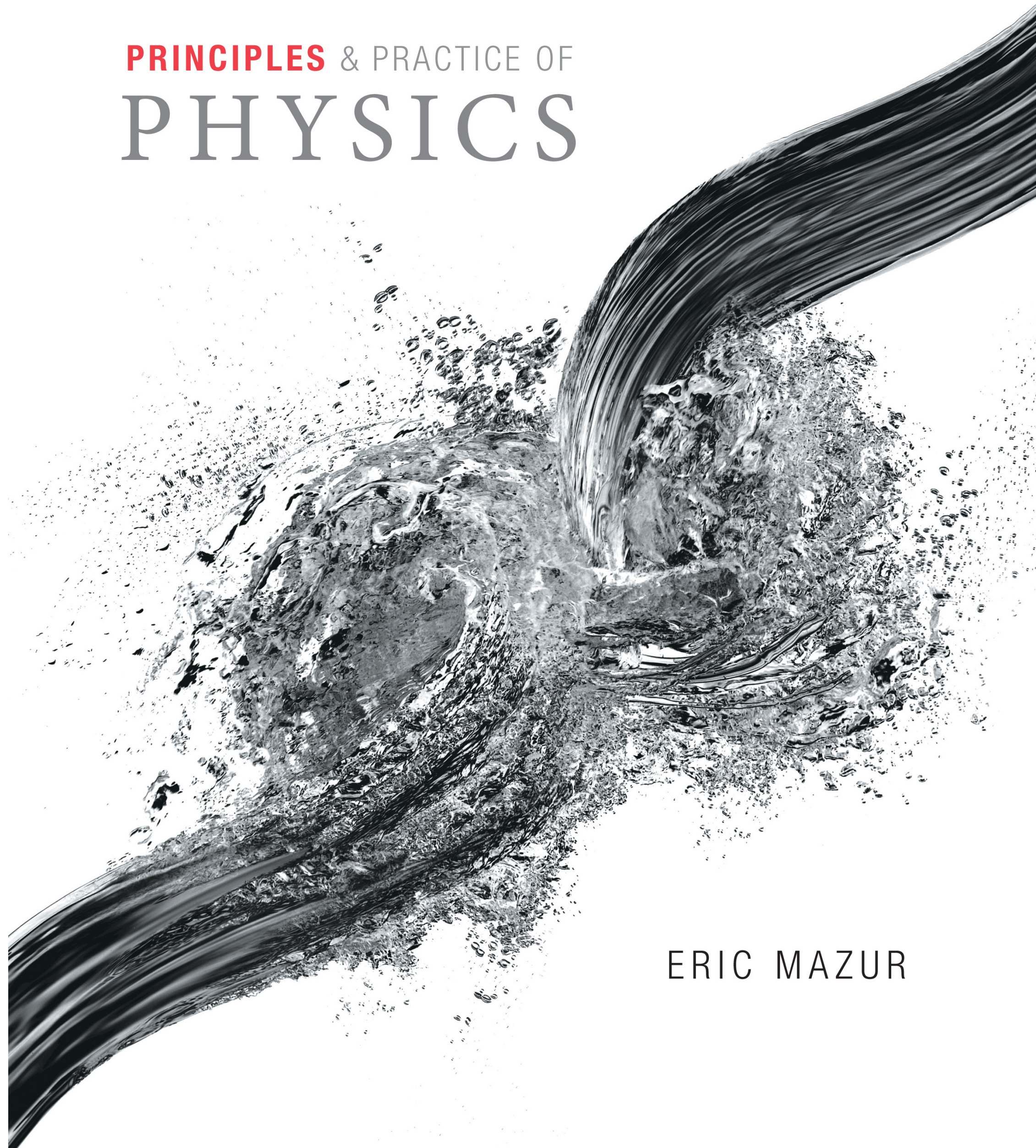
❹ EVALUATE RESULT An alternative approach is to consider the **closed Earth-ball system**. For that system, the sum of the gravitational potential energy and kinetic energy does not change, and so, from Eq. 7.13, $\Delta K + \Delta U^G = \frac{1}{2}m_b(\upsilon_f^2 - \upsilon_i^2) + m_b g(x_f - x_i) = 0$. Because the ball starts at rest, $\upsilon_i = 0$, and so I obtain the same result for the final kinetic energy:

$$\tfrac{1}{2}m_b\upsilon_f^2 = -m_b g(x_f - x_i).$$

- The two approaches used in the previous example are shown schematically in the figure.



Work



Various & Sundry

- Midterm grades: should be OK now
  - Software is still just terrible. So terrible.
  - You don’t want to know.
  - Please check grades so I’m sure this works

- “I can explain the law of conservation of momentum in 15 minutes, but three hours in the lab would only convince an honest student that the law is false.” – David Griffiths

Section 9.5
Question 6

When you do positive work on a particle, its kinetic energy

1. increases.
2. decreases.
3. remains the same.
4. We need more information about the way the work was done.

Section 9.5
Question 6

When you do positive work on a particle, its kinetic energy

✔ 1. increases.
2. decreases.
3. remains the same.
4. We need more information about the way the work was done.

That pesky reading quiz

10.06

- Starting from your campsite you walk 3.0 km east, 6.0 km north, 1.0 km east, and then 4.0 km west. How far are you from your campsite?

(We are reminding you about vectors for next week)

That pesky reading quiz

10.06

- Being pedantic, let north = +y, east = +x.

$$\vec{r} = (3.0\,\hat{\imath} + 6.0\,\hat{\jmath} + 1.0\,\hat{\imath} - 4.0\,\hat{\imath})\,\mathrm{km} = (0\,\hat{\imath} + 6.0\,\hat{\jmath})\ \mathrm{km}$$

$$|\vec{r}| = \sqrt{0^2 + 6.0^2}\,\mathrm{km} = 6.0\,\mathrm{km}$$

- Being sensible, your east-west motion cancels out, leaving only the northy bit

That pesky reading quiz

10.09

- For general projectile motion, which of the following best describes the horizontal component of a projectile's velocity? Assume air resistance is negligible.

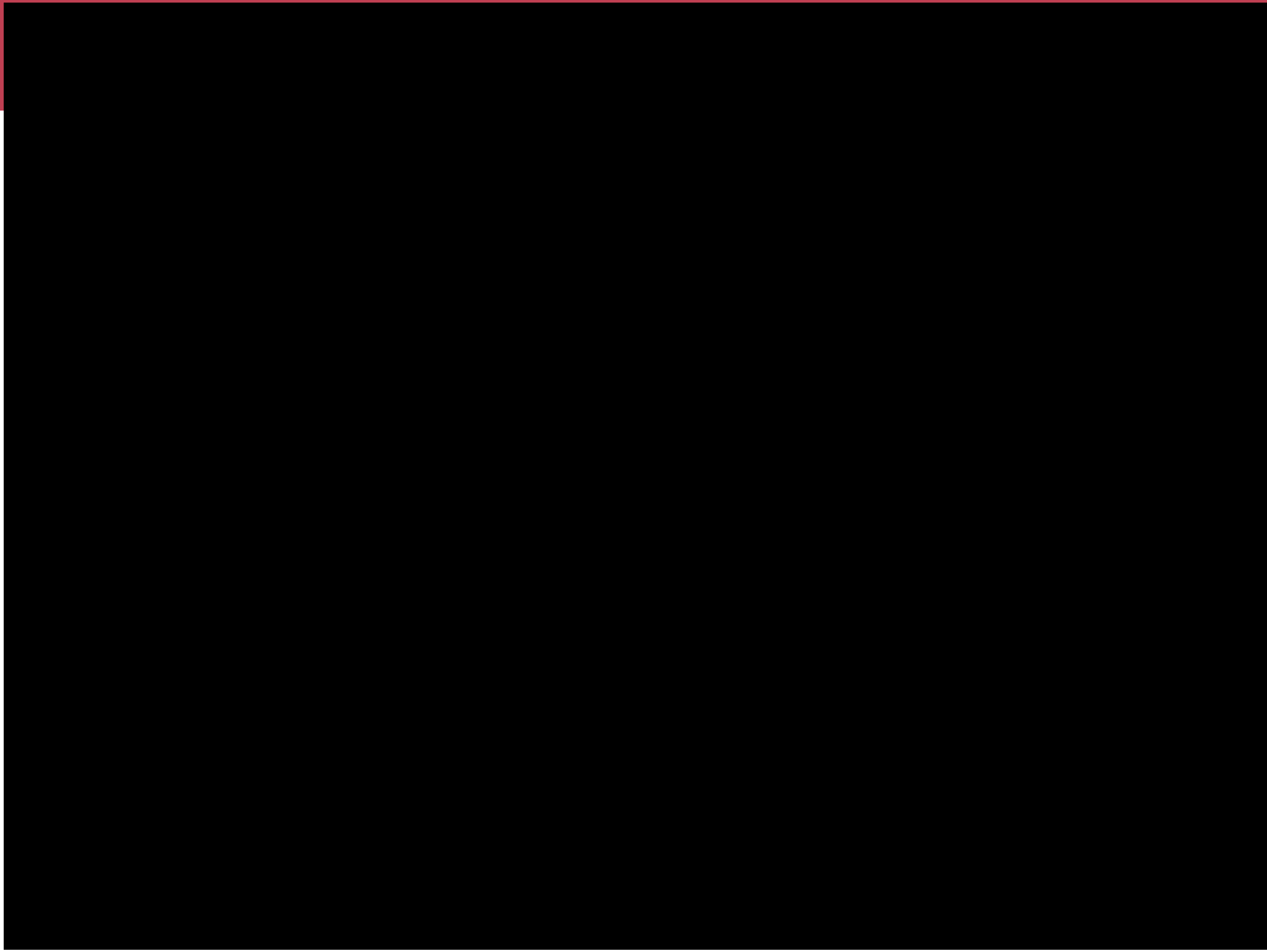
- Think about this: what is the interaction in the horizontal direction?

That pesky reading quiz

10.09

- It is just constant – the only interaction for a projectile in free-fall is gravity, which only acts vertically.

- No, really.



That pesky reading quiz

10.11

- For general projectile motion, which of the following best describes the vertical component of a projectile's acceleration? Assume air resistance is negligible.

- It is still just gravity, don’t let new words fool you. Nonzero constant.

That pesky reading quiz

10.10

- For general projectile motion, which of the following best describes the horizontal component of a projectile's acceleration? Assume air resistance is negligible.

- Same as 10.09 – no interaction means no acceleration, which means constant velocity.

Section 9.6: Work done on a many-particle system

Section Goals

You will learn to

- Extend the work-force-displacement relationship for single objects to **systems of interacting objects**.
- Recognize that **only** external forces contribute to the work done for many particle systems. Since the **internal** forces are members of an interaction pair the **work done** by that pair of forces always sums to **zero**.

Section 9.6: Work done on a many-particle system

Example 9.7 Landing on his feet

A 60-kg person jumps off a chair and lands on the floor at a speed of 1.2 m/s. Once his feet touch the floor surface, he slows down with constant acceleration by bending his knees. During the slowing down, his center of mass travels 0.25 m.

Determine the magnitude of the force exerted by the floor surface on the person and the work done by this force on him.

What?

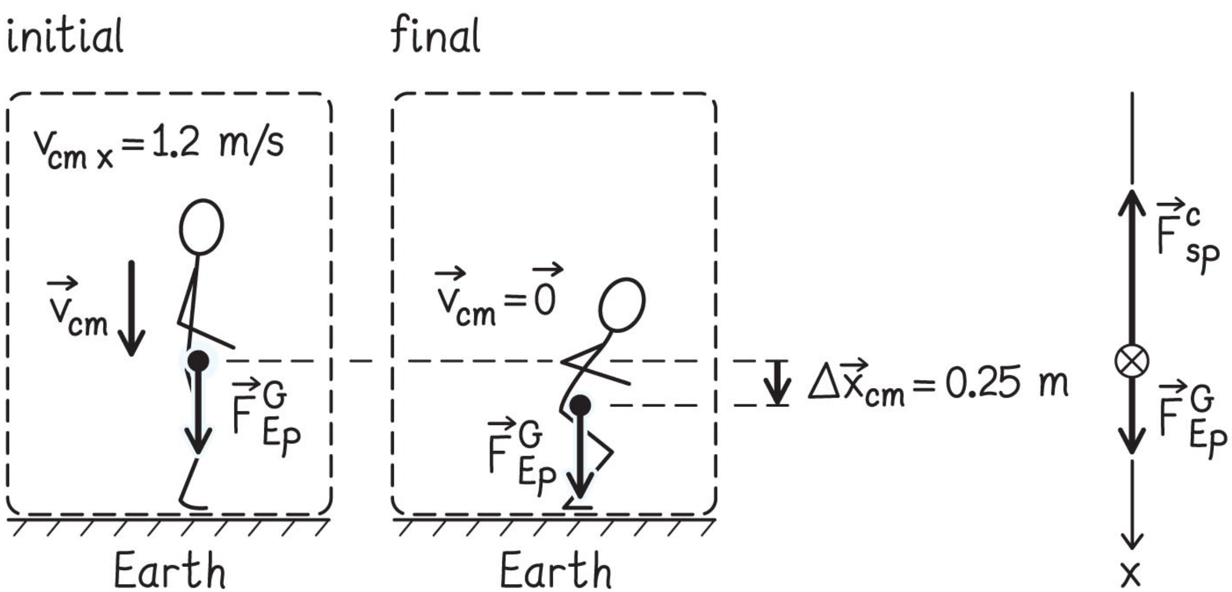
I have no idea what to do.

- What is the physics?
  - person's KE changes
  - external forces cause this change
  - the change in KE must be due to the work done by these forces

- Figure the change in KE and the work done by gravity slowing down. From work you get force, knowing the displacement.

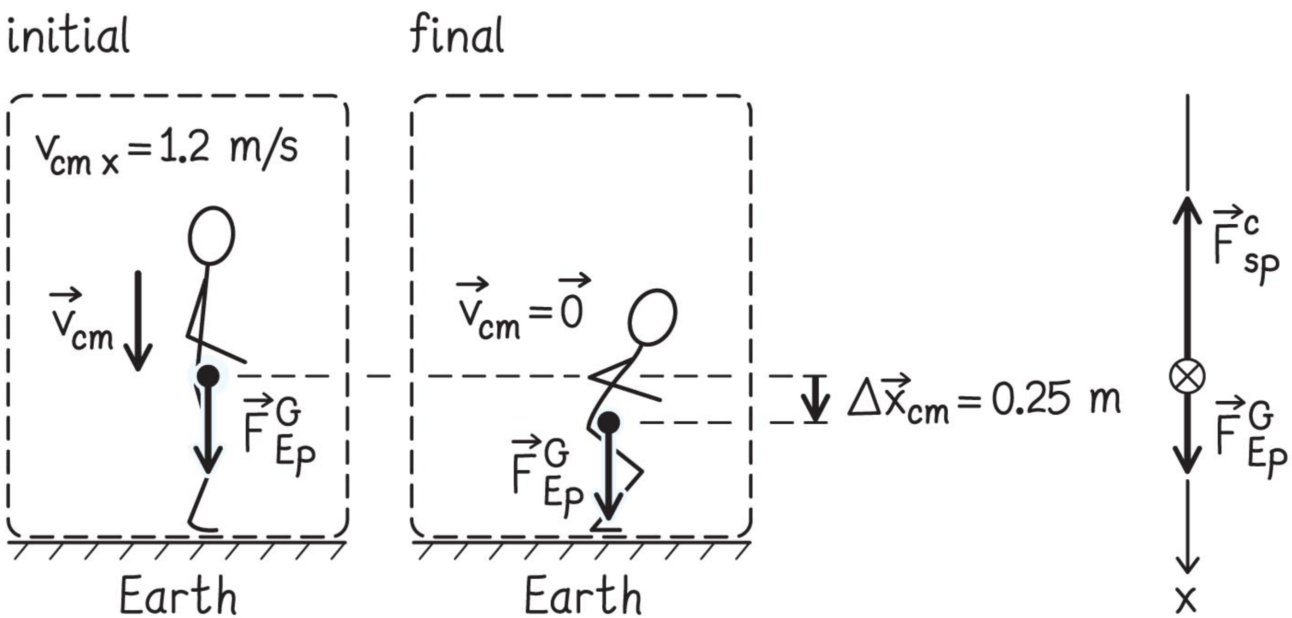
Example 9.7 Landing on his feet (cont.)

❶ GETTING STARTED I begin by making a sketch of the initial and final conditions, choosing my person as the system and assuming the motion to be entirely vertical (Figure 9.21).



Example 9.7 Landing on his feet (cont.)

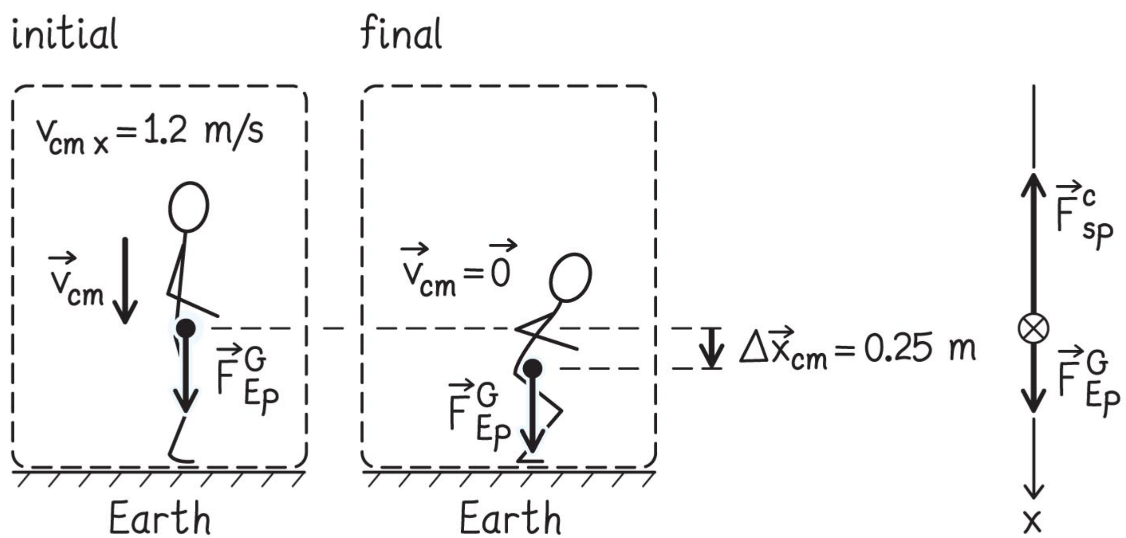
❶ GETTING STARTED I point the x axis downward in the direction of motion, which means that the x components of both the displacement and the velocity of the center of mass are positive: $\Delta x_{cm} = +0.25$ m and $v_{cm\,x} = +1.2$ m/s.



Section 9.6: Work done on a many-particle system

Example 9.7 Landing on his feet (cont.)

❶ GETTING STARTED Two external forces are exerted on the person: a downward force of gravity $\vec{F}^G_{\text{Ep}}$ exerted by Earth and an upward contact force $\vec{F}^c_{\text{sp}}$ exerted by the floor surface. Only the point of application of the force of gravity undergoes a displacement, and so I need to include only that force in my diagram.



Example 9.7 Landing on his feet (cont.)

❷ DEVISE PLAN Knowing the initial center-of-mass velocity, I can use Eq. 9.13 to calculate the change in the person's translational kinetic energy ΔK_{cm}.

This change in kinetic energy must equal the work done by the net external force.

From that and the displacement $\Delta x_{cm} = +0.25$ m we can find the vector sum of the forces exerted on the person.

Example 9.7 Landing on his feet (cont.)

❷ DEVISE PLAN If I then subtract the force of gravity, I obtain the force exerted by the floor surface on the person. To determine the work done by this force on the person, I need to multiply it by the force displacement.

Example 9.7 Landing on his feet (cont.)

❷ DEVISE PLAN Because the person slows down as he travels downward, his acceleration is upward and so the vector sum of the forces is upward too. To remind myself of this, I draw a free-body diagram in which the arrow for the upward contact force is longer than the arrow for the downward force of gravity.

Example 9.7 Landing on his feet (cont.)

❸ EXECUTE PLAN Because the person ends at rest, his final translational kinetic energy is zero

$$\Delta K_{\mathrm{cm}} = 0 - \tfrac{1}{2} m v_{\mathrm{cm,i}}^2 = \tfrac{1}{2}(60\, kg)(1.2\ \mathrm{m/s})^2 = -43\ \mathrm{J}.$$

Example 9.7 Landing on his feet (cont.)

❸ EXECUTE PLAN Substituting this value and the displacement of the center of mass into Eq. 9.14 yields

$$\Sigma F_{\text{ext}\,x} = \frac{\Delta K_{\text{cm}}}{\Delta x_{\text{cm}}} = \frac{-43\ \text{J}}{0.25\ \text{m}} = -170\ \text{N}.$$

This is the *net* force. We need a free body diagram to disentangle the forces.

Example 9.7 Landing on his feet (cont.)

❸ EXECUTE PLAN To obtain the force exerted by the floor from this vector sum, look back to the free body diagram: just two forces.

$$\Sigma F_{\text{ext}\,x} = F^G_{\text{Ep}\,x} + F^c_{\text{sp}\,x}$$

and so $F^c_{\text{sp}\,x} = \Sigma F_{\text{ext}\,x} - F^G_{\text{Ep}\,x}$. The x component of the force of gravity is $F^G_{\text{Ep}\,x} = mg = (60\text{ kg})(9.8\ (\text{m/s}^2)) = +590\text{ N}$ and so $F^c_{\text{sp}\,x} = -170\text{ N} - 590\text{ N} = -760\text{ N}$. ✔

Section 9.6: Work done on a many-particle system

Example 9.7 Landing on his feet (cont.)

❸ EXECUTE PLAN To determine the work done by this force on the person, I must multiply the x component of the force by the force displacement.

The point of application is at the floor, which doesn't move. This means that the force displacement is zero, and so the work done on the person is zero too: $W = 0$. ✔

Example 9.7 Landing on his feet (cont.)

❹ EVALUATE RESULT The contact force $F^{c}_{\mathrm{sp}\,x}$ is negative because it is directed upward, as I expect. Its magnitude is larger than that of the force of gravity, as it should be in order to slow the person down.

Section 9.7: Variable and distributed forces

Section Goals

You will learn to

- Derive the relationship for the **work** done by a **variable force**.
- Interpret the work done by a variable force **graphically**.
- Understand that distributed forces, like friction, have **no single point of application** on an object.

Section 9.7: Variable and distributed forces

- The acceleration of the center of mass of a system consisting of many interacting particles is given by

$$\vec{a}_{\mathrm{cm}} = \frac{\Sigma \vec{F}_{\mathrm{ext}}}{m}$$

- Following the same derivation as in the single-particle system, we can write

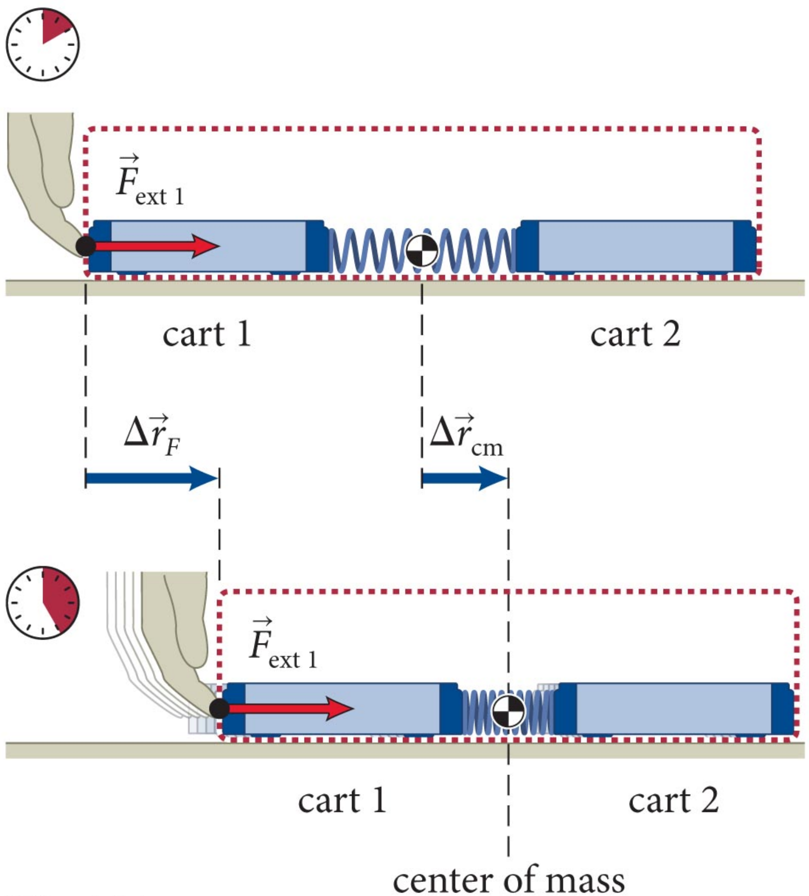
$$\Delta K_{\mathrm{cm}} = m a_{\mathrm{cm}\,x} \Delta x_{\mathrm{cm}} = (\Sigma F_{\mathrm{ext}\,x}) \Delta x_{\mathrm{cm}} \text{(constant forces, one dimension)}$$

- So?
  - treat object as a point particle, concentrated at center of mass
  - work done in moving the center of mass gives change in center of mass kinetic energy
  - if you can calculate a ball, you can calculate a wrench

Section 9.7: Variable and distributed forces

- For a system of many particles $K = K_{cm} + K_{conv}$ – there is some KE due to internal motion of constituents
- Therefore, $\Delta K_{cm} \neq \Delta E$, and since $\Delta E = W$, we can see that

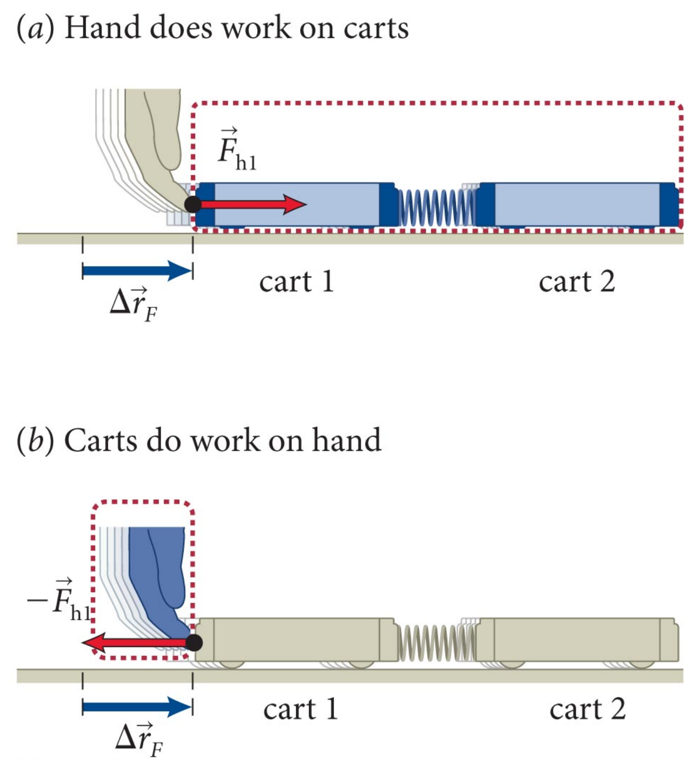
  $\Delta K_{cm} \neq W$ (many-particle system)
- This is explicitly illustrated in the example shown in the figure.
- The external force on cart 1 increases the kinetic energy **and** the internal energy of the system.



Section 9.7: Variable and distributed forces

- To determine the work done by external forces on a many particle system, we can use the fact that $W_{\text{env}} = -W_{\text{sys}}$.
- This makes sense – work is what crosses the boundary, and a loss to the environment is the same as a gain to the system (& vice versa)
- We can see from the figure that the work done by the two-cart system on the hand is $= -F_{\text{h}1x}\Delta x_F$.
- Then the work done by the external force on the two-cart system is

$$W = F_{\text{ext }1x}\Delta x_F \text{ (constant nondissipative force, one dimension)}$$



Section 9.7: Variable and distributed forces

- Generalizing this work equation to many-particle systems subject to several constant forces, we get

$$W = W_1 + W_2 + \cdots = F_{\text{ext}\,1x}\Delta x_{F1} + F_{\text{ext}\,2x}\Delta x_{F2} + \cdots$$

or

$$W = \sum_n (F_{\text{ext}\,nx}\Delta x_{Fn}) \text{ (constant nondissipative forces, one dimension)}$$

If we consider a varying force $F(x)$, we take infinitesimal displacements, and this becomes an integral

$$W = \int_{x_\text{i}}^{x_\text{f}} F_x(x)\,dx \text{ (nondissipative force, one dimension)}$$

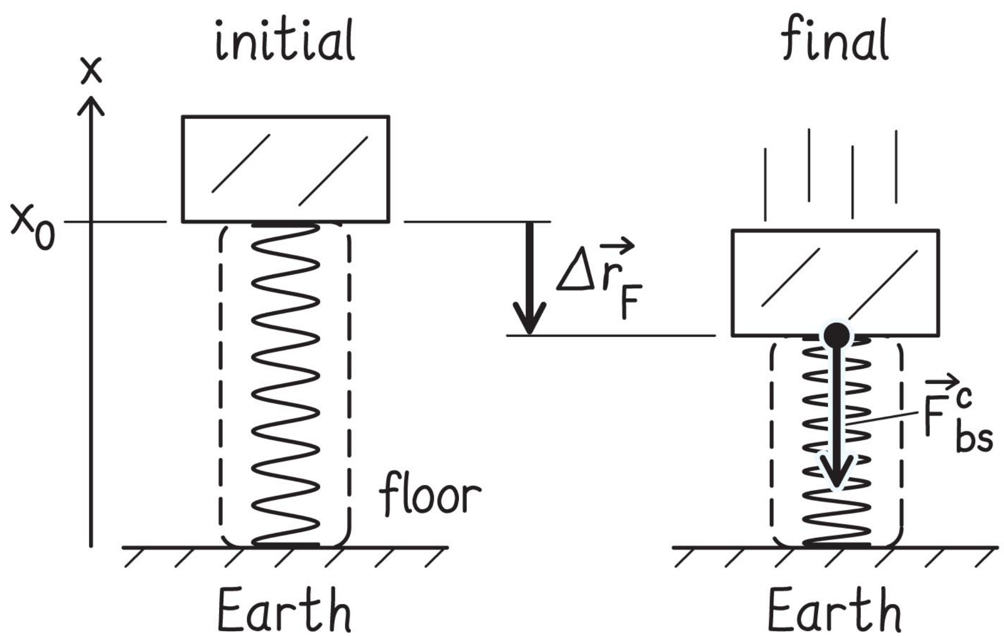
work is the area under the force-displacement curve!

Example 9.8 Spring work

A brick of inertia m compresses a spring of spring constant k so that the free end of the spring is displaced from its relaxed position. What is the work done by the brick on the spring during the compression?

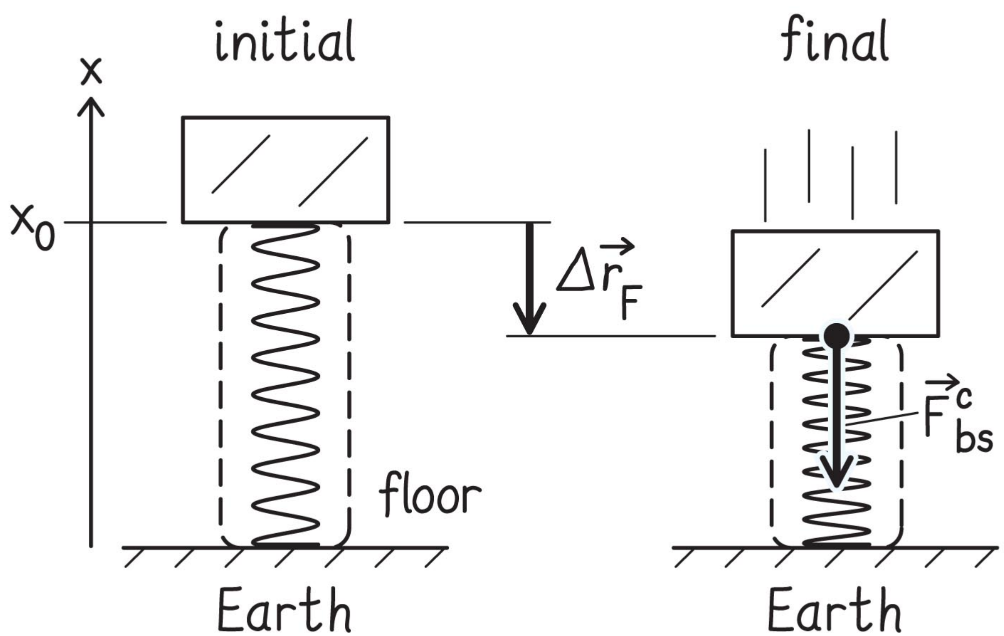
Example 9.8 Spring work (cont.)

❶ GETTING STARTED I begin by making a sketch of the situation as the free end of the spring is compressed from its relaxed position x_0 to a position x (Figure 9.23). Because I need to calculate the work done by the brick on the spring, I choose the spring as my system.



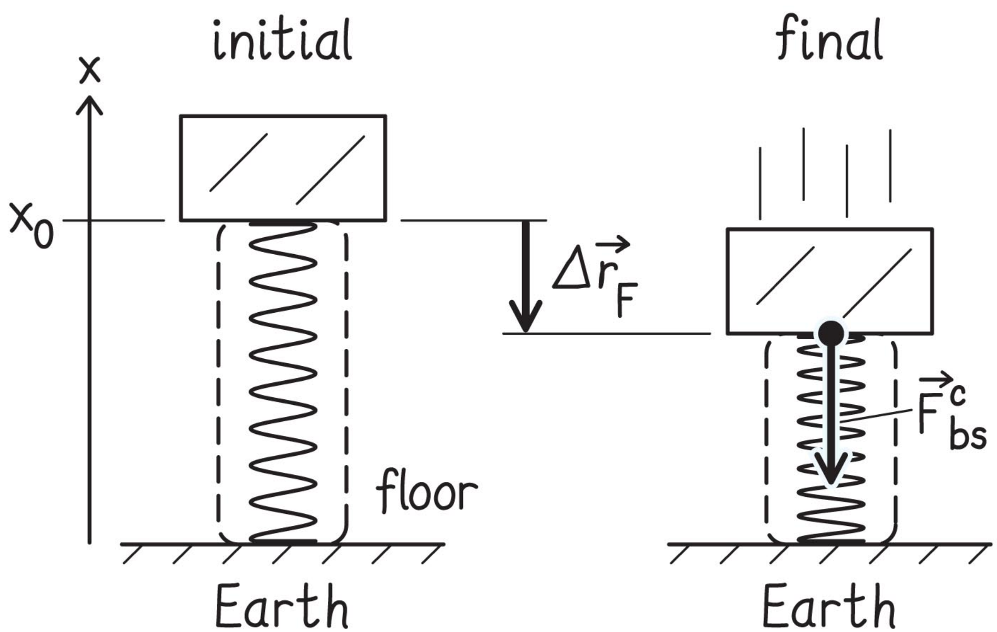
Example 9.8 Spring work (cont.)

❶ GETTING STARTED Three forces are exerted on the spring: contact forces exerted by the brick and by the floor, and the force of gravity. As usual when dealing with compressed springs, I ignore the force of gravity exerted on the spring (see Section 8.6).



Example 9.8 Spring work (cont.)

❶ GETTING STARTED Only the force $\vec{F}^{c}_{bs}$ exerted by the brick on the spring undergoes a nonzero force displacement, so I need to show only that force in my diagram. Because the brick and spring do not exert any forces on each other when the spring is in the relaxed position, I do not draw this force in the initial state.



Example 9.8 Spring work (cont.)

❷ DEVISE PLAN I need to calculate the work done by the brick on the spring. I could use Eq. 9.22 if I knew the force the brick exerts on the spring. That force is not given, but the force exerted by the brick on the spring and the force exerted by the spring on the brick form an interaction pair: $\vec{F}^{c}_{bs} = -\vec{F}^{c}_{sb}$. I can use Eq. 8.20 to determine $\vec{F}^{c}_{sb}$ and then use it in Eq. 9.22.

Example 9.8 Spring work (cont.)

❸ EXECUTE PLAN Equation 8.20 tells me that the x component of the force exerted by the spring on the brick varies depending on how far the spring is compressed:

$$F_{\mathrm{sb}\,x} = -k(x - x_0),$$

where x_0 is the coordinate of the relaxed position of the free end of the spring.

Example 9.8 Spring work (cont.)

❸ EXECUTE PLAN The x component of the force exerted by the brick on the spring is thus

$$F_{\text{bs}\,x} = +k(x - x_0). \qquad (1)$$

Because $x_0 > x$, $F_{\text{bs}\,x}$ is negative, which means that $\vec{F}^{\text{c}}_{\text{bs}}$ points in the same direction as the force displacement. Thus the work done by the brick on the spring is positive.

Example 9.8 Spring work (cont.)

❸ EXECUTE PLAN Now I substitute Eq. 1 into Eq. 9.22 and work out the integral to determine the work done by the brick on the spring:

$$W_{\mathrm{bs}} = \int_{x_0}^{x} F_{\mathrm{bs}\,x}(x)\,dx = \int_{x_0}^{x} k(x - x_0)\,dx$$

$$= \left[\tfrac{1}{2}kx^2 - kx_0x\right]_{x_0}^{x} = \tfrac{1}{2}k(x - x_0)^2. \checkmark \qquad (2)$$

Example 9.8 Spring work (cont.)

❹ Evaluate result Because the spring constant k is always positive (see Section 8.9 on Hooke's law), the work done by the brick on the spring is also positive. This is what I expect because the work done in compressing the spring is stored as potential energy in the spring.

Section 9.7
Question 7

When you plot the force exerted on a particle as a function of the particle's position, what feature of the graph represents the work done on the particle?

1. The maximum numerical value of the force
2. The area under the curve
3. The value of the displacement
4. You need more information about the way the work was done.

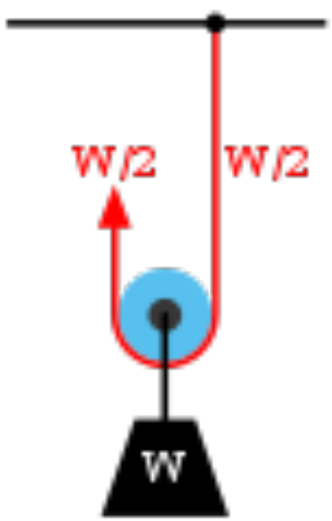
Question 7

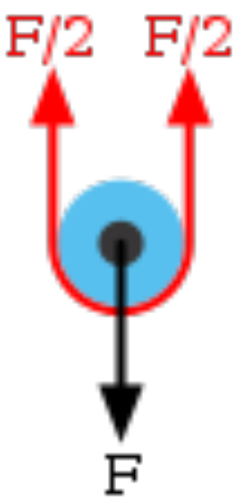
When you plot the force exerted on a particle as a function of the particle's position, what feature of the graph represents the work done on the particle?

1. The maximum numerical value of the force
2. ✔ The area under the curve
3. The value of the displacement
4. You need more information about the way the work was done.

Pulley

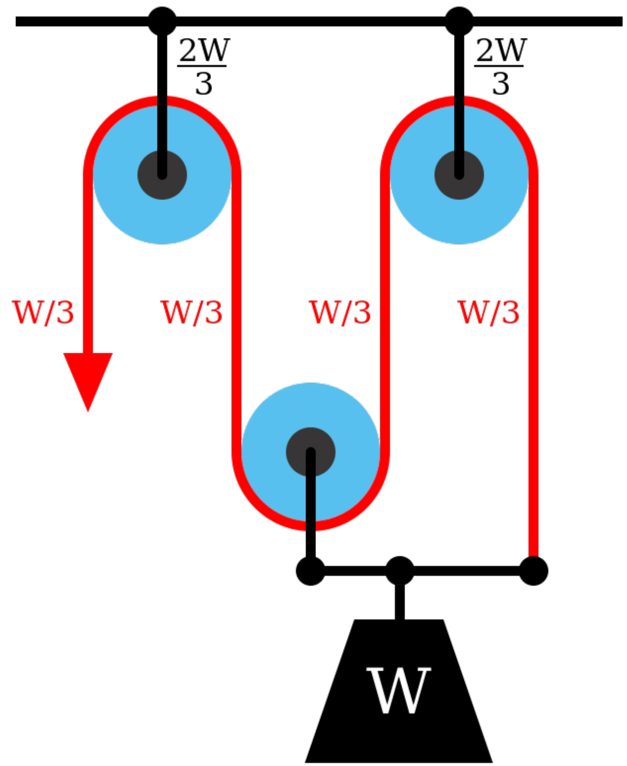
- Why use a pulley?
- Simple pulley just redirects force





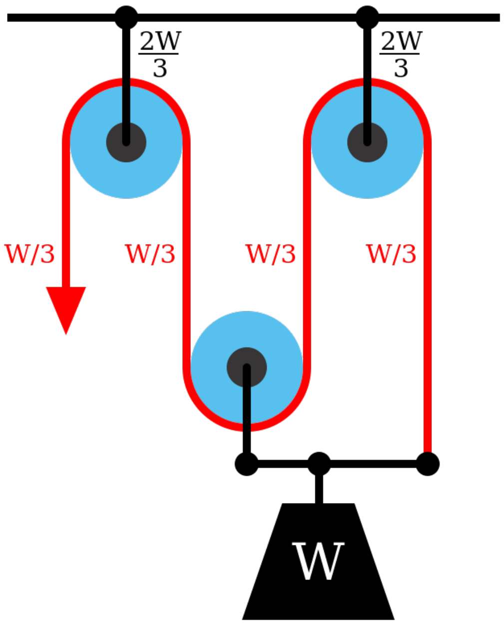
Pulley

- Compound pulley?
- Same rope, same tension, but split it up
- 3 sections, pull with 1/3 weight



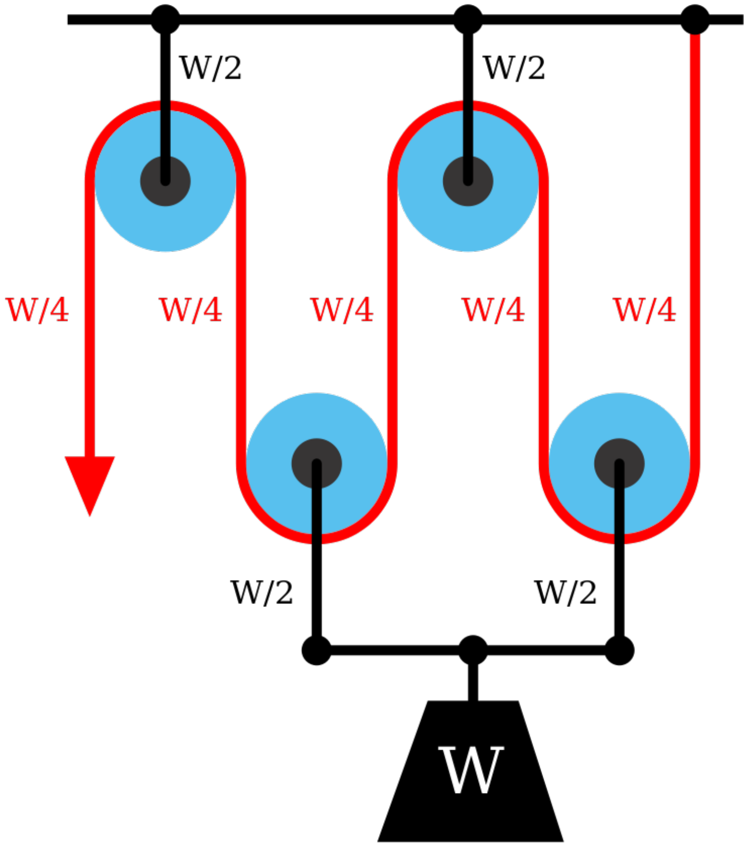
Pulley

- Work?
- if load moves by x, you have to pull L
- Work done by you = work by gravity
- $(W/3)L = Wx$ so $L = 3x$
- pull with 1/3 the force for 3x the distance



Pulley

- Pull with ¼ the force, but 4 times as far
- Mechanical advantage – trade force for distance



That pesky homework

9.24

- A beetle of know mass jumps. Its center of mass rises by y_c, it travels to a height y_f after that. What is the force exerted by the floor on the beetle?

- First: the work done by the contact force (jumping) must equal the change in kinetic energy, which itself must equal the change in gravitational potential energy.

That pesky homework

9.24

- Mathing that up a bit, we just said

$$W = F^{c}_{mb} y_{c} = \Delta K = \Delta U^{G} = mgy_{f}$$

- That's enough to get you the force, you know the rest.
- How about the acceleration?

That pesky homework

9.24

- This implies

$$F^{c}_{mb} - F^{G}_{Eb} = +ma$$

- you know the gravitational force, just solve for *a*
- it will seem unreasonably large. bugs are weird that way.

There is still more homework

9.34

- Ice skater (mass m) pushes off from a wall. You know how far the center of mass moves (x), and the final velocity (v).

- Force by the wall on him?
- Work by the wall?
- Change in KE of his center of mass?

There is still more homework

9.34

- Force by the wall on him?

- Work done by contact force = change in KE

$$W = F^{c}_{ws}\Delta x = \frac{1}{2}m(v_f^2 - v_i^2) = \frac{1}{2}mv_f^2$$

- solve for the force. Similar to his weight …

Homework

9.34

- Work done by wall? The wall doesn’t move.
- Change in KE? All of it.

Homework is still happening

9.50

- You have W(x). Recall $W = \int F\,dx$
- This implies

$$F(x) = \frac{dW}{dx}$$

- Do that.

- shortcut: try typing “\Delta” in the response, you can avoid the drop-down. works for all Greek characters

Dr. LeClair there is so much homework

Car with constant power

- Power is $P = dW/dt = dK/dt$ by the way
- Car can do 0 to v in t seconds
- At full power, how long to get to $2v$?

- if $P = dK/dt$ is constant, then K is linear in time

$$K(t) = K_o + (\text{const})t$$

- This means

$$\frac{K_1}{K_2} = \frac{t_1}{t_2} = \frac{v_1^2}{v_2^2}$$

Dr. LeClair there is so much homework

Car with constant power

- What if force were constant?

- If F is constant, so is a, which means velocity is linear in time

$$a = \text{const} \qquad \Longrightarrow \qquad v(t) = v_o + at$$

$$\Longrightarrow \qquad \frac{v_1}{v_2} = \frac{t_1}{t_2}$$

Stahp with the homework

9.58

- Girl of mass *m* climbs rope, *x* meters in *t* seconds
- Average power?

- Power = dK/dt = W/dt
- Given dt, need to find work
- Acting external force is gravity, so W = mgx

You’ve got to feel like the cubs are just being set up for something totally devastating. Again.

9.66

- We are lifting an elevator cab and occupants. Constant cruising speed *v*, but must achieve it within *t* seconds.
- Do the second part first.

Solving it backwards

9.66

- At cruising speed, the work per unit time is easy. Doing it symbolically, we find a relationship with force & velocity

$$P = \frac{W}{\Delta t} = \frac{F\Delta x}{\Delta t} = Fv = (m_{car} + m_{occ})\, gv$$

Solving it backwards

9.66

- The acceleration phase is harder.
- Total change in energy is kinetic *plus* gravitational potential energy. Need change in height!

- Given final velocity, time, $a=v_f/t$, find the change in height over the acceleration phase
- Change in energy is change in KE plus

  (total mass)g(change in height)
- Power is this energy change divided by given time

Section 9.8
Question 8

A sports car accelerates from zero to 30 mph in 1.5 s. How long does it take for it to accelerate to 60 mph, assuming that the power delivered by the engine is independent of velocity and neglecting friction?

1. 2.0 s
2. 3.0 s
3. 4.5 s
4. 6.0 s
5. 9.0 s
6. 12.0 s

Clicker Question 8

A sports car accelerates from zero to 30 mph in 1.5 s. How long does it take for it to accelerate to 60 mph, assuming that the power delivered by the engine is independent of velocity and neglecting friction?

1. 2.0 s
2. 3.0 s
3. 4.5 s
4. ✔ 6.0 s twice the speed, four times as long.
5. 9.0 s
6. 12.0 s

Concepts: Work done by a constant force

- In order for a force to do work on an object, the point of application of the force must undergo a displacement.
- The SI unit of work is the **joule** (J).
- The work done by a force is positive when the force and the force displacement are in the same direction and negative when they are in opposite directions.

Quantitative Tools: Work done by a constant force

- When one or more constant forces cause a particle or a rigid object to undergo a displacement Δx in one dimension, the work done by the force or forces on the particle or object is given by the **work equation**:

$$W = \left(\sum F_x\right)\Delta x_F$$

- In one dimension, the work done by a set of constant nondissipative forces on a system of particles or on a deformable object is

$$W = \sum_n (F_{\text{ext}\,nx}\Delta x_{Fn})$$

Quantitative Tools: Work done by a constant force

- If an external force does work W on a system, the **energy law** says that the energy of the system changes by an amount

$$\Delta E = W$$

- For a closed system, $W = 0$ and so $\Delta E = 0$.
- For a particle or rigid object, $\Delta E_{\text{int}} = 0$ and so

$$\Delta E = \Delta K$$

- For a system of particles or a deformable object,

$$\Delta K_{\text{cm}} = \left(\sum F_{\text{ext}\,x}\right)\Delta x_{\text{cm}}$$

Concepts: Energy diagrams

- An **energy diagram** shows how the various types of energy in a system change because of work done on the system.
- In choosing a system for an energy diagram, avoid systems for which friction occurs at the boundary because then you cannot tell how much of the thermal energy generated by friction goes into the system.

Concepts: Variable and distributed forces

- The force exerted by a spring is variable (its magnitude and/or direction changes) but nondissipative (no energy is converted to thermal energy).
- The frictional force is dissipative and so causes a change in thermal energy. This force is also a distributed force because there is no single point of application.

Quantitative Tools: Variable and distributed forces

- The work done by a variable nondissipative force on a particle or object is
$$W = \int_{x_\text{i}}^{x_\text{f}} F_x(x)\,dx$$
- If the free end of a spring is displaced from its relaxed position x_0 to position x, the change in its potential energy is
$$\Delta U_\text{spring} = \tfrac{1}{2}k(x - x_0)^2$$
- If a block travels a distance d_path over a surface for which the magnitude of the force of friction is a constant F^f_sb, the energy dissipated by friction (the thermal energy) is
$$\Delta E_\text{th} = F^\text{f}_\text{sb}\, d_\text{path}$$

Concepts: Power

- **Power** is the *rate* at which energy is either converted from one form to another or transferred from one object to another.

- The SI unit of power is the **watt** (W), where 1 W = 1 J/s.

Quantitative Tools: Power

- The **instantaneous power** is

$$P = \frac{dE}{dt}$$

- If a constant external force $F_{\text{ext}\,x}$ is exerted on an object and the x component of the velocity at the point where the force is applied is υ_x, the power this force delivers to the object is

$$P = F_{\text{ext}\,x}\upsilon_x$$