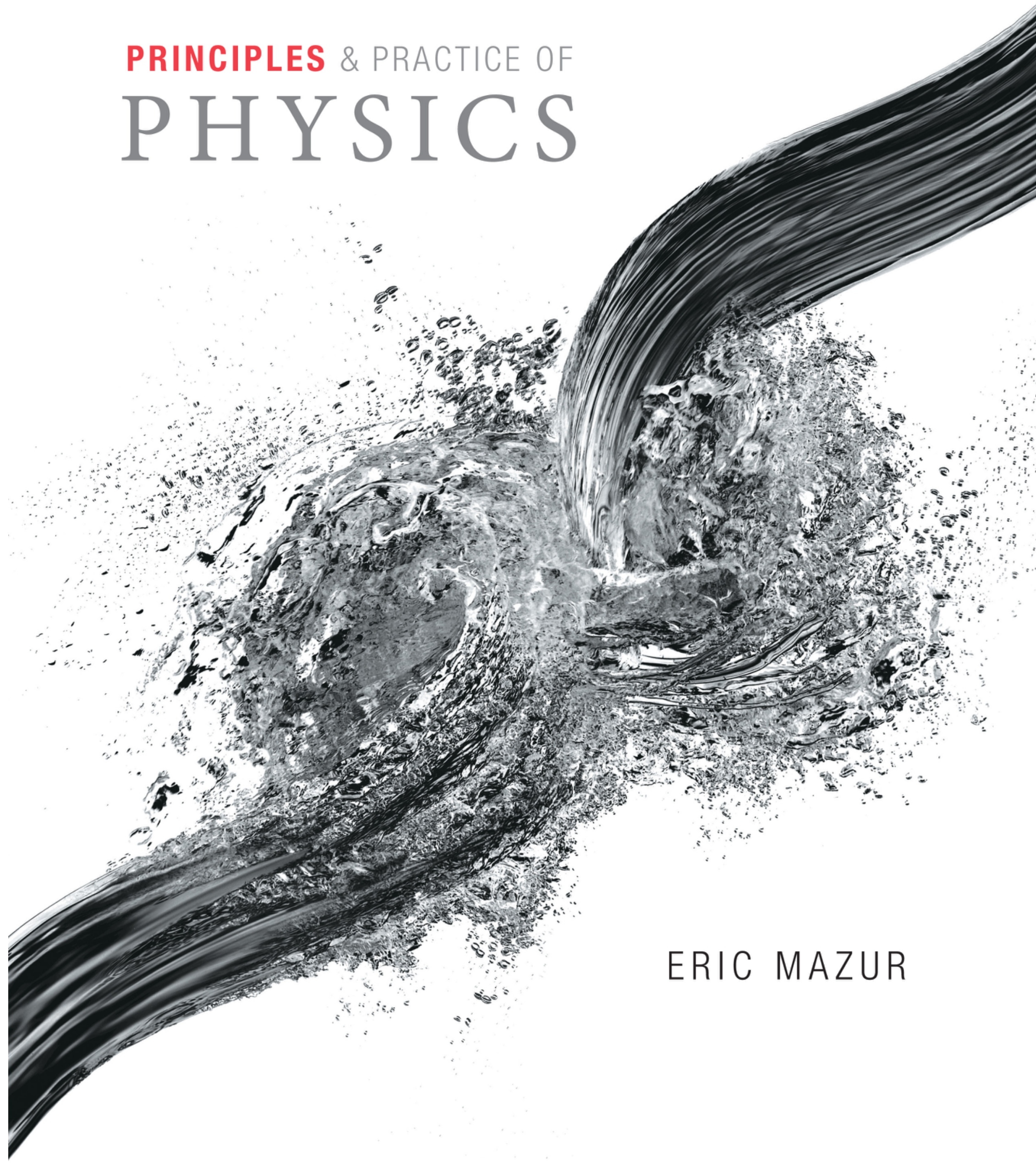
Chapter 7
Interactions



Chapter 7: Interactions

Chapter Goal: To investigate how interactions convert energy from one form to another in physical processes within the universe.

Chapter 7 Preview

Looking Ahead: The basics of interactions

- An **interaction** is an event that produces either a change in physical state or a change in motion.

- You learned that the four fundamental interactions in our universe are gravitational, electromagnetic, weak nuclear, and strong nuclear.

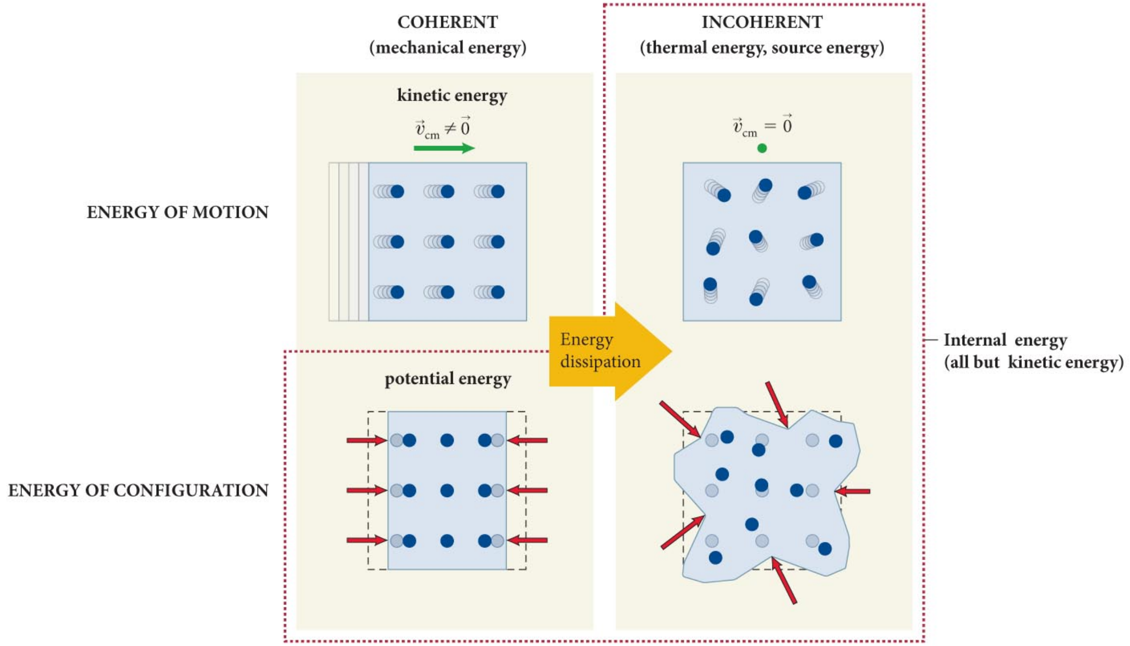
Chapter 7 Preview

Looking Ahead: Potential energy

- **Potential energy** is a coherent form of internal energy associated with the **reversible** changes in the configuration of an object or system.
- You will learn about the potential energy associated with **gravitational** and elastic **interactions**.

Looking Ahead: Energy dissipation during interactions

- **Dissipative interactions** are **irreversible** interactions that involve changes in thermal energy.



- You will learn to mathematically account for the types of energy in dissipative and nondissipative interactions.

Concepts

Section 7.1: The effects of interactions

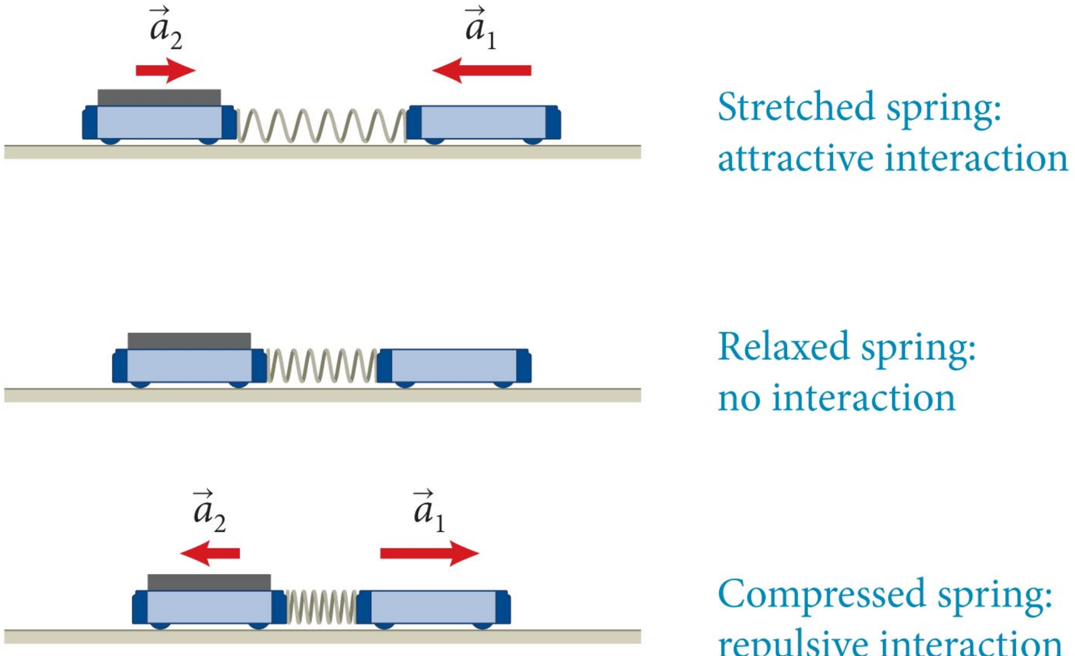
Section Goals

You will learn to

- Define **interactions** as a mutual influence between two objects that produces either physical change or a change in motion.
- Develop criteria that allow interactions to be identified and classified.

Section 7.1: The effects of interactions

- Interactions are mutual influences between two objects that produce change, either change in motion or physical change.
- The figure below shows an interaction between two carts linked by a spring.



Checkpoint 7.1

7.1

(a) Imagine holding a ball a certain height above the ground. If you let the ball go, it accelerates downward. An interaction between the ball and what other object causes this acceleration? Is this interaction attractive or repulsive?

(b) Once the ball hits the ground, its direction of travel reverses. Is this reversal the result of an attractive interaction or a repulsive one?

Checkpoint 7.1

7.1

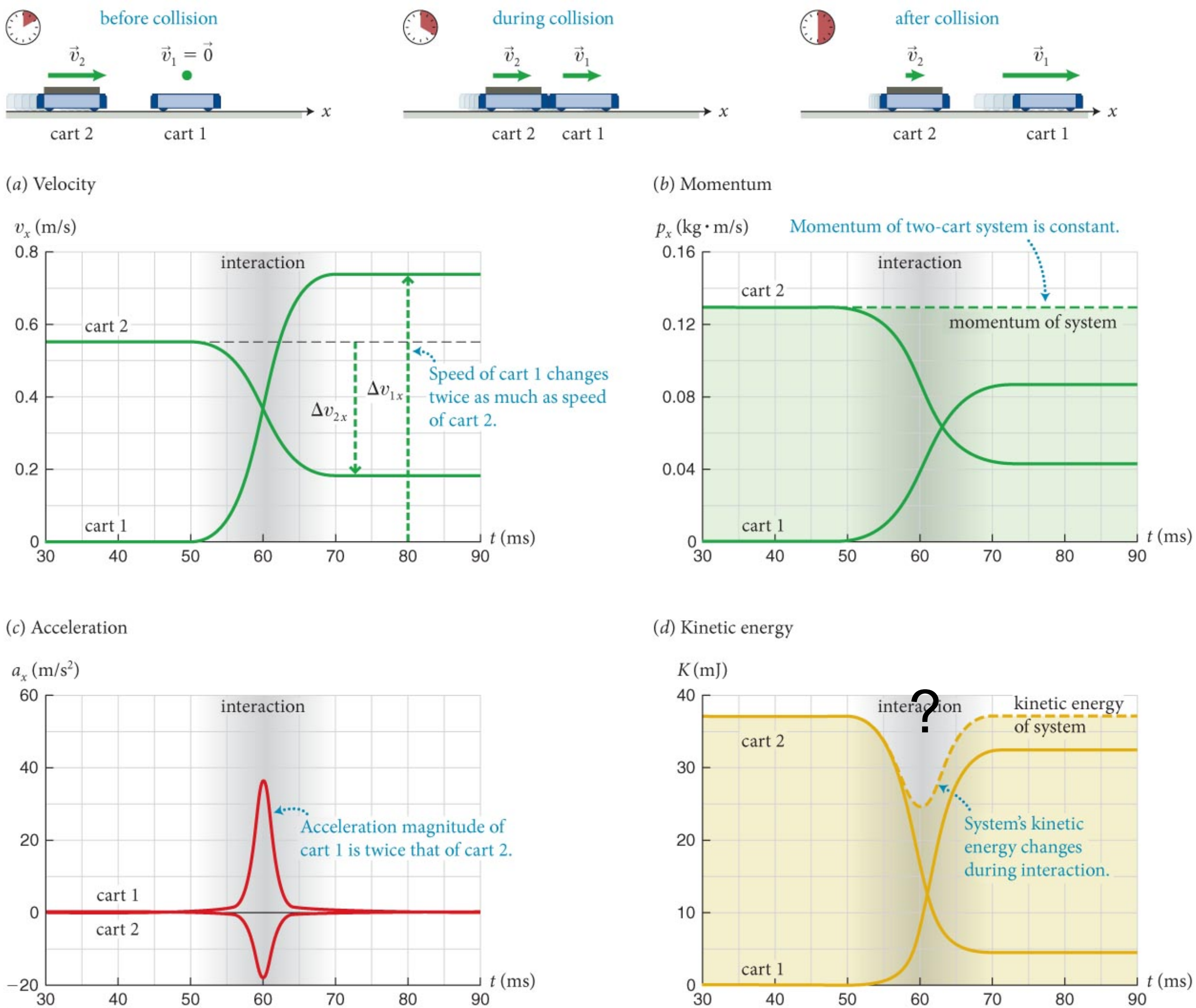
(a) Imagine holding a ball a certain height above the ground. If you let the ball go, it accelerates downward. An interaction between the ball and what other object causes this acceleration? Is this interaction attractive or repulsive?

attractive – 2 objects are the ball & earth, accelerated toward each other

(b) Once the ball hits the ground, its direction of travel reverses. Is this reversal the result of an attractive interaction or a repulsive one?

repulsive – same 2 objects, now accelerated apart

Section 7.1: The effects of interactions



Section 7.1: The effects of interactions

- The figure on the previous slide shows data for an **elastic** collision.
- The inertia of cart 1 is m_1 and the inertia of cart 2 is m_2, where $m_2 = 2m_1$.

- We can observe that
  - The relative velocities of the two carts before and after the interaction (or collision) are the same.
  - The momentum of the two-cart system remains constant before, after, and even during the collision.
  - The ratio of the x component of the carts' accelerations is equal to the negative inverse of the ratio of their inertias.
  - Kinetic energy is briefly transferred during the collision

Example 7.1 Crash

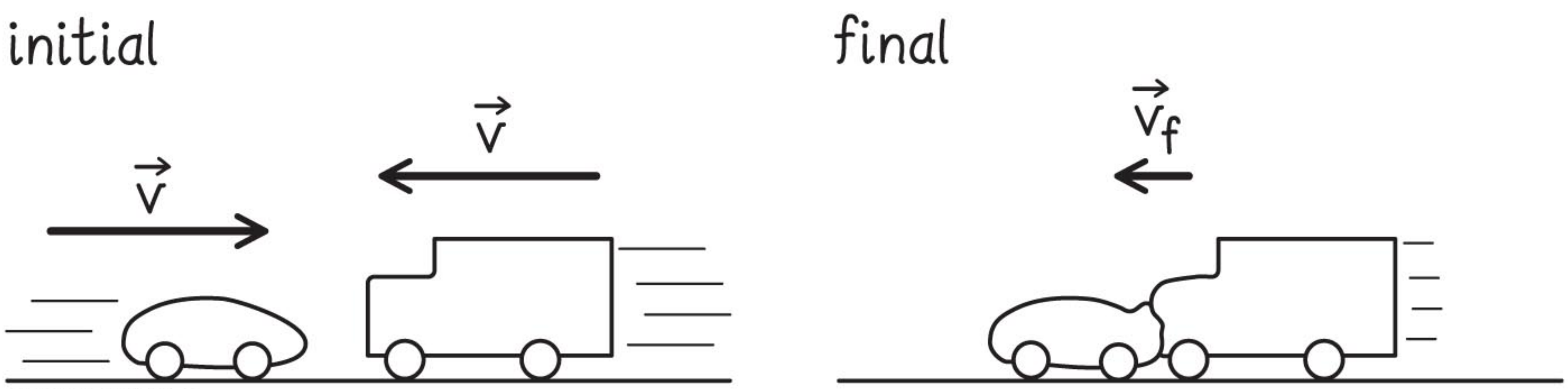
A small car and a heavy truck moving at equal speeds in opposite directions collide head-on in a totally inelastic collision. Compare the magnitudes of

(a) the changes in momentum and

(b) the average accelerations of the car and the truck.

Example 7.1 Crash (cont.)

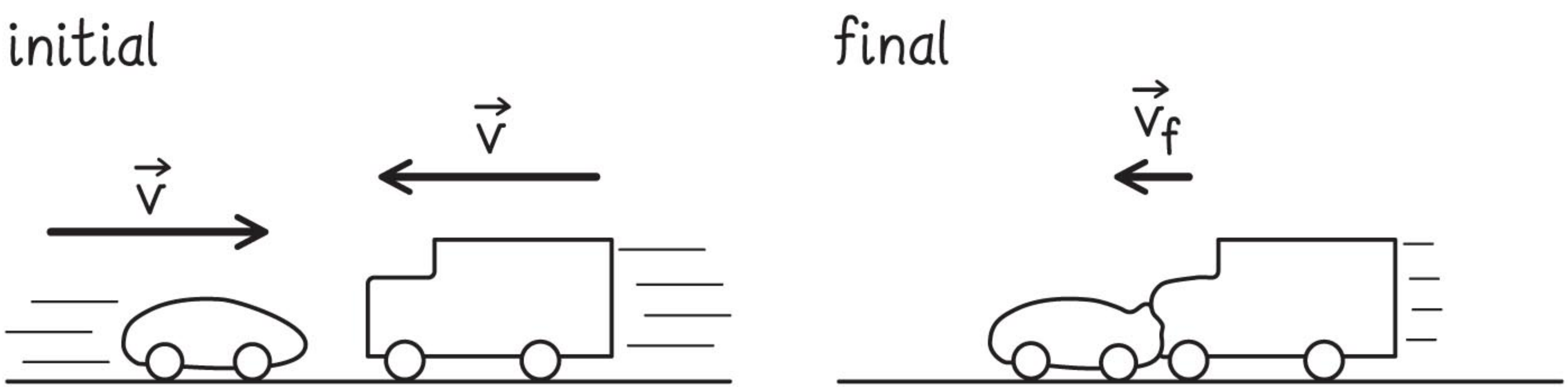
❶ GETTING STARTED I begin by making a sketch of the situation before and after the collision. Before the collision, the truck and car both move at the same speed. After the totally inelastic collision, the two move as one unit with zero relative velocity.



Section 7.1: The effects of interactions

Example 7.1 Crash (cont.)

❶ GETTING STARTED Because the inertia m_t of the truck is greater than the inertia m_c of the car, the momentum of the system points in the same direction as the direction of travel of the truck. The combined wreck must therefore move in the same direction after the collision.



Example 7.1 Crash (cont.)

❷ DEVISE PLAN

- To compare the changes in momentum, I can apply conservation of momentum to the isolated truck-car system.
- I can obtain the change in velocity by dividing the change in momentum by the inertia.
- Because the changes in velocity occur over the same time interval for both, and because $|a_{avg}| = \Delta v/\Delta t$, the ratio of the accelerations is the same as the ratio of the changes in velocity.

Example 7.1 Crash (cont.)

❸ EXECUTE PLAN (*a*) The momentum of the isolated truck-car system does not change in the collision, and so the magnitudes of the changes in momentum for the car and the truck are the same.✔

Example 7.1 Crash (cont.)

❸ EXECUTE PLAN (*b*) The change in the *x* component of the velocity of the truck is $\Delta p_{\text{t}\,x}/m_{\text{t}}$, and the change in the *x* component of the velocity of the car is $\Delta p_{\text{c}\,x}/m_{\text{c}}$.

Because $m_{\text{t}} > m_{\text{c}}$ and because the magnitudes of the changes in momentum are equal, I conclude that the magnitude of the velocity change of the car is larger than that of the truck.✔

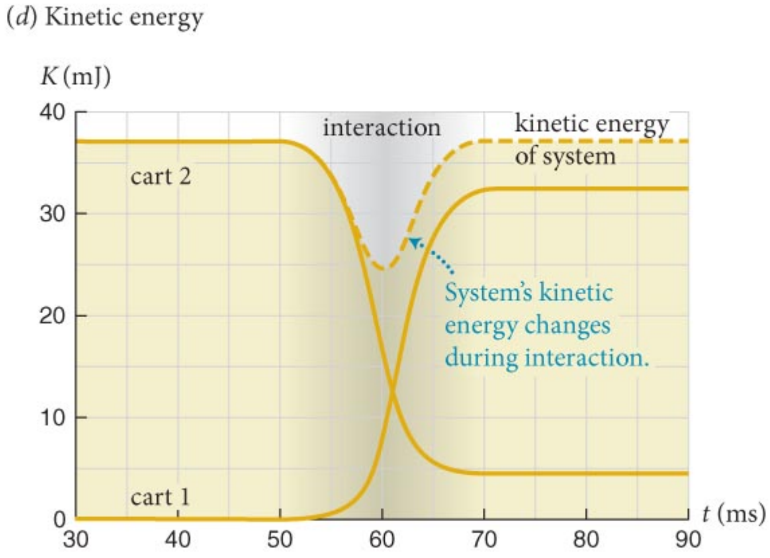
Example 7.1 Crash (cont.)

❹ EVALUATE RESULT In any collision the magnitudes of the changes in momentum are the same for the two colliding objects, and so the answer to part *a* does not surprise me.

That the magnitude of the velocity change for the car is larger also makes sense: the velocity of the car reverses, whereas the truck slows down but keeps traveling in the same direction.

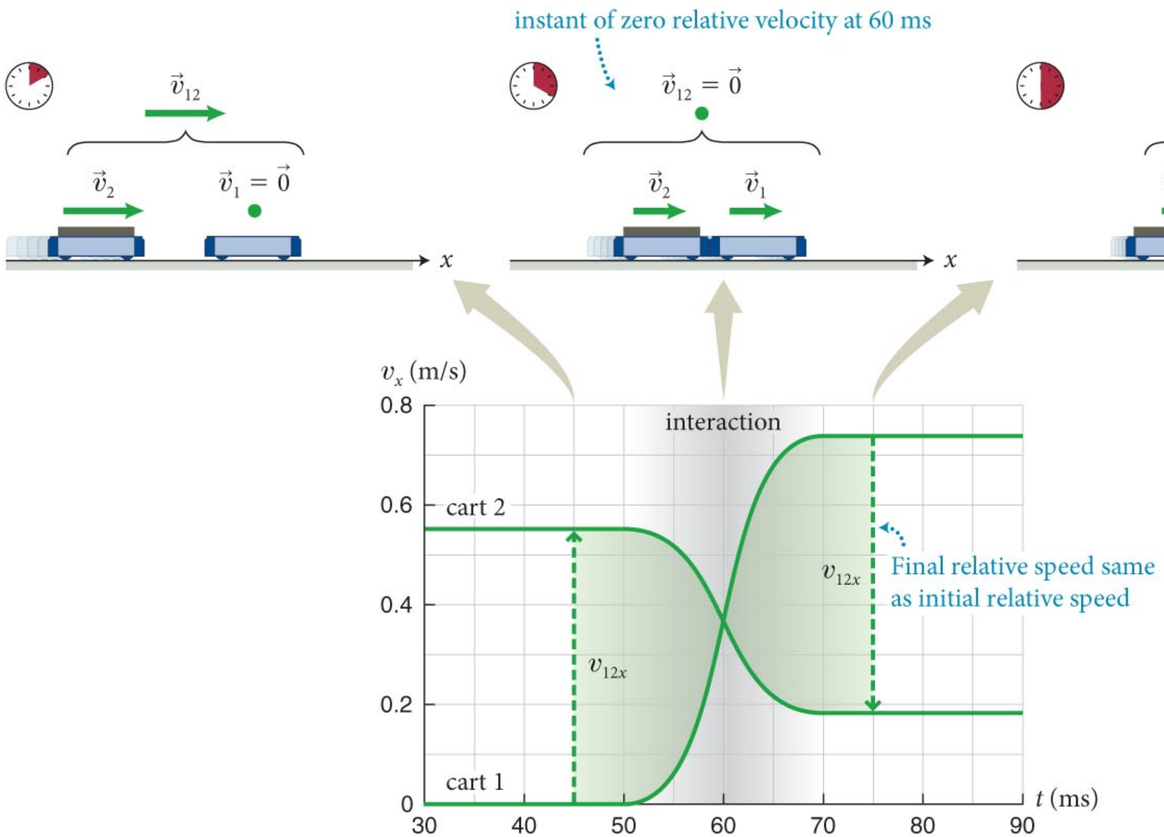
Section 7.1: The effects of interactions

- From Figure 7.2*d* we can conclude that the kinetic energy of the system before the interaction is the same as after the interaction, as required for elastic collisions.
- However, unlike momentum, kinetic energy does not remain constant during the interaction.



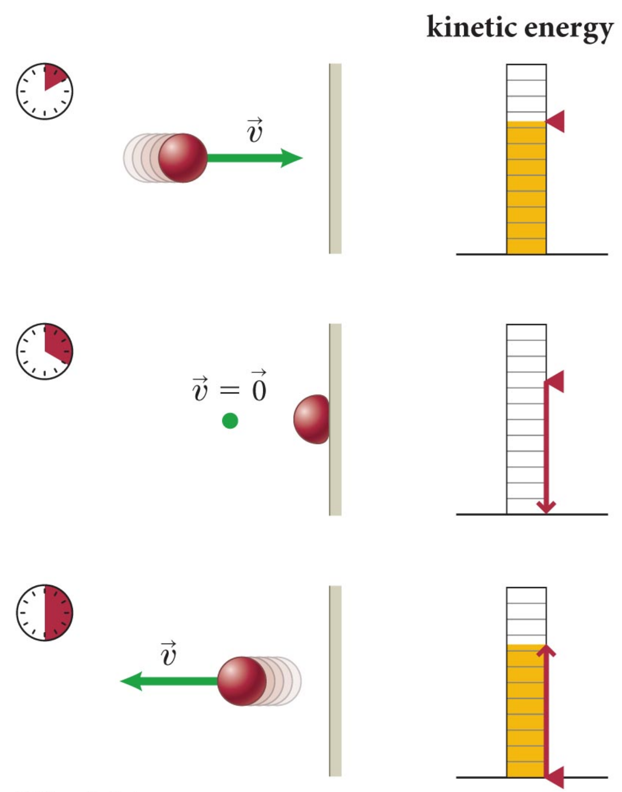
Section 7.1: The effects of interactions

- The figure below shows that whenever two objects interact, their relative speeds have to change, and therefore the kinetic energy of the system must also change *during* the interaction.



Section 7.1: The effects of interactions

- So, does the system violate energy conservation during the interaction?
  - No: The kinetic energy “missing” during the interaction has merely been temporarily converted to internal energy. <squish>
  - As seen in the figure, the kinetic energy of the bouncing ball goes into changing the shape of the ball during the interaction with the wall.
  - As the ball regains its original shape, the kinetic energy that was converted to internal energy reappears as kinetic energy after the collision.



Section 7.1: The effects of interactions

- We can summarize the key characteristics of an interaction:
  1. Two objects are needed.
  2. The momentum of an isolated system of interacting objects is the same before, during, and after the interaction.

Section 7.1: The effects of interactions

- In addition, for interactions that affect the motion of objects (not all do):
    1. The ratio of the *x* component of the accelerations of the interacting objects is the negative inverse ratio of their inertias.

$$\frac{a_{1x}}{a_{2x}} = -\frac{m_2}{m_1}$$

or

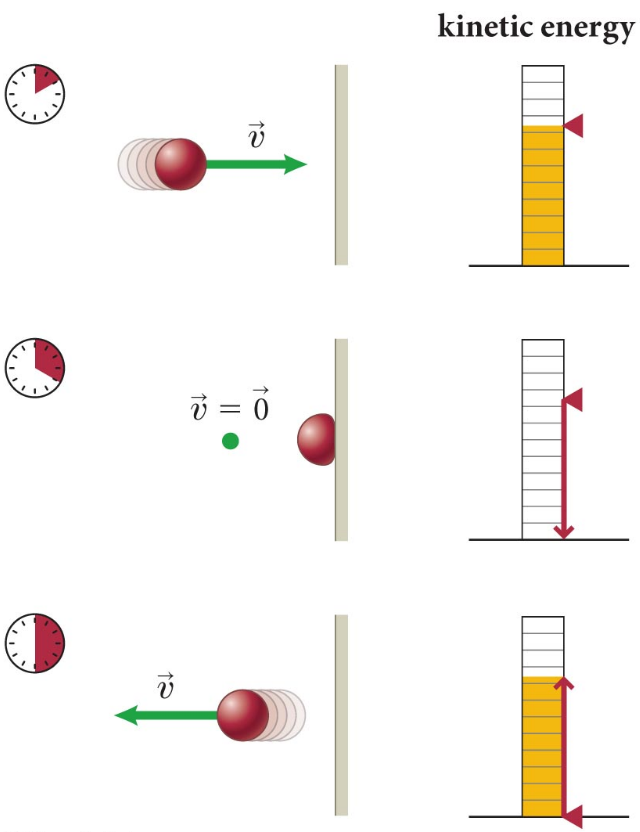
$$m_1 a_{1x} = -m_2 a_{2x}$$

Section 7.1: The effects of interactions

2. The system's kinetic energy changes during the interaction. Part of it is converted to (or from) some internal energy:
   - In elastic collisions, all of the converted energy reappears as kinetic energy after the collisions.
   - In inelastic collisions, *some* of the converted kinetic energy reappears as kinetic energy.

Checkpoint 7.4

7.4 (*a*) In Figure 7.5, what is the momentum of the ball during the collision? (*b*) Is the momentum of the ball constant before, during, and after the collision? If so, why? If not, why not, and for what system is the momentum constant?

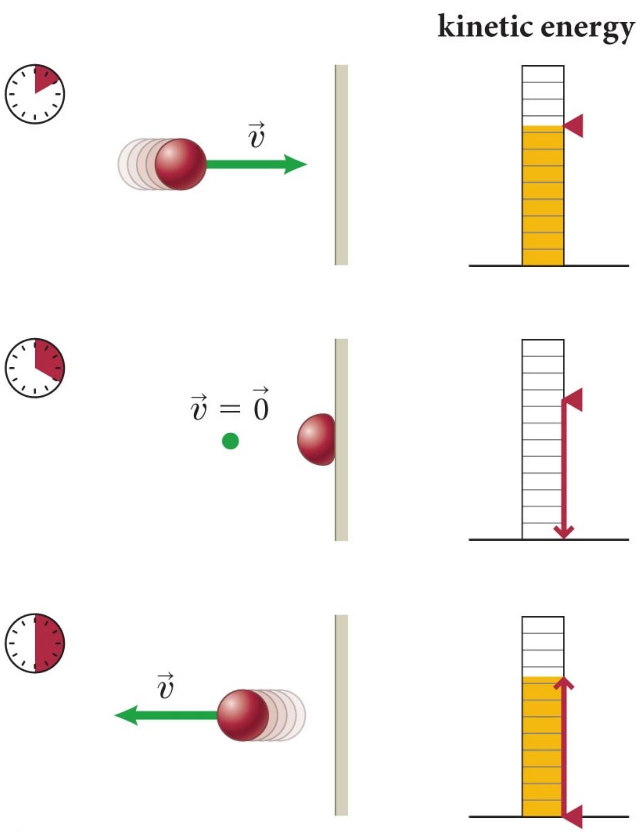


Checkpoint 7.4

7.4 *p=0* during the collision – its speed is zero

momentum is constant only when ball is *isolated*

while interacting with the wall, only *net p* is constant



during collision:
system = ball + wall

Section 7.1
Question 1

A pool ball collides head-on and elastically with a second pool ball initially at rest. Which properties of the system made up of the two balls change during the interaction. Answer all that apply.

1. Momentum
2. Kinetic energy
3. The sum of all forms of energy in the system

Section 7.1
Question 1

A pool ball collides head-on and elastically with a second pool ball initially at rest. Which properties of the system made up of the two balls change during the interaction. Answer all that apply.

1. Momentum
2. ✔ Kinetic energy – v_{12} is briefly zero
3. The sum of all forms of energy in the system

Section 7.2: Potential energy

Section Goals

You will learn to

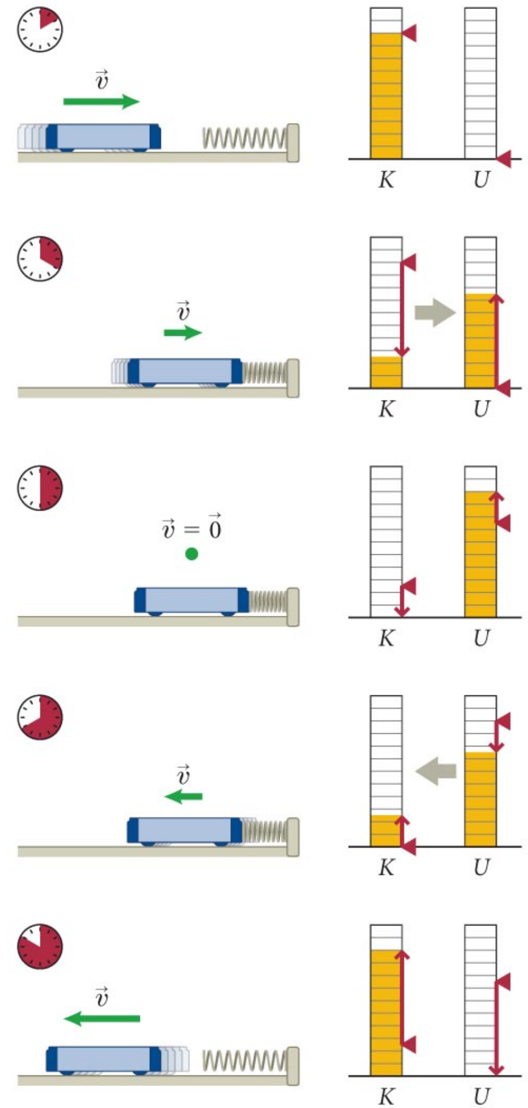
- Identify **potential energy** as the part of the converted kinetic energy in a collision or interaction that is temporarily stored in reversible changes of physical state.
- Recognize that potential energy is a type of **internal energy**.
- Describe the fundamental interactions responsible for **gravitational potential energy** and **elastic potential energy**.

Section 7.2: Potential energy

- In any interaction, the part of the converted kinetic energy that is temporarily stored as internal energy and is then converted back to kinetic energy after the transaction is called **potential energy (*U*)**.
- Potential energy is stored in reversible changes in the *configuration state* of the system or the spatial arrangement of the system's interacting components.
- There are many forms of potential energy related to the way the interacting objects arrange themselves spatially.

Section 7.2: Potential energy

- When you squeeze a ball or a spring, you change the configuration state of the atoms that make up the ball or spring.
- Reversible deformation corresponds to changes in **elastic potential energy**.
- As seen in the figure, during the interaction between cart and spring, the kinetic energy is temporarily converted to elastic potential energy in the spring.



Section 7.2: Potential energy

- Are all deformations elastic and reversible?
- No – try to bend your pencil. Too far?
- Paper clip – can break it by repeated bending. (Also note that it heats up!)
- Can make *nearly* ideal springs, etc., but real materials are complicated

Section 7.2: Potential energy

- If you throw a ball up in the air, you change the configuration state of the ball-Earth system.
- As the ball moves upward, the form of potential energy called **gravitational potential energy** is stored in the system in exchange for kinetic energy
- As the ball moves back toward the Earth, gravitational potential energy converts back to kinetic energy and the ball speeds up.
- **Potential energy is the form of internal energy associated with reversible changes in the configuration state of an object or system. Potential energy can be converted entirely to kinetic energy.**

Exercise 7.2 Launch

A ball is pressed down on a spring and then released from rest. The spring launches the ball upward. Identify the energy conversions that occur between the instant the ball is released and the instant it reaches the highest point of its trajectory.

Exercise 7.2 Launch (cont.)

SOLUTION As the spring expands, elastic potential energy stored in the spring is converted to kinetic energy of the ball.

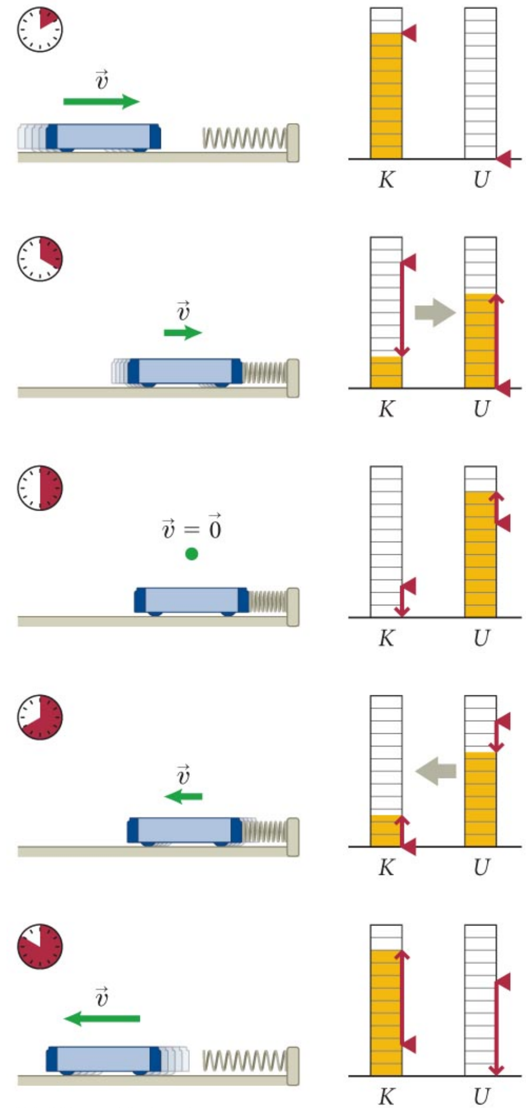
As the ball travels upward, it slows down and the kinetic energy is converted to gravitational potential energy of the ball-Earth system.✔

Checkpoint 7.5

7.5 In Figure 7.7, the initial speed of the cart is v_i. Assuming no potential energy is initially stored in the spring, how much potential energy is stored in the spring at the instant depicted in the middle drawing?

How about at the instant depicted in the bottom drawing?

(Give your answers in terms of m, v_i, and v.)



Checkpoint 7.5

7.5

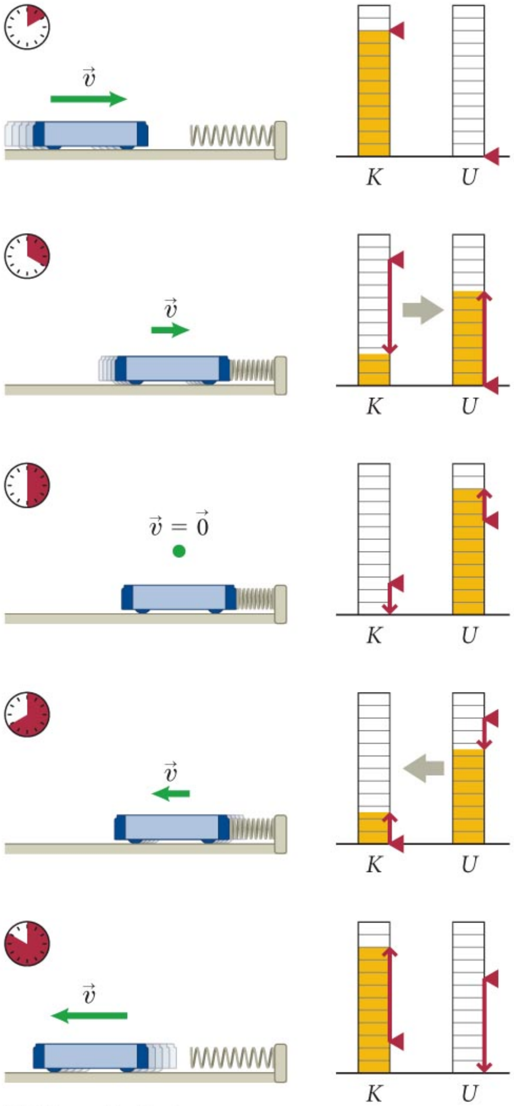
Top: all kinetic energy, $K_i = \frac{1}{2}mv^2$

Middle: cart stops, all potential energy

conservation implies $U_m = K_i = \frac{1}{2}mv^2$

Bottom: all kinetic again

conservation: $K_f = U_m = K_i = \frac{1}{2}mv^2$



Section 7.3: Energy dissipation

Section Goals

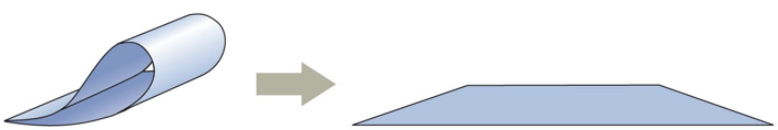
You will learn to

- Identify dissipated energy as the part of the converted kinetic energy in a collision or interaction that does not reappear after the process.
- Classify energy into the categories of motion energy/configuration energy and coherent energy/incoherent energy.
- Understand how **internal energy** is quantified in this classification scheme.

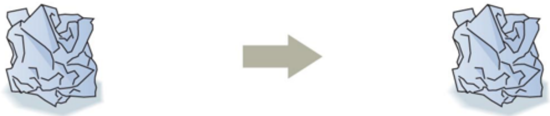
Section 7.3: Energy dissipation

- Part of the converted kinetic energy that does not reappear after an **inelastic** collision is said to be *dissipated*.
- To illustrate the idea of energy dissipation, consider the example shown below:
  - Coherent deformation (reversible): A piece of paper that is gently bent returns spontaneously to its original shape.
  - Incoherent deformation (irreversible): If crumpled, it does not regain its original shape.

(*a*) Coherent deformation: reversible



(*b*) Incoherent deformation: irreversible

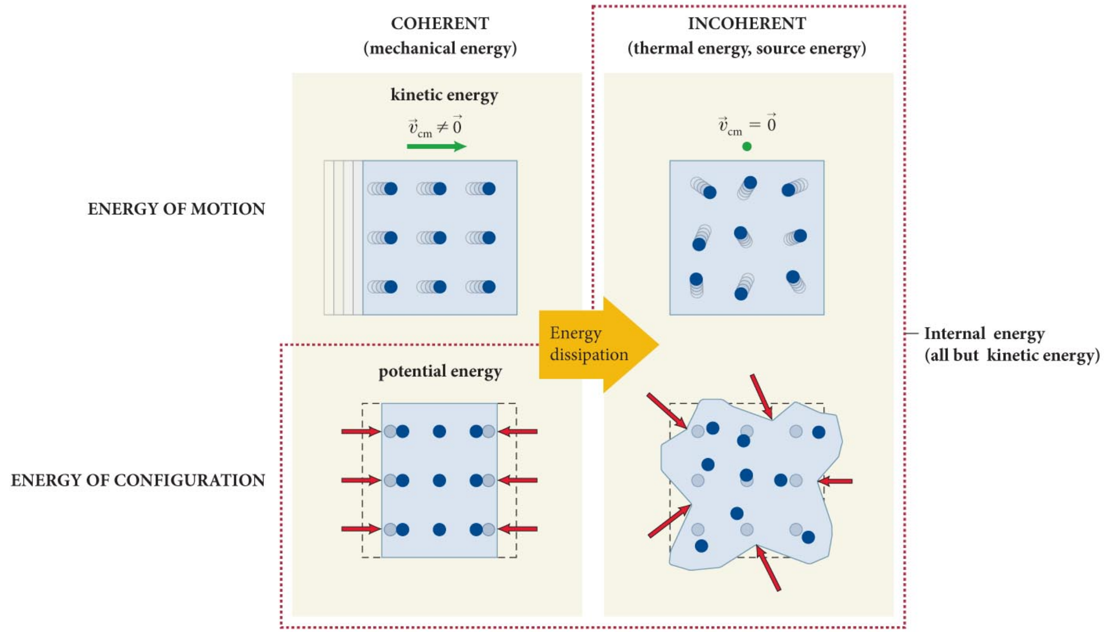


Section 7.3: Energy dissipation

- In coherent deformations there is a pattern to the displacement of atoms.
- By deforming an object in this manner, you store potential energy in it. When you release the object, this potential energy converts back to kinetic energy.
- In incoherent deformations, the atoms are randomly displaced.
- When you release the object, the atoms get in one another's way and the object cannot regain its original shape.

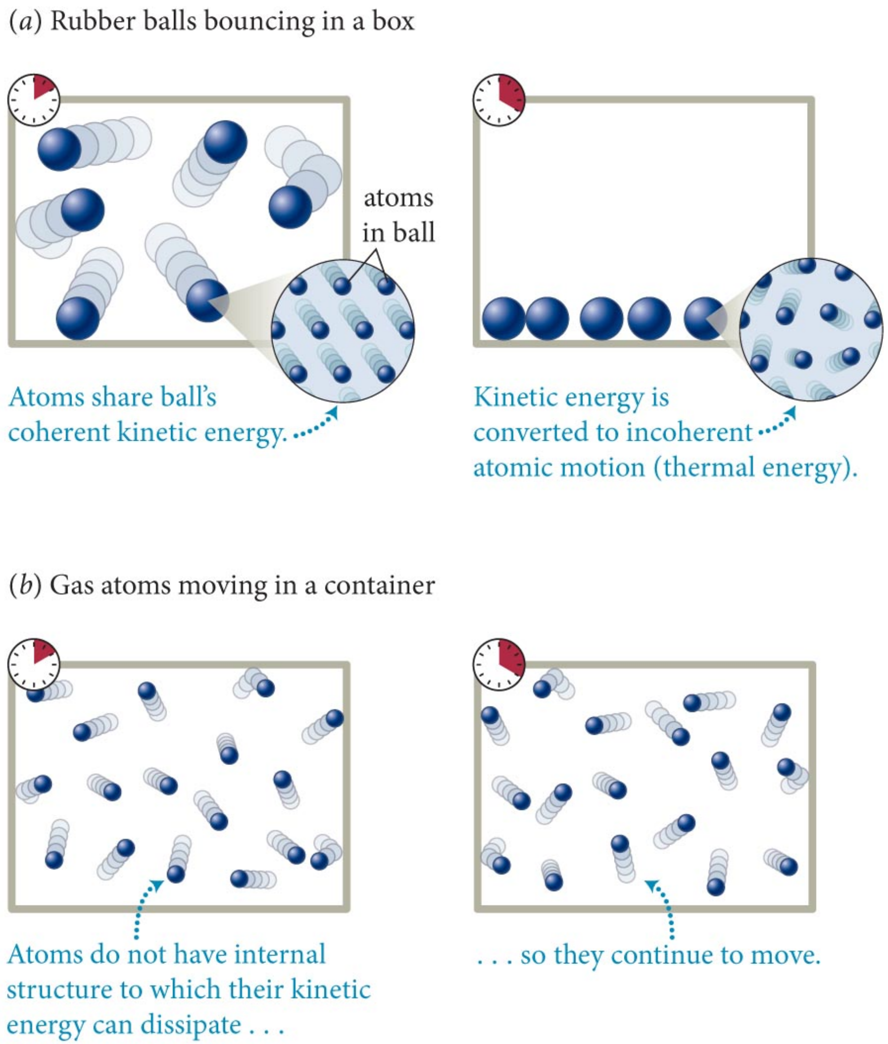
Section 7.3: Energy dissipation

- We can now give a complete classification of energy:
  - The sum of a system's kinetic energy and potential energy is called the system's **mechanical energy** or **coherent energy**.
  - A system can also have **incoherent energy** associated with the incoherent motion and configuration of its parts.
  - An important part of a system's incoherent energy is its **thermal energy**.
  - The higher the thermal energy of an object, the higher the temperature.



Section 7.3: Energy dissipation

- What happens to the energy once it has become thermal energy?



Checkpoint 7.6

7.6 Because of friction, a 0.10-kg hockey puck initially sliding over ice at 8.0 m/s slows down at a constant rate of 1.0 m/s^2 until it comes to a halt.

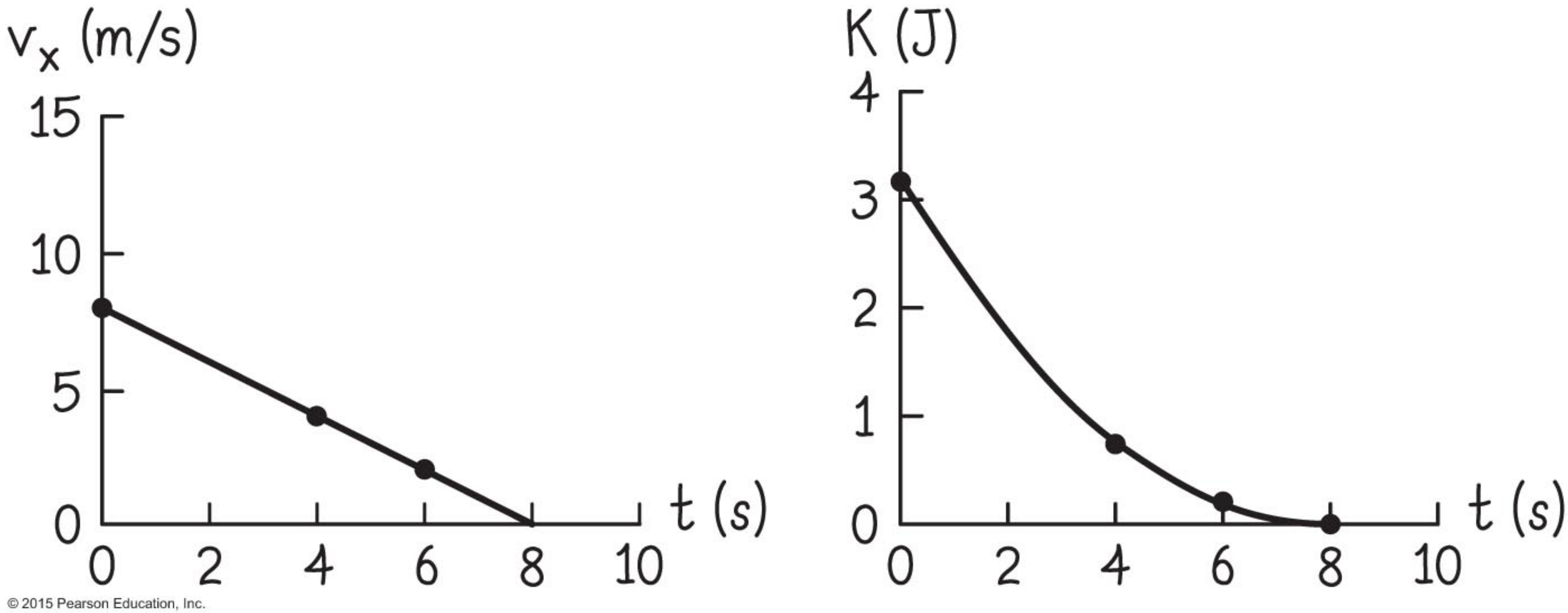
(a) On separate graphs, sketch the puck's speed and its kinetic energy as functions of time.

(b) To what form of energy is the kinetic energy of the puck converted?

7.6 v_i = 8m/s, loses 1m/s per s. Straight line $v(t)$.

Given v at a few times, find $K = \frac{1}{2}mv^2$

Converted to heat – puck & ice get warmer



Section 7.4: Source energy

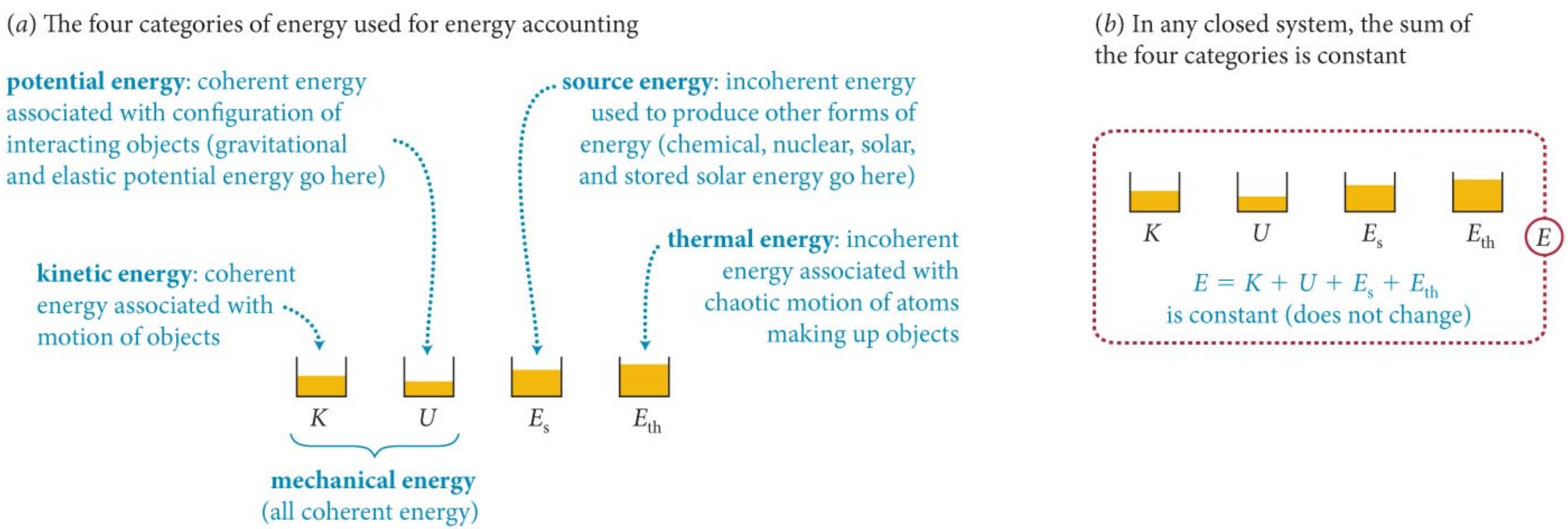
Section Goals

You will learn to

- Define **source energy** as an incoherent energy used to produce other forms of energy.
- Classify the **types of energy** in a process using the kinetic, potential, source, and thermal energies scheme.

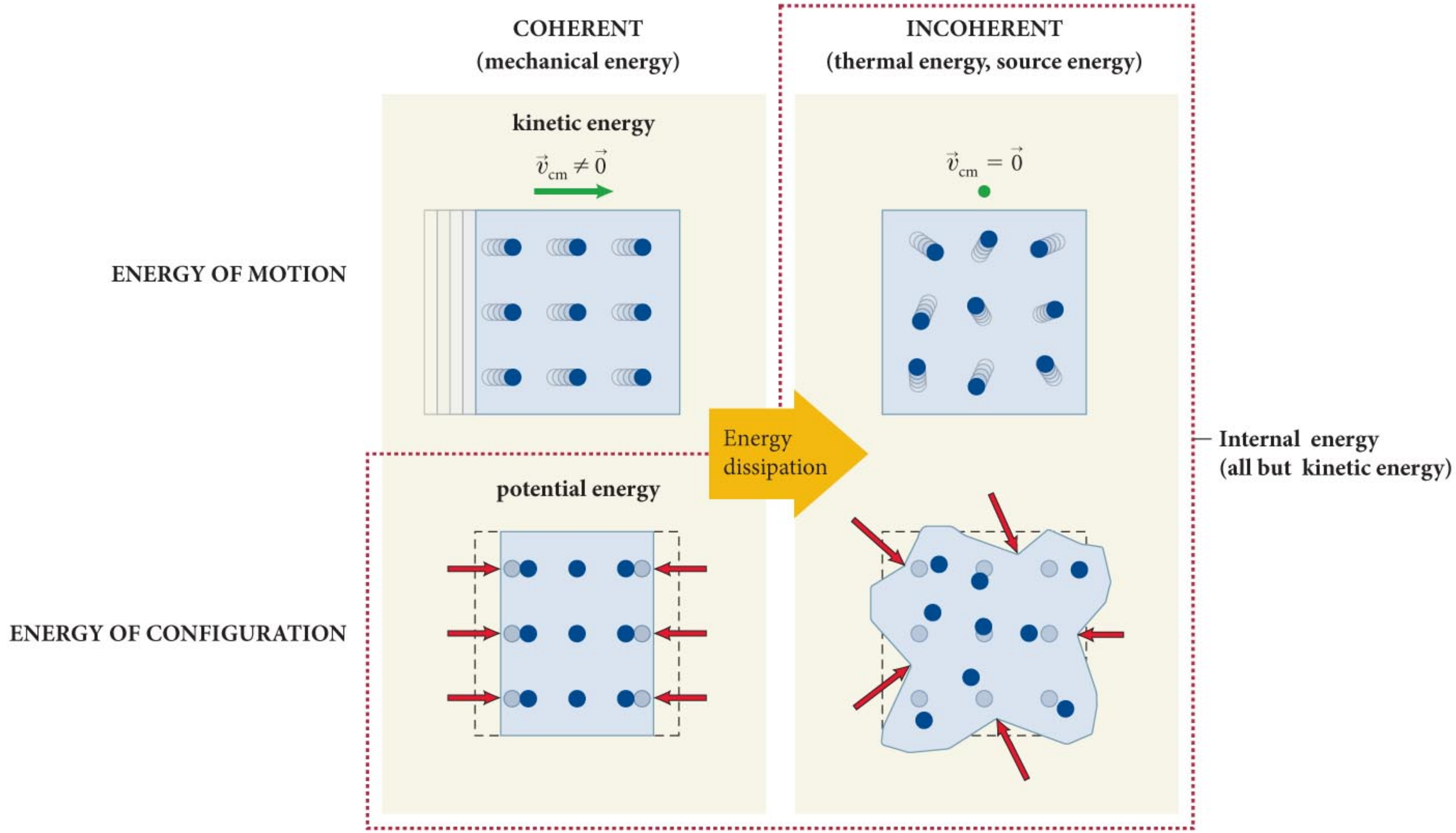
Section 7.4: Source energy

- Energy obtained from sources such as fossil fuels, nuclear fuels, biomass fuels, water reservoirs, solar radiation, and wind are collectively called **source energy**.
- Broadly speaking, there are four kinds of source energy: *chemical*, *nuclear*, *solar*, and *stored solar energy*.
- To facilitate our accounting of energy, we divide all energy into four categories: kinetic energy K, potential energy U, source energy E_s, and thermal energy E_{th}.



Checkpoint 7.7

7.7 How should chemical energy be classified in Figure 7.10?



7.7

Chemical energy – incoherent configuration energy

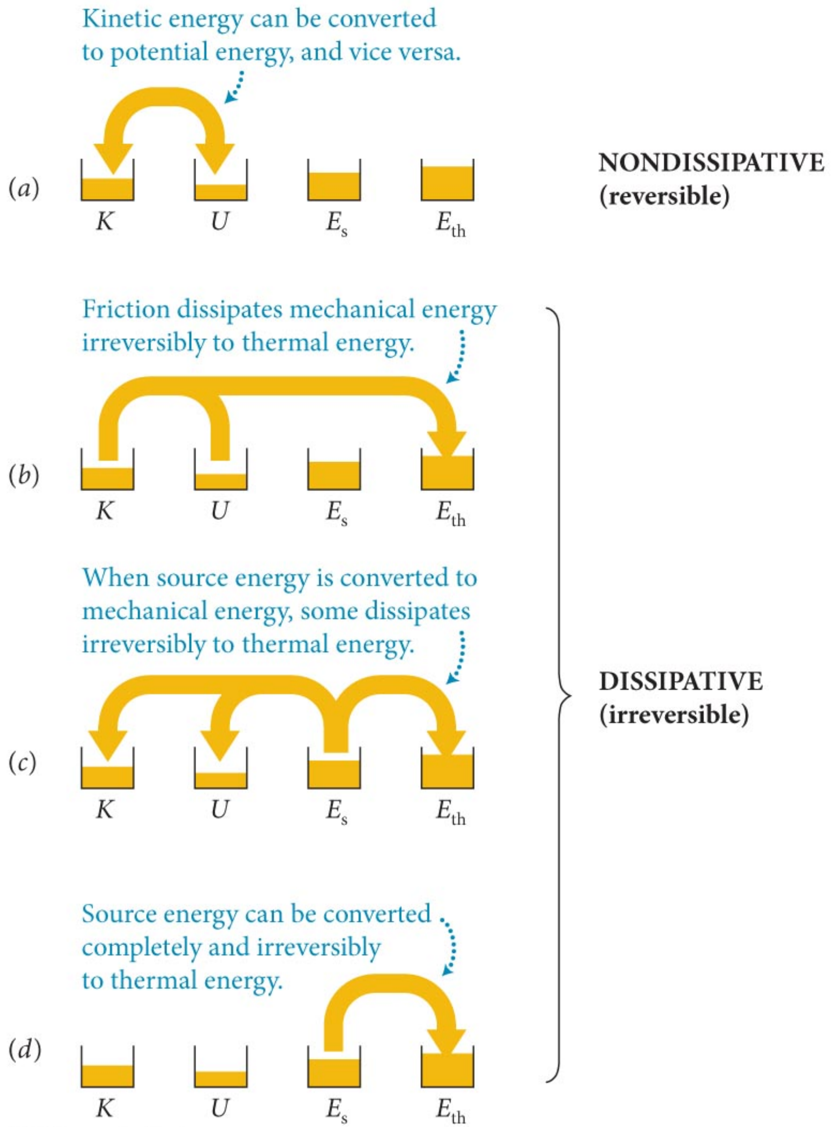
Configuration because it involves arrangement of atoms

Incoherent because arrangement of molecules and their velocities before reaction & after are random

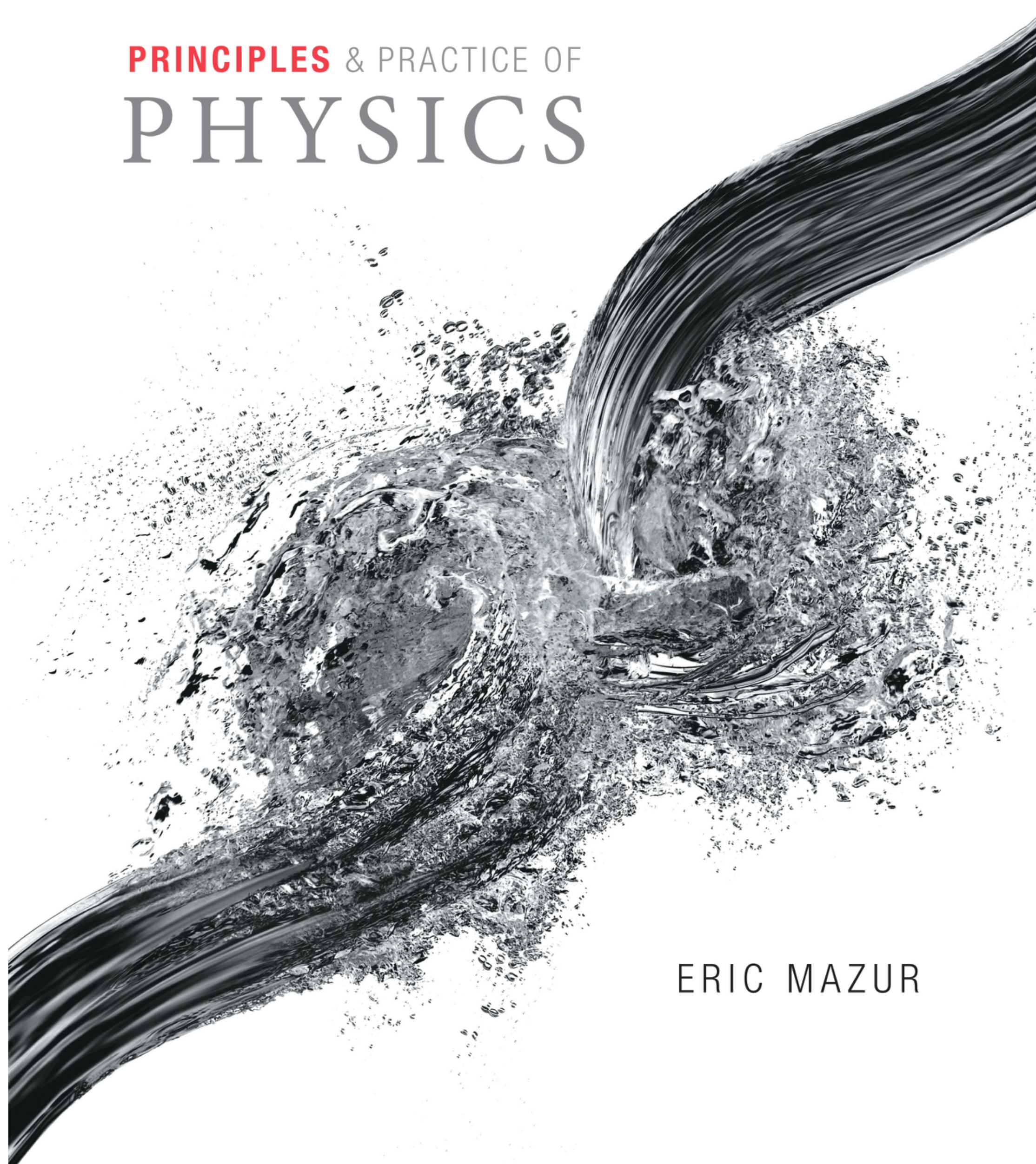
(Also: you can't make all reaction products move in a single direction and extract coherent KE; violates p conservation at least)

Section 7.4: Source energy

- The figure illustrates various types of energy conversions that can occur.
- Heaters are easy.
- Most everything is a heater, intentionally or not.



Chapter 7
Interactions



Section 7.4: Source energy

- To determine whether or not an interaction is dissipative, check if the interaction is reversible:
  - **Interactions that cause reversible changes are non-dissipative; those that cause irreversible changes are dissipative.**
  - **If it is reversible, playing it backwards would not look weird**
  - **If it is reversible, use conservation of energy.** ***Only the initial and final states matter, not the path.***

Exercise 7.3 Converting energy

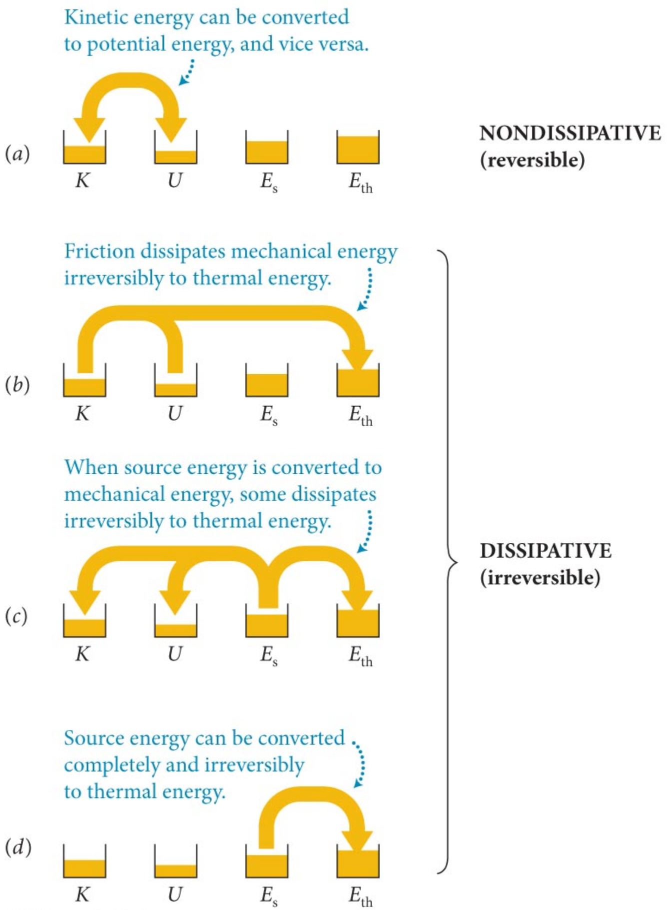
Identify the energy conversions that take place, and classify each according to the processes at right.

(a) A person lifts a suitcase.

(b) A toy suspended from a spring bobs up and down.

(c) A pan of water is brought to a boil on a propane burner.

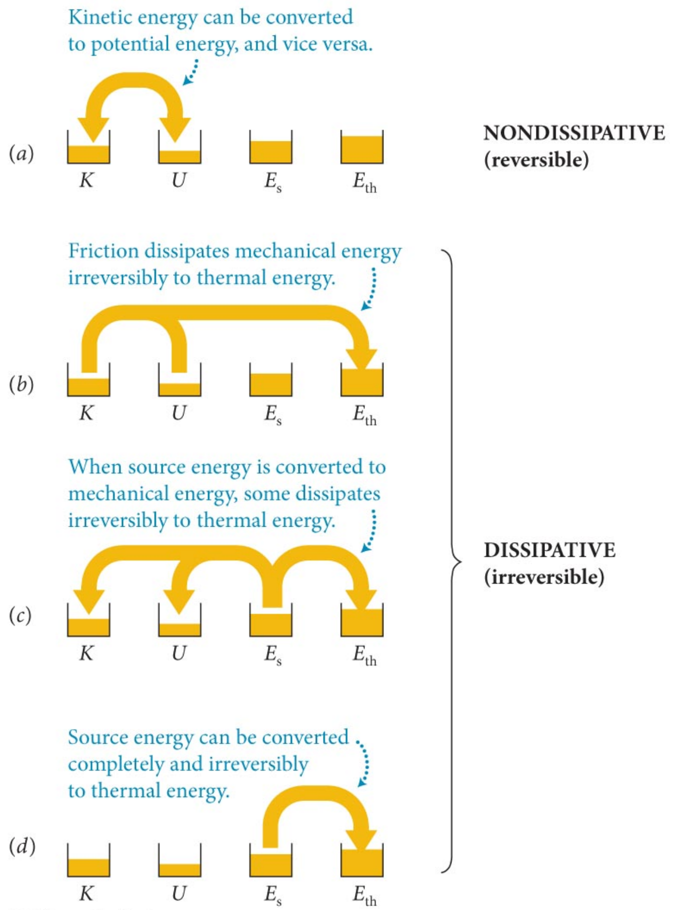
(d) A cyclist brakes and comes to a stop.



Exercise 7.3 Converting energy (cont.)

SOLUTION (*a*) Closed system: person, suitcase, and Earth.

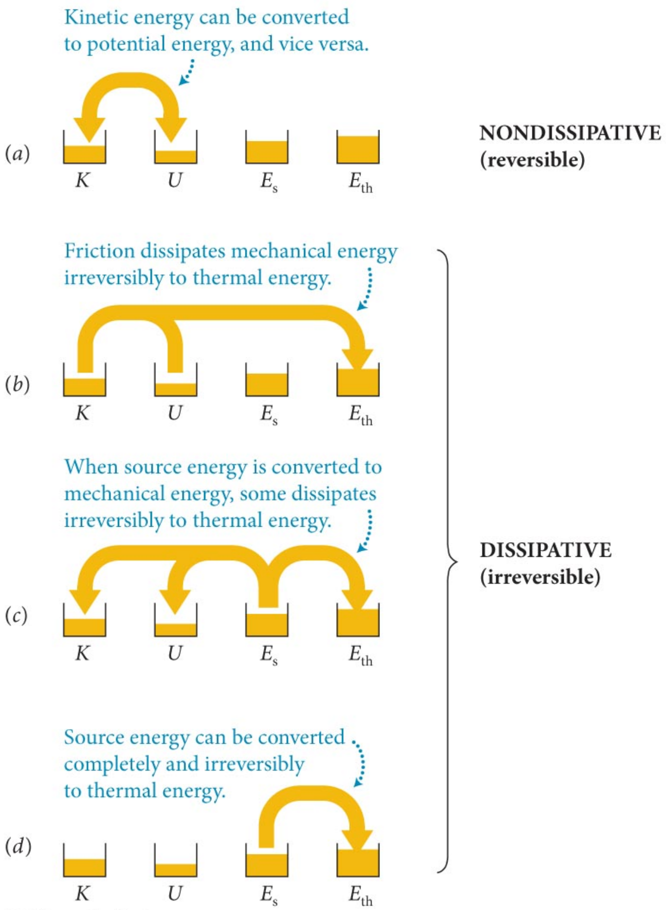
- During lifting, potential energy of the Earth-suitcase system increases and the kinetic energy of the suitcase increases.
- The source energy is supplied by the person doing the lifting, who converts chemical (source) energy from food.
- In the process of converting this source energy, thermal energy is generated (the person gets hot). This process is represented in Figure 7.13c. ✔



Exercise 7.3 Converting energy (cont.)

(*b*) Closed system: toy, spring, Earth.

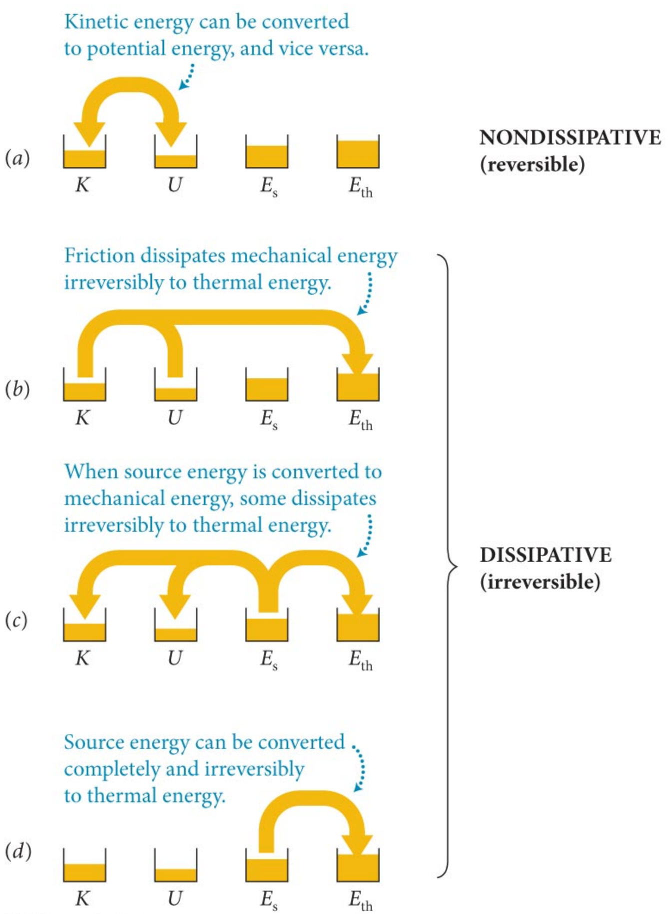
- As the toy bobs, its height changes, its velocity changes, and the configuration of the spring changes.
- The bobbing involves conversions of gravitational & elastic potential energy & kinetic energy. This reversible process is represented in Figure 7.13*a*. ✔



Exercise 7.3 Converting energy (cont.)

(*c*) Closed system: pan of water and propane tank.

As chemical (source) energy is released by burning the propane, the water is heated and its thermal energy increases. This process is represented in Figure 7.13*d*.✔



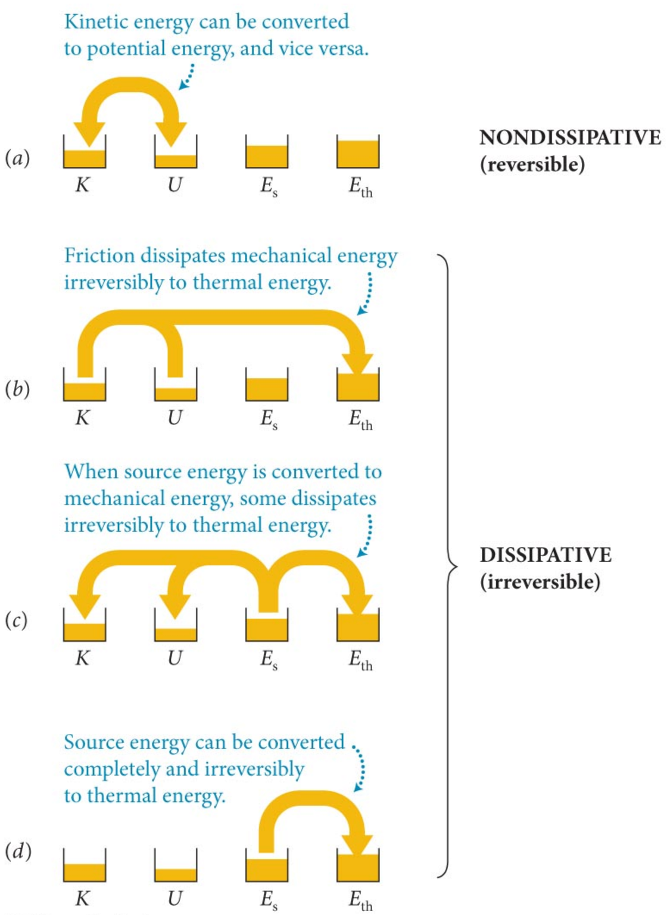
Exercise 7.3 Converting energy (cont.)

(*d*) Closed system: Earth and cyclist.

During the braking, the bicycle's kinetic energy is converted to thermal energy by friction

(Ignoring the muscle source energy required to pull the brakes)

This process is represented in Figure 7.13*b*.✔



Coherent versus incoherent energy

- To get a feel for the different types of energy, let’s look at a very ordinary object – a pencil. How many types of energy are (or can be) stored in a pencil?

Coherent versus incoherent energy (cont.)

- **Coherent (mechanical) energy:**
  - **Kinetic energy:** Throw it across the room, you give it a kinetic energy of about **1 J**.
  - **Potential energy:** Pencils are stiff. If you are lucky, you might be able to store **0.1 J** of elastic potential energy in it by bending before it snaps.

Coherent versus incoherent energy (cont.)

- **Incoherent energy:**
  - **Thermal energy:** Thermal energy is the energy associated with the random jiggling of atoms. It is impossible to convert all of this energy to another form
  - Imagine you take the pencil out of a drawer and carry it around in your pocket so that its temperature rises from room temperature to body temperature.
  - This rise in temperature increases its thermal energy by **100 J**.
  - If you could convert this to kinetic energy, your pencil would be moving at the speed of an airplane!

Coherent versus incoherent energy (cont.)

- **Incoherent energy:**
  - **Chemical energy:**
  - You can burn it to release chemical energy.
  - Configuration energy stored in chemical bonds is converted to thermal energy, which you feel as heat.
  - The energy converted by burning the pencil is **100,000 J**, an amount equal to the kinetic energy of a medium-sized car moving at 35 mi/h.

Coherent versus incoherent energy (cont.)

- **Incoherent energy:**
  - **Broken chemical bonds:** If you bend the pencil enough, it breaks.
  - The energy required to break the chemical bonds in the pencil is about **0.001 J**.
  - This is only 1% of that 0.1 J you added by bending the pencil to its breaking point; the remaining 99% ends up as thermal energy
  - When the pencil snaps, the stress (elastic energy) created by bending is relieved, and the snapping increases the jiggling of the atoms.

Coherent versus incoherent energy (cont.)

This comparison of energies makes two important points that are valid more generally.

First, coherent forms of energy are insignificant compared with incoherent forms – most of the energy around us is incoherent.

Second, when energy is dissipated, virtually all of it becomes thermal energy; the incoherent configuration energy associated with deformation, breaking, and abrasion is generally negligible compared to the energies required to cause these changes.

Checkpoint 7.9

7.9 For each of the following processes, determine what energy conversion takes place and classify the interaction as dissipative or nondissipative. (Hint: Imagine what you would see if you played each situation in reverse.)

(a) The launching of a ball by expanding a compressed spring

(b) the fall of a ball released a certain height above the ground,

(c) the slowing down of a coasting bicycle

(d) the acceleration of a car.

Checkpoint 7.9

7.9

(a) The launching of a ball by expanding a compressed spring

– elastic U to kinetic; reversible → nondissipative

(b) The fall of a ball released a certain height above the ground

– gravitational U to kinetic; reversible → nondissipative

(c) The slowing down of a coasting bicycle

– friction: kinetic to thermal; irreversible → dissipative

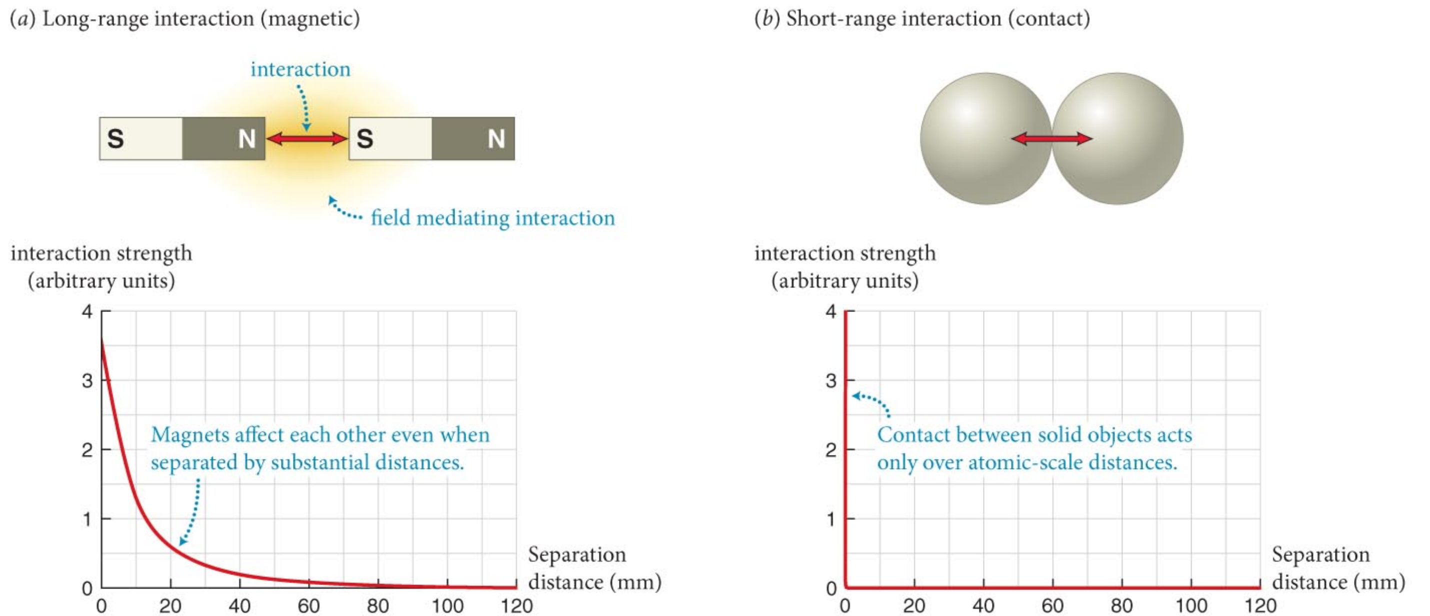
(d) The acceleration of a car

– combustion: source to kinetic + thermal

irreversible → dissipative

Section 7.5: Interaction range

- Matter can be classified according to its interactions.
- Attributes we give to various types of matter are a way of indicating the types of interactions they take part in.
- The strength of any interaction between two objects is a function of the distance separating them, as illustrated in the figure below.



Section 7.5: Interaction range

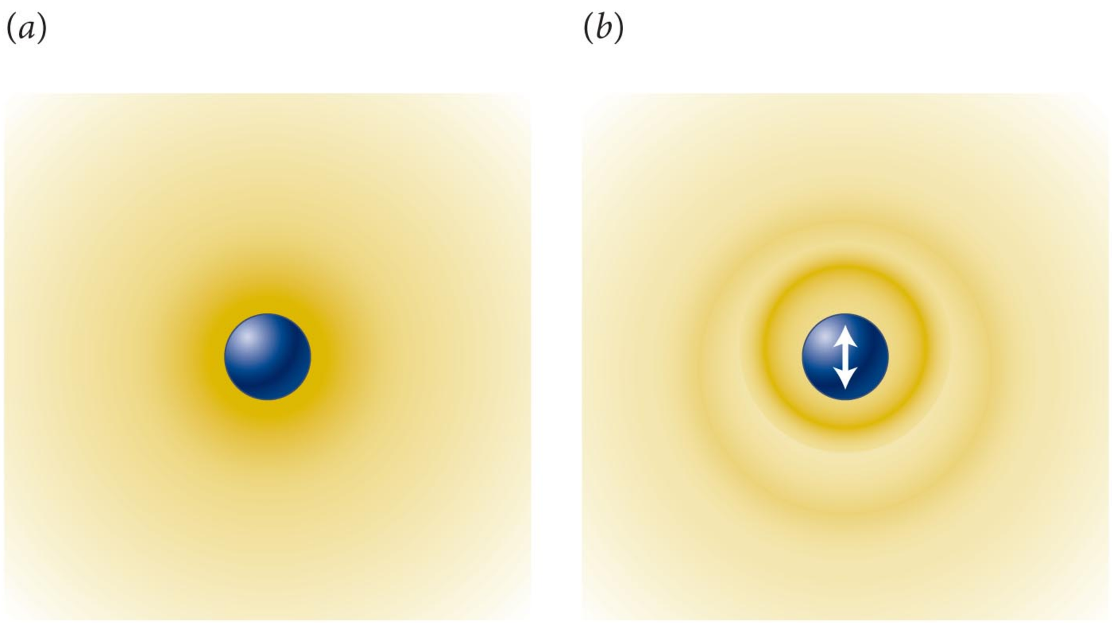
- As seen in the previous slide, the magnetic interactions are said to be long-range because magnets can "feel" each other over large distances.

- In contrast, interaction between two billiard balls is said to be *short-range* because the balls do not interact with each other when they are not "touching."

- *a key distinction is contact vs non-contact interactions*
  - the former are fundamental, the latter are derived

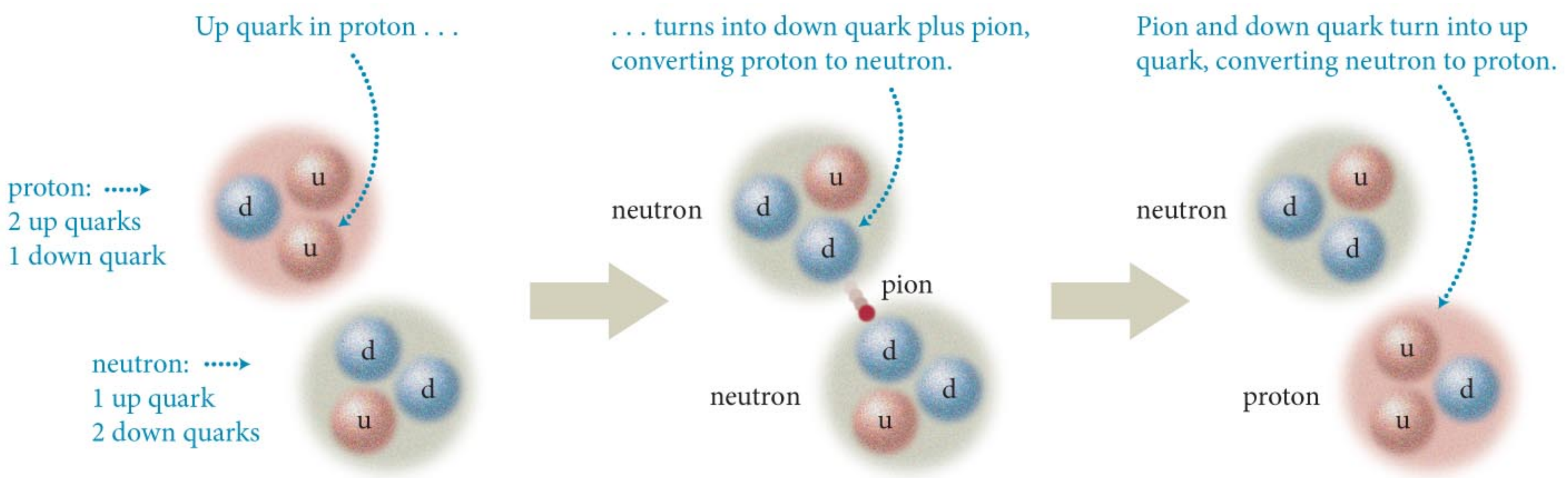
Section 7.5: Interaction range

- One model widely used to illustrate long-range interactions is the **field**, shown in the figure below.
  - For example, an electrically charged object has an electric field, and interactions are mediated by these fields.



Section 7.5: Interaction range

- An alternate model explains interactions in terms of an exchange of fundamental particles called *gauge particles*.
- Mathematically equivalent.



Section 7.6: Fundamental interactions

- An interaction is **fundamental** if it cannot be explained in terms of other interactions.
- All known interactions can be traced to four fundamental interactions:

Table 7.1 Fundamental Interactions

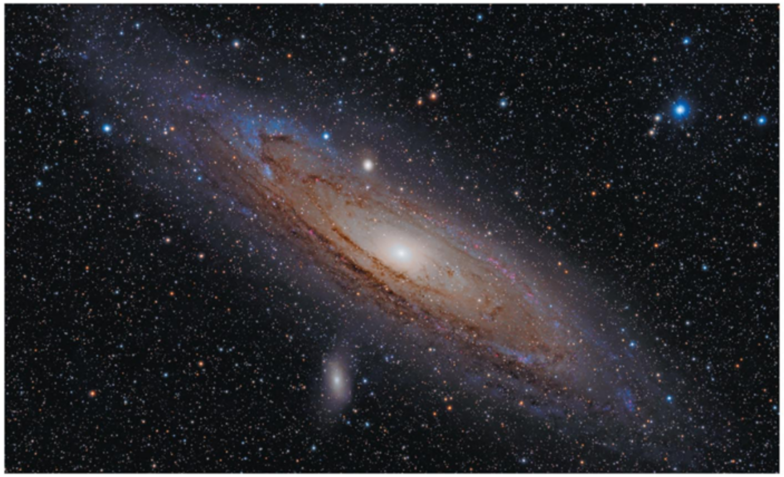
Type	Required attribute	Relative strength	Range	Gauge particle	Propagation speed
gravitational	mass	1	∞	graviton?	c?
weak	weak charge	10^{25}	10^{-18} m	vector bosons	varies
electromagnetic	electrical charge	10^{36}	∞	photon	c
strong	color charge	10^{38}	10^{-15} m	gluon	c

The relative strength is a measure of the magnitude of the effects of these interactions on two protons separated by about 10^{-15} m. The question marks in the last two columns indicate that the information provided has not yet been verified experimentally. The symbol c represents the speed at which lights travels.

- Dark matter/energy – do we miss one here?

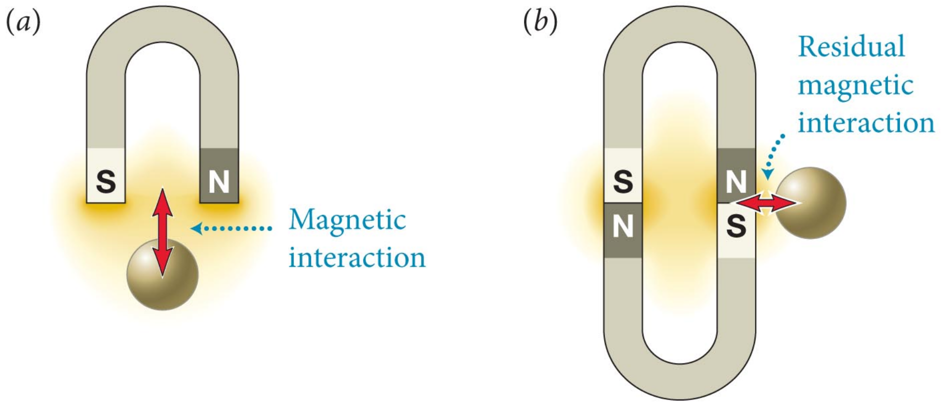
Brief overview of the four fundamental interactions

1. **Gravitational interaction**:
   - Long-range interaction between all objects that have mass.
   - Probably mediated by a gauge particle called the *graviton* (still undetected, but its basic properties are known).
   - Determines the large-scale structure of the universe.



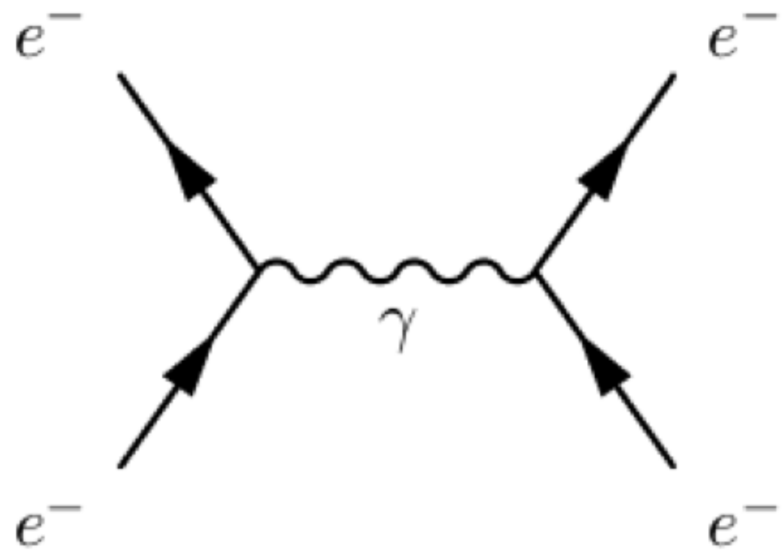
Brief overview of the four fundamental interactions

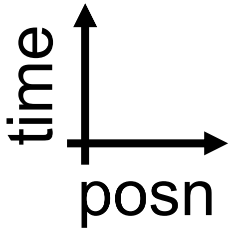
2. **Electromagnetic interaction**: Responsible for most of what happens around us.
   - Responsible for the structure of atoms and molecules, for all chemical and biological processes, for repulsive interactions between objects such as a bat and a ball, and for light and other electromagnetic interactions.
   - Long-range interaction mediated by a gauge particle called the *photon*.



Section 7.5: Interaction range

- Two electrons repel each other by exchanging a photon
- Both recoil, repulsive (photon has momentum, ph253)
- Equivalent to field approach (ph106)

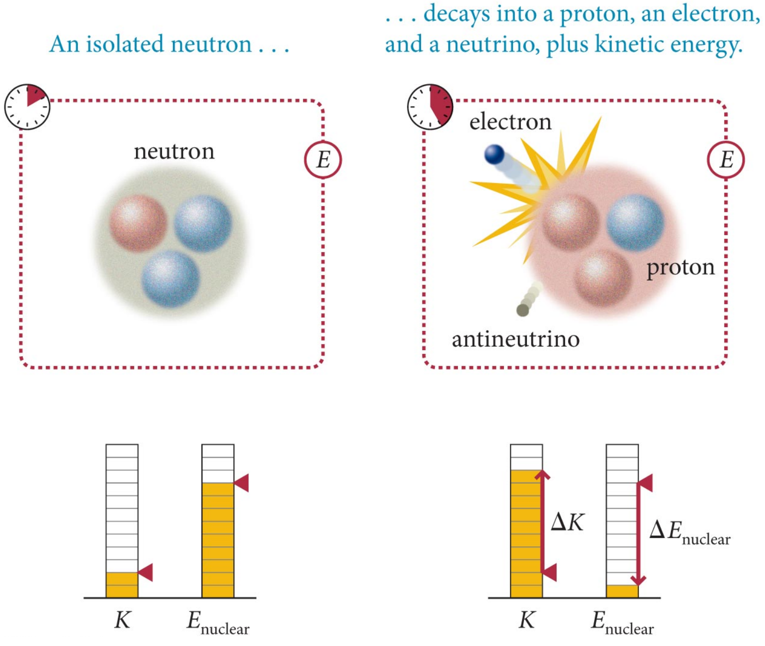




http://sciencevspseudoscience.files.wordpress.com/2011/12/moller_feynman_tree.png?w=500

Brief overview of the four fundamental interactions

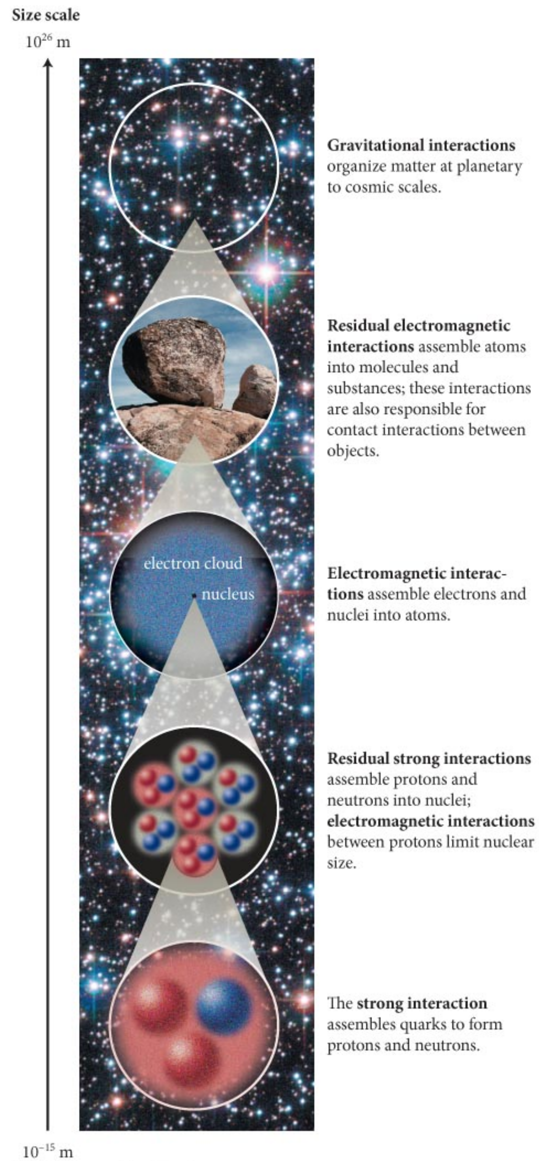
3. **Weak interaction**: Responsible for some radioactive decay processes and for converting hydrogen to helium in stars.
   - Acts inside the nucleus of atoms between subatomic particles that carry an attribute called *weak charge*.
   - Mediated by gauge particles called *vector bosons*.
   - nucleus lowers it potential energy



Brief overview of the four fundamental interactions

4. **Strong interaction**: Acts between quarks, which are the building blacks of protons and neutrons, and other particles.
   - The attribute required for this interaction is called *color charge*.
   - Mediated by a gauge particles called *gluons*.
   - Responsible for holding the nucleus of an atom together.

Section 7.6: Fundamental interactions



Section 7.6
Question 4

Which fundamental interaction exerts the most control (*a*) in chemical processes and (*b*) in biological processes?

1. Electromagnetic, gravitational respectively
2. Gravitational, electromagnetic respectively
3. Electromagnetic, electrostatic respectively
4. Gravitational, gravitational respectively

Question 4

Which fundamental interaction exerts the most control (*a*) in chemical processes and (*b*) in biological processes?

1. Electromagnetic, gravitational respectively
2. Gravitational, electromagnetic respectively
3. ✔ Electromagnetic, electrostatic respectively
4. Gravitational, gravitational respectively

hint: gravity is basically irrelevant

Section 7.6
Question 5

The strength of the gravitational interaction is minuscule compared with the strength of the electromagnetic interaction. Yet we can study the interactions of most ordinary objects without considering electromagnetic interactions, while it is essential that we include gravitational interactions. This is because

1. electromagnetic interactions occur only in atoms, molecules, and subatomic particles.
2. most ordinary matter is electrically neutral.
3. atoms, molecules, and subatomic particles have no mass.
4. None of the above.

Section 7.6
Question 5

The strength of the gravitational interaction is minuscule compared with the strength of the electromagnetic interaction. Yet we can study the interactions of most ordinary objects without considering electromagnetic interactions, while it is essential that we include gravitational interactions. This is because

1. electromagnetic interactions occur only in atoms, molecules, and subatomic particles.
2. ✔ most ordinary matter is electrically neutral.
3. atoms, molecules, and subatomic particles have no mass.
4. None of the above.

Quantitative Tools

Section 7.7: Interactions and accelerations

- Now let us prove the relationship between accelerations and inertia of interacting objects that we saw in section 7.1:
  - Momentum conservation requires that the momentum of an isolated two-object system remains constant during an interaction:

$$\Delta\vec{p}_1 = -\Delta\vec{p}_2$$

  - If the time-interval of the interaction is Δt, then we can write

$$\frac{\Delta\vec{p}_1}{\Delta t} = -\frac{\Delta\vec{p}_2}{\Delta t}$$

  - If the inertias of the two objects are m_1 and m_2, we have 7.3:

$$\frac{m_1\Delta\vec{\upsilon}_1}{\Delta t} = -\frac{m_2\Delta\vec{\upsilon}_2}{\Delta t}$$

Section 7.7: Interactions and accelerations

- Using the definition of acceleration,

$$\lim_{\Delta t \to 0} \frac{\Delta \upsilon_x}{\Delta t} \equiv a_x$$

- We can then rewrite Equation 7.3 as

$$m_1 a_{1x} = -m_2 a_{2x}$$

- Rearranging the previous equation, we get

$$\frac{a_{1x}}{a_{2x}} = -\frac{m_2}{m_1}$$

- This relationship between the accelerations of two interacting objects of constant inertia holds for all interactions in an isolated two-object system.

Section 7.7: Interactions and accelerations

- What is most interesting?
- We haven't specified anything about the interaction at all! Therefore, it must be true for any interacting objects
- Conservation of momentum and the "ma" relationship are perfectly general

Checkpoint 7.11

7.11 A 1000-kg compact car and a 2000-kg van, each traveling at 25 m/s, collide head-on and remain locked together after the collision, which lasts 0.20 s.

(*a*) According to Eq. 7.6, their accelerations during the collision are unequal (*ma* is the same for both). How can this be if both initially have the same speed and the time interval during which the collision takes place is the same amount of time for both?

(*b*) Calculate the average acceleration in the direction of travel experienced by each vehicle during the collision.

$$\frac{a_{1x}}{a_{2x}} = -\frac{m_2}{m_1}$$

Checkpoint 7.11

7.11 (*a*) According to Eq. 7.6, their accelerations during the collision are unequal. How can this be if both initially have the same speed and the time interval during which the collision takes place is the same amount of time for both?

(They have the same initial *speed*. Velocities are in opposite directions.)

They do have the same change in *momentum* and $|ma|$

They don't have the same change in velocity – the (lighter) car changes its velocity more because it will change directions.

Checkpoint 7.11

7.11 (*b*) Calculate the average acceleration in the direction of travel experienced by each vehicle during the collision.

purely inelastic, same final velocity:

v_c = -25 m/s

v_v = +25 m/s

$m_v v_v + m_c v_c = (m_v + m_c) v_f$ first find final velocity

$v_f = (m_v v_v - m_c v_c)/(m_v + m_c) = +8.33$ m/s

$a_c = (v_f - v_c)/\Delta t = -170 \text{ m/s}^2$ now acceleration

$a_v = (v_f - v_v)/\Delta t = +83 \text{ m/s}^2$

Section 7.7
Question 6

How are the acceleration and inertia of an object 1 related to the acceleration and inertia of an object 2 when the objects collide (*a*) elastically and (*b*) inelastically?

1. Directly proportional, directly proportional
2. Directly proportional, inversely proportional
3. Inversely proportional, directly proportional
4. Inversely proportional, inversely proportional

Section 7.7
Question 6

How are the acceleration and inertia of an object 1 related to the acceleration and inertia of an object 2 when the objects collide (*a*) elastically and (*b*) inelastically?

1. Directly proportional, directly proportional
2. Directly proportional, inversely proportional
3. Inversely proportional, directly proportional
4. ✔ Inversely proportional, inversely proportional

$a_{1x}/a_{2x} = -m_2/m_1$ holds in either case

Section 7.8: Nondissipative interactions

- Using the four categories of energy introduced in the previous section, we can write conservation of energy of any closed system as

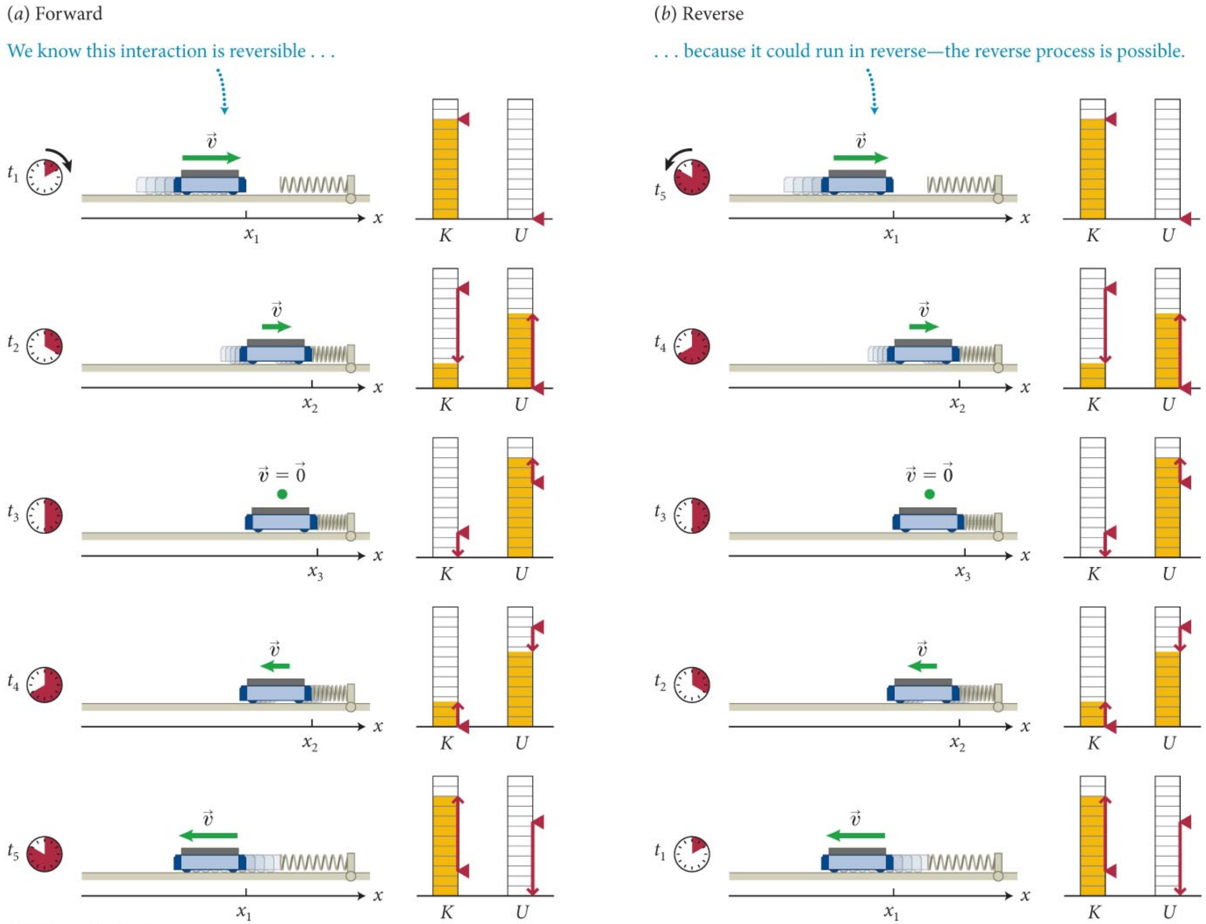
$$\Delta E = \Delta K + \Delta U + \Delta E_s + \Delta E_{th} = 0 \text{ (closed system)}$$

- For nondissipative systems, $\Delta E_S = 0$ and $\Delta E_{th} = 0$.
- If we introduce mechanical energy of a system as $E_{mech} = K + U$, we can write

$$\Delta E_{mech} = 0 \text{ (closed system, nondissipative interaction)}$$

Section 7.8: Nondissipative interactions

- Consider the nondissipative interaction shown in the figure below.



Section 7.8: Nondissipative interactions

- The interaction between the cart and Earth is non-dissipative (reversible), and no changes occur
- K_{Earth} does not change, and we have no source energy,

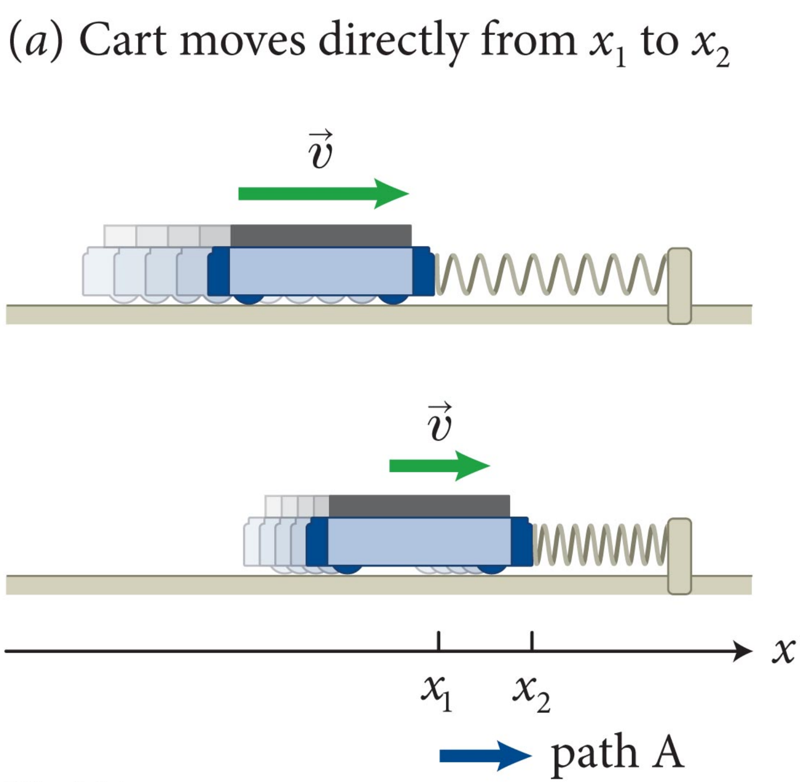
$$\Delta K_{\text{cart}} = -\Delta U_{\text{spring}}$$

  where U_{spring} is the elastic potential energy associated with the shape of the spring.
- U_{spring} has a definite value at each position x of the end of the spring.
- More generally, the potential energy of any system depends only on position

$$U = U(x)$$

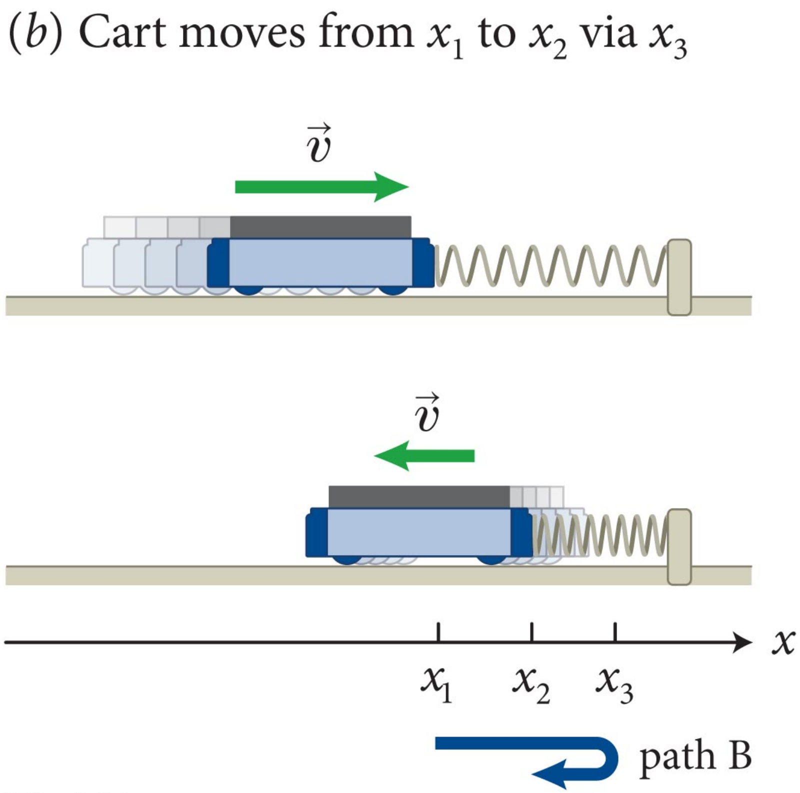
Example 7.4 Path independence of change in potential energy

Figure 7.26 shows a cart striking a spring. In Figure 7.26*a*, consider the motion of the cart along the direct path from the initial position x_1 , which is the position at which the cart makes initial contact with the free end of the spring, to the position x_2 (path A).



Example 7.4 Path independence of change in potential energy (cont.)

In Figure 7.26*b*, consider the motion along the path from x_1 to the position of maximum compression x_3 and then back to x_2 (path B). Show that the change in the cart's kinetic energy is the same for both paths if the interaction caused by the spring is reversible.



Example 7.4 Path independence of change in potential energy (cont.)

❶ GETTING STARTED As the cart moves from x_1 to x_2 along path A, the spring is compressed and the cart's kinetic energy steadily decreases.

Along path B, the spring is first compressed and the cart comes to a stop at x_3. The spring then expands, accelerating the cart back to x_2. To solve this problem, I'll consider the closed system made up of the cart, the spring, and Earth.

Example 7.4 Path independence of change in potential energy (cont.)

❷ DEVISE PLAN If the change in the elastic potential energy of the spring is the same along both paths, then the change in the kinetic energy of the cart must also be the same along both paths.

First determine the change in potential energy between the initial and final positions of path A, then do the same between the initial and final positions of the two parts of path B.

Example 7.4 Path independence of change in potential energy (cont.)

❸ EXECUTE PLAN Because the potential energy associated with a reversible interaction is a function of x only (Eq. 7.12), the change in elastic potential energy along path A is

$$\Delta U_{\text{path A}} = U_\text{f} - U_\text{i} = U(x_2) - U(x_1)$$

Example 7.4 Path independence of change in potential energy (cont.)

❸ EXECUTE PLAN Along path B I have two contributions to ΔU_{spring}: an increase in U from x_1 to x_3 and a decrease from x_3 to x_2:

$$\begin{aligned}\Delta U_{\text{path B}} &= \Delta U_{13} + \Delta U_{32} \\ &= [U(x_3) - U(x_1)] + [U(x_2) - U(x_3)] \\ &= U(x_2) - U(x_1) = \Delta U_{\text{path A}}. \checkmark\end{aligned}$$

So, the change in the cart's kinetic energy is the same for both paths.

Example 7.4 Path independence of change in potential energy (cont.)

❹ EVALUATE RESULT The change in the cart's kinetic energy is independent of the path joining x_1 and x_2 even though the cart ends up moving in opposite directions along the two paths.

This is because the change in potential energy ΔU_{12} depends only on the coordinates x_1 and x_2.

In fact, this is a *necessary condition* for potential energy.

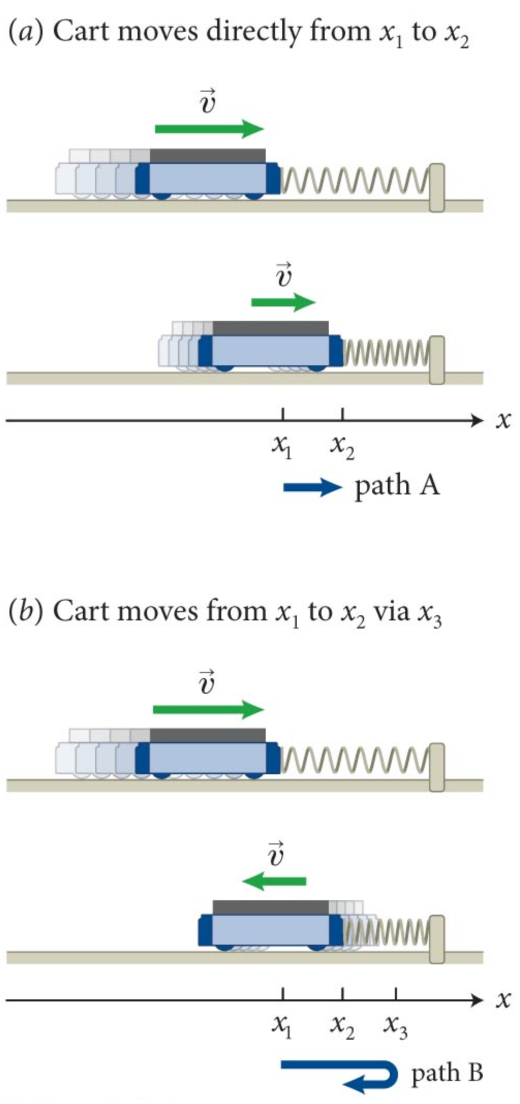
Checkpoint 7.13

7.13 By the same logic, the change in potential energy for any closed path (round trip) must be zero!

Potential energy must depend only on coordinates to be well-defined. Implies reversibility, non-dissipative interaction.

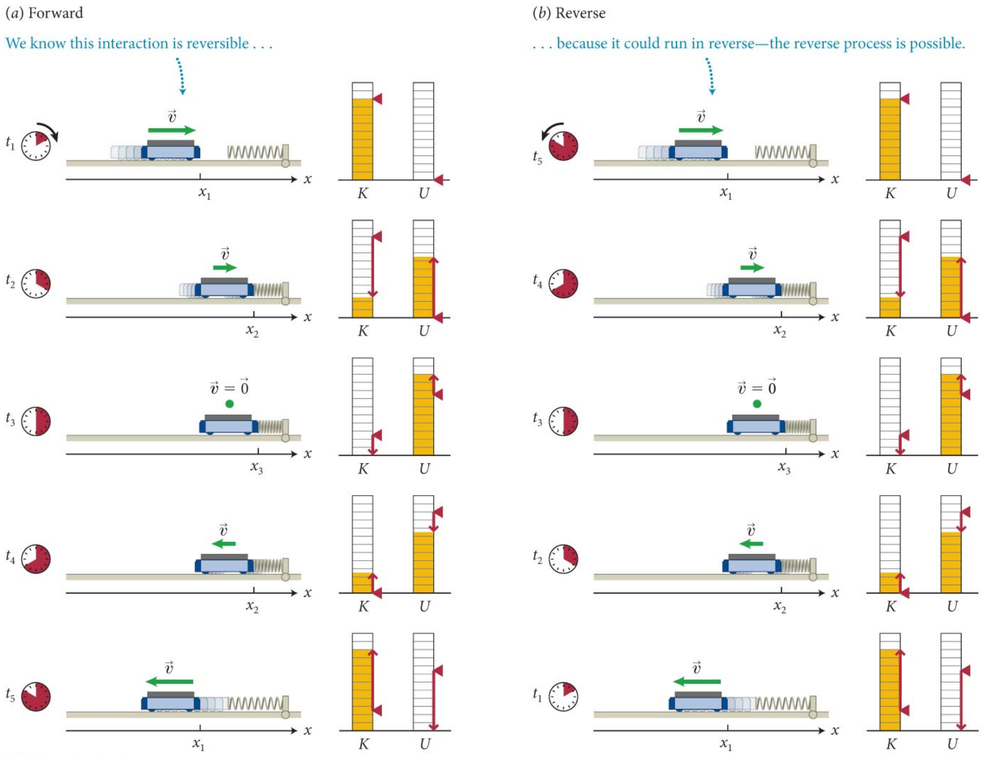
Given this, closed paths give no change.

Some interactions don't have potential energy – e.g., friction (path-dependent, round trip doesn't bring back original state)



Section 7.8: Nondissipative interactions

- The fact that potential energy is a unique function of position leads to a very important point:
  - For an example, consider a closed system with the potential energy function $U(x)$, as shown.
  - We can state in general that:
    - **The parts of any closed system always tend to accelerate in the direction that lowers the system's potential energy.**



Nature doesn't want *potential* energy, it wants to use all of it.

Checkpoint 7.14

7.14 Consider a ball launched upward. Verify that its acceleration points in the direction that lowers the gravitational potential energy of the Earth-ball system.

Homework 7.08

A ring is attached at the center of the underside of a trampoline. A sneaky teenager crawls under the trampoline and uses the ring to pull the trampoline slowly down while his 75-kg mother is sleeping on it. When he releases the trampoline, she is launched upward. As she passes through the position at which she was before her son stretched the trampoline, her speed is 3.5 m/s .

How much elastic potential energy did the son add to the trampoline by pulling it down? Assume the interaction is nondissipative.

stored elastic energy in deforming trampoline

starts with $K_i=0$, all stored elastic U_i converted to K_f

$$K_f = U_i = \frac{1}{2}mv_f^2 = 460 \text{ J}$$

Section 7.9: Potential energy near Earth's surface

Section Goals

You will learn how to

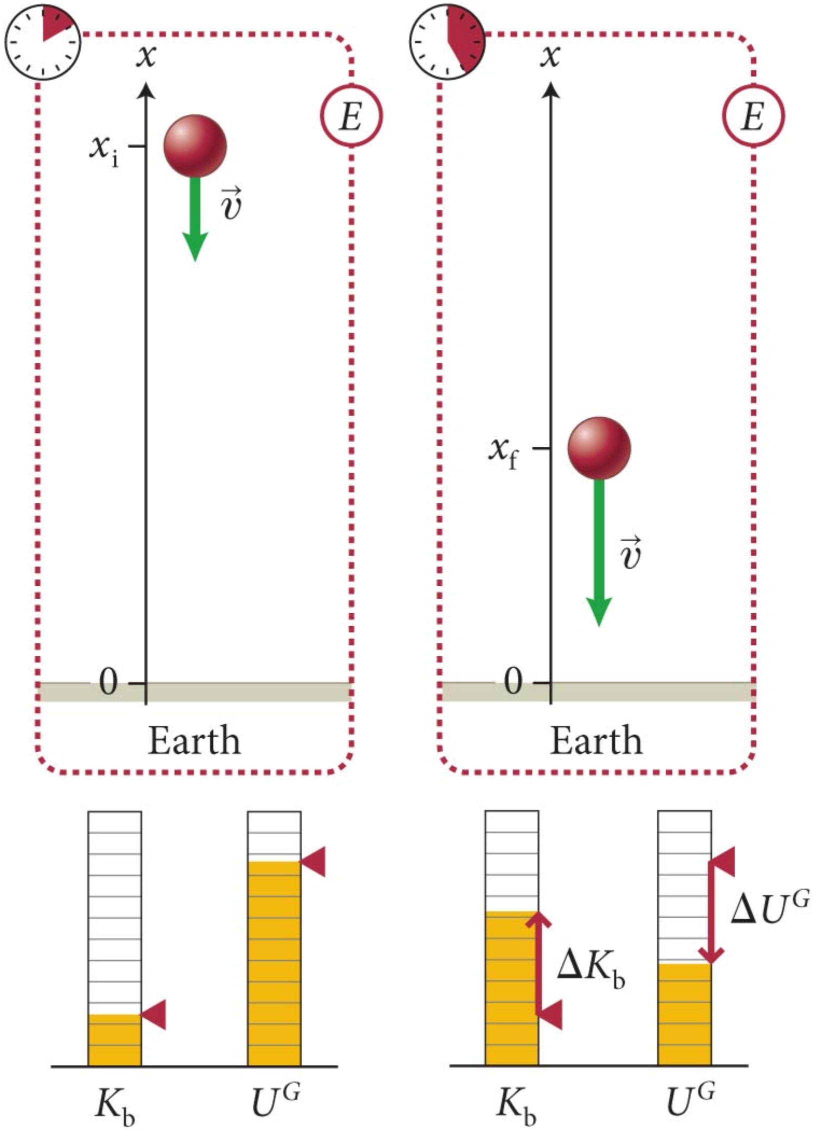
- Calculate the **gravitational potential energy** of an object near Earth's surface.
- Demonstrate that the change in gravitational potential energy for an object near Earth between two points is **independent of the path** connecting the points.

Section 7.9: Potential energy near Earth's surface

- Free-falling objects near Earth's surface fall with an acceleration $g = 9.8\ \text{m/s}^2$.
- The gravitational interaction is non-dissipative
- Given $\Delta K_{\text{Earth}} = 0$, we can write energy conservation as

$$\Delta U^G + \Delta K_b = 0$$

where ΔU^G is the change in gravitational potential energy of Earth-ball system, and ΔK_b is the change in the ball's kinetic energy.



Section 7.9: Potential energy near Earth's surface

- Recall our 'no time' equation with a_x = -g

$$x_f - x_i = -\frac{v_f^2 - v_i^2}{2g}$$

- Multiply both sides by m_bg and rearrange

$$m_b g\left(x_f - x_i\right) + \frac{1}{2}m_b\left(v_f^2 - v_i^2\right) = 0$$

- The second term above is ΔK_b, and so from the energy conservation law, the first term must be ΔU^G.
- Therefore, the change in gravitational potential energy is

$$\Delta U^G = mg\Delta x$$

- Expanding,

$$\Delta U^G = U_f^G - U_i^G = mg\left(x_f - x_i\right) = mgx_f - mgx_i$$

Section 7.9: Potential energy near Earth's surface

$$\Delta U^G = U_f^G - U_i^G = mg(x_f - x_i) = mgx_f - mgx_i$$

- Comparing terms, we can conclude that the gravitational potential energy of the Earth-object system near Earth's surface is

$$U^G(x) = mgx \text{ (near Earth's surface)}$$

- Implies we need to choose a zero/reference height!
- Only *changes* in U are measureable (choice of zero is arbitrary)

Checkpoint 7.15

7.15 Suppose you raise your textbook (inertia $m = 3.4$ kg) from the floor to your desk, 1.0 m above the floor.

(a) Does the gravitational potential energy of the Earth-book system increase or decrease?

(b) By how much?

(c) Conservation of energy requires that this change in potential energy be compensated for by a change in energy somewhere in the universe. Where?

Checkpoint 7.15

7.15 Suppose you raise this book (inertia m = 3.4 kg) from the floor to your desk, 1.0 m above the floor.

(a) Does the gravitational potential energy of the Earth-book system increase or decrease? increases

(b) By how much? $\Delta U^G = mgh = 33J$

(c) Conservation of energy requires that this change in potential energy be compensated for by a change in energy somewhere in the universe. Where? your arm muscles burn some chemical energy

Checkpoint 7.16

7.16 Suppose that instead of choosing Earth and the ball as our system in the previous discussion, we had chosen to consider just the ball. Does it make sense to speak about the gravitational potential energy of the ball (the way we speak of its kinetic energy)?

No – ball is not a closed system. It doesn't fall by itself, an interaction requires two objects.

Though people say this, it is sloppy. Potential energy requires 2 interacting objects (at least)

Section 7.9
Question 8

The gravitational potential energy of a particle at a height *z* above Earth's surface

1. depends on the height *z*.
2. depends on the path taken to bring the particle to *z*.
3. both 1 and 2

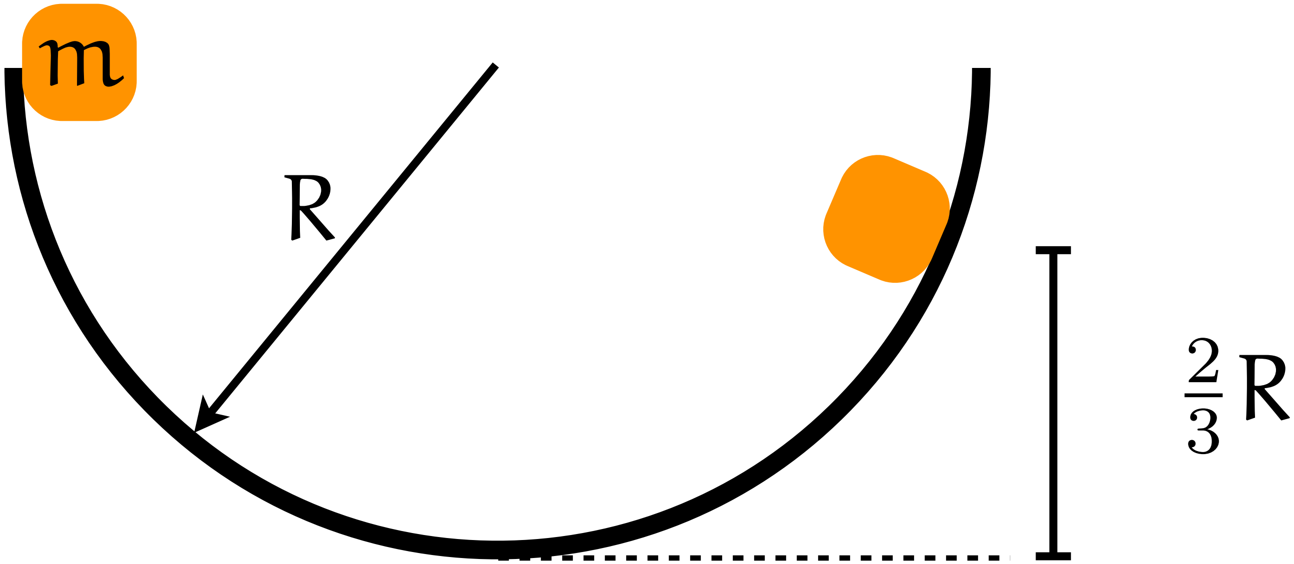
Section 7.9
Question 8

The gravitational potential energy of a particle at a height *z* above Earth's surface

✔ 1. depends on the height *z*.
2. depends on the path taken to bring the particle to *z*.
3. both 1 and 2

Problem

A ball slides in a frictionless bowl, released from rest at the top. When it reaches a height 2/3R from the top, what is its speed?



Problem

ΔKE = - ΔU if we assume no dissipation or source E

system = ball + earth

ignore friction = ignore bowl

let bottom of bowl be height 0

$$\Delta K = K_f - K_i = \tfrac{1}{2}mv_f^2 - 0 = \tfrac{1}{2}mv_f^2$$

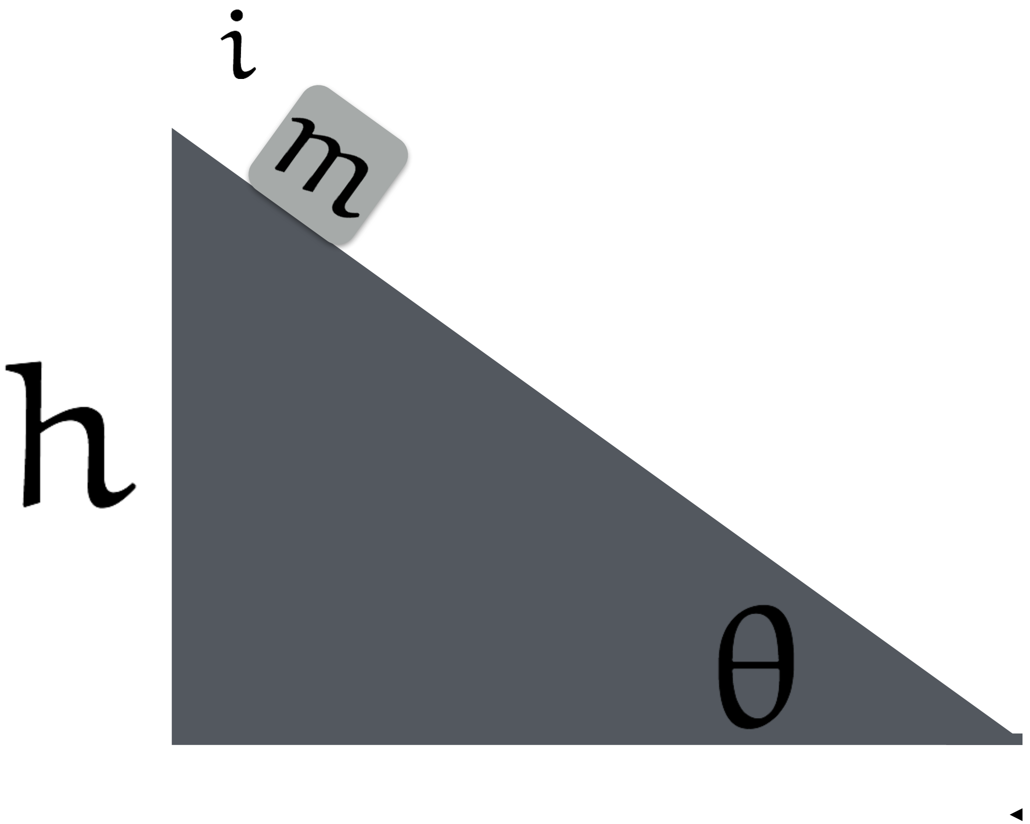
$$\Delta U = U_f - U_i = mg(2/3\ R) - mg(R) = -mgR/3$$

$$\Delta K = -\Delta U$$

$$\tfrac{1}{2}mv_f^2 = mgR/3$$

$$v_f^2 = 2gR/3$$

Speed at the bottom of the ramp?



Frictionless, released from rest.

Speed at the bottom of the ramp?

change K = - change in U

let floor be height 0

– *need to define a zero point, but it is a free choice*

$K_f - K_i = \frac{1}{2}mv_f^2 - 0 = \frac{1}{2}mv_f^2$

$U_f - U_i = 0 - mgh - 0 = -mgh$

$\Delta K = -\Delta U$

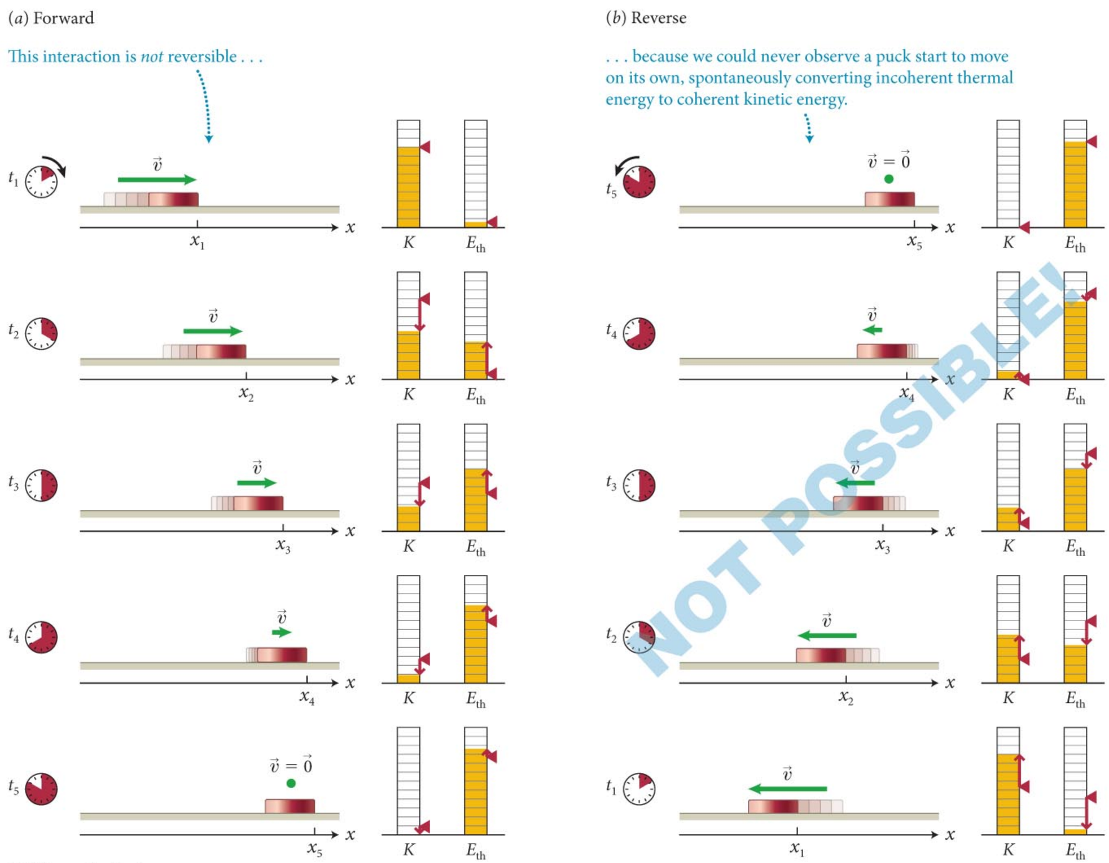
$\frac{1}{2}mv_f^2 = mgh$

$v_f^2 = 2gh$

the same as dropping a ball from height h!

Section 7.10: Dissipative interactions

- An example of a dissipative interaction is shown below:
  - Dissipative interactions are irreversible.
  - There is a change in thermal energy in dissipative interactions.



Section 7.10: Dissipative interactions

- In the example shown previously, the friction acting on the puck causes its kinetic energy to be converted to thermal energy.
- Since there is no change in potential energy and there is no source energy, energy conservation simplifies to

$$\Delta K + \Delta E_{th} = 0$$

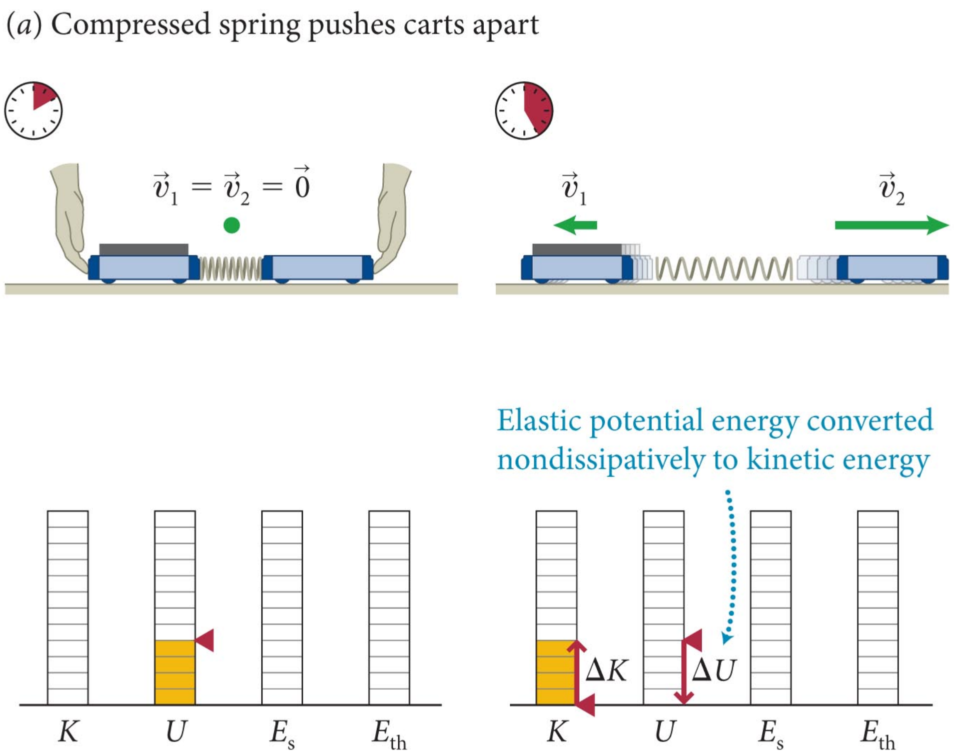
which can be written as

$$\Delta K = -\Delta E_{th.}$$

- In this example only the kinetic energy of the puck changes, and therefore $\Delta K = \Delta K_{puck}$.
- This is an irreversible interaction because incoherent thermal energy cannot spontaneously convert to coherent kinetic energy.

Section 7.10: Dissipative interactions

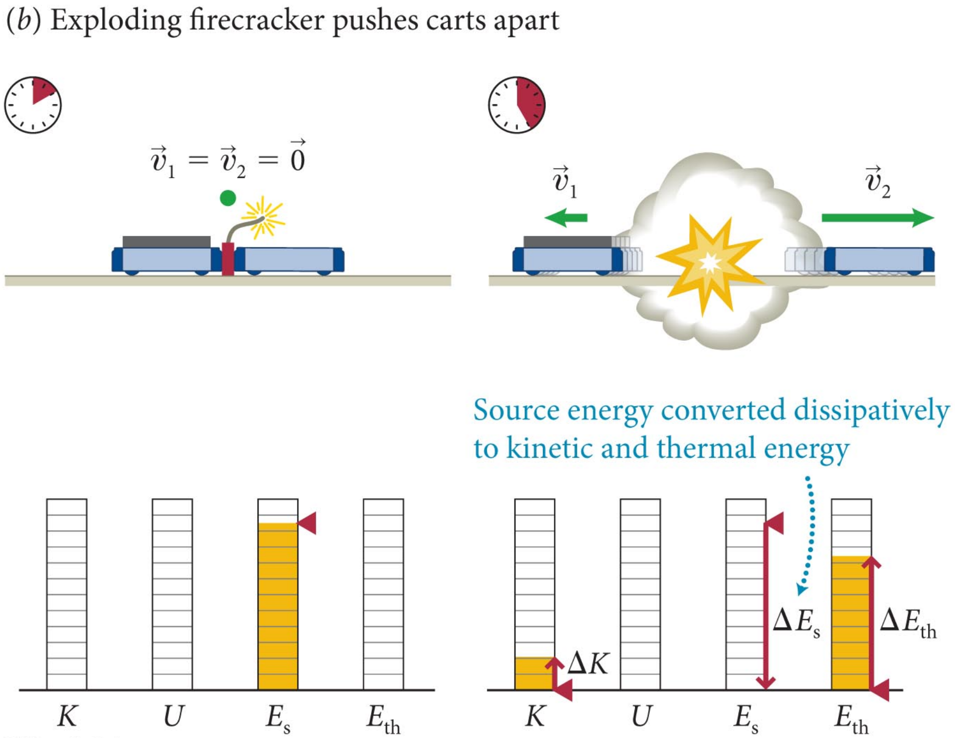
- The figure below shows an explosive separation.
- The interaction is reversible because one form of coherent energy (elastic potential energy) is converted to another form of coherent energy (kinetic energy).
- This type of nondissipative explosive separation is described by $\Delta K + \Delta U = 0$.



Section 7.10: Dissipative interactions

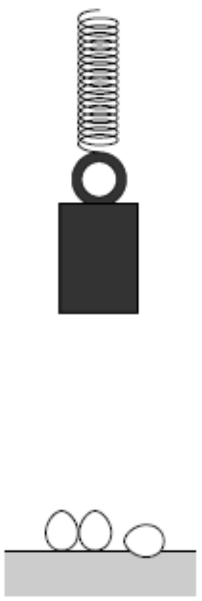
- The interaction shown is an irreversible explosive separation.
- During the separation, stored chemical energy in the firecracker is partly converted to (coherent) kinetic energy and partly to (incoherent) thermal energy.
- For this interaction, we get

$$\Delta K + \Delta E_{\text{chem}} + \Delta E_{\text{th}} = 0$$



Section 7.10
Question 9

In the following figure, a 10-kg weight is suspended from the ceiling by a spring. The weight-spring system is at equilibrium with the bottom of the weight about 1 m above the floor. The spring is then stretched until the weight is just above the eggs. When the spring is released, the weight is pulled up by the contracting spring and then falls back down under the influence of gravity.

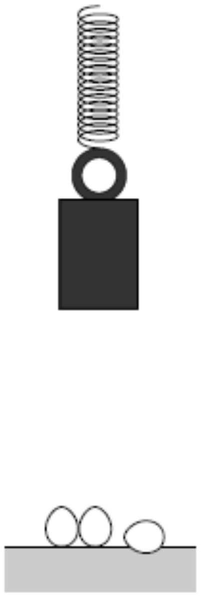


On the way down, it

1. reverses its direction of travel well above the eggs.
2. reverses its direction of travel precisely as it reaches the eggs.
3. makes a mess as it crashes into the eggs.

Clicker Question 9

In the following figure, a 10-kg weight is suspended from the ceiling by a spring. The weight-spring system is at equilibrium with the bottom of the weight about 1 m above the floor. The spring is then stretched until the weight is just above the eggs. When the spring is released, the weight is pulled up by the contracting spring and then falls back down under the influence of gravity.



On the way down, it

1. reverses its direction of travel well above the eggs.
2. ✔ reverses its direction of travel precisely as it reaches the eggs.
3. makes a mess as it crashes into the eggs.

really

http://physics.wfu.edu/demolabs/demos/avimov/bychptr/chptr3_energy.htm#ConservationEnergy

Chapter 7: Summary

Concepts: The basics of interactions

- An **interaction** is an event that produces either a physical change or a change in motion. A *repulsive interaction* causes the interacting objects to accelerate away from each other, and an *attractive interaction* causes them to accelerate toward each other.
- The **interaction range** is the distance over which an interaction is appreciable. A long-range interaction has an infinite range; a short-range interaction has a finite range.

Chapter 7: Summary

Concepts: The basics of interactions

- A **field** is a model used to visualize interactions between objects. According to this model, each object that takes part in an interaction produces a field in the space surrounding itself, and the fields mediate the interaction between the objects.

Chapter 7: Summary

Concepts: The basics of interactions

- A **fundamental interaction** is one that cannot be explained in terms of other interactions. The four known fundamental interactions are
  - the **gravitational interaction** (a long-range attractive interaction between objects that have *mass*),
  - the **electromagnetic interaction** (a long-range interaction between objects that have *electrical charge*; this interaction can be either attractive or repulsive),
  - the **weak interaction** (a short-range repulsive interaction between subatomic particles), and
  - the **strong interaction** (a short-range interaction between *quarks*, the building blocks of protons, neutrons, and certain other subatomic particles; this interaction can be either attractive or repulsive).

Chapter 7: Summary

Quantitative Tools: The basics of interactions

- If two objects of inertias m_1 and m_2 interact, the ratio of the x components of their accelerations is

$$\frac{a_{1x}}{a_{2x}} = -\frac{m_2}{m_1}.$$

Concepts: Potential energy

- **Potential energy** is a coherent form of internal energy associated with reversible changes in the *configuration* of an object or system. Potential energy can be converted entirely to kinetic energy.
- **Gravitational potential energy** is the potential energy associated with the relative position of objects that are interacting gravitationally.

Concepts: Potential energy

- **Elastic potential energy** is the potential energy associated with the reversible deformation of objects.
- Changes in potential energy are *independent of path*. This means that the change in an object's potential energy as the object moves from a position x_1 to any other position x_2 depends *only* on x_1 and x_2, and *not* on the path the object takes in moving from x_1 to x_2.

Chapter 7: Summary

Quantitative Tools: Potential energy

- The potential energy U of a system of two interacting objects can always be written in the form

$$U = U(x),$$

where $U(x)$ is a unique function of a position variable x that quantifies the configuration of the system.

- Near Earth's surface, if the vertical coordinate of an object of inertia m changes by Δx, the gravitational potential energy U^G of the Earth-object system changes by

$$\Delta U^G = mg\Delta x.$$

Concepts: Energy dissipation during interactions

- All energy can be divided into two fundamental classes:
  - Energy associated with motion (kinetic energy) and
  - Energy associated with the configuration of interacting objects (potential energy).
- Each class of energy comes in two forms: *coherent* and *incoherent*:
  - Energy is coherent if it involves ordered motion or configuration; it is incoherent if it involves random motion or configuration. For example, the kinetic energy of a moving object is coherent because all of its atoms move in the same way, whereas the thermal energy of an object is incoherent because the atoms move randomly.

Chapter 7: Summary

Concepts: Energy dissipation during interactions

- **Source energy** E_s is incoherent energy (such as chemical, nuclear, solar, and stored solar energy) used to produce other forms of energy.
- **Dissipative interactions** are irreversible interactions that involve changes in thermal energy.
- **Nondissipative interactions** are reversible interactions that convert kinetic energy to potential energy, and vice versa.

Chapter 7: Summary

Quantitative Tools: Energy dissipation during interactions

$$E_{mech} = K + U.$$

- During a dissipative interaction, the sum of the changes in all forms of energy in a closed system is zero:

$$\Delta K + \Delta U + \Delta E_{\mathrm{s}} + \Delta E_{\mathrm{th}} = 0.$$

- During a nondissipative interaction, the mechanical energy of a closed system does not change:

$$\Delta E_{mech} = \Delta K + \Delta U = 0.$$