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BROOKS/COLE
CENGAGE Learning

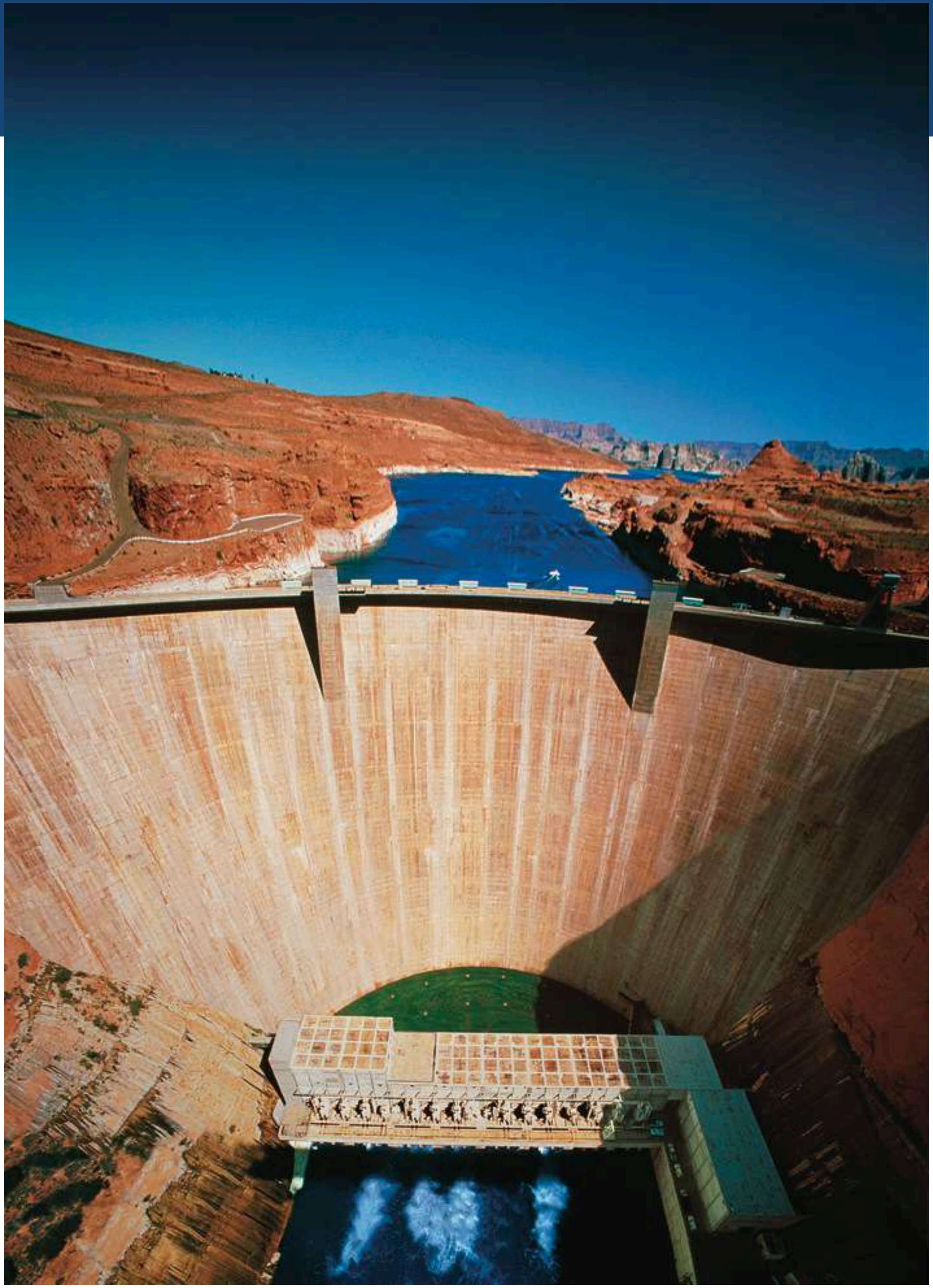
Chapter 10

Energy

Gretchen M. Adams • University of Illinois at Urbana-Champaign

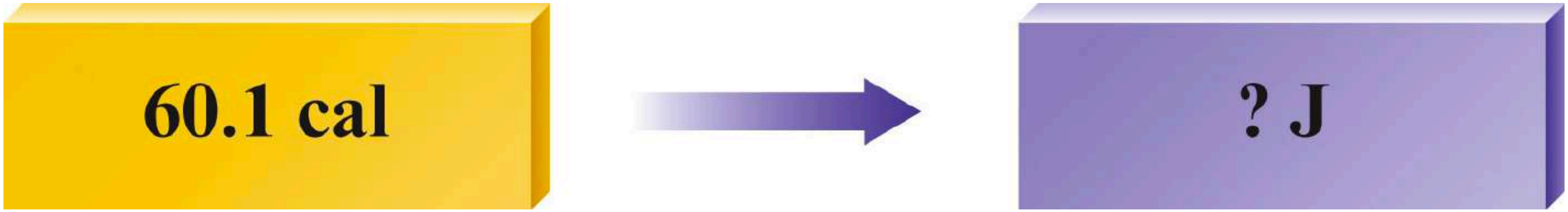

Elsam

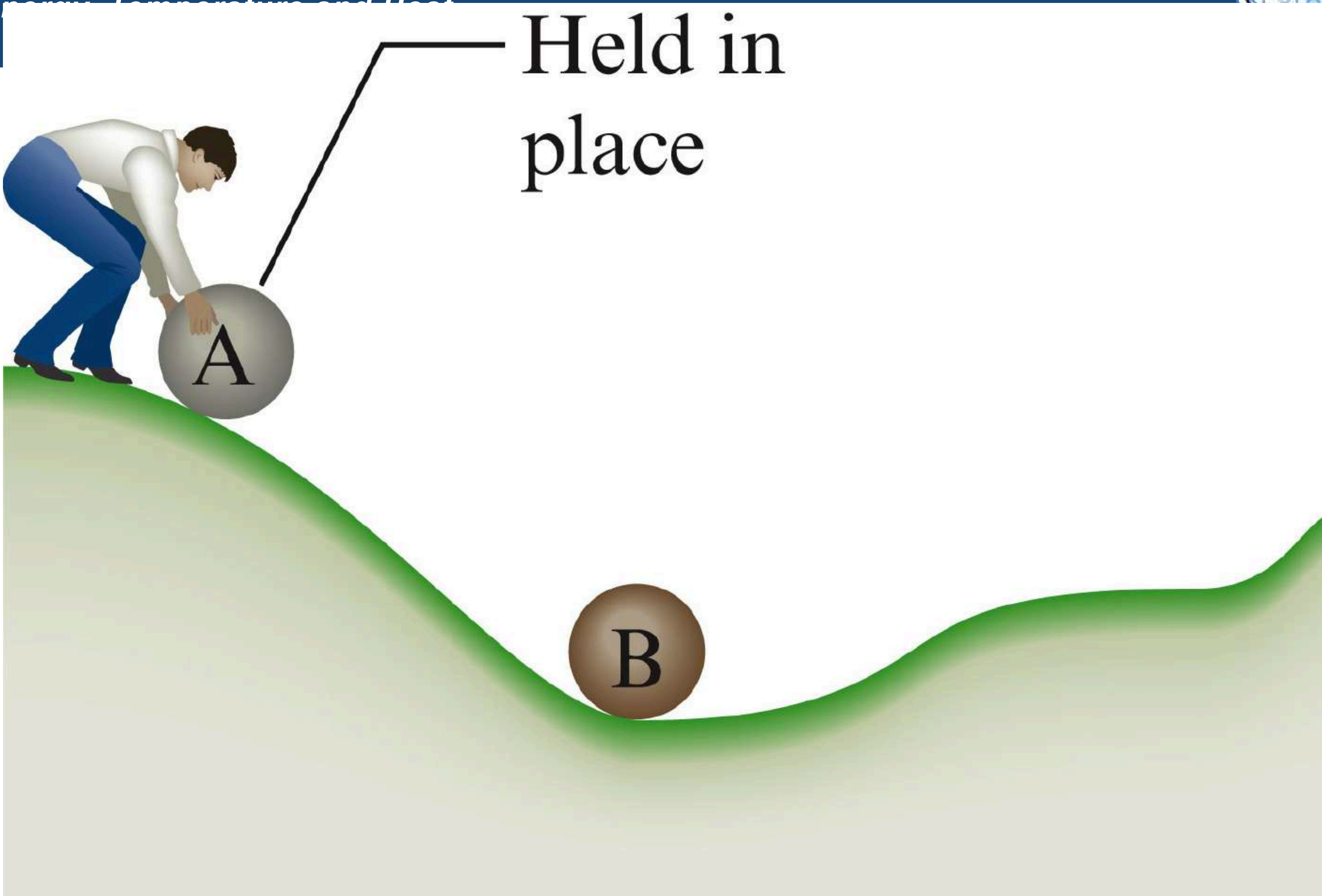
p339

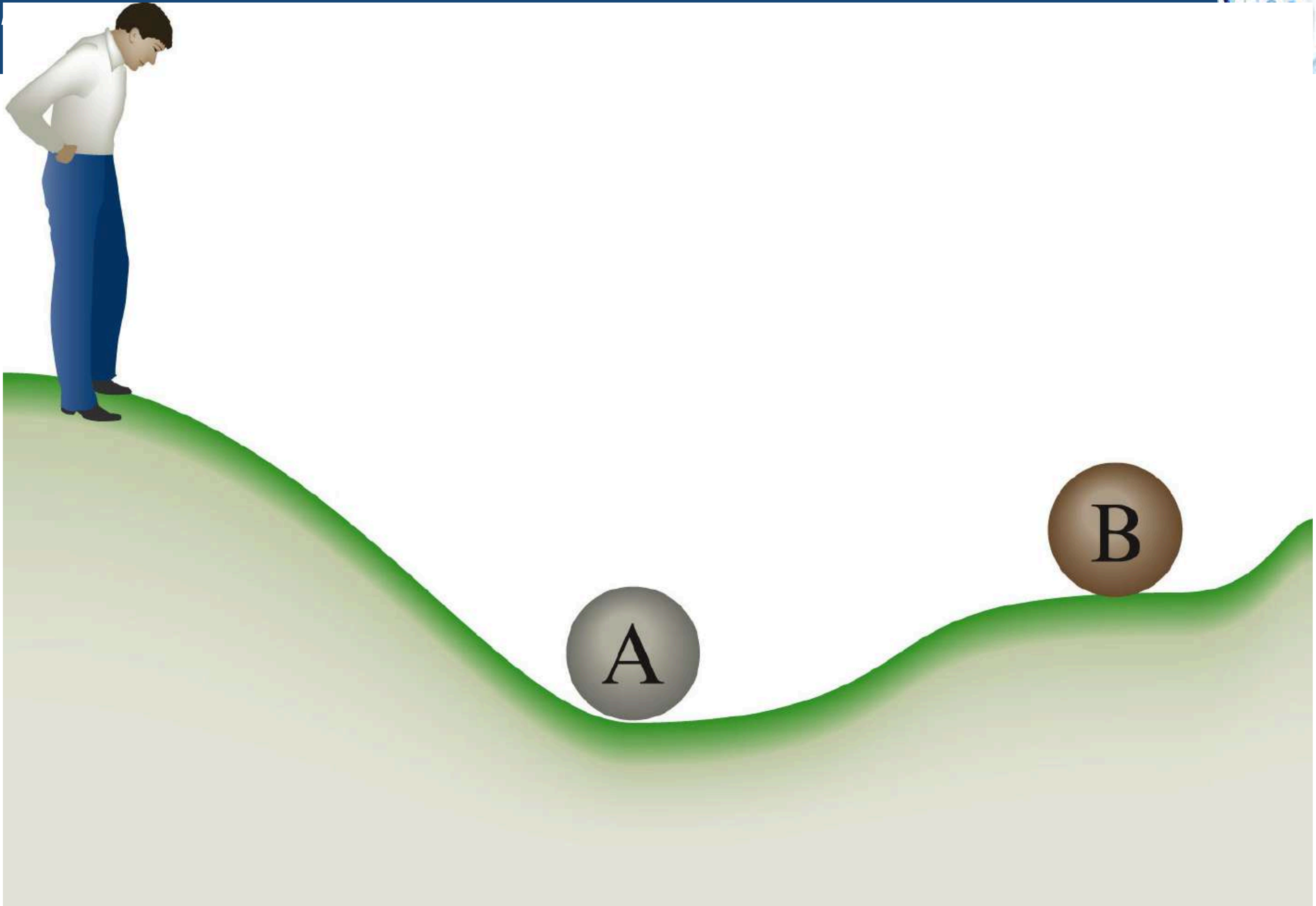


Objectives

1. To understand the general properties of energy
2. To understand the concepts of temperature and heat
3. To understand the direction of energy flow as heat


60.1 cal
? J


Held in place
A
B


A
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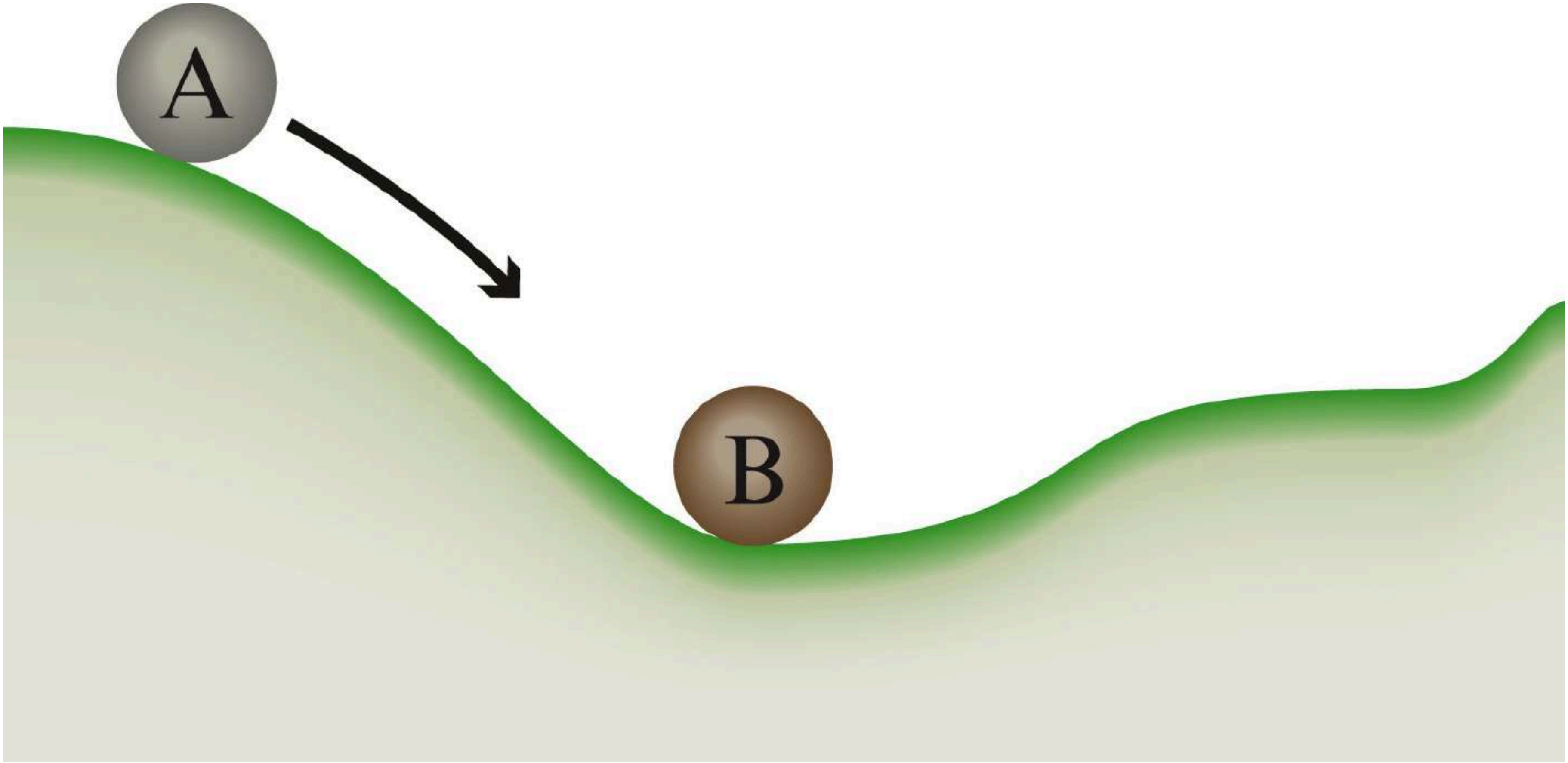
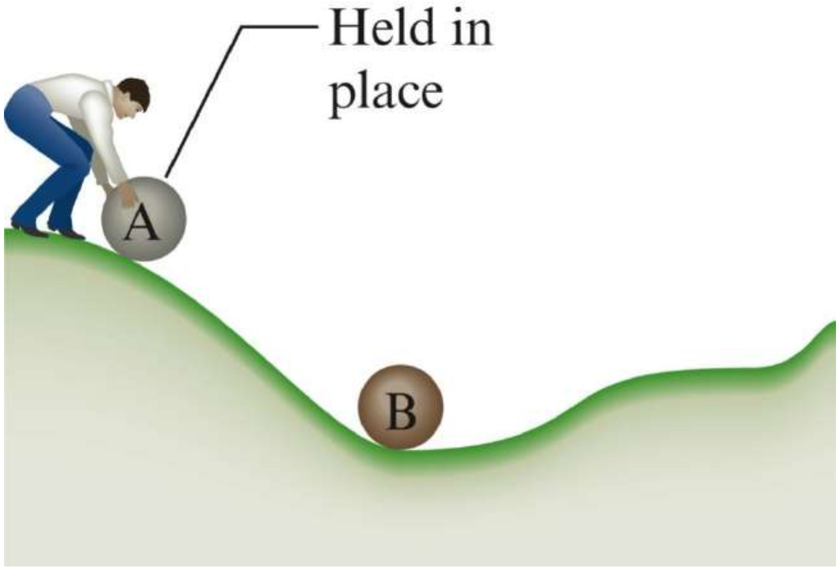

A
B

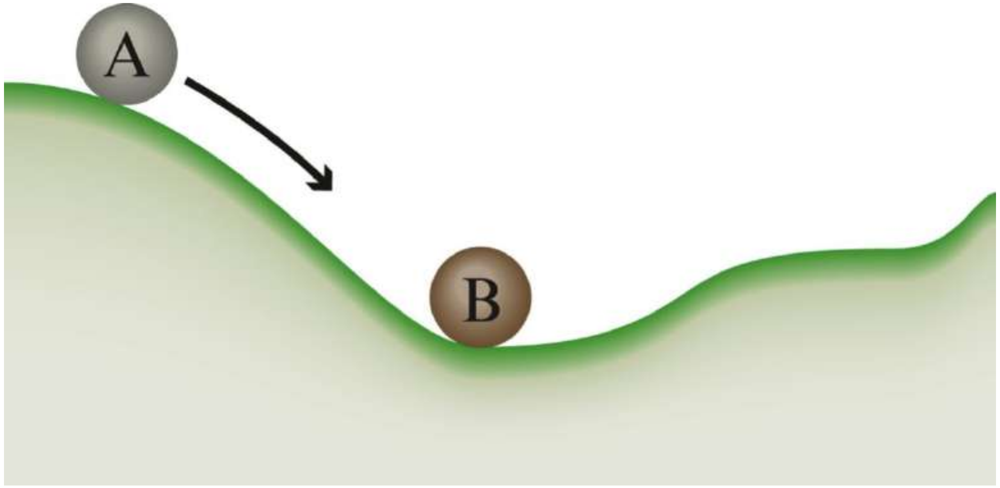
A. The Nature of Energy

- Energy is the ability to do work or produce heat.

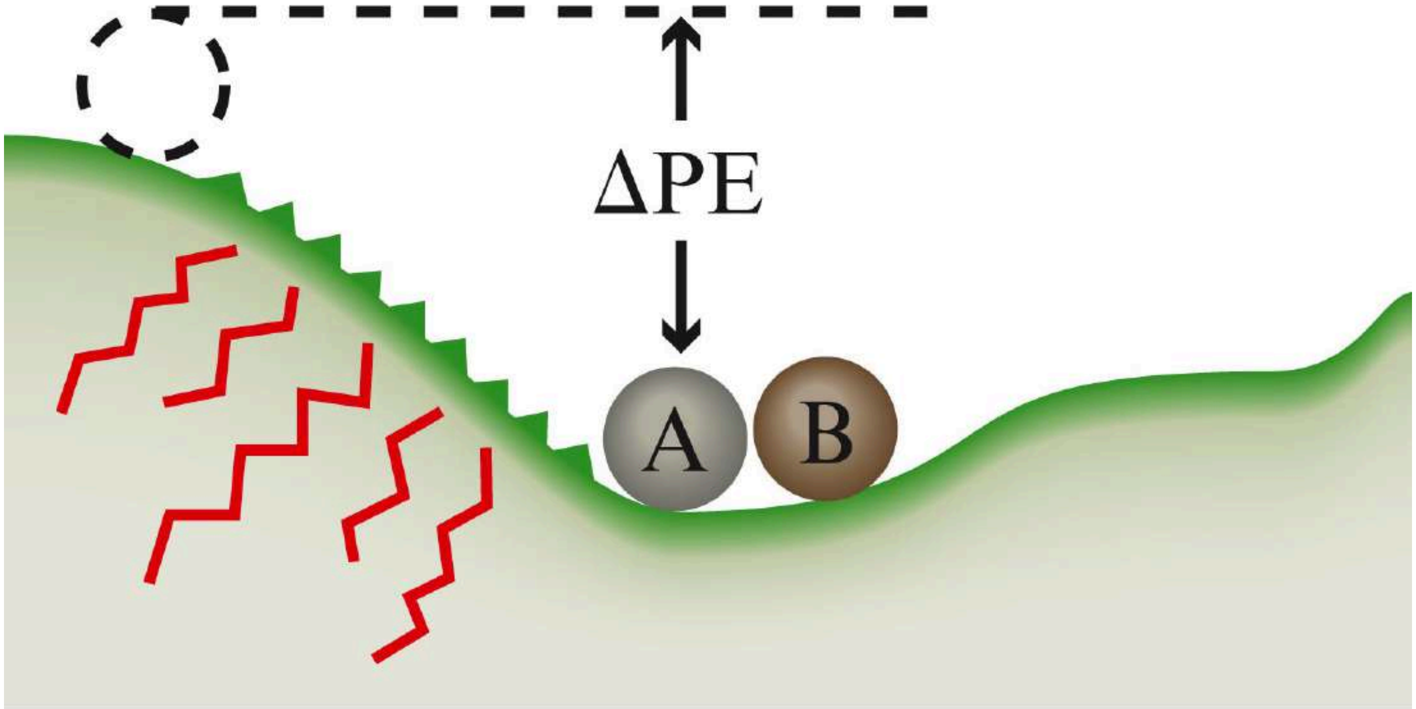
Potential energy
Energy of position

Kinetic energy
Energy of motion
$E = \frac{1}{2} mv2$





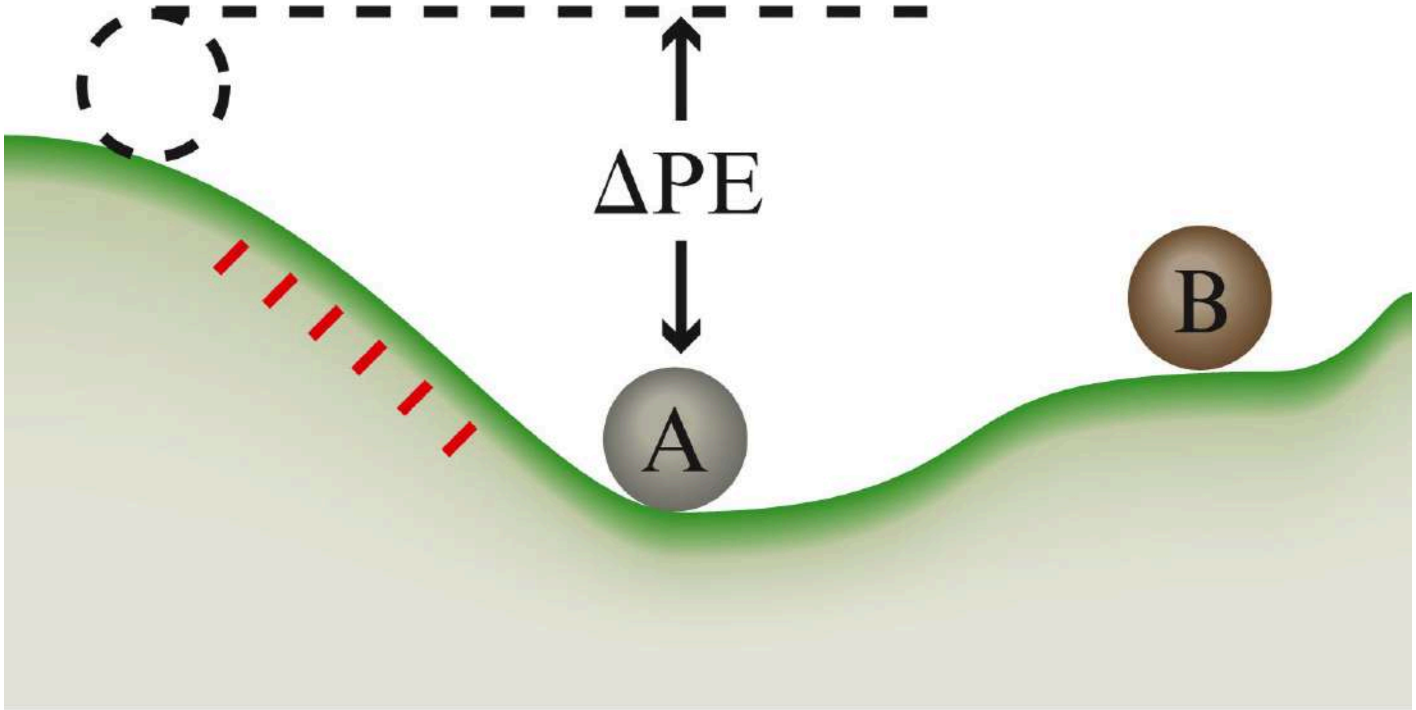
Rough surface



Less work

More heat

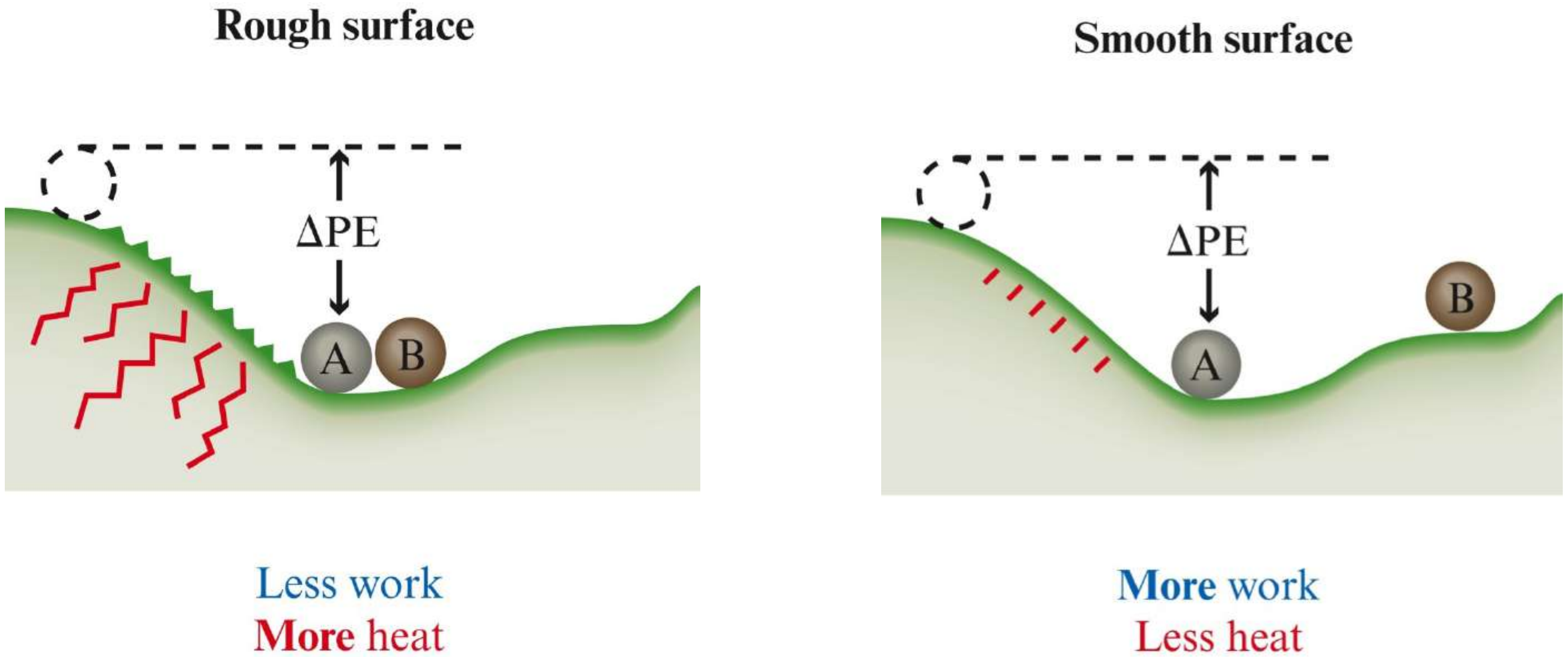
Smooth surface



More work
Less heat

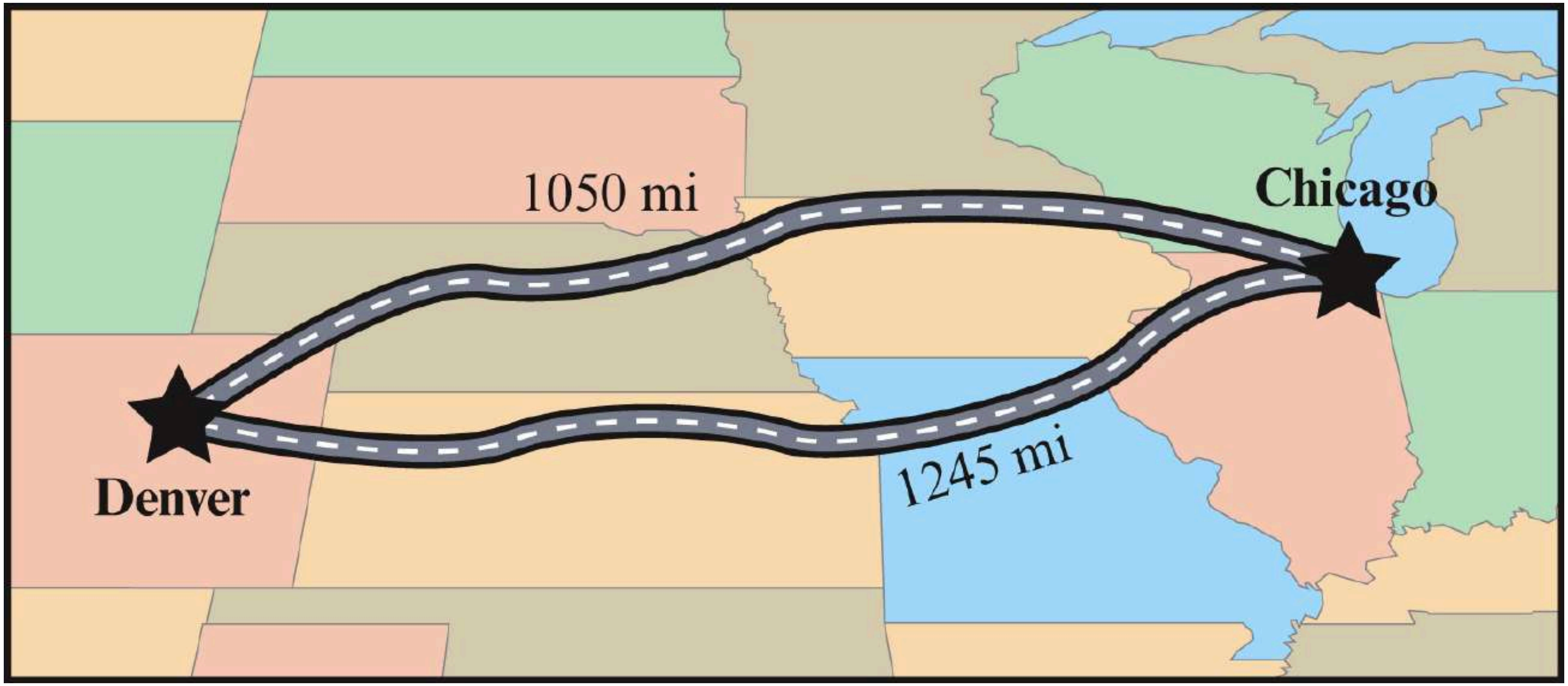
A. The Nature of Energy

- Law of conservation of energy
  - Energy can be converted from one form to another but can neither be created or destroyed.



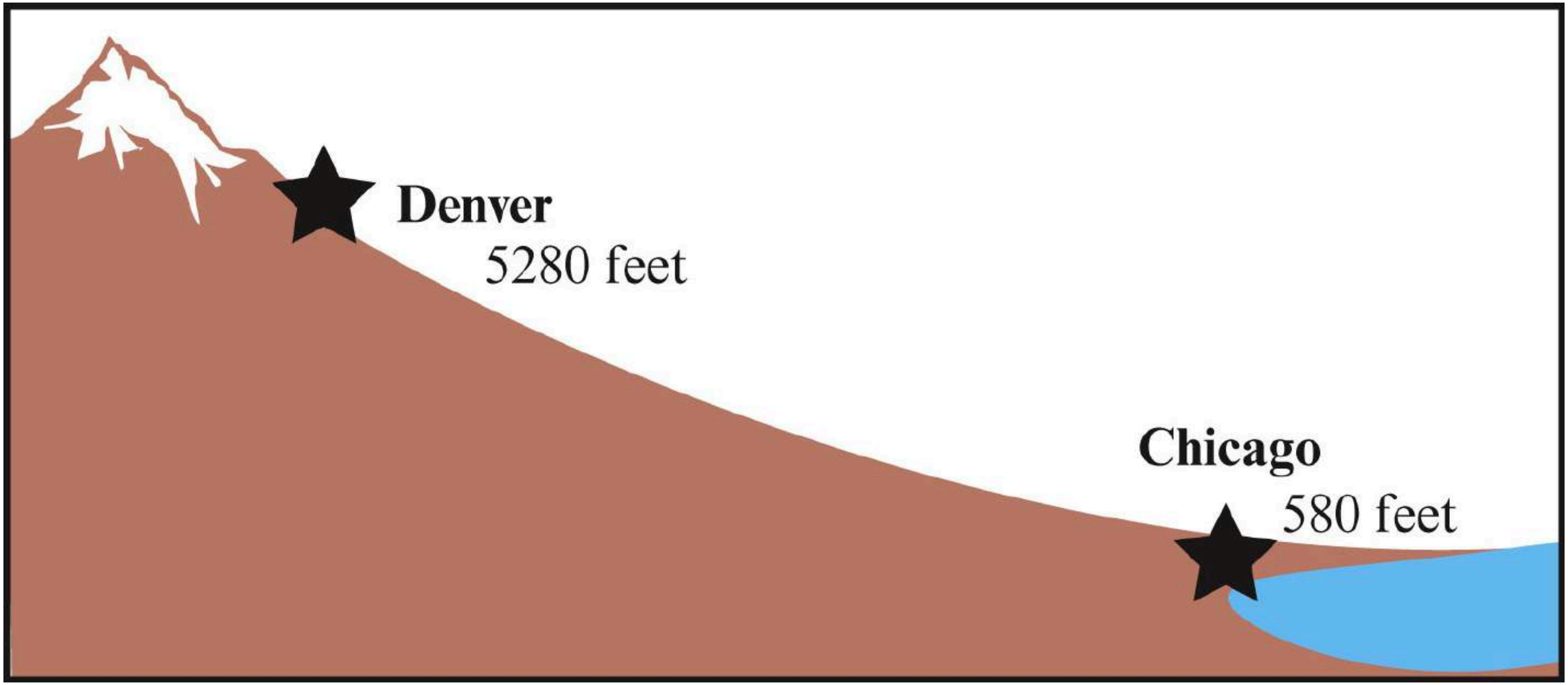
A. The Nature of Energy

- State function
  - Property of the system that changes independent of path
  - Is this a state function?



A. The Nature of Energy

- Is this a state function?



A. The Nature of Energy

- Are these state functions?

  Energy
  Work
  Heat

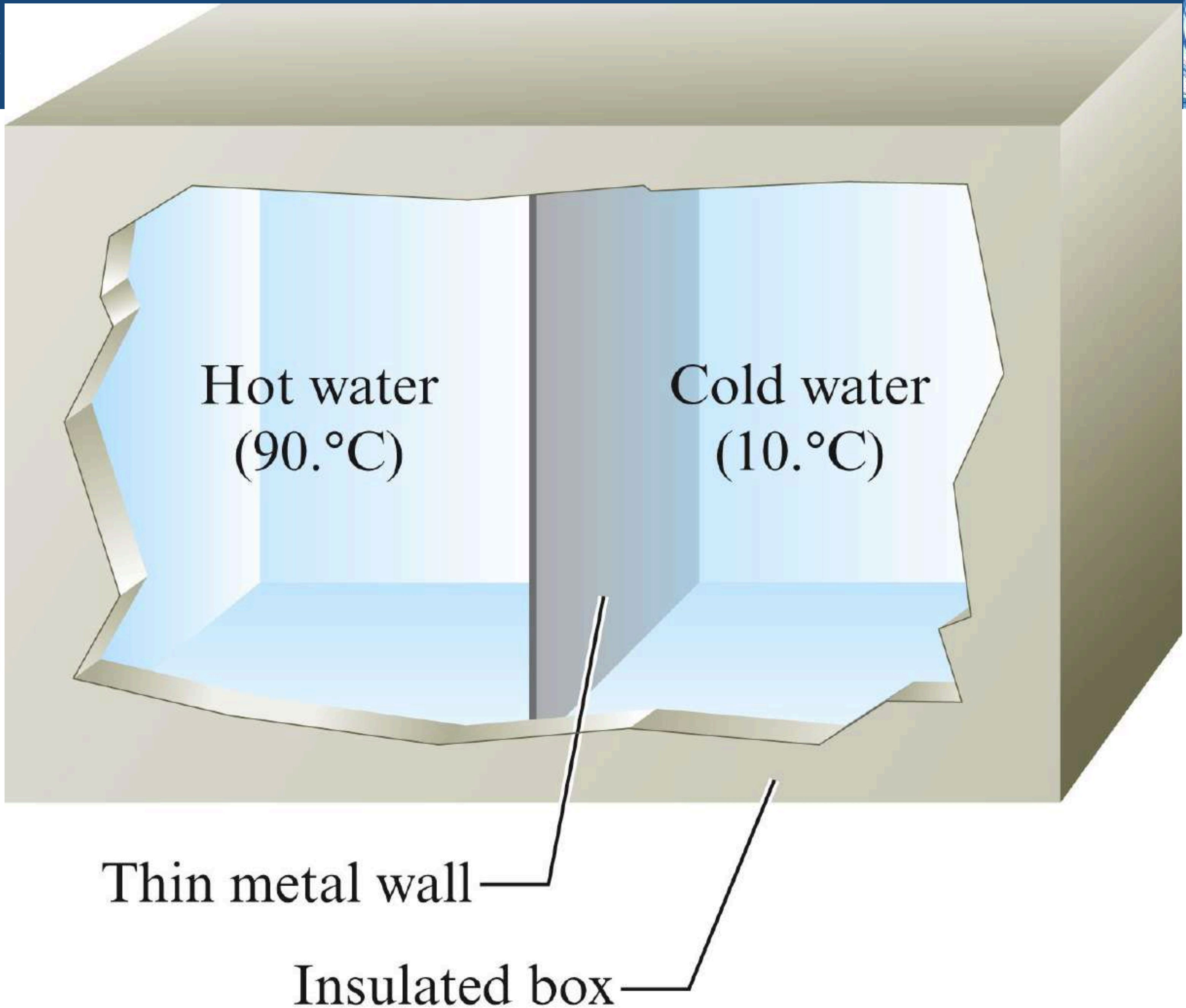


Figure 10-1 p343

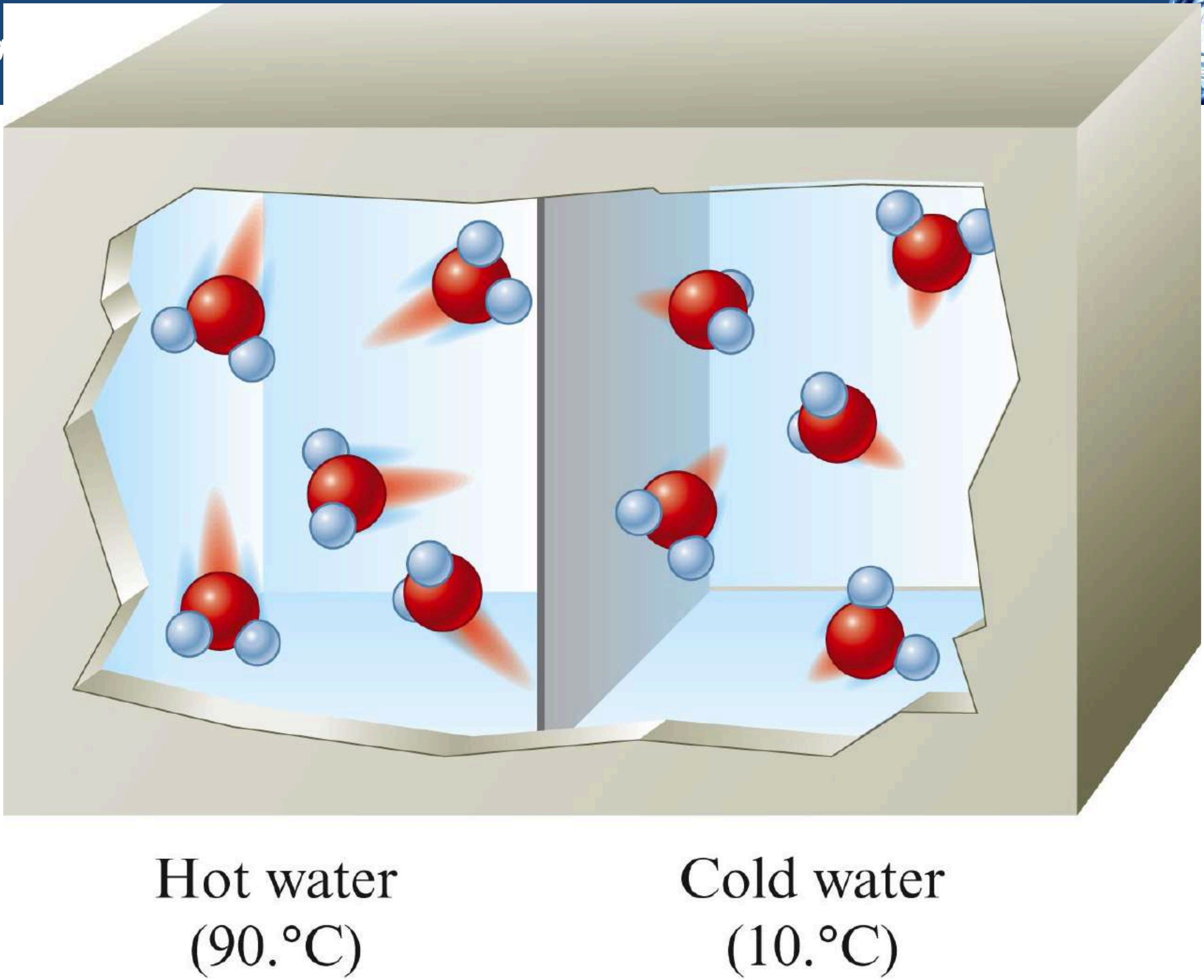
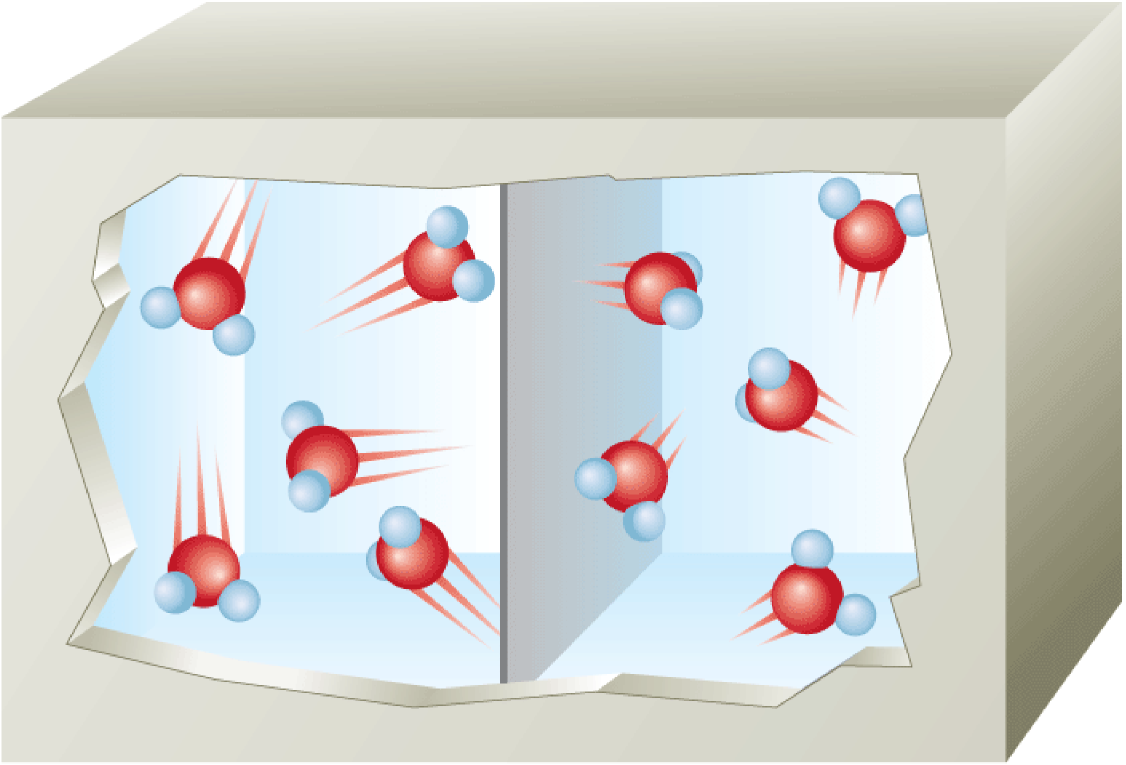


Figure 10-2 p343

B. Temperature and Heat

- Temperature is a measure of the random motions of the components of a substance.



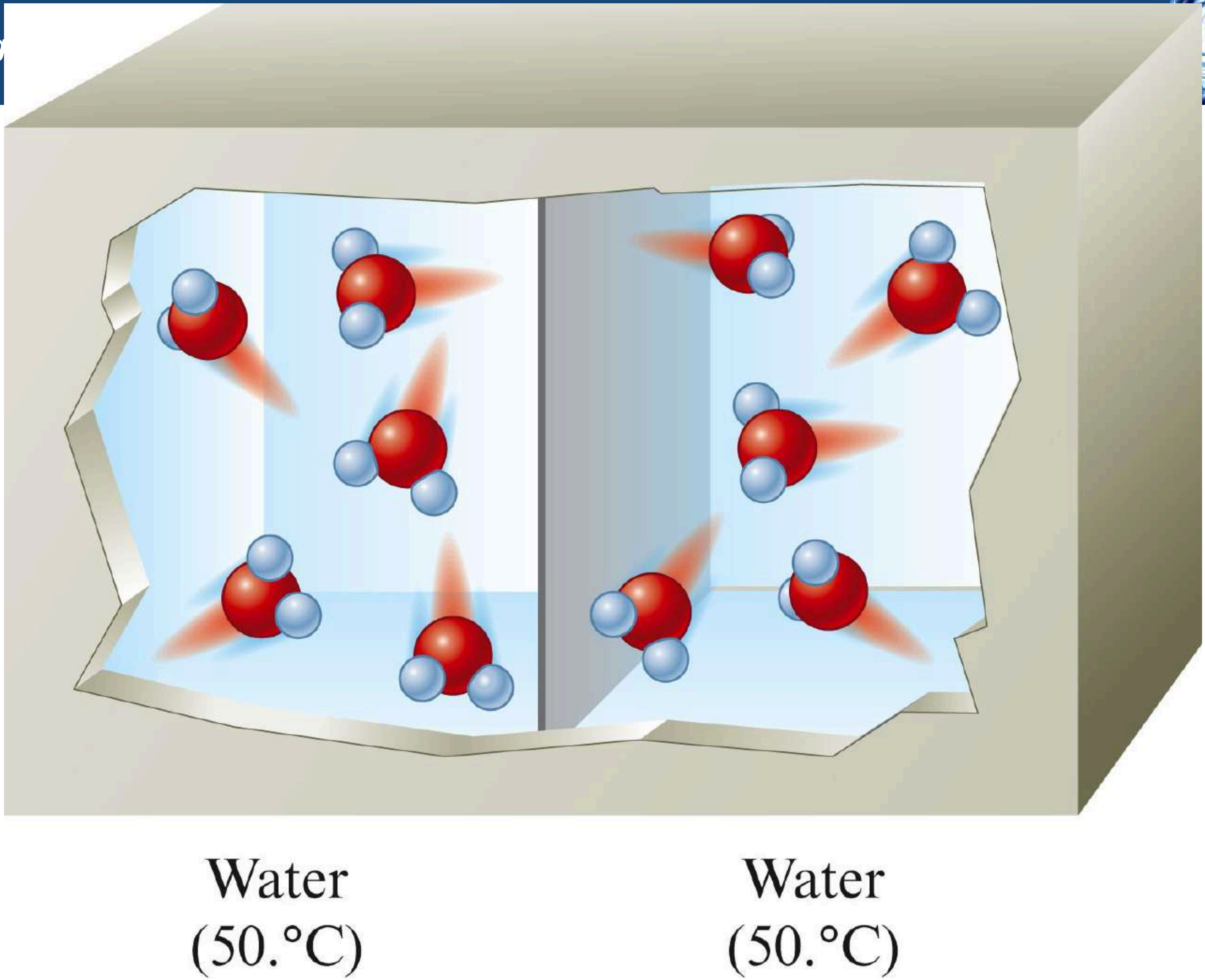
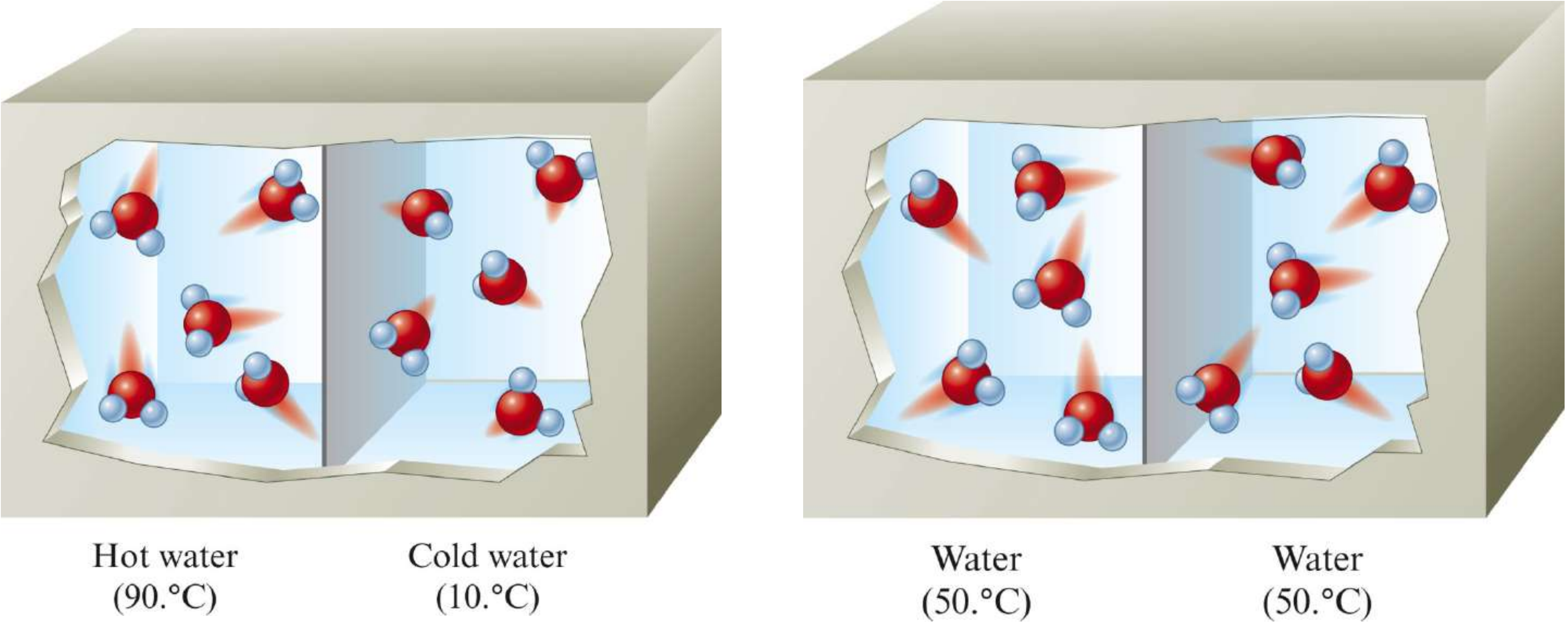


Figure 10-3 p343

B. Temperature and Heat

- Heat is a *flow* of energy between two objects due to a temperature difference between the objects.

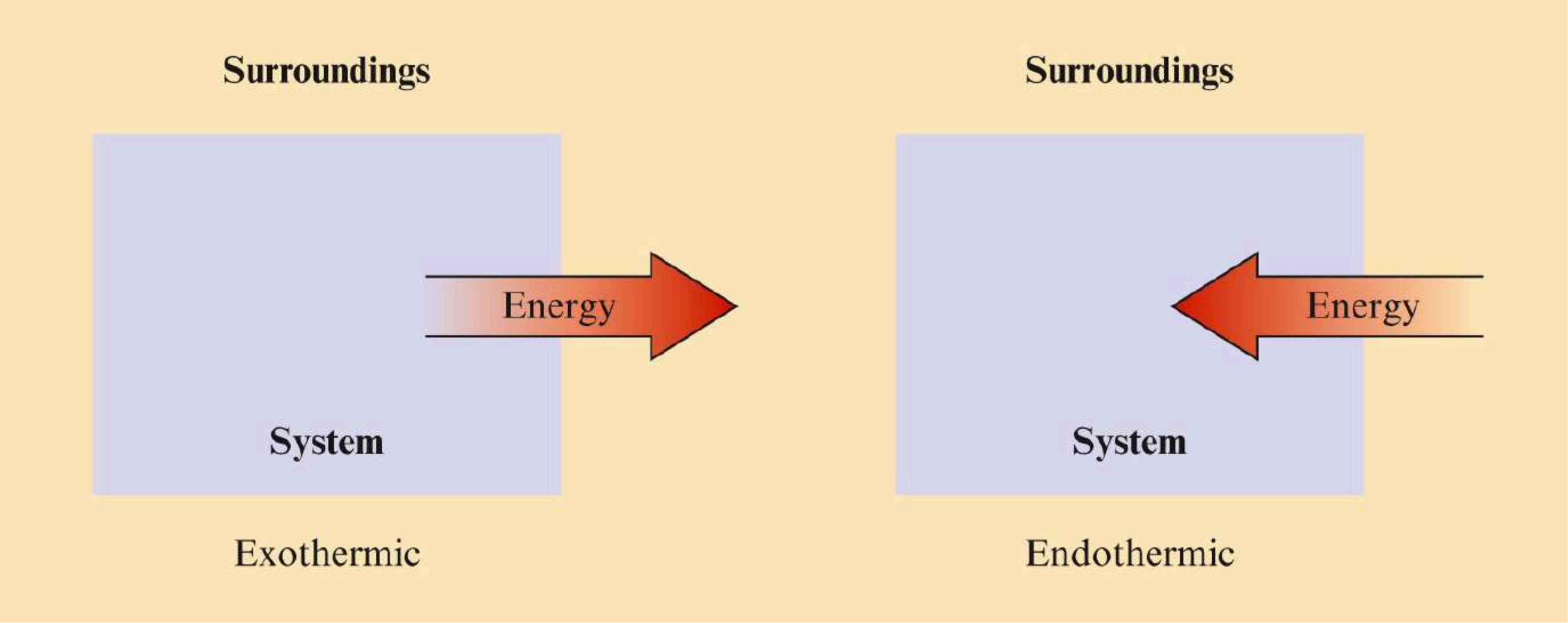


B. Temperature and Heat

- Heat is the way in which thermal energy is transferred from a hot object to a colder object.

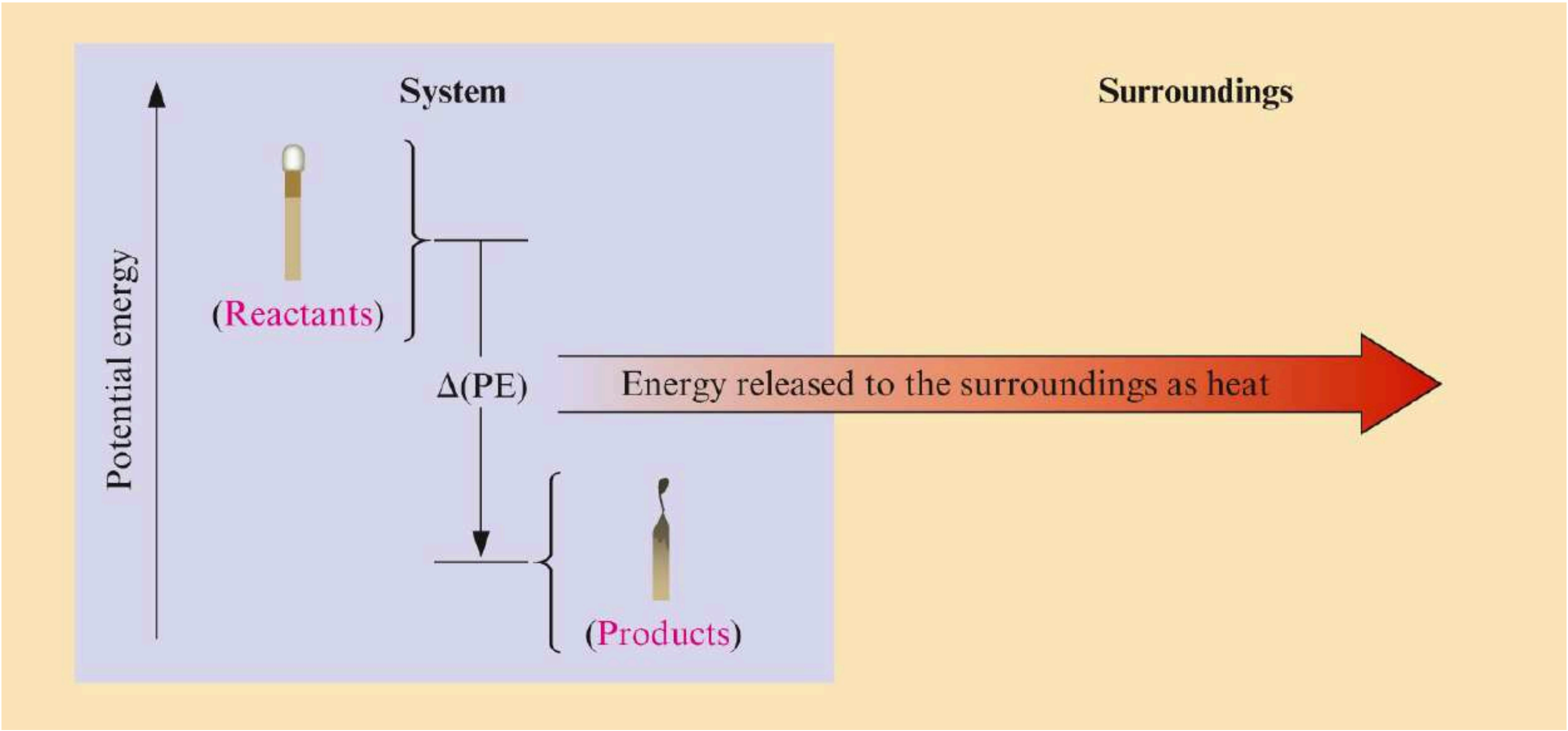
C. Exothermic and Endothermic Processes

- Exothermic – energy flows out of the system
- *Endothermic – energy flows into the system*



C. Exothermic and Endothermic Processes

- System – part of the universe on which we focus attention
- Surroundings – everything else in the universe
- Burning a match



Concept Check

Is the freezing of water an endothermic or exothermic process? Explain.

Figure 10-4b p345

Concept Check

Classify each process as exothermic or endothermic. Explain. The system is underlined in each example.

- Exo — a) Your hand gets cold when you touch ice.
- Endo — b) The ice gets warmer when you touch it.
- Endo — c) Water boils in a kettle being heated on a stove.
- Exo — d) Water vapor condenses on a cold pipe.
- Endo — e) Ice cream melts.

Concept Check

For each of the following, define a system and its surroundings and give the direction of energy transfer.

a) Methane is burning in a Bunsen burner in a laboratory.

b) Water drops, sitting on your skin after swimming, evaporate.

Concept Check

Hydrogen gas and oxygen gas react violently to form water. Explain.

- Which is lower in energy: a mixture of hydrogen and oxygen gases, or water?

Objectives

1. To understand how energy flow affects internal energy
2. To understand how heat is measured

A. Thermodynamics

- Thermodynamics – study of energy
- First law of thermodynamics
  - Energy of the universe is constant.

A. Thermodynamics

- Internal energy, E – sum of kinetic and potential energies of all the "particles" in a system
  - Internal energy can be changed by two types of energy flow:

    Heat (q)

    Work (w)

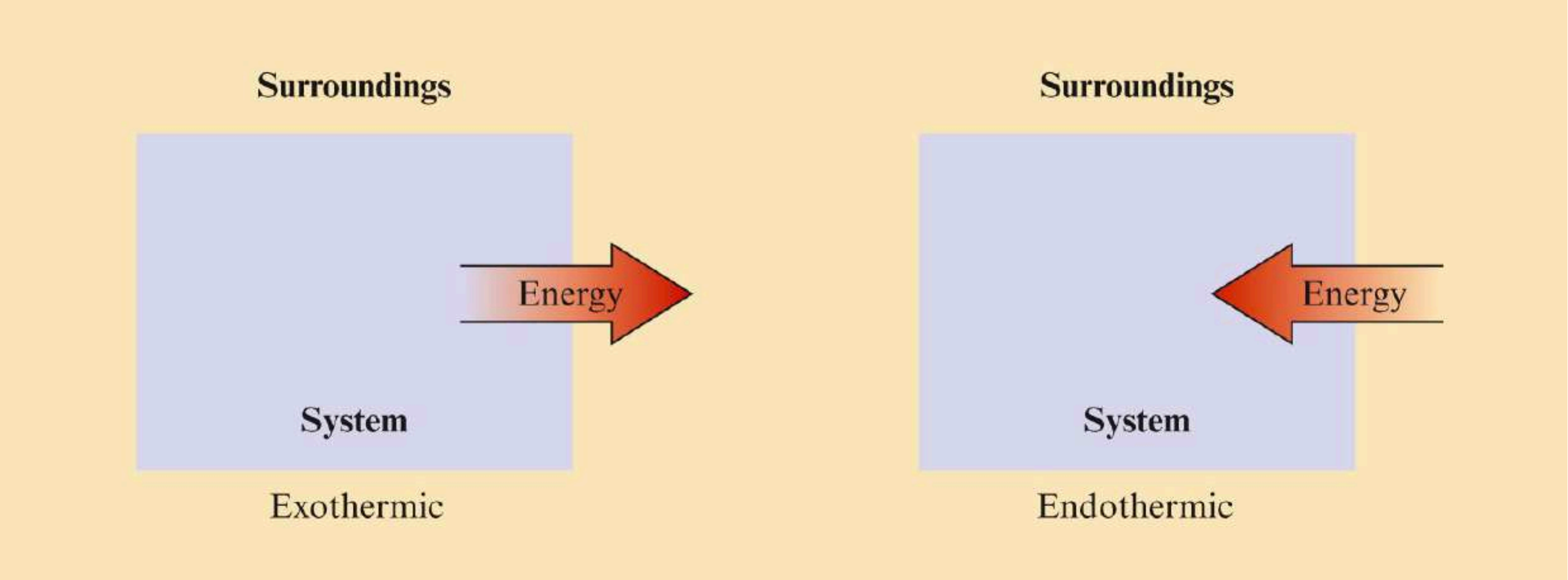
$$\Delta E = q + w$$

A. Thermodynamics

- Thermodynamic quantities always consist of 2 parts:
  - A number (magnitude of the change)
  - A sign (indicates the direction of flow)

    Reflects the systems point of view

A. Thermodynamics



- $q = -x$
- negative q → system's energy decreases
- $\Delta E < 0$

- $q = +x$
- positive q → system's energy increases
- $\Delta E > 0$

Exercise

A gas absorbs 55 kJ of heat and does 23 kJ of work. Calculate ΔE.

+32 kJ

Concept Check

Determine the sign of ΔE for each of the following with the listed conditions:

a) An endothermic process that performs work.

- |work| > |heat| ΔE = negative
- |work| < |heat| ΔE = positive

b) Work is done on a gas and the process is exothermic.

- |work| > |heat| ΔE = positive
- |work| < |heat| ΔE = negative

Conceptual Problem Solving

- Where do we want to go?
  - Read the problem and decide on the final goal.
- How do we get there?
  - Work backwards from the final goal to decide where to start.
- Reality check.
  - Does my answer make sense? Is it reasonable?

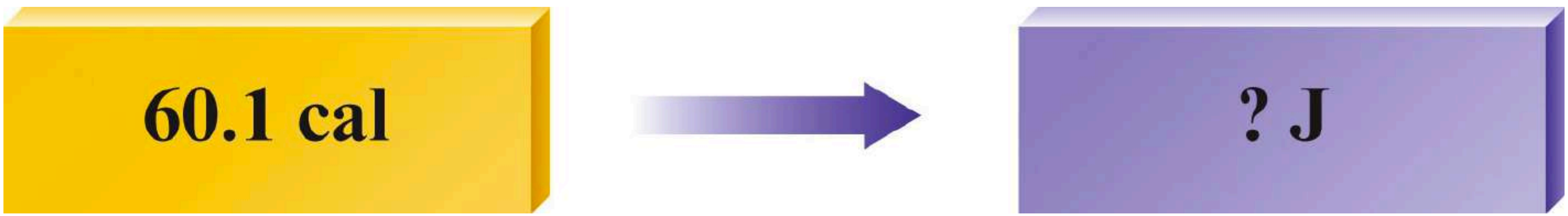

Diet
LIME CRUSH
LOW JOULE LIME
NATURAL
COLOURS & FLAVOURS

B. Measuring Energy Changes

- The common energy units for heat are the calorie and the joule.
  - Calorie – the amount of energy (heat) required to raise the temperature of one gram of water 1^{o}C
  - Joule – 1 calorie = 4.184 joules

Section 10.2

The Flow of Energy



B. Measuring Energy Changes

⟪ Let's Review

The energy (heat) required to change the temperature of a substance depends on

- the amount of substance being heated (number of grams)
- the temperature change (number of degrees)

B. Measuring Energy Changes

- Specific heat capacity is the energy required to change the temperature of a mass of one gram of a substance by one Celsius degree.

Table 10.1 The Specific Heat Capacities of Some Common Substances

Substance	Specific Heat Capacity (J/g°C)
water (*l*)* (liquid)	4.184
water (*s*) (ice)	2.03
water (*g*) (steam)	2.0
aluminum (*s*)	0.89
iron (*s*)	0.45
mercury (*l*)	0.14
carbon (*s*)	0.71
silver (*s*)	0.24
gold (*s*)	0.13
copper (*s*)	0.385

*The symbols (*s*), (*l*), and (*g*) indicate the solid, liquid, and gaseous states, respectively.

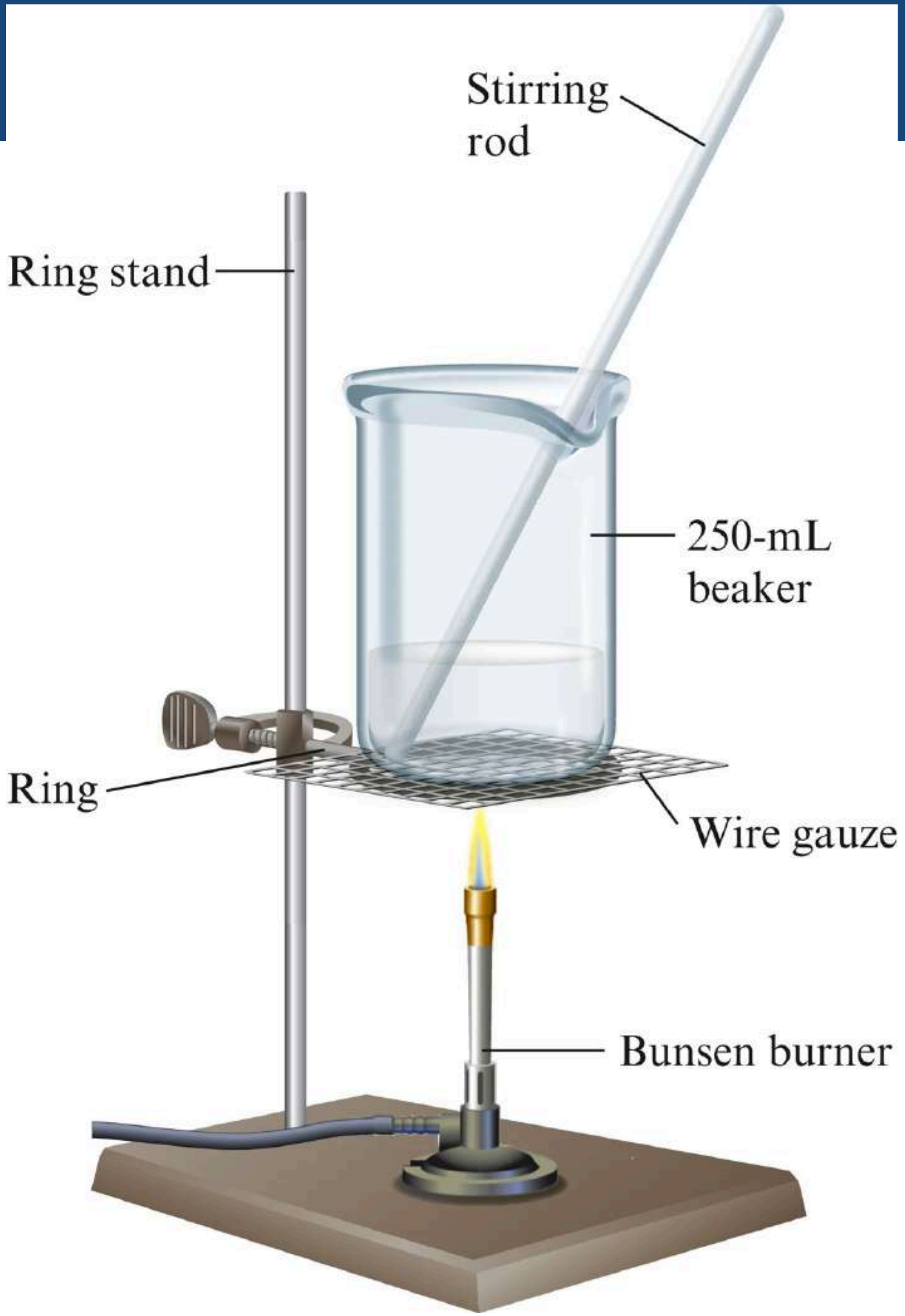
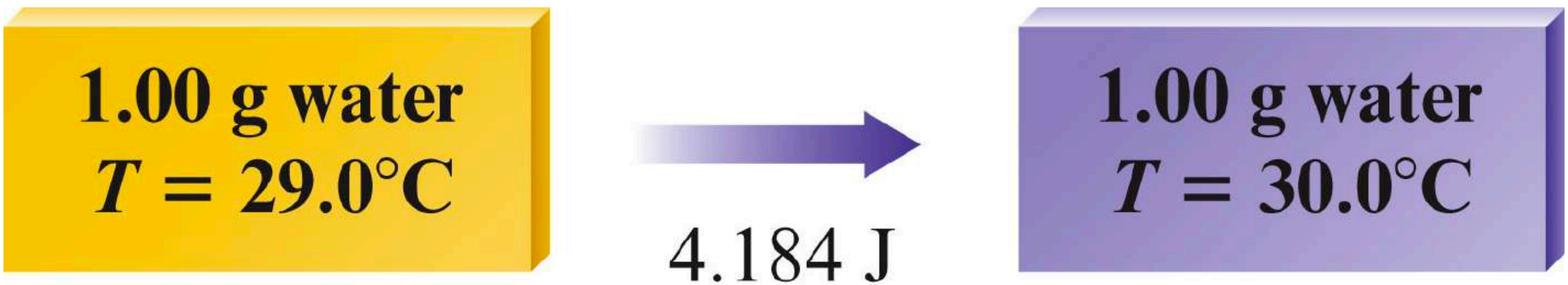


Figure 1 p380

The Flow of Energy



B. Measuring Energy Changes

- To calculate the energy required for a reaction:

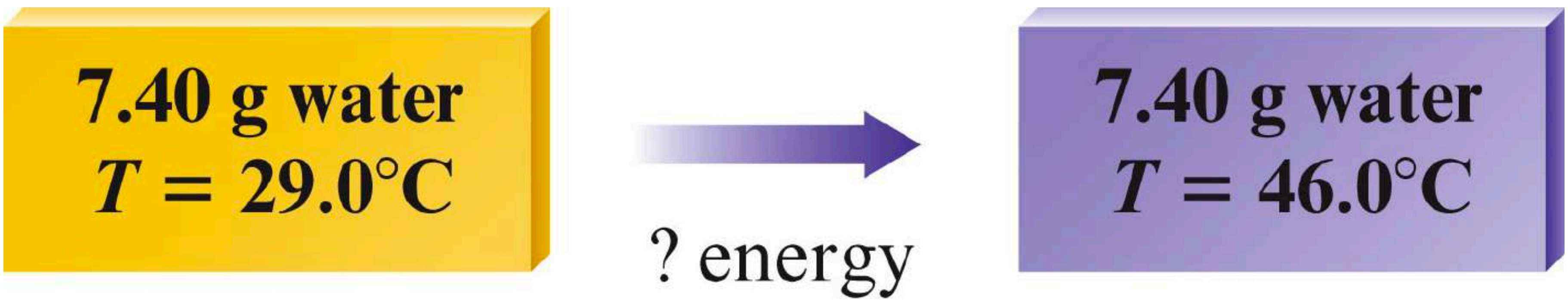
Energy (heat) required (Q) = **Specific heat capacity (s)** × **Mass (m) in grams of sample** × **Changes in temperature (ΔT) in °C**

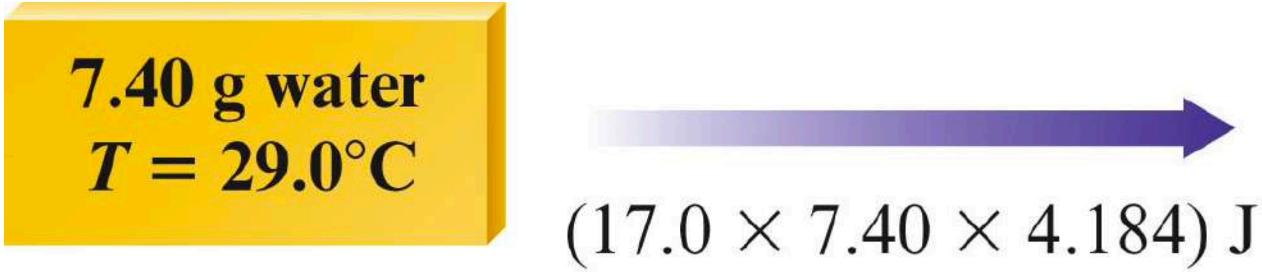
$$Q = s \times m \times \Delta T$$

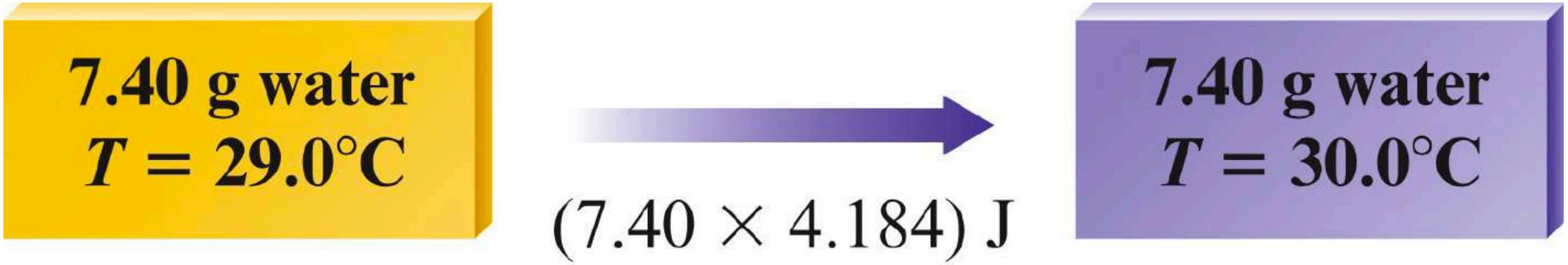
Exercise

If 75.0 kJ of heat is applied to a 986-g block of metal, the temperature of the metal increases by 85.5°C. Calculate the specific heat capacity of the metal in J/g°C.

0.89 J/g°C

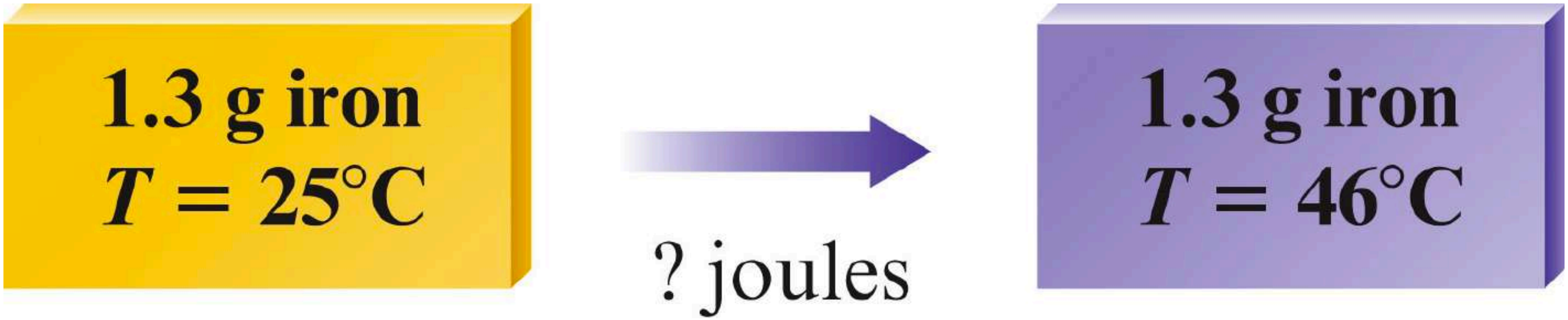

7.40 g water
T = 29.0°C
? energy
7.40 g water
T = 46.0°C

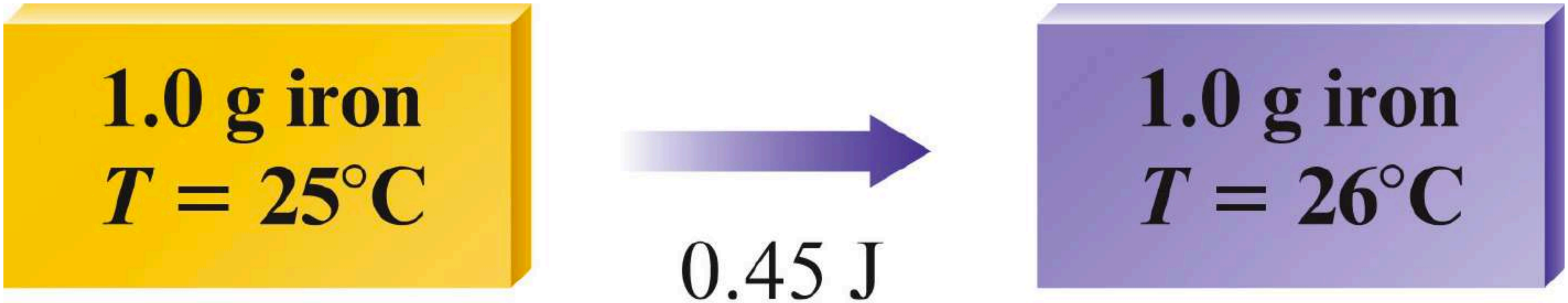

7.40 g water
T = 29.0°C
(17.0 × 7.40 × 4.184) J
7.40 g water
T = 46.0°C

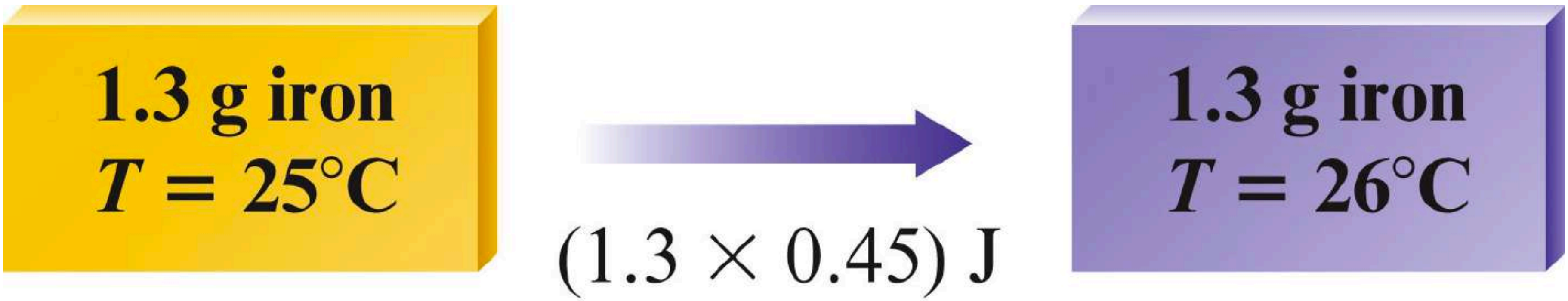

7.40 g water
T = 29.0°C
(7.40 × 4.184) J
7.40 g water
T = 30.0°C

Objectives

1. To consider the heat (enthalpy) of chemical reactions
2. To understand Hess’s Law


1.3 g iron
T = 25°C
? joules
1.3 g iron
T = 46°C


1.0 g iron
T = 25°C
0.45 J
1.0 g iron
T = 26°C

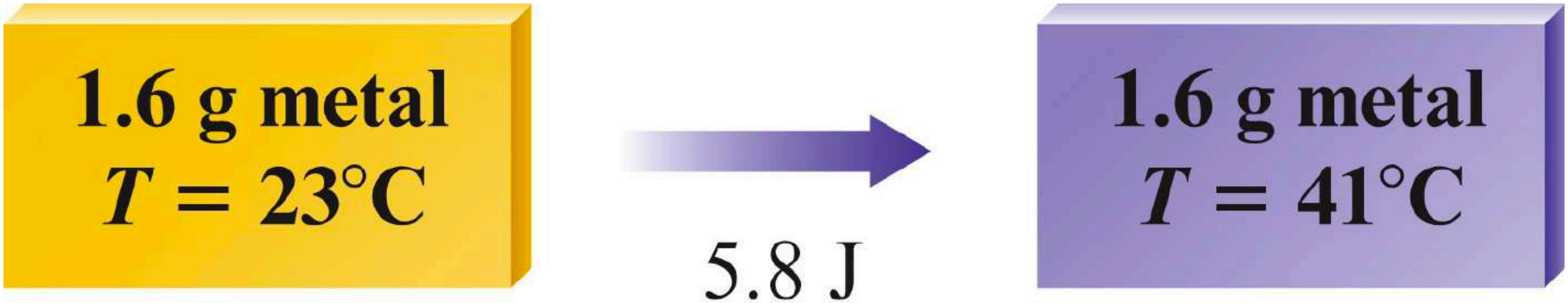

1.3 g iron
T = 25°C
(1.3 × 0.45) J
1.3 g iron
T = 26°C

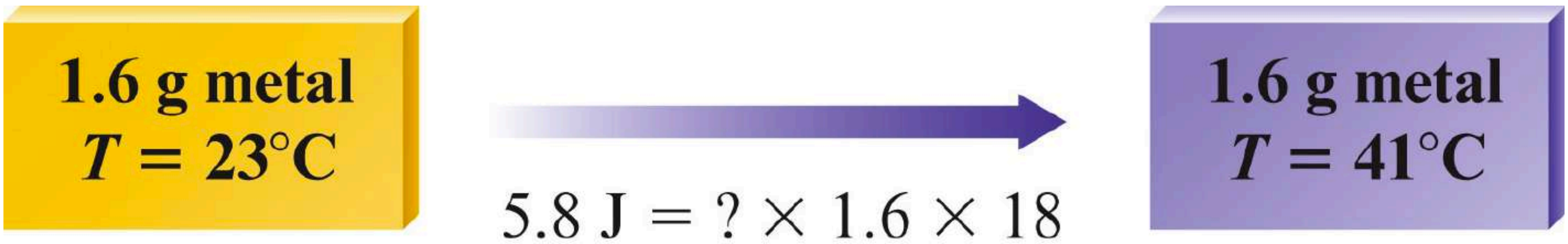

1.3 g iron
T = 25°C
(21 × 1.3 × 0.45) J
1.3 g iron
T = 46°C

Energy and Chemical Reactions

Energy (heat) required (Q) = Specific heat capacity (s) × Mass (m) in grams of sample × Changes in temperature (ΔT) in °C


HOT & fresh TOASTED
Cal
6" sub
560 Meatball Marinara
450 Italian B.M.T.®
480 Spicy Italian
400 Prime Rib
380 Subway Melt®
580 Chicken & Bacon Ranch
FAVORITES


1.6 g metal
T = 23°C
5.8 J
1.6 g metal
T = 41°C


1.6 g metal
T = 23°C
5.8 J = ? × 1.6 × 18
1.6 g metal
T = 41°C

A. Thermochemistry (Enthalpy)

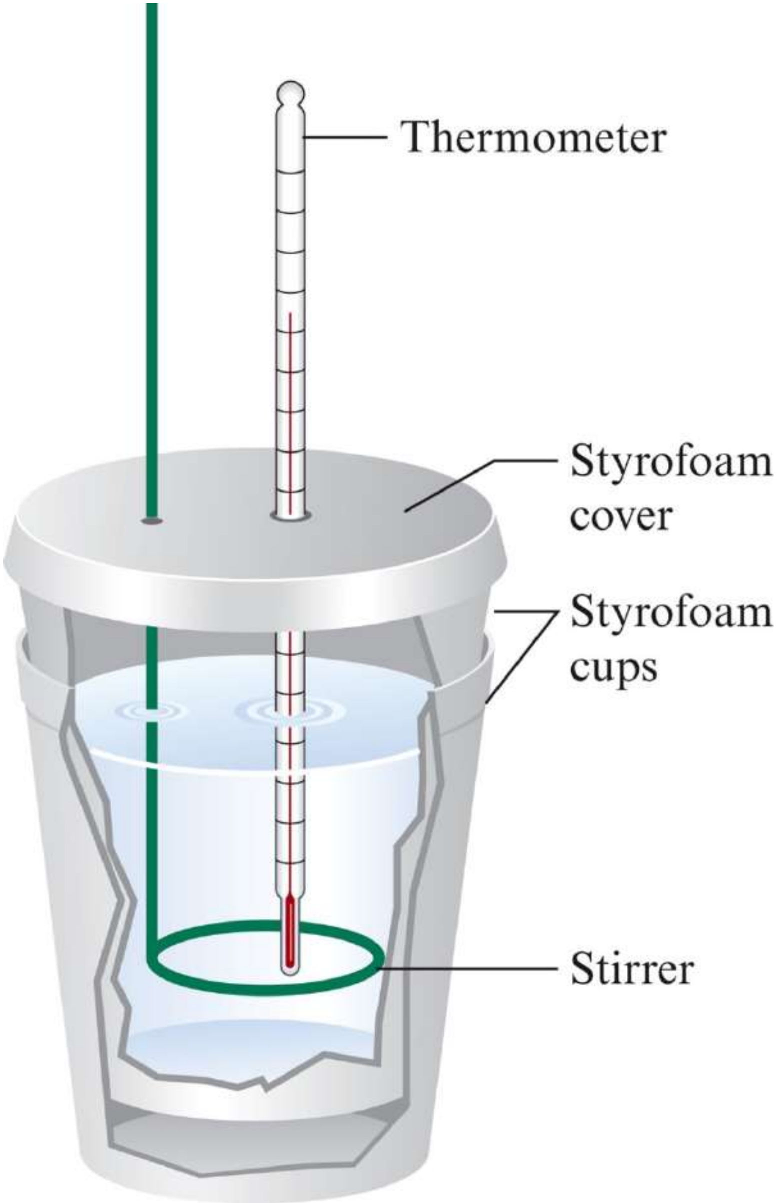
- Enthalpy, H – energy function
  - At constant pressure ΔH is equal to the energy that flows as heat.

  ΔH_p = heat

A. Thermochemistry (Enthalpy)

Calorimetry

- Enthalpy, *H* is measured using a calorimeter



B. Hess's Law

- In going from a particular set of reactants to a particular set of products, the change in enthalpy is the same whether the reaction takes place in one step or in a series of steps.

$N_2(g) + 2O_2(g) \rightarrow 2NO_2(g)$ $\Delta H_1 = 68\ kJ$

- This reaction also can be carried out in two distinct steps, with enthalpy changes designated by ΔH_2 and ΔH_3.

$$N_2(g) + O_2(g) \rightarrow \cancel{2NO(g)} \qquad \Delta H_2 = 180\ kJ$$

$$\cancel{2NO(g)} + O_2(g) \rightarrow 2NO_2(g) \qquad \Delta H_3 = -112\ kJ$$

$$N_2(g) + 2O_2(g) \rightarrow 2NO_2(g) \qquad \Delta H_2 + \Delta H_3 = 68\ kJ$$

$$\Delta H_1 = \Delta H_2 + \Delta H_3 = 68\ kJ$$

Characteristics of Enthalpy Changes

- If a reaction is reversed, the sign of ΔH is also reversed.
- The magnitude of ΔH is directly proportional to the quantities of reactants and products in a reaction. If the coefficients in a balanced reaction are multiplied by an integer, the value of ΔH is multiplied by the same integer.

Example

- Consider the following data:

$$NH_3(g) \longrightarrow \frac{1}{2}N_2(g) + \frac{3}{2}H_2(g) \qquad \Delta H = 46 \text{ kJ}$$

$$2\ H_2(g) + O_2(g) \longrightarrow 2\ H_2O(g) \qquad \Delta H = -484 \text{ kJ}$$

- Calculate ΔH for the reaction

$$2\ N_2(g) + 6\ H_2O(g) \longrightarrow 3\ O_2(g) + 4\ NH_3(g)$$

Problem-Solving Strategy

- Work *backward* from the required reaction, using the reactants and products to decide how to manipulate the other given reactions at your disposal.
- Reverse any reactions as needed to give the required reactants and products.
- Multiply reactions to give the correct numbers of reactants and products.

Example

- Reverse the two reactions:

$$\frac{1}{2}N_2(g) + \frac{3}{2}H_2(g) \longrightarrow NH_3(g) \qquad \Delta H = -46 \text{ kJ}$$

$$2\ H_2O(g) \longrightarrow 2\ H_2(g) + O_2(g) \qquad \Delta H = +484 \text{ kJ}$$

- Desired reaction:

$$2\ N_2(g) + 6\ H_2O(g) \longrightarrow 3\ O_2(g) + 4\ NH_3(g)$$

Example

- Multiply reactions to give the correct numbers of reactants and products:

$$4\left(\frac{1}{2}N_2(g) + \frac{3}{2}H_2(g) \longrightarrow NH_3(g)\right) \quad 4(\Delta H = -46\text{ kJ})$$

$$3\left(2\,H_2O(g) \longrightarrow 2\,H_2(g) + O_2(g)\right) \quad 3(\Delta H = +484\text{ kJ})$$

- Desired reaction:

$$2\,N_2(g) + 6\,H_2O(g) \longrightarrow 3\,O_2(g) + 4\,NH_3(g)$$

Example

- Final reactions:

$$2\ N_2(g) + \cancel{6\ H_2(g)} \longrightarrow 4\ NH_3(g) \qquad \Delta H = -184\ kJ$$

$$6\ H_2O(g) \longrightarrow \cancel{6\ H_2(g)} + 3\ O_2(g) \qquad \Delta H = +1452\ kJ$$

- Desired reaction:

$$2\ N_2(g) + 6\ H_2O(g) \longrightarrow 3\ O_2(g) + 4\ NH_3(g)$$

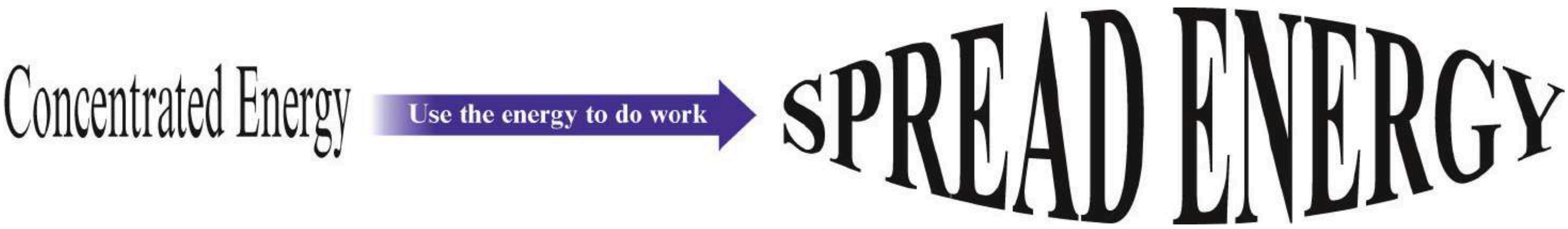
ΔH = +1268 kJ

Objectives

1. To understand how the quality of energy changes as it is used
2. To consider the energy resources of our world
3. To understand energy as a driving force for natural processes

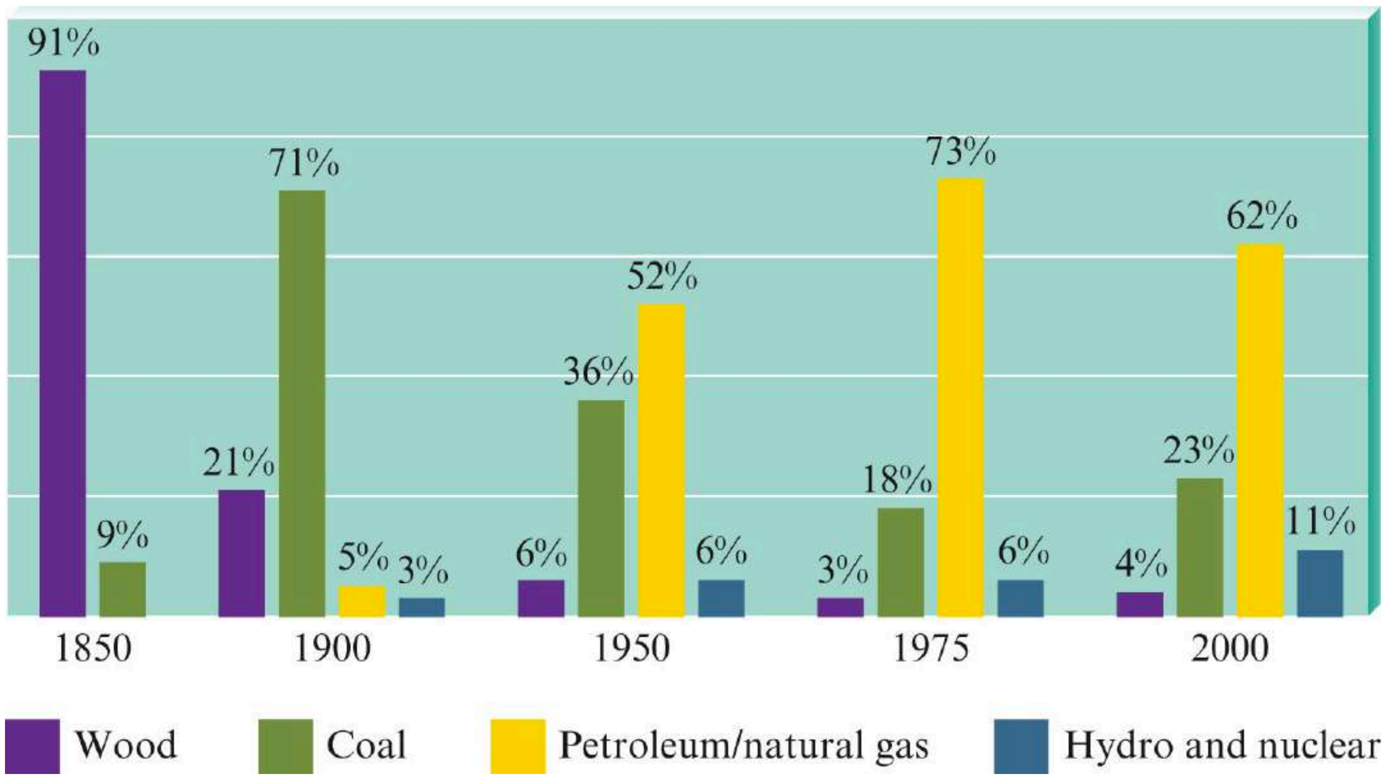
A. Quality Versus Quantity of Energy

- When we use energy to do work, we degrade its usefulness.

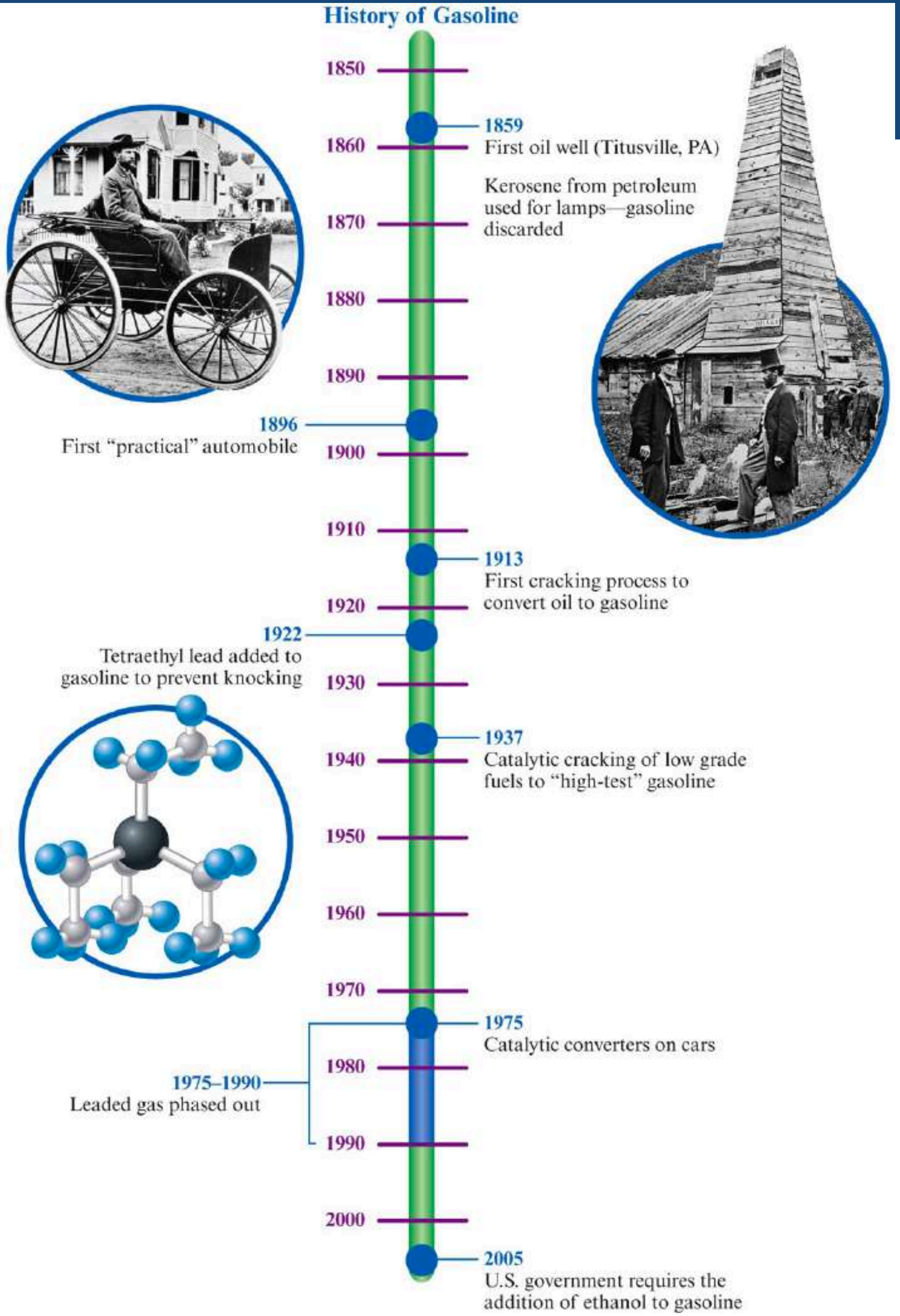


B. Energy and Our World

- Fossil fuel – carbon based molecules from decomposing plants and animals
  - Energy source for United States

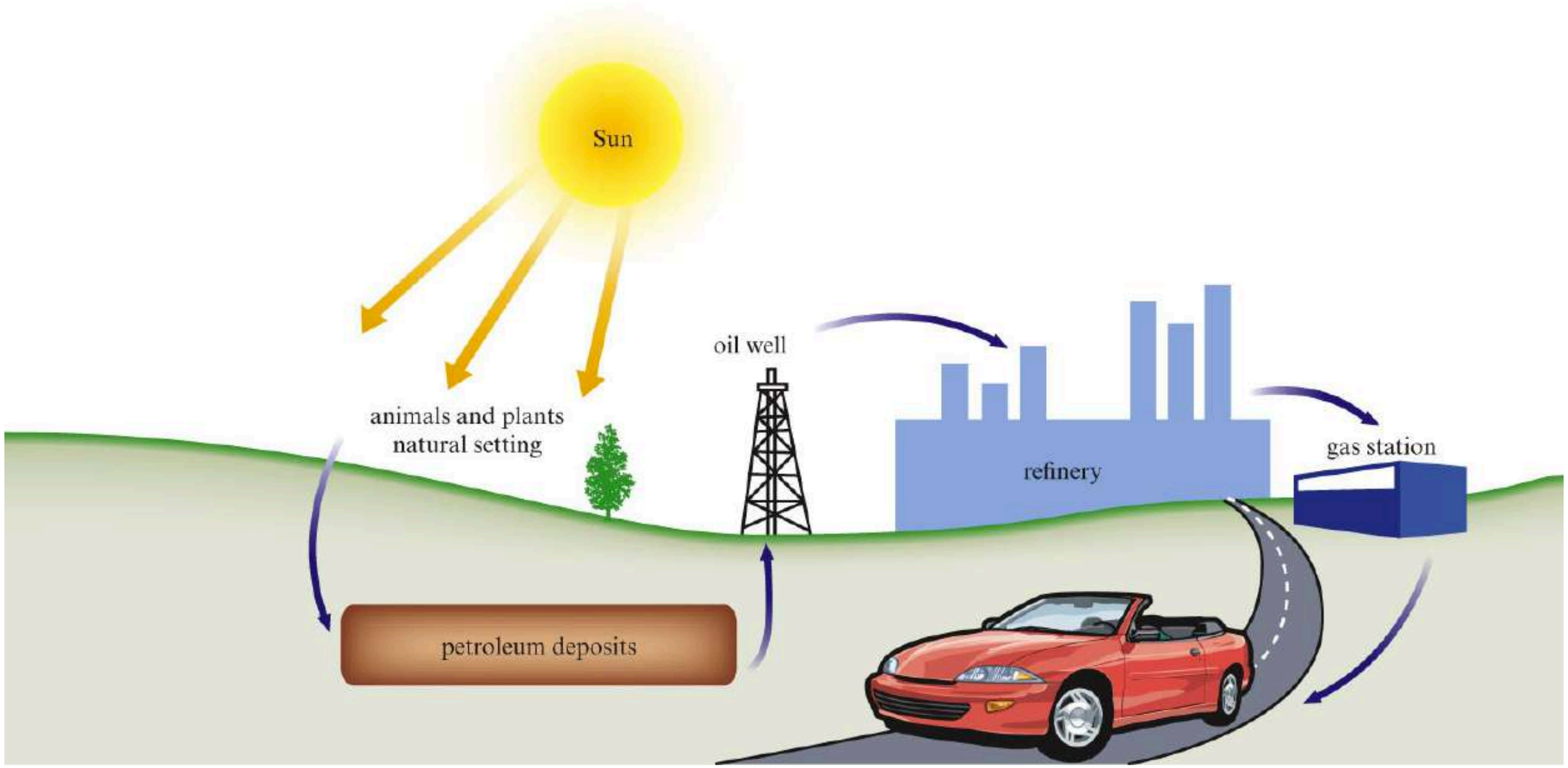


Using Energy in the Re



A. Quality Versus Quantity of Energy

- Petroleum as energy



Using Energy in the Real World

B. Energy and Our World

- Petroleum – thick liquids composed of mainly hydrocarbons
  - Hydrocarbon – compound composed of C and H

Table 10.3 Uses of the Various Petroleum Fractions

Petroleum Fraction in Terms of Numbers of Carbon Atoms	Major Uses
C_5–C_{10}	Gasoline
C_{10}–C_{18}	Kerosene Jet fuel
C_{15}–C_{25}	Diesel fuel Heating oil Lubricating oil
$>C_{25}$	Asphalt

B. Energy and Our World

- Natural gas – gas composed of hydrocarbons

Table 10.2 Formulas and Names of Some Common Hydrocarbons

Formula	Name
CH_4	Methane
C_2H_6	Ethane
C_3H_8	Propane
C_4H_{10}	Butane
C_5H_{12}	Pentane
C_6H_{14}	Hexane
C_7H_{16}	Heptane
C_8H_{18}	Octane

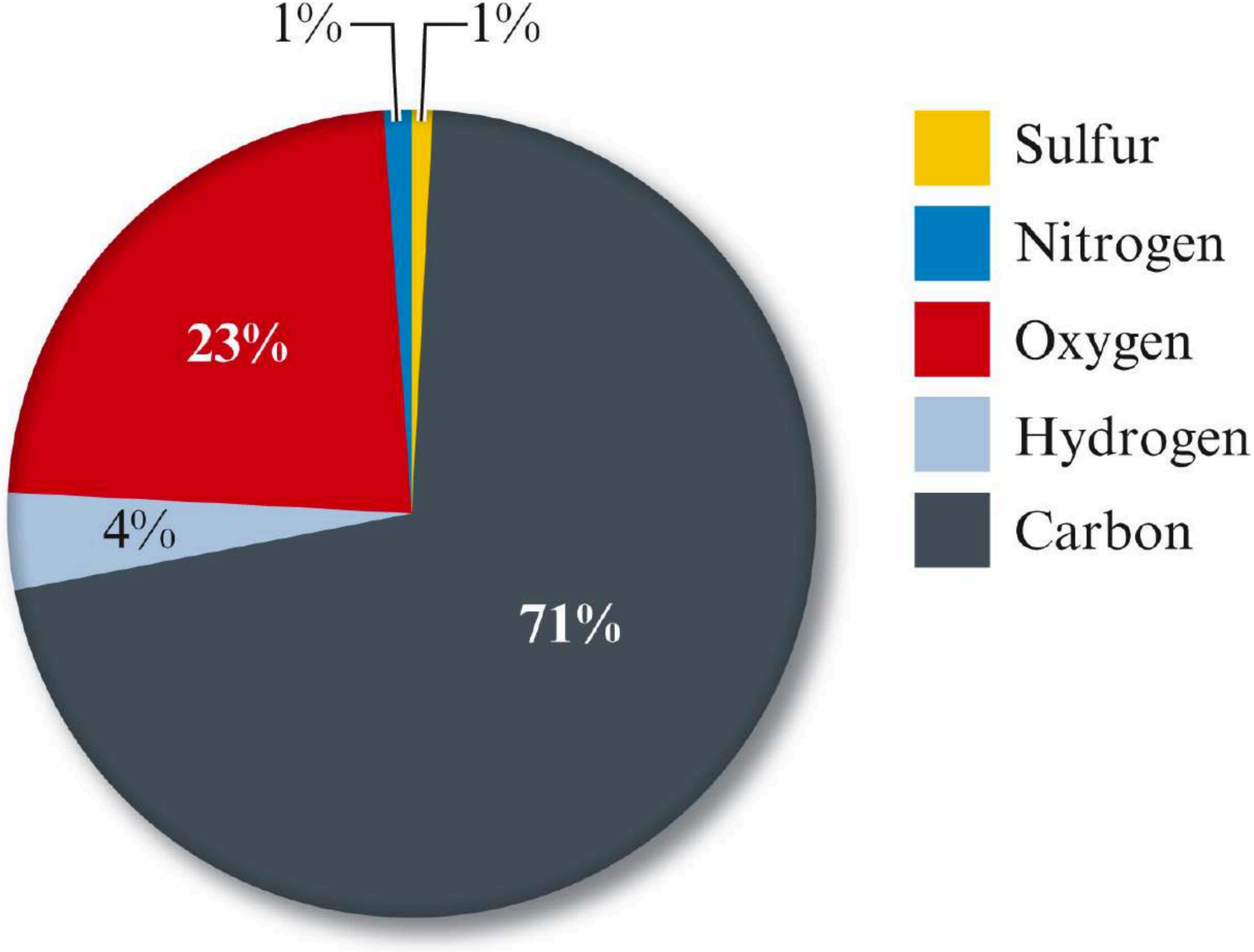
B. Energy and Our World

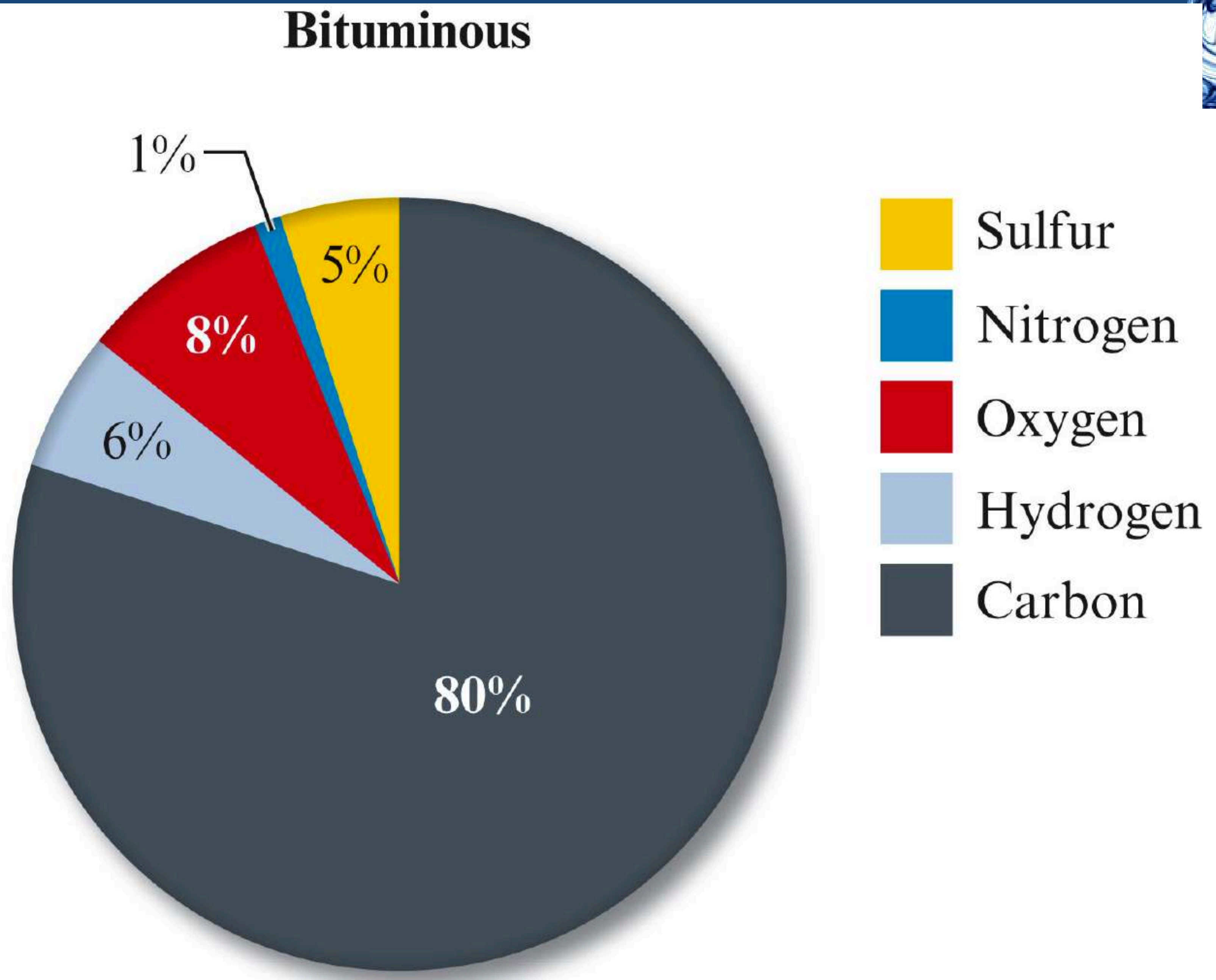
- Coal – formed from the remains of plants under high pressure and heat over time

Table 10.4 Element Composition of Various Types of Coal

	Mass Percent of Each Element				
Type of Coal	**C**	**H**	**O**	**N**	**S**
Lignite	71	4	23	1	1
Subbituminous	77	5	16	1	1
Bituminous	80	6	8	1	5
Anthracite	92	3	3	1	1

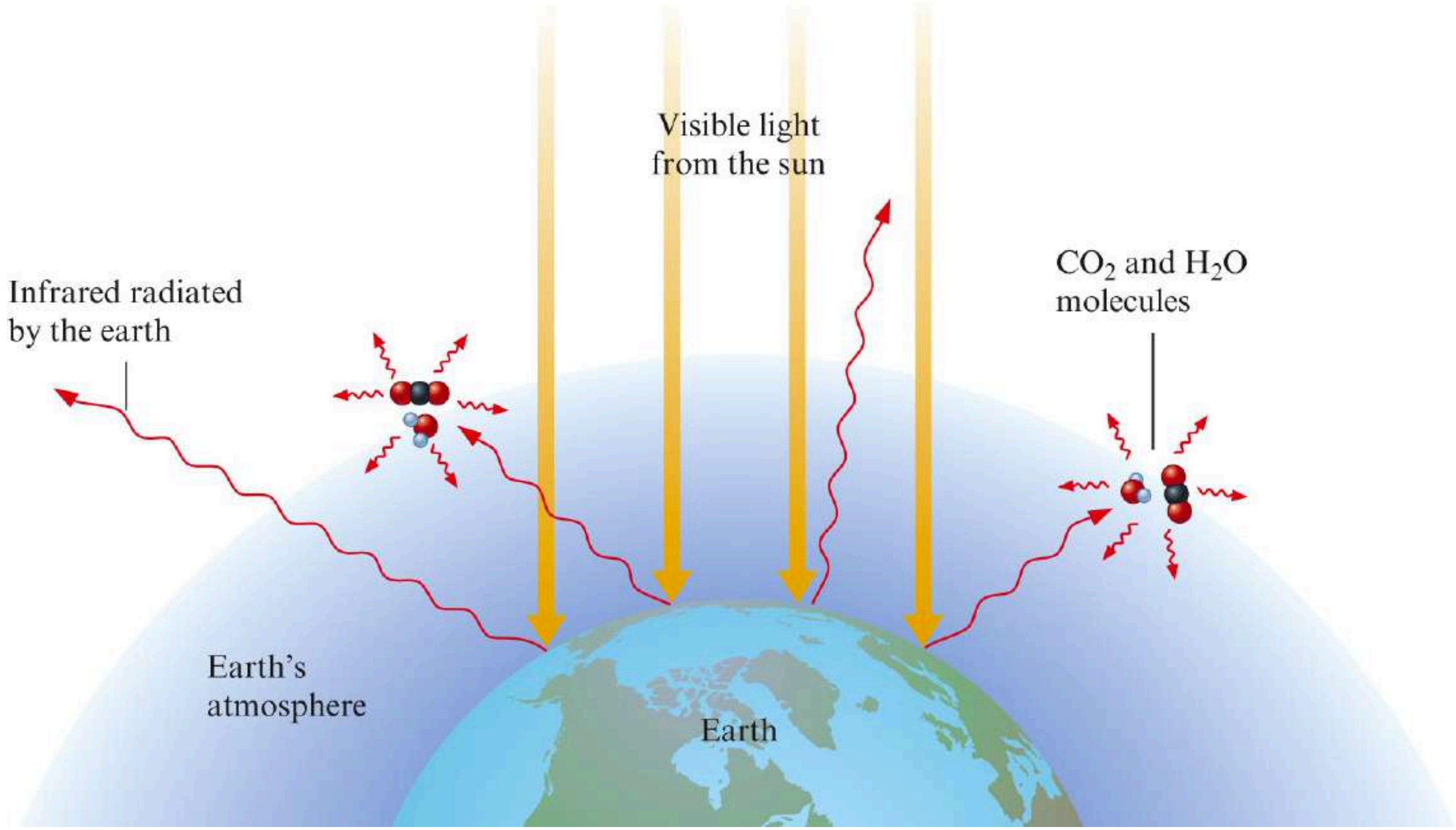
Lignite




Bituminous
1%
5%
8%
6%
80%
Sulfur
Nitrogen
Oxygen
Hydrogen
Carbon

B. Energy and Our World

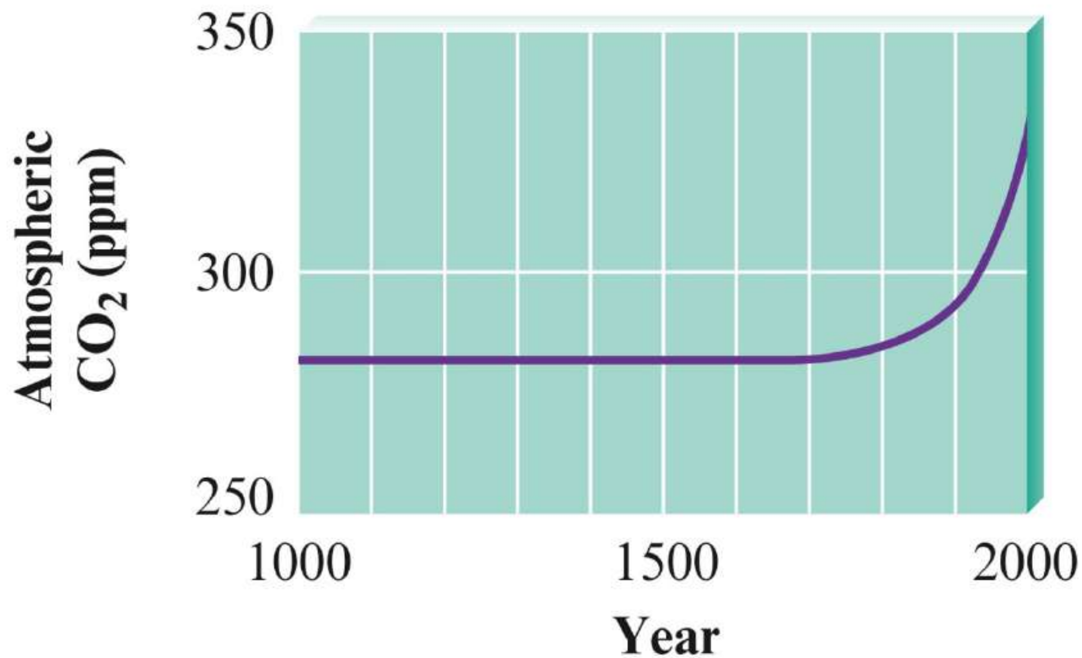
- Effects of carbon dioxide on climate
- *Greenhouse effect*




SOYBEAN POWERED
This Bus Runs On Soybean Bio-Diesel
54
This Bus Gets 250
Miles Per Acre.

B. Energy and Our World

- Effects of carbon dioxide on climate
- *Atmospheric CO2*
  - Controlled by water cycle
  - Could increase temperature by 10°C

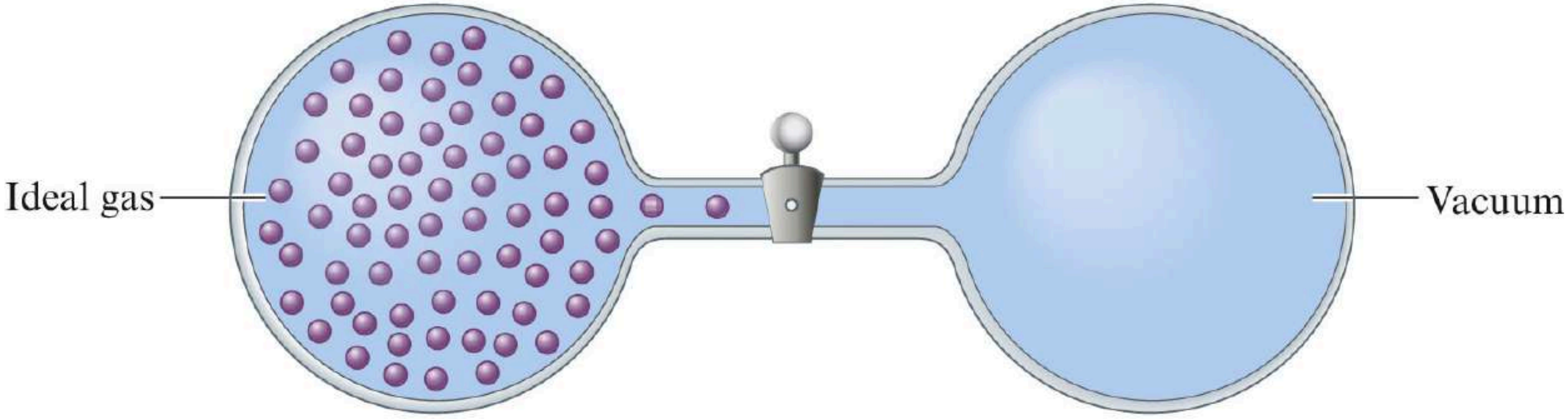


B. Energy and Our World

- New energy sources
  - Solar
  - Nuclear
  - Biomass
  - Wind
  - Synthetic fuels

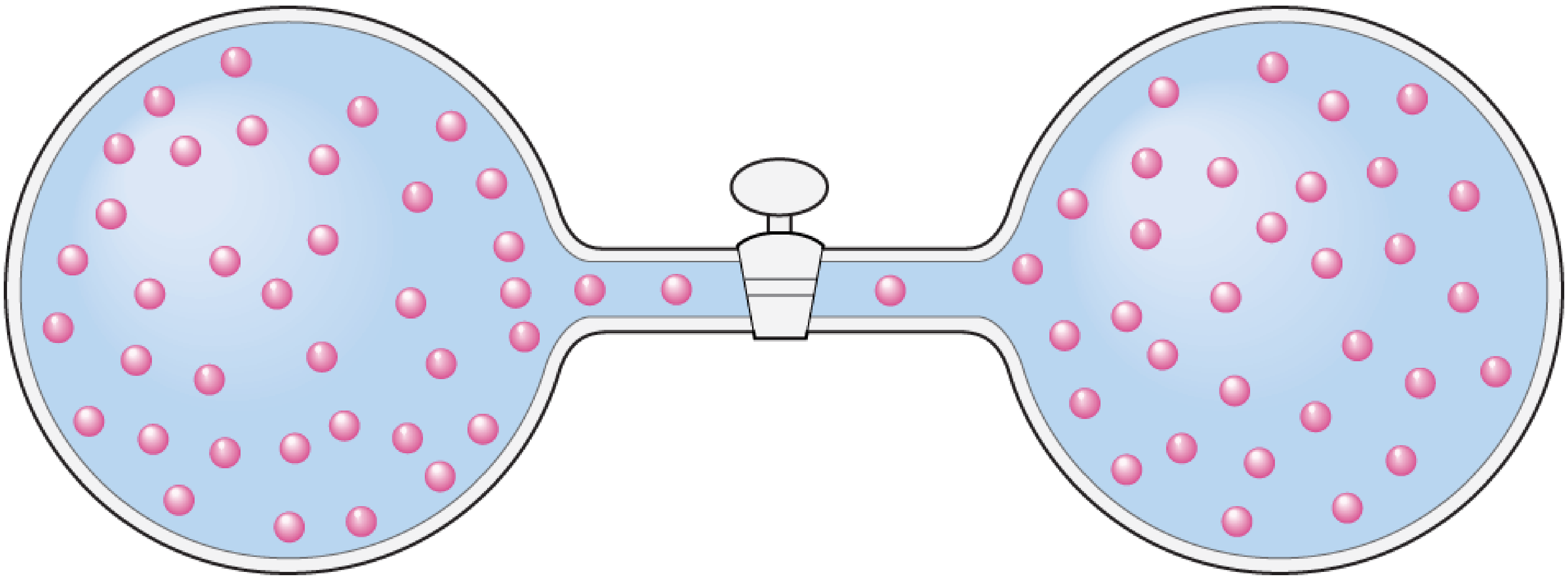
C. Energy as a Driving Force

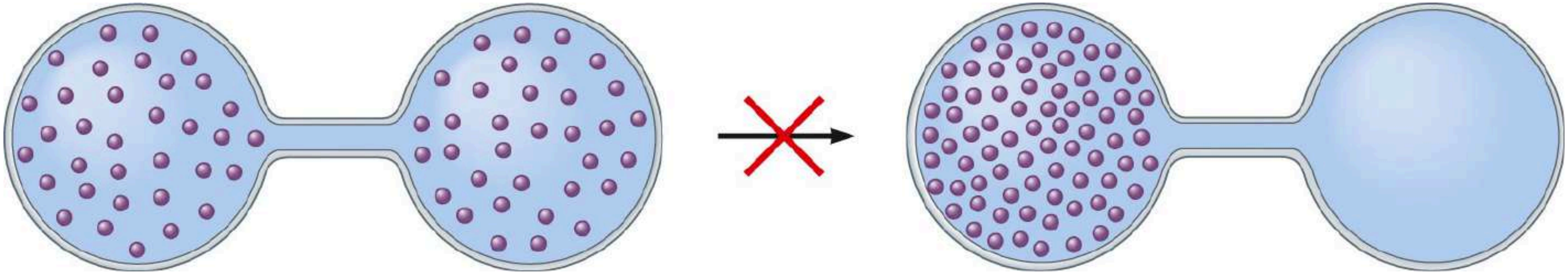
- Natural processes occur in the direction that leads to an increase in the disorder of the universe.
- Example
  - Consider a gas trapped as shown



C. Energy as a Driving Force

- What happens when the valve is opened?



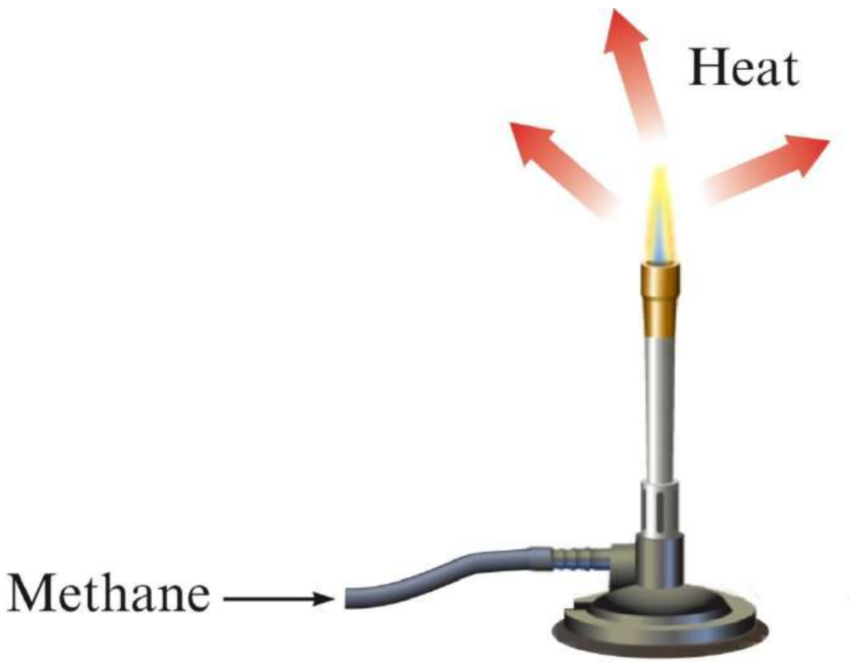


C. Energy as a Driving Force

- Two driving forces
  - Energy spread
  - Matter spread

C. Energy as a Driving Force

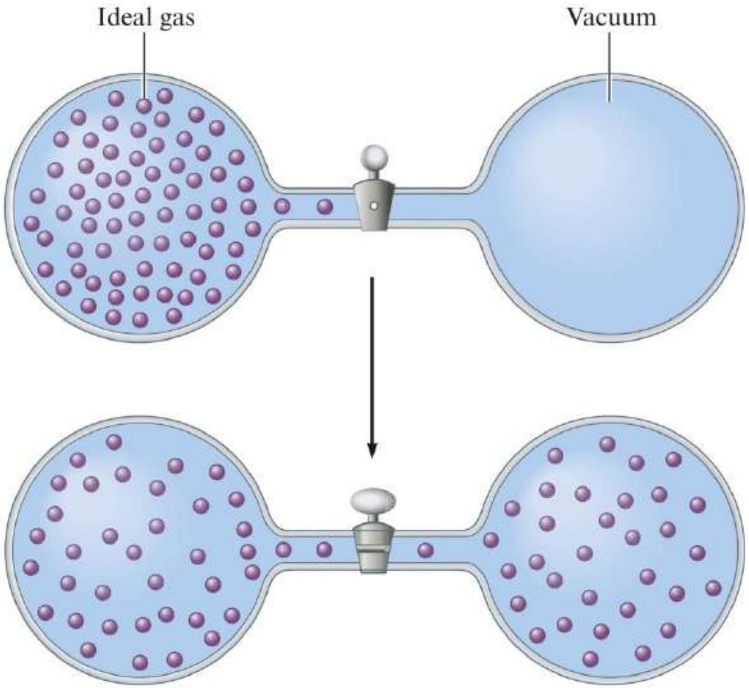
- Energy spread
  - In a given process, concentrated energy is dispersed widely.



  - This happens in every exothermic process.

C. Energy as a Driving Force

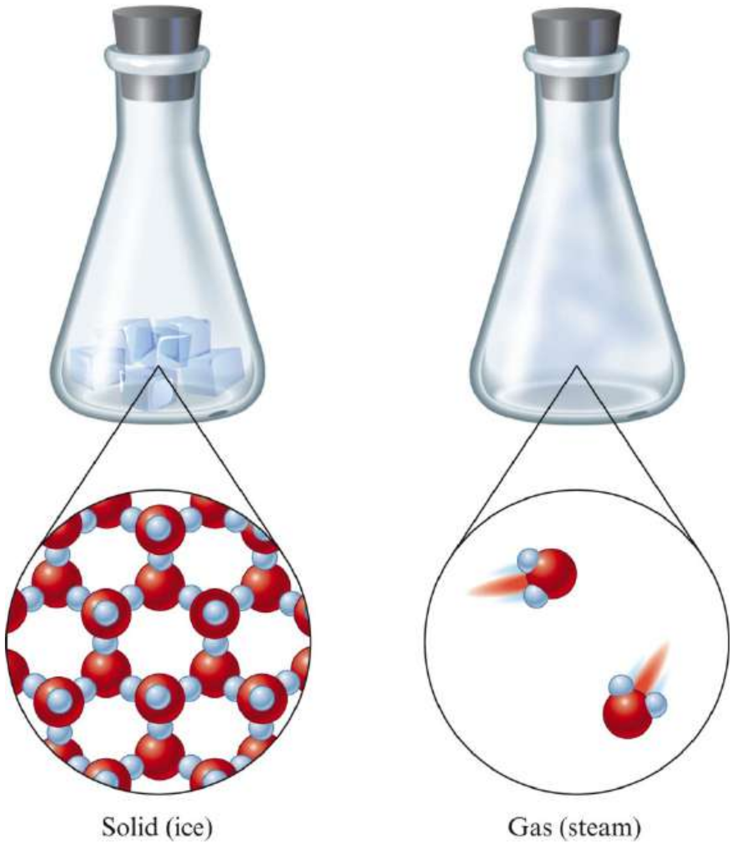
- Matter spread
  - Molecules of a substance spread out to occupy a larger volume.

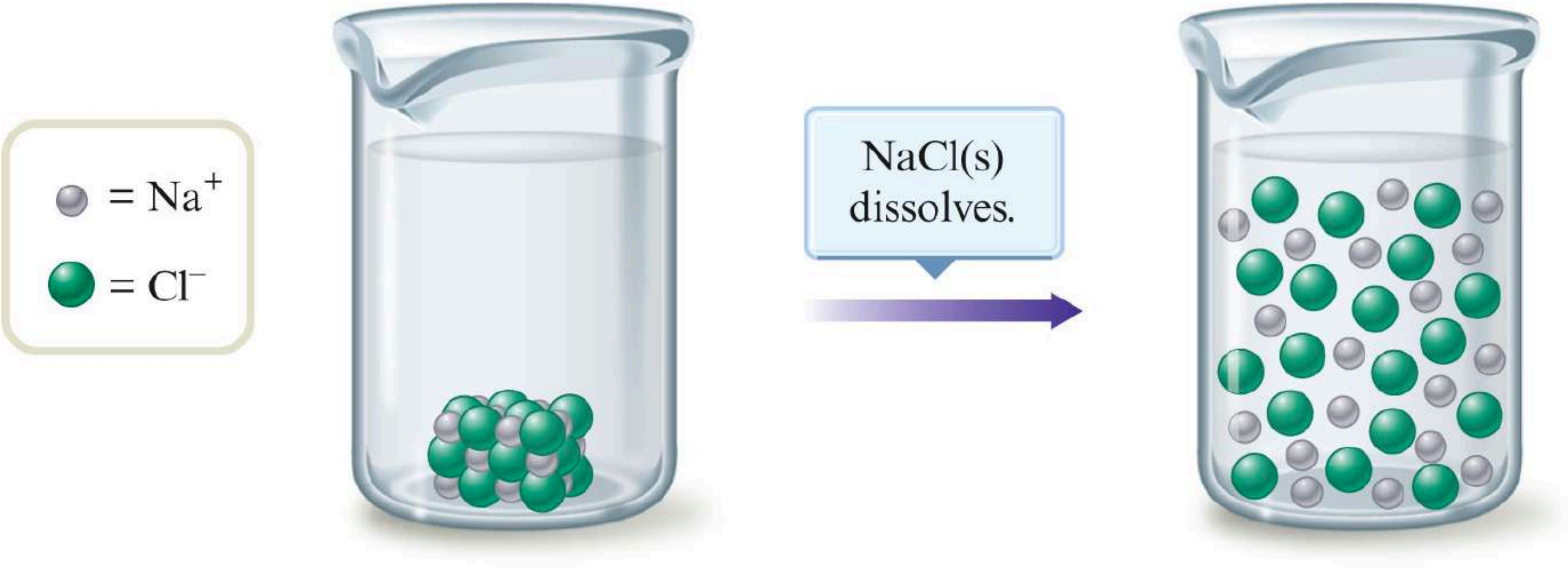


  - Processes are favored if they involve energy and matter spread.

C. Energy as a Driving Force

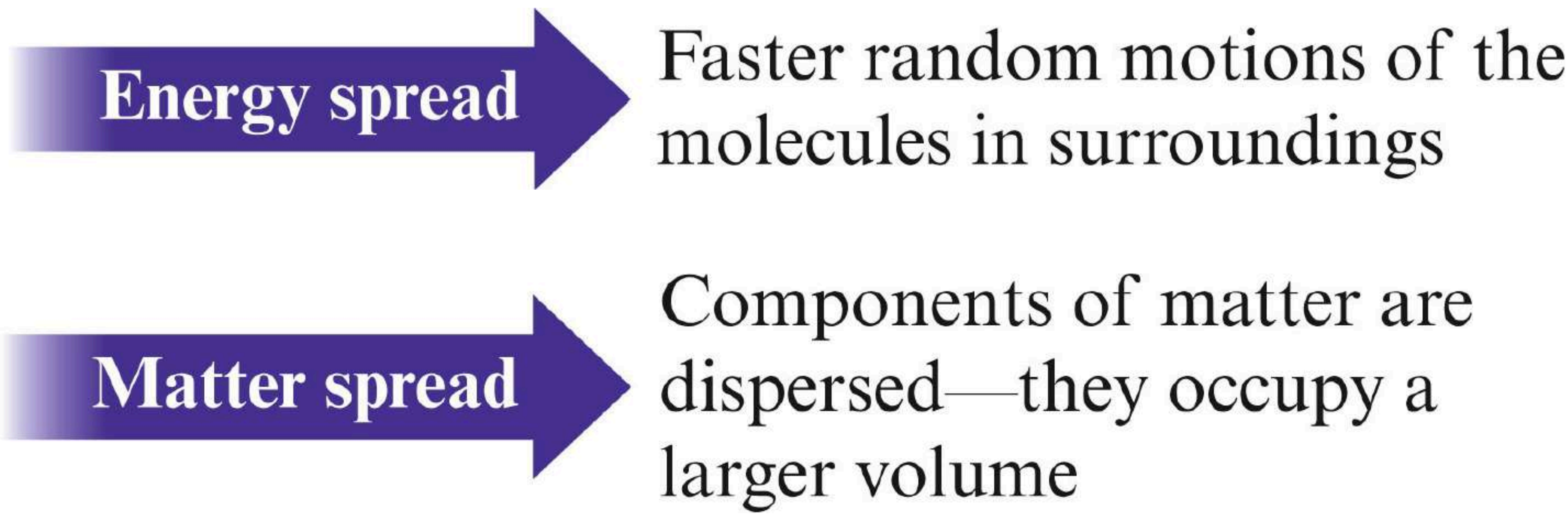
- Entropy, *S* – function which keeps track of the tendency for the components of the universe to become disordered




= Na^+
= Cl^-
NaCl(s) dissolves.

C. Energy as a Driving Force

- What happens to the disorder in the universe as energy and matter spread?



C. Energy as a Driving Force

- Second law of thermodynamics
  - The entropy of the universe is always increasing.