Karen Timberlake

CHEMISTRY

Thirteenth Edition, Global Edition

Chapter 3

Matter and Energy

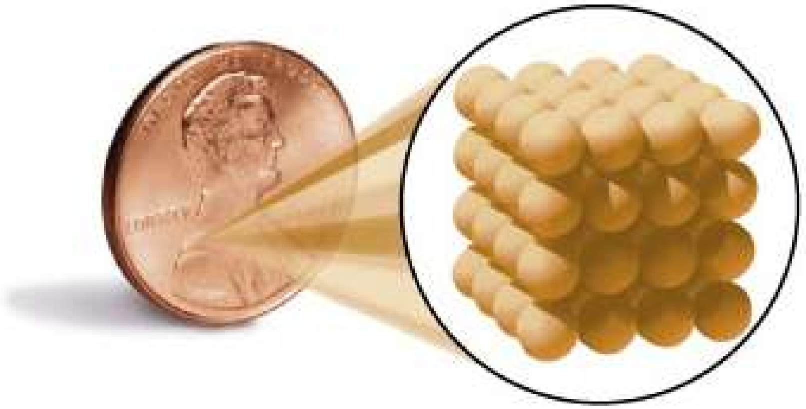
(Lecture PPTs)

Chapter 3 Matter and Energy

Dietitians specialize in helping individuals learn about good nutrition and the need for a balanced diet

3.1 Classification of Matter

Elements



Copper

Learning Goal Classify examples of matter as pure substances or mixtures.

Classification of Matter

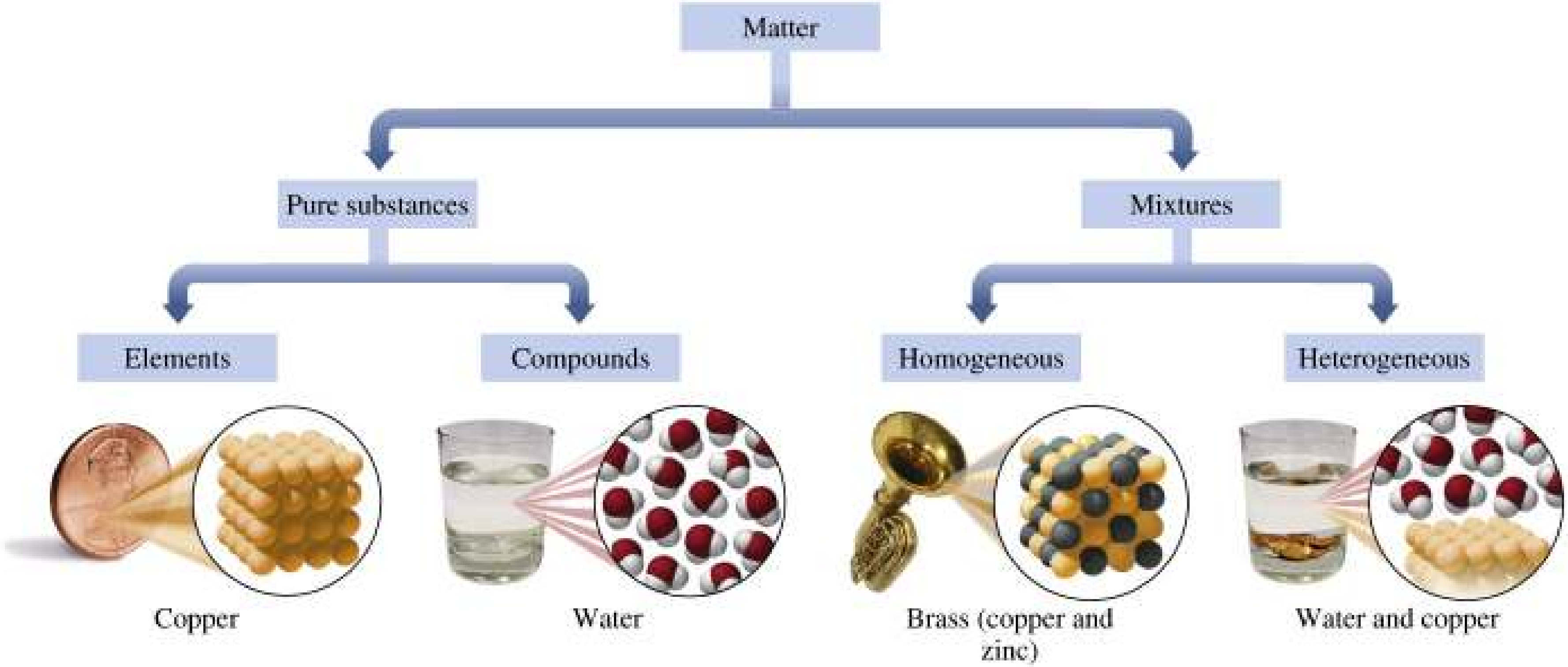
Matter is anything that has mass and occupies space. It makes up all things we use, such as

- water;
- wood; and
- plastic bags.

We can classify matter according to its composition:

- **Pure substances** have a fixed or definite composition.
- **Mixtures** contain two or more different substances that are physically mixed but not chemically combined.

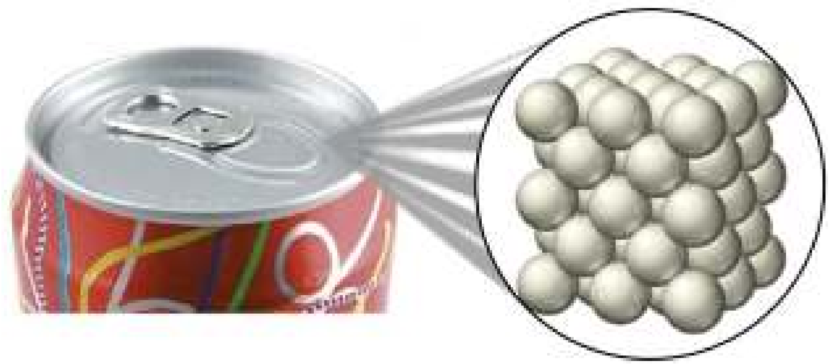
Classification of Matter



Pure Substances: Elements and Compounds

A **pure substance** is classified as

- a type of matter with a fixed or definite composition
- an **element** that is composed of one type of atom
- a **compound** that is composed of two or more elements always combined in the same proportion

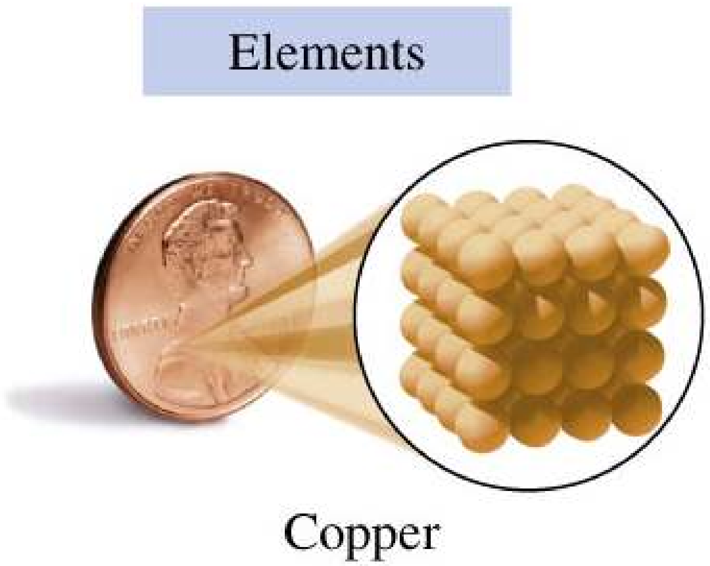


An aluminum can consists of many atoms of aluminum.

Elements

Elements are pure substances that contain only one type of material, such as

- copper, Cu
- lead, Pb
- aluminum, Al



The element copper consists of copper atoms.

Compounds

A **compound** consists of two or more elements chemically combined in a definite ratio, such as

- hydrogen peroxide (H_2O_2)
- table salt (NaCl)
- sugar ($C_{12}H_{22}O_{11}$)
- water (H_2O)

Hydrogen peroxide, H_2O_2, consists of two atoms of hydrogen (white) for every two atoms of oxygen (red).

Compounds Contain Elements

"Table salt" is a compound that contains the elements sodium and chlorine.

The decomposition of salt, NaCl, produces the elements sodium and chlorine.

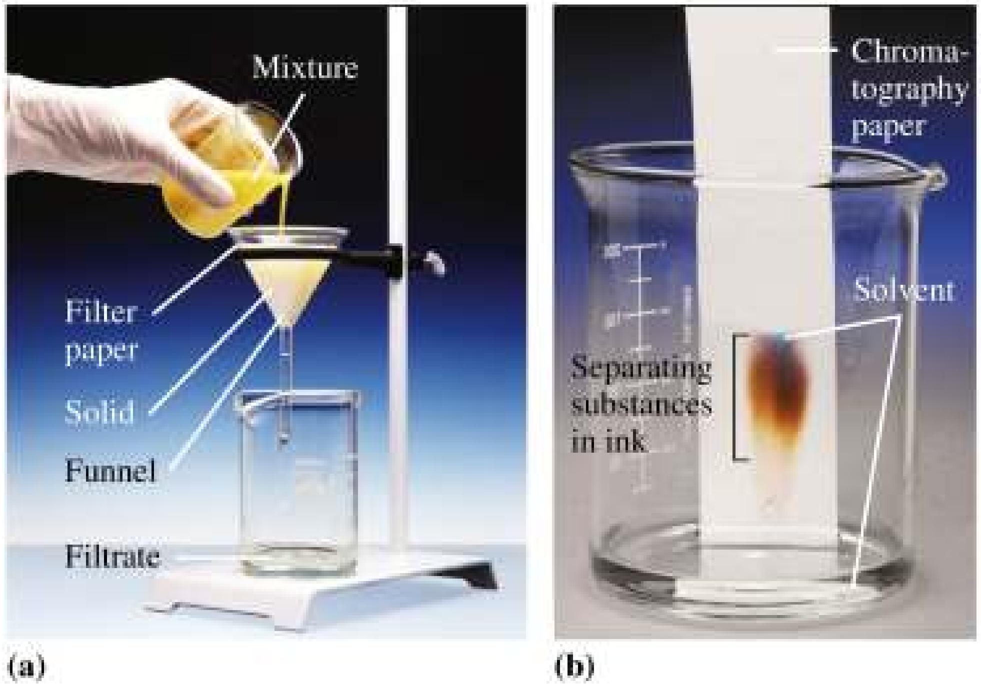
Mixtures

A **mixture** is a type of matter that consists of

- two or more substances that are physically mixed, but not chemically combined
- two or more substances in different proportions that can be separated by physical methods

A mixture of spaghetti and water is separated using a strainer, a physical method of separation.

Laboratory Separation of Mixtures



(a) A mixture of a liquid and a solid is separated by filtration.
(b) Different substances are separated as they travel at different rates up the surface of chromatography paper.

Homogeneous Mixtures

In a **homogeneous mixture**,

- the composition is uniform throughout the sample
- the different parts of the mixture are not visible

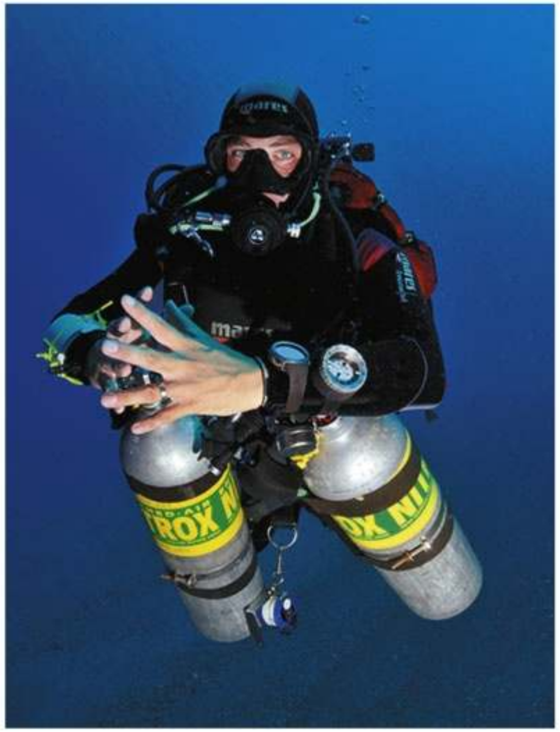
Brass (copper and zinc)

Brass is a homogeneous mixture of copper and zinc atoms.

Scuba Breathing Mixtures

Breathing mixtures for scuba are homogeneous mixtures. Some examples are

- nitrox (oxygen and nitrogen gases)
- heliox (oxygen and helium gases)
- trimix (oxygen, helium, and nitrogen gases)

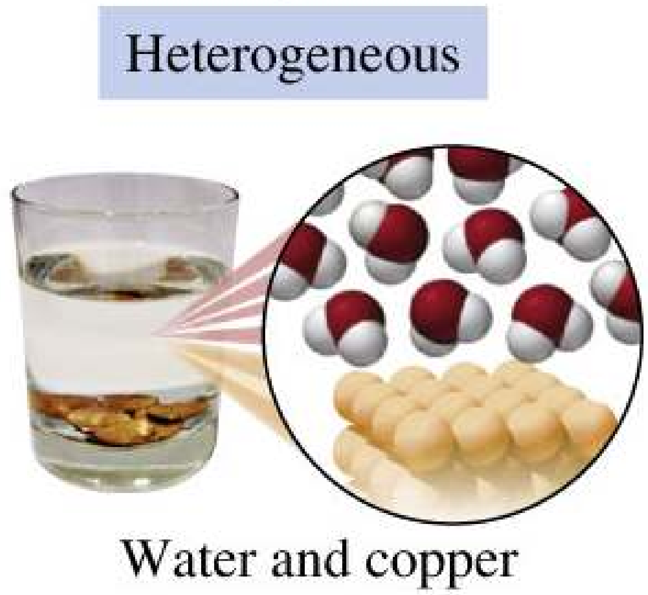


A nitrox mixture is used to fill scuba tanks.

Heterogeneous Mixtures

In a **heterogeneous mixture**,

- the composition varies from one part of the mixture to another
- the different parts of the mixture are visible



Copper metal and water form a heterogeneous mixture.

Learning Check

Identify each of the following as a pure substance or a mixture:

A. pasta and tomato sauce

B. aluminum foil

C. helium

D. air

Solution

Identify each of the following as a pure substance or a mixture:

A. pasta and tomato sauce	**mixture**
B. aluminum foil	**pure substance**
C. helium	**pure substance**
D. air	**mixture**

Learning Check

Identify each of the following as a homogeneous or heterogeneous mixture:

A. hot fudge sundae

B. baby shampoo

C. sugar water

D. peach pie

Solution

Identify each of the following as a homogeneous or heterogeneous mixture:

A. hot fudge sundae **heterogeneous mixture**

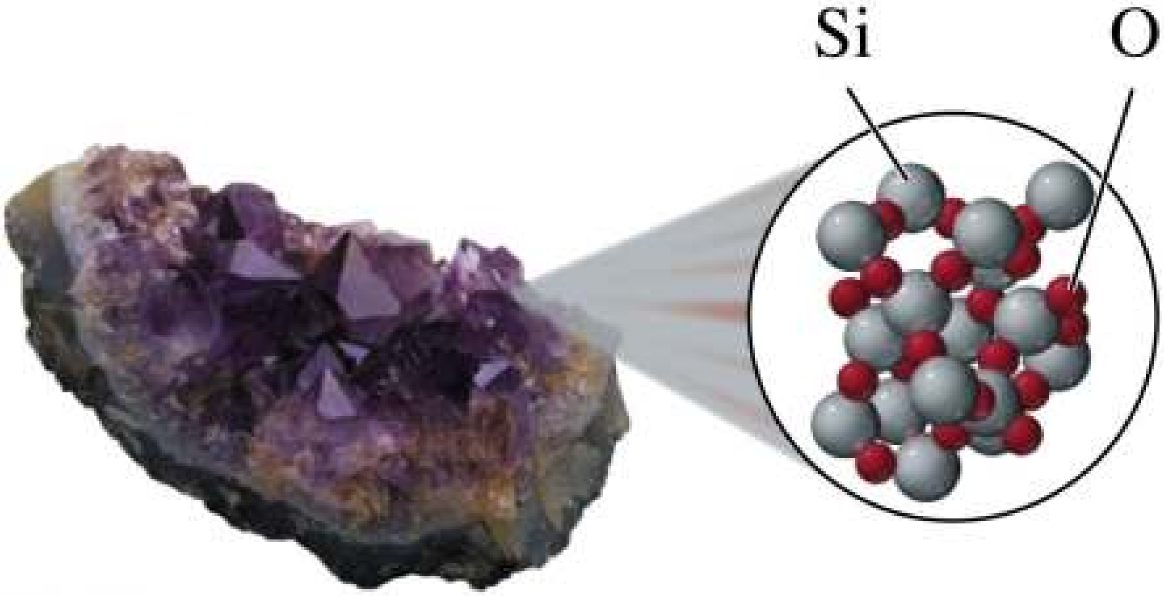
B. baby shampoo **homogeneous mixture**

C. sugar water **homogeneous mixture**

D. peach pie **heterogeneous mixture**

3.2 States and Properties of Matter

Matter on Earth exists in one of three physical states: solid, liquid, or gas.

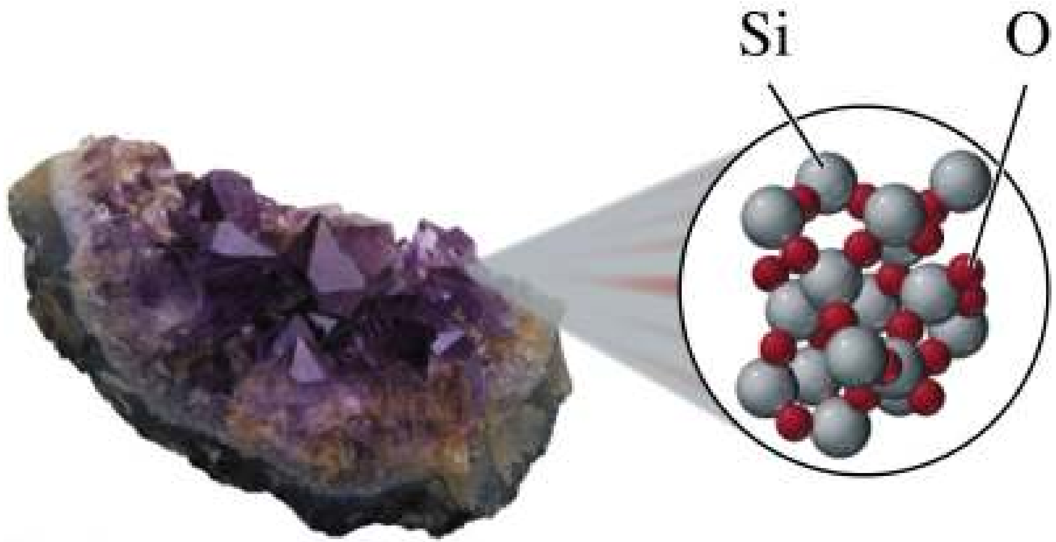


Learning Goal Identify the states and physical and chemical properties of matter.

Solids

Solids have

- a definite shape
- a definite volume
- particles are held close together by strong attractive forces
- particles are arranged in a rigid pattern and can only vibrate slowly in fixed positions

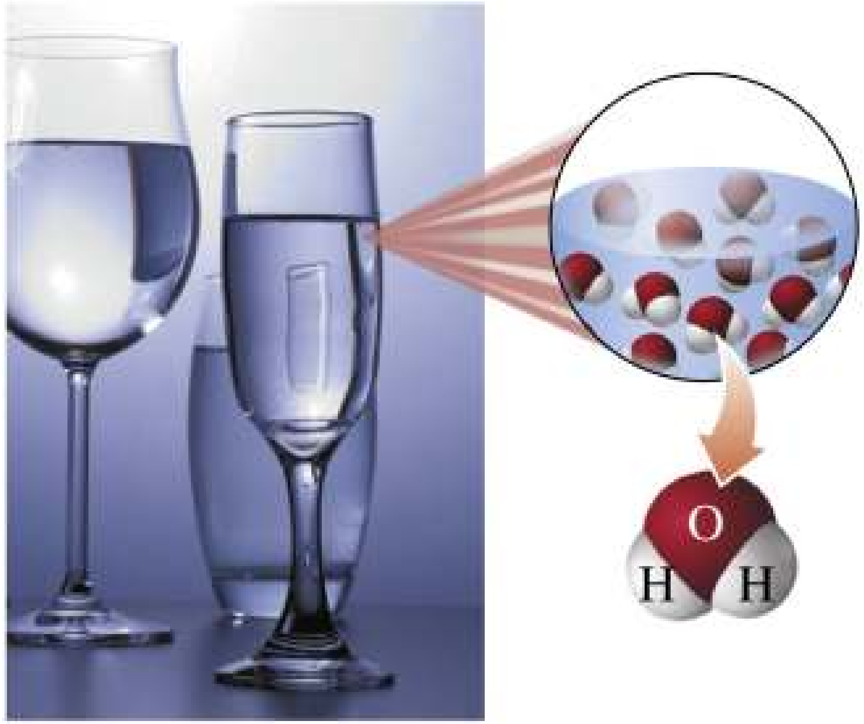


Amethyst, a solid, is a purple form of quartz (SiO_2).

Liquids

Liquids have

- a definite volume, but not a definite shape
- the same shape as their container
- particles that move slowly in random directions

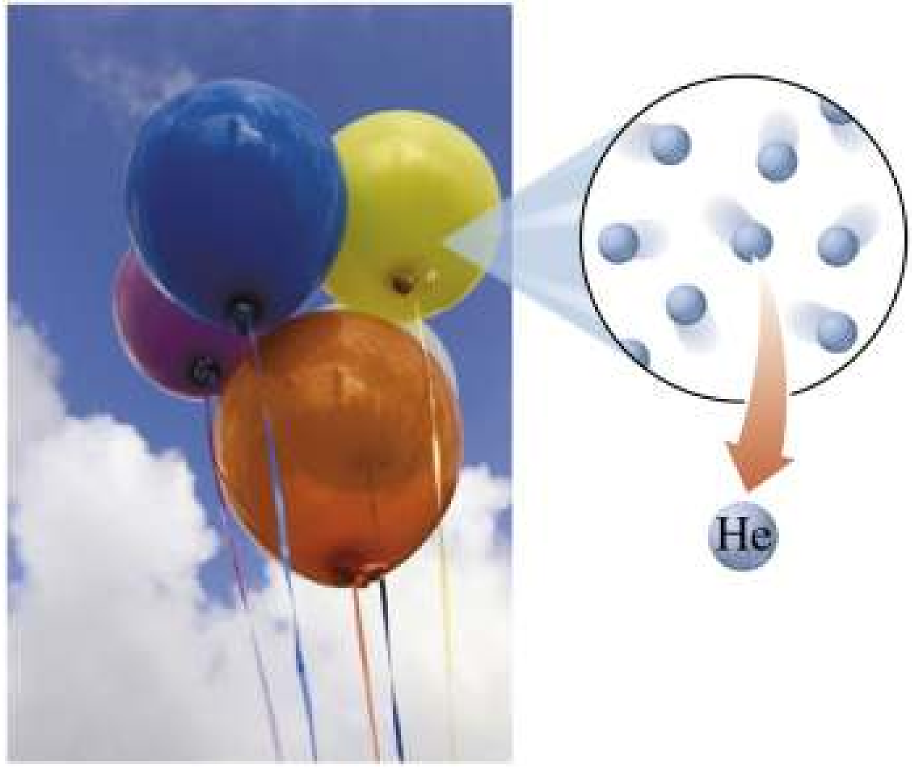


Water as a liquid takes the shape of its container.

Gases

Gases have

- an indefinite shape
- an indefinite volume
- the same shape and volume as their container
- particles that are far apart, move at high speeds, and have little attraction to each other



A gas takes the shape and volume of its container.

Physical States of Matter

TABLE 3.1 A Comparison of Solids, Liquids, and Gases

Characteristic	Solid	Liquid	Gas
Shape	Has a definite shape	Takes the shape of the container	Takes the shape of the container
Volume	Has a definite volume	Has a definite volume	Fills the volume of the container
Arrangement of Particles	Fixed, very close	Random, close	Random, far apart
Interaction between Particles	Very strong	Strong	Essentially none
Movement of Particles	Very slow	Moderate	Very fast
Examples	Ice, salt, iron	Water, oil, vinegar	Water vapor, helium, air

Learning Check

Identify each description as that of particles of a

1) solid 2) liquid 3) gas

__ **A.** has definite volume but takes the shape of the container

__ **B.** particles are moving rapidly

__ **C.** particles fill the entire volume of a container

__ **D.** particles have a fixed arrangement

__ **E.** particles are close together but moving randomly

Solution

Identify each description as that of particles of a

1) solid 2) liquid 3) gas

A. **2) liquid** has definite volume, but takes the shape of the container

B. **3) gas** particles are moving rapidly

C. **3) gas** particles fill the entire volume of a container

D. **1) solid** particles have a fixed arrangement

E. **2) liquid** particles are close together, but moving randomly

Learning Check

Identify the state of matter for each of the following:

A. vitamin tablets

B. eye drops

C. vegetable oil

D. a candle

E. air in a basketball

Solution

Identify the state of matter for each of the following:

A. vitamin tablets	**solid**
B. eye drops	**liquid**
C. vegetable oil	**liquid**
D. a candle	**solid**
E. air in a basketball	**gas**

Physical Properties

Physical properties

- are characteristics observed or measured without changing the identity of a substance.
- include the shape, physical state, boiling and freezing points, density, and color of that substance.

Physical Properties of Copper

Copper has these physical properties:

- reddish-orange color
- shiny
- excellent conductor of heat and electricity
- solid at 25 °C
- melting point 1083 °C
- boiling point 2567 °C

Copper, used in cookware, is a good conductor of heat.

Physical Changes

Physical changes occur when matter undergoes a physical change of state, but its composition remains constant.

Water exists in three states: (1) ice, (2) water, and (3) steam.

Physical Changes

CORE CHEMISTRY SKILL
Identifying Physical and Chemical Changes

The physical appearance of a substance can also change with a physical change.

For example, when salt is dissolved in water, the salt crystals are no longer visible but can be re-formed when the water evaporates.

A gold ingot undergoes a physical change when it is hammered to form gold leaf.

Learning Check

Classify each of the following as a
1) change of state 2) change of shape

A. chopping a log into kindling
B. water boiling in a pot
C. ice cream melting
D. ice forming in a freezer
E. cutting dough into strips

Solution

Classify each of the following as a

1) change of state 2) change of shape

A. chopping a log into kindling **2) change of shape**

B. water boiling in a pot **1) change of state**

C. ice cream melting **1) change of state**

D. ice forming in a freezer **1) change of state**

E. cutting dough into strips **2) change of shape**

Chemical Properties and Changes

Chemical properties describe the ability of a substance

- to interact with other substances
- to change into a new substance

When a **chemical change** takes place, the original substance is turned into one or more new substances with new physical and chemical properties.

Chemical Changes

During a **chemical change**, a new substance forms that has

- a new composition
- new physical properties
- new chemical properties

For example, when iron nails corrode in the presence of water, a new substance forms on them, a red-orange powder called rust (Fe_2O_3).

Sugar caramelizing at a high temperature is an example of a chemical change.

Physical and Chemical Changes

TABLE 3.3 Examples of Some Physical and Chemical Changes

Physical Changes	Chemical Changes
Water boils to form water vapor.	Shiny, silver metal reacts in air to give a black, grainy coating.
Copper is drawn into thin copper wires.	A piece of wood burns with a bright flame and produces heat, ashes, carbon dioxide, and water vapor.
Sugar dissolves in water to form a solution.	Heating sugar forms a smooth, caramel-colored substance.
Paper is cut into tiny pieces of confetti.	Iron, which is gray and shiny, combines with oxygen to form orange-red rust.

Physical and Chemical Properties and Changes

TABLE 3.4 Summary of Physical and Chemical Properties and Changes

	Physical	Chemical
Property	A characteristic of a substance: color, shape, odor, luster, size, melting point, or density.	A characteristic that indicates the ability of a substance to form another substance: paper can burn, iron can rust, silver can tarnish.
Change	A change in a physical property that retains the identity of the substance: a change of state, a change in size, or a change in shape.	A change in which the original substance is converted to one or more new substances: paper burns, iron rusts, silver tarnishes.

Learning Check

Classify each of the following properties as physical or chemical:

A. Ice melts in the sun.

B. Copper is a shiny metal.

C. Paper can burn.

D. A silver knife can tarnish.

E. A magnet removes iron particles from a mixture.

Solution

Classify each of the following properties as physical or chemical:

A. Ice melts in the sun.	**physical**
B. Copper is a shiny metal.	**physical**
C. Paper can burn.	**chemical**
D. A silver knife can tarnish.	**chemical**
E. A magnet removes iron particles from a mixture.	**physical**

Learning Check

Classify each of the following changes as physical or chemical:

A. burning a candle

B. ice melting on the street

C. toasting a marshmallow

D. cutting a pizza

E. iron rusting in an old car

Solution

Classify each of the following changes as physical or chemical:

A. burning a candle	**chemical**
B. ice melting on the street	**physical**
C. toasting a marshmallow	**chemical**
D. cutting a pizza	**physical**
E. iron rusting in an old car	**chemical**

3.3 Temperature

A digital ear thermometer is used to measure body temperature.

Learning Goal Given a temperature, calculate the corresponding temperature on another scale.

Temperature

Temperature

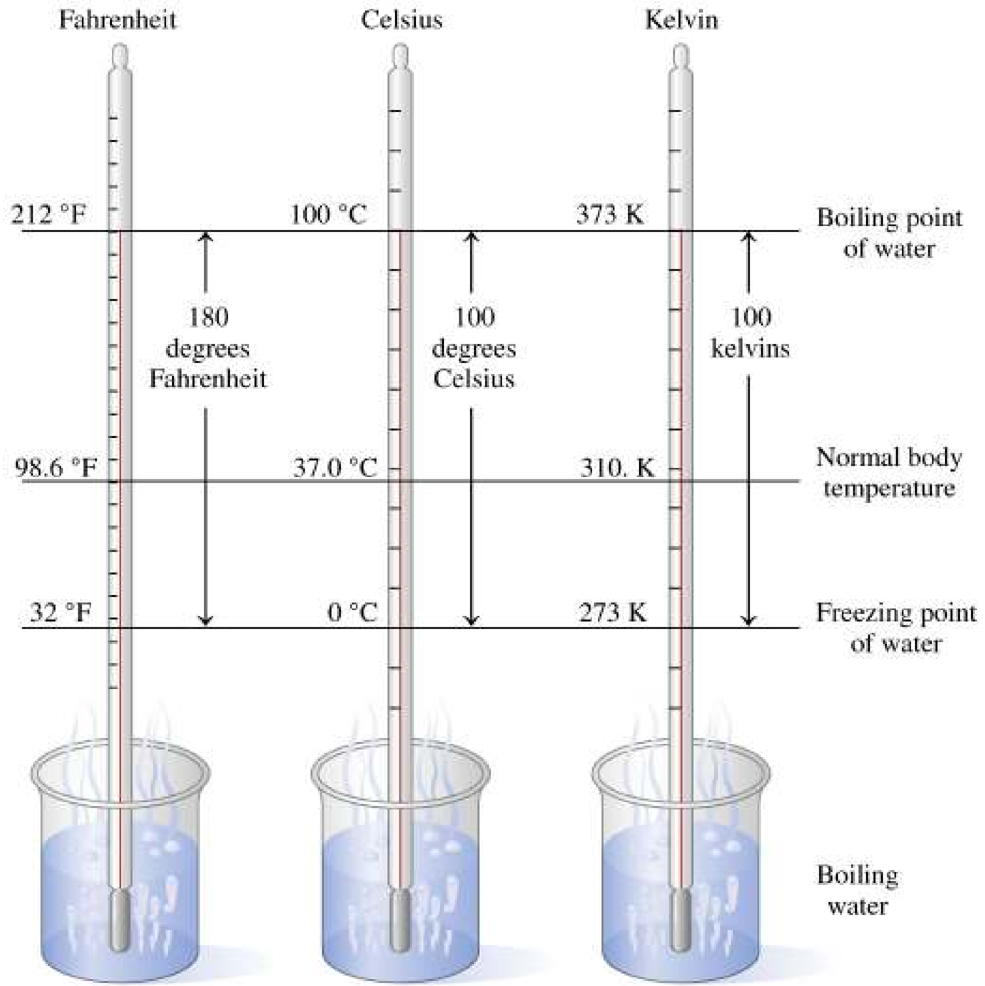
- is a measure of how hot or cold an object is compared to another object
- is measured using a thermometer
- is measured and reported in Celsius (°C) units in science

Temperature Scales

CORE CHEMISTRY SKILL
Converting between Temperature Scales

The **temperature scales**

- are Fahrenheit, Celsius, and Kelvin
- have reference points for the boiling and freezing points of water



Fahrenheit and Celsius Scales

- On the Celsius scale, there are 100 degrees Celsius between the freezing and boiling points of water.
- On the Fahrenheit scale, there are 180 degrees Fahrenheit between the freezing and boiling points of water.
- 180 Fahrenheit degrees = 100 degrees Celsius

$$\frac{180 \text{ Fahrenheit degrees}}{100 \text{ degrees Celsius}} = \frac{1.8\ ^{\circ}\text{F}}{1\ ^{\circ}\text{C}}$$

Learning Check

A. What is the temperature at which water freezes?

1) 0 °F 2) 0 °C 3) 0 K

B. What is the temperature at which water boils?

1) 100 °F 2) 32 °F 3) 373 K

C. How many Celsius units are between the boiling and freezing points of water?

1) 100 2) 180 3) 273

Solution

A. What is the temperature at which water freezes?

2) 0 °C

B. What is the temperature at which water boils?

3) 373 K

C. How many Celsius units are between the boiling and freezing points of water?

1) 100

Converting Between °F to °C

We can write equations that relate these two scales.

To obtain °F from °C:

$$T_F = 1.8(T_C) + 32$$

Temperature equation to obtain degrees Fahrenheit

1.8: Changes °C to °F

32: Adjusts freezing point

To obtain °C from °F:

$$\frac{T_F - 32}{1.8} = \frac{\cancel{1.8}(T_C)}{\cancel{1.8}}$$

$$\frac{T_F - 32}{1.8} = T_C$$

Temperature equation to obtain degrees Celsius

Solving a Temperature Problem

Example: The typical temperature in a room is 21 °C. What is that temperature in degrees Fahrenheit?

STEP 1 State the given and needed quantities.

ANALYZE THE PROBLEM	Given	Need	Connect
	21 °C	T in °F	temperature equation

STEP 2 Write a temperature equation.

$$T_F = 1.8(T_C) + 32$$

Solving a Temperature Problem

Example: The typical temperature in a room is 21 °C. What is that temperature in degrees Fahrenheit?

STEP 3 Substitute in the known values and calculate the new temperature.

$$T_F = 1.8(21) + 32$$

1.8 is exact; 32 is exact

$$T_F = 38 + 32 = 70.\ °F$$

Answer to the ones place

Kelvin Temperature Scale

Scientists have learned that the coldest temperature possible is −273 °C. On the **Kelvin** scale, this is called **absolute zero** and is represented as 0 K.

The Kelvin scale has

- units called kelvins (K)
- no degree symbol in front of K to represent temperature
- no negative temperatures
- the same size units as Celsius 1 K = 1 °C

$$T_K = T_C + 273$$ Temperature equation to obtain kelvins

Learning Check

What is normal body temperature of 37 °C in kelvins?

A. 236 K

B. 310 K

C. 342 K

D. 98.0 K

Solution

What is normal body temperature of 37 °C in kelvins?

STEP 1 State the given and needed quantities.

ANALYZE THE PROBLEM	Given	Need	Connect
	37 °C	*T* in K	temperature equation

STEP 2 Write a temperature equation.

$$T_K = T_C + 273$$

Solution

What is normal body temperature of 37 °C in kelvins?

STEP 3 **Substitute in the known values and calculate the new temperature.**

$$T_K = 37 + 273$$

$T_K = 310.$ K **Answer is B.**

Learning Check

On a cold winter day, the temperature is −15 °F. What is that temperature in degrees Celsius?

A. −85 °C

B. −47 °C

C. −42 °C

D. −26 °C

Solution

On a cold winter day, the temperature is −15 °F. What is that temperature in degrees Celsius?

STEP 1 State the given and needed quantities.

ANALYZE	Given	Need	Connect
THE PROBLEM	−15 °F	*T* in °C	temperature equation

STEP 2 Write a temperature equation.

$$T_C = \frac{T_F - 32}{1.8}$$

Solution

On a cold winter day, the temperature is −15 °F. What is that temperature in degrees Celsius?

STEP 3 Substitute in the known values and calculate the new temperature.

$$T_C = \frac{(-5 - 32)}{1.8}$$

1.8 is exact; 32 is exact

$$T_C = \frac{-47}{1.8} = -26\ ^\circ C$$

Answer to the ones place

Answer is D.

Temperature Comparisons

TABLE 3.5 A Comparison of Temperatures

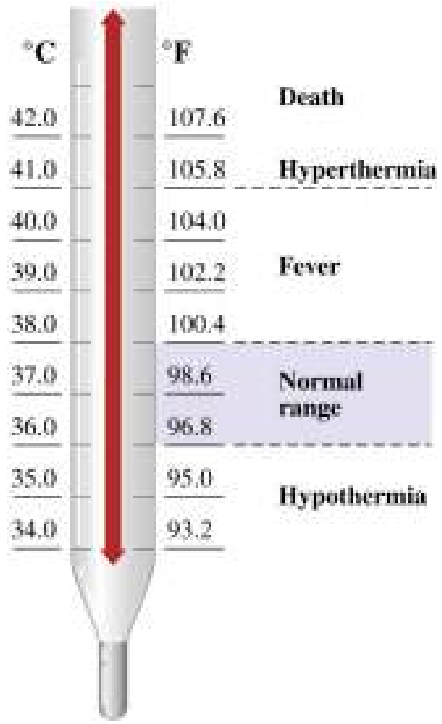
Example	Fahrenheit (°F)	Celsius (°C)	Kelvin (K)
Sun	9937	5503	5776
A hot oven	450	232	505
Water boils	212	100	373
A high fever	104	40	313
Normal body temperature	98.6	37.0	310
Room temperature	70	21	294
Water freezes	32	0	273
A northern winter	−66	−54	219
Nitrogen liquefies	−346	−210	63
Absolute zero	−459	−273	0

Chemistry Link to Health

Variation in Body Temperature

Body temperatures above 41 °C, called *hyperthermia*, can lead to convulsions and may cause permanent brain damage.

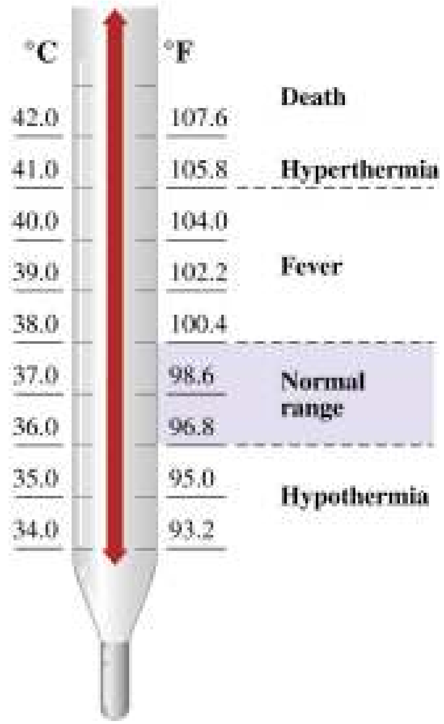
Heatstroke occurs above 41.1 °C. Treatment may include immersing the person in an ice-water bath.



Chemistry Link to Health

Variation in Body Temperature

In *hypothermia*, body temperature can drop as low as 28.5 °C. Treatment involves providing oxygen and increasing blood volume with glucose and saline fluids. Injecting warm fluids (37.0 °C) into the peritoneal cavity may restore the internal temperature.



Learning Check

A person with hypothermia has a body temperature of 34.8 °C. What is that temperature in degrees Fahrenheit?

Solution

A person with hypothermia has a body temperature of 34.8 °C. What is that temperature in degrees Fahrenheit?

STEP 1 State the given and needed quantities.

ANALYZE THE PROBLEM	Given	Need	Connect
	34.8 °C	T in °F	temperature equation

STEP 2 Write a temperature equation.

$$T_F = 1.8(T_C) + 32$$

Solution

A person with hypothermia has a body temperature of 34.8 °C. What is that temperature in degrees Fahrenheit?

STEP 3 Substitute in the known values and calculate the new temperature.

$$T_F = 1.8(34.8) + 32$$

1.8 is exact; 32 is exact

$$T_F = 62.6 + 32 = 94.6\ °F$$

Answer to the tenths place

3.4 Energy

A defibrillator provides electrical energy to heart muscle to reestablish normal rhythm.

Learning Goal Identify energy as potential or kinetic; convert between units of energy.

Energy

Energy

- is defined as the ability to do work
- can be classified as either kinetic or potential energy

Kinetic energy is the energy of motion.

Potential energy is determined by the position of an object or its chemical composition.

Potential or Kinetic Energy?

Water in a reservoir behind a dam has potential energy.

When the water is released and flows over the dam, its potential energy is converted to kinetic energy.

Learning Check

Identify the energy in each example as potential or kinetic.

A. rollerblading

B. a peanut butter and jelly sandwich

C. mowing the lawn

D. gasoline in the gas tank

Solution

Identify the energy in each example as potential or kinetic.

A. rollerblading	**kinetic**
B. a peanut butter and jelly sandwich	**potential**
C. mowing the lawn	**kinetic**
D. gasoline in the gas tank	**potential**

Heat and Units of Energy, Joules

Heat is

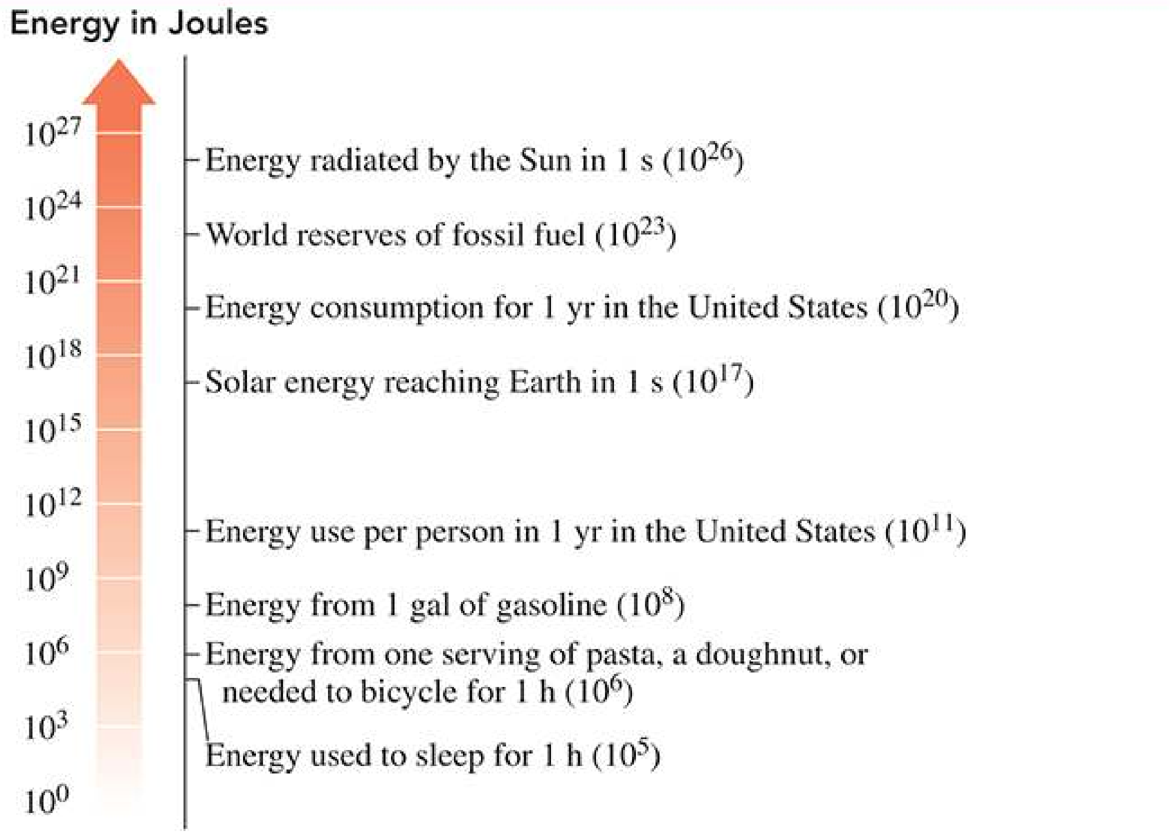
- the energy associated with the motion of particles
- the faster the particles move, the greater the heat or thermal energy of the substance

The SI unit of energy and work is the **joule (J)**.

$$1 \text{ kJ} = 1000 \text{ J}$$

Energy Comparison

TABLE 3.6 A Comparison of Energy for Various Resources and Uses



Heat and Units of Energy, Calories

The unit **calorie** is defined as the amount of energy needed to raise the temperature of 1 g of water by 1 °C.

$$1 \text{ cal} = 4.184 \text{ J (exact)} \qquad \frac{4.184 \text{ J}}{1 \text{ cal}} \text{ and } \frac{1 \text{ cal}}{4.184 \text{ J}}$$

1 kilocalorie (kcal) = 1000 calories (cal)

1 Calorie (kcal) = 1000 calories (cal)

Learning Check

CORE CHEMISTRY SKILL
Using Energy Units

How many calories are obtained from a pat of butter if it provides **150 J** of energy when metabolized?

A. 0.86 cal

B. 630 cal

C. 36 cal

Solution

How many calories are obtained from a pat of butter if it provides 150 J of energy when metabolized?

STEP 1 State the given and needed quantities.

ANALYZE THE PROBLEM	Given	Need	Connect
	150 J	calories	energy factor

STEP 2 Write a plan to convert the given unit to the needed unit.

joules → Energy factor → calories

Solution

How many calories are obtained from a pat of butter if it provides 150 J of energy when metabolized?

STEP 3 Substitute in the known values and calculate the new temperature.

$$1 \text{ cal} = 4.184 \text{ J}$$

$$\frac{4.184 \text{ J}}{1 \text{ cal}} \quad \text{and} \quad \frac{1 \text{ cal}}{4.184 \text{ J}}$$

STEP 4 Set up the problem to calculate the needed quantity.

$$150 \cancel{\text{J}} \times \frac{1 \text{ cal}}{4.184 \cancel{\text{J}}} = 36 \text{ cal}$$

150 J: 2 SFs; 1 cal: Exact; 4.184 J: Exact; 36 cal: 2 SFs

Answer is C.

3.5 Energy and Nutrition

One hour of swimming uses 2100 kJ of energy.

Learning Goal Use the energy values to calculate the kilocalories (kcal) or kilojoules (kJ) for a food.

Energy and Nutrition

Carbohydrates are the body’s primary source of energy; however, when carbohydrate reserves are exhausted, fats and then proteins are used for energy.

Primary Fuel

Carbohydrates → Fats → Proteins

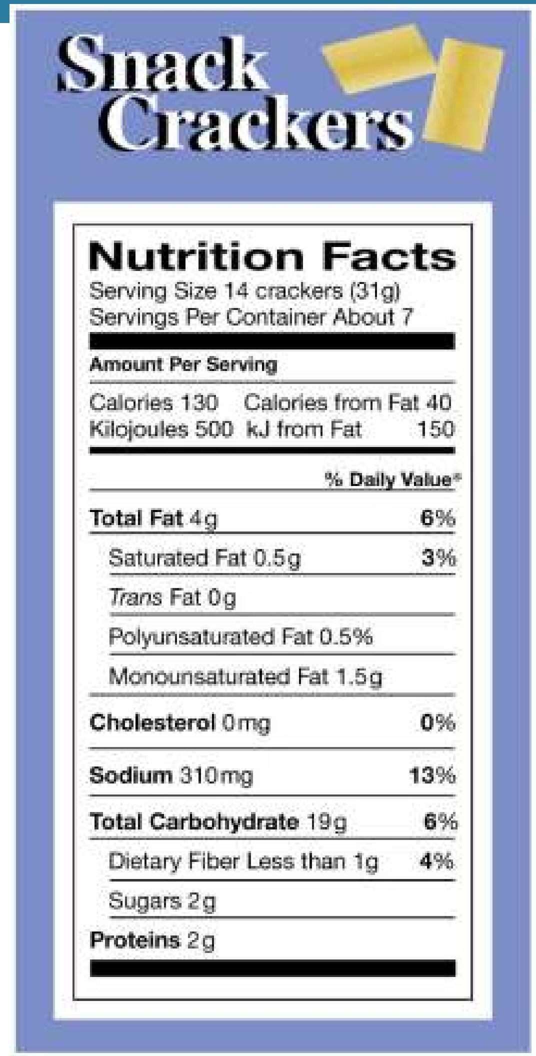
Energy and Nutrition

On food labels, energy is shown as the nutritional Calorie, written with a capital C.

In countries other than the United States, energy is shown in kilojoules (kJ).

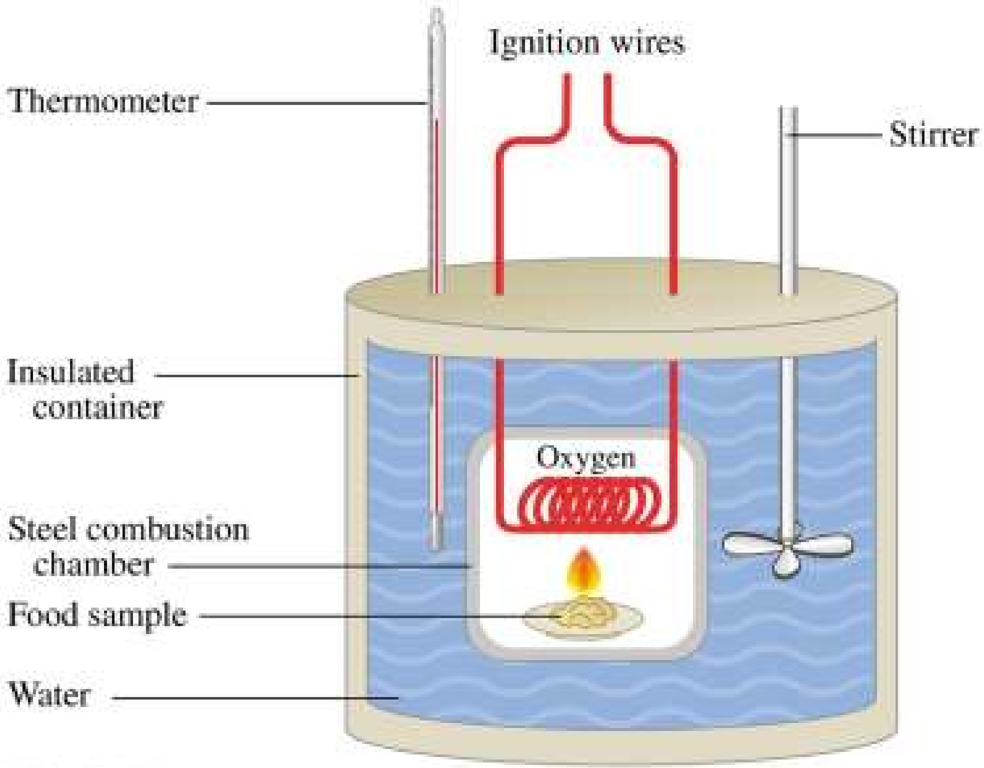
$$1 \text{ Cal} = 1 \text{ kcal} = 1000 \text{ calories}$$

$$1 \text{ Cal} = 4.184 \text{ kJ} = 4184 \text{ J}$$



Calorimeters Measure Energy Values

Heat released from burning a food sample in a calorimeter is used to determine the energy value for the food.



Food Energy Values

The **energy values** for the three food types are given in kcal/g and kJ/g.

TABLE 3.7 Typical Energy Values for the Three Food Types

Food Type	kcal/g	kJ/g
Carbohydrate	4	17
Fat	9	38
Protein	4	17

Food Energy Values

We can use the energy values given in Table 3.7 to calculate the energy from a food type when its mass is known.

$$\text{kilocalories} = \cancel{\text{g}} \times \frac{\text{kcal}}{\cancel{\text{g}}}$$

$$\text{kilojoules} = \cancel{\text{g}} \times \frac{\text{kJ}}{\cancel{\text{g}}}$$

Energy Values for Some Foods

TABLE 3.8 Composition and Energy Content for Some Foods

Food	Carbohydrate (g)	Fat (g)	Protein (g)	Energy
Apple, 1 medium	15	0	0	60 kcal (260 kJ)
Banana, 1 medium	26	0	1	110 kcal (460 kJ)
Beef, ground, 3 oz 85 g	0	14	22	220 kcal (900 kJ)
Broccoli, 3 oz	4	0	3	30 kcal (120 kJ)
Carrots, 1 cup	11	0	2	50 kcal (220 kJ)
Chicken, no skin, 3 oz	0	3	20	110 kcal (450 kJ)
Egg, 1 large	0	6	6	70 kcal (330 kJ)
Milk, nonfat, 1 cup	12	0	9	90 kcal (350 kJ)
Potato, baked	23	0	3	100 kcal (440 kJ)
Salmon, 3 oz	0	5	16	110 kcal (460 kJ)
Steak, 3 oz	0	27	19	320 kcal (1350 kJ)

Learning Check

A cup of whole milk contains 12 g of carbohydrate, 9 g of fat, and 9 g of protein. How many kilocalories does a cup of whole milk contain? (Round off the answer for each food type to the tens place.)

Solution

A cup of whole milk contains 12 g of carbohydrate, 9 g of fat, and 9 g of protein. How many kilocalories does a cup of whole milk contain? (Round off the answer for each food type to the tens place.)

STEP 1 State the given and needed quantities.

ANALYZE THE PROBLEM	Given	Need	Connect
	12 g of carbohydrate 9 g of fat 9 g of protein	total number of kilocalories	energy values

Solution

A cup of whole milk contains 12 g of carbohydrate, 9 g of fat, and 9 g of protein. How many kilocalories does a cup of whole milk contain? (Round off the answer for each food type to the tens place.)

STEP 2 **Use the energy value for each food type to calculate the kilocalories, rounded off to the tens place.**

12 g carbohydrate	×	4 kcal/g	=	50 kcal
9 g fat	×	9 kcal/g	=	80 kcal
9 g protein	×	4 kcal/g	=	40 kcal

Solution

A cup of whole milk contains 12 g of carbohydrate, 9 g of fat, and 9 g of protein. How many kilocalories does a cup of whole milk contain? (Round off the answer for each food type to the tens place.)

STEP 3 Add the energy for each food type to give the total energy from the food.

Total energy = 50 kcal + 80 kcal + 40 kcal = 170 kcal

Chemistry Link to Health

Losing and Gaining Weight

The number of kilocalories or kilojoules needed in the daily diet of an adult depends on gender, age, and level of physical activity.

A person loses weight when food intake is less than energy output.

TABLE 3.9 Typical Energy Requirements for Adults

Gender	Age	Moderately Active kcal (kJ)	Highly Active kcal (kJ)
Female	19–30	2100 (8800)	2400 (10 000)
	31–50	2000 (8400)	2200 (9200)
Male	19–30	2700 (11 300)	3000 (12 600)
	31–50	2500 (10 500)	2900 (12 100)

TABLE 3.10 Energy Expended by a 70.0-kg (154-lb) Adult

Activity	Energy (kcal/h)	Energy (kJ/h)
Sleeping	60	250
Sitting	100	420
Walking	200	840
Swimming	500	2100
Running	750	3100

3.6 Specific Heat

The high specific heat of water keeps temperature more moderate in summer and winter.

Learning Goal Use specific heat to calculate heat loss or gain.

Specific Heat

Specific heat (*SH*)

- is different for different substances
- is the amount of heat needed to raise the temperature of exactly 1 g of a substance by exactly 1 °C
- has units of J/g °C in the SI system and of cal/g °C in the metric system

$$\text{Specific heat } (SH) = \frac{\text{heat}}{\text{mass} \quad \Delta T} = \frac{\text{cal (or J)}}{\text{g} \quad {}^\circ\text{C}}$$

$$SH \text{ for } H_2O(l) = \frac{1.00 \text{ cal}}{\text{g } {}^\circ\text{C}} = \frac{4.184 \text{ J}}{\text{g } {}^\circ\text{C}}$$

Calculating Specific Heat

Example: What is the specific heat if 24.8 g of a metal absorbs 275 J of energy and the temperature rises from 20.2 °C to 24.5 °C?

Solution

Example: What is the specific heat if 24.8 g of a metal absorbs 275 J of energy and the temperature rises from 20.2 °C to 24.5 °C?

STEP 1 State the given and needed quantities.

ANALYZE THE PROBLEM	Given	Need	Connect
	24.8 g metal 275 J energy $T_{initial}$ = 20.2 °C T_{final} = 24.5 °C	specific heat	temperature change, specific heat expression

STEP 2 Calculate the temperature change (Δ*T*).

$$\Delta T = 24.5\ °C - 20.2\ °C = 4.3\ °C$$

Solution

Example: What is the specific heat if 24.8 g of a metal absorbs 275 J of energy and the temperature rises from 20.2 °C to 24.5 °C?

STEP 3 Write the relationship for specific heat.

$$SH = \frac{\text{heat}}{m \times \Delta T}$$

STEP 4 Substitute in the given values and calculate the specific heat.

$$SH = \frac{\overset{\text{3 SFs}}{275\ \text{J}}}{\underset{\text{3 SFs}}{24.8\ \text{g}} \times \underset{\text{2 SFs}}{4.3\ °\text{C}}} = \frac{2.6\ \text{J}}{\underset{\text{2 SFs}}{\text{g}\ °\text{C}}}$$

Specific Heats for Some Substances

TABLE 3.11 Specific Heats for Some Substances

Substance	cal/g °C	J/g °C
Elements		
Aluminum, Al(*s*)	0.214	0.897
Copper, Cu(*s*)	0.0920	0.385
Gold, Au(*s*)	0.0308	0.129
Iron, Fe(*s*)	0.108	0.452
Silver, Ag(*s*)	0.0562	0.235
Titanium, Ti(*s*)	0.125	0.523
Compounds		
Ammonia, $NH_3(g)$	0.488	2.04
Ethanol, $C_2H_6O(l)$	0.588	2.46
Sodium chloride, NaCl(*s*)	0.207	0.864
Water, $H_2O(l)$	1.00	4.184
Water, $H_2O(s)$	0.485	2.03

Specific Heat of Liquid Water

Because of the high specific heat of water, a large mass of water near a coastal city can absorb or release five times the energy absorbed or released by the same amount of rock near an inland city.

Learning Check

1. When ocean water cools, the surrounding air

A. cools **B.** warms **C.** stays the same

2. Sand in the desert is hot in the day and cool at night. Sand must have a

A. low specific heat **B.** high specific heat

Solution

1. When ocean water cools, the surrounding air

B. warms

2. Sand in the desert is hot in the day and cool at night.
Sand must have a

A. low specific heat

Calculations Using Specific Heat

When we know the specific heat of a substance, we can

- rearrange the specific heat expression to give the *heat equation*
- calculate the heat lost or gained by a given mass of the substance over a certain temperature change

$$\text{Heat} = \text{mass} \times \text{temperature change} \times \text{specific heat}$$

$$\text{Heat} = m \times \Delta T \times SH$$

$$\text{cal} = \cancel{\text{g}} \times \cancel{^\circ\text{C}} \times \frac{\text{cal}}{\cancel{\text{g}}\ \cancel{^\circ\text{C}}}$$

$$\text{J} = \cancel{\text{g}} \times \cancel{^\circ\text{C}} \times \frac{\text{J}}{\cancel{\text{g}}\ \cancel{^\circ\text{C}}}$$

Using the Heat Equation

CORE CHEMISTRY SKILL
Using the Heat Equation

Example: Use the heat equation to calculate the energy, in kJ, needed to heat 255 g of copper from 24 °C to 185 °C.

Solution

Example: Use the heat equation to calculate the energy, in kJ, needed to heat 255 g of copper from 24 °C to 185 °C.

STEP 1 State the given and needed quantities.

ANALYZE THE PROBLEM	Given	Need	Connect
	255 g of copper $T_{initial}$ = 24 °C T_{final} = 185 °C	joules	heat equation, specific heat of copper

STEP 2 Calculate the temperature change (Δ*T*).

$$\Delta T = 185\text{ °C} - 24\text{ °C} = 161\text{ °C}$$

Solution

Example: Use the heat equation to calculate the energy, in kJ, needed to heat 255 g of copper from 24 °C to 185 °C.

STEP 3 Write the heat equation and needed conversion factors.

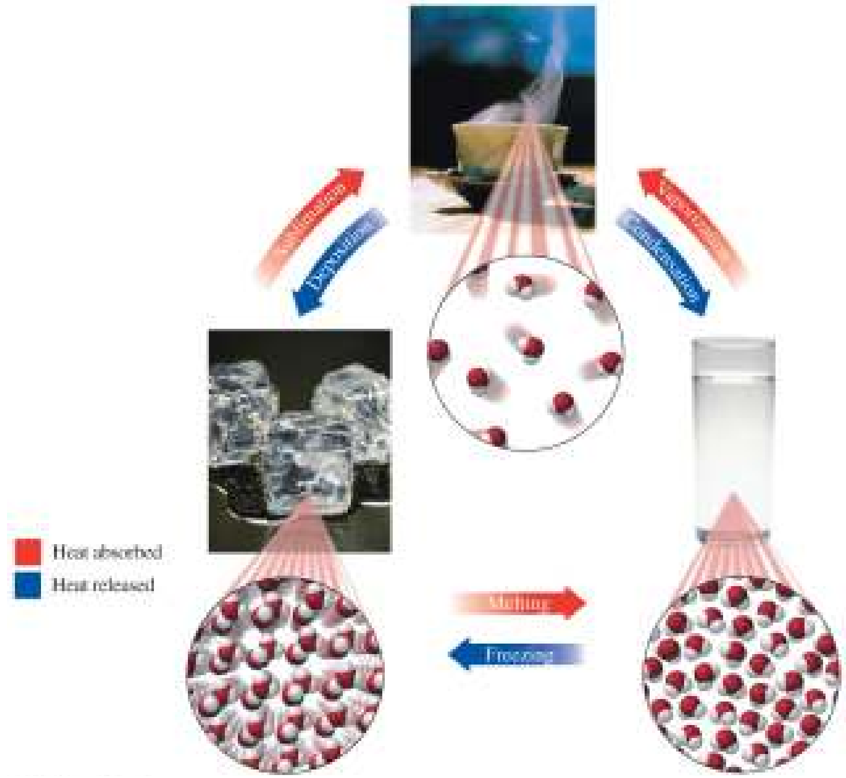
$$\text{Heat} = m \times \Delta T \times SH \qquad SH_{\text{copper}} = \frac{0.385\ \text{J}}{\text{g}\ °\text{C}}$$

STEP 4 Substitute in the given values and calculate the heat, making sure units cancel.

$$\text{Heat} = \underset{\text{3 SFs}}{255\ \text{g}} \times \underset{\text{3 SFs}}{161\ °\text{C}} \times \overset{\text{3 SFs}}{\frac{0.385\ \text{J}}{\text{g}\ °\text{C}}} \times \frac{\overset{\text{Exact}}{1\ \text{kJ}}}{\underset{\text{Exact}}{1000\ \text{J}}} = \underset{\text{3 SFs}}{15.8\ \text{kJ}}$$

3.7 Changes of State

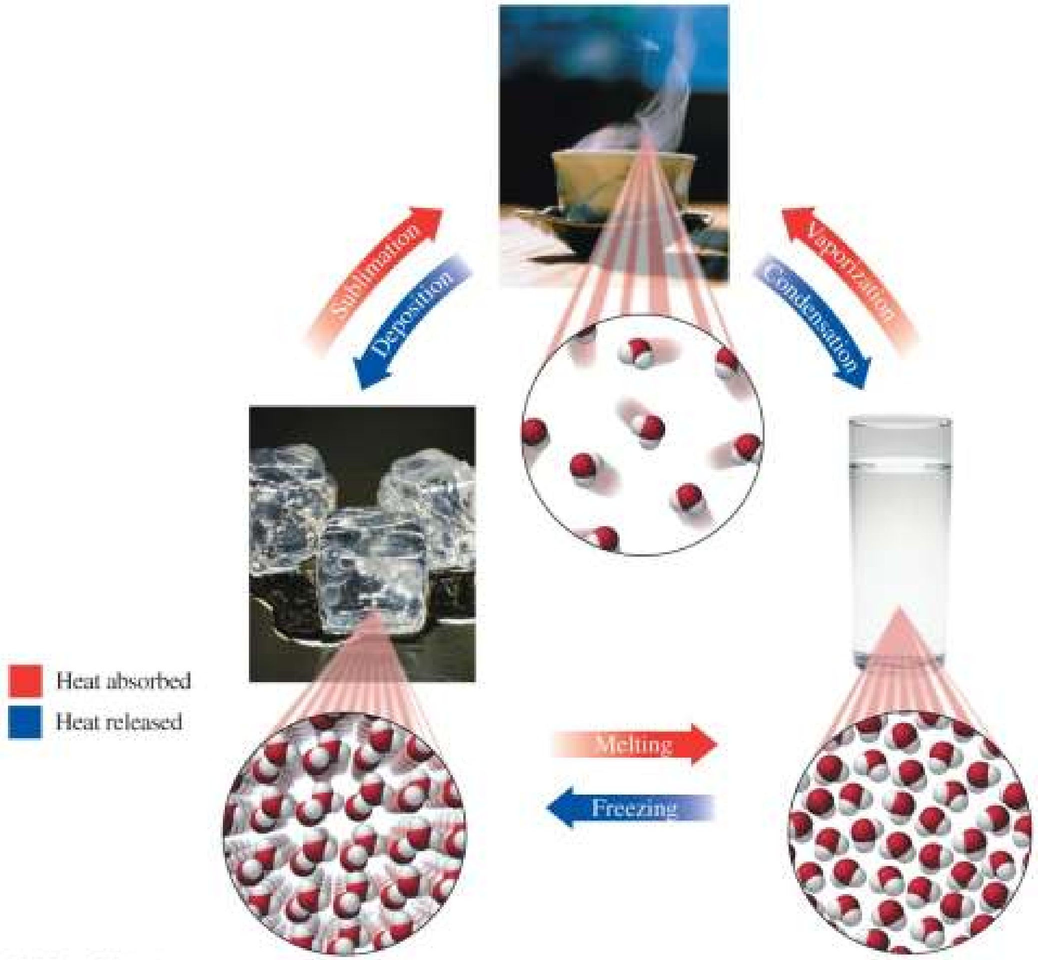
Changes of state include melting and freezing, boiling and condensation, and sublimation and deposition.



Learning Goal Describe the changes of state between solids, liquids, and gases; calculate the energy released or absorbed.

Changes of State

Matter undergoes a **change of state** when it is converted from one state to another state at a constant temperature.

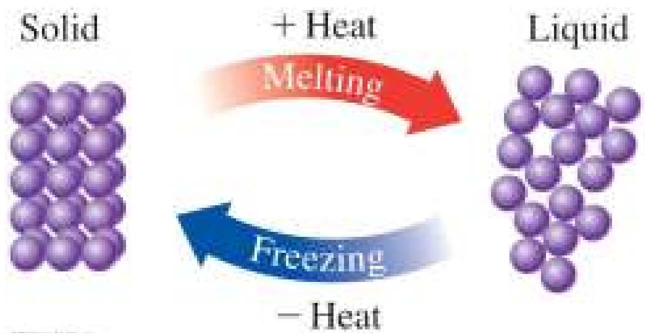


Melting and Freezing

A substance

- is **melting** while it changes from a solid to a liquid at its **melting point (mp)**
- is **freezing** while it changes from a liquid to a solid at its **freezing point (fp)**

Water has a freezing (melting) point of 0 °C.



Melting and freezing are reversible processes.

Heat of Fusion

The **heat of fusion** is the energy that must be added to convert exactly 1 g of solid to a liquid at its melting point.

For H_2O, 80. cal (334 J) of heat is needed to melt 1 g of ice at its melting point (0 °C).

$$H_2O(s) + 80.\ \text{cal/g}\ (334\ \text{J/g}) \longrightarrow H_2O(l)$$

Heat of Fusion

The **heat of fusion** is also the quantity of heat that must be removed to convert exactly 1 g of liquid to a solid at its freezing point.

For H_2O, 80. cal (334 J) of heat is removed to freeze 1 g of water at its freezing point (0 °C).

$$H_2O(l) \longrightarrow H_2O(s) + 80.\ \text{cal/g}\ (334\ \text{J/g})$$

Heat of Fusion, H_2O

The heat of fusion for water can be used as a conversion factor.

$$1\text{ g } H_2O\ (s \rightarrow l) = 80.\text{ cal } (334\text{ J})$$

$$\frac{80.\text{ cal}}{1\text{ g } H_2O} \text{ and } \frac{1\text{ g } H_2O}{80.\text{ cal}} \qquad \frac{334\text{ J}}{1\text{ g } H_2O} \text{ and } \frac{1\text{ g } H_2O}{334\text{ J}}$$

When calculating the heat needed to melt (or released when freezing) water, we use the following equation:

$$\text{Heat} = \text{mass} \times \text{heat of fusion}$$

$$\text{cal} = \cancel{\text{g}} \times \frac{80.\text{ cal}}{\cancel{\text{g}}} \qquad \text{J} = \cancel{\text{g}} \times \frac{334\text{ J}}{\cancel{\text{g}}}$$

Learning Check

CORE CHEMISTRY SKILL
Calculating Heat for Change of State

How many kilojoules are needed to melt 32.0 g of ice at 0 °C?

Solution

How many kilojoules are needed to melt 32.0 g of ice at 0 °C?

STEP 1 State the given and needed quantities.

ANALYZE THE PROBLEM	**Given**	**Need**	**Connect**
	32.0 g of ice at 0 °C	kilojoules	heat of fusion

STEP 2 Write a plan to convert the given quantity to the needed quantity.

grams of ice → Heat of fusion → joules → Metric factor → kilojoules

Solution

How many kilojoules are needed to melt 32.0 g of ice at 0 °C?

STEP 3 Write the heat conversion factor and any metric factor.

$$1 \text{ g of } H_2O\ (s \rightarrow l) = 334 \text{ J} \qquad 1 \text{ kJ} = 1000 \text{ J}$$

$$\frac{334 \text{ J}}{1 \text{ g } H_2O} \text{ and } \frac{1 \text{ g } H_2O}{334 \text{ J}} \qquad \frac{1000 \text{ J}}{1 \text{ kJ}} \text{ and } \frac{1 \text{ kJ}}{1000 \text{ J}}$$

Solution

How many kilojoules are needed to melt 32.0 g of ice at 0 °C?

STEP 4 Set up the problem and calculate the needed quantity.

$$\underset{\text{3 SFs}}{32.0\ \cancel{\text{g H}_2\text{O}(s)}} \times \frac{\overset{\text{3 SFs}}{334\ \cancel{\text{J}}}}{\underset{\text{Exact}}{1\ \cancel{\text{g H}_2\text{O}(s)}}} \times \frac{\overset{\text{Exact}}{1\text{ kJ}}}{\underset{\text{Exact}}{1000\ \cancel{\text{J}}}} = \underset{\text{3 SFs}}{10.7\text{ kJ}}$$

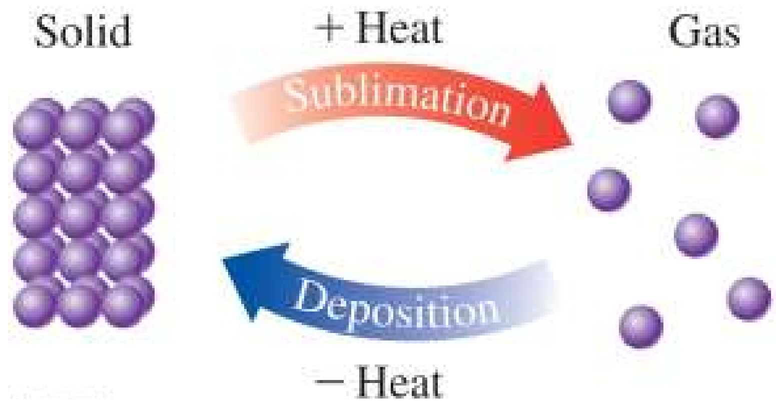
Sublimation and Deposition

When **sublimation** occurs,

- the particles on the surface of a solid change directly to a gas without going through the liquid state
- there is no change in temperature

In the reverse process, called **deposition**, gas particles change directly to a solid.

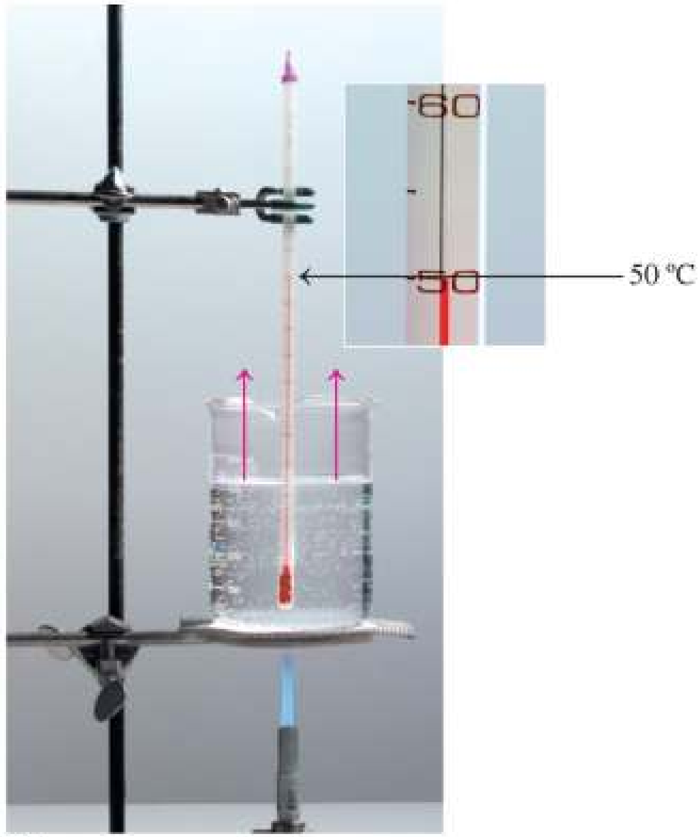
Dry ice undergoes sublimation.



Sublimation and deposition are reversible processes.

Evaporation, Boiling, and Condensation

Evaporation occurs when water molecules gain sufficient energy to escape the liquid surface and enter the gas phase.

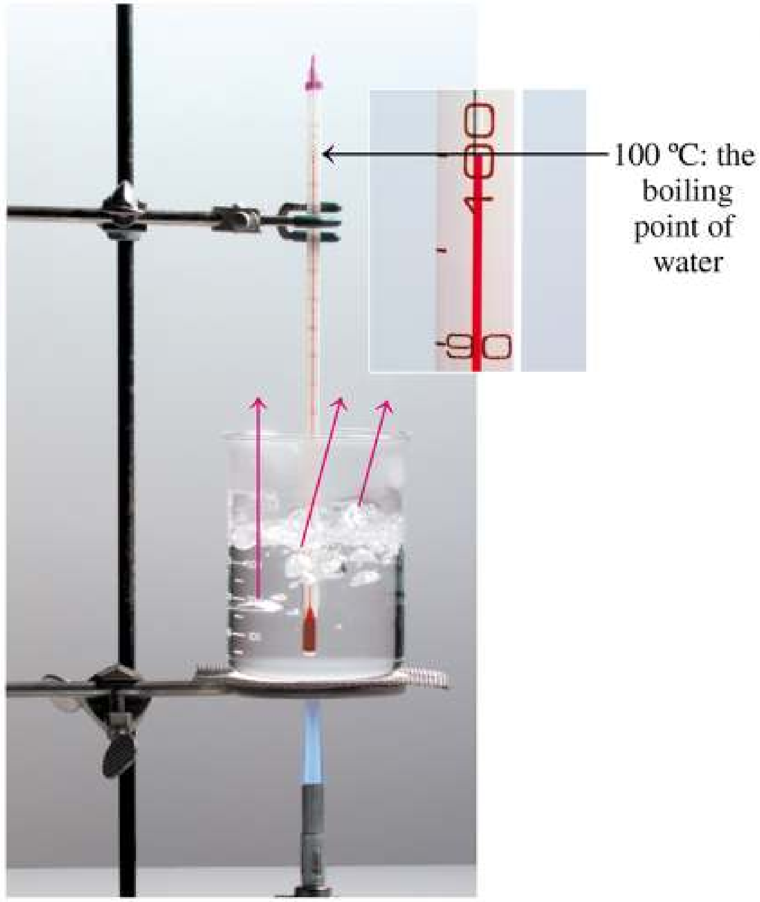


(a)

During evaporation, molecules of the liquid are converted to gas at the surface of the liquid.

Evaporation, Boiling, and Condensation

At the **boiling point**, the molecules have enough energy to overcome their attractive forces and become a gas.

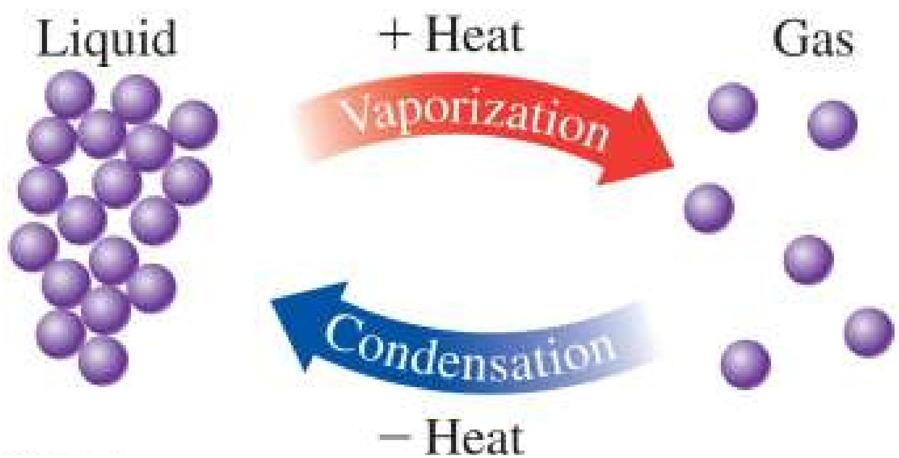


Boiling occurs as bubbles of gas form throughout the liquid.

Evaporation, Boiling, and Condensation

In **condensation**, water vapor is converted to a liquid as the water molecules lose kinetic energy and slow down.

Condensation occurs at the same temperature as boiling, but heat is removed.



Vaporization and condensation are reversible processes.

Heat of Vaporization

The **heat of vaporization** is the amount of heat

- absorbed to change 1 g of liquid to gas at the boiling point
- released when 1 g of gas changes to liquid at the boiling point

For H_2O, 540 cal (2260 J) of heat is needed to convert 1 g of water to steam (vapor) at 100 °C.

$$H_2O(l) + 540\ \text{cal/g}\ (2260\ \text{J/g}) \longrightarrow H_2O(g)$$

Heat of Condensation

This same amount of heat is released when 1 g of water vapor (gas) changes to liquid at 100 °C.

$$H_2O(g) \longrightarrow H_2O(l) + 540\ \text{cal/g}\ (2260\ \text{J/g})$$

Therefore, 540 cal/g or 2260 J/g is also the *heat of condensation* of water.

Heat of Vaporization, H_2O

The heat of vaporization (condensation) for water can be used as a conversion factor.

$$1 \text{ g of } H_2O\ (l \rightarrow g) = 540 \text{ cal } (2260 \text{ J})$$

$$\frac{540 \text{ cal}}{1 \text{ g } H_2O} \text{ and } \frac{1 \text{ g } H_2O}{540 \text{ cal}} \qquad \frac{2260 \text{ J}}{1 \text{ g } H_2O} \text{ and } \frac{1 \text{ g } H_2O}{2260 \text{ J}}$$

When calculating the heat needed to vaporize (or released when condensing) water, we use the following equation:

Heat = mass × heat of vaporization

$$\text{cal} = \cancel{\text{g}} \times \frac{540 \text{ cal}}{\cancel{\text{g}}} \qquad \text{J} = \cancel{\text{g}} \times \frac{2260 \text{ J}}{\cancel{\text{g}}}$$

Learning Check

How many kilojoules are released when 50.0 g of steam from a volcano condenses at 100 °C?

Solution

How many kilojoules are released when 50.0 g of steam from a volcano condenses at 100 °C?

STEP 1 State the given and needed quantities.

ANALYZE THE PROBLEM	Given	Need	Connect
	50.0 g of steam at 100 °C	kilojoules released	heat of condensation

STEP 2 Write a plan to convert the given quantity to the needed quantity.

grams of steam → [Heat of condensation] → joules → [Metric factor] → kilojoules

Solution

How many kilojoules are released when 50.0 g of steam from a volcano condenses at 100 °C?

STEP 3 **Write the heat conversion factor and any metric factor.**

$$1 \text{ g of } H_2O\ (g \rightarrow l) = 2260 \text{ J} \qquad 1 \text{ kJ} = 1000 \text{ J}$$

$$\frac{2260 \text{ J}}{1 \text{ g } H_2O} \text{ and } \frac{1 \text{ g } H_2O}{2260 \text{ J}} \qquad \frac{1000 \text{ J}}{1 \text{ kJ}} \text{ and } \frac{1 \text{ kJ}}{1000 \text{ J}}$$

Solution

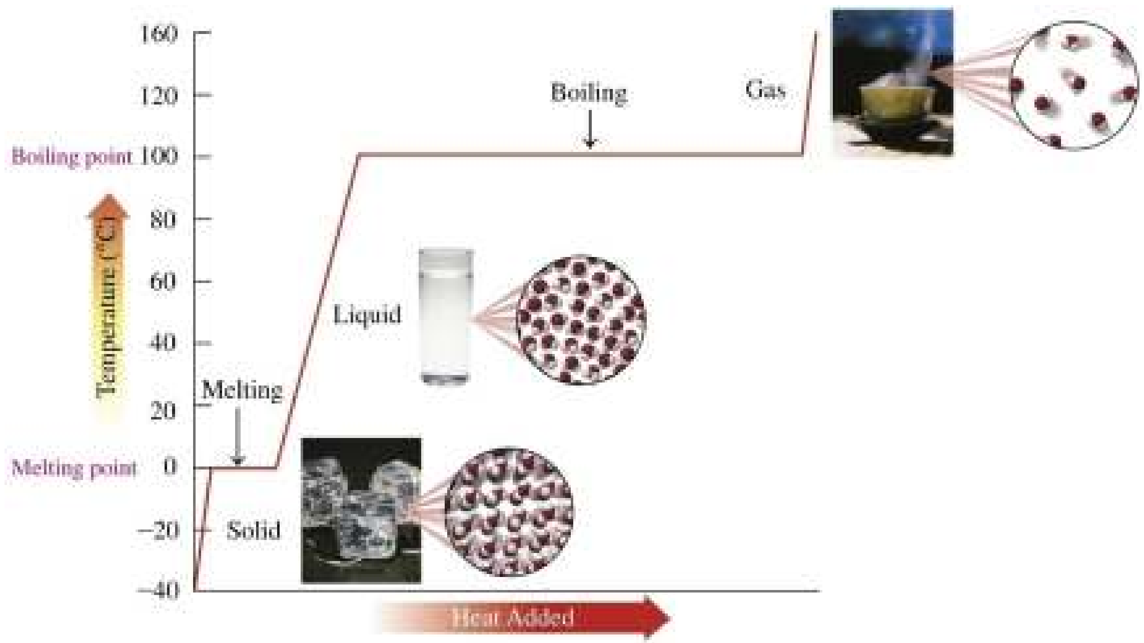
How many kilojoules are released when 50.0 g of steam from a volcano condenses at 100 °C?

STEP 4 **Set up the problem and calculate the needed quantity.**

$$\underset{\text{3 SFs}}{50.0\ \cancel{\text{g H}_2\text{O}(g)}} \times \frac{\overset{\text{3 SFs}}{2260\ \cancel{\text{J}}}}{\underset{\text{Exact}}{1\ \cancel{\text{g H}_2\text{O}(g)}}} \times \frac{\overset{\text{Exact}}{1\ \text{kJ}}}{\underset{\text{Exact}}{1000\ \cancel{\text{J}}}} = \underset{\text{3 SFs}}{113\ \text{kJ}}$$

Heating Curve

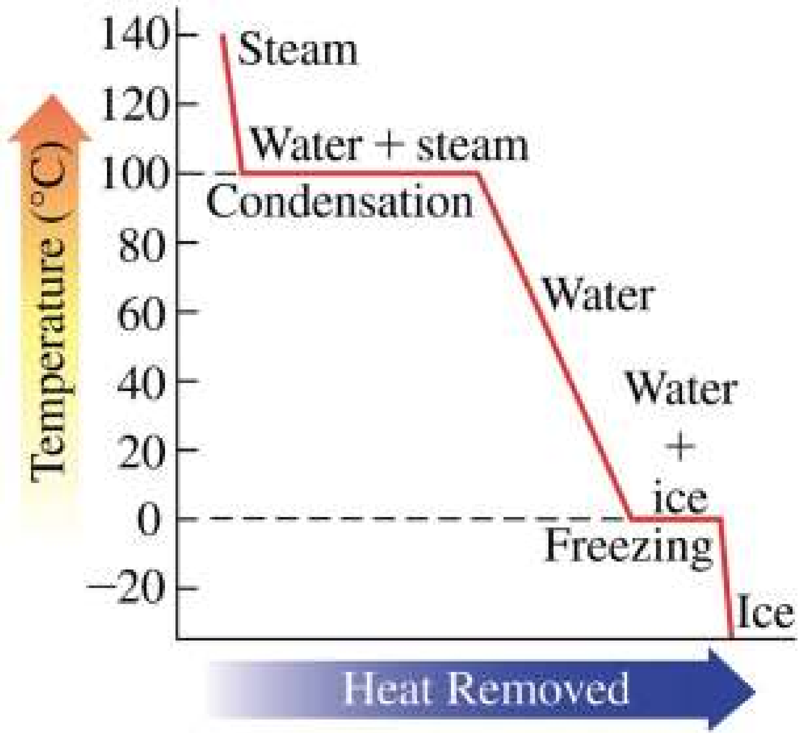
On a **heating curve**, diagonal lines indicate changes in temperature for a physical state, and horizontal lines (plateaus) indicate changes of state.



A heating curve for water diagrams the temperature increases and changes of state as heat is added.

Cooling Curve

On a **cooling curve**, diagonal lines indicate changes in temperature for a physical state, and horizontal lines (plateaus) indicate changes of state.



A cooling curve for water diagrams the temperature increases and changes of state as heat is added.

Learning Check

1. A plateau (horizontal line) on a heating curve represents

A. a temperature change

B. a constant temperature

C. a change of state

2. A sloped line on a heating curve represents

A. a temperature change

B. a constant temperature

C. a change of state

Solution

1. A plateau (horizontal line) on a heating curve represents
   B. a constant temperature
   C. a change of state

2. A sloped line on a heating curve represents
   A. a temperature change

Learning Check

Use the cooling curve for water to answer each of the following:

1. Water condenses at a temperature of

A. 0 °C **B.** 50 °C **C.** 100 °C

2. At a temperature of 0 °C, liquid water

A. freezes **B.** melts **C.** changes to a gas

3. At 40 °C, water is a

A. solid **B.** liquid **C.** gas

4. When water freezes, heat is

A. removed **B.** added

Solution

Use the cooling curve for water to answer each of the following:

1. Water condenses at a temperature of

C. 100 °C

2. At a temperature of 0 °C, liquid water

A. freezes

3. At 40 °C, water is a

B. liquid

4. When water freezes, heat is

A. removed

Learning Check

A 175-g sample of steam at 100 °C is emitted from a volcano. It condenses, cools, and falls as snow at 0.0 °C. How many kilojoules were released?

A. 396 kJ

B. 528 kJ

C. 133 kJ

Solution

A 175-g sample of steam at 100. °C is emitted from a volcano. It condenses, cools, and falls as snow at 0.0 °C. How many kilojoules were released?

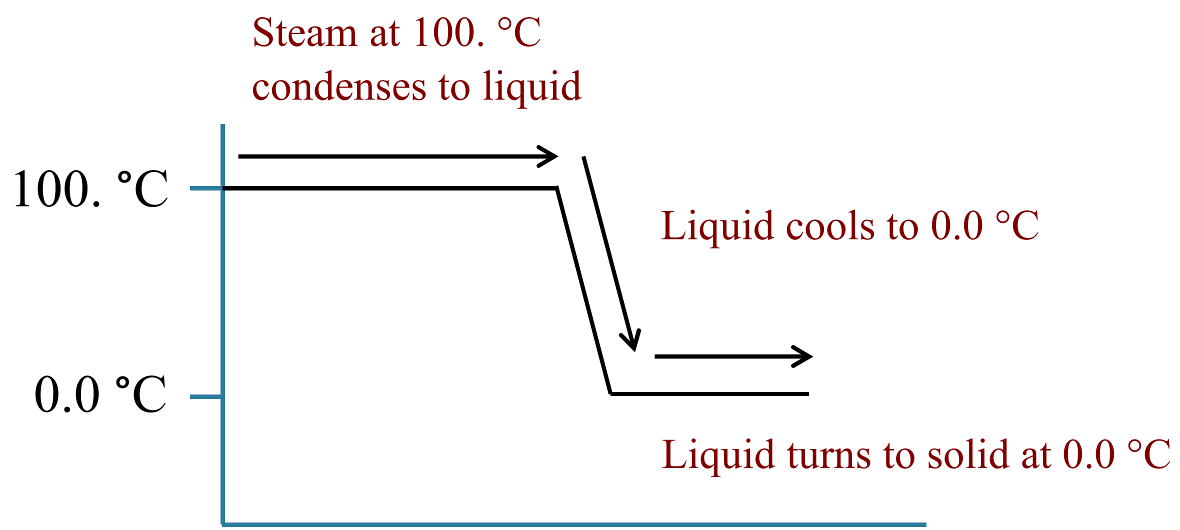
STEP 1 State the given and needed quantities.

ANALYZE THE PROBLEM	Given	Need	Connect
	175 g of steam at 100. °C	total heat released when condense steam at 100. °C, cool to 0.0 °C, and freeze to snow	heat of condensation, specific heat of water, heat of fusion

Solution

STEP 2 Write a plan to convert the given quantity to the needed quantity.

Use the cooling curve to determine kilojoules released.



Solution

STEP 3 **Write the heat conversion factors and any metric factor.**

$$1 \text{ g of } H_2O\ (g \rightarrow l) = 2260 \text{ J} \qquad SH_{H_2O} = \frac{4.184 \text{ J}}{\text{g °C}}$$

$$\frac{2260 \text{ J}}{1 \text{ g } H_2O} \text{ and } \frac{1 \text{ g } H_2O}{2260 \text{ J}} \qquad \frac{4.184 \text{ J}}{\text{g °C}} \text{ and } \frac{\text{g °C}}{4.184 \text{ J}}$$

$$1 \text{ g of } H_2O\ (l \rightarrow s) = 334 \text{ J} \qquad 1 \text{ kJ} = 1000 \text{ J}$$

$$\frac{334 \text{ J}}{1 \text{ g } H_2O} \text{ and } \frac{1 \text{ g } H_2O}{334 \text{ J}} \qquad \frac{1000 \text{ J}}{1 \text{ kJ}} \text{ and } \frac{1 \text{ kJ}}{1000 \text{ J}}$$

Solution

STEP 4 Set up the problem and calculate the needed quantity.

(1) Calculate the heat released as steam is condensed:

$$\underset{\text{3 SFs}}{175\ \cancel{\text{g H}_2\text{O}(g)}} \times \frac{\overset{\text{3 SFs}}{2260\ \cancel{\text{J}}}}{\underset{\text{Exact}}{1\ \cancel{\text{g H}_2\text{O}(g)}}} \times \frac{\overset{\text{Exact}}{1\ \text{kJ}}}{\underset{\text{Exact}}{1000\ \cancel{\text{J}}}} = \underset{\text{3 SFs}}{396\ \text{kJ}}$$

(2) Calculate temperature change of the liquid:

$\Delta T = 100.\ ^{\circ}\text{C} - 0.0\ ^{\circ}\text{C} = 100.\ ^{\circ}\text{C}$

Solution

STEP 4 (continued)

(3) Calculate the heat released as liquid is cooled:

$$\underset{\text{3 SFs}}{175\ \cancel{\text{g H}_2\text{O}(l)}} \times \underset{\text{3 SFs}}{100.\ \cancel{^\circ\text{C}}} \times \frac{\overset{\text{4 SFs}}{4.184\ \cancel{\text{J}}}}{\underset{\text{Exact}}{\cancel{\text{g}}\ \cancel{^\circ\text{C}}}} \times \frac{\overset{\text{Exact}}{1\ \text{kJ}}}{\underset{\text{Exact}}{1000\ \cancel{\text{J}}}} = \underset{\text{3 SFs}}{73.2\ \text{kJ}}$$

(4) Calculate the heat released as liquid freezes:

$$\underset{\text{3 SFs}}{175\ \cancel{\text{g H}_2\text{O}(l)}} \times \frac{\overset{\text{3 SFs}}{334\ \cancel{\text{J}}}}{\underset{\text{Exact}}{1\ \cancel{\text{g H}_2\text{O}(l)}}} \times \frac{\overset{\text{Exact}}{1\ \text{kJ}}}{\underset{\text{Exact}}{1000\ \cancel{\text{J}}}} = \underset{\text{3 SFs}}{58.5\ \text{kJ}}$$

Solution

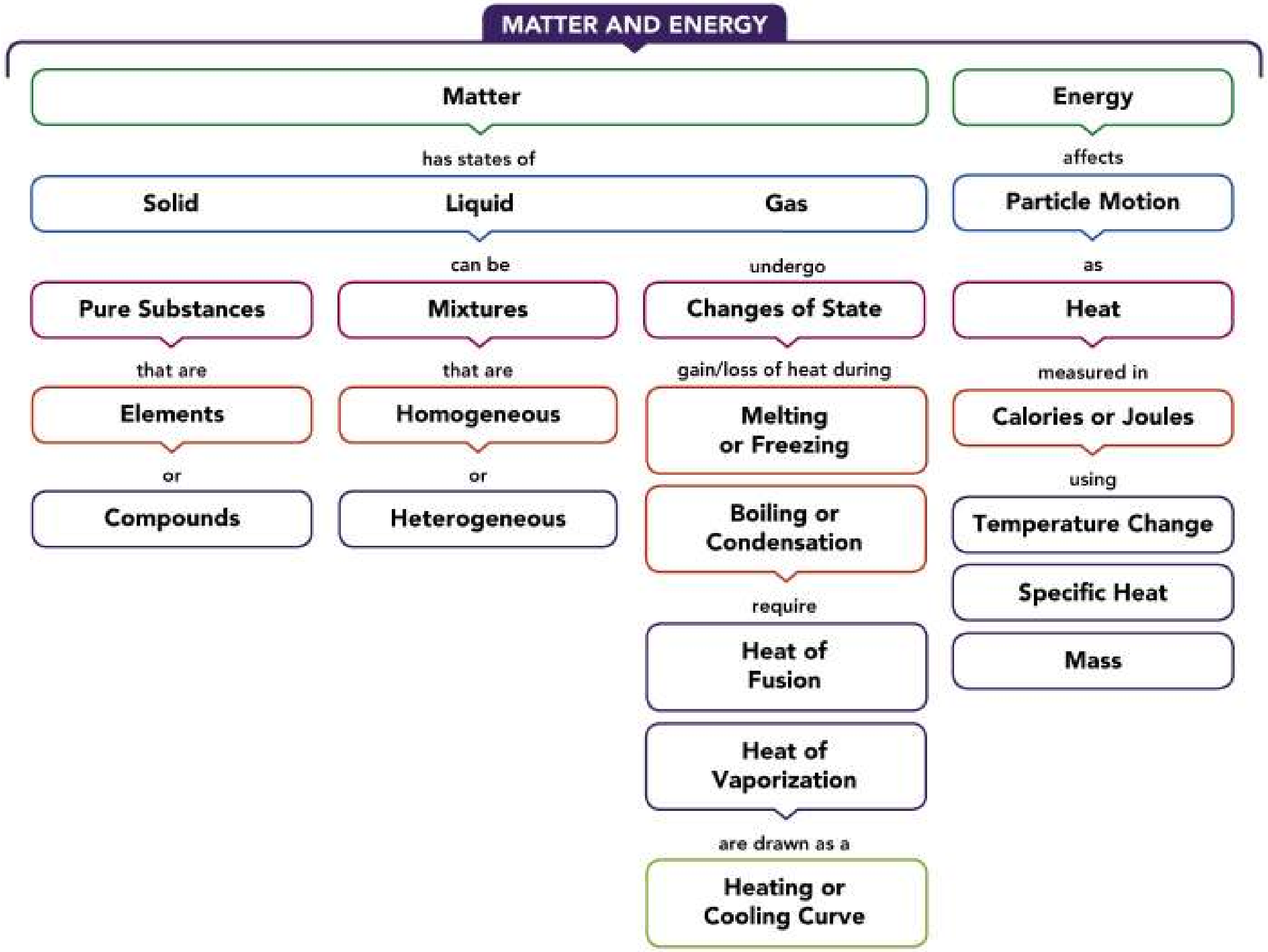
STEP 4 (continued)

Calculate the total energy needed:

Heat released as steam is condensed	= 396 kJ
Heat released as liquid is cooled	= 73.2 kJ
Heat released as liquid freezes	= 58.5 kJ
Total heat needed	= 528 kJ

Answer is B.

Concept Map


MATTER AND ENERGY
Matter
has states of
Solid
Liquid
Gas
can be
undergo
Pure Substances
Mixtures
Changes of State
that are
that are
gain/loss of heat during
Elements
Homogeneous
Melting or Freezing
or
or
Compounds
Heterogeneous
Boiling or Condensation
require
Heat of Fusion
Heat of Vaporization
are drawn as a
Heating or Cooling Curve
Energy
affects
Particle Motion
as
Heat
measured in
Calories or Joules
using
Temperature Change
Specific Heat
Mass