Chapter 3
Matter and Energy

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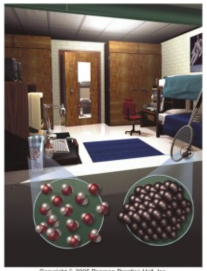
Chem 118
Introductory Chemistry

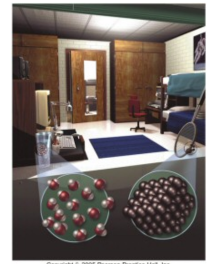


Map: Introductory Chemistry (Tro) https://chem.libretexts.org/@go/page/45050 (accessed Mar 25, 2022).

Matter

In Your Room

- Everything you can see, touch, smell or taste in your room is made of **matter**.
- Chemists study the differences in matter and how that relates to the structure of matter.

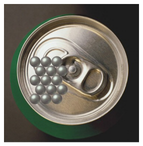


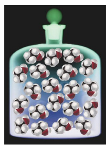
What is Matter?

- **Matter** is defined as anything that occupies space and has mass
- Even though it appears to be smooth and continuous, matter is actually composed of a lot of tiny little pieces we call **atoms** and **molecules**

Atoms and Molecules

- **Atoms** are the tiny particles that make up all matter.
- In most substances, the atoms are joined together in units called **molecules**





Classifying Matter by Physical State

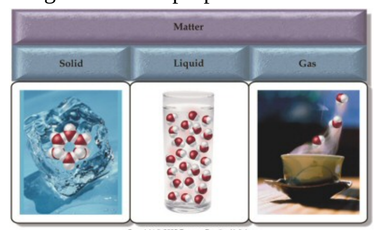
- matter can be classified as solid, liquid or gas based on what properties it exhibits

State	*Shape*	*Volume*	*Compress*	*Flow*
Solid	Fixed	Fixed	No	No
Liquid	Indef.	Fixed	No	Yes
Gas	Indef.	Indef.	Yes	Yes

•Fixed = keeps shape when placed in a container,
•Indefinite = takes the shape of the container

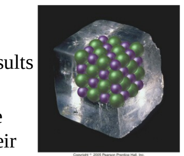
Structure Determines Properties

- the atoms or molecules have different structures in solids, liquid and gases, leading to different properties



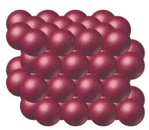
Solids

- the particles in a solid are packed close together and are fixed in position
  - ✓ though they may vibrate
- the close packing of the particles results in solids being incompressible
- the inability of the particles to move around results in solids retaining their shape and volume when placed in a new container; and prevents the particles from flowing

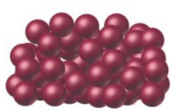


Solids

- some solids have their particles arranged in an orderly geometric pattern – we call these **crystalline solids**
  - ✓ salt and diamonds
- other solids have particles that do not show a regular geometric pattern over a long range – we call these **amorphous solids**
  - ✓ plastic and glass



(a) Crystalline solid



(b) Amorphous solid

Liquids

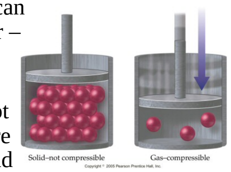
- the particles in a liquid are closely packed, but they have some ability to move around
- the close packing results in liquids being incompressible
- but the ability of the particles to move allows liquids to take the shape of their container and to flow – however they don't have enough freedom to escape and expand to fill the container

Gases

- in the gas state, the particles have complete freedom from each other
- the particles are constantly flying around, bumping into each other and the container
- in the gas state, there is a lot of empty space between the particles
  - ✓ on average

Gases Compressible and Expandable

- because there is a lot of empty space, the particles can be squeezed closer together – therefore gases are compressible
- because the particles are not held in close contact and are moving freely, gases expand to fill and take the shape of their container, and will flow



Classification of Matter

Matter
- Pure Substance
  Constant Composition
  Homogeneous
- Mixture
  Variable Composition

- **Pure Substance** = all samples are made of the same atom or molecule in the same percentages
  - ✓ salt
- **Mixtures** = different samples may have components present in different percentages
  - ✓ salt water

Classifying Matter by Composition

- matter that is composed of only one kind of atom or molecule is called a **pure substance**
  - ✓ **All samples show the same properties**
- matter that is composed of different kinds of pieces is called a **mixture**
  - ✓ **Because mixtures have variable composition, different samples will show different properties**

Classifying Pure Substances Elements and Compounds

- Substances which can not be broken down into simpler substances by chemical reactions are called **elements**
- Most substances are chemical combinations of elements. These are called **compounds**.
  - ✓ Compounds can be broken down into elements
  - ✓ Properties of the compound not related to the properties of the elements that compose it

Atoms & Molecules

- Smallest piece of an element is called an **atom**
  - ✓ there are subatomic particles, but these are no longer the element
- Smallest piece of a compound is called a **molecule**
  - ✓ molecules are made of atoms
  - ✓ all molecules of a compound are identical
  - ✓ each molecule has the same number and type of atoms

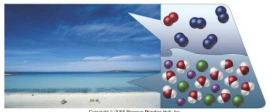
Elements

- 118 known, of which about 91 are found in nature
  - ✓ others are man-made
- Abundance = percentage found in nature
  - ✓ oxygen most abundant element (by mass) on earth and in the human body
- the abundance and form of an element varies in different parts of the environment
- every sample of an element is made up of lots of identical atoms

Compounds

- composed of elements in fixed percentages
  - ✓ water is 89 mass% O & 11 mass% H
- billions of known compounds
- organic or inorganic
- same elements can form more than one different compound
  - ✓ water and hydrogen peroxide contain just hydrogen and oxygen
  - ✓ carbohydrates all contain just C, H & O

Classification of Mixtures



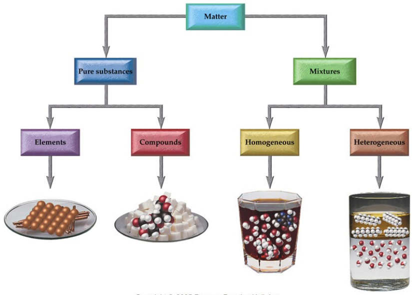
- **homogeneous** = matter that is uniform throughout
  - ✓ appears to be one thing
  - ✓ every piece of a sample has identical properties, though another sample with the same components may have different properties
  - ✓ solutions (homogeneous mixtures)
- **heterogeneous** = matter that is non-uniform throughout
  - ✓ contains regions with different properties than other regions

Pure Substances vs. Mixtures

- **Pure Substances**
1) all samples have the same physical and chemical properties
2) constant composition = all samples have the same pieces in the same percentages
3) homogeneous
4) separate into components based on **chemical properties**
5) temperature usually stays constant while melting or boiling

- **Mixtures**
1) different samples may show different properties
2) variable composition = samples made with the same pure substances may have different percentages
3) homogeneous or heterogeneous
4) separate into components based on **physical properties**
5) temperature changes while melting or boiling because composition changes

Classifying Matter



Properties of Matter

- **Physical Properties** are the characteristics of matter that can be changed without changing its composition
- **Chemical Properties** are the characteristics that determine how the composition of matter changes as a result of contact with other matter or the influence of energy

Some Physical Properties

mass	volume	density
phase	magnetism	specific heat
melting point	boiling point	volatility
taste	odor	color
texture	shape	solubility
electrical conductance	thermal conductance	
malleability	ductility	

Some Chemical Properties

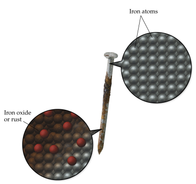
Acidity	Basicity (aka Alkalinity)
Causticity	Corrosiveness
Reactivity	Stability
Inertness	Explosiveness
(In)Flammability	Combustibility
Oxidizing Ability	Reducing Ability

Some Physical Properties of Iron

- iron is a silvery solid at room temperature with a metallic taste and smooth texture
- iron melts at 1538°C and boils at 4428°C
- iron's density is 7.87 g/cm^3
- iron can be magnetized
- iron conducts electricity, but not as well as most other common metals
- iron's ductility and thermal conductivity are about average for a metal
- it requires 0.45 J of heat energy to raise the temperature of one gram of iron by 1°C

Some Chemical Properties of Iron

- iron is easily oxidized in moist air to form rust
- when iron is added to hydrochloric acid, it produces a solution of ferric chloride and hydrogen gas
- iron is more reactive than silver, but less reactive than magnesium

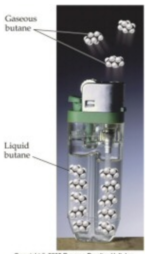


Brass – a Mixture

Type	Color	% Cu	% Zn	Density g/cm^3	MP °C	Tensile Strength psi	Uses
Gilding	reddish	95	5	8.86	1066	50K	pre-83 pennies, munitions, plaques
Commercial	bronze	90	10	8.80	1043	61K	door knobs, grillwork
Jewelry	bronze	87.5	12.5	8.78	1035	66K	costume jewelry
Red	golden	85	15	8.75	1027	70K	electrical sockets, fasteners & eyelets
Low	deep yellow	80	20	8.67	999	74K	musical instruments, clock dials
Cartridge	yellow	70	30	8.47	954	76K	car radiator cores
Common	yellow	67	33	8.42	940	70K	lamp fixtures, bead chain
Muntz metal	yellow	60	40	8.39	904	70K	nuts & bolts,

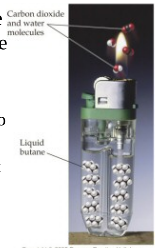
Changes in Matter

- **Physical Changes** - changes in the properties of matter that do not effect its composition
  - ✓ Heating water
    - ➢ raises its temperature, but it is still water
  - ✓ Evaporating butane from a lighter
  - ✓ Dissolving sugar in water
    - ➢ even though the sugar seems to disappear, it can easily be separated back into sugar and water by evaporation



Changes in Matter

- **Chemical Changes** involve a change in the properties of matter that change its composition
  - ✓ a Chemical Reaction
  - ✓ rusting is iron combining with oxygen to make iron(III) oxide
  - ✓ burning butane from a lighter changes it into carbon dioxide and water
  - ✓ silver combines with sulfur in the air to make tarnish



Is it a Physical or Chemical Change?

- a physical change results in a different form of the same substance
  - ✓ the kinds of molecules don't change
- a chemical change results in one or more completely new substances
  - ✓ the new substances have different molecules than the original substances
  - ✓ you will observe different physical properties because the new substances have their own physical properties

Phase Changes are Physical Changes

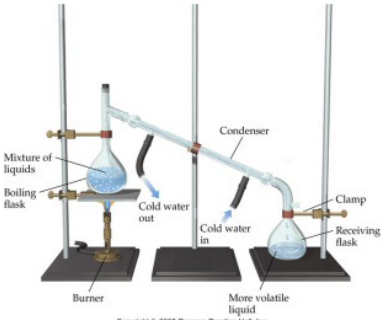
- Boiling = liquid to gas
- Melting = solid to liquid
- Subliming = solid to gas
- Condensing = gas to liquid
- Freezing = liquid to solid
- Deposition = gas to solid
- state changes require heating or cooling the substance
  - ✓ evaporation is *not* a simple phase change, it is a solution process

Separation of Mixtures

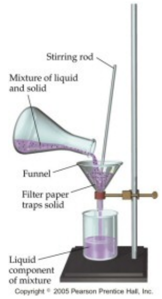
- Separate mixtures based on different physical properties of the components
  - ✓ Physical change

Different Physical Property	Technique
Boiling Point	Distillation
State of Matter (solid/liquid/gas)	Filtration
Adherence to a Surface	Chromatography
Volatility	Evaporation
Density	Centrifugation & Decanting

Distillation



Filtration



Law of Conservation of Mass

- Antoine Lavoisier
- *"Matter is neither created nor destroyed in a chemical reaction"*
- the total amount of matter present before a chemical reaction is always the same as the total amount after
- the total mass of all the reactants is equal to the total mass of all the products

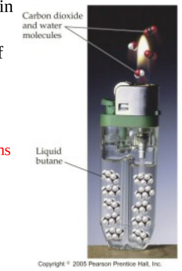
Conservation of Mass

- Total amount of matter remains constant in a chemical reaction
- 58 grams of butane burns in 208 grams of oxygen to form 176 grams of carbon dioxide and 90 grams of water.

butane + oxygen → carbon dioxide + water

58 grams + 208 grams → 176 grams + 90 grams

266 grams = 266 grams



Energy

Energy

- We have observed something that has neither mass or volume, **Energy**.
- Energy is anything that has the capacity to do work
- even though Chemistry is the study of matter, matter is effected by energy
  - ✓it can cause physical and/or chemical changes in matter

Law of Conservation of Energy

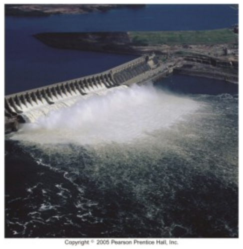
- *"Energy can neither be created nor destroyed"*
- the total amount of energy in the universe is constant – there is no process that can increase or decrease that amount
- however we can transfer energy from one place in the universe to another, and we can change its form

Matter Possesses Energy

- when a piece of matter possesses energy, it can give some it to another object
- all chemical and physical changes result in matter releasing or absorbing energy

Kinds of Energy
Kinetic and Potential

- **Kinetic Energy** is energy of motion, or energy that is being transferred from one object to another
- **Potential Energy** is energy that is stored



Some Forms of Energy

- Electrical
  - ✓kinetic energy associated with the flow of electrical charge
- Heat or Thermal Energy
  - ✓kinetic energy associated with molecular motion
- Light or Radiant Energy
  - ✓kinetic energy associated with energy transitions in an atom
- Nuclear
  - ✓potential energy in the nucleus of atoms
- Chemical
  - ✓potential energy in the attachment of atoms or because of their position

Using Energy

- we use energy to accomplish all kinds of processes, but according to the Law of Conservation of Energy we don't really use it up!
- when we use energy we are changing it from one form to another
  - ✓for example, converting the chemical energy in gasoline into mechanical energy to make your car move

"Losing" Energy

- if a process was 100% efficient, we could theoretically get all the energy transformed into a useful form
- but unfortunately we cannot get a 100% efficient process
- the energy "lost" in the process is energy transformed into a form we cannot use
- most of the energy in the combustion of gasoline is transformed into sound or heat energy that escapes into the air

Units of Energy

- **calorie (cal)** is the amount of energy needed to raise one gram of water by 1°C
- **Calorie (Cal)** is 1,000 cal
  - ✓1 Cal = 1000 cal = 1 kcal
  - ✓Also called a food calorie
- **Joule (J)** is equal to the amount of work done when a force of 1 newton displaces a mass through a distance of 1 meter in the direction of the force applied.
  - ✓It is the standard SI unit for energy
- **Kilowatt-hour (kWh)** is the energy delivered by 1000 Watts of power over one hour.
  - ✓Typically used when dealing with large amounts of energy

Example 3.5: Conversion of Energy Units

Energy Conversion Factors

1 calorie (cal) = 4.184 joules (J)

1 Calorie (Cal) = 1000 calories (cal)

1 kilowatt-hour (kWh) = 3.60×10^6 joules (J)

1 kilowatt-hour (kWh) = 860.421 Calories

Example:

- A candy bar contains 225 Cal of nutritional energy. How many joules does it contain?

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- Write down the given quantity and its units.

Given: 225 Cal

Example:
A candy bar contains 225 Cal of nutritional energy. How many joules does it contain?

Information
Given: 225 Cal

- Write down the quantity to find and/or its units.

Find: ? joules

Example:
A candy bar contains 225 Cal of nutritional energy. How many joules does it contain?

Information
Given: 225 Cal
Find: ? J

- Collect Needed Conversion Factors:

1000 cal = 1 Cal
4.184 J = 1 cal

Example:
A candy bar contains 225 Cal of nutritional energy. How many joules does it contain?

Information
Given: 225 Cal
Find: ? J
Conv. Fact. 1000 cal = 1 Cal; 4.184 J = 1 cal

- Write a Solution Map for converting the units :

Cal → cal → J

$$\frac{1000\ \text{cal}}{1\ \text{Cal}} \qquad \frac{4.184\ \text{J}}{1\ \text{cal}}$$

Example:
A candy bar contains 225 Cal of nutritional energy. How many joules does it contain?

Information
Given: 225 Cal
Find: ? J
Conv. Fact. 1000 cal = 1 Cal; 4.184 J = 1 cal
Sol'n Map: Cal → cal → J ($\frac{1000\ \text{cal}}{1\ \text{Cal}}$, $\frac{4.184\ \text{J}}{1\ \text{cal}}$)

- Apply the Solution Map:

$$225\ \text{Cal} \times \frac{1000\ \text{cal}}{1\ \text{Cal}} \times \frac{4.184\ \text{J}}{1\ \text{cal}}$$

= 941400 J

- Sig. Figs. & Round:

= 9.41 x 10^5 J

Example:
A candy bar contains 225 Cal of nutritional energy. How many joules does it contain?

Information
Given: 225 Cal
Find: ? J
Conv. Fact. 1000 cal = 1 Cal; 4.184 J = 1 cal
Sol'n Map: Cal → cal → J ($\frac{1000\ \text{cal}}{1\ \text{Cal}}$, $\frac{4.184\ \text{J}}{1\ \text{cal}}$)

- Check the Solution:

225 Cal = 9.41 x 10^5 J

The units of the answer, J, are correct.
The magnitude of the answer makes sense since joules are much smaller than Cals.

The Meaning of Heat

- Heat is the exchange of thermal **energy** between samples of matter
- heat flows from the matter that has high thermal energy to matter that has low thermal energy
  - ✓until they reach the same temperature
- heat is exchanged through molecular collisions between two samples

The Meaning of Temperature

- Temperature is a **measure** of the average kinetic energy of the molecules in a sample
- Not all molecules have in a sample the same amount of kinetic energy
- a higher temperature means a larger average kinetic energy

Fahrenheit

- The Fahrenheit Temperature Scale used as its two reference points the freezing point of concentrated saltwater (0°F) and average body temperature (100°F)
  - ✓more accurate measure now set average body temperature at 98.6°F
- Room temperature is about 75°F

Celsius

- The Celsius Temperature Scale used as its two reference points the freezing point of distilled water (0°C) and boiling point of distilled water (100°C)
  - ✓more reproducible standards
  - ✓most commonly used in science
- Room temperature is about 25°C

Fahrenheit vs. Celsius

- a Celsius degree is 1.8 times larger than a Fahrenheit degree
- the standard used for 0° on the Fahrenheit scale is a lower temperature than the standard used for 0° on the Celsius scale

$$T_{^\circ C} = \frac{T_{^\circ F} - 32}{1.8} \qquad T_{^\circ F} = 1.8 T_{^\circ C} + 32$$

The Kelvin Temperature Scale

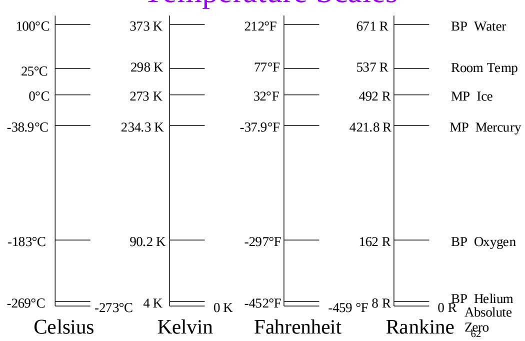
- both the Celsius and Fahrenheit scales have negative numbers
- the Kelvin scale is an absolute scale, meaning it does not allow for negative values.
- 0 K is called **Absolute Zero**. It is the lowest possible temperature.
  - ✓All molecular motion would stop at 0 K
  - ✓Absolute Zero is a theoretical value obtained by following patterns mathematically

Kelvin vs. Celsius

- the size of a "degree" on the Kelvin scale is the same as on the Celsius scale
  - ✓though technically, we don't call the divisions on the Kelvin scale degrees; we called them kelvins!
  - ✓that makes 1 K 1.8 times larger than 1°F
- the 0 standard on the Kelvin scale is a much lower temperature than on the Celsius scale

$$T_K = T_{^\circ C} + 273$$

Temperature Scales



Example 3.8: Converting Between Fahrenheit and Kelvin Temperature Scales

Example:

- Convert 310 K to Fahrenheit

Example:
Convert 310 K to Fahrenheit

- Write down the given quantity and its units.

  Given: 310 K

Example:
Convert 310 K to Fahrenheit

Information
Given: 310 K

- Write down the quantity to find and/or its units.

  Find: ? °F

Example:
Convert 310 K to Fahrenheit

Information
Given: 310 K
Find: ? °F

- Collect Needed Equations:

$$°C = \frac{(°F-32)}{1.8}$$

$$K = °C + 273$$

Example:
Convert 310 K to Fahrenheit

Information
Given: 310 K
Find: ? °F
Eq'ns: $°C = \frac{(°F-32)}{1.8}$ $K = °C + 273$

- Write a Solution Map:

K → °C → °F

$K = °C + 273$ $°C = \frac{(°F-32)}{1.8}$

$K - 273 = °C$ $1.8 \times °C = (°F-32)$

$1.8 \times °C + 32 = °F$

Example:
Convert 310 K to Fahrenheit

Information
Given: 310 K
Find: ? °F
Eq'ns: $K - 273 = °C$ $1.8 \times °C + 32 = °F$
Sol'n Map: K → °C → °F

- Apply the Solution Map:

$K - 273 = °C$ $1.8 \times °C + 32 = °F$

$310 - 273 = °C$ $1.8 \times 37 + 32 = °F$

$37 = °C$ $98.6 = °F$

- Sig. Figs. & Round: = 99°F

Example:
Convert 310 K to Fahrenheit

Information
Given: 310 K
Find: ? °F
Eq'ns: $K - 273 = °C$ $1.8 \times °C + 32 = °F$
Sol'n Map: K → °C → °F

- Check the Solution:

310 K = 99 °F

The units of the answer, °F, are correct.
The magnitude of the answer makes sense
since both are above, but close to, Room Temperature.

Energy and the Temperature of Matter

- The amount the temperature of an object increases depends on the amount of heat energy added (q).
  - ✓ If you double the added heat energy the temperature will increase twice as much.
- The amount the temperature of an object increases depends on its mass
  - ✓ If you double the mass it will take twice as much heat energy to raise the temperature the same amount.

Heat Capacity

- **heat capacity** is the amount of heat a substance must absorb to raise its temperature 1°C
  - ✓ cal/°C or J/°C
  - ✓ metals have low heat capacities, insulators high
- **specific heat** = heat capacity of 1 gram of the substance
  - ✓ cal/g°C or J/g°C
  - ✓ waters specific heat = 4.184 J/g°C for liquid
    - ➢ or 1.000 cal/g°C
    - ➢ less for ice and steam

Specific Heat Capacity

- Specific Heat is the amount of energy required to raise the temperature of one gram of a substance by one Celsius degree
- the larger a material's specific heat is, the more energy it takes to raise its temperature a given amount
- like density, specific heat is a property of the type of matter
  - ✓ it doesn't matter how much material you have
  - ✓ it can be used to identify the type of matter
- water's high specific heat is the reason it is such a good cooling agent
  - ✓ it absorbs a lot of heat for a relatively small mass

Specific Heat Capacities

Substance	*Specific Heat J/g°C*
Aluminum	0.895
Calcium	0.656
Carbon (dia)	0.508
Carbon (gra)	0.708
Copper	0.377
Gold	0.129
Iron	0.448
Lead	0.129
Silver	0.712
Water (l)	4.184
Water (s)	2.03
Water (g)	2.02

Heat Gain or Loss by an Object

- the amount of heat energy gained or lost by an object depends on 3 factors – how much material there is, what the material is, and how much the temperature changed

Amount of Heat = Mass x Heat Capacity x Temperature Change

$$q = m \times C \times \Delta T$$

Example 3.9: Relating Heat Energy to Temperature Change

Example:

- Gallium is a solid metal at room temperature, but melts at 29.9°C. If you hold gallium in your hand, it melts from body heat. How much heat must 2.5 g of gallium absorb from your hand to raise its temperature from 25.0°C to 29.9°C? The heat capacity of gallium is 0.372 J/g°C

Example:
How much heat must 2.5 g of gallium absorb from your hand to raise its temperature from 25.0°C to 29.9°C? The heat capacity of gallium is 0.372 J/g°C

- Write down the given quantity and its units.

  Given: mass of Ga = 2.5 g
  starting temp. = 25.0°C
  final temp. = 29.9°C
  spec. heat of Ga = 0.372 J/g°C

Example:
How much heat must 2.5 g of gallium absorb from your hand to raise its temperature from 25.0°C to 29.9°C? The heat capacity of gallium is 0.372 J/g°C

Information
Given: m = 2.5 g; T_i = 25.0°C; T_f = 29.9°C; C = 0.372 J/g°C

- Write down the quantity to find and/or its units.

  Find: amount of heat in joules

Example:
How much heat must 2.5 g of gallium absorb from your hand to raise its temperature from 25.0°C to 29.9°C? The heat capacity of gallium is 0.372 J/g°C

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Given: m = 2.5 g; T_i = 25.0°C; T_f = 29.9°C; C = 0.372 J/g°C
Find: q (J)

- Collect Needed Equations:

$$q = m \cdot C \cdot \Delta T$$

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Information
Given: m = 2.5 g; T_i = 25.0°C; T_f = 29.9°C; C = 0.372 J/g°C
Find: q (J)
Eq'n: q = m · C · ΔT

- Write a Solution Map:

C, m, ΔT → q

$$q = m\cdot C\cdot \Delta T$$

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Eq'n: q = m · C · ΔT
Sol'n Map: m,C,ΔT → q

- Apply the Solution Map: $q = m\cdot C\cdot \Delta T$

$$q = (2.5\,g)\cdot\left(0.372\,\frac{J}{g{}^\circ C}\right)\cdot(29.9\,{}^\circ C - 25.0\,{}^\circ C)$$

$$q = (2.5\,g)\cdot\left(0.372\,\frac{J}{g{}^\circ C}\right)\cdot(4.9\,{}^\circ C) \quad = 4.557\ J$$

- Sig. Figs. & Round: q = 4.6 J

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Information
Given: m = 2.5 g; T_i = 25.0°C; T_f = 29.9°C; C = 0.372 J/g°C
Find: q (J)
Eq'n: q = m · C · ΔT
Sol'n Map: m,C,ΔT → q

- Check the Solution:

q = 4.6 J

The units of the answer, J, are correct.
The magnitude of the answer makes sense since the temperature change, mass and specific heat are small.