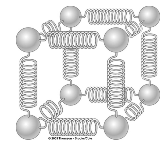
Thermal Physics

Internal Energy: total potential energy and random kinetic energy of the molecules of a substance

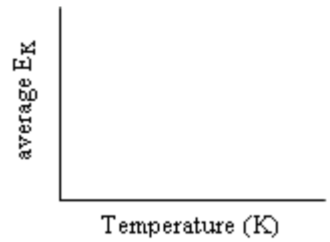
Symbol: U Units: J

Internal Kinetic Energy: arises from random translational, vibrational, and rotational motion



Internal Potential Energy: arises from forces between the molecules

Temperature (Definition #1): a measure of the average random kinetic energy of all the particles of a system

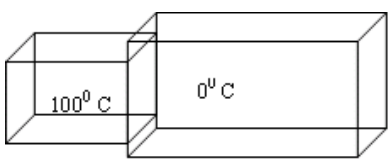


Symbol: T

Units: ^oC, K

Thermal Energy (Heat): the transfer of energy between two substances by non-mechanical means – conduction, convection and radiation

Symbol: Q Units: J



Temperature (Definition #2): a property that determines the direction of thermal energy transfer between two objects

Thermal Equilibrium: at same temperature – no thermal energy transfer – independent of mass, etc.

Thermal Capacity: amount of energy required to raise the temperature of a substance by 1 K

Formula: $C = Q/\Delta T$ $Q = C\Delta T$

Symbol: C Units: J/K

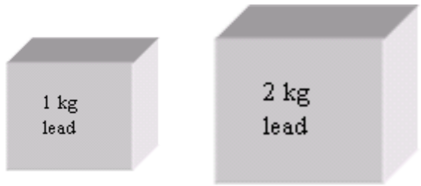
Specific Heat Capacity: amount of energy required per unit mass to raise the temperature of a substance by 1 K

Formula: $c = Q/m\Delta T$ $Q = mc\Delta T$

Symbol: c Units: J/(kg K)

1. Compare the thermal capacities and specific heat capacities of these samples.

A



lower C
same c

higher C
same c

Why do different amounts of the same substances have different thermal capacities? more molecules to store internal potential and kinetic energy

B

higher C
higher c

lower C
lower c

Table 10-4 Specific heat capacities

Substance	c_p (J/kg•°C)	Substance	c_p (J/kg•°C)
aluminum	8.99×10^2	lead	1.28×10^2
copper	3.87×10^2	mercury	1.38×10^2
glass	8.37×10^2	silver	2.34×10^2
gold	1.29×10^2	steam	2.01×10^3
ice	2.09×10^3	water	4.186×10^3
iron	4.48×10^2		

Why do the same amounts of different substances have different specific heat capacities? substances contain different numbers of molecules with different molecular masses

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2. The thermal capacity of a sample of lead is 3.2×10^3 J K^{-1}. How much thermal energy will be released if it cools from 61^0 C to 25^0 C?

$Q = C\Delta T$
$Q = 1.2 \times 10^5$ J

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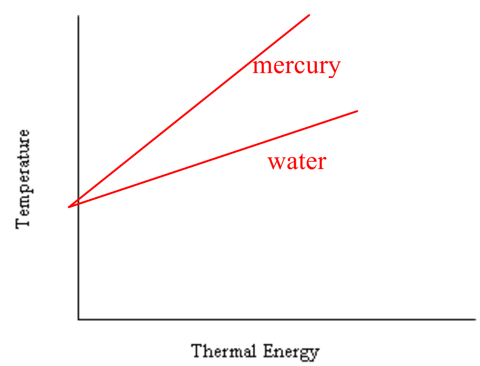
3. How much thermal energy is needed to raise the temperature of 2.50 g of water from its freezing point to its boiling point?

$Q = mc\Delta T$
$Q = (2.50 \times 10^{-3})\,(4.186 \times 10^3)\,(100 - 0)$
$Q = 1.05 \times 10^3$ J



Slope

$$slope = \frac{\Delta T}{\Delta Q} = \frac{1}{mc}$$

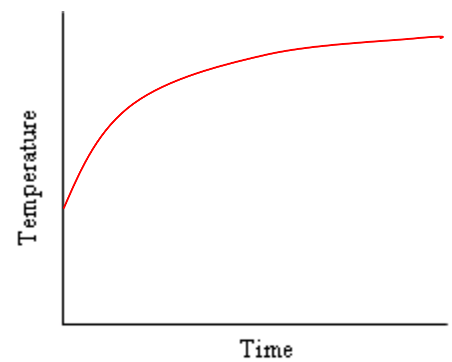
Compare your answer to the amount of thermal energy needed to raise the temperature of liquid mercury the same amount.

more Q needed for water since higher c

4. A hole is drilled in an 800g iron block and an electric heater is placed inside. The heater provides thermal energy at a constant rate of 600 W.

a) Assuming no thermal energy is lost to the surrounding environment, calculate how long it will take the iron block to increase its temperature by 15^0 C. 9.0 s

b) The temperature of the iron block is recorded as it varies with time and is shown at right. Comment on reasons for the shape of the graph.



begins at room temp
increases linearly as $Q = cm\Delta T$
as gets hotter, more energy lost to environment
levels out when heat gained by heater = heat lost to room

c) Calculate the initial rate of increase in temperature. 1.7 ^{0}C/s

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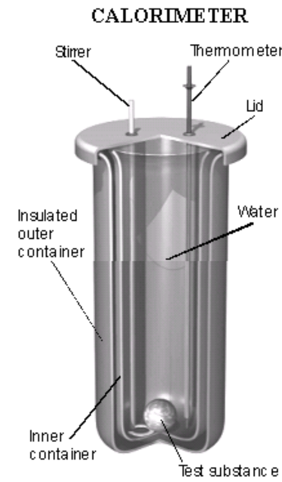
5. An active solar heater is used to heat 50 kg of water initially at 12^0 C. If the average rate that the thermal energy is absorbed in a one hour period is 920 J min^{-1}, determine the equilibrium temperature after one hour. 12^0 C

Calorimetry

Calorimetry: determining the specific heat capacity (or latent heat capacity) of a substance



Method of Mixtures

Conservation of Energy

$$Q_c = -Q_h$$
$$m_c c_c \Delta T_c = -m_h c_h \Delta T_h$$

Assumption: no thermal energy lost to environment, container, thermometer

1. A 0.10 kg sample of an unknown metal is heated to 100^0 C by placing it in boiling water for a few minutes. Then it is quickly transferred to a calorimeter containing 0.40 kg of water at 10^0 C. After thermal equilibrium is reached, the temperature of the water is 15^0 C.

   a) What is the specific heat capacity of the metal sample? 983 J/(kg ^{0}C)

   b) What is the thermal capacity of the metal sample? 98.3 J/ ^{0}C

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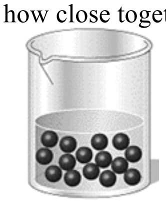
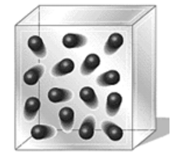
2. A 3.0 kg block of copper at 90^0 C is transferred to a calorimeter containing 2.00 kg of water at 20^0 C. The mass of the calorimeter cup, also made of copper, is 0.210 kg. Determine the final temperature of the water. 28.3^0 C

Phases of Matter

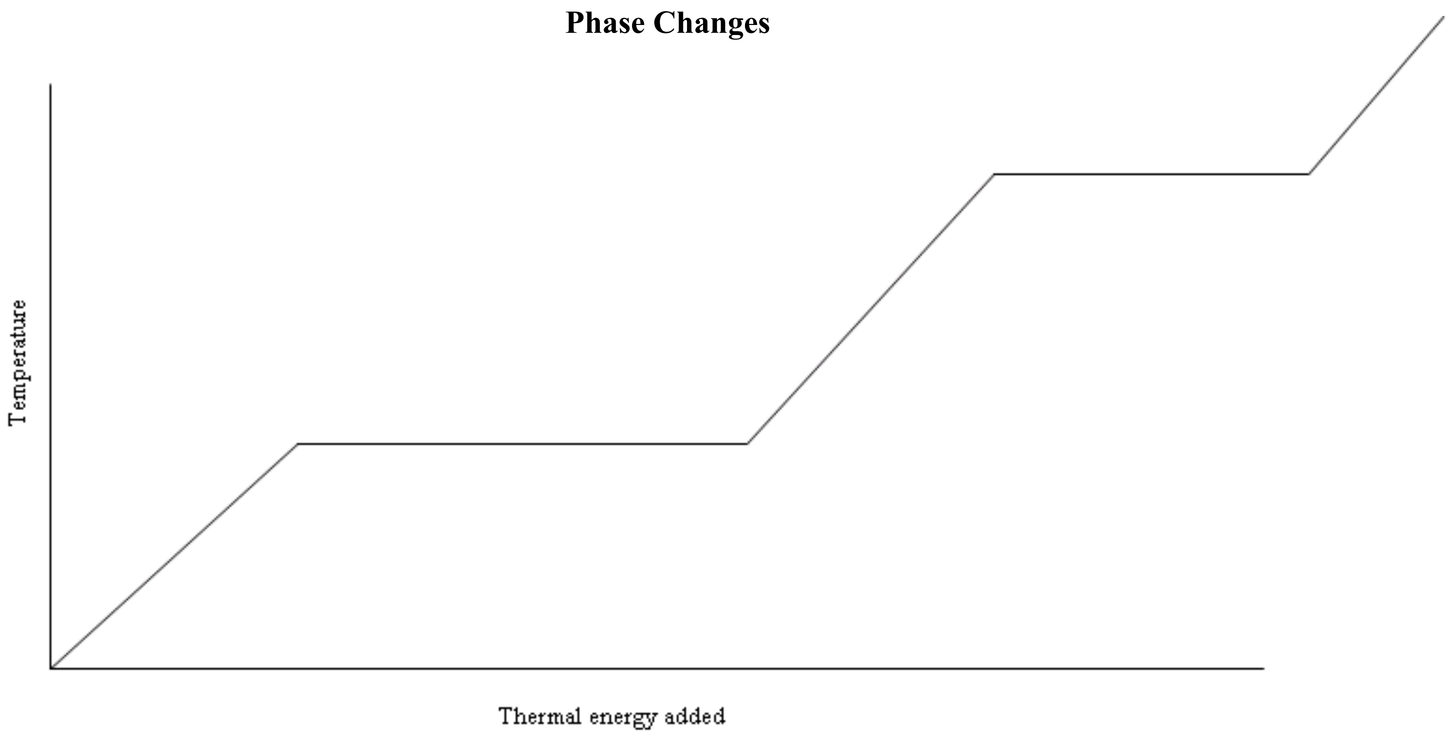
Kinetic theory says that:

1. All matter is made up of atoms, and
2. the atoms are in continuous random motion at a variety of speeds.
3. Whether a substance is a solid, liquid, or gas basically depends on how close together its molecules are and how strong the bonds are that hold them together.

	Solid	Liquid	Gas
Macroscopic description	Definite volume Definite shape	Definite volume Variable shape	Variable volume Variable shape
Microscopic description	Molecules are held in fixed positions relative to each other by strong bonds and vibrate about a fixed point in the lattice	Molecules are closely packed with strong bonds but are not held as rigidly in place and can move relative to each other as bonds break and reform	Molecules are widely spaced apart without bonds, moving in random motion, and intermolecular forces are negligible except during collisions
Comparative density	High	High	Low
Kinetic energy	Vibrational	Vibrational Rotational Some translational	Mostly translational Higher rotational Higher vibrational
Potential energy	High	High	Highest
Average molecular separation	Atomic radius (10^{-10} m)	Atomic radius (10^{-10} m)	10 x atomic radius (10^{-9})
Molecules per m^3	10^{28}	10^{28}	10^{25}
Volume of molecules/volume of substance	1	1	10^{-3}

Phase Changes



1. Describe and explain the process of phase changes in terms of molecular behavior.

When thermal energy is added to a solid, the molecules gain kinetic energy as they vibrate at an increased rate. This is seen macroscopically as an increase in temperature. At the melting point, a temperature is reached at which the kinetic energy of the molecules is so great that they begin to break the permanent bonds that hold them fixed in place and begin to move about relative to each other. As the solid continues to melt, more and more molecules gain sufficient energy to overcome the intermolecular forces and move about so that in time the entire solid becomes a liquid. As heating continues, the temperature of the liquid increases due to an increase in the vibrational, translational and rotational kinetic energy of the molecules. At the boiling point, a temperature is reached at which the molecules gain sufficient energy to overcome the intermolecular forces that hold them together and escape from the liquid as a gas. Continued heating provides enough energy for all the molecules to break their bonds and the liquid turns entirely into a gas. Further heating increases the translational kinetic energy of the gas and thus its temperature increases.

2. Explain in terms of molecular behavior why temperature does not change during a phase change.

The making or breaking of intermolecular bonds involves energy. When bonds are broken (melting and vaporizing), the potential energy of the molecules is increased and this requires input energy. When bonds are formed (freezing and condensing), the potential energy of the molecules is decreased as energy is released. The forming or breaking of bonds happens independently of the kinetic energy of the molecules. During a phase change, all energy added or removed from the substance is used to make or break bonds rather than used to increase or decrease the kinetic energy of the molecules. Thus, the temperature of the substance remains constant during a phase change.

3. Explain in terms of molecular behavior the process of evaporation.

Evaporation is a process by which molecules leave the surface of a liquid, resulting in the cooling of the liquid. Molecules with high enough kinetic energy break the intermolecular bonds that hold them in the liquid and leave the surface of the substance. The molecules that are left behind thus have a lower average kinetic energy and the substance therefore has a lower temperature.

Factors affecting the rate of evaporation:

a) surface area b) drafts c) temperature d) pressure e) latent heat of vaporization

4. Distinguish between evaporation and boiling.

Evaporation – process whereby liquid turns to gas, as explained above

- occurs at any temperature below the boiling temperature
- occurs only at surface of liquid as molecules escape
- causes cooling of liquid

Boiling – process whereby liquid turns to gas when the vapor pressure of the liquid equals the atmospheric pressure of its surroundings

- occurs at one fixed temperature, dependent on substance and pressure
- occurs throughout liquid as bubbles form, rise to surface and are released
- temperature of substance remains constant throughout process

Specific Latent Heat

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Specific Latent Heat: amount of energy per unit mass required to change phase of a substance at constant temperature and pressure

Symbol: L

Units: J/kg

Formula: $L = Q/m$ $Q = mL$

Specific latent heat of fusion: L_f
melting and freezing

Specific latent heat of vaporization: L_v
boiling and condensing

Table 10-6 **Latent heats of fusion and vaporization at standard pressure**

Substance	Melting point (°C)	L_f (J/kg)	Boiling point (°C)	L_v (J/kg)
nitrogen	–209.97	2.55×10^4	–195.81	2.01×10^5
oxygen	–218.79	1.38×10^4	–182.97	2.13×10^5
ethyl alcohol	–114	1.04×10^5	78	8.54×10^5
water	0.00	3.33×10^5	100.00	2.26×10^6
lead	327.3	2.45×10^4	1745	8.70×10^5
aluminum	660.4	3.97×10^5	2467	1.14×10^7

1. How much energy is needed to change 500 grams of ice into water?

   a) Assume the ice is already at its melting point.

   b) Assume the ice is at -15^0 C.

2. Thermal energy is supplied to a pan containing 0.30 kg of water at 20^0 C at a rate of 400 W for 10 minutes. Estimate the mass of water turned into steam as a result of this heating process. 0.060 kg

The Kinetic Model of an Ideal Gas

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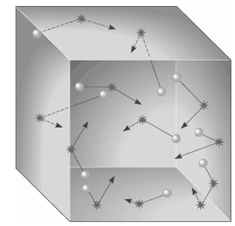


Kinetic theory views all matter as consisting of individual particles in continuous motion in an attempt to relate the macroscopic behaviors of the substance to the behavior of its microscopic particles.

Certain microscopic assumptions need to be made in order to deduce the behavior of an ideal gas, that is, to build the **Kinetic Model of an Ideal Gas**.

Assumptions:

1. A gas consists of an extremely large number of very tiny particles (atoms or molecules) that are in continuous random motion with a variety of speeds.

2. The volume of the particles is negligible compared to the volume occupied by the entire gas.

3. The size of the particles is negligible compared to the distance between them.

4. Collisions between particles and collisions between particles and the walls of the container are assumed to be perfectly elastic and take a negligible amount of time.

5. No forces act between the particles except when they collide (no intermolecular forces). As a consequence, the internal energy of an ideal gas consists solely of random kinetic energy – no potential energy.

6. In between collisions, the particles obey Newton's laws of motion and travel in straight lines at a constant speed.

Explaining Macroscopic Behavior in terms of the Kinetic Model

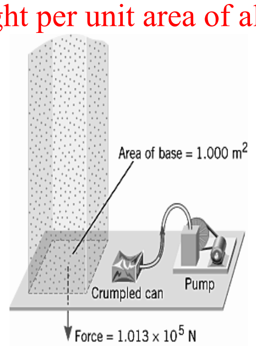
Pressure

Macroscopic definition: force per unit area acting on a surface

Formula: $P = F/A$ Units: N/m^2 = Pa (Pascals)

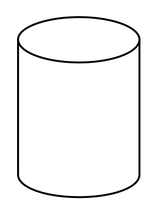
Atmospheric Pressure

Weight per unit area of all air above

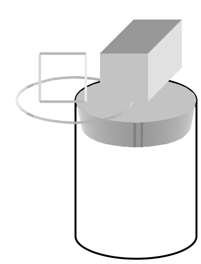


Atmospheric pressure at sea level
$1.01 \times 10^5\ N/m^2 = 1.01 \times 10^5$ Pa
= 101 kPa
= 760 mm Hg

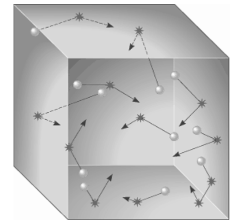
1. A cylinder with diameter 3.00 cm is open to the air. What is the pressure on the gas in this open cylinder?



2. What is the pressure on the gas after a 500. gram piston and a 5.00 kg block are placed on top?



Pressure



Microscopic definition: total force per unit area from the collisions of gas particles with walls of container

Explanation:

1) A particle collides with the wall of container and changes momentum. By Newton's second law, a change in momentum means there must have been a force by the wall on the particle.

2) By Newton's third law, there must have been an equal and opposite force by the particle on the wall.

$$F = \frac{\Delta p}{\Delta t}$$

3) In a short interval of time, there will be a certain number of collisions so the average result of all these collisions is a constant force on the container wall.

4) The value of this constant force per unit area is the pressure that the gas exerts on the container walls.

$$P = \frac{\Sigma F}{A}$$

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1. **Macroscopic behavior**: Ideal gases increase in pressure when more gas is added to the container.

   Microscopic explanation: More gas means more gas particles in the container so there will be an increase in the number of collisions with the walls in a given interval of time. The force from each particle remains the same but an increased number of collisions in a given time means the pressure increases.

2. **Macroscopic behavior**: Ideal gases increase in temperature when their volume is decreased.

   animation: Serway: chap 12: TDM06AN1

   Microscopic explanation: As the volume is reduced, the walls of the container move inward. Since the particles are now colliding with a moving wall, the wall transfers momentum (and kinetic energy) to the particles, making them rebound faster from the moving wall. Thus the kinetic energy of the particles increases and this means an increase in the temperature of the gas.

3. **Macroscopic behavior**: At a constant temperature, ideal gases increase in pressure when their volume decreases.

   Microscopic explanation: The decrease in volume means the particles hit a given area of the wall more often. The force from each particle remains the same but an increased number of collisions in a given time means the pressure increases.

   Relationship: pressure is inversely related to volume (Boyle's Law) $$P \alpha \frac{1}{V}$$

4. **Macroscopic behavior**: At a constant volume, ideal gases increase in pressure when their temperature increases.

   Microscopic explanation: The increased temperature means the particles have, on average, more kinetic energy and are thus moving faster. This means that the particles hit the walls more often and, when they do, they exert a greater force on the walls during the collision. For both these reasons, the total force on the wall in a given time increases which means that the pressure increases.

   Relationship: pressure is directly related to temperature (Pressure Law – Admonton Law) $$P \alpha T$$

5. **Macroscopic behavior**: At a constant pressure, ideal gases increase in volume when their temperature increases.

   Microscopic explanation: A higher temperature means faster moving particles that collide with the walls more often and with greater force. However, if the volume of the gas is allowed to increase, the rate at which these particles hit the walls will decrease and thus the average force exerted on the walls by the particles, that is, the pressure can remain the same.

   Relationship: volume is directly related to temperature (Charles Law – Gay-Lussac Law) $$V \alpha T$$