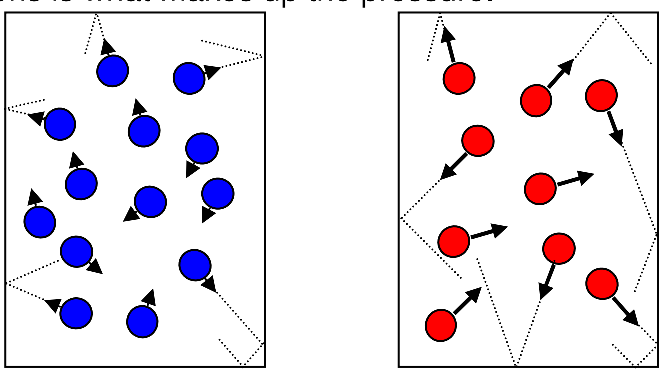
Kinetic Molecular Theory:

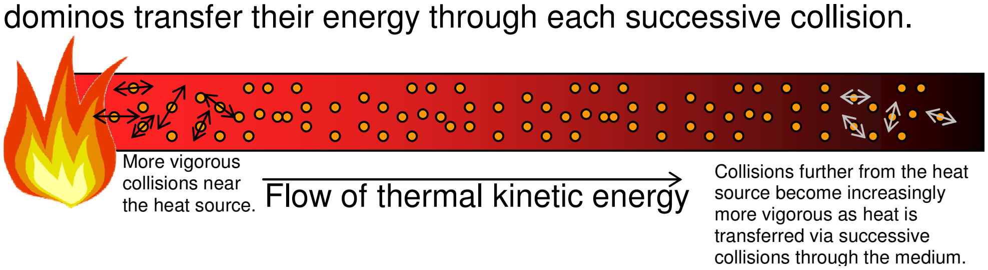
What we most commonly experience as **heat** is a direct result of the movement of the individual particles of matter.

The kinetic molecular theory helps to explain many observable phenomena such as **pressure** changes, heat **conduction**, and **convection**. Heat in the form of **radiation** can also be explained in part by the kinetic molecular theory.

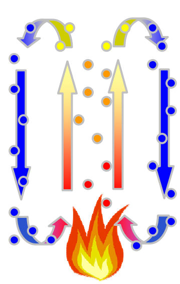
Pressure: as temperature increases, so does the pressure. Here's why; as the temperature increases the particles move more quickly. When they collide against the edge of the container they experience reflection, like a billiard ball against a bumper. The **increased velocities** require **more force** to change the motion of each particle. The container must produce this force. As a result of **Newton's 3rd law**, the container is experiencing an outward force as a result of these high-speed collisions. The sum of all these force from these molecular-level collisions is what makes up the pressure.



Conduction: this is the form of heat transfer mostly experienced by solids. Heat is transferred from one point to another via successive collisions between adjacent particles, not unlike how dominos transfer their energy through each successive collision.

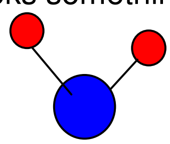


Convection: this is the form of heat transfer that is specific to gases and liquids. Heat is transferred by the movement of the fluid itself. As the heat source warms the surrounding fluid, the increased kinetic energy of the particles cause the fluid to expand, thus decreasing the density. The less dense heated fluid rises as a result of the increased pressure generated by the expanding fluids below. As the warm fluid is pushed upward, cooler fluid from below fills in the spaces left behind.

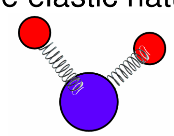


Radiation: this is the only form of heat transfer that does not require direct contact of the particles. It is the only form of heat transfer that can travel through the vacuum of space. This heat transfer is associated with the production of **electromagnetic waves** by **warm bodies**, with **infrared light** being the most familiar type of this radiation. However there are other segments of the electromagnetic spectrum that are associated with heat, **microwaves** being the most obvious example. In fact the **heat received from the sun by the Earth** can only arrive here by the various forms of **electromagnetic radiation** produced by the sun.

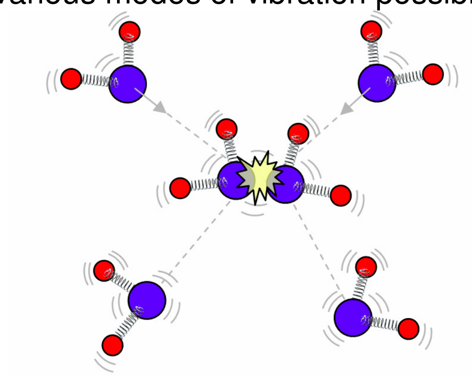
This type of radiation is associated **quantum-mechanical properties** of the atom which are beyond the scope of this course. However, it suffices to say that this type of radiation can be produced by the kinetic energy of molecules and vice versa. Here is the basic idea, collisions between adjacent particles / atoms / molecules can cause vibration in individual particles. The traditional model for a molecule looks something like this:



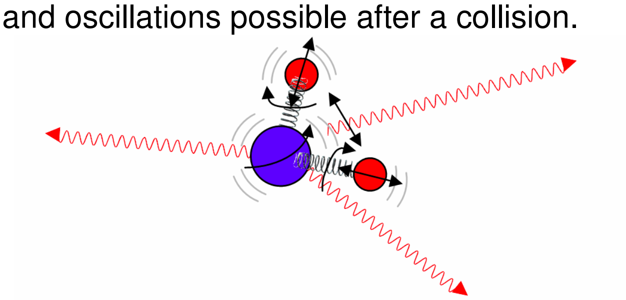
where the bonds between the atoms of the molecules are represented by the lines. However, this representation doesn't represent the elastic nature of these bonds.



We can change our perspective a little by representing the bonds as miniature springs. One can now better imagine the various modes of vibration possible after a collision.



After the collision the molecules are quite rattled. The arrows below demonstrate the some of the types of vibrations and oscillations possible after a collision.



These vibrations activate quantum related **excitations** that generated these electromagnetic waves, specifically **infrared radiation**. The heat is transfer when these electromagnetic waves come in contact with other particles some distance away causing them to vibrate.

Thermal Kinetic Energy and Temperature

We experience thermal kinetic energy as heat and that heat is related to the temperature of the substance. The temperature change of a substance is dependent on a few factors, the amount of energy added to the substance, the substance's mass, and the **specific heat capacity** of the substance.

Specific Heat: this is a measurement of the amount of energy required to raise a certain mass of a substance by 1ºC. There are a few standards so be careful of which standard you are working with.

- Specific heat in **physics** is measured using Joules, **kilograms**, and degrees Celsius or Kelvin.

  Eg: The specific heat of water is $4.18 \times 10^3 \frac{J}{kg \cdot {}^oC}$. This means that 1 kg of water requires **4180 J** of energy to raise the temperature by 1ºC.

- In **chemistry** it is measured in Joules, **grams**, and degrees Celsius or Kelvin.

  Eg: The specific heat of water is $4.18 \frac{J}{g \cdot {}^oC}$. This means that 1 gram of water requires **4.180 J** of energy to raise the temperature by 1ºC.

- Note that the calorie is non-metric measure for heat energy and is based on the following premise. **1 cal** of energy is required to raise **1 gram** of water by **1ºC**. Therefore **1 cal = 4.18 J**. Also food calories are actually kilo calories i.e. **1 Cal = 1000 cal**. Notice food calories are spelled with a capital "C". That's how you can differentiate.

We can calculate the change in thermal energy using the following formula

$$Q = cm\Delta T \quad \text{or} \quad \Delta E_H = cm\Delta T$$

Where Q or ΔE_H represents the change in heat energy in Joules (J)

c represents the specific heat in $\frac{J}{kg \cdot {}^oC}$

ΔT represents the change in temperature in degrees Celsius (${}^oC$)

To add to the confusion, chemistry uses a slightly different notation.

$$q = cm\Delta T$$

Where q represents the change in heat energy in Joules (J)

c represents the specific heat in $\frac{J}{g \cdot {}^oC}$

ΔT represents the change in temperature in degrees Celsius (${}^oC$)

Heat transfer and the conservation of energy

Conservation of energy applies the transfer of heat as well. This means that the heat energy lost by one substance (A) is gained by the other (B). Therefore

$$-\Delta E_{H_A} = +\Delta E_{H_B}$$
$$-m_A c_A (T_{A_2} - T_{A_1}) = +m_B c_B (T_{B_2} - T_{B_1})$$

Where m is the mass, c is the specific heat, T is the temperature.

Example Problems:

I. How much energy is required to raise 357.0 g of gold by 13ºC?

Given	RTF	Formula
$m = 0.3570kg$ $\Delta T = +13°C$ $c = 1.3\times10^{2} J/kg\cdot°C$	Q	$Q = cm\Delta T$

Solution

$$Q = cm\Delta T$$
$$= \left(1.3\times10^{2}\right)(0.3570)(+13)$$
$$= 603.33J$$

∴ 603.33J of energy is required to raise the gold by 13ºC

Table 8.4
Specific Heat Capacities

Material	Specific heat capacity (J/kg°C)
Liquid nitrogen	1.1×10^2
Gold	1.3×10^2
Lead	1.3×10^2
Mercury	1.4×10^2
Steam	2.0×10^2
Silver	2.3×10^2
Ethyl alcohol	2.4×10^2
Glycerine	2.4×10^2
Methyl alcohol	2.5×10^2
Brass	3.8×10^2
Copper	3.9×10^2
Iron	4.6×10^2
Crown glass	6.7×10^2
Pyrex®	7.8×10^2
Granite	8.0×10^2
Sand	8.0×10^2
Aluminium	9.1×10^2
Air	1.0×10^3
Wood	1.8×10^3
Ice	2.1×10^3
Concrete	2.9×10^3
Water	4.2×10^3

II. Determine the temperature change of 7.54kg of concrete if 4542 J of thermal energy is lost.

Given	RTF	Formula
$m = 7.54kg$ $Q = -4542J$ $c = 2.9\times10^{2} J/kg\cdot°C$	ΔT	$Q = cm\Delta T$

Solution

$$Q = cm\Delta T$$
$$\frac{Q}{cm} = \Delta T$$
$$\Delta T = \frac{Q}{cm}$$
$$\Delta T = \frac{-4542}{\left(2.9\times10^{2}\cdot7.54\right)}$$
$$\Delta T = -2.077°C$$

∴ the temperature change of the concrete is -2.077ºC

III. A 200W kettle takes 4.0 minutes to come to a boil. If the initial temperature of the water was 14ºC, how much water was in the kettle?

<table>
<tr><td><u>Given</u>
$t = 4.0\min$ $T_1 = 14°C$
$= 240s$ $T_2 = 100°C$
$P = 200W$ $c = 4.18\times10^3 J/kg\cdot°C$</td><td><u>RTF</u>
m</td><td><u>Formula</u>
$P = \frac{\Delta E_e}{t}$ $Q = cm\Delta T$</td></tr>
<tr><td colspan="3"><u>Solution</u></td></tr>
<tr><td><u>Find energy transferred by the kettle</u>
$P = \frac{\Delta E_e}{t}$
$\Delta E_e = Pt$
$\Delta E_e = (200)(240)$
$\Delta E_e = 48000J$</td><td colspan="2"><u>Find the mass of the water</u>
$Q = cm\Delta T$
$\Delta E_e = cm\Delta T$
$m = \frac{\Delta E_e}{c\Delta T}$
$m = \frac{\Delta E_e}{c(T_2 - T_1)}$
$m = \frac{48000}{4.18\times10^3(100-14)}$
$m = 0.1335kg$
$m = 133.5g$
∴ 133.5g of water was heated by the kettle.</td></tr>
</table>

IV. A 200.0g chunk of iron heated to 175ºC and placed in a bucket of water that contains 1L of water that is initially at 15ºC. If no heat is lost determine the final temperature of the water and the iron.

<table>
<tr><td><u>Given</u>
$m_I = 0.2000kg$ $T_{I_1} = 175°C$
$V_W = 1.0l$ $c_I = 4.6\times10^2 J/kg\cdot°C$
$T_{W_1} = 15°C$ $c_W = 4.18\times10^3 J/kg\cdot°C$</td><td><u>RTF</u>
T_f</td><td><u>Formula</u>
$-\Delta E_{H_A} = +\Delta E_{H_B}$
$-m_A c_A (T_{A_2} - T_{A_1}) = +m_B c_B (T_{B_2} - T_{B_1})$</td></tr>
<tr><td colspan="3"><u>Solution</u></td></tr>
<tr><td><u>Determine the mass of the water</u>
Since 1.0L has a mass of 1.0kg therefore $m_W = 1.0kg$

<u>Consider final temperature</u>
Also, since the final temperature for both the iron and water are the same, therefore $T_{W_2} = T_{I_2} = T_f$</td><td colspan="2"><u>Determine the expression for T_f</u>
$-\Delta E_{H_I} = +\Delta E_{H_W}$
$-m_I c_I (T_{I_2} - T_{I_1}) = +m_W c_W (T_{W_2} - T_{W_1})$
$-m_I c_I (T_f - T_{I_1}) = +m_W c_W (T_f - T_{W_1})$
$-m_I c_I T_f + m_I c_I T_{I_1} = +m_W c_W T_f - m_W c_W T_{W_1}$
$m_W c_W T_{W_1} + m_I c_I T_{I_1} = +m_W c_W T_f + m_I c_I T_f$
$m_W c_W T_{W_1} + m_I c_I T_{I_1} = (m_W c_W + m_I c_I) T_f$
$\frac{m_W c_W T_{W_1} + m_I c_I T_{I_1}}{(m_W c_W + m_I c_I)} = T_f$
$T_f = \frac{1.0(4.18\times10^3)(15) + 0.2000(4.6\times10^2)(175)}{1.0(4.18\times10^2) + 0.2000(4.6\times10^2)}$
$T_f = 18.45°C$</td></tr>
</table>