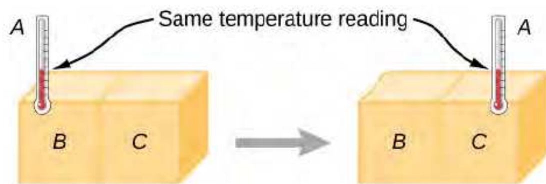
Temperature and Heat Chapter 1

Temperature is how hot or cold an object is. Temperature is operationally defined as the quantity of what we measure with a thermometer. Temperature and heat are **not** the same thing. We will see later that heat is a form of energy and temperature is a measure of the kinetic energy of the atoms or molecules in a substance.

If you heat up one end of an iron rod in a fire, one end is hot (even red hot) and the other end is cool. Wait for a minute and the heat distributes through out the iron. We would say the iron rod is in thermal equilibrium. The hotter iron atoms at the hot end collide with the slower moving iron atoms further down the rod toward the cooler end. These collision transfer energy to the cooler atoms and the bar eventually reaches thermal equilibrium i.e. the entire rod has the same temperature.

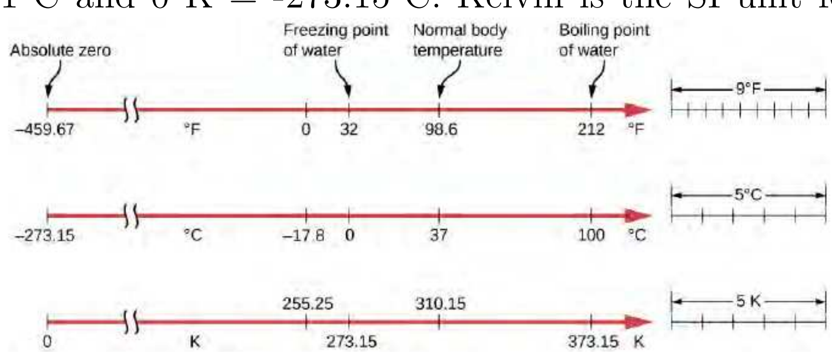


This is known as the 0^{th} law of thermodynamics i.e. if two objects have the same temperature they are in thermal equilibrium.

Temperature Scales: There are three common temperature scales: Fahrenheit, Celsius and Kelvin. Celsius is based on the freezing (0^oC) and boiling point (100^oC) of water.In Fahrenheit, water freezes at 32^oF and boils at 212^oF. We can convert from Fahrenheit to Celsius or Celsius to Fahrenheit using:

$$\text{C} = (\text{F - }32)\tfrac{5}{9} \qquad \text{or} \qquad \text{F} = (\text{C}\tfrac{9}{5} + 32)$$

The idea that temperature is related to the motion of molecules lead to the idea that when something is so cold that all molecular motion stops it has a lowest possible temperature. The Kelvin scale is based on absolute zero where all molecular motion stops. 1^o K = 1^oC and 0 K = -273.15^{o}C. Kelvin is the SI unit for temperature.



Problem: 1-43

Thermal Expansion

The common thermometer relies on a property of matter call **linear thermal expansion**. When a length of material, L_0 experiences a change in temperature ΔT, the material expands. The formula for linear thermal expansion is;

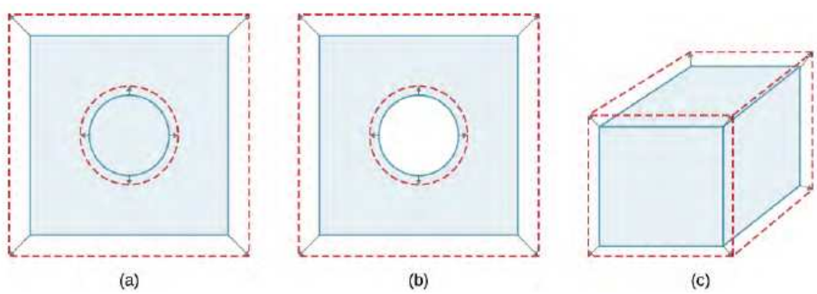
$$\Delta L = \alpha\, L_0\, \Delta T \qquad \text{or} \qquad \frac{dL}{dT} = \alpha\, L$$

where ΔL is the amount the material expands, and α is called the coefficient of thermal expansion (Table 1.2 in the text). The units for α are $1/^oC$ ($^oC^{-1}$).

If we heat an object, the entire volume expands much like with linear thermal expansion. If a volume, V_0 experiences a change in temperature, ΔT, the change in volume, ΔV is given by

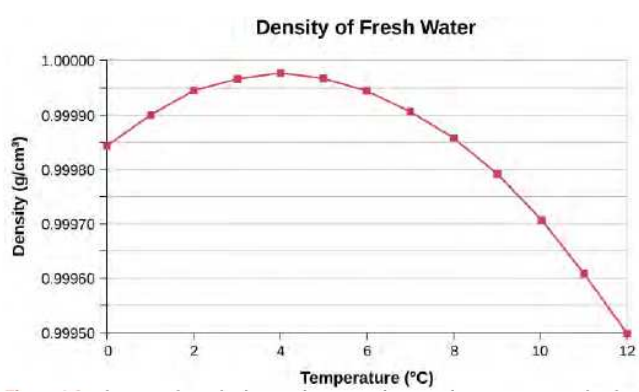
$$\Delta V = \beta\, V_0\, \Delta T \qquad \text{or} \qquad \frac{dV}{dT} = \beta\, V_0$$

where β is the **coefficient of volume expansion**. The unit for β are $1/^oC(^oC^{-1})$. Note that $\beta = \mathbf{3}\alpha$ in the table and liquids thermal expansion coefficients normally don't make sense.



Problem: 1-51, 1-57

Water is an Exception: Most thing expand when heated and contract when cooled. Water is an exception. The maximum density of water is at 4^oC.



In Physics 101 you learned about elasticity, strain and stress. Thermal expansion of a object can cause stress on an object if it is prevented for expanding (constrained). With a Young's modulus of Y the stress (F/A) is given by

$$\frac{F}{A} = Y\frac{\Delta L}{L_0}$$

if we substitute the ΔL for the thermal expansion relation we have

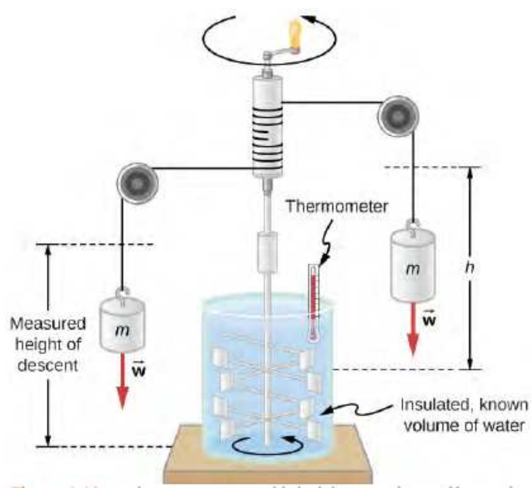
$$\frac{F}{A} = Y\frac{\alpha L_O \Delta T}{L_0} = Y\alpha\Delta T$$

Heat and Internal Energy

- **Heat is energy** that flows from a higher temperature object to a lower temperature object because of the temperature difference.

Heat is a form of energy, its SI unit is the joule (J). Another common unit of energy often used for heat is the calorie (cal), defined as the energy needed to change the temperature of 1.00 g of water by 1 ^{o}C. Also commonly used is the kilocalorie (kcal), which is the energy needed to change the temperature of 1.00 kg of water by 1.00 ^{o}C. Food label calories (sometimes called 'big calories', abbreviated Cal)are actually kilocalories.

In the 19th century, James Joule showed that doing mechanical work on an object would increase the objects heat.



The result is know as the mechanical equivalence of heat and is given by:

$$4186 \text{ Joule} = 1 \text{ kcal} \qquad \text{or} \qquad 4.186 \text{ Joule} = 1 \text{ calorie}$$

Temperature Change and Heat Capacity: The amount of heat (energy) that an object can contain depends on the substance. This property of different materials is reflected in their **specific heat capacity**. Specific heat capacity is defined by:

$$Q = c\ m\ \Delta T$$

where Q is the heat required to change the temperature, ΔT, of a mass,m. The specific heat capacity is c. It depends on the material. Table 1.3 has the specific heat capacity of common materials. The units are J/(kg ^{o}C). Note the large specific heat of water.

For solids and liquids, the heat capacity does not general depend on the pressure or volume. For gases this is not the case. With a gas, the heat capacity is different if the pressure is held constant or if the volume is held constant.

Calorimetry Since heat is a form of energy, we can apply energy conservation. If heat moves from one object to another, we have:

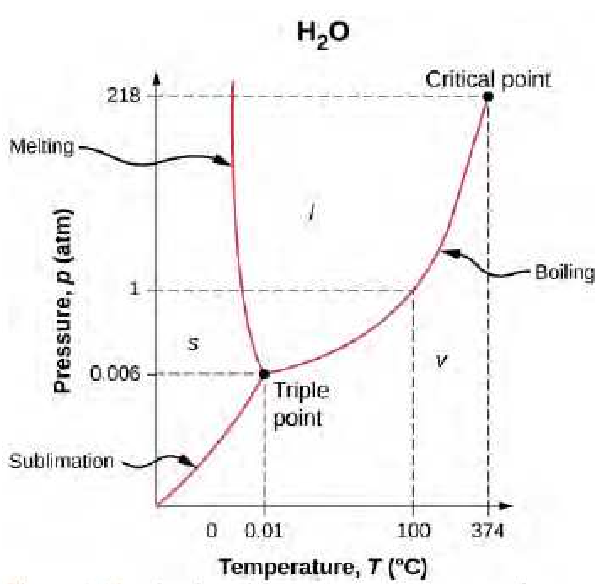
$$\Delta Q_1 = -\Delta Q_2$$

$$c_1\ m_1\ (T_1^f - T_1^i) = -\ c_2\ m_2\ (T_2^f - T_2^i)$$

The heat lost by object 1 is the negative of the heat gained by the object 2. **Problem 1-62, 1-68**

Heat and Phase Change

Phase Diagrams:

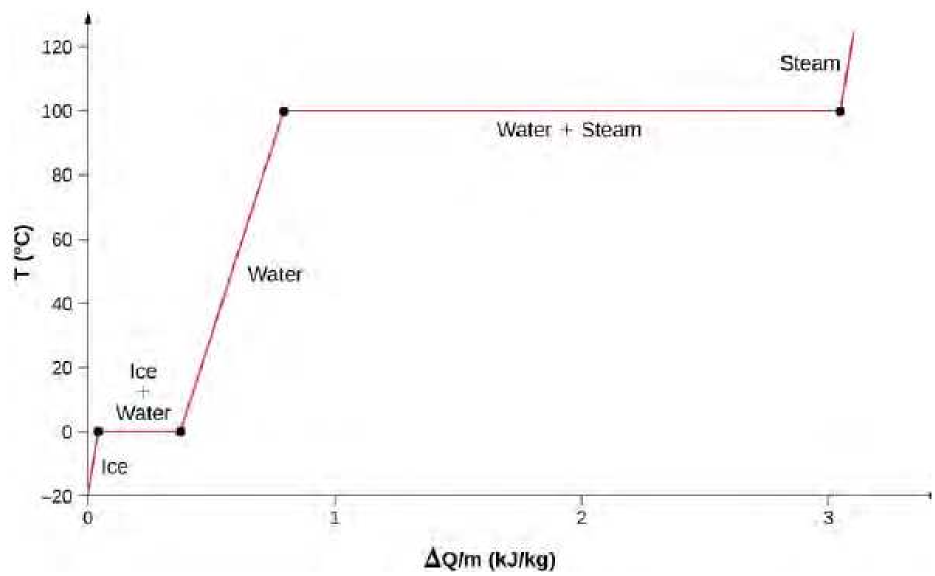


Latent heats: When matter changes phase, e.g., when ice melts into water or water boils into steam, a certain amount of energy is required to change the phase. The heat per kg required to melt a solid into a liquid is called the **latent heat of fusion**. The heat per kg required to change a liquid to a gas is called the **latent heat of vaporization**.

$$\Delta Q = L_f \, m$$

where L is the latent heat of fusion (vaporization), m the mass and ΔQ is the heat (energy) required to change the phase. Table 1.4 has values for common materials. Note this heat is required to change the phase. It does not change the temperature.

This diagram shows the latent heat of fusion (melting) of changing ice into water at 0^oCand the latent heat of vaporization (water to steam) at 100 ^{o}C.

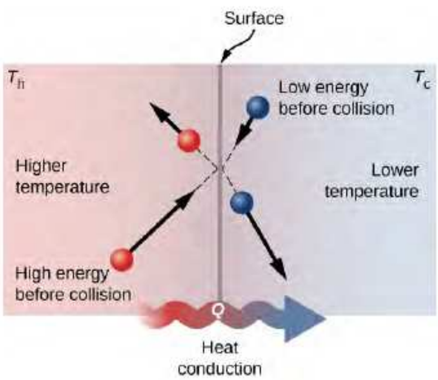


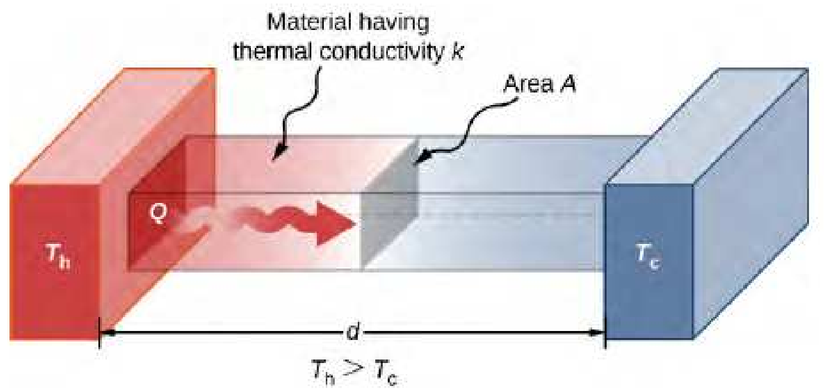
Problem: 1-73, 1-82

Heat Transfer: When there is a temperature difference heat will be transferred. There are three methods of heat transfer:

- **Conduction** where heat is transferred by physical contact.
- **Convection** where heat is transferred by motion of a fluid due to density changes as part of the fluid is heated.
- **Radiation** where heat is transferred by electromagnetic radiation

On the microscopic level, heat is conducted from an object at a higher temperature to an object at lower temperature by collisions of molecules with higher velocity (and energy) in the hotter object with lower velocity molecules in the colder object.





Heat conduction depends on the temperature difference. Heat conduction depends on the material. It also depends on the cross-sectional area in contact, the thickness of the material through which heat is transferred. We can model the rate of heat conduction with the relationship:

$$P = \frac{dQ}{dT} = \frac{kA(T_h - T_c)}{d}$$

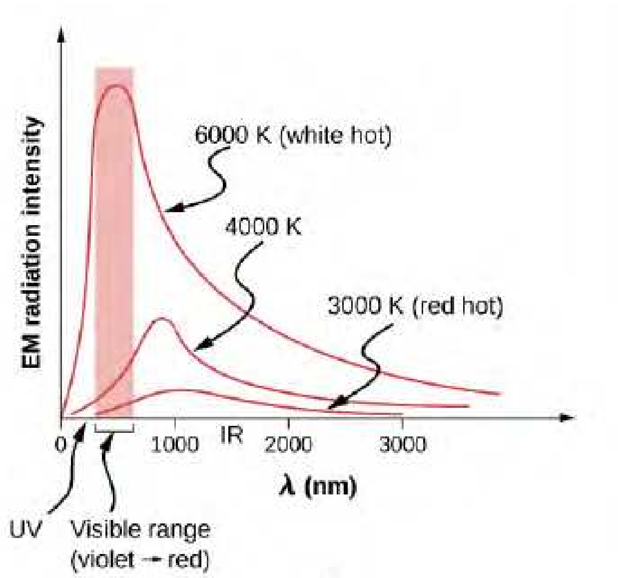
where P is the power (or heat energy per time) in watts, $T_h - T_c$ is the temperature difference, A is the area, d is the thickness and k is the thermal conductivity $(\frac{W}{m^oC})$ (see Table 1.5).

Problem: 1-89, 1-100

Convection is move complicated than conduction is approximately proportional to the temperature difference.

All objects about zero Kelvin emit electromagnetic radiation. A perfect emitter (or absorber) of radiation is known as a black body. A poor emitter is also a poor absorber. This property of the emitter of radiation is called the emissivity and is a dimensionless number between zero and 1 for a perfect emitter (black body).

The wavelength ('color' for visible radiation) depends on the temperature. The radiation is not a single wavelength but a range of wavelengths known as a black body spectrum.



The power that an object emits as radiation is given by the Stefan-Boltzmann law:

$$P = \sigma A e T^4$$

where P is the power in watts, $\sigma = 5.67 \text{ x } 10^{-8} \frac{J}{sm^2K^4}$ is the Stefan-Boltzmann constant, A is the area of the emitter, e is the emissivity.

Problem: 1-121