Thermodynamics

What is Heat?

* We use the term heat, but so far we have only defined temperature.

* Heat is a type of energy. When you add heat to something you tend to increase its temperature. When you remove heat from something you tend to decrease its temperature.

* Chemists (and others) use the unit of calorie for heat. A calorie can be converted to our MKS unit of energy the joule by

$$4.186J = 1cal$$

Internal Energy

* The internal energy of a substance is the sum of all of the energy of all of the molecules in a substance.
* This is different then the temperature, the temperature is the average kinetic energy of each molecule in a substance.
* Something with only 10 molecules could have a very high temperature. Something with a lower temperature but vastly more molecules is likely to have a greater internal energy.
* Heat is the flow of energy from one substance to another. Note that the direction of heat flow depends on temperature, not the internal energy.

Specific Heat

* The rate at which heat is converted into temperature in a substance is called the specific heat and its value depends on the substance. The following equation shows this relationship

$$Q = mc\Delta T$$

* where Q is the heat energy, m is the objects mass and c is the specific heat.

* For water at 15°C and 1 atm of pressure it takes 1kcal to raise 1 kg of water 1 degree. That is the specific heat of water is

$$c = 1kcal/(kg \cdot C) = 4186J/(kg \cdot C)$$

Thermal Equilibrium

* If two substances are brought into contact heat will flow from the hotter one to the colder one until the two have the same temperature.
* The time this takes to occur depends on the substance, but given enough time the same temperature will be reached.
* Since heat is just energy, energy conservation tells us that the heat that flows from one substance is equal to the heat gained by the other substance.

$$Q_L = Q_G$$

Example 19-3

* If 200cm^3 of tea at 95°C is poured into a 150g glass cup initially at 25°C what will be the common final temperature T when equilibrium is reached, assuming no heat flows to the surroundings?

known

V = 200cm^3

T_t = 95C

m_{cup} = 0.15kg

T_c = 25C

unknown

T = ?

tea is mostly water

physics

$$Q_L = Q_G$$

$$Q = mc\Delta T$$

$$c_{tea} = 4186 J/kg \qquad c_{cup} = 840 J/kg$$

$$m_{tea} = \rho_{H_2O} V_{tea} = (1000 kg/m^3)(200 \times 10^{-6} m^3) = 0.20 kg$$

$$Q_{tea} = Q_{cup} = m_{tea} c_{tea}(95 - T) = m_{cup} c_{cup}(T - 25)$$

$$(0.2kg)(4186 J/kg)(95 - T) = (0.15kg)(840 J/kg)(T - 25)$$

$$79,500J - (837J/C)T = (126J/C)T - 3150J$$

$$T = 86^{\circ}C$$

Latent Heat

* When ice melts or water boils the water changes state with out changing temperature. However, there is still heat absorbed in these transitions.

* This heat is called latent heat. Instead of increasing the temperature of the substance the energy is used to change state. The formula for this is very straightforward it is just

$$Q = mL$$

* where L is the latent heat which depends on the substance. Notice there is no temperature dependence. This heat does not change the temperature, it just changes the state. The latent heat is called the heat of fusion when converting solids to liquids and the heat of vaporization when converting liquids to solids.

Example 19-5

* A 0.50kg chunk of ice at -10°C is placed in 3.0kg of 'iced' tea at 20°C. At what temperature and in what phase will the final mixture be? The tea can be considered as water. Ignore any heat flow to the surroundings.

known	unknown	physics
m_{ice} = 0.50kg	T = ?	First we have to figure out what the final state will be, all liquid, all solid, or a mixture.
T_{ice} = -10°C		
m_{tea} = 3.0kg		
T_{tea} = 20°C		

To bring the water to 0°C takes: $Q = mc\Delta T = (3.0kg)(4186J/kg)(20C) = 250kJ$

To bring the ice to 0°C takes: $Q = mc\Delta T = (0.5kg)(2100J/kg)(-10C) = -10.5kJ$

To melt the ice takes: $Q = mL = (0.5kg)(333kJ/kg) = -167kJ$

250 kJ > 177.5 kJ so we will be left with all liquid 'iced' tea

Example 19-5

* A 0.50kg chunk of ice at -10°C is placed in 3.0kg of ‘iced’ tea at 20°C. At what temperature and in what phase will the final mixture be? The tea can be considered as water. Ignore any heat flow to the surroundings.

So the heat gained by the ice is the amount to heat it to 0°C, the amount to melt it, and then the amount to raise it to the equilibrium temperature T. This is the same amount as the heat lost by the ‘iced’ tea.

$$Q_{tea} = m_{tea}c(20C - T) \quad = m_{ice}c(T - 0) + 167kJ + 10.5kJ$$

$$(3.0kg)(4186J/kg)(20C - T) = (0.5kg)(4186J/kg)(T - 0) + 177.5kJ$$

$$T = 5.0°C$$

Return of the Jedi - Star Wars Episode VI

How much energy would it take to unfreeze Han Solo?

Let's assume Han Solo has a mass of 80kg.

Carbonite is apparently a form of frozen carbon dioxide which has a melting point of -56.6°C.

Human body temperature is 37°C so Han's body temperature has to be raised $\Delta T = (37 - -56.6) = 93.6°C$.

You can tell Han Solo is very cold from his shaking so he might not be all the way to 37°C; however, he must be very close. You get hypothermia at only 2°C lowering of your core temperature.

Since the human body is mostly water we can just pretend a person is water, but at temperatures below 0°C water is frozen as ice. So to calculate the heat needed for this temperature change we need the specific heat of water, c_w = 4186 J/kg°C, the specific heat of ice, c_i = 2093 J/kg°C, and the latent heat of fusion for water, L_f = 333 kJ/kg. Given these facts we can write the heat energy as:

$$Q = m(c_i \Delta T_i + c_w \Delta T_w + L_f) =$$

$$180kg(2093J/(kgC)(56.6) + 4186J/(kgC)(37) + 333,000J/kg) = 606.3kJ$$

which is a whole lot of energy. In terms of kinetic energy it would be equivalent of changing Han Solo's velocity by about 82m/s.

First Law of Thermodynamics

* The first law of thermodynamics is that the change of internal energy of a system is equal to the heat added to the system minus any work the system does to its surroundings. That is

$$\Delta E_{int} = Q - W$$

* This is just another way of saying energy is conserved. It has a separate name only because these ideas were developed by different people in different places over many years and only much later did we realize they were saying the same thing. Including all the forms of energy we have discussed we can write

$$\Delta K + \Delta U + \Delta E_{int} = Q - W$$

Example 19-3

* A 3.0g bullet traveling at a speed of 400m/s enters a tree and exists the other side is with a speed of 200m/s. Where did the bullet's lost kinetic energy go and what was the energy transfered?

known	**unknown**	**physics**
$m = 0.003kg$	$\Delta K = ?$	energy conservation
$v_i = 400m/s$		
$v_f = 200m/s$		

$Q = W = \Delta U = 0$

The kinetic energy lost goes into internal energy of the tree.

$$\Delta E_{int} = -\Delta K = -\frac{1}{2}m(v_f^2 - v_i^2) = -\frac{1}{2}(0.003kg)\left[(200m/s)^2 - (400m/s)^2\right] = 180J$$

Example 3.3

* **Polishing a Fitting** - A machinist polishes a 0.50-kg copper fitting with a piece of emery cloth for 2.0 min. He moves the cloth across the fitting at a constant speed of 1.0 m/s by applying a force of 20 N, tangent to the surface of the fitting. (a) What is the total work done on the fitting by the machinist? (b) What is the increase in the internal energy of the fitting? Assume that the change in the internal energy of the cloth is negligible and that no heat is exchanged between the fitting and its environment. (c) What is the increase in the temperature of the fitting?

known	**unknown**	**Physics**
$m = 0.5$ kg	$W = ?$	$P = F \cdot v$
$\Delta t = 2$ min $= 120$s	$\Delta E_{int} = ?$	$\Delta E_{int} = Q - W$
$v = 1.0$ m/s	$\Delta T = ?$	$Q = mc\Delta T$
$F = 20$ N		

$$P = \frac{dE}{dt} = \frac{\Delta E}{\Delta t} \quad \rightarrow \Delta E = P\Delta t = Fv\Delta t = (20N)(1.0m/s)(120s) = 2.4 \times 10^3 J$$

$$\Delta E_{int} = 2.4 \times 10^3 J$$

$$\Delta T = \frac{Q}{mc} = \frac{2.4 \times 10^3 J}{(0.5kg)(3.9 \times 10^2 J/kg°C)} = 12°C$$

Heat Transfer

* Heat can be transferred between places by three different methods.
    * Conduction - is heat transfer by molecules that are touching one another.
    * Convection - is heat transfer by hot and cold material moving in bulk to different locations.
    * Radiation - is heat transfer from electromagnetic waves.

Second Law of Thermodynamics

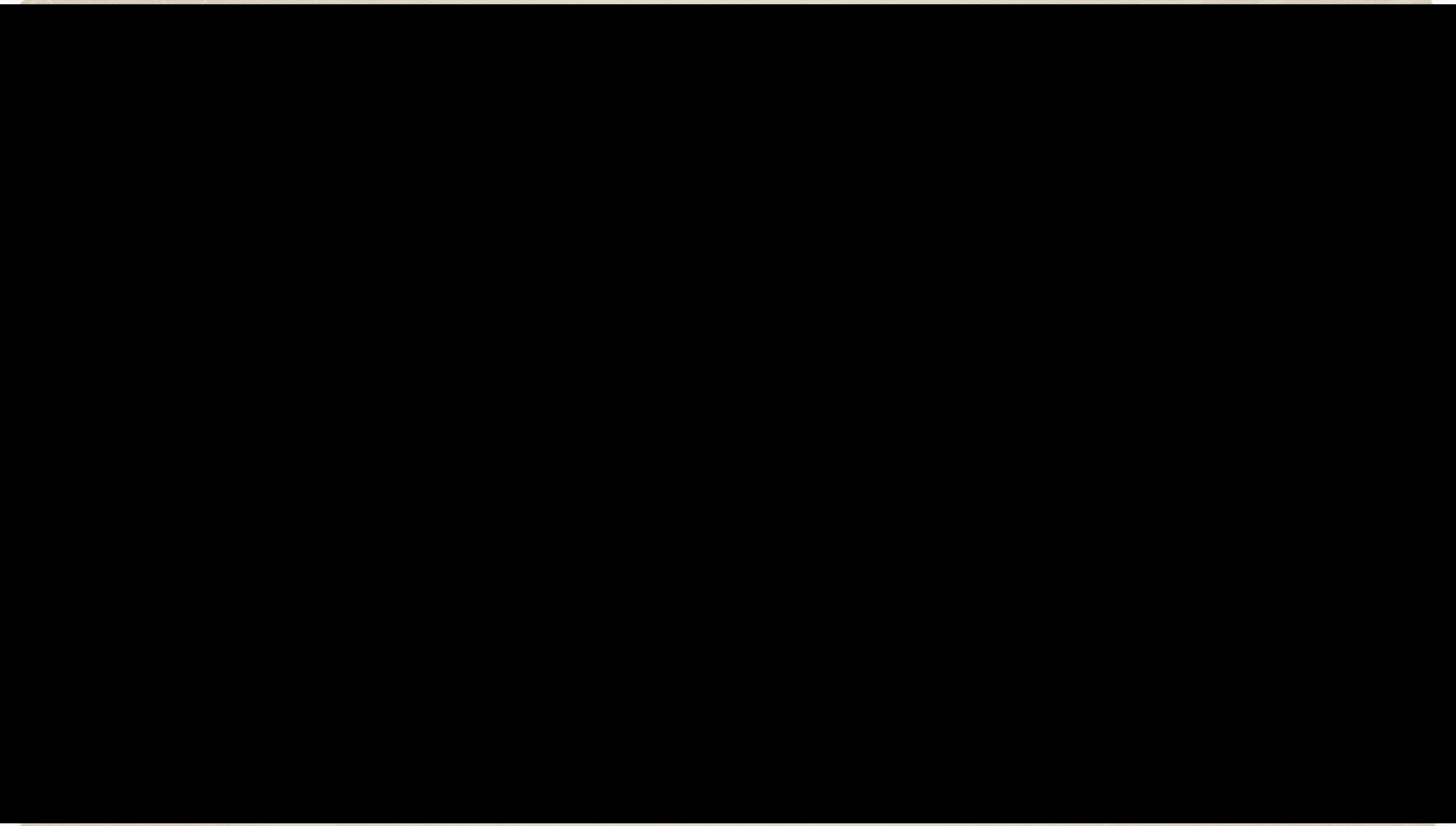
* We have learned that when heat is transferred between objects energy is conserved. But energy conservation allows heat to flow from hot to cold or from cold to hot.
* The second law of thermodynamics states that heat will only flow spontaneously from a hot to a cold object; never from a cold object to a hot object.
* Another way to express the second law of thermodynamics is to say that entropy must always increase.

Entropy

* Entropy is a measure of the disorder of a system. The more disordered the system the greater the entropy. Entropy can be expressed as

$$\Delta S = \frac{Q}{T}$$

* The second law of thermodynamics states that when heat flows the entropy or disorder of the system increases. Note this equation is only good if the temperature doesn't change.



Forward by Messe Kopp

Example 4.4

* **Entropy Change of Melting Ice** - Heat is slowly added to a 50-g chunk of ice at 0°C until it completely melts into water at the same temperature. What is the entropy change of the ice?

known	unknown	physics
$m = 50g = 0.050\ kg$	$\Delta S = ?$	$\Delta S = Q/T$
$T = 0°C = 273K$		$Q = mL$
$L_{ice} = 333kJ/kg$		

$$\Delta S = mL/T = (0.05kg)(333kJ/kg)/273K = 61.5\ J/K$$

Entropy with Changing T

* If the temperature changes it doesn't mean the entropy doesn't change, it just means we have to integrate to calculate it.

$$dS = \frac{dQ}{T} \qquad \Delta S = \int_a^b \frac{dQ}{T(Q)}$$

* In general this is complicated to solve which is why we don't do it here. But remember our simple formula is only good for constant T.

Homework

* Vol 2, Chapter 3 - 22, 26
* Vol 2, Chapter 4 - 44, 46