For now I would like to skip over fluids (Chapters 5 & 6) in the text book and move on to heat and thermodynamics (Chapter 7 & 8 in the text book).

Chemical Bonds

When you burn natural gas for heat in the winter or gasoline in your car, a chemical reaction takes place where the molecules of natural gas (mainly methane CH_4) or gasoline (something like octane C_8H_{18}) combine with oxygen which results in carbon dioxide (CO_2) and water (H_2O). This re-arranging of atoms releases energy. This energy is is the from of random and disordered motion of the molecules. It can be translational motion, rotational motion or even vibrational motion of the molecules.

Chemical Bonds

The chemical bonds between the atoms is the result of electrical effects between the atoms. To understand these bonds in detail one needs quantum mechanics. There are different types of bonds and depends on the type of atom (element) involved. Some bonds are stronger than others so the chemical reactions can release (or take) energy to occur.

Heat and Temperature

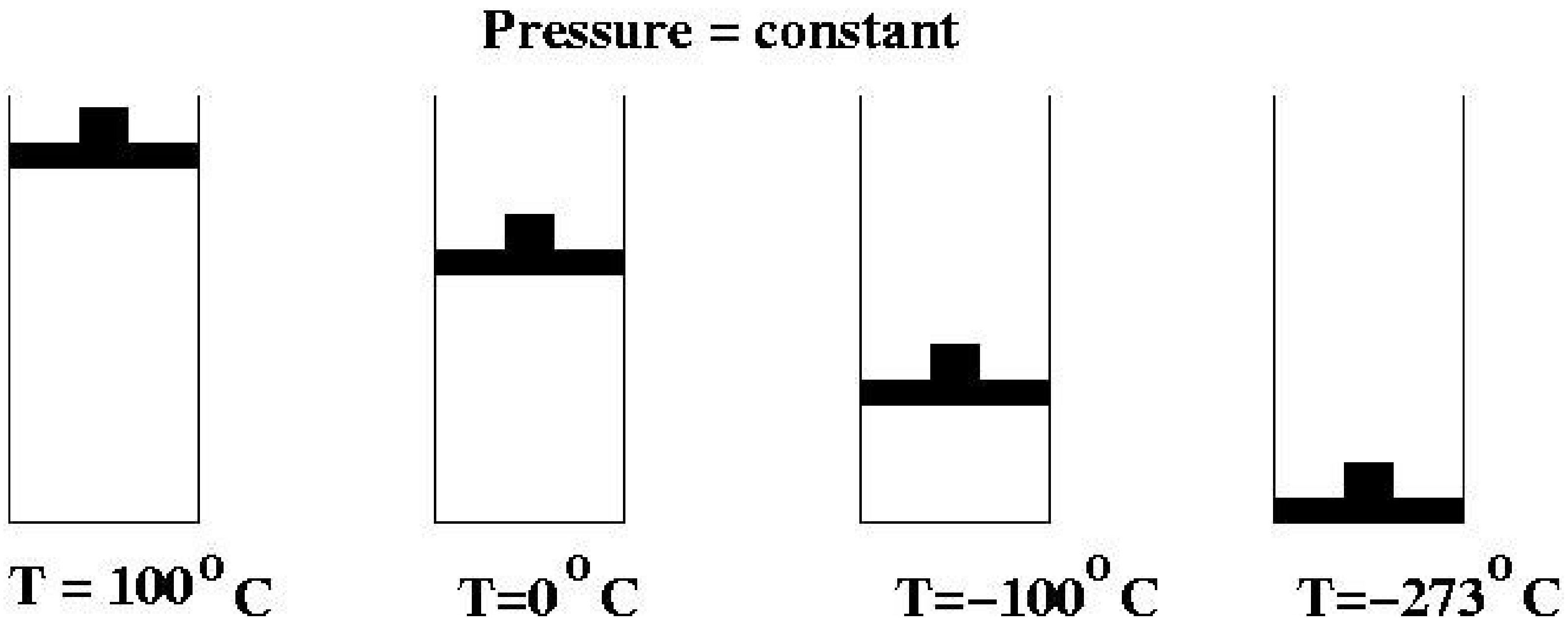
Heat is the energy an object contains because the random motion of the atoms or molecules. Heat is a form of energy. Heat can be measured in Joules (J). Another common unit used for heat is the calorie. One calorie is the heat energy it takes to raise the temperature of 1 gram of water 1^{o}C. (A BTU is the heat to raise 1 pound of water 1^{o}F.) When you see 'Calorie' (Big 'C') on food it means 1000 calories (little 'c').

Temperature tells us how hot or cold something is. There are three common temperature scales. The Celsius scale is define by 100º C being boiling water and 0º C for ice. The Fahrenheit scale has boiling water at 212º F and ice at 32º F. Temperature is related to the random motion of molecules in a substance. Temperature is proportional to the **average** kinetic energy of the molecules due to their translational motion. Some molecules will move faster and some slower but there is some average speed. If the average speed is slower (faster) then temperature is lower (higher).

There is no upper limit on temperature since the molecules can mover faster and faster (even breaking atoms down into a plasma on electrons and nuclei). However, there is a lower limit to temperature when the the atoms stop moving. This occurs at absolute zero or -273ºC.

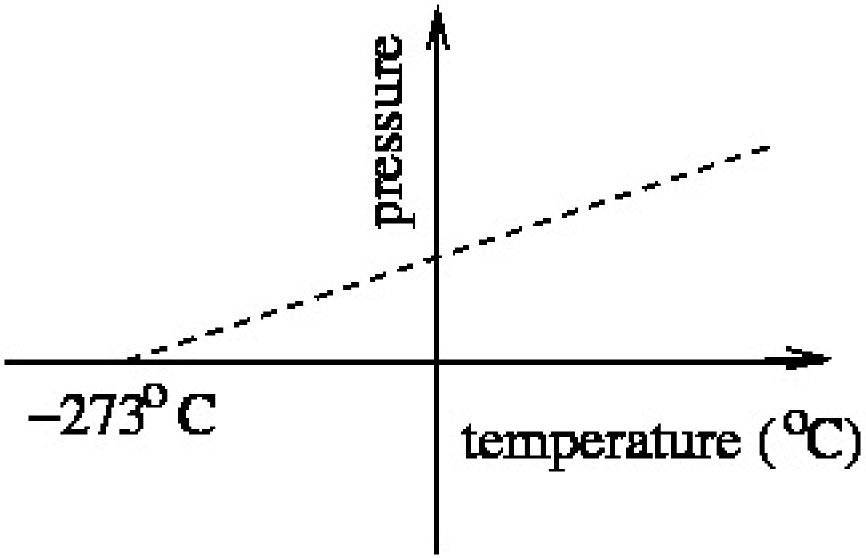
Absolute Zero

Absolute zero was understood long before the idea of atoms was accepted. Physical chemist working with gases developed laws which explain how gases work. These laws relate the pressure (force per unit area), volume, temperature and amount of gas. Charles' law say the ratio of volume over temperature is constant if the pressure stays constant. Consider a gas in a cylinder held at constant pressure. As the temperature changes the volume of the gas will change. The volume goes to zero at -273 ^{o}C.



Absolute Zero

Another law gas law says the product of pressure and volume is a constant. If you hold the volume constant and change the temperature, the temperature where the pressure goes to zero is absolute zero (-273° C or -459.7° F). (All of these gas laws are contained in the ideal gas law pv = nRT.)



We can define a temperature scale based on this where 0 is absolute zero and the size of each degree is the Celsius scale. This is called the Kevin scale. Water ice freezes at 273 K. Room temperature is approximately 293 K

Heat Transfer - Conduction

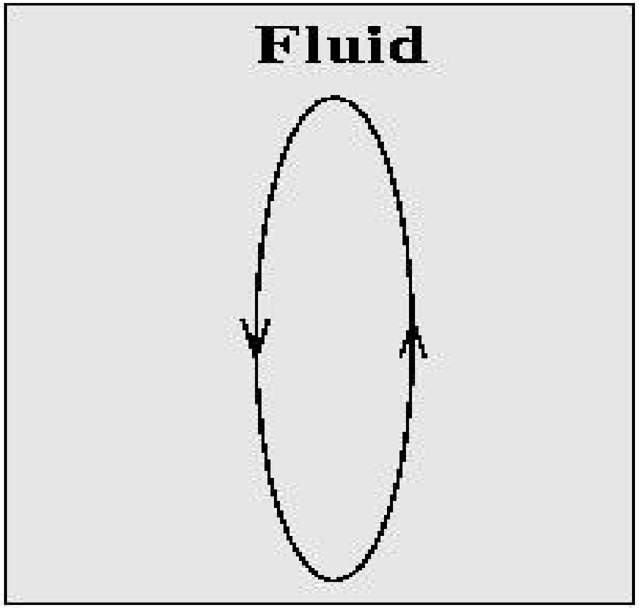
Heat energy can be transferred in three ways: conduction, convection and radiation.

If one end of a long iron rod is placed in a campfire, the heat will transfer over time to the other end. The atoms of metals have loosely held electrons. The heat caused the electrons to move around. This motion transfers the heat energy from one end of the rod to the other. (The nuclei are fixed in a 'lattice' site but they do vibrate around this fixed position.) Conduction occurs when the heat is transferred directly through the material with an bulk motion. Copper, iron and most other metals are good conductors.

Metals are good conductors of heat and electricity. Other things like gases and liquids are generally poor conductors of heat. Materials that conduct heat poorly are called insulators. Wood, most plastics and gases are good insulators.

Heat Transfer - Convection

Convection occurs in fluids (gases or liquids) when heat causes the material to expand or contract in one part of the fluid. This reduces the density for warmer parts of the fulid and the fluid will rise. Cooler fluid will have a lower density and sink. The transfer of heat by bulk motion in the fluid Is called convection. Wind is an example of convection. Convection causes the air in a room to be hotter near the ceiling and cooler near the floor. This is why a ceiling fan is useful even in the winter.



Heat Transfer - Radiation

Heat can be transmitted by electromagnetic radiation. All objection emit radiation (even very cold objects) which depends on the temperature object. If a object is hot enough we can see the object start to glow 'red hot'. If the object is not hot enough to be seen as visible light, the object will emit infrared radiation which is not visible but can be felt. If you open an oven door, you can feel the heat even though you can not 'see' it. Even the Universe 'glows' with the heat left over from the Big Bang but the radiation is in the microwave region of the spectrum and corresponds to 2.75 K! In all cases it is electromagnetic radiation moving at the speed of light. We will discuss electromagnetic radiation in more detail later.

Heat Capacity

Some objects contain more heat energy than other objects even if they are at the same temperature. Some materials are easier to heat up than others. The characteristic of materials is called specific heat capacity. Specific heat capacity is define by:

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

where Q is the heat require to change the temperature ΔT of a mass m of the material. The specific heat capacity is 'c'. 'c' depends of the material. The units are J/(kg K) or calories/(gram ^{o}C). Table 7.1.2 in the text has a table of common specific heat capacities. The heat specific capacity of water is very large at 4190 J/(kg K) or 1.0 calorie/gram ^{o}C (just the definition of a calorie)

Change of Phase

Materials can melt (solid → liquid), freeze (liquid → solid) or vaporized (liquid → gas) or even go from a solid → gas. We call this a phase change. Matter exist in three (four) phases: gas, liquid, solid (plasma). In a solid, the atoms or molecules are localized but vibrate around some position. In a liquid, the atoms or molecules are loosely attracted to one another but can move around in the material. In a gas, the atoms or molecules are free to move around except for collision with the container walls or each other. In a plasma, the electrons are stripped from the nuclei and move around like an electrically charged gas.

Change of Phase

A pan of water will evaporate even at room temperature. Temperature is a measure of the average kinetic energy of the water molecules. Some molecules have more KE and some have less. Some molecules near the surface of the water have enough energy to 'escape'. This cools off the water slightly. The water absorbs some heat from the surrounding environment and the process repeats. In the 1800s a lot of thought by Maxwell, Boltzmann and others went into finding the speed distribution of the atoms in a fluid.

Condensation is the reverse of evaporation. When this happens, energy is removed from the vapor. When water vapor turns into water (rain) the atmosphere cools off. Fog is when the air is saturated with water and forms a cloud on or near the ground.

Change of Phase

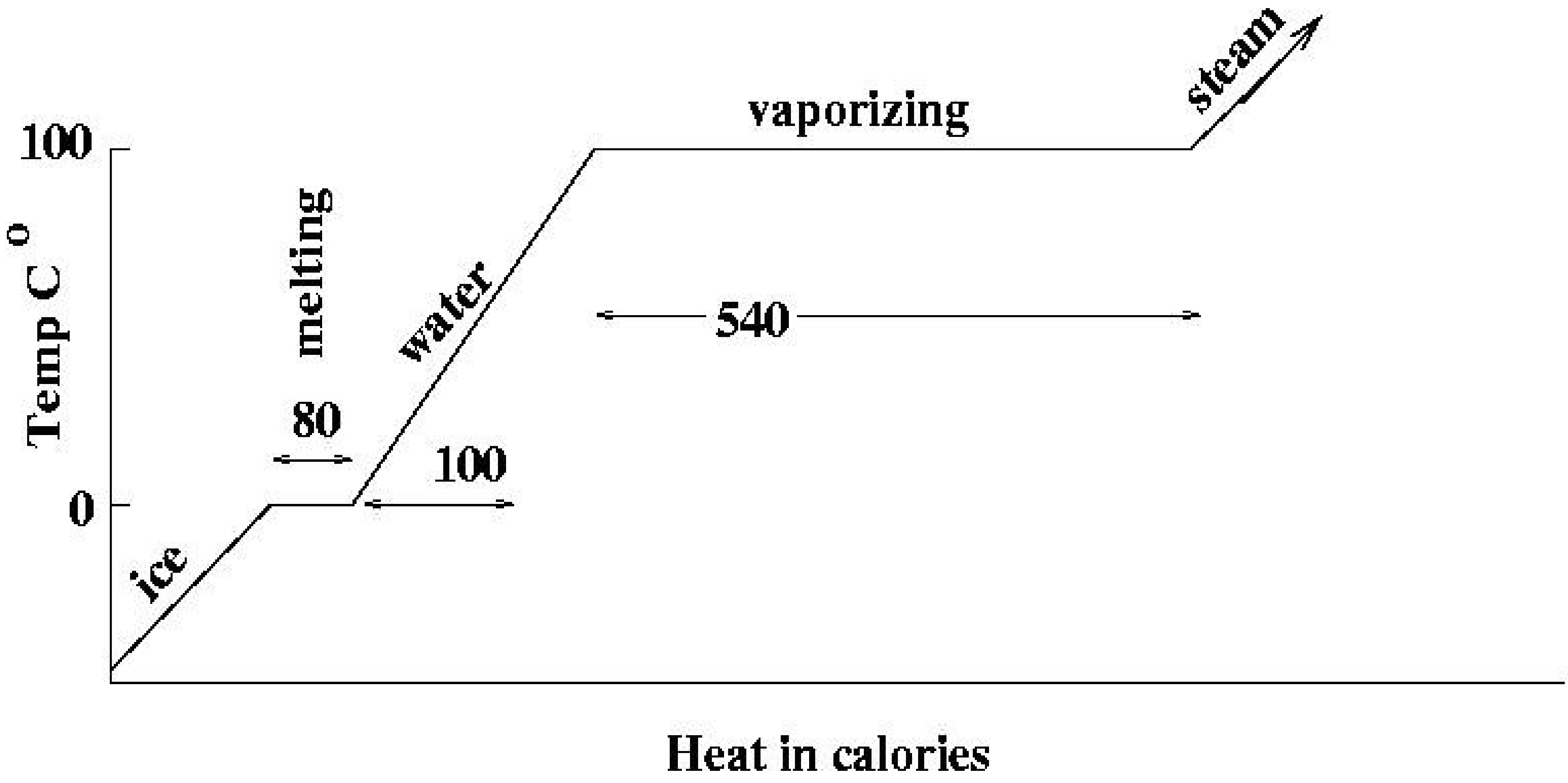
Freezing and melting are similar processes. When something melts it requires heat energy. When something freezes, the material gives up heat energy.

Another type of phase change is sublimation. This is going from a solid to a gas. Dry ice (solid CO_2) goes directly from a solid to a gas. You also see sublimation when you leave an ice cube tray in the freezer for a long time. The reverse (gas to solid) is called deposition. Deposition is used to make computer chips and aluminized plastics.

All three phases can coexist. If you put ice water in a sealed jar, the relative humidity will eventually be 100% (as much water as the air can hold: vapor ↔ liquid). The ice and water will also be in equilibrium (liquid ↔ ice). This is known as the triple point or phase equilibrium.

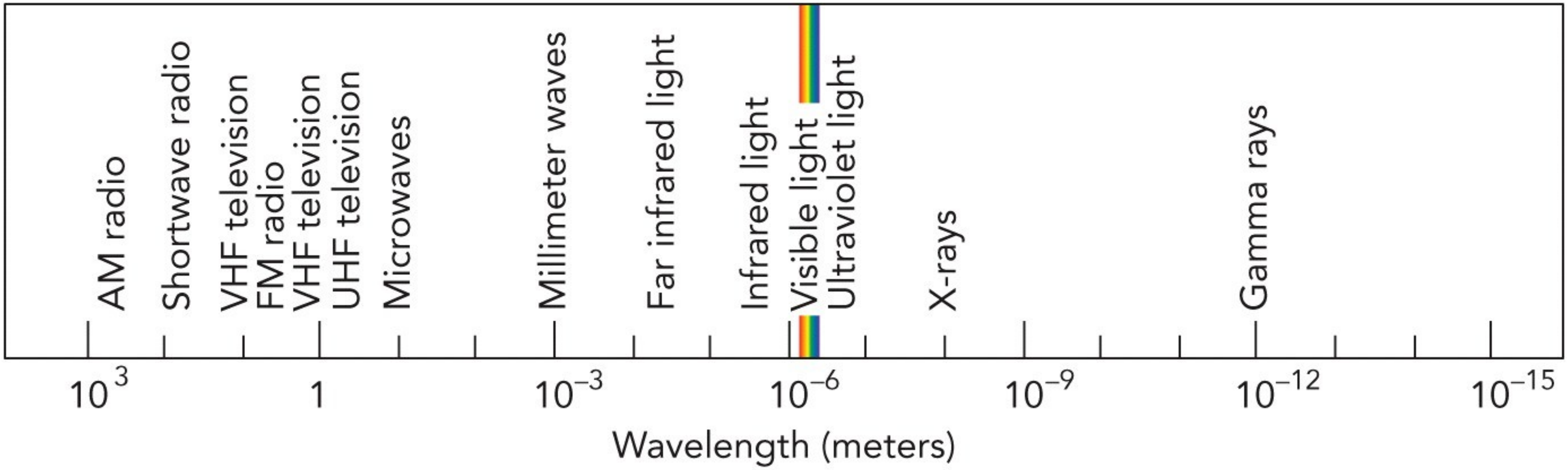
Change of Phase

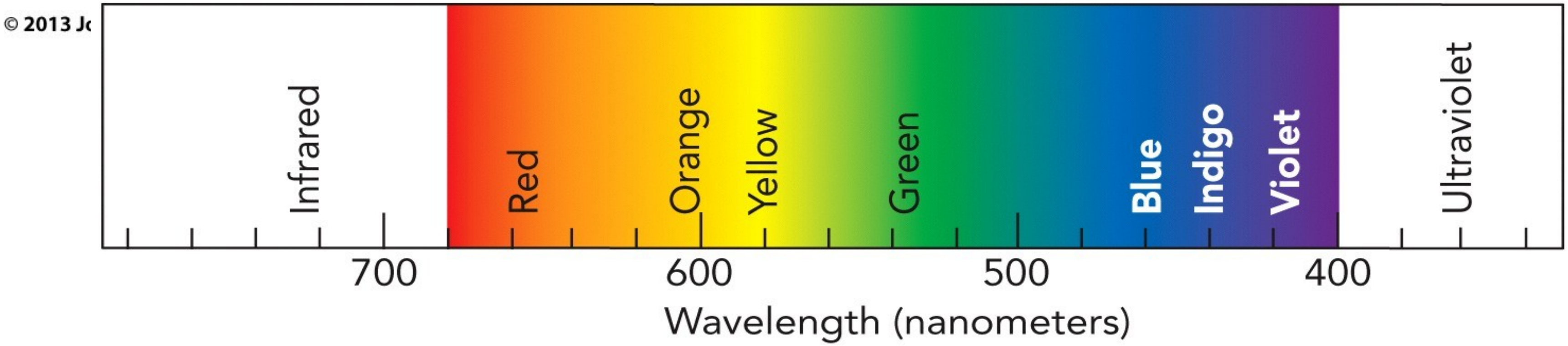
Energy is absorbed or release when a substance changes phase. The temperature does not change during the phase change. To melt ice requires 80 calories/gram. To turn water into steam requires 540 calories/gram.



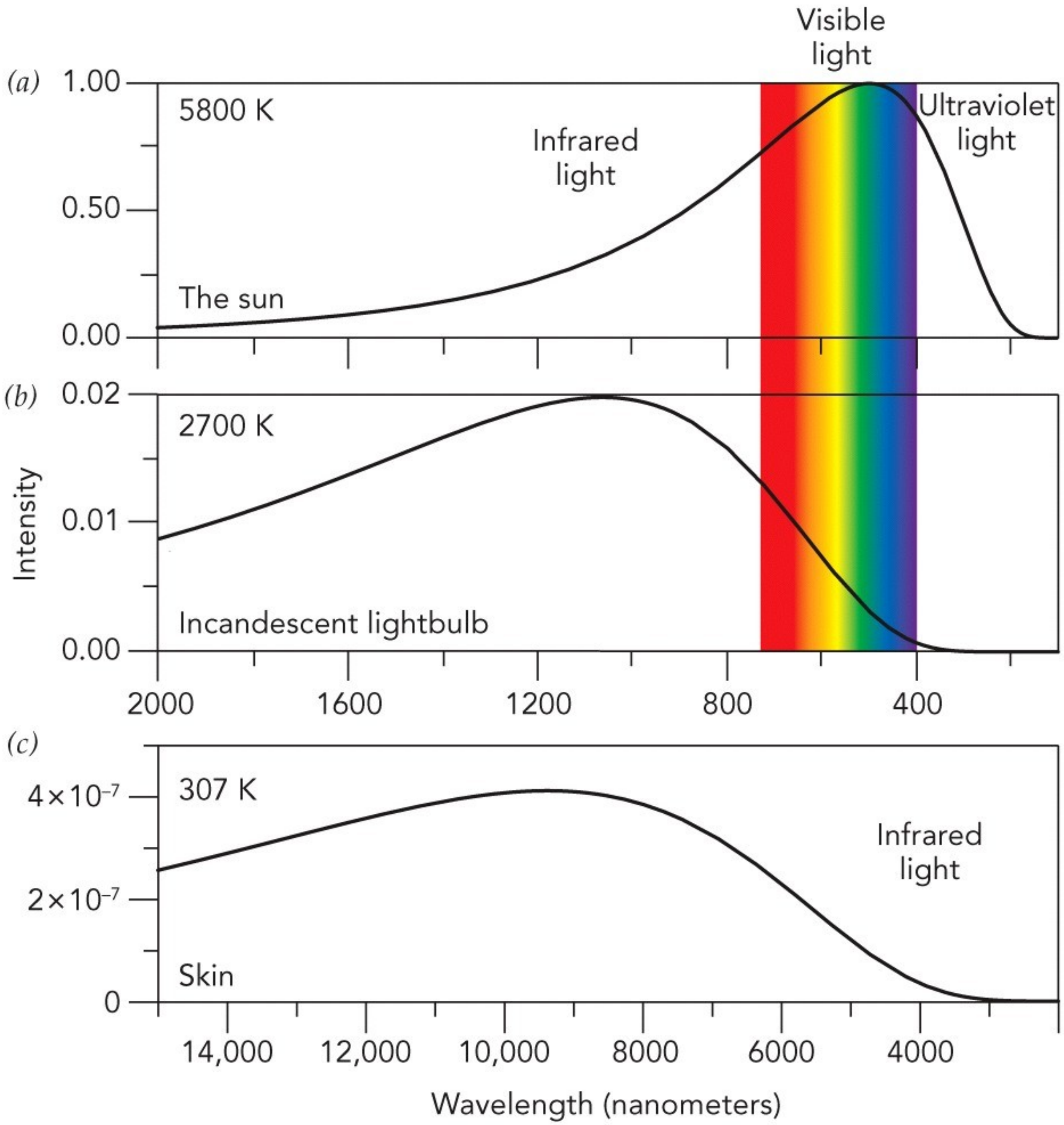
Electromagnetic Radiation

An old style incandescent light bulb has more to do with heat than electricity. An electrical current heats a very thin coil of Tungsten to ≈2500 ^{o}C. This makes light but it also makes a lot of heat. Any object radiates electromagnetic radiation which is related to its absolute (kelvin) temperature. Visible light is only a tiny part of the electromagnetic spectrum





Electromagnetic Radiation and Temperature

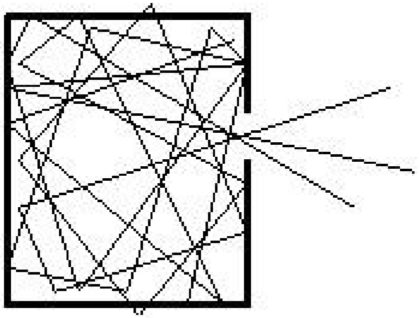


All objects emit electromagnetic radiation depending on their temperature. The radiation is not a single wavelength ('color') but a distribution. The peak of the distribution increases with temperature

Black Body Radiation

Some objects emit radiation better than others. A good radiator is also a good absorber. A bad absorber is also a bad emitter.

Consider a box with a small hole. Any electromagnetic radiation that enters through the hole will have to bounce around so must (there are no perfect reflectors) it will not get out. The hole in the box will be a near perfect absorber. If you heat up the box, the hole will be a perfect emitter. A blackbody is a perfect emitter.



The spectra on the previous slide are examples of blackbody spectra at various temperatures. It was not until 1900 that Max Planck calculated a blackbody spectrum. It was the first hint of a lot of things to come.

Stefan-Boltzmann Law

The power radiated (energy/second) by an object at an absolute temperature T is given by:

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

Where A is the surface area of the object, T is the temperature in Kelvin, $\sigma = 5.67 \times 10^{-8}$ j/(s m^2 K^4) is the Stefan-Boltzmann constant and e is the emissivity. The emissivity is a number between 0 and 1 which determines how good (1) the object is as a blackbody. Zero is a perfect reflector.

Insulation, Climate etc.

If you have heard someone say they had their house insulated to 'keep the cold out in the winter' they have it backwards. They insulate the house to keep the heat in. Winter clothes trap your body heat. Most insulation materials involve trapped air. Gases are poor conductors and if the air is trapped in a small space convection is not a problem. Wool is 'warm' because air is trapped between all the fibers. Even a 'resting' person generates about 100 W of heat so keeping that heat from dissipating to the air will keep you warm. Ever been in a small room with several people … it gets hot. Thermal windows use the same idea with two plates of glass with Ar between them.

The concern about 'Global Warming' from CO_2 is because traps infrared energy like a blanket. Visible light warms the earth which radiates in the infrared which is trapped by the CO_2. Look at Venus for an extreme case!

Light bulbs

Incandescent light bulbs use a lot of energy for the amount of light they output. They work by heating a very thin (μm) coiled wire of tungsten to about ≈ 2500^{o} C. They are being phased out to save energy.

Halogen bulbs use thinner filaments which would normally burn out quicker. Normal filaments burn out because the sublimate away the tungsten. Halogen bulbs have a small of bromine (Br) to capture the tungsten where it is deposited back on the filament.

A fluorescent bulbs excite a low pressure mercury (Hg) gas which emits UV radiation. This is converted to visible white light by a phosphor coating on the inside of the bulb. A compact fluorescent bulb is one that fits in a normal lamp base.

Light bulbs

For home lighting compact fluorescent bulbs are the most efficient lighting currently available as the graph shows. They cost more per bulb but save money in the long run.

LEDs (light emitting diode) have been around for many years but recently their color has been expanded to the point that generating white light is possible. LEDs require lower voltage DC current but are significantly more efficient than even CFLs. You see then currently in flashlights and other small items.