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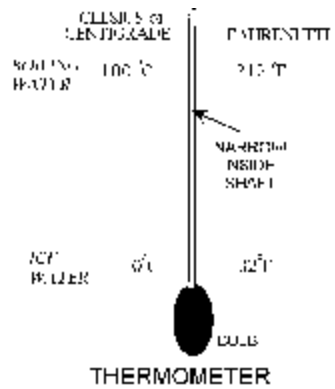
# 16. Temperature and Heat

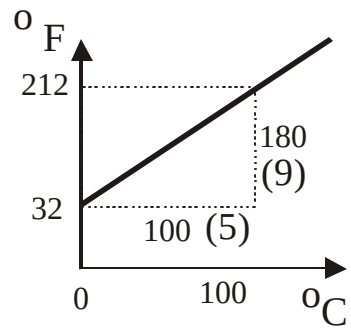
16.1 Temperature T [°], it's hot or it's cold. That's all we can say.
Units: ° K (Kelvin), °C (Celsius or centigrade), °F (Fahrenheit)

**16.1.1 Temperature Scales** - the thermometer Some things are hot, others are cold. Of the cold, some are barely cold, some sort of cold, others very cold. The same for hot. On the earth water is everywhere. Ice water is cold, boiling water hot. Things expand when they get hotter: Some things like the silver colored liquid metal called mercury expand a lot, others like glass expand very little. So, put some mercury in a glass tube with a very narrow inside shaft and a large bulb at the bottom as the reservoir. The reservoir holds lots of mercury. Only tiny amounts rise up into the narrow inside shaft. We call this a thermometer (thermo - temperature, meter - measure). Put its bottom bulb into boiling water and mark the mercury level 212° Fahrenheit and 100° Celsius. Next put the bulb in ice water mark it 32°F and 0°C. Now, a degree F (°F) is one 180th of the distance between the two marks. A degree C (°C) is one 100th (hence, centi = 1/100) of the distance between two marks.



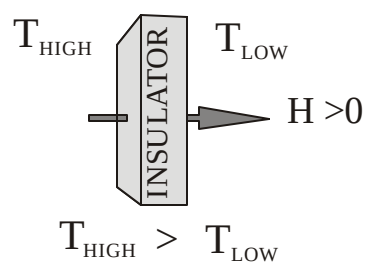

$^{o}F = 9/5\ ^{o}C + 32$

$^{o}C = 5/9\ (^{o}F - 32)$



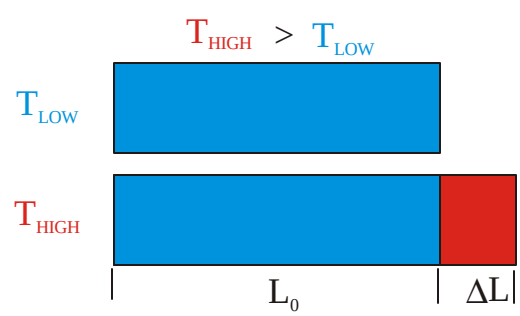

## 16.2 Thermal Insulator

A thermal insulator is something that prevents thermal contact between two bodies or systems. The ideal insulator totally prevents any thermal contact. Asbestos is on of the best insulators. The opposite is a conductor. Silver is one of the best conductors.




## 16.3 O-th Law of Thermodynamics (Thermal Equilibrium)

Any two bodies in thermal contact with each other will eventually come to have a common temperature.



Thermal Expansion

## 16.4 Thermal Expansion

most materials expand when

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heated. In the first approximation it is linear.

$$\Delta L = \alpha L_0 (T - T_0)$$

$$(L - L_0) = \alpha L_0 \Delta T$$

" is called the coefficient of linear thermal expansion. It is characteristic of the material.

$\alpha_{Aluminum}$ = $2.4 \times 10^{-5}/C^o$- a 1 m long aluminum rod lengthens by 2.4 mm when the temp increases by 100 $C^o$ ,
$\alpha_{Copper}$ = $1.7 \times 10^{-5}/C^o$ - a 1 m long copper rod lengthens by 1.7 mm when the temp increases by 100 $C^o$ ,
$\alpha_{Steel}$ = $1.2 \times 10^{-5}/C^o$ - a 1 m long steel rod lengthens by 1.2 mm when the temp increases by 100 $C^o$ ,
$\alpha_{Glass}$ = $0.4 - 0.9 \times 10^{-5}/C^o$ - a 1 m long glass rod lengthens by 0.4 - 0.9 mm when the temp increases by 100 $C^o$ ,
$\alpha_{Quartz}$ = $0.04 \times 10^{-5}/C^o$ - a 1 m long quartz rod lengthens by 0.04 mm when the temp increases by 100 $C^o$ ,

Water violates this behavior. Below 4°C, water expands as it further cools rather than contracting as do other materials.

**The change in length of a 1 meter long item**

**ΔL (white) vs ΔT (blue) for various materials**

| Material | **a** of material (1/°K) | Change in temperature °K, ΔT: 10 | 20 | 50 | 100 | 150 |
|---|---|---|---|---|---|---|
| Aluminum | 2.40E-05 | 2.40E-04 | 4.80E-04 | 1.20E-03 | 2.40E-03 | 3.60E-03 |
| Steel | 1.20E-05 | 1.20E-04 | 2.40E-04 | 6.00E-04 | 1.20E-03 | 1.80E-03 |
| Glass | 6.00E-06 | 6.00E-05 | 1.20E-04 | 3.00E-04 | 6.00E-04 | 9.00E-04 |
| Invar | 9.00E-07 | 9.00E-06 | 1.80E-05 | 4.50E-05 | 9.00E-05 | 1.35E-04 |
| Quartz | 4.00E-07 | 4.00E-06 | 8.00E-06 | 2.00E-05 | 4.00E-05 | 6.00E-05 |
| Pine (parallel to grain | 5.00E-06 | 5.00E-05 | 1.00E-04 | 2.50E-04 | 5.00E-04 | 7.50E-04 |
| Pine (across grain) | 3.40E-05 | 3.40E-04 | 6.80E-04 | 1.70E-03 | 3.40E-03 | 5.10E-03 |
| | | ΔL(m) for ΔT=10°K | | | ΔL (m) for ΔT=100°K | |

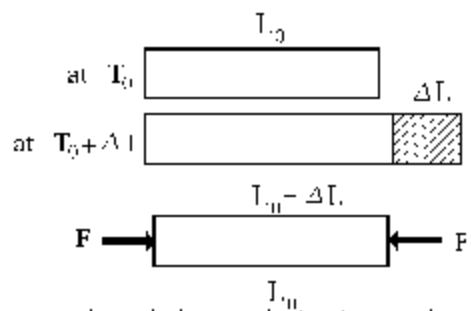
**Exercise**: By direct calculation verify all of the values in the above table.

## 16.5 Thermal Stress

when a body is constrained to stay a fixed size, then thermal expansion is impossible. So, the material becomes stressed. To calculate this stress: first calculate how much it would expand if it could; then calculate the force (stress) needed to return it to its original length.

$$\sigma = F/A = M_Y \Delta L/L_0$$

$$= M \alpha_Y \Delta T$$




THERMAL STRESS

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**Thermal Stress, $\sigma$, caused by temperature change of a material constrained so it cannot expand or contract**

**$\sigma$ (white) vs $\Delta T$ (blue) for various materials**

| | **a of material** | **$M_Y$ of material** | **Change in temperature $^oK$, $\Delta T$** | | | | |
|---|---|---|---|---|---|---|---|
| **Material** | (1/$^o$K) | (N / m^2) | 10 | 20 | 50 | 100 | 150 |
| Aluminum | 2.40E-05 | 7.00E+10 | 1.68E+07 | 3.36E+07 | 8.40E+07 | 1.68E+08 | 2.52E+08 |
| Steel | 1.20E-05 | 2.00E+11 | 2.40E+07 | 4.80E+07 | 1.20E+08 | 2.40E+08 | 3.60E+08 |
| Glass | 6.00E-06 | 6.00E+10 | 3.60E+06 | 7.20E+06 | 1.80E+07 | 3.60E+07 | 5.40E+07 |
| Lead | 2.90E-05 | 1.60E+10 | 4.64E+06 | 9.28E+06 | 2.32E+07 | 4.64E+07 | 6.96E+07 |
| | | | $\sigma$ (N/m$^2$) for $\Delta T=10^oK$ | | | $\sigma$ (N/m$^2$) for $\Delta T=100^oK$ | |

**16.5.1 Exercise**: By direct calculation verify all of the values in above table.

## 16.6 Quantities of Heat

The **calorie** is the heat required to raise the temperature of 1 gram of pure water by 1 $^o$C. (Presently, the heat needed to raise the temperature from 14.5$^o$C to 15.5$^o$C because the value varies with temperature.)

The **Calorie or Kcal** (= 1000 calories) is the heat required to raise the temperature of 1 kg of pure water by 1 $^o$C.

The **British Thermal Unit (BTU)** is the heat required to raise the temperature of 1 pound of pure water by 1 $^o$F. (Presently, the heat required to raise one pound of water from 60$^o$F to 61$^o$F .)

**16.6.1 Joule and the "Mechanical Equivalent of Heat"** In a very ingenious experiment James Joule, an English scientist, in the late 1700's showed that 1cal = 4.186 Nm units of work. This conclusively demonstrated that heat was simply a form of energy. Without this, the entire science of Thermodynamics would not exist. The unit of work was later named the Joule in his honor. The following conversions result from his work.

1 cal = 4.186 J, 1 Btu = 1055 J = 252 cal = 778 fp , 1 kWh = $3.600 \times 10^6$ J.

## 16.7 Specific Heat, C,

is the heat required to raise the temperature of 1 gram or kilogram (pound) of a substance by 1 $^o$C ( 1 $^o$F ). It is characteristic of the material.

$$C = Q/(m\Delta T)$$

The heat, Q, held or stored by a body as a result of a temperature rise $\Delta T$ = Specific Heat * mass *$\Delta T$ = Specific Heat * density*Volume*$\Delta T$ (remember mass = density*Vol, m = $\rho$Vol ) .

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$$Q = C\, m\, \Delta T = C\, \rho\, Vol\, \Delta T,$$

where $\rho$ is the mass density of the substance .

A few typical values for C

$C_{Water}$ = 4190 J/kg K , that's 4190 ($4.19 \times 10^3$ J) for 1 kg of water changing temperature by 100 C°.
$C_{Aluminum}$ = 910 J/kg K , that's 910 ($0.910 \times 103^3$ J) for 1 kg of aluminum changing temperature by 100 C°.
$C_{Iron}$ = 470 J/kg K , that's 470 ($0.470 \times 10^3$ J) for 1 kg of iron changing temperature by 100 C°.
$C_{Lead}$ = 130 J/kg K , that's 130 ($0.130 \times 10^3$ J) for 1 kg of lead changing temperature by 100 C°.
$C_{Etnanol}$ = 2428 J/kg K, that's 2428 ($2.428 \times 10^3$ J) for 1 kg of ethanol changing temperature by 100 C°.
( All are for constant pressure)

This table shows the heat absorbed or liberated by 1 kg of the listed substances as it undergo a the given temperature changes. The heat is in Joules (J).

**Heat (J) , ΔQ, Aborbed or Liberated per Kg of Substance as a result of a temperature change ΔT**

| | C of material | Change in temperature °K, ΔT | | | | |
|---|---|---|---|---|---|---|
| **Material** | (J/[kg °K]) | 10 | 20 | 50 | 100 | 150 |
| Aluminum | 910 | 9.10E+03 | 1.82E+04 | 4.55E+04 | 9.10E+04 | 1.37E+05 |
| Copper | 390 | 3.90E+03 | 7.80E+03 | 1.95E+04 | 3.90E+04 | 5.85E+04 |
| Ethanol | 2428 | 2.43E+04 | 4.86E+04 | 1.21E+05 | 2.43E+05 | 3.64E+05 |
| Ethylene glycol | 2386 | 2.39E+04 | 4.77E+04 | 1.19E+05 | 2.39E+05 | 3.58E+05 |
| Ice | 2000 | 2.00E+04 | 4.00E+04 | 1.00E+05 | 2.00E+05 | 3.00E+05 |
| Iron | 470 | 4.70E+03 | 9.40E+03 | 2.35E+04 | 4.70E+04 | 7.05E+04 |
| Lead | 130 | 1.30E+03 | 2.60E+03 | 6.50E+03 | 1.30E+04 | 1.95E+04 |
| Mercury | 138 | 1.38E+03 | 2.76E+03 | 6.90E+03 | 1.38E+04 | 2.07E+04 |
| Salt (naCl) | 879 | 8.79E+03 | 1.76E+04 | 4.40E+04 | 8.79E+04 | 1.32E+05 |
| Silver | 234 | 2.34E+03 | 4.68E+03 | 1.17E+04 | 2.34E+04 | 3.51E+04 |
| Water | 4190 | 4.19E+04 | 8.38E+04 | 2.10E+05 | 4.19E+05 | N.A. |
| | | ΔQ (J) for ΔT=10°K | | | ΔQ (J) for ΔT=100°K | |

**16.7.1** **Exercise:** By direct calculation verify all of the values in the above table.

## 16.8 Heats of Combustion

This is the heat liberated when a substance "burns". The most productive situation is when the substance is used as a fuel. The last two columns in the table below show the number of kg of the substance used as fuel needed to boil and to raise 1 kg of water, $H_2O$ , by 70° C. The table also lists the specific gravity (SpGr = $\rho_{Substance} / \rho_{water}$) at 68 °F and densities (N/m$^3$) for some substances.

### 16.8.1 Exercise:

1. It takes 2256 kJ to boil 1 kg of water that is already at 100 °C. Show that it takes about 0.0155 gal of petroleum to boil 1 kg of fresh water.

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| Heats of Combustion $L_c$ | | | 157.316 | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $C_{H2O}$ = | 4.19 | kJ/(kg °K) | g | ρ water | | Relative Fuel to | |
| | $L_{VH2O}$ = | 2256.0 | kJ/(kg °K) | 9.81 | 1.00E+03 | 9.81E+03 | boil $H_2O$ | raise liquid $H_2O$ by 70°C |
| | Kcal/kg | BTU/p | kJ/kg | p/f3 | N/m3 | SpGr | kg fuel/kg$H_2O$ | kg fuel/kg$H_2O$ |
| **Solid fuels** | | | | | | | | |
| Anthracite coal | 8,000 | 14,400 | 33,472 | 250 | 39,329 | 4.0091 | 6.74E-02 | 8.76E-03 |
| Bituminous coal | 7,500 | 13,500 | 31,380 | 250 | 39,329 | 4.0091 | 7.19E-02 | 9.35E-03 |
| Coke | 6,000 | 11,000 | 25,104 | 250 | 39,329 | 4.0091 | 8.99E-02 | 1.17E-02 |
| Pine wood | 4,500 | 8,000 | 18,828 | 30 | 4,719 | 0.4811 | 1.20E-01 | 1.56E-02 |
| **Liquid fuels** | | | | | | | | |
| Gasoline | 11,400 | 20,500 | 47,698 | 42.5 | 6,686 | 0.6815 | 4.73E-02 | 6.15E-03 |
| Kerosine | 11,200 | 20,000 | 46,861 | 49.9 | 7,850 | 0.8002 | 4.81E-02 | 6.26E-03 |
| Diesil Oil | 10,500 | 19,000 | 43,932 | 56 | 8,810 | 0.8980 | 5.14E-02 | 6.68E-03 |
| Alcohol | 6,400 | 11,500 | 26,778 | 49.4 | 7,771 | 0.7922 | 8.42E-02 | 1.10E-02 |
| petroleum | 11,000 | 0 | 46,024 | 52 | 8,180 | 0.8339 | 4.90E-02 | 6.37E-03 |
| **Foodstuffs** | | | | | | | | |
| Proteins | 4,000 | 7,200 | 16,736 | 50 | 7,866 | 0.8018 | 1.35E-01 | 1.75E-02 |
| Carbohydrates | 4,000 | 7,200 | 16,736 | 50 | 7,866 | 0.8018 | 1.35E-01 | 1.75E-02 |
| Fats | 9,500 | 17,000 | 39,748 | 50 | 7,866 | 0.8018 | 5.68E-02 | 7.38E-03 |
| | | | | | | | $=L_{VH2O}/L_{Cfuel}$' | $=70*C_{H2O}/L_{Cfuel}$' |

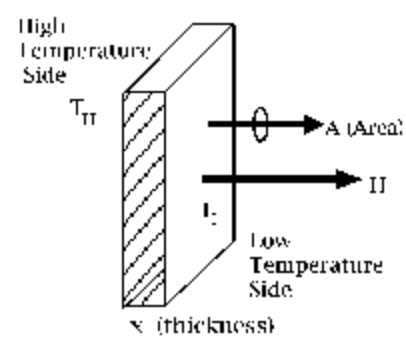
**16.9 HEAT TRANSFER** are the processes by which energy transfers or transmits from one body or region to another. There are three processes:

**16.9.1 Conduction -** energy is transmitted by way of molecular motion.

$$\frac{dQ}{dt} = H = \frac{kA}{x}(T_H - T_L) = \frac{kA}{x}\Delta T$$

H is the heat transferred per unit time - Watts = Joules/second, or BTU/hr . k is called the thermal conductivity and is characteristic of each material.

| | x (m) = | 0.01 | | | | |
|---|---|---|---|---|---|---|
| **Thermal Conductivity - Heat Flow (W) passing through a slab with** | | | | | | |
| | | | Area A($m^2$) = | 1.00 | Thickness x (m)= | 0.01 |
| | | **Change in temperature ΔT** | | | | |
| | | 5.0oK | 10.0oK | 20.0oK | 50.0oK | 100.0oK |
| | k (W/[m°K | 9.0oF | 18.0oF | 36.0oF | 90.0oF | 180.0oF |
| Silver | 406 | 2.03E+05 | 4.06E+05 | 8.12E+05 | 2.03E+06 | 4.06E+06 |
| Copper | 385 | 1.93E+05 | 3.85E+05 | 7.70E+05 | 1.93E+06 | 3.85E+06 |
| Steel | 50.2 | 2.51E+04 | 5.02E+04 | 1.00E+05 | 2.51E+05 | 5.02E+05 |
| Aluminum | 205 | 1.03E+05 | 2.05E+05 | 4.10E+05 | 1.03E+06 | 2.05E+06 |
| Lead | 34.7 | 1.74E+04 | 3.47E+04 | 6.94E+04 | 1.74E+05 | 3.47E+05 |
| Brick, insul | 0.15 | 7.50E+01 | 1.50E+02 | 3.00E+02 | 7.50E+02 | 1.50E+03 |
| Red Brick | 0.6 | 3.00E+02 | 6.00E+02 | 1.20E+03 | 3.00E+03 | 6.00E+03 |
| Concrete | 0.8 | 4.00E+02 | 8.00E+02 | 1.60E+03 | 4.00E+03 | 8.00E+03 |
| Glass | 0.8 | 4.00E+02 | 8.00E+02 | 1.60E+03 | 4.00E+03 | 8.00E+03 |
| Cork,Felt,R | 0.04 | 2.00E+01 | 4.00E+01 | 8.00E+01 | 2.00E+02 | 4.00E+02 |
| wood | 0.03 | 1.50E+01 | 3.00E+01 | 6.00E+01 | 1.50E+02 | 3.00E+02 |
| styrofoam | 0.01 | 5.00E+00 | 1.00E+01 | 2.00E+01 | 5.00E+01 | 1.00E+02 |
| air | 0.024 | 1.20E+01 | 2.40E+01 | 4.80E+01 | 1.20E+02 | 2.40E+02 |
| | | Power (Watts) H = k*A($m^2$)*ΔT(oK)/x(m) | | | | |



THERMAL CONDUCTIVITY

**16.9.1.1 Exercise:** If electricity costs $0.15 /Kwhr, show that the heat lost through an aluminum slab with area A= 1 sq m , x= thickness1 cm at temperature difference ΔT 20°C would cost $448,950 / month, $219 for the same conditions for the same sized slab of rock wool. Use 720 hours for the average month (24 hr/day * 365.25 day/year /[12( months /year)] = 730.5 hr/month .

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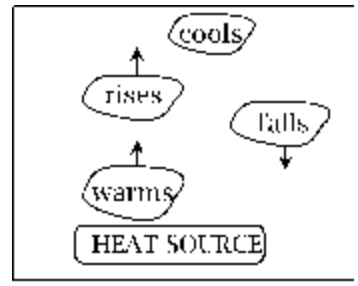
**16.9.2 Convection** - energy is transferred by the flow of fluid matter. Fluid gets warmed at the heat source on the bottom. It becomes less dense than the cooler fluid above, so it rises. This creates convection currents. The effect is proportional to the exposed surface areas.



CONVECTION

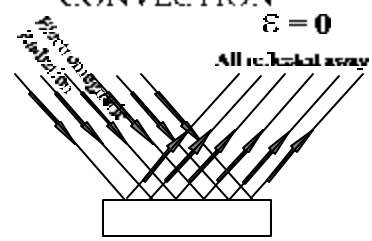
**16.9.3 Radiation** - energy transfers by way of electromagnetic radiation. It requires no media - it can travel through a vacuum. That's how the sun's energy reaches us.

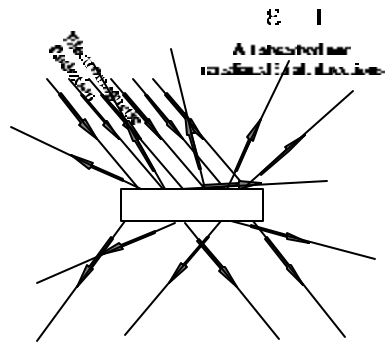
$$H = \varepsilon\sigma A(T_H^4 - T_L^4),$$

where A is the area of the surface of the irradiated body. F is the Stefan-Boltzmann constant: it's a universal constant.

$$\sigma = 5.669 \times 10^{-8}\ J/(m^2\ {}^oK^4)$$

$\varepsilon$ is the emissivity of the body of interest: it depends on the color and smoothness of the surface of interest.



## 16.10 Size Effects

The heat producing or holding capacity of a body is proportional to its volume. The ability to dissipate heat by way of conduction, convection or radiation is proportional to the body's surface area.

Capacity to hold heat = c m = c ρ Vol
Capacity to produce or generate heat = heat of combustion/unit mass * ρ Vol

Heat Dissipation = Area * property of surface*function($T_{body}$, $T_{Environment}$).

For a cube with sides of length L , its

Capacity to hold or generate heat % Vol = $L^3$
(proportional)
Heat Dissipation % Exposed Area = #of exposed sides * $L^2$ - $6L^2$
(approximately)

So, the for this cube

$$\frac{\text{Capacity for holding or generating heat}}{\text{Ability for dissipating heat}} \propto \frac{L^3}{L^2} = L$$

The larger the body the easier it generates or hold heat relative to its ability to dissipate heat. As an example, a shrew ( a rodent that is the smallest mammal in the world is characterized by an L = ½ inch, while an elephant is

characterized by L = 8 ft (about 100 inches). So the elephant is holds or generate about 200 times more heat than it can dissipate compared to a shrew. This shows up in the fact that an elephant eats about 100 to 200 pounds of food a day, about 1/100th to 1/50th of its weight: A shrew eats about twice its weight a day just to stay alive. This size effect is why rodents and insects are such a danger to food supplies. 10,000 pounds of deer eat about 300 to 500 pounds of food a day: 10,000 pounds of mice eat about 2000 to 5000 pounds of food a day.

This is also why some very large volume buildings that are heavily used and occupied often have to run their air conditioning , or circulate outside cold air inside, even in the dead of a cold winter.

## 16.11 Some Thermal Properties and Behaviors of Matter

### 16.11.1 Phases of Matter

There are four phases of matter - solid, liquid, gas and plasma.

**Solid** has a structure which preserves the shape and volume of a body.

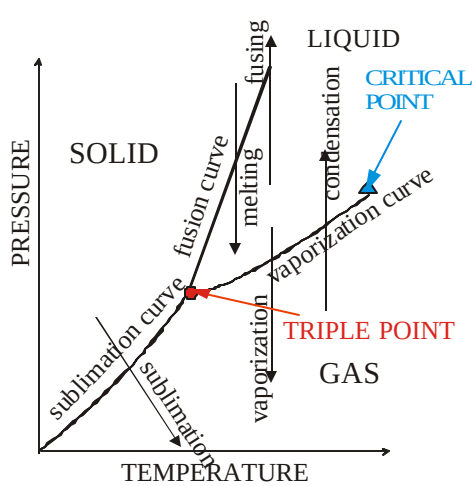
**Liquid** has a structure which only preserves the volume of the body, but not its shape. Glass and cold tar are examples of very slow liquids - their flow is so slow that they are frequently mislabeled as solids.

**Gas** has a structure that preserves neither shape nor volume. A gas will fill any space to which it has access.

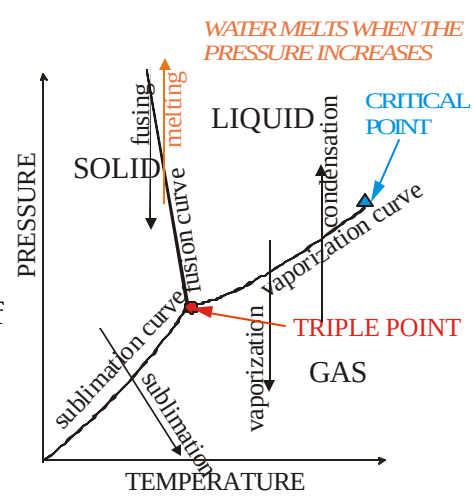
**Plasma** is a state of matter where the positive nuclei and the normally orbiting electrons separate into an electron "fluid" with positive ions (the nuclei) embedded in the fluid. Fluorescent lights and neon signs are examples. This is the most common state of ordinary matter in the universe as a whole; such as stars and interstellar and intergalactic gas nebulae.

### 16.11.2 Phase Diagrams.

The two diagrams shown are called **phase diagrams**. They are graphs showing the pressure-temperature, P-T, ranges for the existence of the solid, liquid and gas of substances. The left shows the pattern of most substances, while the right shows the peculiar behavior of water.




MOST SUBSTANCES




STRANGE BEHAVIOR OF WATER

There are three curves of phase separation: (1) the **sublimation curve** separates the

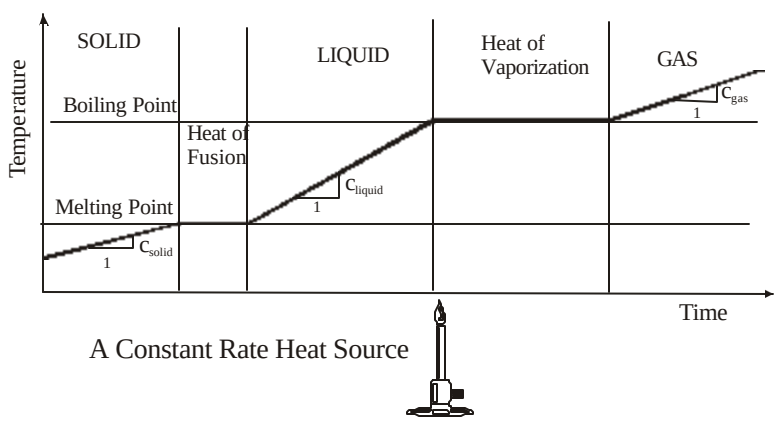
solid and gas phases; (2) the **fusion curve** separates the solid and liquid phases; (3) the **vaporization curve** separates the liquid and gas phases. The transition paths are shown as arrows crossing the phase separation curves. For examples: **Sublimation** is the path of a substance that goes directly from the solid to the gas phase (carbon dioxide, $CO_2$, is a common example: Solid $CO_2$ is called "dry ice") ; **Condensation** is the path of a substance going from gas to liquid, **vaporization** is its opposite.

The diagram has two points of extreme interest. One is the **Triple Point**, the P-T value at which the solid, liquid and gas phases simultaneously exist. For water it is (P,T) = (4.58 mm of Hg, 273.16 K). The other is the **Critical Point**, the P-T value beyond which the difference between the liquid and gas phases vanishes; at which density of both phases become same. For water It is (P,T) = (218.3 atmospheres, 647.4 K).

The path for going to and from the liquid and solid phases, **melting** and **fusing**, require special attention because *water behaves differently* from all other substances. Unlike most substances, when the pressure on ice (solid water) increases and crosses the fusion curve , the ice melts to become liquid . This is why you slip on ice: You are actually walking on water, not ice. As you put your foot down on the ice, you raise the pressure on ice, if it crosses the fusion line, it melts. This is also the secret behind ice skating. The coefficient of friction for ice with many other substances is quite high, about 0.5 or so. Hence at P-T ranges where the ice does not melt (does not cross the fusion curve), you will not slip.

### 16.11.3 Phases and Heat.

When heat is added to a substance, the substance undergoes a variety of behaviors. The picture below illustrates the behavior of a substance, when starting a solid, has heat is added at a constant rate by a constant rate heat. The because the constant rate heat, the time translates to heat by Heat added = source watts(J/s) x time.




Starting as a solid, its temperature rises. Since the heat source is adding the same amount of heat per unit time, the slope of this curve divided by the mass is the specific heat of this substance. At some temperature, the temperature stops rising as heat is added. After a while, the substance has completely become a liquid, and the temperature starts to rise again. The substance has undergone a change in phase - from solid to liquid. The temperature at which the transition took place is called the **Melting Point**. The heat added during this transition, determined by the time that it took, is called the **Heat of Fusion, $L_f$**.

As a liquid, the temperature steadily rises, with its slope representing the specific heat of the substance as a liquid. At a temperature called the **Boiling Point** the temperature stops rising as the substance transforms from a liquid to a gas. The heat added during this transition is call the **Heat of Vaporization, $L_v$**.

Finally, as a gas, the temperature steadily rises, with its slope representing the specific heat of the substance as a gas.

If the substance starts as a gas and eventually becomes a solid, it will follow the same graph, but in reverse. On this path it liberates heat instead of absorbing heat.

**$L_{f\ Water}$ = 334x10$^3$J/kg** - it takes as much heat to melt 1 kg of ice as to raise the temp of 1 kg of water 80 °C, or conversely, it takes as much heat to freeze 1 kg of ice as to cool the temp of 1 kg of water 80 °C.

**$L_{v\ Water}$ = 2256x10$^3$ J/kg** -it takes 5.38 times as much heat to boil 1 kg of water as to raise the temp of 1 kg of water by 100 °C, from ice-water to water-steam, or conversely, it takes 5.38 times as much heat to condense 1 kg of water as to cool 1 kg of water by 100 °C, from steam-water to water-ice .

**Fusion and Vaporization Data for a few substances**

| Substance | Fusion Normal Melt Temp | | Heat of Fusion, $L_F$ | Vaporization Normal Boiling Temp | | Heat of Vaporization $L_V$ |
|---|---|---|---|---|---|---|
| | °K | °C | $10^3$ J/kg | °K | °C | $10^3$ J/kg |
| Helium | 13.84 | -259.31 | 5.23 | 4.216 | -268.93 | 20.90 |
| Nitrogen | 63.18 | -209.97 | 25.50 | 77.34 | -195.81 | 201.00 |
| Water | 273.15 | 0.00 | 334.00 | 373.15 | 100.00 | 2256.00 |
| Lead | 600.5 | 327.35 | 24.50 | 2023 | 1749.85 | 871.00 |
| Silver | 1223.4 | 950.25 | 88.30 | 2466 | 2192.85 | 2336.00 |

**Note**: In the above curve, the in-phase curve is not exactly a straight line with constant slope because the specific heat various a little bit with temperature.

### 16.11.4 Cooling By Evaporation and Other Such Processes.

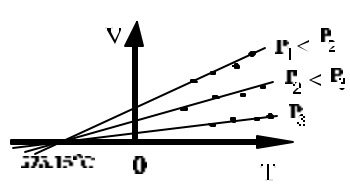
Whenever matter changes state it either liberates or absorbs heat. If a mass of that matter is in an environment that has neither heat sources or sinks, the temperature of that environment will increase when the mass of matter liberates heat, and will decrease when the mass of matter absorbs heat.

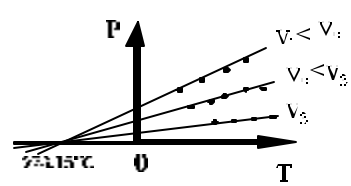
Cooling by evaporation is an important example of this situation. Many warm blooded animals maintain their body temperature by perspiring. For humans water evaporates though the pores. Each kilogram of water that vaporizes through our pores takes 2.256 x 10$^6$ Joules (539 Calories) from our body and transfers it to the local environment around us. This is why a room full of people can get quite hot and humid (sticky).

Another example of this process is the slight rise in temperature of the air just before a snow storm. Each kilogram of water vapor solidifies into snow flakes liberates 2.256 x 10$^6$ Joules (gas-> liquid) plus 334 Joules (liquid -> solid).

## 17. The Ideal Gas

Historically, the idea of the ideal gas model and of absolute temperature grew from a series of experiments shown in the two figures at the right. The first, a sample of gas was kept at various fixed pressures, $P_1$, $P_2$, etc. In each case the



temperature was varied and the volume measured. At each fixed pressure the points fitted a straight line that passed through the point -273.15 $^{o}$C. The seond, a sample of gas was kept at various fixed volumes, $V_1$, $V_2$, etc. In each case the temperature was varied and the pressure measured. At each fixed volume the points fitted a straight line that passed through the point -273.15 $^{o}$C. . This was found to be true for all gases when the temperatures of the data points were above the temperature at which a gas would tend to form liquid droplets - say 30 to 50 $^{o}$C above the boiling point of the given gas.

The temperature -273.15 $^{o}$C was then called the ideal gas temperature. At that temperature gas volume and pressure both shrank to zero. The zero pressure meant that all molecular motion had ceased. Further work in thermodynamics, especially by Kelvin, Maxwell and Boltzmann during the mid and latter 19$^{th}$ century, proved this temperature to more fundamental than just for ideal gases. It was the "universal" absolute zero. In the twentieth century this absolute temperature scale was renamed the Kelvin Scale in honor of Kelvin.

The idea gas is a model for gases at high temperatures. The ideal gas is characterized by the formula, called the Ideal Gas Law.

$$PV = nRT = NkT ,$$

where P is the pressure of the gas, V is its volume, T its temperature, n the number of moles, R the Universal Gas Constant (8314 J/kmole K = 1.987 kcal/kmole K) , N the number of molecules and k is Boltzmann's Constant (1.3805 x $10^{-23}$ J/K) , and

$$N = n/N_A ,$$

$N_A$ is Avogadro's Number, (6.0225 x $10^{26}$ molecules/kmole), the number of molecules in a kilomole of substance.