Changing Temperature and States of Matter in Materials

• There are *3 Classical States of Matter: SOLID, LIQUID and GAS*. In Modern Physics, we can add two more: *CRYOGENIC* (extremely odd behaviors at extremely low temps) and *PLASMA* (very high temperatures where we rip the electrons from the gas molecules or atom and make them into highly charged ions).

• To change the temperature of a material while keeping it in the same state, we need to add (or remove) heat energy Q to the material, which has a *heat capacity, C,* or a *specific heat, c,* (heat capacity per mass) that is based on the material and the state it is currently in. Our equation is $Q = mc\Delta T$. Since we are looking at a change in temperature, you can use either °C or Kelvins for your temperatures.

• A change in state of matter occurs at a single temperature. For example, a melting ice cube appears wet because it consists of water in both solid and liquid forms at 0°C. If the ice cube was at T < 0°C, it would not be melting, and if it were at T > 0°C, it couldn't be ice (all this at 1 standard atmosphere pressure = 101,300 Pa).

• To change from solid to liquid (or back) we have to add (or subtract) energy based on the *latent heat of fusion*, L_f, of the material. $Q = mL_f$.

• To change from liquid to gas (or back) we have to add (or subtract) energy based on the *latent heat of vaporization*, L_v, of the material. $Q = mL_v$.

Problem: Suppose we wish to turn a 1.00 kg block of ice at T = -20°C into 1.00 kg of steam at T = 100°C.

Step 1: Heat ice from -20° C to 0°C.

$$Q = mc\Delta T = (1.00\text{ kg})(2090\text{ J/kg}\cdot°\text{C})(+20°\text{C}) = 41{,}800\text{ J}$$

Step 2: Melt ice into water at 0°C.

$$Q = mL_f = (1.00\text{ kg})(333{,}000\text{ J/kg}) = 333{,}000\text{ J}$$

Step 3: Heat water from 0°C to 100°C.

$$Q = mc\Delta T = (1.00\text{ kg})(4186\text{ J/kg}\cdot°\text{C})(+100°\text{C}) = 418{,}600\text{ J}$$

Step 4: Boil water into steam at 100°.

$$Q = mL_v = (1.00\text{ kg})(2{,}260{,}000\text{ J/kg}) = 2{,}260{,}000\text{ J}$$

Total Energy to Vaporize the Block of Ice

$$41{,}800\text{ J} + 333{,}000\text{ J} + 418{,}600\text{ J} + 2{,}260{,}000\text{ J} = 3{,}053{,}400\text{ J}$$

Time for Each Step

If we use a stove that runs at *1000 W*, then *1000 J per second* of heat energy is being added to the water. So the largest time is the 2260 seconds (37 minutes 40 seconds) to boil the water into steam at 100°C. This helps explain why pots of boiling water are useful for cooking – because

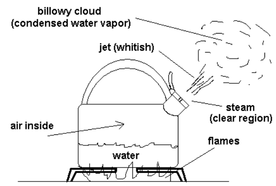
you can work at a uniform temperature for a long period of time before the water boils away. In contrast, it takes 418.6 seconds (just under 7 minutes) to heat water from freezing to boiling. And a mere 41.8 seconds for the ice to go from deep freeze to the melting temperature, which is why ice cubes start melting right away when you take them out of the freezer.

2,260,000 Joules per kilogram

That the latent heat of vaporization is so high for water helps explain why firemen pour water on a fire. They're not drowning the fire, they're turning the water into steam and robbing the fire of heat energy, cooling it. Only when the fire is cooled below its ignition point does the water make it all the way down to where it can "drown" the fire.

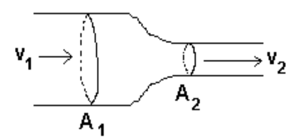
A Safety Issue!

In a whistling steam kettle, many people mistake the billowy white cloud for steam. But the cloud is cool and damp – it is condensed water vapor. Steam is gaseous water, and is clear. There should be a gap between the hole in the kettle's cap and the start of the white jet. This clear region is the steam, and though you can't see it, it can burn you quite severely. Don't pass your finger through the clear region!



Bernoulli's Law (Consequences)

• Bernoulli's Law has consequences all over the place. Take our Continuity Equation diagram. If you narrow the pipe, the speed of the liquid has go faster. But, if the pipe doesn't change, then for Bernoulli's to work, then the *Pressure* has to *drop* when the liquid speeds up.



• In Physics, we often talk of the *3 Classical States of Matter (Solid, Liquid, Gas)*. But liquids and gasses have some similar properties – these joint properties describe the action of *fluids*. (Similarly, solids and liquids have some similarities as *condensed matter*.) Since Bernoulli's and the Continuity Equations describes the actions of *fluids*, they work with both liquids and gasses. (For that matter, they describe fluidized solids like grain or sand, too.) This has uses all over the place, from why airplanes work (Whatever the cross-sectional shape of the wing, for smooth air flow, the air going over the top path must meet the air going along the bottom path. Therefore the top air must be going *faster*. The pressure difference between top and bottom creates *lift*.) to why the Mackinac Bridge *isn't* a wing (the inside lanes are metal grates, which act like *spoilers* in the wing of a commercial jetliner – they *spoil* the lift by allowing air to flow from the high pressure side to the low pressure side) to why your shower curtain wants to stick to your leg while taking a shower (solutions include: using glass doors instead of a shower curtain, using a double shower curtain with an inner liner that allows air to flow through or punching small air holes in your shower curtain [not recommended if you want to live in domestic tranquillity]).