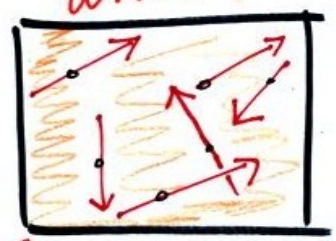
<u>Module 4 - Lecture 11</u>

When you add energy to an object and the object becomes warmer, what exactly is happening inside the object? Temperature provides a measure of the <u>average</u> kinetic of the atoms or molecules in a material. The atoms or molecules in a cold material will be moving more slowly than the atoms or molecules in a warmer object.

COLD

shorter arrows
lower speed motion
lower kinetic energy

WARM



longer arrows
higher speeds
higher kinetic energy

**Temperature is a measure of the <u>average</u> kinetic energy of the atoms or molecules in a substance. [need to be sure to use a temperature scale that does not go below zero]**

Kelvin scale

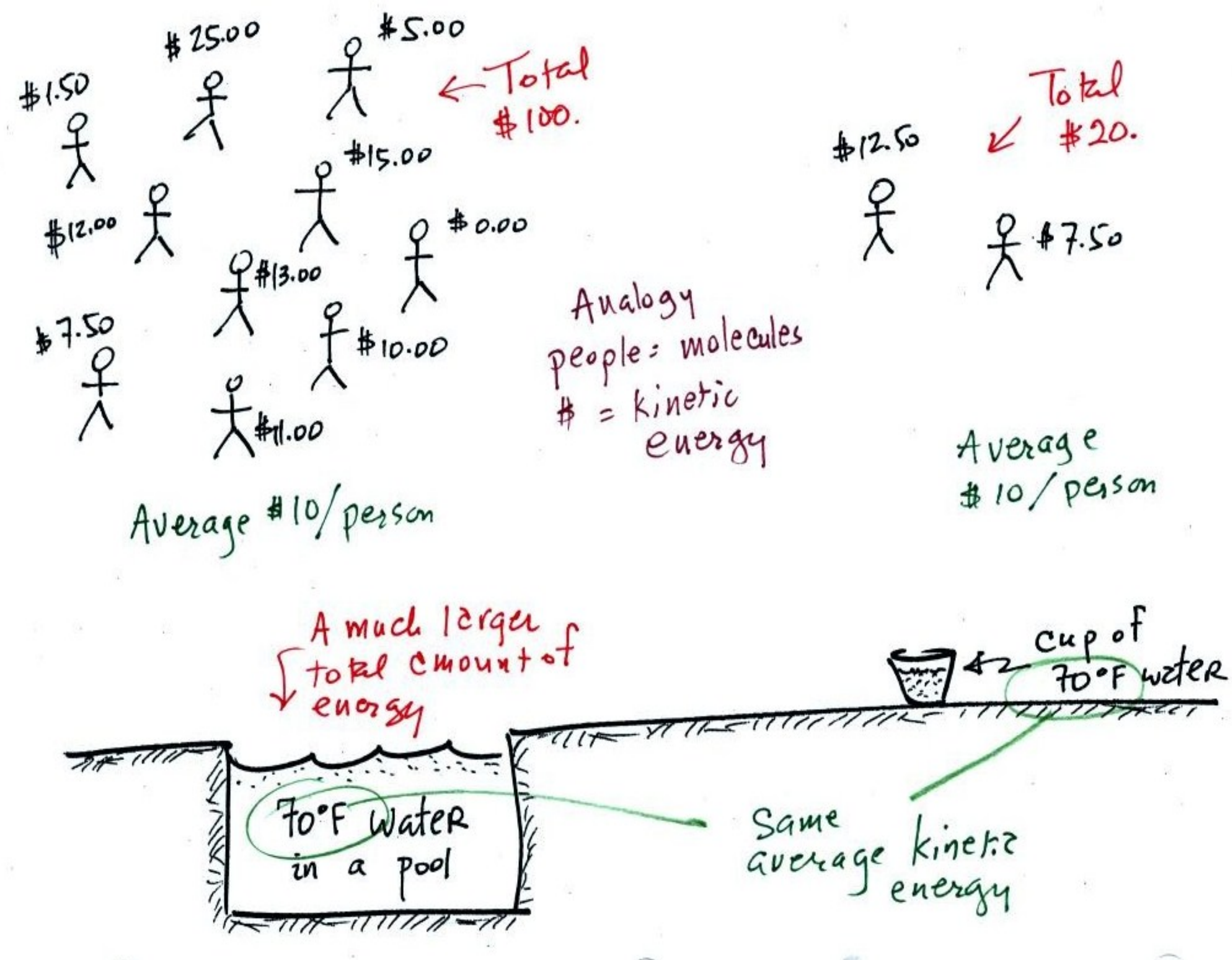
the smallest amount of kinetic energy possible is <u>zero</u> kinetic energy

energy of motion

Heat - Sum total kinetic energy of all the atoms or molecules in a material

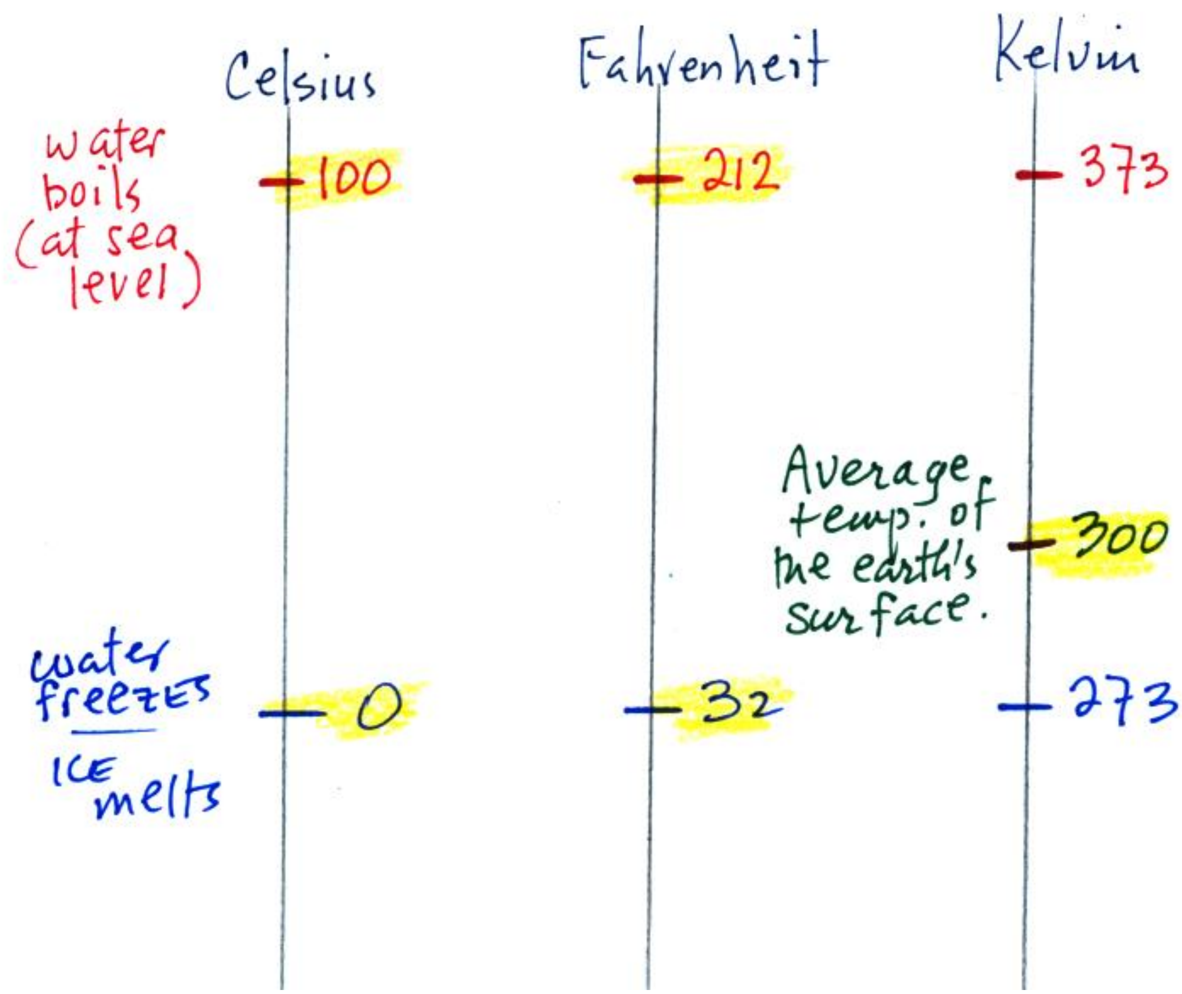
You can think of heat as the total kinetic energy of all the molecules or atoms in a material. The next figure should make the distinction between temperature (average kinetic energy) and heat (total kinetic energy) more clearly. The two groups of people in the figure have the same average amount of money per person, which is analogous to the average kinetic energy. The $100 held by the larger group at the left is greater than the $20 total possessed by the smaller group of people on the right. The total amount of money is analogous to heat.

A cup of water and a pool of water both have the same average kinetic energy because they are at the same temperature. There are a lot more molecules in the pool than in the cup. If you sum the kinetic energies of all the molecules in the pool you are going to get a much bigger number than if you sum the kinetic energies of the molecules in the cup. There is a lot more stored energy in the pool than in the cup and it would require more energy to cool (or warm) the water in the pool.

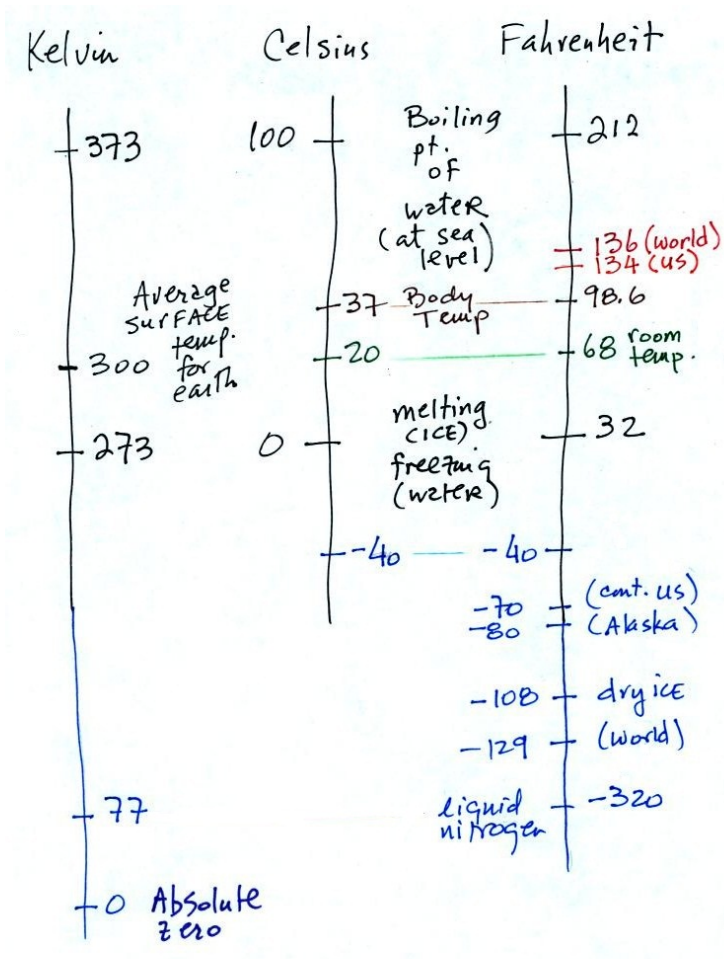


You need to be careful which temperature scale you use when evaluating the average kinetic energy. The zero value of the Fahrenheit and Centigrade scales does not correspond to zero kinetic energy and negative kinetic energy makes no sense physically. Zero degrees Kelvin is the temperature at which the average kinetic energy equals zero, a point called ***absolute zero***. The interval of the Kelvin scale is the same size as the Centigrade interval. To convert Centigrade to Kelvin, add 273. For example, room temperature is about $20^0$C and $293^0$K.

The following figure compares the three temperature scales. You should remember the temperatures of the boiling point and freezing point of water on the Fahrenheit, Celsius, and perhaps the Kelvin scales. $300^0$K is an easy-to-remember value for the global annual average surface temperature of the earth.



The following picture illustrates more temperature values using the three temperature scales. You certainly do not need to try to remember all these numbers. The world high temperature record was set in Libya and the US record in Death Valley. The continental US cold temperature record of -70$^0$F was set in Montana and the -80$^0$F value in Alaska. The world record -129$^0$F was measured at Vostok station in Antarctica. This unusually cold reading was the result of three factors: high latitude, high altitude, and location in the middle of land rather than being near or surrounded by ocean. The lowest temperature in this figure is liquid nitrogen at 77$^0$K. This is very cold but still quite a bit warmer than absolute zero.

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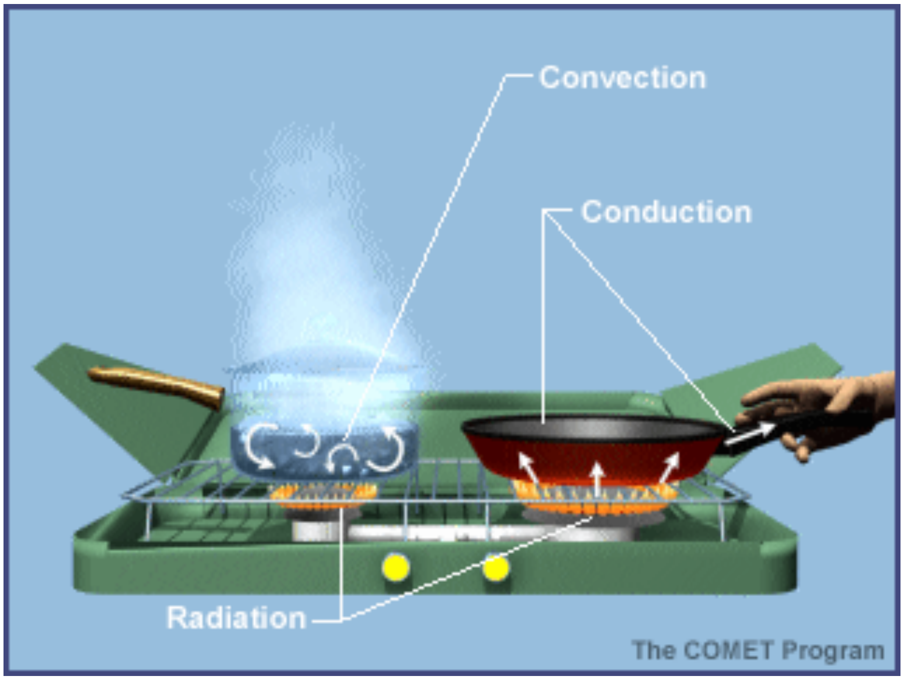
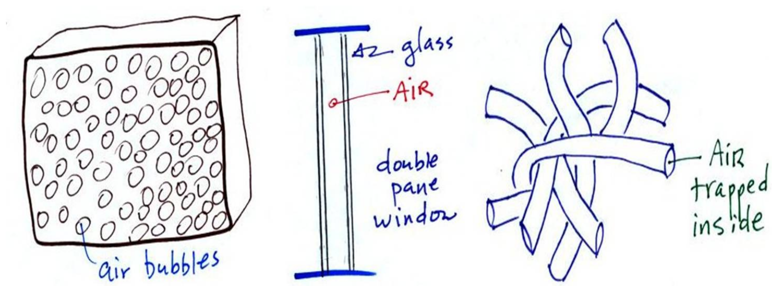
In this section we will discuss conduction and convection. ***Conduction*** is the process by which heat energy is transmitted through contact with neighboring molecules. ***Convection*** is the transport of heat energy by the movement of groups of molecules, such as the bubbles observed in boiling water. Convection can occur in liquids and gases but not solids. Conduction and convection are illustrated in the figure below (from www.ucar.edu/learn).



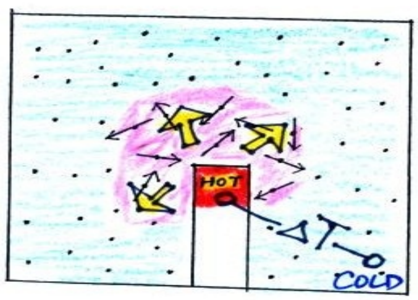

The rate of energy transport through conduction depends upon the material. Metals are generally very good conductors. Cooking pans are often made of stainless steel with aluminum or copper bottoms to evenly spread out heat when placed on a stove. Diamonds have a very high thermal conductivity. Diamonds are sometimes called "ice" because they feel cold when you touch them. The cold feeling is due to the fact that they conduct energy very quickly away from your warm fingers when you touch them.

The rate of energy transport also depends on the temperature difference. If the temperature difference is large, the energy flow into the surrounding material is greater than for small temperature differences.

Air is such a poor conductor of energy that it is generally regarded as an insulator. It is important, however, to keep the air trapped in small pockets or small volumes so the air cannot transport energy by convection. The picture below illustrates some examples of how air can be used as an insulator. Foam is filled with lots of small air bubbles that serve as an insulator and Hollow fibers (Hollofil) filled with air is used in sleeping bags and winter coats.. A thin, insulating layer of air is used in a double pane window.



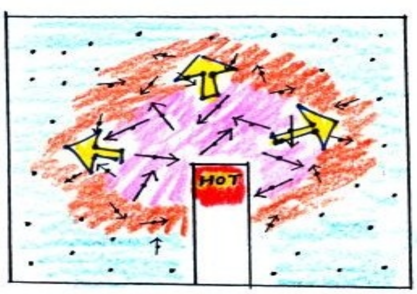
The following figure illustrates the process of conduction in the atmosphere. A hot object is in contact with air. In the top picture some of the atoms or molecules near the hot object have collided with the object. The air molecules acquire energy from the object and their speed or average kinetic has increased (the pink zone of this figure). In the middle picture, the energetic molecules have collided with some of their neighbors and shared energy with them (orange zone). The average kinetic energy of the orange zone is lower than the average kinetic energy of the pink zone. In the third picture, molecules further out have also gained some energy (yellow zone). To summarize, through random motions and collisions between molecules, energy has been transported from the hot object into the atmosphere.




1st of 4 energy transport processes.

CONDUCTION

energy gets transported from HOT to COLD by the random (haphazard) motions of atoms or molecules in a material (solid, liquid, or gas)



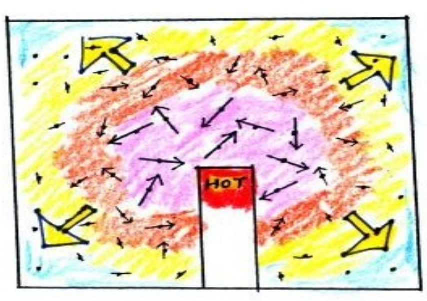

rate of energy transport depends on:

① temp. difference or gradient

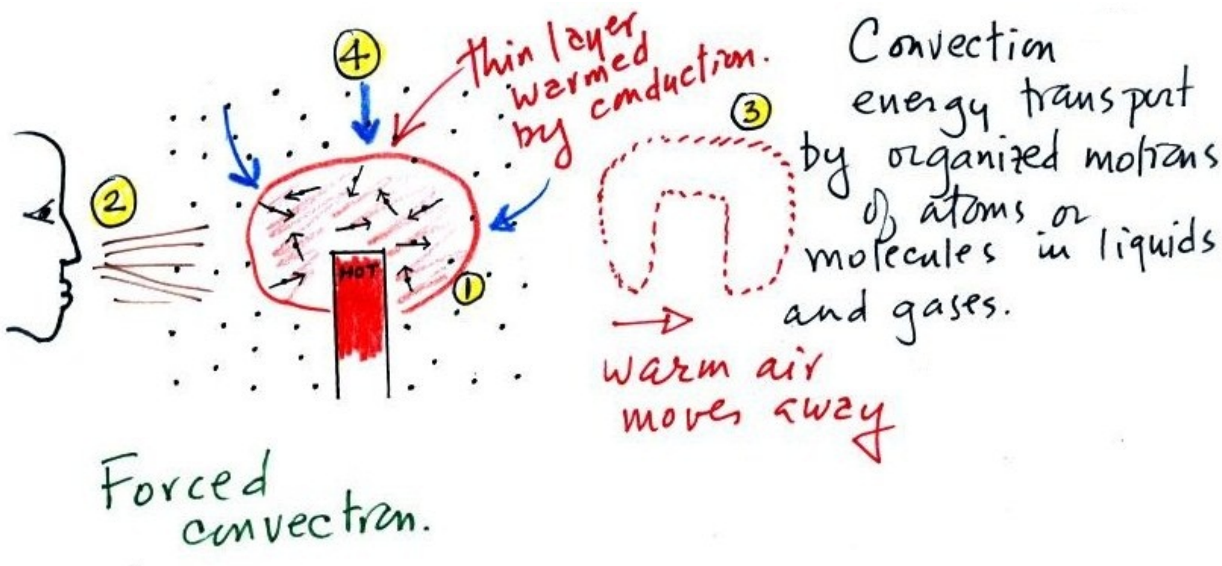
② material

Thermal Conductivities of some common materials

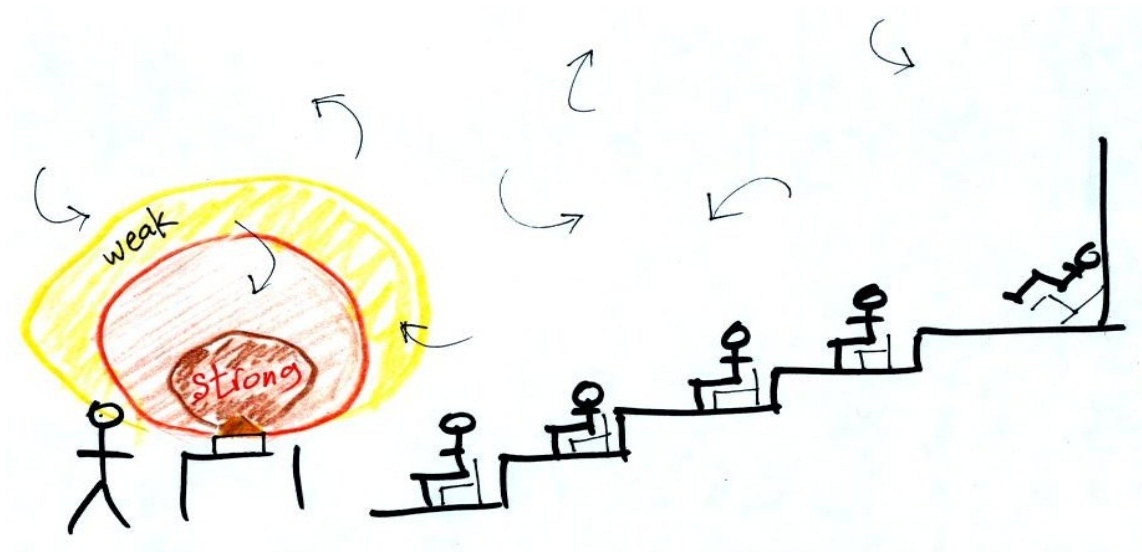
| | | |
|---|---|---|
| has a nickname: ICE | diamond | 1000 - 2600 |
| ↑ | Silver | 406 |
| good | Copper | 385 |
| ↓ | Aluminum | 205 |
| | Steel | 50 |
| | Mercury | 8 |
| | Glass | 0.8 |
| better than air | Water | 0.6 |
| poor | Air | 0.02 |



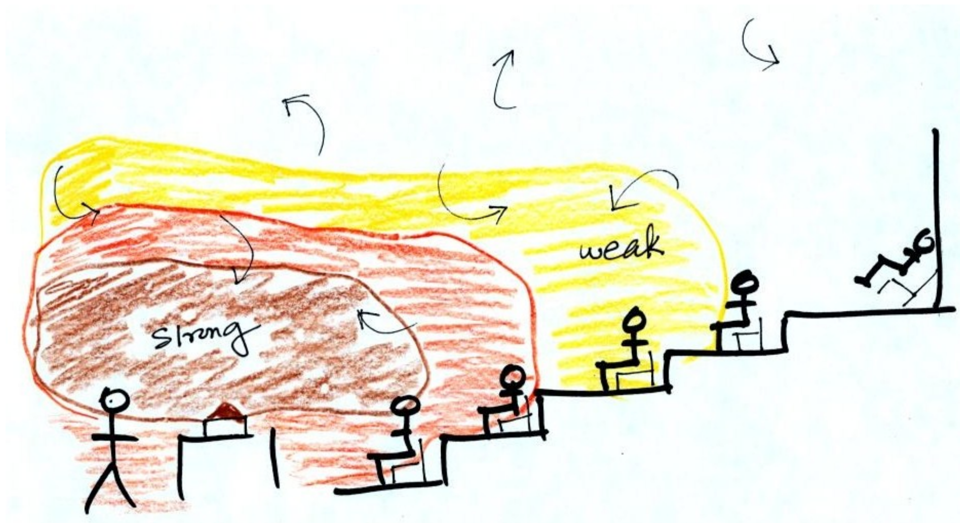
The figure below illustrates how the processes of conduction and convection work together to transport energy in the atmosphere. At Point 1, a thin layer of air surrounding a hot object has been heated by conduction. Then at Point 2 a person is blowing the blob of warm air off to the right. The warm air molecules are moving away at Point 3 from the hot object together as a group (that's the organized part of the motion). At Point 4 cooler air moves in and surrounds the hot object and the whole process can repeat itself.




In the classroom version of this course, curry heated on a hotplate demonstrated the processes of conduction and convection. The instructor even mixed his own curry so that it would be more pungent than the curry found in most grocery stores. Initially the smell diffused through the air surrounding the hot plate, which is comparable to conduction. A small fan placed behind the hot plate created small eddies which transported the odor throughout the classroom.




With time and plenty of fresh curry, the smell spread throughout the classroom. Even the students in the back of the room could detect a faint hint of the curry smell.

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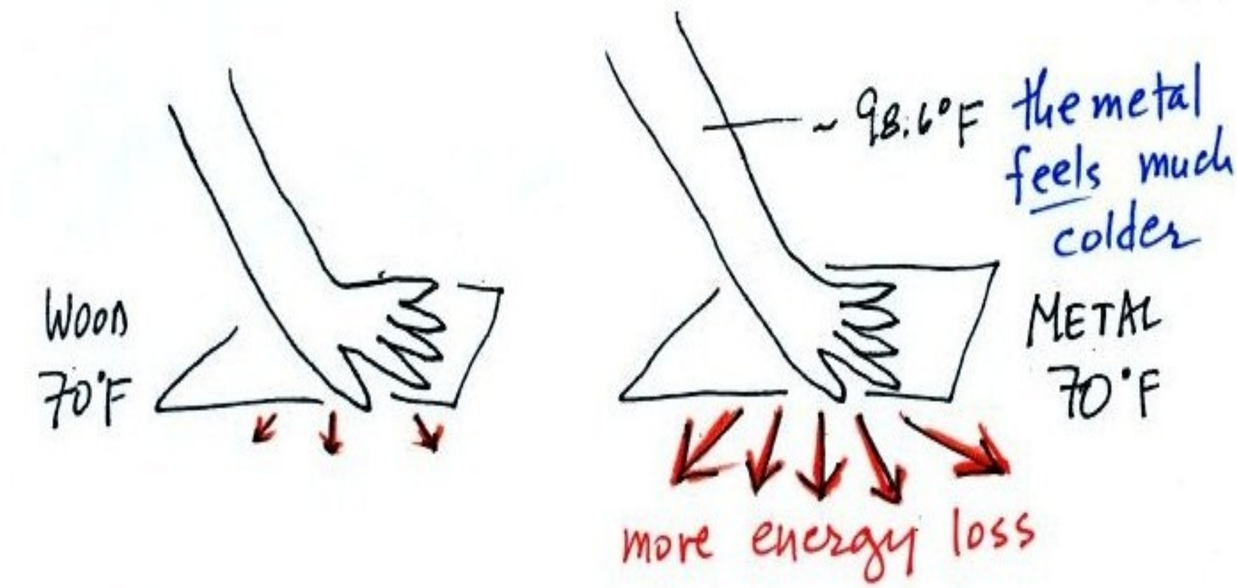
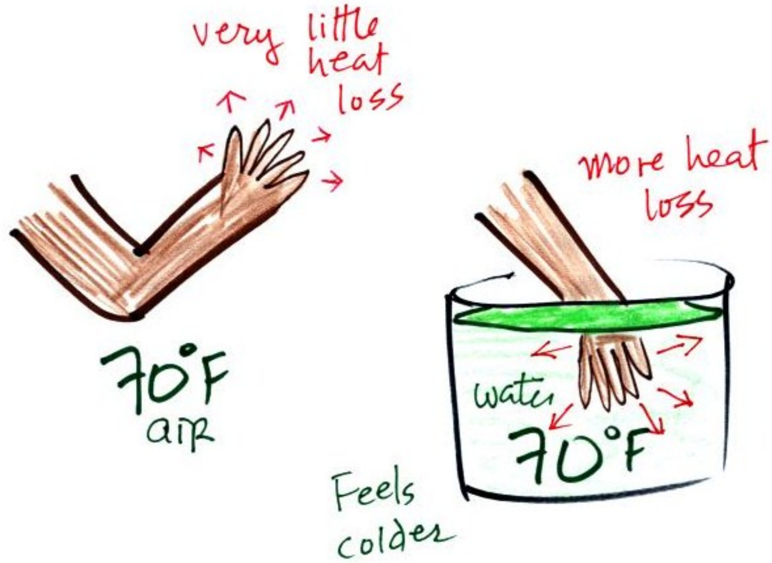
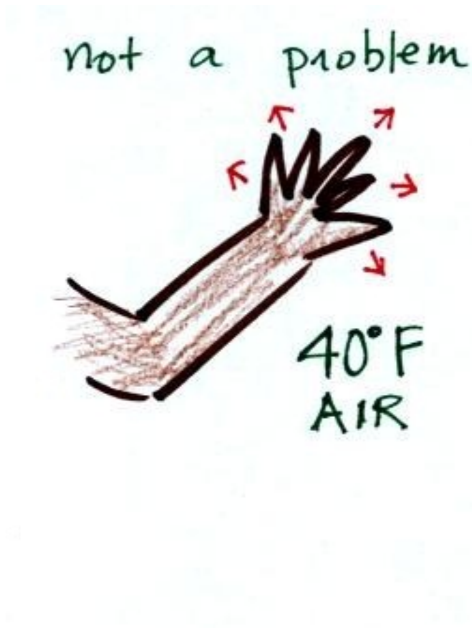
Now here are some practical applications of what we have learned about conductive and convective energy transport. Because there is a temperature difference between your hand and a $70^0$F object, energy will flow from your warm hand to the colder object. Metals are better conductors than wood. If you touch a piece of $70^0$F metal it will feel much colder than a piece of wood of the same temperature. Our perception of cold is more of an indication of how quickly our hand is losing energy than a reliable measurement of temperature.




Here is a another example. It is pleasant standing outside on a nice day in $70^0$F air. But if you jump into $70^0$F pool water you will probably feel cold, at least until you "get used" to the water temperature (your body might reduce blood flow to your extremities and skin to try to reduce energy loss).

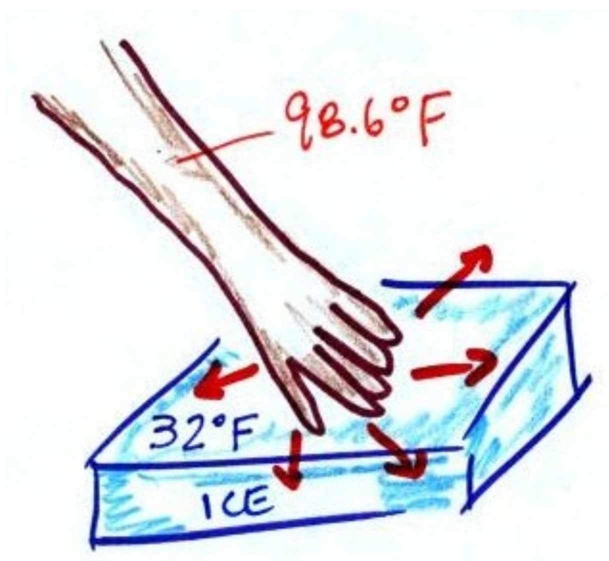



If you go outside in $40^0$F weather you will feel cold because of the large temperature difference between you and your surroundings (and temperature difference is one of the factors that affect rate of energy transport by conduction). If you stick your hand into a bucket of $40^0$F water, it will feel very cold and your hand will soon begin to hurt. Because water is a much better conductor than air, energy flows much more rapidly from your hand into the cold water.

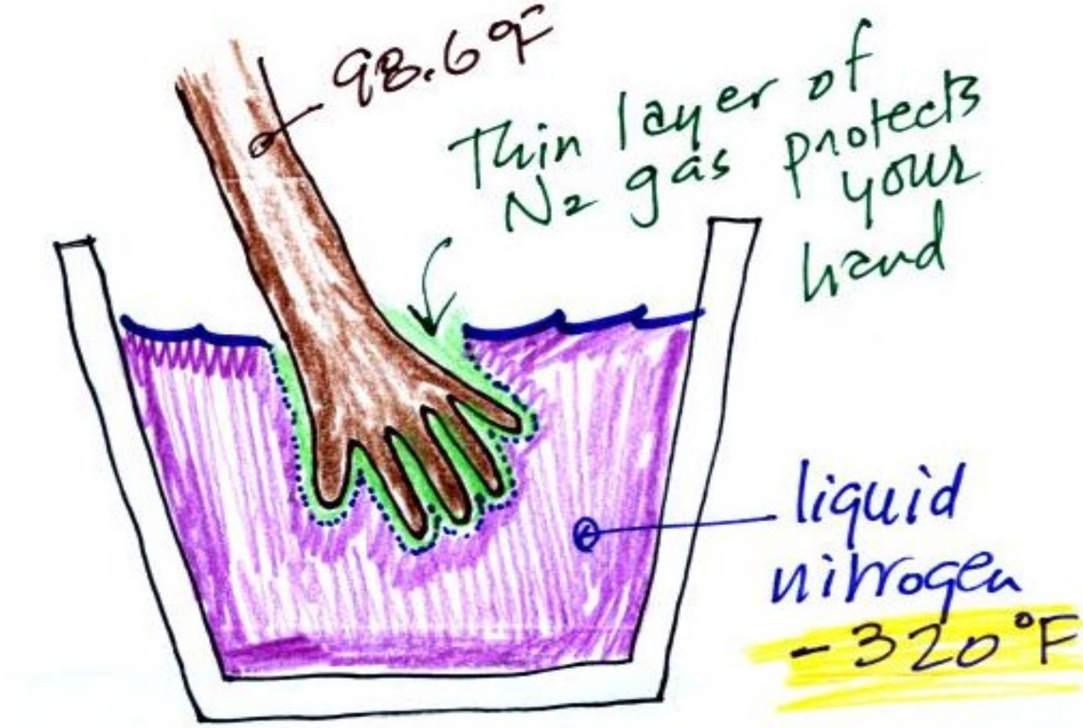




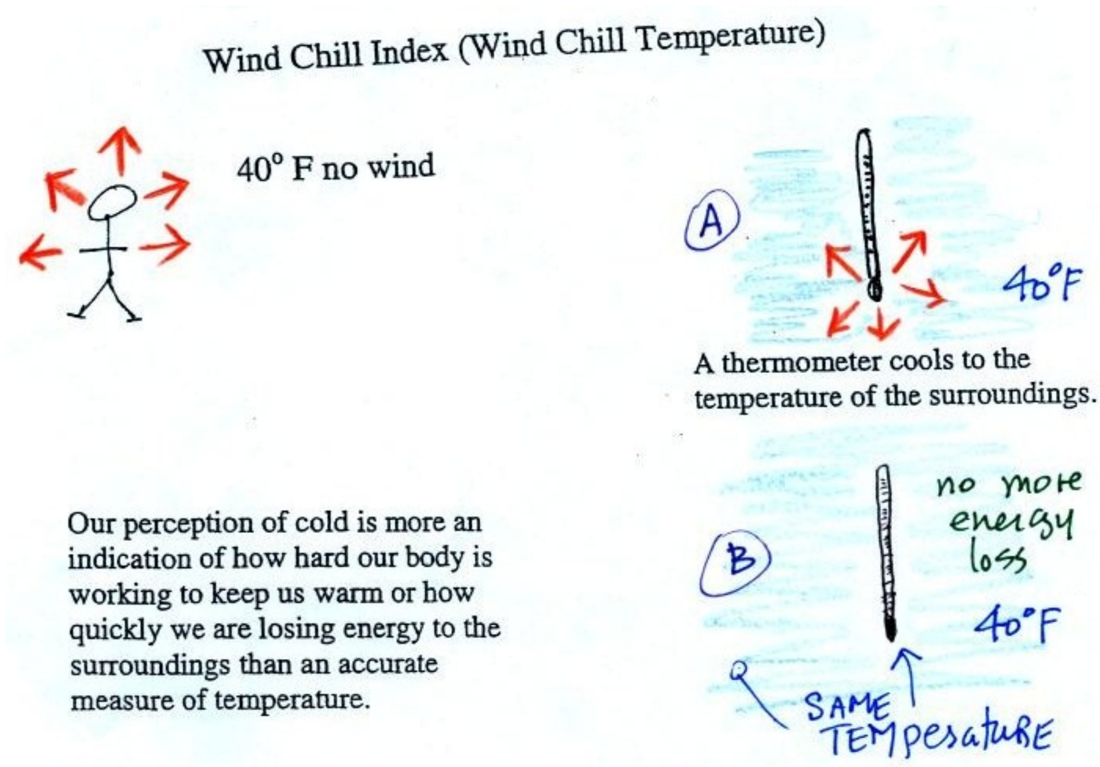
Ice feels cold even though it is not a particularly good conductor because of the large temperature difference between your hand and the water.



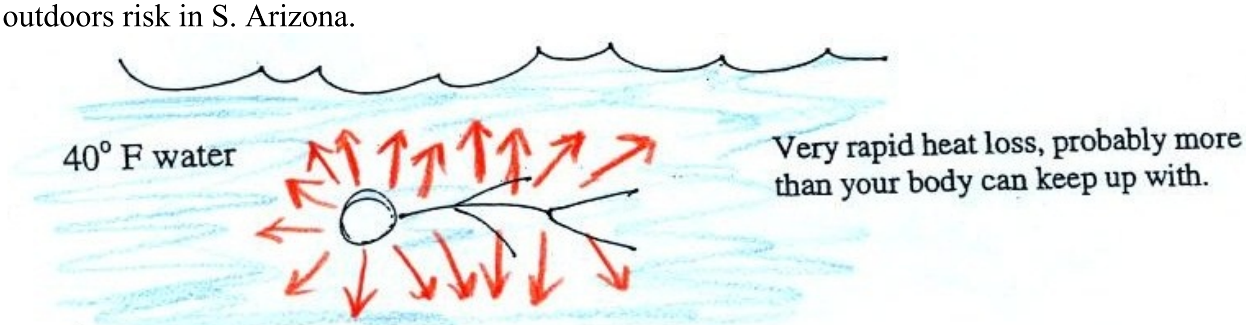

What about liquid nitrogen? It has a temperature of $-32^0$F! You can safely stick your hand in liquid nitrogen for a "split second". Your hand would not feel particularly cold and or wet because some of the liquid nitrogen quickly evaporates and surrounds your hand with a layer of nitrogen gas. This gas is a poor conductor and insulates your hand from the cold for a short time. (Do not try this experiment under any circumstances.)


98.6°F
Thin layer of N2 gas protects your hand
liquid nitrogen
-320°F

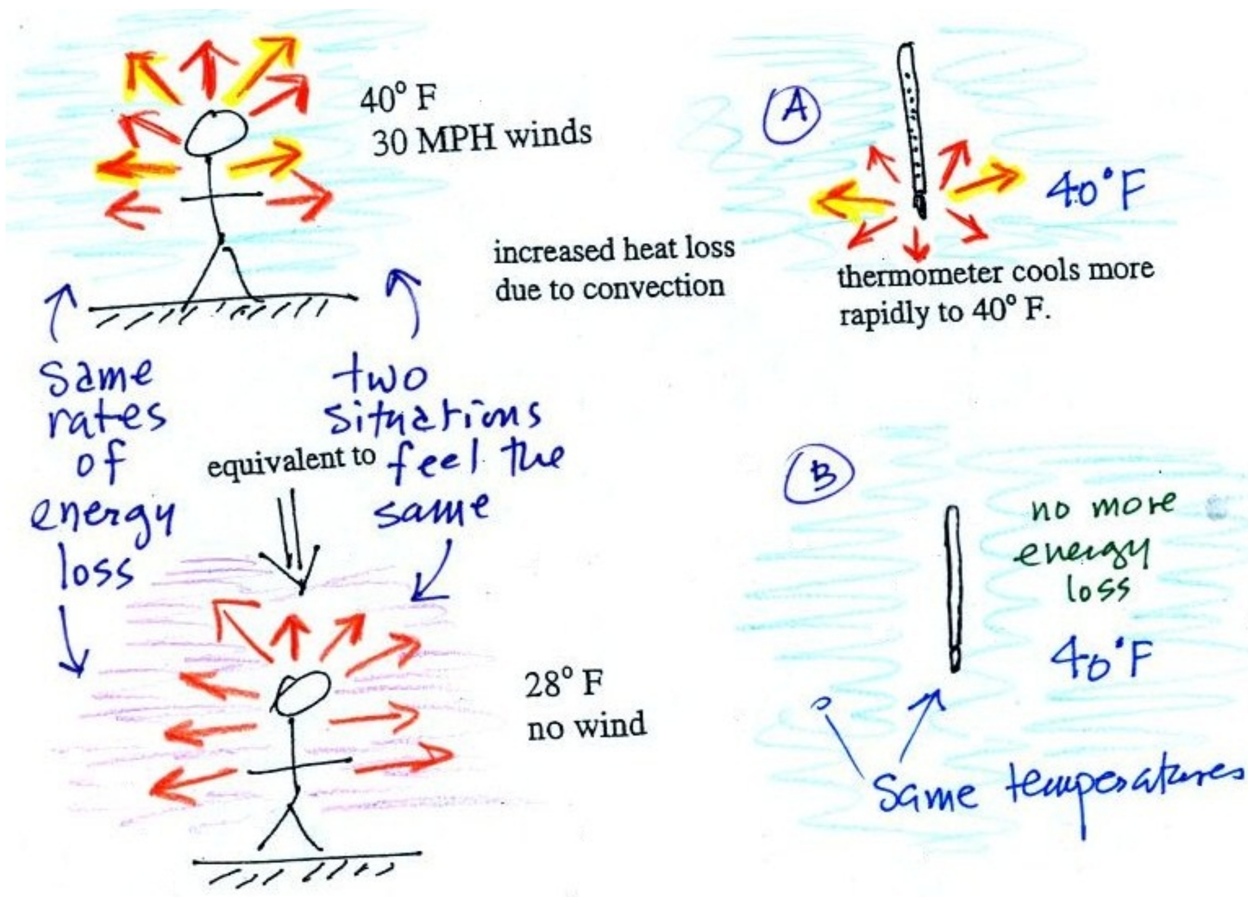
With this basic knowledge of conductive and convective energy transport, we are now able to understand the concept of wind chill temperature. Your body works hard to keep its core temperature around 98.6$^0$F. If you go outside on a 40$^0$F day with no wind you will feel cold because your body is losing energy to the colder surroundings primarily through conduction. If you wear a winter coat, your body will be able to keep you warm for a reasonable amount of time. For a person used to living in the frigid Midwest, 40$^0$F feels warm for a winter day.




Standing outside on a 40$^0$F day is not an immediately life threatening situation but falling into water of the same temperature would be. Water is a much better conductor of heat than air and energy will be conducted away from your body more quickly than your body can replace it. Your core body temperature will drop and bring on [hypothermia](). Be sure not to confuse hypothermia with [hyperthermia]() which can bring on heatstroke and which is also a serious outdoors risk in S. Arizona.



On a $40^0$F day with winds of 30 miles per hour, your body will lose energy at a more rapid rate because both convection and conduction are transporting energy away from your body. Note the additional arrows drawn on the figure below indicating the greater heat loss. The higher rate of energy loss will make it <u>feel</u> colder than a $40^0$F day with calm winds. You will actually be losing energy as if the temperature is $28^0$F with no wind, which means that the wind chill temperature is $28^0$F.

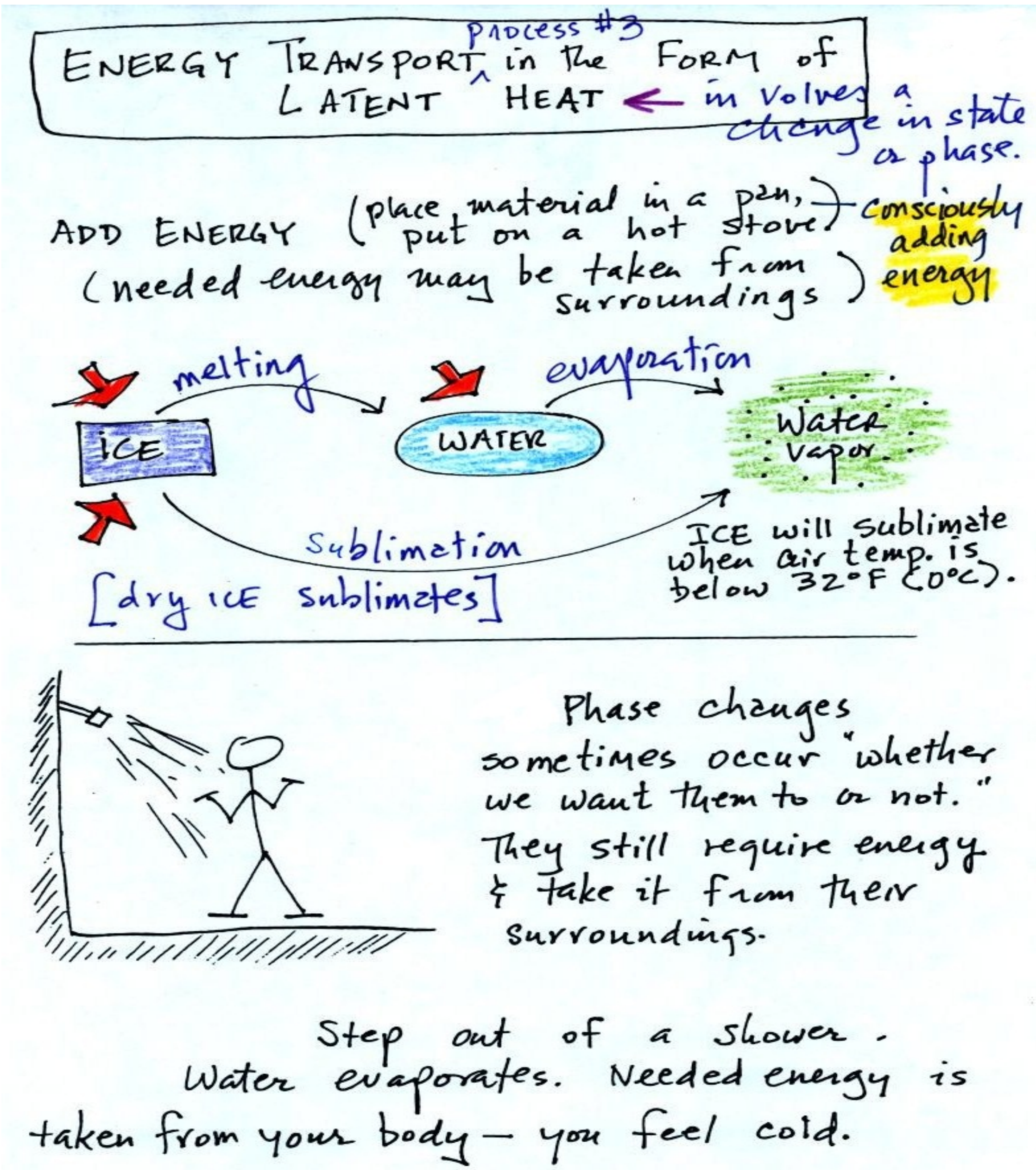



We will now discuss energy transport in the form of latent heat, the second most important energy transport process (second only to electromagnetic radiation).

Latent heat energy transport is sometimes a little hard to visualize or understand because the energy is "hidden" in water vapor and liquid water droplets. Latent heat is the energy released when water changes phase; water vapor condensing into liquid or the liquid water droplets in a cloud freezing.

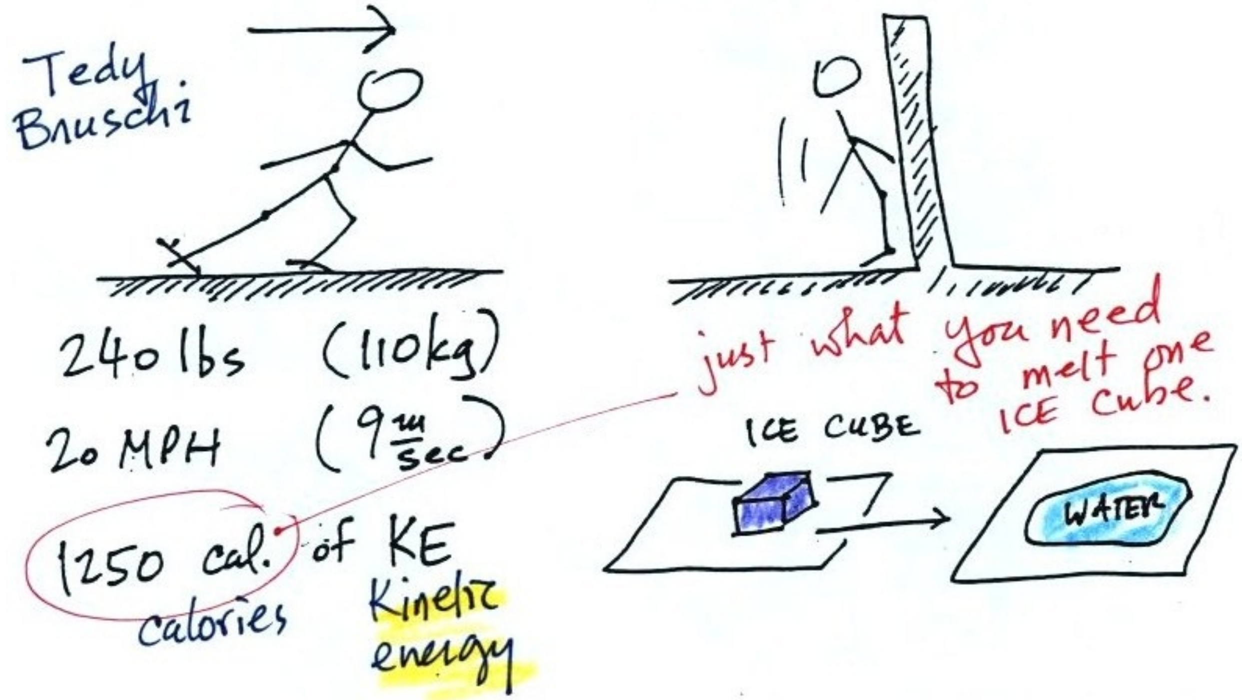
Water vapor can also freeze without become liquid first and ice crystals can evaporate without melting. This is called sublimation. A good example of sublimation is the frost that forms on the windshield on cold winter mornings. In the Midwest, scrapers are absolutely essential because this phenomenon happens almost every winter morning.

Energy is required for phase changes. You can consciously add or supply the energy (such as when you put water in a pan and put the pan on a hot stove) or the needed energy will be taken from the surroundings. When you step out of the shower in the morning, the water takes energy from your body and evaporates. Because your body is losing energy your body feels cold.



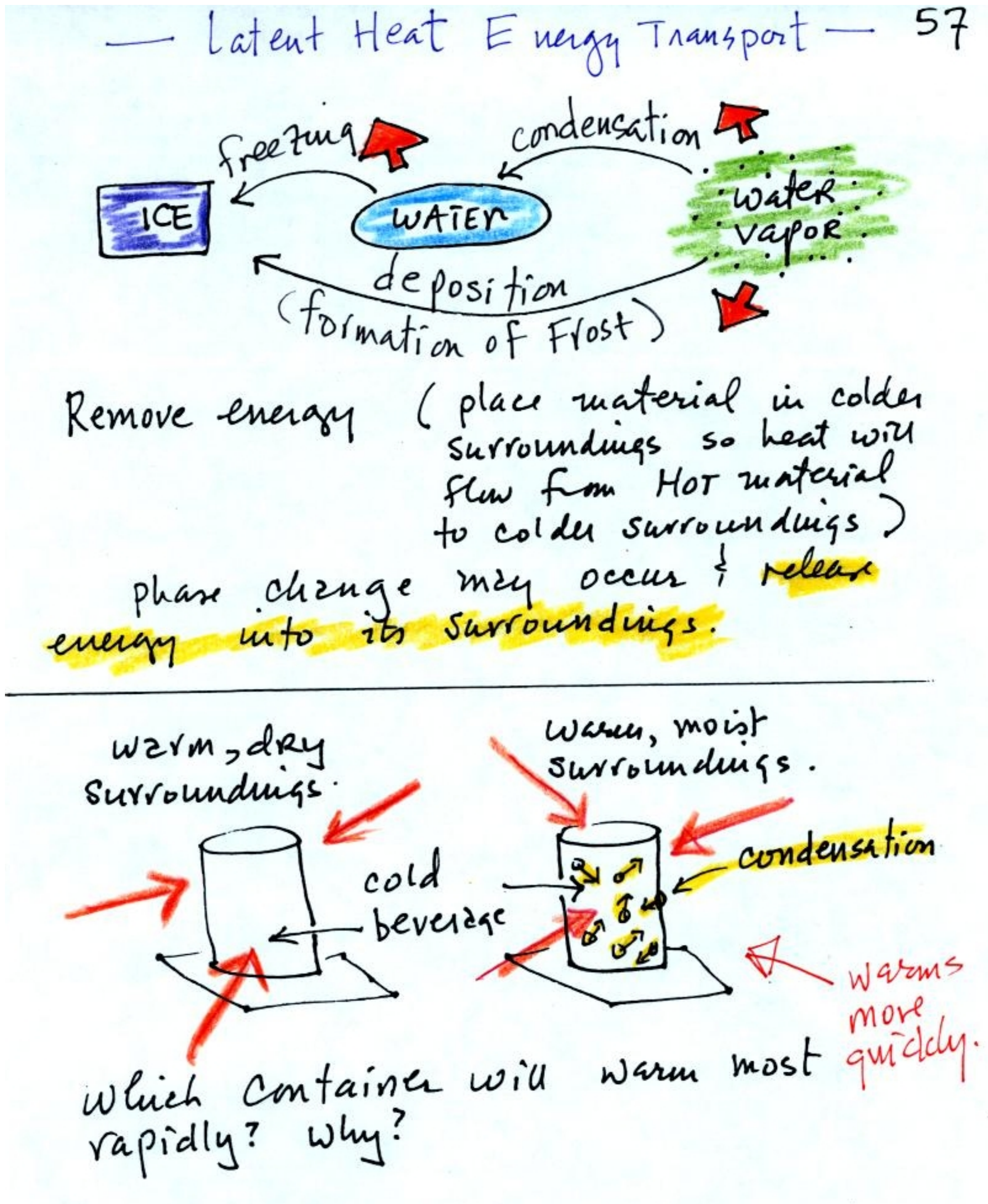
The purpose of this figure is to give you some appreciation for the amount of energy involved in phase changes. A 240 pound man or woman running at 20 MPH has just enough kinetic energy (if you could capture it) to be able to melt an ordinary ice cube. It would take 8 people running at 20 MPH to evaporate the resulting water. When you freeze water and make an ice cube, energy is released into the surroundings. You can picture the released energy as being a 240 lb person running at full speed.

There are ~~large~~ enormous amounts of energy involved in phase changes.

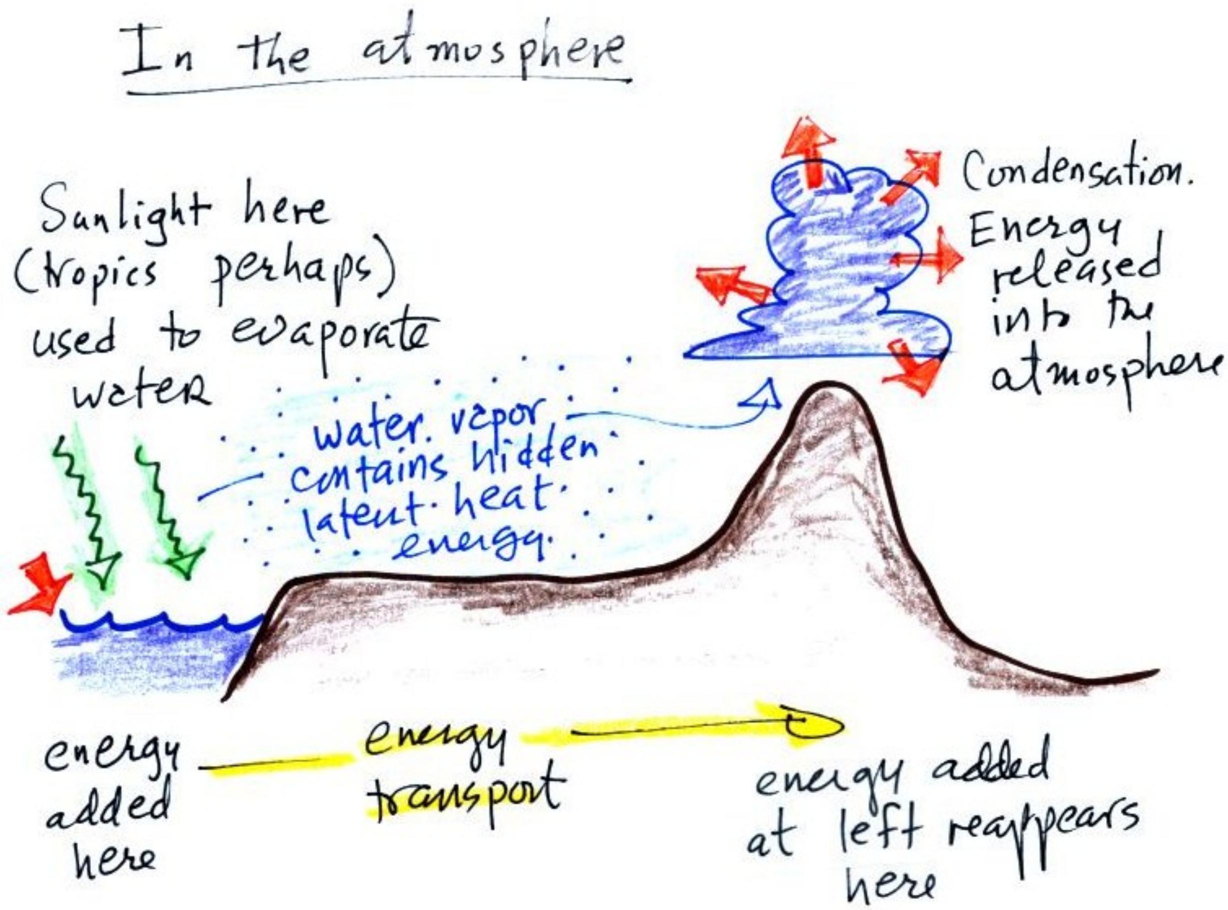



About 8 of these people would need to run into walls to give up enough kinetic energy to evaporate the water.

A can of cold drink will become warm more quickly in moist surroundings than in dry surroundings. In both cases, heat will flow from the warm air into the cold cans. Condensation of water vapor is an additional source of energy and will warm that can more rapidly. The condensation may actually be the dominant process.



This figure shows how the atmosphere transports energy in the form of latent heat. In the tropics, there is an abundance or surplus of sunlight energy. Some of the incoming sunlight evaporates ocean water, and the moist air travels north carrying latent heat energy. When the air is lifted by one of the four mechanisms we have discussed, the water vapor condenses and the latent heat energy is released.

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To summarize, there are four processes that transport energy in the atmosphere: latent heat, EM radiation, conduction and convection. EM radiation in the form of sunlight reaches the earth and the earth emits infrared radiation back into space. The atmosphere transports the energy from sunlight using the processes of conduction, convection and the latent heat of water vapor.

Latent heat is a very important means by which energy from the tropics is transported to the mid-latitude regions. Warm ocean currents such as the Gulf Stream also transport energy to the poles.