Workshop Tutorials for Introductory Physics

Solutions to TI3: **Heat Transfer**

A. Review of Basic Ideas:

Convection, conduction and radiation

Imagine a day at the beach, on a mild day with a maximum temperature of 25^{o}C. You find a nice sheltered spot in the dunes and lie on the sand for a while enjoying the sunshine. Even though it's not a particularly hot day after a while you get quite warm. This seems odd, because heat flows from **hot** regions to **cold** regions, and as your skin temperature is warmer than the air, it seems odd that you are getting hotter. To understand why you are getting hotter you need to consider the heat transfer processes that are occurring. You get hot because you are absorbing radiation from the **sun**. This is one way in which heat can be transferred. All hot bodies radiate heat, in proportion to their temperature. You can absorb a lot of **radiation** from the sun when the weather is cold, and lose heat to the air by **conduction**, convection and radiation quite quickly. When this happens you don't get hot even though you are absorbing a lot of radiation.

You decide to take a swim to cool off. When you get into the water it feels very cold, because your body quickly loses heat by conduction to the water. The water molecules in contact with your skin can absorb heat from your skin which is **conducted** away by the water.

The movement of the water also helps you cool off quickly. The water molecules can absorb heat as they get close to your skin, increasing their own kinetic energy, and then move away taking that energy with them. Convection involves a **flow** of material, while conduction and radiation involve a flow of **energy** (heat), but not matter.

If you lie very still in a rock pool so that the water hardly moves you feel a little warmer after a while, because the water around you has warmed up a bit, and is not being moved away by convection. A **wetsuit** also keeps you warm this way, by trapping a layer of water against your skin, and not letting it flow around. A wetsuit also works by decreasing conduction of heat.

B. Activity Questions:

1. Thermal conductivity

The blocks are all at room temperature. Your skin is usually a little warmer than room temperature, and when you touch something like metal it feels cold because heat is quickly conducted away from our skin by the metal. Wood and polystyrene are good insulators, and do not conduct heat away from your skin, hence they feel warm. What are you are really feeling when you feel for "temperature" is the rate at which heat is transferred to or from your skin.

2. "Stubby holder"

The stubby holder prevents heat loss by convection and conduction. When a wetsuit traps a layer of water it also prevents convection, as there is no longer a flow of water over the skin.

3. Thermos Flask

A thermos flask has double walls, which are evacuated and the vacuum bottle is silvered on the inside. The vacuum between the two walls prevents heat being transferred from the inside to the outside by conduction and convection. The silvered walls reflect radiated heat back to the inside, the same way a space blanket does.

4. Measuring air temperatures

A thermometer always measures its own temperature. If it is in the shade, it reaches thermal equilibrium with the surrounding air molecules and measures that temperature. When heated by the sun's radiation it measures its own raised temperature. The equilibrium temperature is greater than the air temperature.

C. Qualitative Questions:

1. You can make a "heat telescope" by putting the bulb of a mercury-in-glass thermometer in a paper cup lined with aluminum foil. On a cool, dry clear night you point the telescope at the sky. After a few minutes you read the thermometer. Then you point the thermometer at the earth for a few minutes and read the thermometer again.

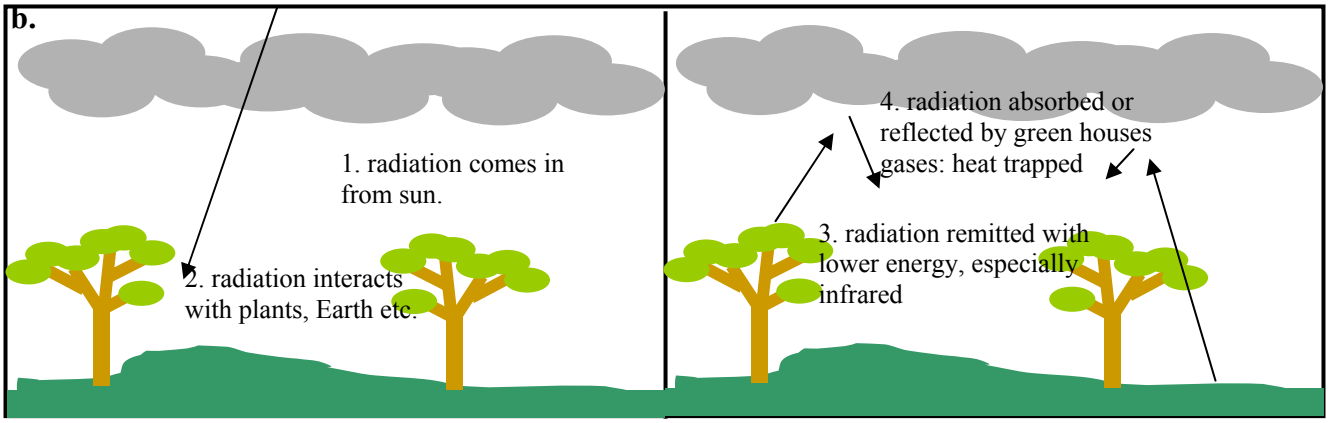
a. The thermometer will have a higher reading when pointed at the ground. This is because the Earth is hotter than the sky and hence radiates energy as infrared radiation. This radiation heats up the liquid in the thermometer and it expands, giving a greater temperature reading than when pointed at the sky.

b. The cup is lined with aluminum foil to reflect the incident radiation onto the thermometer. The cup acts as a radiation collector.

2. The greenhouse effect.

a. Greenhouse gases like carbon dioxide and methane in the atmosphere absorb energy which is radiated by the Earth's surface. These gases then radiate in all directions, so some radiation is absorbed back at the Earth's surface rather than being lost to space. In a glass greenhouse there is this effect of preventing radiation escaping, and also prevention of heat loss by convection, much as in a closed car. Note that this is quite different to the effect of ozone depleting gases (chloro-fluoro-carbons or CFCs), which break up ozone molecules which shield us from UV radiation.

b.



D. Quantitative Question:

A house has well insulated walls which are 0.32 m thick with a total area of 360 m^2, a roof of tiles 0.08 m thick and area 280 m^2, and (uncovered) glass windows, 0.85 cm thick with total area 42 m^2. The temperature inside the house is 22^0C and the outside temperature is 34^0C.

$k_{wall} = 0.25$ J.s^{-1}.m^1 .^{o}C^{-1}, $k_{tiles} = 0.55$ J.s^{-1}.m^1 .^{o}C^{-1}, $k_{glass} = 0.84$ J.s^{-1}.m^1 .^{o}C^{-1}

The rate of flow of heat, Q, in J.s^{-1}(= watts) across an area A of material with thermal conductivity k is given by $Q = kA(\Delta T/l)$ where ΔT is the temperature difference and l is the thickness of the material. The total heat flow into the room will be $Q_{total} = Q_{wall} + Q_{wood} + Q_{glass}$

$= (0.25)(360)\left(\frac{34-22}{0.32}\right) + (0.55)(280)\left(\frac{34-22}{0.08}\right) + (0.84)(42)\left(\frac{34-22}{0.0085}\right)$

$= 3375$ J.s^{-1} + 23100 J.s^{-1} + 49800 J.s^{-1} = 76 kJ.s^{-1} = 76 kW.

which is the heat to be removed to maintain the temperature at 22ºC. Note that most of this is due to heat loss from the uncovered windows, simply closing curtains or blinds can make a big difference to your heating or air conditioning bill!