TEACHING SCIENCE BY OCEAN INQUIRY
Heat and Temperature

Goals: The following activities address different aspects of heat and temperature. ***Activities 1-4*** (and the optional ***Activity #10***) demonstrate the 3 modes of heat transfer, namely conduction, convection, and radiation (absorption of radiation). ***Activities 5-6*** focus on the effects of temperature on volume and density. ***Activities 7-8*** (and the optional ***Activity #9***) focus on the concept of latent heat.

1. Conduction

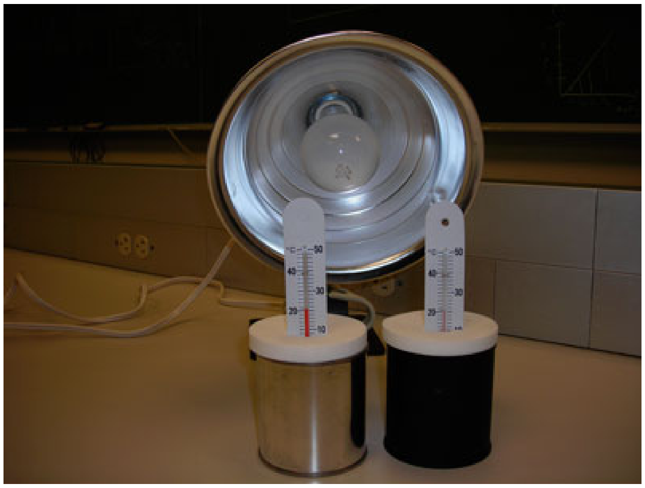
Materials:

- Three types of material at room temperature: wood, metal, and cloth

Instructions:

- All three materials on the desk have been at room temperature for quite a while. If you touch them, do you think they will all feel the same with respect to temperature? Predict whether some items will feel colder or warmer. Suggest possible explanations.
- Briefly place your hand on each type of material. Does it match your expectations in (a)? How would you explain your observations given that all items have been at room temperature?
- When and where do you think conduction comes into play in the ocean?

2. Absorption of Radiation



Materials (note: you can get a pre-made radiation kit at Sciencekit.com):

- Two same size cans, one black and one silver. The top lid of the cans should have a hole through which you can insert a thermometer
- Two thermometers
- A heat lamp

Instructions:

1. Observe the two thermometers; one immersed in a shiny tin can, the other in a black one. If the same light source shines on both cans, will the thermometers show the same temperature?
2. Turn on the light and observe the change in temperature. What so you see? How can you explain your observation?
3. Will the temperature increase forever or will a final temperature be reached? Why? Describe the different heat gain and loss mechanisms at play and how they depend on the temperature of the can.
4. Can you think of a way by which principles learned from this activity can be linked to absorption of electromagnetic radiation at the earth's surface and the regulation of earth's temperature?

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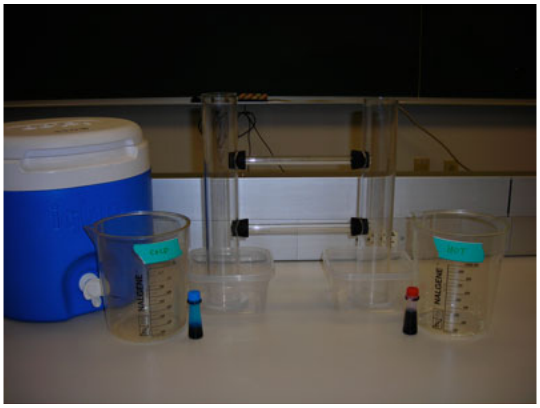
3. Convection

Materials:

- Convection set-up (science kit.com or homemade)
- Food coloring (2 colors)
- A container with ice water
- A container with hot water

Instructions:

1. Fill the apparatus with water. (Make sure there are no bubbles in the horizontal tubes).
2. What direction would you expect the water in the apparatus to flow through the horizontal tube if the left column of the apparatus were to warm up, and the right column of the apparatus were to cool down?
3. Place the left column of the apparatus in the container with the hot water and the right column in the container with the cold water. Add few drops of dye to the two columns (different color to each column) and observe whether the circulation in the apparatus agrees with your prediction.
4. What if you warm (cool) only one column of the apparatus? Try it.
5. What ocean process(es) can be demonstrated using this activity? Where does the analogy break down? How about the atmosphere?

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4. Convection under Ice

Materials:

- Blocks of colored ice
- A large transparent container for water
- Salt
- Ice cubes
- Two identical beakers, 1 filled with tap water and the other filled with salt water (both at room temperature)

Instructions:

1. What do you expect will happen to the colored water in the ice?
2. Place the block of ice in the container filled with freshwater. Compare your prediction with your observations. How could you explain your observations?
3. Would your observations be different if the tank contained salty water? Try it.

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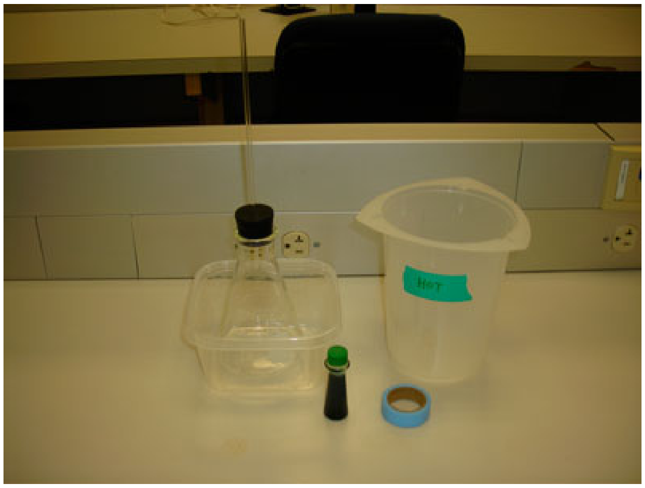
5. Thermal Expansion/ Water Thermometer



Materials:

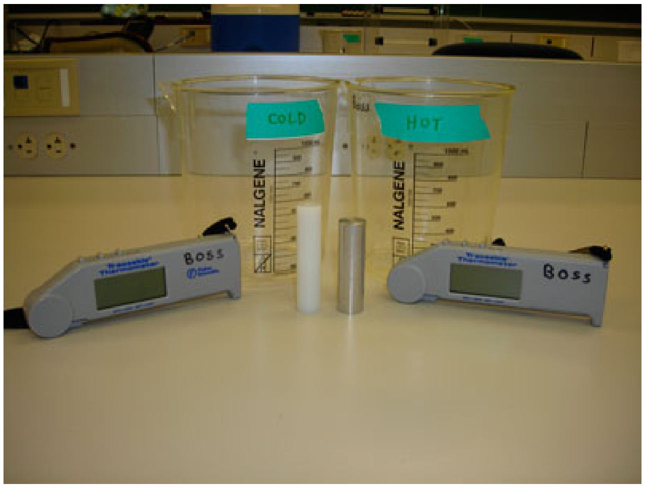
- A flask
- One-hole stopper
- A long glass tube
- A container filled with hot water
- Food coloring
- Lab tape

Instructions:

1. Fill the bottle with colored water. Push the stopper until the fluid rises 1/3 the length of the tube above the stopper. Mark the water level with tape.
2. What do you expect will happen to the water level in the tube when you place the flask in a container with hot water? Why?
3. Place the flask in a container filled with hot water. Mark the new water level. Does it agree with your prediction?
4. Apply what you have learned in this activity to predict and explain what will happen to the ocean's volume if it becomes warmer? What would be the implications to sea-level?
5. What other processes influence sea-level?

Challenge: Would the melting of land-based ice and floating ice have the same effect on sea level? Why? How would you demonstrate it to your students?

6. Effects of Temperature on Density



Materials:

- Two glass beakers: one filled with cold water (~6-15^{o}C) and one with warm water (~40^{o}C)
- A set of reverse density rods: 1 Aluminum rod, 1 plastic rod (from Arbor Scientific)
- Thermometer
- Ice (+ ice cooler to store ice)
- Hot plate (but hot tap water will work fine)

Instructions:

1. What will happen to the rods (float/sink) if you place them in a beaker with cold water? What is the reasoning behind your prediction?
2. Place the rods in the beaker with cold water. Make sure that no air bubbles are attached to the rods. Does your observation meet your prediction?
3. Observe the rods for a few minutes. What is happening?
4. Repeat this experiment, this time using the beaker filled with hot water.
5. How would you explain the different behaviors of the rods in cold versus warm water? With your group, discuss possible explanations for what you have observed.

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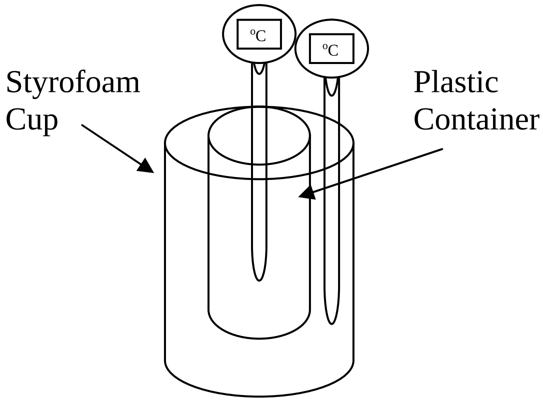
7. Heat Flow and Latent Heat

Materials:

- A small plastic container with a top (the container should be small enough to fit in a Styrofoam cup. Drill a hole in the top of the container that is large enough to fit a thermometer
- Styrofoam cup(s) (stick several cups together for better insulation)
- Two digital thermometers
- A ring stand with a clamps and platform
- Hot tap water, ice-cold water and ice

Instructions:

1. Below is a cartoon of the experimental set up. What would be the direction of the heat transport if the small container contained ice-cold water (with no ice) and the Styrofoam cup contained hot water? (Draw arrows to show it)? What would happen to the temperature of the water in the small container? In the Styrofoam cup?



2. Fill the small container (to the top) with ice-cold water (only water, no ice!). Record the initial temperature of the water in the container.

3. Fill the Styrofoam cup with hot tap water (to the marked line, so the volume of water in the container equals the volume of water in the cup) and record the initial temperature of the water.
4. Slide the arm of the clamp down and place the small container in the Styrofoam cup so that the water level in the cup reaches the bottom of the container's top. Record the temperature in the container and the cup every 30 seconds for 4 minutes. Using the rod of the thermometer, make sure to mix the water in the cup and the container while doing the measurements, to avoid gradients in temperature within the cap or within the container (with light warm water on top of cold denser water).
5. Plot the temperature in the container and the Styrofoam cup, as a function of time. Does it agree with your prediction? What do you expect the temperature gradient to be after a longer period of time?
6. Assume that you repeat the experiment, but this time you fill the small container with ice + water and fill the Styrofoam cup with hot tap water. Do you expect to see similar changes in temperature in this set-up? Why or why not?
7. Fill the small container (to the top) with ice and water (approximately 60% ice and 40% water). Record the initial temperature of the water in the container.
8. Repeat steps 3-4. Plot the temperature of water in the container and the Styrofoam cup, as a function of time. Do you see the same trend as in 5? Why or why not?

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8. Class Demonstration: Latent Heat

Materials:

- Two containers with water
- Reusable heat pack (Arbor Scientific)
- Two thermometers
- A watch/ stopwatch

Instructions:

1. Observe, feel, and describe the heat pack (e.g., material and temperature).
2. Fill the containers with room temperature water and record the initial temperature in each of them.
3. Activate the heat pack by pressing the button (use the ball of your fingers; don't use your nails as they might damage the pack) and add it to one of the containers (the other container serves as a control).
4. Record starting temperature immediately, in both containers.
5. Continue recording the temperature in each container, once every minute for 10 minutes.
6. Did you observe differences between the two containers?

What causes the change in temperature? How does this pack work? (Hint: does the material in the pack look the same before and after you activated the pack?

Group discussion:
The reaction in the pack that you have just observed is similar to what occurs during ice or cloud formation. Do you agree (or disagree) with this statement? Why?

OPTIONAL ACTIVITIES

9. **Sling Psychrometer (Hygrometer)**

Materials:

- A Sling psychrometer (Sciencekit.com)

Instructions:

A sling psychrometer is a device that allows us to measure relative humidity by measuring the temperature of a thermometer wrapped in a wet cloth (the wet bulb) and a dry one. Before you begin this activity, have a group discussion defining what humidity is, and what is the relationship between humidity, evaporation, and temperature?

1. How do you expect the temperature between the two to vary as function of humidity?

2. Why should there be a difference between the two readings?
3. Swing the psychrometer for 20 seconds and then note if there is any difference in temperature between the two thermometers.
4. Use a table to compute the relative humidity in the lab, based on the temperature differences between the two thermometers.
5. Repeat the process two more times. An average of at least 3 readings should be taken to ensure accuracy in your measurement of relative humidity.
6. What concept(s) of heat and temperature are demonstrated by this activity?

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10. Radiometer

Materials:

- Radiometer (Arbor Scientific)
- A heat lamp

Instructions:

1. Observe the radiometer. Can you spin the vanes of the radiometer without touching it? How?

   [DO NOT READ FURTHER: PLEASE THINK BEFORE PROCEEDING]

2. Put it near a light source and observe it spin. Move the light source away from the radiometer and observe it slow down.
3. Based on what you know about heat, heat absorption, and the relationship between gas volume, temperature and pressure, write an explanation for how a radiometer works.

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HEAT AND TEMPERATURE: EXPLANATIONS FOR LAB ACTIVITIES

1. Conduction

Materials that are good conductors feel colder to the touch because heat is transferred away quickly; keeping the area we touched from heating up. Poor conductors heat locally and thus feel warmer as heat transfer away from our hands is smaller. In fluids, heat is transferred by direct collisions between molecules. Non-metal solids transfer heat by lattice vibration. Metals have higher thermal conductivity compared to non-metal solids. In metals, not only do the bonded atoms vibrate faster when heated but free electrons, which participate in electrical conduction, also take part in the transfer of heat (for more details about conduction see “heat and temperature-background” handout). Conduction is not a significant process of heat transfer in the ocean but always occurs in the interface between materials of different properties i.e., liquid and solids. For example, marine organisms and the surrounding water, liquid and gas (for example, ocean and atmosphere).

2. Absorption of Radiation

Although the two cans are exposed to the same source of light, the two thermometers will not show the same temperature. The black can absorbs heat better than the shiny can and therefore heats faster. The temperature of each can will reach a final temperature when the gain of short wave radiation equals the loss to long wave radiation + the loss of heat to the surrounding air through conduction (for more details see “heat and temperature-background” hand-out).

3. Convection

When you warm up one column and cool down the other, a pressure gradient forms within the apparatus causing water to flow from high pressure (cold water) to low pressure (warm water). Remember that pressure is proportional to density at a given depth. Since the cold water is denser it will move along the lower connecting tube and the hot water will move along the upper connecting tube. If you cool or warm only one column you’ll see the same effect though it may not appear as dramatic because the pressure gradient will be smaller. This activity provides a good illustration of density driven circulation in the ocean (for example: the global conveyor belt, although the cooling and heating are done at the water surface). Density differences cause water masses to sink or rise until they reach their density equilibrium level; once a water mass reaches its equilibrium density level, it begins to move horizontally in response to a pressure gradient. The pressure gradient results from differences in the vertical distributions of density (and hence hydrostatic pressure) between regions where water masses sink or rise relative to their surroundings (recall that hydrostatic pressure at a given depth is a function of the density of the water column above that depth).

4. Convection under Ice

The colored ice water is denser than the freshwater in the container and therefore will sink to the bottom of the beaker. As the cold water sinks, warmer water from the bottom of the container rises, resulting in a convective flow. This process is similar to the cooling and freezing of lakes in winter. When air temperature gets cold, heat is transferred from the surface layer of a lake to the atmosphere. As a result, the temperature of the surface water decreases, becomes denser, and sinks (max. density of freshwater is 4^{o}C). The warmer water underneath the surface layer will rise to replace the sinking water as it has a lower density. Convection takes place and the entire lake will eventually be cooled down to 4^{o}C.. Convection takes place and the entire lake will eventually be cooled down to 4^{o}C. When further cooled, the lake becomes stratified, with denser water at the bottom and colder less dense water above. When the temperature of surface water reaches 0^{o}C (isothermal), surface water begins to freeze and the frozen layer deepens as further cooling occurs.

5. Thermal Expansion/Water Thermometer

When a fluid is heated up it expands; when cooled down it contracts. This is the principle by which a mercury thermometer operates. This demonstration can be used to explain sea level changes due to thermal expansion. Thermal expansion is thought to be a principle cause of modern-day sea-level rise, on decadal to century time scales. Estimates of the contribution of thermal expansion to global sea level rise, however, are uncertain and range from less than 25% to 50%. Other processes that contribute to sea level change are the melting of land ice (via the addition of water to the ocean) and the rise and fall of lithospheric plates, due to isostatic leveling.

Melting of glaciers and land ice caps result in the addition of water to the ocean and a subsequent rise in sea level. Melting of sea ice will not change the sea level because the volume of water it displaces equals the volume that will be added when it melts. To demonstrate this, you can ask the students to put a large block of ice in an aquarium and record the water level before and after the ice melts. (note some level change may happen if the ice cools the whole water enough. Compare the level with the ice in room temperature water to the level when the water is back at room temperature).

6. Effects of Temperature on Density

In this activity, the rods are used to demonstrate the effect of temperature on the density of liquids and solids. In addition, this activity can be used as a discrepant event. It requires the understanding of the following concepts: temperature, thermal expansion, and density. One rod is made out of aluminum and the other is made out of PVC.

When you place the rods in cold water, both will initially float because their density is lower than the cold water. Over time, the PVC rod gets colder and contracts, which results in a density change (volume decreases but its mass remains the same). When the density of the rod exceeds that of the water, the PVC rod sinks. Aluminum has a much lower thermal expansion coefficient, therefore its density is less affected by temperature and it remains floating. When you place the rods in hot water, the density of the water is now lower than that of the aluminum rod and it will sink. The PVC rod is initially denser than the water and sinks, but as it warms up it begins to expand. As a result, its density changes (again, the mass remains constant but the volume increases) and when its density becomes lower than that of the water, it floats.

7. Heat Flow and Latent Heat

Transfer of heat is from a high temperature object to a lower temperature object. Therefore, in this experiment, heat is transferred from the hot water in the Styrofoam cup to the cold water in the plastic container. As a result, the temperature of the water in the Styrofoam cup decreases (heat is removed) and the temperature of the water in the plastic container increases (heat is gained). After a long period of time, the system will reach equilibrium and there will be no temperature gradient between the water in the Styrofoam cup and the water in the container. When ice + water are added to the plastic container and hot water to the Styrofoam cup, heat transfer is in the same direction as before but while the temperature of the hot water in the Styrofoam cup decreases there is no observed change in the temperature of the water + ice. This is a good demonstration for showing that heat transfer does not necessarily result in a change in temperature. Transitions between phases (solid, liquid, gaseous phases) typically require a large amount of energy (latent "hidden" heat). Heat energy from the source (hot water in the Styrofoam cup) goes into breaking the bonds between water molecules in the ice (melting the ice) therefore there is no observed change in the temperature of the water in the container. Only after all the ice melts will the temperature of the water in the plastic container rise.

8. Class Demonstration: Latent Heat

This activity demonstrates the concept of latent heat. Latent heat refers to the amount of heat that must be added or released as material undergoes phase transition. The heat pack contains a supercooled solution of sodium acetate. To maintain the sodium acetate in a liquid phase you need to invest energy which is stored in the chemical bonds of the material. When you activate the pack, the sodium acetate begins to crystallize, releasing this stored energy as heat. To return the sodium acetate in the pack to a liquid phase you need to heat the pack ("invest" energy).

Similarly, a phase transition from liquid water to ice results in the release of latent heat. During winter, latent heat is released to the atmosphere as water freezes. Conversely, in the summer, heat added to high latitudes is used to melt the ice. Because the heat loss and heat gain are in the form of latent heat, the surface water at high latitudes remain close to freezing point throughout the year.

Evaporation of water results in heat loss from oceans. Latent heat is then carried into the atmosphere with water vapor, redistributed geographically, and released when the water condenses to form rain.

When does this analogy fail? The reaction in the heat pack is an exothermic ("heat-releasing") chemical reaction of sodium acetate with water and not just a simple substance phase change. Although ice or cloud formation involves nucleation, the reaction itself is not a chemical reaction as in the case of the heat pack. Yet, this demonstration is a good demonstration of the release of latent heat as the substance goes from liquid to solid.

9. **Sling Psychrometer (Hygrometer)**

The sling psychrometer consists of two thermometers mounted together. One is a regular thermometer, the other is a wet-bulb thermometer (has a cloth wick over the bulb). When you whirl the instrument, water evaporates from the wet cloth, cooling the wet bulb thermometer. The temperature of the wet bulb reaches an equilibrium when the cooling due to evaporation of the fluid (which depends on the relative humidity in the room), is in equilibrium with the gain of heat through conduction from the surrounding air. If the surrounding air is dry, evaporation will be high and there will be greater difference between the two thermometers. If the air is saturated with water vapor, no evaporative cooling will take place and there will be no difference between the two thermometers.

This activity demonstrates heat loss associated with evaporation and can explain why we feel cold when we get out of a pool and why regions with high humidity and low evaporation feel warmer to us compared to regions with low humidity and high evaporation.

10. Radiometer

The radiometer is set in motion by heat energy. It consists of a rotating shaft with 4 vanes (painted black and white on opposite sides). The shaft and the vanes are sealed in a glass container with air inside. When you expose the radiometer to a light source (lamp or sun) heat is radiated through the glass towards the shaft. The black side absorbs heat better than the white painted side and as a result, air in the vicinity of the black side increases in temperature with an associated pressure increase (remember the ideal gas law). The pressure difference causes movement of the vane from high to low pressure both directly and through air-flow. A microscopic explanation is that the kinetic energy of air molecules near the black side is higher than near the white side resulting in more collisions with the vanes (pressure) on that side relative to the white resulting in net momentum transfer to the vane. Note that when air is removed from the radiometer (that is in vacuum) the shaft could rotate in the opposite direction due to a transfer momentum of photons (a quantum mechanical effect). Photons hitting the black side of the vane are absorbed while those hitting the white side bounce back with an opposite momentum, imparting a higher momentum to the white vane than the black. Usually this effect (called radiation pressure) is not strong enough to overcome the friction of the shaft and no rotation occurs (for more see Nichols Radiometer in Wikipedia).