Name:

Biology 641
12 September, 2006

Lab 2: Life in fluctuating environments: organisms as environmental filters, and the roles of mass and specific heat

Specific heat capacity is defined as the amount of heat energy (measured in Joules, J) required to raise one kilogram of material one degree Kelvin (K), where Kelvin = °C +273 (For the moment just remember that a temperature *change* of 1°C is the same as a temperature *change* of 1K). It is important to remember that specific heat capacity is a material property, and is independent of the size, shape or mass of the object. Thus, *per unit mass*, it takes the same amount of heat energy to raise the temperature of a 1kg block of aluminum 1°C as it does to raise the temperature of a 1000kg block the same amount. However, because the 1000kg block weighs 1000 times as much as the 1kg block, it takes 1000 times as much heat energy to raise the larger block 1°C. Again, it is important to distinguish heat (=*total* kinetic energy in an object) from temperature (=*average* kinetic energy of molecules within the object). The *total* heat energy within an object is thus the product of the object's temperature (T), it's mass (m), and the specific heat (c) of the molecules which comprise the object. Changes (Δ) in the heat content of an organism or other object are thus quantified as:

$$m\,c\,\Delta T$$

We can calculate the specific heat of an organism or other object by measuring the flux of heat from that object into a material for which the specific heat is known, usually water. If we measure the transfer of heat energy, and assume that no other sources or sinks of heat exist, we can calculate the specific heat of an unknown using the following equation. In other words, the heat energy gained by one material is equal to that lost by the other, and the change of heat in the system is zero:

$$m_1\,c_1\,\Delta T_1 + m_2\,c_2\,\Delta T_2 = 0$$

where m_1 = mass of material 1 (in this case, water, in kg); c_1 = specific heat of water = 4180 J/(kg K); and ΔT_1 = change in temperature (K) of water once it is in contact with the object of unknown specific heat. Likewise, m_2 = mass of second material (e.g. brass, aluminum, etc); ΔT_2= temperature change of object one its in contact with water, and c_2 is the specific heat that you're solving for.

Rearrange the above equation to solve for c_2. Show that the units balance.

For this exercise, divide up into 4 groups of 6 people each. Two groups will work on calculating the specific heat of aluminum and brass (A), one group will do the same for shell (B), and one group will study fluctuating environments (C). Be sure to allow enough time to trade places (every 20 minutes) so that you can accomplish all four sections of the lab. **Lab reports are due Tuesday September 13.**

A. Calculating specific heat of brass and aluminum
Using the equation that you just derived and the materials on hand (a balance, a source of hot aluminum and brass balls, and a thermocouple temperature logger), calculate the specific heat of aluminum and brass.

BRASS:

Mass of ball (kg) =

Initial temperature of ball (K) =

Final temperature of ball (K) =

ΔT of ball (Initial –final) =

Mass of water (kg) =

Initial temperature of water (K) =

Final temperature of water (K) =

ΔT of water (Initial –final) =

Specific heat capacity of water = 4180 J/kg K

Specific heat capacity of brass =

ALUMINUM:

Mass of ball or cylinder (kg) =

Initial temperature of ball or cylinder (K) =

Final temperature of ball or cylinder (K) =

ΔT of ball or cylinder (Initial –final) =

Mass of water (kg) =

Initial temperature of water (K) =

Final temperature of water (K) =

ΔT of water (Initial –final) =

Specific heat capacity of aluminum =

B. Calculating the specific heat of a natural material

Now, repeat this procedure that you used in to calculate the specific heat capacity for shell, using one of the oyster, mussel or snail shells provided.

Mass of shell (kg) =

Initial temperature of shell (K) =

Final temperature of shell (K) =

ΔT of shell (Initial –final) =

Mass of water (kg) =

Initial temperature of water (K) =

Final temperature of water (K) =

ΔT of water (Initial –final) =

Specific heat capacity of shell =

C. Organisms in fluctuating environments

As you (hopefully) observed during Lab1, environmental conditions are seldom constant in the natural world. Cloud cover causes solar radiation to fluctuate considerably, and wind speeds can change rapidly. What effects do these variable conditions have on body temperature, and how does body size alter this relationship? For example, one approach might be to record average solar radiation over some predetermined period of time (hourly, daily, etc). However, what if we're interested in maximum body temperature, or the time that an organism's body is above some threshold temperature? One way to approach such questions is to think of organisms as *filters* to environmental signals. Organisms made of materials with high specific heats, and organisms with a lot of mass, require considerably more heat energy to raise their body temperatures any given amount than do smaller organisms or those constructed of materials such as shell. The capacity to dampen the response in body temperature to changes in the environment is called "thermal inertia" and is quantified as a time constant, a ratio of factors that resist changes in temperature (mass and specific heat) to factors that promote them (such as area of exchange).

Using the heat lamps and fans, create an artificial environment where solar radiation and wind speed vary. In this environment, put two silicone-filled mussel shells, one large and one small, in front of the heat lamp and fan. It's up to you what fan speed you want to use, and how far away from the heat lamp you want to place the mussels, but make sure that both are exposed to the same "environments". Turn the heat lamp on and the fan off for a period of 5 minutes, allowing both mussels to heat. Record solar radiation and "body" temperature of the two mussels every minute for the next 5 minutes. Now turn off the heat lamp and turn the fan on. Again, it's up to you what speed to use, but make sure the two mussels experience the same wind conditions. Again, measure body temperature and wind speed every minute for the next 5 minutes. Turn the fan off and the lamp on and repeat the heating experiment for another 5 minutes.

Time(min)	Large Mussel Temp (°C)	Small Mussel Temp (°C)	Wind or Solar
Lamp on, wind off			
1			
2			
3			
4			
5			
Lamp off, wind on			
6			
7			
8			
9			
10			
Lamp on, wind off			
11			
12			
13			
14			
15			

1. Which mussel showed the highest temperature and range of temperatures? Why?

2. Which mussel showed the greatest "thermal inertia?" Explain in your own words what thermal inertia means, and what factors contribute to an organism's thermal inertia.

3. Assume you were doing this for large numbers of animals in the field, and were limited in the number of measurements that you could have recorded over each 15 minute period. About how often would you have needed to take measurements from the large mussel in order to see its peak temperature? From the small mussel?

Study questions:

1. How do the specific heats of aluminum, brass and water compare? How much heat energy is required to raise the temperature of 10g of each of these materials by 15K?

2. Imagine you're an engineer being asked to construct a heat sink for a cooling system (i.e., a device that is designed to remove as much heat energy from the surrounding fluid as possible), and you have a choice of materials. The maximum volume that the heat sink can be is $3m^3$. Material 1 has a density of 5 kg/m^3, and a specific heat capacity of 481 J/(kg K). Material 2 has a density of 22 kg/m^3, and a specific heat capacity of 119 J/(kg K). Which material should you use to maximize the total amount of heat that can be absorbed by the system? Why?

3. As above, you've been asked to design a heat sink for another system. However, in this case, the volume of the sink is not limited. Instead, you are limited by cost: Material 1 costs $400 per kg, and material 2 costs $100 per kg. Your maximum budget is $2000. Which material should you use? Why?

4. For cryin' out loud- this is a class in physiology, not marketing and design! Why should you care about questions 2 and 3, from the perspective of a biologist? (Think about evolutionary constraints and materials that organisms are made out of).

5. You graduate from USC with honors, go on to graduate school, and your new advisor tells you that you need to design an experiment which requires you to record the maximum temperature experienced by a mushroom living in a clear-cut in the Pacific northwest (hey, it could happen) . How often does your data logger need to take a reading? How would you determine this rate before you start the real experiments, and what factors would you need to consider when making this decision? What might happen if you recorded samples too infrequently?