SPECIFIC HEAT CAPACITY

Apparatus: Thermometer, balance, two large double Styrofoam cups, lid, hooked metal cube, lifting tool, hot plate, boiling pot.

Any material is capable of storing some heat or thermal energy. The amount of heat that an object can store will depend on the amount of material in the object, the type of material, and the temperature change that the object will undergo. Using the same heat energy source (flame, burner, hotplate, etc.), it takes much longer to warm a large pan of water through a fixed temperature change than it does to warm a very small amount of water in the pan through the same temperature change. Thus, the larger the mass (m) of the material, the longer it takes to cause the temperature change, and the more heat (Q) transferred into the object. This same amount of heat would be released to the environment if the object were cooled back down to its original temperature.

Similarly, a cup of water heated by some constant source takes less time to warm through a temperature change of 10 C° than the same cup of water would take to warm through a temperature change of 20 C°. Therefore, the amount of heat transferred into a substance is also dependent on the temperature change (ΔT), which the object undergoes.

Finally, a block of iron, for example, will not require as long to heat through a set temperature change as a block of aluminum of the same mass. The aluminum atoms are more numerous than the iron atoms for the same mass. The more numerous aluminum atoms would have to be heated longer in order to get each to hold the same amount of heat as each of the iron atoms. The type of material of the object then also determines the amount of heat that the object can hold. Since Q is proportional to each of three factors, they are put together into one mathematical relationship as follows:

$$\Delta Q = m * c * \Delta T \qquad (1)$$

where ΔQ is the amount of heat added or removed from the object, m is the mass of the object, ΔT is the temperature change which the object undergoes, and c is a number which indicates the type of material of which the object is made. The usual terminology is to call c, the specific heat capacity of the material.

Though all forms of energy, including heat, are measured in the SI unit Joules, the heat which an object absorbs or releases was traditionally reported in calories (1 physics calorie = 4.186 J = 0.001 nutritional Calories.) One physics calorie (not capitalized) is defined as the amount of heat which 1 gram of water will absorb as the temperature of the water is increased by 1 C°. In SI form, 4186 Joules is the amount of heat which 1 kilogram of water will absorb as the temperature of the water is increased by 1 C°. The exact amounts vary slightly with temperature, but for our purposes here, this is close enough. If we heat 20 grams of water through a temperature difference of 10 C° the amount of heat required would be 20 * 10 or 200 calories. Each gram of water holds 1 calorie for each C degree change in temperature. The specific heat capacity (c) of water is then defined as 1.000 calorie/gram/C° or in standard units, 4186 Joules/kg/C°. Other materials will have different intrinsic values for c as you can see in the attached table. Again, specific heat capacity does change somewhat with temperature, but it is negligible for typical ΔT's like those in this experiment.

In order to determine the specific heat capacity of an unknown material, the procedure we will use in this lab is to heat an object to a high temperature and then place it in a container of water at a known temperature. The hot object will lose some of its heat as it cools and the water, which is the cooling agent, will absorb the lost heat. If a simple precaution of isolating the system from the surroundings (keeping the water in a Styrofoam container and keeping a lid on the container) the amount of heat lost by the object will numerically equal the amount of heat that the water absorbs. We will be able to determine the amount of heat the water gains, because we will be able to measure the temperature change of the water and we will know the mass of water. Hence

$$\Delta Q_{water} = m_{water} * c_{water} * \Delta T_{water} \qquad (1)$$

This amount of heat is equal to the amount of heat that the hot object lost. If we know the temperature change of the object and we know the mass of the object, we can then use equation 1 again to determine the specific heat capacity of the object.

$$c_{object} = \Delta Q_{object} /(m_{object} * \Delta T_{object})$$

Since the object loses heat and the water gains heat, we must replace ΔQ_{object} by $-\Delta Q_{water}$ giving us the following

$$c_{object} = - (m_{water} * c_{water} * \Delta T_{water})/(m_{object} * \Delta T_{object}) \qquad (2)$$

In our process, we have ignored the heat that is gained by the Styrofoam container that holds the water. Both the mass and ΔT of the cup are very small, therefore the heat lost to the cup can be ignored. If the container which held the water had a large mass, a significant specific heat capacity, and/or went through a great ΔT , the container would have absorbed much of the heat which the object lost. In that case, the outside of the cup would get noticeably hot to the touch, and you would have to account for the heat absorbed both by the water and by the container, and set that total equal to the amount of heat which the object lost.

It is not always the case that an object must have a temperature change as it gains or loses heat. If the object changes its state from a solid to a liquid or from a liquid to a vapor, it must absorb heat in order for the change to occur. During the change of state, the object will gain the heat but the temperature of the object will remain unchanged. Similarly, if the material condenses from a vapor to a liquid or if it goes from a liquid to a solid, it will give off heat at a constant temperature while the change of state is taking place. The amount of heat that is necessary for the change of state to occur will depend on the amount of material as well as on the type of material. Mathematically this is written as

$$\Delta Q = m * H \qquad (3)$$

where H is the heat of fusion or the heat of vaporization of the material. The heat of fusion is the amount of heat per unit mass that the object must absorb in order to change from the solid to the liquid state. In changing from a liquid to a solid, the object must give off that same amount of heat. The heat of vaporization is the amount of heat necessary per unit mass of substance to change from liquid to vapor or vapor to liquid.

Procedure:

ALWAYS USE EXTREME CAUTION WHEN WORKING WITH OR NEAR THE HOTPLATE AND HOT MATERIALS!!!

0. For use later: Fill the boiling pot about 2/3 of the way with water, submerge metal block, and set pot on hotplate at full power (if adjustable.)

1. Determine the mass of each of the two double Styrofoam containers. From the cold water tap, fill one of the containers about 1/3 full of water, and then place about an equal amount of steaming hot tap water in the other container. Use entirely separate faucet spouts for getting the hot and cold tap water. Determine the mass of the hot water and the mass of the cold water. Record on the data sheet. Also determine the temperature of each sample of water, and then QUICKLY proceed to step 2 so initial temperatures don't change much.

2. Immediately after measuring the separate initial temperatures, pour the cold water into the container of warm water, cover and very gently stir with thermometer to obtain the temperature of the system after equilibrium has been reached (no temperature change for a half minute). Record the *experimental* equilibrium temperature. Note: Heat energy is transferred from hot materials to cold materials until both are at exactly the same temperature (equilibrium).

3. Empty the Styrofoam containers and fill one of them with nearly 180 cubic centimeters of cold water. (Use your knowledge of the density of water to measure about 180 cc with the pan balance!) Record the precise temperature and precise mass of the cold water.

4. Record the initial temperature of your hot object simmering in water on the hot plate (assuming it has been simmering for at least 10 minutes), and then using the lifting tool, CAREFULLY place it into the cold water. Stir the container of water very gently and monitor the temperature. When an equilibrium temperature is reached, record the value. Dry the object, determine its mass, and then CAREFULLY return it to the simmering water on the hot plate. Object must again remain in near-boiling water for at least 10 minutes before being used in the next experiment.

5. Inserting your data into the appropriate equation, determine the specific heat capacity of the object. If you have taken poor measurements, be prepared to repeat steps 3, 4 and 5.

6. Make a prediction: If the same hot object is placed in twice the volume of cold water and the experiment is repeated, should your calculation with the new data result in an equivalent result for specific heat capacity of the object? Why or why not?

7. Empty the Styrofoam container and refill with about 360 cc of cold water. Record the temperature and mass of the cold water.

8. Record the initial temperature of your hot object simmering in water on the hot plate, and then using the lifting tool, CAREFULLY place it into the cold water. Again, measure and record the equilibrium temperature.

9. Inserting your new data into the equation, again determine the specific heat capacity of the object. If you have taken poor measurements, be prepared to repeat steps 7, 8 and 9.

10. What is the % difference between the two heat capacities found for the unknown? Was your answer in step 6 supported by the heat capacities you found? If not, why not? Justify your answer based on the equation and /or measurable evidence.

11. Use the textbook list of specific heat capacities on the last page to identify the material the block is made from based on the heat capacity values found in your experiments.

12. From the first set of data recorded in step 1, determine a *theoretical* equilibrium temperature prediction for the hot water and cold water mixture. Since the amount of heat lost by the hot water equals the amount of heat gained by the cool water, set $-\Delta Q_{hot} = +\Delta Q_{cold}$ and solve for T_f

EXPERIMENT 1

Mass of Styrofoam cup #1: __________ Mass of Styrofoam cup # 2: _________

Mass of cold water: ___________ Mass of warm water: ___________

Temperature of cold water: ________ Temperature of warm water: _________

Experimental equilibrium temperature of water mixture (DO NOT USE THIS VALUE IN ANY CALCULATION!): ________________

Theoretical equilibrium temperature of water mixture: __________

EXPERIMENT 2

Mass of cold water (180 cc): _____________ Initial Temperature of cold water:_________

Initial Temperature of hot object: ________ Mass of object: ____________

Equilibrium temperature: _________

Specific heat capacity of object: ___________

EXPERIMENT 3

Mass of cold water (360 cc): _____________ Initial Temperature of cold water: _________

Initial Temperature of hot object: ________ Mass of object: ____________

Equilibrium temperature: _________

Specific heat capacity of object: ___________ % Difference: _______________

Type of material from table:___________________

As always, you must show one carefully-labeled, step-by-step sample of each type of calculation.

Specific Heat Capacity, c of some Substances at 25^{o}C and Atmospheric Pressure

SI (J/kg · ^{o}C)	**Substance**	**Non-SI (cal/g · ^{o}C)**
	Elemental Solids:	
900	Aluminum	0.215
1,830	Beryllium	0.436
230	Cadmium	0.055
387	Copper	0.0924
322	Germanium	0.077
129	Gold	0.0308
448	Iron	0.107
128	Lead	0.0305
703	Silicon	0.168
234	Silver	0.056
	Other Solids:	
380	Brass	0.092
837	Glass	0.200
2,090	Ice (-5^{o}C)	0.500
860	Marble	0.210
1,700	Wood	0.410
	Liquids:	
2,400	Ethyl Alcohol	0.580
140	Mercury	0.033
4,186	Water (15 ^{o}C)	1.000
	Gas:	
2,010	Steam (100 ^{o}C)	0.480