Radiation and specific heat

Introduction:

In our previous experiments, we have looked at forms of kinetic energy. We know that the total energy of an *isolated* system remains constant, yet in the collision lab, we observed that some of the kinetic energy was lost. Where did the energy go? Through the process of friction, the orderly form of motion (kinetic) energy was converted to the random form of motion energy called **heat**. When kinetic energy is converted to heat, we speak of **mechanical energy** being converted to heat energy. Creating heat in a fluid by stirring it, rubbing your hands together to get them warm, and stepping on the brakes of your car are all examples of the conversion of mechanical energy to heat. Another way

of creating heat is to transform the electrical energy. Electrical current flowing through a wire encounters wire resistance and generates heat. This heat can be transferred via convection or by a process of radiation. Temperature is a quantity which describes the average kinetic energy per particle (atom, molecule) in an object or system. When we say that something is "hot" we usually mean that it has a very high temperature. This is not equivalent to saying that it "contains heat." The concept of heat only makes sense when considering heat transferred. The **heat** added to or subtracted from a body is usually represented by the symbol Q and a heat transfer takes place when objects of different temperatures are placed in contact. Q is given in units of **joules** or in units of **calories** (1 calorie = 4.186 joules). *The* ***calorie*** *is defined as the amount of heat required to produce a temperature change of 1° Celsius in one gram of water*.

An important quantity which relates the change in temperature to the heat flow is the **specific heat** (c). ***Specific heat*** *is defined as the amount of heat required to produce a temperature change of 1° C in one gram of a substance* ***with no change in physical state or form.*** The specific heat of water, is therefore define as one calorie / g °C.

In our experiment we will measure the specific heat of water using three cans as water containers and infrared lamp as a heat source. The lamp produces infrared radiation which is partially absorbed and partially reflected by the cans. The absorbed radiation will increase the temperature of water. ***Coefficient of absorption***(K_{abs}) for any material object is defined as the ratio between energy absorbed by the object and the total energy intercepted by the surface of the object normalized to the unit surface area. Cans of different colors have different coefficients of absorption.

The amount of energy emitted by the lamp in 1 second is called ***power*** (P), and the unit of the power is 1***Watt*** (watt = joule/sec). From this definition one can see that the amount of energy (heat) emitted by the lamp during the time t is:

$$Q_{emitted} = P \times t$$

(1)

Not all of the energy emitted by the lamp is intercepted by the can. The fraction of the energy falling onto the can, ε, depends on the geometrical arrangement of the can and the lamp called geometrical acceptance. For the cans placed on the specially marked places on the wooden plate, this parameter is approximately:

$$e = 0.1$$

(2)

The energy absorbed by the can, $Q_{absorbed}$, can be written as a product of geometrical acceptance, the amount of the emitted heat and the coefficient of absorption:

$$Q_{absorbed} = e\,K_{abs}\,Q_{emitted}$$

(3)

During the heating process the temperature of water will changed from some initial temperature T_o to a final temperature T_f.

This change will depend on the amount of the absorbed heat, on the mass of water in the can, m, and on the specific heat of water, c.

$$Q_{absorbed} = c\,m\,(T_0 - T_f)$$

(4)

Equations (3) and (4) allow us to derive the formula for the specific heat of water:

$$c = \frac{e \times K_{abs} \times P \times t}{m(T_0 - T_f)}$$

(5)

In the formula derived above we neglected the heat used up to increase the temperature of the metal can. We can do it because the specific heat of water is much greater than the specific heat of aluminum from which the cans are made.

Equipment:

Three cans: black, silver and white, thermometer, lamp with infrared bulb, clamp with metal rod, piece of wood, specially prepared paper with marks for cans, graduated beaker, graph paper.

Procedure:

1. Fill the cans with 350ml (0.035 m^3) of cold tap water. You must be **very** careful to use the same amount of water for each can.
2. Insert a metal rod into the table socket and using the clamp attach lamp to the rod. Place the wooden block on the table. Lamp **must not** touch neither the table nor the wooden block. It must be positioned in a way such, that the direction of infrared radiation is parallel to the table surface.
3. Place the alignment paper in front of the lamp with the lamp's edge overlapping the mark on the paper.
4. Place the three cans on the marked places.
5. Measure the temperature of water in all three cans and then turn on the light.
6. Every 5 minutes do the following:
   a). Turn off the lamp.
   b). Close the cans and shake them well to equalize any internal temperature difference.
   c). Open each can and measure the water temperature.
   d). Record the measurements, put cans in the **same** positions and turn on the lamp.
7. Make 5 measurements of the temperature. The total time of the exposure to heat will be 25 minutes.
8. After completion of the measurements , disassemble the setup and pour the water away.

Analysis:

Plot the recorded temperatures for the cans versus the time of exposition. This will give you three lines. Find a slope of each line near the origin and record your calculations.

The slope is a ratio of the change in temperature to the corresponding time interval.
It makes sense only for a section of your graph which looks linear.
The ratio of these slopes is equal to the ratio of the coefficients of absorption for the different colors of the cans. Although the cans have equal sizes and are made from the same material, the coefficients of absorption are different because the heat emission from the lamp is not uniform.
Assuming that the absorption coefficient for the black can is equal to 1, calculate the absorption coefficients of the other two cans.
Calculate the specific heat of the water, using equation (5). Use 25 minutes as a time t and T_0 and T_f as the initial and final temperature of the water. Power of the bulb is 250Watts.
1 Watt = 1 joule/ 1 second.

Conclusions:

1 Write down your general conclusions for this experiment.
2. Compare measured specific heat with accepted value which is equal to c_{real} = 4,186 Joules/kg C°. Calculate % error.
3. **Bonus question:** What color dress should you wear during a summer day when the air temperature is lower then the body temperature? What color should you wear when the air temperature is higher then body temperature? Explain your answer.

Error Analysis:

Describe significant sources of error. What would change if you would not shake the cans before measuring the temperature? How your result would be affected, if the amount of water would be different in each can?

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Name:__________________________
Abstract:

Data:

m_{water} = ________________ T_o = ________________

Data:

n	T_{final} **black**	T_{final} **silver**	T_{final} **white**
1			
2			
3			
4			
5			

Calculations:

Slope for black can = _______________

Slope for silver can = _______________

Slope for white can = _______________

K_{abs}(black):K_{abs}(silver):K_{abs}(white) = ___________________________

Specific heat for water c = _________________________

Conclusions:

Error Analysis: