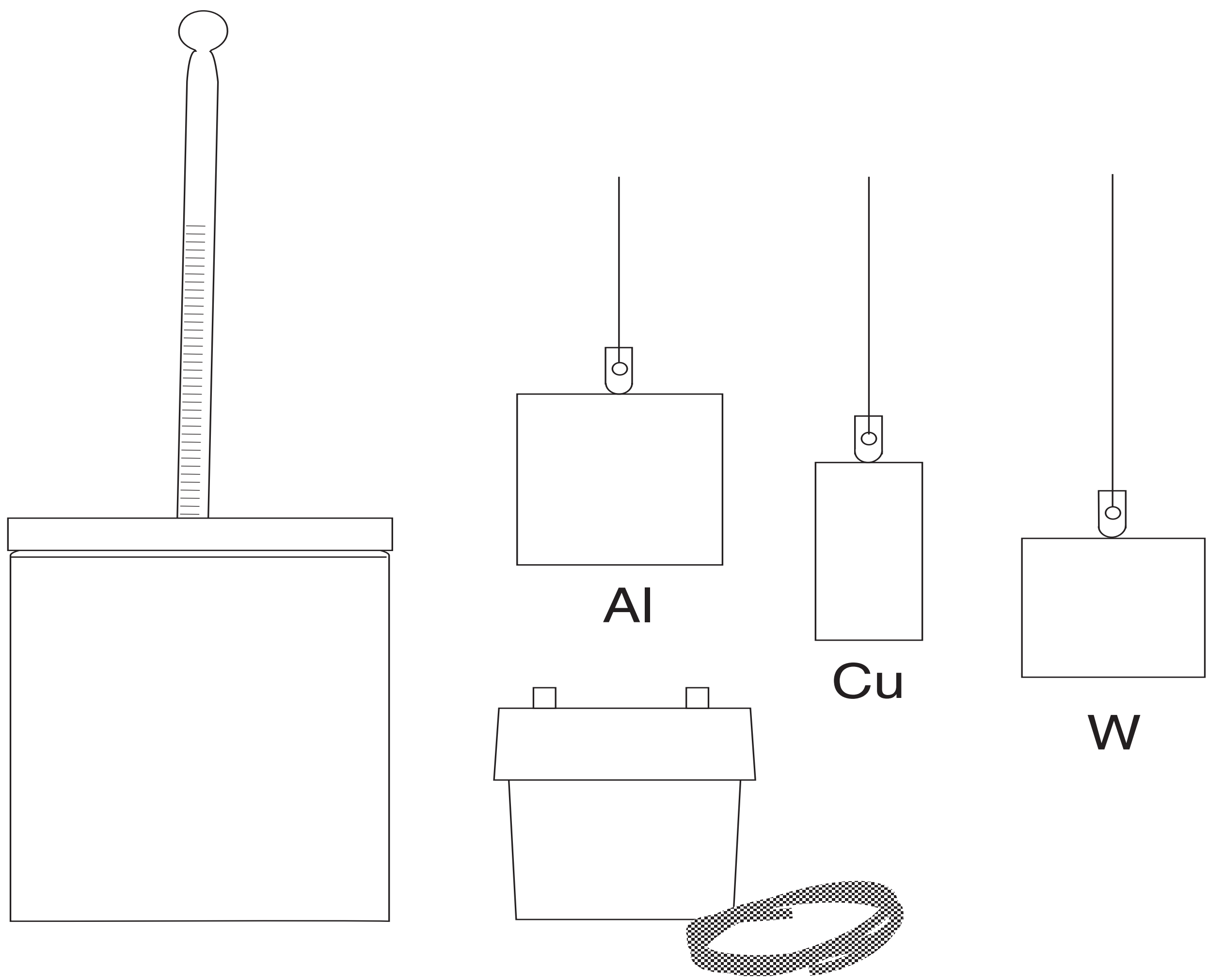
PASCO®

Instruction Manual and
Experiment Guide
012-03060F

Basic Calorimetry Set

TD-8557A



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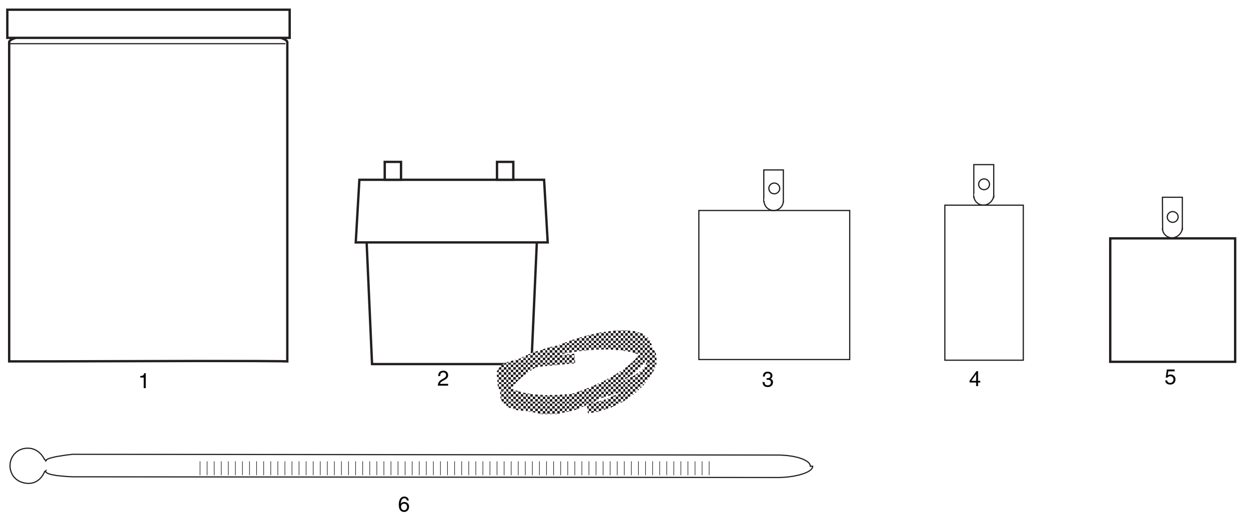

Included Parts

1. Calorimeter with lid, 6 pieces
2. Water trap with plastic tubing
3. Aluminum sample
4. Copper sample
5. Tungsten sample
6. Thermometer

Introduction

Understanding calorimetry is the first step into the field of thermodynamics, the study of the role of heat in physical processes. With the addition of a balance, ice, and a heat source, such as PASCO's Model TD-8556 Steam Generator, this Basic Calorimetry Set provides the equipment necessary to perform a variety of calorimetry experiments. Four important, introductory experiments are described in this manual:

Experiment 1: What is a Calorie? An introduction to the ideas of temperature and heat, and a demonstration of the conservation of energy.

Experiment 2: Thermal Capacity and Specific Heat The specific heats of aluminum, copper, and tungsten are measured.

Experiment 3: Latent Heat of Vaporization The role of heat transfer in the conversion of steam into water is investigated.

Experiment 4: Latent Heat of Fusion The role of heat transfer in the conversion of ice into water is investigated.

Notes on Calorimetry

A calorimeter is a vessel or device that thermally isolates an experiment from its surroundings. Ideally, this means that the results of an experiment performed in a calorimeter are independent of the temperature of the surroundings, because no heat flows into or out of the calorimeter.

However, no calorimeter is perfect, and there is always some unwanted and unaccountable heat flow affecting the results of any calorimetric experiment. To minimize unwanted heat flow, always plan the experiment to follow these rules:

1. The time between the taking of initial and final temperatures is minimal. In other words, do the critical portion of the experiment quickly, so there is minimal time for unwanted heat flow between measurements. (Don't rush; just plan carefully.)

2. Whenever possible, room temperature is approximately midway between the beginning and ending temperatures of the experiment. When the experimental temperature is colder than room temperature, heat flows from the surroundings into the calorimeter. When the experimental temperature is hotter than room temperature, heat flows from the calorimeter into the surroundings. If the experimental temperature varies above and below room temperature by equal amounts, the heat gained and lost to the environment will be approximately equal, minimizing the net affect on the experiment.

3. Mass measurements of liquids are made as near the critical temperature measurements as possible. This reduces the effects of mass loss by evaporation. Measuring liquid masses by taking appropriate differences is a useful technique (see the instructions in the individual experiments).

NOTE: In applying the above rules, it is often helpful to perform a quick preliminary experiment to determine the best choice for initial masses and temperatures.

Calorimeter

The calorimeter cup has two holes in its lid for inserting a thermometer, tubing from a Steam Generator, etc. The rim of the cup has a pouring notch that makes it easier to pour liquids out of the calorimeter.

Item	Approximate Value
Mass with lid	26 g
Mass without lid	21 g
Outside diameter	10 cm
Inside diameter	7.5 cm
Height with lid	12.3 cm
Height without lid	11.4 cm
Volume	500 cm^3

Experiment 1: What is a Calorie?

Equipment Needed

- Calorimeters, 2 pieces
- Thermometer
- Balance
- Hot and cold water

Introduction

When two systems or objects of different temperature come into contact, energy in the form of heat is transferred from the warmer system into the cooler. This transfer of heat raises the temperature of the cooler system and lowers the temperature of the warmer system. Eventually the two systems reach some common, intermediate temperature, and the heat transfer stops.

The standard unit for measuring heat transfer is the calorie. A calorie is defined as the amount of energy required to raise the temperature of one gram of water from 14.5° C to 15.5° C. However, for our purposes, we can generalize this definition by simply saying that a calorie is the amount of energy required to raise the temperature of one gram of water one degree Celsius (the variation with temperature is slight).

In this experiment, you will combine hot and cold water of known temperature and mass. Using the definition of the calorie, you will be able to determine the amount of heat energy that is transferred in bringing the hot and cold water to their final common temperature, and thereby determine if heat energy is conserved in this process.

Procedure

1. Determine the mass of the empty calorimeter, M_{cal}. Record your result in Table 1.1.

2. Fill the calorimeter about 1/3 full with cold water. Measure the mass of the calorimeter and water together to determine $M_{cal + water\ cold}$. Record your result.

3. Fill a second calorimeter approximately 1/3 full of hot water. The water should be at least 20° C above room temperature. Weigh the calorimeter and water together to determine $M_{cal + water\ hot}$. Record your result

4. Measure T_{hot} and T_{cold}, the temperatures the hot and cold water, and record your results.

5. Immediately after measuring the temperatures, add the hot water to the cold water and stir with the thermometer until the temperature stabilizes. Record the final temperature of the mixture, T_{final}.

6. Measure the final mass of the calorimeter and mixed water, M_{final}.

7. Repeat the procedure twice with different masses of water at different temperatures. (You might try adding cold water to hot instead of hot to cold.)

Data

Table 1.1: Data

	Trial 1	Trial 2	Trial 3
M_{cal}			
$M_{\text{cal + water cold}}$			
$M_{\text{cal + water hot}}$			
T_{cold}			
T_{hot}			
T_{final}			
M_{final}			

Calculations

From your data, make the calculations necessary to determine the mass of the cold and hot water ($M_{\text{water cold}}$ and $M_{\text{water hot}}$), and also the temperature changes undergone by each (ΔT_{cold} and ΔT_{hot}). Enter your results in Table 1.2.

Using the equations shown below, calculate ΔH_{cold} and $\Delta \text{H}_{\text{hot}}$, the heat gained by the cold and hot water, respectively. Enter your results in the table.

$$\Delta H_{\text{cold}} = (M_{\text{water cold}})(\Delta T_{\text{cold}})(1\ \text{cal/g K})$$

$$\Delta H_{\text{hot}} = (M_{\text{water hot}})(\Delta T_{\text{hot}})(1\ \text{cal/g K})$$

Table 1.2: Calculations

	Trial 1	Trial 2	Trial 3
$M_{\text{water cold}}$			
$M_{\text{water hot}}$			
ΔT_{cold}			
ΔT_{hot}			
ΔH_{cold}			
ΔH_{hot}			

Questions

1. Which had more thermal energy, the two cups of water before they were mixed together or after they were mixed? Was energy conserved?

2. Discuss any unwanted sources of heat loss or gain that might have had an effect on the experiment.

3. If 200 g of water at 85° C were added to 150 g of water at 15° C, what would be the final equilibrium temperature of the mixture?

Experiment 2: Specific Heat

Equipment Needed

- Calorimeter
- Thermometer
- Samples of aluminum, copper, and tungsten
- Balance
- Boiling water
- Cool water
- Thread
- Antifreeze, approximately 100 g

Introduction

The Specific Heat of a substance, usually indicated by the symbol c, is the amount of heat required to raise the temperature of one gram of the substance by 1° C (or 1 K). From the definition of the calorie given in Experiment 1, it can be seen that the specific heat of water is 1.0 cal/g K. If an object is made of a substance with specific heat equal to c_{sub}, then the heat, ΔH, required to raise the temperature of that object by an amount ΔT is:

$$\Delta H = (\text{mass of object})\,(c_{sub})\,(\Delta T)$$

In Part 1 of this experiment you will measure the specific heats of aluminum, copper, and tungsten. In Part 2 you will measure the specific heat of antifreeze.

⚠ ***CAUTION:*** *This experiment involves the use of boiling water and the handling of HOT metal objects. Work carefully.*

Part 1: The Specific Heats of Aluminum, Copper, and Tungsten

1. Measure M_{cal}, the mass of the calorimeter you will use (it should be empty and dry). Record your result in Table 2.1.

2. Measure the masses of the aluminum, copper, and tungsten samples. Record these masses in Table 2.1 in the row labeled M_{sample}.

3. Attach a thread to each of the metal samples and suspend each of the samples in boiling water. Allow a few minutes for the samples to heat thoroughly.

4. Fill the calorimeter approximately 1/2 full of cool water—use enough water to fully cover any one of the metal samples.

5. Measure T_{cool}, the temperature of the cool water. Record your measurement in the table.

6. Immediately following your temperature measurement, remove one of the metal samples from the boiling water, quickly wipe it dry, then suspend it in the cool water in the calorimeter (the sample should be completely covered but should not touch the bottom of the calorimeter).

7. Swirl the water and record T_{final}, the highest temperature attained by the water as it comes into thermal equilibrium with the metal sample.

8. Immediately after taking the temperature, measure and record M_{total}, the total mass of the calorimeter, water, and metal sample.

Part 2: The Specific Heat of Antifreeze

Repeat Part 1 of this experiment, but instead of using the metal samples, heat approximately 100 g of antifreeze to approximately 60° C. Measure and record the temperature, then quickly pour the antifreeze into a calorimeter containing cool water and stir until the highest stable temperature is reached (about 1 minute). Record your data and calculations on a separate sheet of paper. You will need the following data:

- M_{cal}, the mass of the calorimeter,
- M_{water} the mass of the calorimeter plus water,
- T_{cool} the temperature of the cool water,
- M_{total}, the mass of the calorimeter plus water plus antifreeze
- T_{final}, the temperature of the water plus antifreeze.

Data and Calculations

Table 2.1: Data and Calculations (Part 1)

	Trial 1	Trial 2	Trial 3
M_{cal}			
M_{sample}			
T_{cool}			
T_{final}			
M_{total}			
M_{water}			
ΔT_{water}			
ΔT_{sample}			
c			

Part 1

For each metal tested, use the equations shown below to determine M_{water}, the mass of the water used, ΔT_{water}, the temperature change of the water when it came into contact with the metal sample, and ΔT_{sample}, the temperature change of the metal sample when it came into contact with the water. Record your results in Table 2.1.

$$M_{water} = M_{total} - (M_{cal} + M_{sample})$$

$$\Delta T_{water} = T_{final} - T_{cool}$$

$$\Delta T_{sample} = 100° \text{ C} - T_{final}$$

From the law of energy conservation, the heat lost by the metal sample must equal the heat gained by the water:

$$\text{Heat lost by sample} = (M_{sample})\,(c_{sample})\,(\Delta T_{sample}) = (M_{water})\,(c_{water})\,(\Delta T_{water}) = \text{Heat gained by water}$$

c_{water} is the specific heat of water, which is 1.0 cal/g K.

Use the above equation, and your collected data, to solve for the specific heats of aluminum, copper, and tungsten. Record your results in the bottom row of Table 2.1.

Part 2

M_{cal} = ____________

M_{water} = ____________

T_{cool} = ____________

M_{total} = ____________

T_{final} = ____________

Perform calculations similar to those performed in part 1 to determine $c_{antifreeze}$, the specific heat of antifreeze.

$c_{antifreeze}$ = ____________

Questions

1. How do the specific heats of the samples compare with the specific heat of water?

2. Discuss any unwanted heat loss or gain that might have effected your results.

3. From your measured specific heat for antifreeze, which should be the better coolant for an automobile engine, antifreeze or water? Why is antifreeze used as an engine coolant?

NOTES

Experiment 3: Latent Heat of Vaporization

Equipment Needed

- Calorimeter
- Thermometer
- Steam Generator
- Water Trap
- Tubing
- Balance

If a steam generator is not available, a distillation flask and Bunsen burner is adequate. A second flask can be used as a water trap.

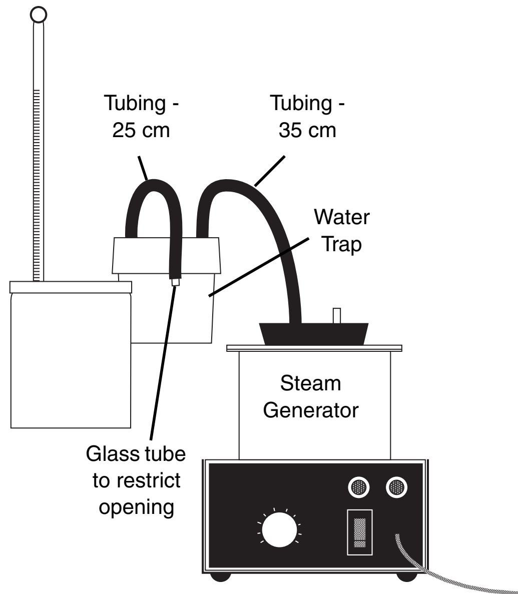

Figure 3.1

Introduction

When a substance changes phase, the arrangement of its molecules changes. If the new arrangement has a higher internal energy, the substance must absorb heat in order to make the phase transition. Conversely, if the new arrangement has a lower internal energy, heat will be released as the transition occurs.

In this experiment you will determine how much more energy is contained in one gram of steam at 100°C, than in one gram of water at the same temperature. This value is called the Latent Heat of Vaporization of water.

⚠ ***CAUTION:*** *This experiment involves the use of boiling water and steam. Work carefully.*

Procedure

1. Measure T_{rm}, the room temperature.

2. Set up a steam generator with a water trap as shown in Figure 3.1. The tube lengths should be approximately as shown in the figure.

3. Determine M_{cal}, the mass of a the empty, dry calorimeter.

4. Fill the calorimeter approximately 1/2 full of cool water about 10° C below room temperature.

5. Turn on the steam generator and wait for the steam to flow freely for at least a minute.

6. Measure $T_{initial}$ and $M_{cal + water}$, the temperature of the cool water and the mass of the water plus calorimeter.

7. Immediately immerse the free end of the short tube into the cool water in the calorimeter. Stir the water continuously with the thermometer.

IMPORTANT: *The bottom of the water trap should be kept higher than the water level in the calorimeter to avoid water being pulled from the calorimeter back into the water trap.*

8. When the water temperature, T, gets as far above room temperature as it was initially below room temperature, remove the steam tube. Continue stirring the water and record the highest stable temperature attained by the water (T_{final}).

IMPORTANT: *Always remove the steam tube from the water before turning off the steam generator heat. (Can you explain why?)*

9. Immediately determine M_{final}, the mass of calorimeter plus water plus (condensed) steam.

Data

T_{rm} = ___________

M_{cal} = ___________

$T_{initial}$ = ___________

$M_{cal + water}$ = ___________

T_{final} = ___________

M_{final} = ___________

Calculations

When steam condenses in cool water, heat energy is released into the water in two ways. First, the latent heat of vaporization is released. With this release of heat, the steam is converted into water, but the newly converted water is still at boiling temperature, 100° C. Second, the newly converted water releases heat as it comes into thermal equilibrium with the cooler water at a final equilibrium temperature, T_{final}.

According to the principle of the conservation of energy, the total heat released by the steam equals the total heat absorbed by the cooler water. Stated mathematically:

$$(M_{steam})(H_v) + (M_{steam})(1\ \text{cal/g K})(T_{steam} - T_{final}) = (M_{water})(1\ \text{cal/g K})(T_{final} - T_{initial})$$

$M_{steam} = M_{final} - M_{cal + water}$ = _________________

$M_{water} = M_{cal + water} - M_{cal}$ = _________________

T_{steam} = 100 °C

H_v = the latent heat of vaporization per gram of water

Use your data and the above information to determine H_v.

NOTE: The thermometer also absorbs a certain amount of heat during the experiment. As a good approximation, assume that the heat capacity of the thermometer is equivalent to that of 1 g of water (i.e., add 1 g to M_{water} the above equation).

H_v = ___________

Questions

1. Why would an injury caused by 1 g of steam at 100° C do more damage than an injury caused by 1 g of water at 100° C?

2. Speculate on how the heat of vaporization might influence climate and weather systems.

3. In what way does water used to cook food serve as a refrigerant? (Hint: What happens when the water all boils away?)

Experiment 4: Latent Heat of Fusion

Equipment Needed

- Calorimeter
- Thermometer
- Ice in water (at melting point)
- Warm water

Introduction

Just as steam has a higher internal energy content than water, so water has a higher internal energy content than ice. It takes a certain amount of energy for the water molecules to break free of the forces that hold them together in the crystalline formation of ice. This same amount of energy is released when the water molecules come together and bond to form the ice crystal.

In this experiment, you will measure the difference in internal energy between one gram of ice at 0° C and one gram of water at 0° C. This difference in energy is called the latent heat of fusion of water.

Procedure

1. Measure T_{rm}, the room temperature.
2. Determine M_{cal}, the mass of the empty, dry calorimeter.
3. Fill the calorimeter approximately 1/2 full of warm water about 15° C above room temperature.
4. Measure $M_{cal + water}$, the mass of the calorimeter and water.
5. Measure $T_{initial}$, the initial temperature of the warm water.
6. Add small chunks of ice to the warm water, wiping the excess water from each piece of ice immediately before adding. Add the ice slowly, stirring continuously with the thermometer until each chunk melts.
7. When the temperature of the mixture is as much below room temperature as the warm water was initially above room temperature and all the ice is melted, measure the final temperature of the water (T_{final}).
8. Immediately after measuring T_{final}, weigh the calorimeter and water to determine M_{final}.

Suggested Additional Experiment

Repeat the above experiment, but, instead of ordinary ice, use the material which is packaged in metal or plastic containers to be frozen and used in picnic coolers.

Data

T_{rm} = ________________

M_{cal} = ________________

$M_{cal + water}$ = ________________

$T_{initial}$ = ________________

T_{final} = ________________

M_{final} = ________________

Calculations

According to the principle of the conservation of energy, the quantity of heat absorbed by the ice as it melts and then heats up to the final equilibrium temperature must equal the quantity of heat released by the warm water as it cools down to the final equilibrium temperature. Mathematically:

$$(M_{ice})(H_f) + (M_{ice})(1 \text{ cal/g K})(T_{final} - 0° \text{ C}) = (M_{water})(1 \text{ cal/g K})(T_{initial} - T_{final})$$

$M_{ice} = M_{final} - M_{cal + water}$ = ____________________

Use your data and the above information to determine H_f, the latent heat of fusion per gram of water.

H_f = the latent heat of fusion per gram of water

Questions

1. What advantage might the commercially packaged coolant material have over ice other than that it produces less mess? (If you didn't perform the optional part of the experiment, what properties would a material need in order to be a better coolant than ice?)

2. Design an experiment to determine which of two substances (for instance, ice and packaged coolant) will keep an insulated food cooler

a. cool for the longest time, and

b. at a lower temperature.

Technical Support

For assistance with any PASCO product, contact PASCO at:

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