LABORATORY VI
ENERGY AND THERMAL PROCESSES

The change of the internal energy of a system is often, but not always, signaled by a change in its temperature. This type of change is clearly very important for biological systems. After all one way to determine if you are ill is to measure your temperature. In this lab you will concentrate on quantifying the changes in internal energy within the framework of conservation of energy.

In the problems of this lab, you will master the relation of the temperature of objects to their internal energy and the notion of specific heat. Specific heat is a historical name for a quantity that isn't actually heat. You now know that energy can be transferred from one object to another by mechanical means. In this laboratory you will also explore the very common energy transfer from an object at higher temperature to an object of lower temperature. The energy transferred is called heat.

Many biological processes depend on energy cycles for their operation. One of the characteristics of a biological cycle is that energy is input and energy is output but the energy and state of the system itself does not change. In this laboratory you will investigate a system that undergoes a cycle: a heat engine.

OBJECTIVES:

After successfully completing this laboratory, you should be able to:

- Use the principle of conservation of energy as a means of predicting the behavior of systems transferring energy by a variety of mechanisms such as mechanical, electrical, and heat.

- Calculate the change of internal energy of an object when its temperature changes.

- Use the concept of specific heat to calculate the energy change of an object.

PREPARATION:

Read Serway & Jewett, sections 6.8, 16.2, 16.4, 17.1, 17.2, 17.4 - 17.7, 18.1 - 18.3, and 25.1.

Before coming to lab you should be able to:

- Define and recognize the differences between these concepts:
    - heat and temperature
    - internal energy and energy transfer
    - heat and specific heat.
    - energy and power.

- Use the principle of conservation of energy and define a system for its use.

- Use the heat capacity to determine the change in internal energy of a system.

- Define what is meant by efficiency.

PROBLEM #1:
POWER AND TEMPERATURE CHANGE

You have a position working with a group investigating biological mechanisms that determine a predisposition to obesity. Your assignment is to measure the rate that energy is output by certain types of cells when a nutrient is introduced. To begin this study, you have decided to use a calorimetric technique. A culture of cells with the appropriate nutrient is placed inside a closed container. That container is submerged in a water bath and you measure the rate that the temperature of the bath changes. To calibrate the apparatus, you decide to use a light bulb connected across a known voltage as a power source. You know that the power output by the bulb is just the current through the bulb times the voltage across the bulb. You then will compare that power to the rate that the internal energy of the water bath changes by measuring its temperature as a function of time. To accomplish this calibration, you calculate rate of temperature change as a function of the voltage across the bulb, the current through the bulb, the specific heat of the water, and the amount of the water. You know that even with good insulation, your apparatus will transfer some energy to the outside and your measurements will allow you to correct for this.

EQUIPMENT

You will have a constant voltage power supply, wires, a light bulb, digital multimeters (DMMs), a digital thermometer, a balance, water, and water containers.
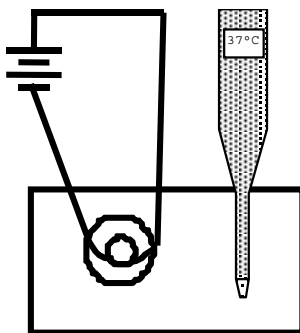
PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.

WARM-UP QUESTIONS

Read Serway & Jewett, sections 6.8, 16.2, 17.1, 17.2, and 25.1.

1. Make a sketch of the situation. Identify and label the quantities you can measure or look up. Write down the general conservation of energy equation and decide how it will apply to this situation.

2. Identify your system. Decide on the initial time for which you want to calculate the energy of your system and draw the system. Write down the expression for the energy of your system at that time. Decide on the final time for which you want to calculate the energy of your system and draw it. Write down the expression for the energy of your system at that time. Write down an expression for any energy transferred to or from your system. Identify the energy transfer on your drawing and whether the terms represent energy input or energy output for your system.

3. Write an equation that gives the rate that the energy of the liquid changes as its temperature changes. Write the equation that gives the rate that energy is output by the bulb.

4. Determine if any of the energy inputs into the system are small enough to be neglected. Determine if any of the energy outputs into the system are small enough to be neglected. Write down the conservation of energy equation specifically for this situation. Change this to a rate equation by using calculus.

5. Assuming that nothing but electricity transfers energy to or from your system, write an equation for the change in the temperature of the liquid as a function of time. Sketch a graph representing this function and write down how you can determine the power transferred from your system.

EXPLORATION

Assemble the circuit. Verify that you can measure current flowing in your circuit and voltage across the bulb. Determine if you need to do these measurements continuously or just once by making the measurements several times before putting the bulb in the liquid. See *Appendix A* for instructions about how to use the DMM to measure current and voltage. **BE SURE TO CONNECT THE DMM CORRECTLY FOR EACH MEASUREMENT!**

The submerged light bulb will heat the liquid in the bottle very slowly. Determine how much liquid should be used for the best result. Explain your reasoning. Try a short trial to see how much time it takes for the temperature of water to go up 1 degree. Try a few ideas to see if you can speed up the processes. Should you measure the temperature in Fahrenheit, or Celsius? Does it matter?

Determine how you can minimize any energy transfer that you cannot measure. Make some quick measurements to see how well they work.

Outline the measurement procedure you plan to use and conduct tests to estimate how long your measurement will last. The longer the measurement takes, the larger will be the affects of uncontrolled and unavoidable energy transfer. Write down your measurement plan.

MEASUREMENT

Using the procedure from your exploration, make the necessary measurements that will allow you to determine the power output of the light bulb from electrical measurements and also from the temperature increase of the water if other energy transfers were negligible.

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ANALYSIS

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From the data you collected, create a graph of the *temperature vs. time*. Use that graph to determine the power input to the water.

Compare the electrically measured power output of the light bulb to its power output calculated from the temperature of the water using the conservation of energy. From your results determine the size of the other sources of energy transfer.

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CONCLUSION

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Did your results match your prediction? Explain if it did not.

How do these two values of the bulb's power compare? Are they within the uncertainty of your measurement accuracy? How significant is the energy transferred to the surrounding air? What other form(s) of energy does a bulb generate?
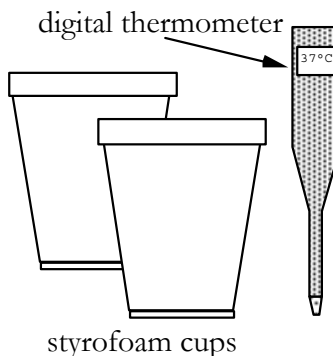
Can you use this type of apparatus to make your measurements of metabolic processes? What modifications might be necessary?

PROBLEM #2:
SPECIFIC HEAT OF SIMPLE OBJECTS

You are working in a research group investigating ways of transporting organs more effectively. Successful organ transplants require the organ be kept within a narrow range of temperatures during transportation from the donor to the recipient. The transportation device must be as small and compact as possible. In the procedure being tested, the organ is immersed in a liquid. You have been asked to calculate how the temperature of the organ responds to the temperature of its surrounding liquid and vice versa so you devise a procedure to measure its specific heat. An organ is very complex so you decide to test your method on metal objects of known specific heat. First you calculate the specific heat of an object as a function of the initial temperatures of both the metal and the liquid, and the final temperature after the metal and liquid reach equilibrium and the relevant properties of the metal and the liquid. Then you will check you calculation in the lab.

EQUIPMENT

You will have two different homogenous metal objects. Styrofoam cups, a digital thermometer, a balance, a stopwatch, a pair of scissors, and a ruler are also available.

digital thermometer

styrofoam cups

PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.

WARM-UP QUESTIONS

Read Serway & Jewett, sections 16.2, 17.1, and, 17.2.

1. Make two sketches of the situation: one just after the object is placed into the water and the other one after the object and water reach the same temperature. Label all of the quantities that you know or wish to know on both sketches.

2. Write down the general conservation of energy equation. To apply it to this situation, first decide on the system that you wish to consider. Write down a conservation of energy equation for this system and the initial and final time represented by your sketches in question 1.

3. Write down an equation that relates the initial internal energy of your system to its temperature or temperatures. Do the same for the final internal energy. Decide if you know the other quantities necessary to calculate the internal energy of your system from its temperature(s) or must calculate them from other information.

4. Determine if there is any energy transferred either to or from your system from another object between the initial time and the final time. Decide if this energy transfer is small enough to be neglected. If it is not, write down the source or receiver of this energy. Calculate this energy transfer by applying the conservation of energy equation to the source or receiver (i.e. taking the source/receiver as the system for another conservation of energy equation).

5. Write down a mathematical plan to solve your conservation of energy equation or equations for the specific heat of the object as a function of quantities you can measure.

EXPLORATION

WARNING: Be careful not to get scalded while handling heated water, as well as the hot plates.

Optimal use of the Styrofoam cups can minimize the energy transfer from the water to the environment. First you need to determine the approximately amount of time you will need to do your measurement. This tells you the time the energy transfer of your cup needs to be negligible. The shorter the time, the less energy will be transferred out of the cup. Try different amounts of water to determine how this time depends on the amount of water in the cup. Do you want to use a lot of water or a little?

Now that you have decided on the amount of water, put that amount of hot water in your cup and measure the temperature change for the time you will need. Is it negligible? If not, try different configurations of Styrofoam cups. Do two cups (one inside the other) work better? Three cups? Does covering the cup with a lid made from another cup help? After you have minimized the energy transfer from the cup and if it is still not negligible, measure that energy transfer as a function of time so that you can use it in your conservation of energy equation.

Determine which initial water temperature will minimize any unwanted energy transfers. Should it be colder than room temperature, equal to room temperature, or greater than room temperature?

You cannot measure the temperature of a metal object by sticking a thermometer in it or putting a thermometer on it. Discuss with your group to decide on a procedure for accurately measuring the initial and final temperature of your object using a thermometer.

The metal object is not the only thing in contact with the water during the measurement. The inside surface of the Styrofoam cup and the thermometer contact the water. Since both of those objects change their temperature to match that of the water, energy is transferred between them and water. Make a quick measurement to determine if this amount of energy is negligible for your purpose. If it is not, measure it and include this energy transfer in your conservation of energy equation.

Carefully examine the thermometer. You can tell if the scale is *Fahrenheit* or *Celsius* by measuring the room temperature. Does this thermometer have a switch to change temperature scales? If so set it to the one best suited for your calculations. Determine what part of the thermometer actually measures

the temperature by holding your hand on different parts and seeing it the readings change. Make sure that the temperature measuring part is fully submerged in the water.

Decide if your measurement will be more accurate if you leave the thermometer in the water for the entire time or if you only insert the thermometer briefly when you want a temperature measurement.

What procedure should you use for putting the object into the cup? Should this be done fast or slow? Does water splash affect your measurement?

Write down a plan for giving you the most accurate results possible.

MEASUREMENTS

Follow the plan that you outlined in your Exploration.

Take temperature measurements for each object if the object starts out much colder than the water temperature and also if it starts out much warmer than room temperature.

ANALYSIS

Based on your temperature measurements, calculate the specific heat of the two homogeneous objects. What is the uncertainty in your measurement? Compare the specific heat for each object if it starts hot or starts cold. Compare this difference with your measurement uncertainty.

Use the chart at the end of this laboratory to look up the specific heat of your objects. What material are your objects made of?

CONCLUSION

Did your results agree with your prediction? Explain.

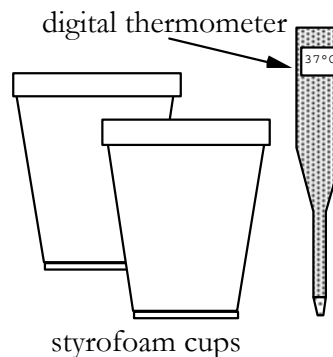Does the specific heat of an object depend on whether it is hot or cold?

If you knew the specific heat of an organ and wished to cool it from body temperature to a certain final temperature by immersing it in a certain amount of liquid, what formula would you use to determine what the initial temperature of the liquid should be?

PROBLEM #3:
SPECIFIC HEAT OF COMPLEX OBJECTS

You are working in a research group investigating ways of transporting organs more effectively. Successful organ transplants require the organ be kept within a narrow range of temperatures during transportation from the donor to the recipient. The transportation device must be as small and compact as possible. In the procedure being tested, the organ is immersed in a liquid. You have been asked to calculate how the temperature of the organ responds to the temperature of its surrounding liquid and vice versa so you devise a procedure to measure its specific heat. Although an organ is very complex you have previously measured the specific heat of the types of tissue of which it is comprised. You also have a computer model of how each type of tissue is distributed in the organ. From this information, you believe you can calculate the specific heat of an organ but you need to check your calculation on a simple laboratory model. The model you decide to use an object consisting of two different kinds of metal that you will immerse in a liquid bath.   First you calculate the specific heat of an object as a function of the initial temperatures of both the metal and the liquid, and the final temperature after the metal and liquid reach equilibrium and the relevant properties of the metal and the liquid. Then you will check you calculation in the lab.

EQUIPMENT

You will have three different metal objects. Two of them will be the homogeneous metals making up a complex object. Styrofoam cups, a digital thermometer, a balance, a stopwatch, a pair of scissors, and a ruler are also available.

digital thermometer

styrofoam cups

PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.

WARM-UP QUESTIONS

Read Serway & Jewett, sections 16.2, 17.1, and, 17.2.

1. Make two sketches of the situation: one just after the object is placed into the water and the other one after the object and water reach the same temperature. Label all of the quantities that you wish to know on both sketches.

2. Write down the general conservation of energy equation. To apply it to this situation, first decide on the system that you wish to consider. Write down a conservation of energy equation for this system and the initial and final time represented by your sketches in question 1.

3. Write down an equation that relates the initial internal energy of your system to its temperature or temperatures. Do the same for the final internal energy. Decide if you know the other quantities necessary to calculate the internal energy of your system from its temperature(s) or must calculate them from other information.

4. Determine if there is any energy transferred either to or from your system from another object between the initial time and the final time. Decide if this energy transfer is small enough to be neglected. If it is not, write down the source or receiver of this energy. Calculate this energy transfer by applying the conservation of energy equation to the source or receiver (i.e. taking the source/receiver as the system for another conservation of energy equation).

5. Write down a mathematical plan to solve your conservation of energy equation or equations for the specific heat of the object as a function of quantities you can measure.

6. Write down an equation to calculate the specific heat of the complex object from the specific heat of each homogeneous object and the measured volume of each material making up the complex object.

EXPLORATION

WARNING: Be careful not to get scalded while handling heated water, as well as the hot plates.

Optimal use of the Styrofoam cups can minimize the energy transfer from the water. First you need to determine the approximately amount of time you will need to do your measurement. This tells you the time the energy transfer of your cup needs to be negligible. Try different amounts of water to determine how this time depends on the amount of water in the cup. Do you want to use a lot of water or a little?

Now that you have decided on the amount of water, put that amount of hot water in your cup and measure the temperature change for the time you will need. Is it negligible? If not, try different configurations of Styrofoam cups. Do two cups (one inside the other) work better? Three cups? Does covering the cup with a lid made from another cup help? After you have minimized the energy transfer from the cup and if it is still not negligible, measure that energy transfer as a function of time so that you can use it in your conservation of energy equation.

Determine which initial water temperature will minimize any unwanted energy transfers. Should it be colder than room temperature, equal to room temperature, or greater than room temperature?

You cannot measure the temperature of a metal object by sticking a thermometer in it or putting a thermometer on it. Discuss with your group to decide on a procedure for accurately measuring the initial and final temperature of your object using a thermometer.

The metal object is not the only thing in contact with the water during the measurement. The inside surface of the Styrofoam cup and the thermometer contact the water. Since both of those objects

change their temperature to match that of the water, energy is transferred between them and water. Make a quick measurement to determine if this amount of energy is negligible for your purpose. If it is not, measure it and include this energy transfer in your conservation of energy equation.

Carefully examine the thermometer. You can tell if the scale is *Fahrenheit* or *Celsius* by measuring the room temperature. Does this thermometer have a switch to change temperature scales? If so set it to the one best suited for your calculations. Determine what part of the thermometer actually measures the temperature by holding your hand on different parts and seeing it the readings change. Make sure that the temperature measuring part is fully submerged in the water.

Decide if your measurement will be more accurate if you leave the thermometer in the water for the entire time or if you only insert the thermometer briefly when you want a temperature measurement. What procedure should you use for putting the object into the cup? Should this be done fast or slow? Does water splash affect your measurement? Write down a plan for giving you the most accurate results possible.

MEASUREMENTS

Follow the plan that you outlined in your Exploration.

To calculate the specific heat of the complex object, you will need to know the mass of each material that makes up the object. You cannot take the object apart and directly measure each mass. You can, however, measure the volume of each of the materials in the complex object. You can determine the density of each material by making measurements on the homogeneous objects.

ANALYSIS

Based on your temperature measurements, calculate the specific heat of the complex object. What is the uncertainty in your measurement? Compare the measured specific heat of the object for cases when it starts hot or cold. Compare this difference with your measurement uncertainty.

Based on your volume and mass measurements and the specific heats of the homogeneous objects, calculate the specific heat of the complex object. What is the uncertainty in your measurement? Compare this specific heat to that calculated from the temperature change.

CONCLUSION

Did your results agree with your prediction? Explain. Does the specific heat of an object depend on whether it is hot or cold? Can you calculate the specific heat of a complex object if you know the specific heats of the materials that comprise it? Can the method be adapted to an object made of more than two different materials?

PROBLEM #4:
MECHANICAL ENERGY AND TEMPERATURE CHANGE

When running, you start thinking about the energy transformations of your body. You know that you are reducing your internal chemical energy stored in body fat. Since you are running at constant speed, your kinetic energy is not changing. Within your body, there are a lot of mechanical energy transformations such as your heart pumping and your muscles expanding and contracting. However, the effect of all of this internal body activity is that your body temperature increases. Your body then tries to maintain a constant temperature by sweating to cool down. Running seems to be the conversion of chemical energy to thermal energy. To test the idea that the primary effect of ordinary biological process is the conversion of chemical energy into thermal energy, you decide to make some measurements in the laboratory.

To make the biological process as simple as possible, you decide to convert your body's chemical energy into a mechanical energy that you can measure by exerting a force on an object for a distance. That mechanical energy is then converted into internal energy of an object and you measure the resulting temperature change. The device you decide to use is a cylinder with a handle that you can turn. The surface of the cylinder rubs against a rope wrapped loosely around it giving a frictional force. One end of that rope is attached to a heavy hanging block. The other end is free. You keep turning the cylinder so that hanging block is stationary. Then you know the frictional force. After a certain number of turns, you also measure the change of temperature of the cylinder.   You then calculate that temperature change as a function of the mass of the hanging object, the radius of the cylinder, the number of turns of the cylinder, and the heat capacity of the cylinder. You check your calculation in the lab.

EQUIPMENT

Side view   Front view
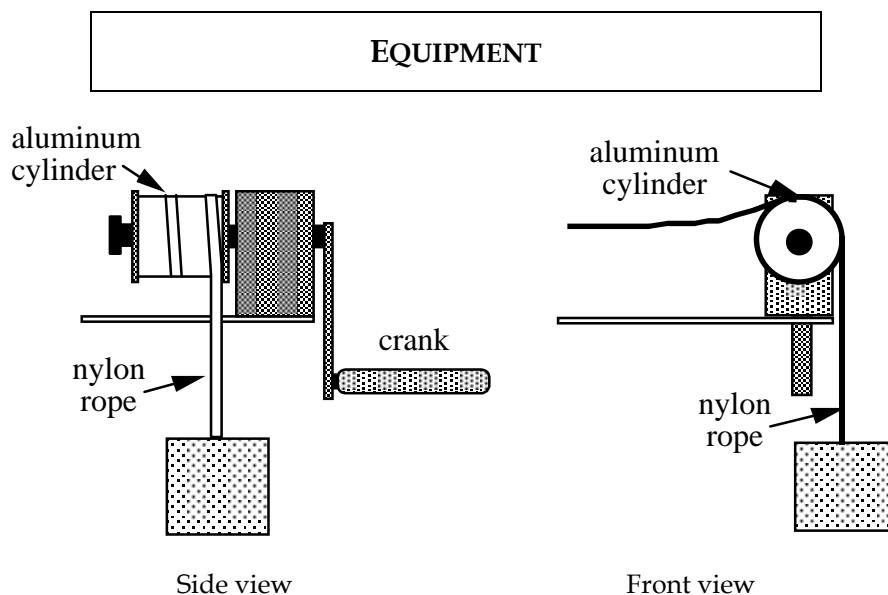
Your device consists of an aluminum cylinder that can be turned with a crank. A rope is wrapped around the cylinder a few times so that, as the crank is turned, the friction between the rope and cylinder is just enough to support a heavy block hanging from one end of the rope. For safety, the other end of the rope is held loosely such that no force is exerted on that end of the rope.

An electronic thermometer is embedded in the cylinder. It is read out with a digital multimeter (DMM). The instructions for using the DMM are in *Appendix A*. A balance, a stopwatch, and ruler are also available.

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PREDICTION

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Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.

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WARM-UP QUESTIONS

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Read Serway & Jewett, Sections 17.1 and 17.5.

1. Draw a picture of the situation. On your picture, label all relevant quantities.

2. Write down the general conservation of energy equation. Decide on the most convenient system for this situation. Decide on your initial time. What energy being transferred to or from your system between the initial and final times?

3. Write down the initial energy of your system, the final energy of your system, and the energy transferred to or from your system. Put these terms into the general conservation of energy equation.

4. Write a relationship between the friction force between rope and the cylinder and the weight of the block. Explain why you believe this relationship is true.

5. What is the direction of the frictional force relative to the motion of the rim of the cylinder where it makes contact? Does all of the frictional force transfer energy to the cylinder? Is this energy transfer an input or an output? Explain.

6. Write down the distance that the frictional force of the rope is exerted on the cylinder when the cylinder makes one complete turn. What is this distance if the cylinder makes N turns?

7. Are any other forces exerted on the cylinder? Explain how they affect the energy of the cylinder. Write down any approximations that you think are justified.

8. Write down the relationship between the temperature change of the cylinder and its internal energy change. Look up the specific heat for aluminum. Use the previous steps to write down an equation for the temperature change as a function of the mass of the hanging object, the radius of the cylinder, the number of turns of the cylinder, and the heat capacity of the cylinder.

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EXPLORATION

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Switch the DMM to the Ohms (Ω) setting and connect it to the electronic thermometer (called a thermistor). Check that you get a numerical reading of *resistance*. Try different scales to determine which is most useful. See *Appendix A* for instructions about how to use the DMM to measure resistance. Touch the cylinder with your hand to make sure the reading responds to your body temperature.

The relationship between the temperature of the thermistor and its resistance is complex and may be different for different devices. Look at the table of *Temperature versus Resistance* that is attached to the

base of the crank for yours. Make a graph of this table so that you can interpolate between temperature readings with sufficient accuracy. Estimate the current temperature of your cylinder and use your graph to see if the DMM reading is reasonable.

Try holding the block with your hand to give you a feeling for the amount of force necessary to hold the block steady. The block is heavy so **always make sure no one's foot is under it in case it drops!**

Practice rotating the aluminum cylinder uniformly so that the block hangs steady several centimeters from the floor. You may have to adjust the amount of rope you have wound around the cylinder. Try not to overlap the rope with itself since you want it to rub against the cylinder. Support the other end of the rope with your hand. Very little force (much less than the weight of the block) should be applied at this end while the crank is being turned.

Watch how the DMM reading changes when you rotate the cylinder to determine how many rotations you will have to make to get a significant temperature change.

Some energy is transferred from the cylinder into the air. This energy transfer is difficult to calculate but needs to be represented in your conservation of energy equation. Plan some way of estimating this. Write down your experimental plan.

MEASUREMENT

Using your plan, make the necessary measurements. Check your conservation of energy equation and all of the energy terms from the Warm-up Questions to make sure you have measured everything you need. Repeat your measurement enough times so that the average of all your measurements gives reliable results.

Make your measurement of the cylinder's energy transfer to the air for the amount of time this transfer actually takes place during your friction measurement. Since this energy transfer depends on the cylinder temperature, it is important to start the measurement at the right cylinder temperature. You can take apart the apparatus to measure the properties of the cylinder.

ANALYSIS

From your measurement results, determine the change in the cylinder's internal energy that you expect from mechanical energy transfer. Compare this to the change of the cylinder's internal energy directly determined from its temperature change.

Compare the size of the measured mechanical energy transferred to the cylinder by the frictional force to your separate measurement of the energy transferred from the cylinder to the air. Which is larger? Is the energy transfer to the air negligible? If not, include it in your conservation of energy equation.

Use your Prediction equation to calculate the *expected* temperature change.

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CONCLUSION

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Compare your predicted and measured temperature difference. Explain any difference. Estimate the amount of energy your body converted from chemical energy turning the cylinder.

PROBLEM #5:
ENERGY CYCLES AND EFFICIENCY

You are trying to understand the efficiency of the complex energy cycles found everywhere in biological systems. For example, plants convert light energy into chemical energy stored in certain molecules (ATP) using intracellular organelles called chloroplasts. The energy is transported by these molecules to the parts of a cell that use it for growth, for moving water, or for moving leaves toward the sun. To test your understanding of energy conservation and the efficiency of cyclic processes, you decide to study a physical model that is simpler than a biological system.

The device that you decide to study uses thermal energy to lift objects. A piston that lifts the objects moves up and down inside of a cylinder filled with air. The air inside the cylinder is connected with a tube to a sealed metal can that can be heated and cooled by placing it in hot or cold water. A cycle starts with an object on top of the piston and the can immersed in cold water. The can is then immersed in hot water and the cylinder rises. At its highest point you remove the object and the piston rises some more. Next the can is placed into cold water. The piston descends to its lowest point and an object is put on it causing it to go lower. The system is now in its original state. Then the cycle is repeated. Even though the process is very simple, compared to a biological cycle, all of the heat from the water does not go into lifting the object. The system has an efficiency which you decide to calculate.

EQUIPMENT

A piston moves freely in the glass cylinder. The metal can is immersed in either cold or hot water to transfer heat to the air in the cylinder. Make sure that the can is tightly sealed. **NEVER IMMERSE THE CYLINDER IN WATER.** You will also have thermometers, weights, a balance, and a ruler.

Platform
Glass Cylinder
Piston
Flexible Tubing
Valves
Tin Can

PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you are making.

WARM-UP QUESTIONS

Read Serway & Jewett, Sections 18.1-18.3.

1. Draw a picture of the system and label the relevant quantities. Using this sketch, describe how to measure the pressure in the cylinder. Assume that air is an ideal gas. Calculate the amount of air in the cylinder in terms of quantities you know or can measure.

2. Write down the general conservation of energy equation. Decide on the most convenient system for this situation. Decide on your initial time and choose your final time when the system returns to its initial state. Is any energy being transferred to or from your system between the initial and final times? The energy transfers may happen at different times in the cycle so write down a list of what the system is doing for each energy transfer.

3. Using your list, draw a pressure versus volume diagram for the cycle. Do this by first drawing axes to represent pressure and volume. Then:

    a. Start with the initial state and label that point. At that point also write the labels for the pressure, volume and, temperature of the system.

    b. Next draw a line or curve that represents the behavior of the system when the can is put into the hot water. During that time, does the pressure and/or volume of the system change? Does the temperature of the system change? Does the energy of the system change? Write equations for all of these changes in terms of quantities you know or can measure.

    c. Label the point where the system stops changing. At that point also write the new labels for the pressure, volume, and temperature of the system.

    d. Next draw a line or curve that represents the behavior of the system when the object is removed. During that time, do the temperature, pressure, volume, and energy of the system change? Write equations for all of these changes in terms of quantities you know or can measure.

    e. Label the point where the system stops changing. At that point also write the new labels for the pressure, volume, and temperature of the system.

    f. Next draw a line or curve that represents the behavior of the system when the can is put into the cold water. During that time, do the temperature, pressure, volume, and energy of the system change? Write equations for all of these changes as a function of quantities you know or can measure.

    g. Label the point where the system stops changing. At that point also write the new labels for the pressure, volume, and temperature of the system.

    h. Next draw a line that represents the behavior of the system when the object is put on the platform. During that time, do the temperature, pressure, volume, and energy of the system change? Write equations for all of these changes as a function of quantities you know or can measure.

    i. Label the point where the system stops changing. At that point also write the new labels for the pressure, volume, and temperature of the system. The system should now be in its original state and ready for the next cycle.

j. For every line on your plot, write symbols that indicate whether, during that time, there is work input or output and heat input or output.

4. Using your labeled P-V diagram, write down the conservation of energy equation for each line of your diagram.

5. Identify the terms you need to calculate the efficiency of the process. The efficiency is the ratio of the useful energy output to the energy input from the energy source. Write down the conservation of energy equation or equations containing those terms.

EXPLORATION

Familiarize yourself with the piston apparatus. Learn how the valves work. Does the piston move easily in the cylinder when the valves are open? When the valves are closed? When one is open and one is closed? All valves are likely to leak at some level. Check if your valves leak enough to seriously affect your measurement. Record how you made this determination.

The piston makes a seal with the cylinder but all such seals leak at some level. Check if your piston leaks enough to seriously affect your measurement. Record how you made this determination. Check to see if this leak depends on how much mass you put on the platform. This will tell you the maximum mass for which your results will be reliable.

How will you measure the height of the piston accurately and consistently? How large a mass will you need to give you a height change that you can measure accurately? This will tell you the minimum mass for which your results will be reliable.

Check that the can does not leak too much to affect the reliability of your measurements. If it does, check the stopper.

Run through the cyclic procedure several times without taking any measurements. Make sure you notice where the piston moves and where it stops when you do each operation. Note how long each motion takes to complete. These are the points you need to measure. When you move the can from one water bath to another, does the piston move as you expect?

Make a plan for moving through the cycle fast to minimize the effects of leaks. Practice your procedures so that you can make accurate measurements.

MEASUREMENT

Execute the measurement plan you created in the Exploration section to get the data you need. Run the cycle a few times for a given platform mass so that your average gives reliable results.

Measure the quantities necessary to determine the pressure in the cylinder at each stage.

Note the uncertainties of all of your measurements.

ANALYSIS

Create a P-V diagram based on your data. Using conservation of energy for the appropriate step(s) of the cycle, determine the efficiency for lifting the object. What is the uncertainty in this value?

CONCLUSION

Were you able to realize experimentally the predicted P-V diagram for the cycle? How much smaller (or larger) was the efficiency you calculated compared to the Carnot efficiency? Provide reasons for the discrepancies.

How could you relate this system's efficiency with a biological system you are interested in? Do you think that this is a reasonable model? Explain.

Thermal Properties of Certain Materials

Material	Specific Heat[†]	Density[‡]	Latent Heat of Fusion[†]
	J/g °C	g/cm^3	kJ/g
Aluminum	0.900	2.7	0.40
Chromium	0.460	7.14	0.33
Cobalt	0.419	8.71	0.28
Copper	0.39	8.92	0.20
Gold	0.13	19.3	0.063
Iron	0.452	7.86	0.27
Lead	0.13	11.34	0.023
Magnesium	1.02	1.75	0.37
Manganese	0.477	7.3	0.27
Mercury	0.14	13.59	0.011
Molybdenum	0.25	10.2	0.29
Nickel	0.444	8.9	0.30
Platinum	0.13	21.45	0.10
Potassium	0.754	.86	0.061
Silicon	0.71	2.33	1.80
Silver	0.24	10.5	0.11
Sodium	1.23	.97	0.11
Tin	0.23	5.75	0.059
Titanium	0.39	4.5	0.42
Zinc	0.093	7.04	0.11

Thermal Properties of Water and Alcohol

Substance	Specific Heat	Latent Heat of Fusion	Melting Temperature	Latent Heat of Vaporization	Boiling Temperature
	J/g °C	J/kg	°C	J/kg	°C
Water	4.19	3.35×10^5	0.00	2.256×10^6	100.00
Ice	2.09	3.35×10^5	0.00	n/a	n/a
Alcohol	2.48	10.42×10^5	-117.3	0.854×10^6	78.5

[†]   Adapted from Handbook of Tables for Applied Engineering Science
       by R. E. Bolz & G. L. Tuve, The Chemical Rubber Co., 1970.
[‡]   Adapted From The Handbook of Chemistry and Physics, R. C. Weast, ed.,
       The Chemical Rubber Co., 1970.

TA Name:

PHYSICS 1201 LABORATORY REPORT

Laboratory VI

Name and ID#:

Date performed: _____ Day/Time section meets: _____

Lab Partners' Names: _____

Problem # and Title: _____

Lab Instructor's Initials: _____

Grading Checklist	Points*
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and warm-up questions completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:	
ORGANIZATION (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL(incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

* An "R" in the points column means to rewrite that section only and return it to your lab instructor within two days of the return of the report to you.