LAB 16. HEAT AND INTERNAL ENERGY

16.1 Problem

- To examine experimentally the physics of heat capacity and phase change.
- To explore the concept of specific heat capacity.

16.2 Equipment

Activity 1: paper towel, container for salt/ice slush, thermometer, salt, crushed ice, timer

Activity 2: Activity 1 supplies plus metal cup, additional thermometer, paint stirrer

Activity 3: gas burner or hot plate, saucepan, water, calorimeter cup (Styrofoam), metal sample, tongs, cool water, thermometer, graduated cylinder, balance

16.3 Background

Temperature is related to heat, but the relationship can be complicated. Heat flows between objects at different temperatures until their temperatures become equal. Since temperature is a measure of molecular kinetic energy and heat is transferred energy, adding heat to an object usually raises its temperature.

However, if the *potential* energy of the system can vary, there are more possible outcomes. Energy transferring between potential and kinetic can change a system's temperature even if the system and its surroundings do not exchange heat. By the same token, transferred heat energy can change a system's potential energy without affecting its kinetic energy, keeping its temperature, though not its total energy, constant.

Phase changes can release or absorb heat without an accompanying change in temperature. Conversely, phase changes can change a system's temperature without a transfer of heat. In this activity, you will see examples of both of these types of process.

The activities in this lab provide a concrete demonstration of these abstractions. The different phases (solid, liquid, gas) of a substance have different potential energies. The difference in potential energy between two phases is called the *latent heat* of the phase change. For example, 80 cal/g must be added to melt 0°C ice, or, inversely, 80 cal/g must be removed from 0°C water to freeze it.

There are three activities in this lab. Activity 1 is very brief and leads into Activity 2. Start Activity 1 first, then begin Activity 2. You can then do Activity 3 while Activity 2 is in progress. *Read all of the directions thoroughly before doing anything.*

16.4 Measurement

Activity 1. Temperature of a Thermometer

In this activity, you will observe the temperature change of a cold thermometer in contact with room-temperature air. This will allow you to see how the rate of heat transfer between objects is related to the difference in the temperatures of the objects.

1. Make a cold bath. Fill a large Styrofoam container about half full of crushed ice or ice cubes. Make sure there is plenty of room in your container for both the cold bath and the water sample in the copper cup. Put in a handful of salt and add a little water to help the salt dissolve. Stir from the bottom frequently and well until the temperature drops to about –10 °C. It should be a soupy mix of ice and salt water. If your cold bath stops getting colder before it reaches –10 °C, stir in more salt.
2. Organize three people for data collection. The roles are (1) call out 5-s intervals using the stopwatch, (2) read and call out the temperature readings, and (3) record the temperatures in Table 1.
3. When you are ready to begin, record the temperature reading of the thermometer in the ice bath into Table 1, 0:00 time.
4. As you remove the thermometer from the ice bath, start the timer. Quickly dab the thermometer with a paper towel to remove any water or ice clinging to it. Place the thermometer on a dry paper towel. Read and record the temperature readings every five seconds until the readings do not change or you run out of room in the table.

Table 1. Thermometer in Air

Time (m:s)	Temp (°C)	Time (s)	Temp (°C)	Time (s)	Temp (°C)	Time (s)	Temp (°C)	Time (s)	Temp (°C)
0:00		1:00		2:00		3:00		4:00	
0:05		1:05		2:05		3:05		4:05	
0:10		1:10		2:10		3:10		4:10	
0:15		1:15		2:15		3:15		4:15	
0:20		1:20		2:20		3:20		4:20	
0:25		1:25		2:25		3:25		4:25	
0:30		1:30		2:30		3:30		4:30	
0:35		1:35		2:35		3:35		4:35	
0:40		1:40		2:40		3:40		4:40	
0:45		1:45		2:45		3:45		4:45	
0:50		1:50		2:50		3:50		4:50	
0:55		1:55		2:55		3:55		4:55	

Activity 2. Phase Change of Water

In this activity, you will immerse a cup of water in the cold bath and observe its temperature at regular intervals. This will allow you to plot a cooling curve for the water-to-ice phase change.

1. Set up your water sample. Add water to the cup to a depth of about 3 cm and measure its temperature. Place the cup in the ice/salt mixture and take temperature readings every minute until the temperature of the water reaches –5 °C. Record your data in Table 1. **Stir the water sample in the cup frequently**, at a very minimum each time before taking its temperature. Check periodically that the cold bath remains cold. If it warms, set up a new cold bath and transfer your sample cup to it.
2. Note the times when you first see ice forming in the cup and when there is no more liquid water. Enter these times in the spaces beneath Table 2. At the end, the thermometer will be stuck in the ice.
3. Once you have begun taking measurements, start Activity 3. Don't forget to continue your one-minute measurements while both activities are in progress. The phase change may take time.

Table 2. Phase change of water

Time (min)	Temp (°C)	Time (min)	Temp (°C)	Time (min)	Temp (°C)	Time (min)	Temp (°C)	Time (min)	Temp (°C)
0		15		30		45		60	
1		16		31		46		61	
2		17		32		47		62	
3		18		33		48		63	
4		19		34		49		64	
5		20		35		50		65	
6		21		36		51		66	
7		22		37		52		67	
8		23		38		53		68	
9		24		39		54		69	
10		25		40		55		70	
11		26		41		56		71	
12		27		42		57		72	
13		28		43		58		73	
14		29		44		59		74	

Time ice first formed: ____________ Time sample froze solid: ____________

Activity 3. Specific Heat Capacity

The property of matter that describes temperature's response to applied heat is called the *specific heat capacity*. In this experiment, you will determine the heat capacity of a metal sample.

You will heat a metal block to a known temperature (that of boiling water) and then measure how much it cools off when it is placed in a cup of cool water. The measured change in temperature will allow you to calculate the block's heat capacity.

When the hot metal contacts the cool water, heat flows from the metal to the water until thermal equilibrium. We will make the approximation that there is no heat flow between the system (water + metal) and the surroundings (everything else). Thus, the energy lost from the metal as it cools is exactly the same as the energy gained by the water as it warms.

The heat input q to the water raises its temperature an amount $\Delta T_{\mathrm{w}} = \frac{q}{c_{\mathrm{w}} M_{\mathrm{w}}}$, where c_{w} is the specific heat capacity of water and M_{w} is the water's mass. Correspondingly, the heat output q from the metal lowers its temperature an amount $\Delta T_{\mathrm{m}} = -\frac{q}{c_{\mathrm{m}} M_{\mathrm{m}}}$, where c_{m} and M_{m} are the metal's specific heat capacity and mass. These two equations contain two unknown quantities between them: q and c_{m}. Your goal is to find c_{m}.

1. Measure the mass of your metal object. Record this and subsequent data in Table 3.

2. Measure the mass of the empty calorimeter cup.

   Mass of cup: ______________

3. Place the metal block in the cup and add just enough water to cover the block.

4. Remove the block and transfer into the pan of boiling water.

5. Make sure that there is enough water in the saucepan that the block is completely covered. Heat the block in boiling water for at least three minutes. If the water stops boiling when you add the block, wait until it resumes boiling and start timing then.

6. While the water is boiling, add a little bit of ice to the water in the calorimeter. Once all the ice has melted (if any ice remains, remove it), measure the mass of the calorimeter containing the cool water.

   Mass of calorimeter and water: ______________

7. Subtract the mass of the empty calorimeter to find the mass of the water inside. Enter this value in Table 3.

8. Just before removing the metal block from the boiling water, stir the cold water in the calorimeter cup and measure its temperature T_1. Record this value in Table 3.

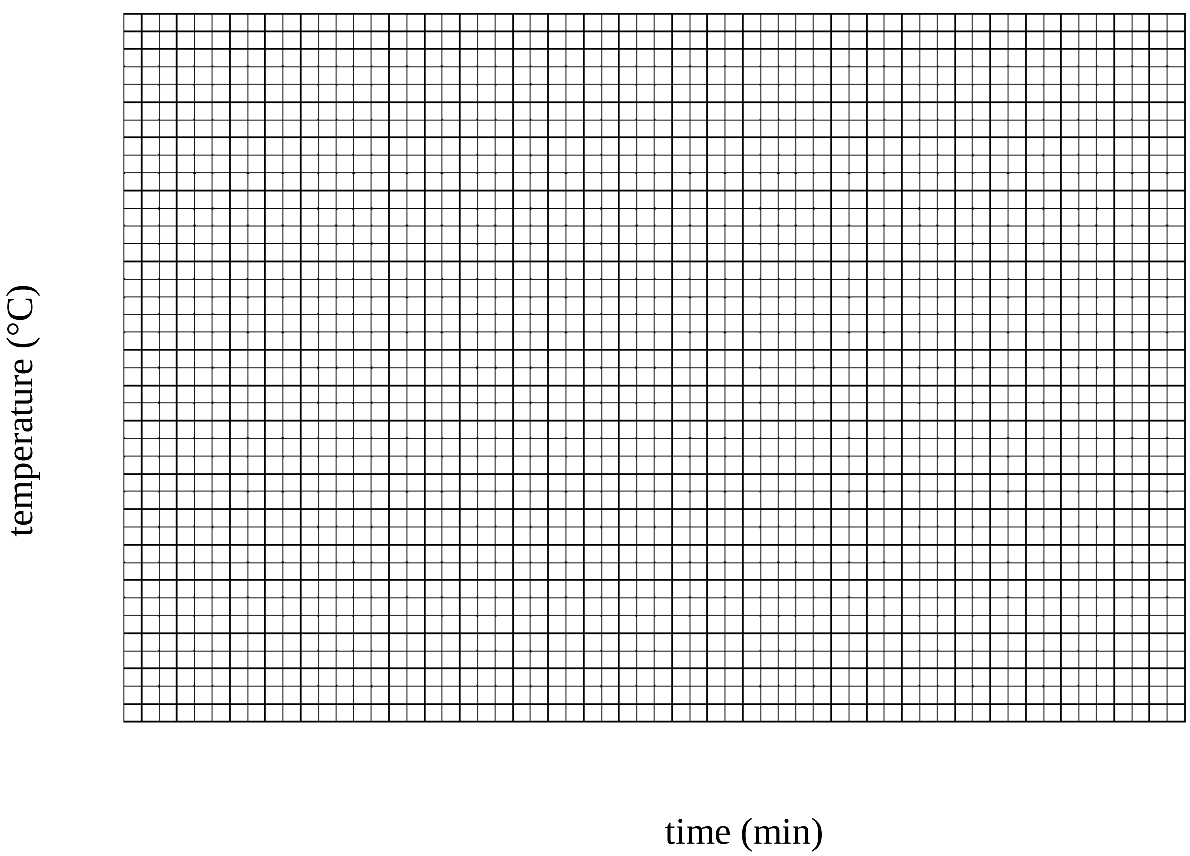
9. Use tongs to remove the metal block from the boiling water and immediately place it in the calorimeter cup. Stir until the temperature of the water in the calorimeter stops increasing. Record this value T_2 in Table 3.

Table 3. Metal Block in Water

Description of object:	
Mass of object:	
Mass of water in calorimeter cup:	
Temperature of cool water before immersion of object (T_1):	
Final temperature of equilibrated calorimeter water + object (T_2):	
Temperature change of calorimeter water $\Delta T_w = T_2 - T_1$	
Temperature change of object $\Delta T_m = T_2 - 100$ °C	

16.5 Analysis and Conclusion

1. Make a plot of temperature vs. time from the data in Table 1 ("Thermometer in Air"). Scale your graph to use at least half of each axis. Title your graph.



2. The slope of the plot is the rate of change of temperature. As time progresses, does the slope increase, decrease, or stay constant?

3. Calculate the temperature changes of the calorimeter water and the metal block. The temperature change of each substance is its final temperature minus its initial temperature, so:

   water: $\Delta T_w = T_2 - T_1 =$_______________

   metal block: $\Delta T_m = T_2 - 100\ °C =$________________

   Make sure you have the correct signs for the two ΔT's! Enter these values in Table 3 ("Metal Block in Water").

4. The following equation expresses the conservation of thermal energy between the water and the block, assuming that no energy goes anywhere else or enters from anywhere else. Below, $c_w = 1$ cal/(g·°C) = 4.184 J/(g·°C) (the specific heat capacity of water), c_m is the specific heat capacity of the metal, and M_w and M_m are the masses of the calorimeter water and metal sample.

   Solve this equation for c_m. Show your steps.

$$M_w \cdot \Delta T_w \cdot c_w = -M_m \cdot \Delta T_m \cdot c_m$$

5. Calculate the specific heat capacity of the metal (c_m) in Activity 3 using the formula you just derived. (Don't forget the units!)

6. Some accepted specific heat capacity values are tabulated in the following chart. Does the value you obtained match the accepted value for the material of your sample?

Values of c_p for some substances[1]

Substance	**Specific heat c_p (cal/g °C)**	**Specific heat c_p (J/g °C)**
Aluminum	0.215	0.900
Brass	0.092	0.380
Bronze	0.104	0.435
Carbon	0.121	0.507
Copper	0.0923	0.386
Iron	0.1075	0.450
Lead	0.0305	0.128
Silver	0.0564	0.236
Tin	0.052	0.217
Titanium	0.125	0.522
Tungsten	0.0321	0.134
Water	1.000	4.184

7. Barring unbelievable coincidence, the specific heat capacity value you obtained is not exactly equal to the value in the chart. What might have caused the difference?

[1] At 20°C and 1.0 atm.