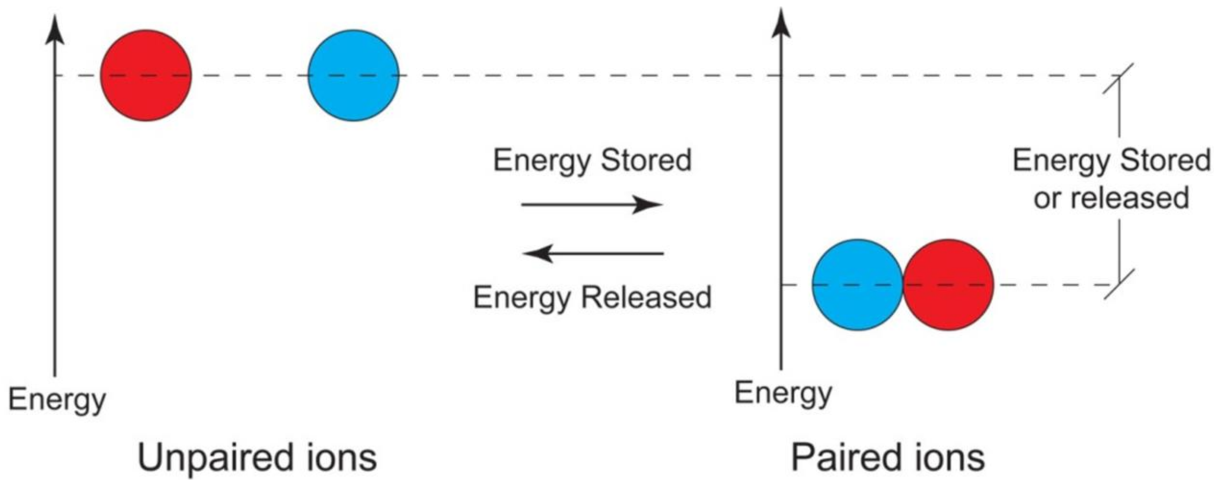
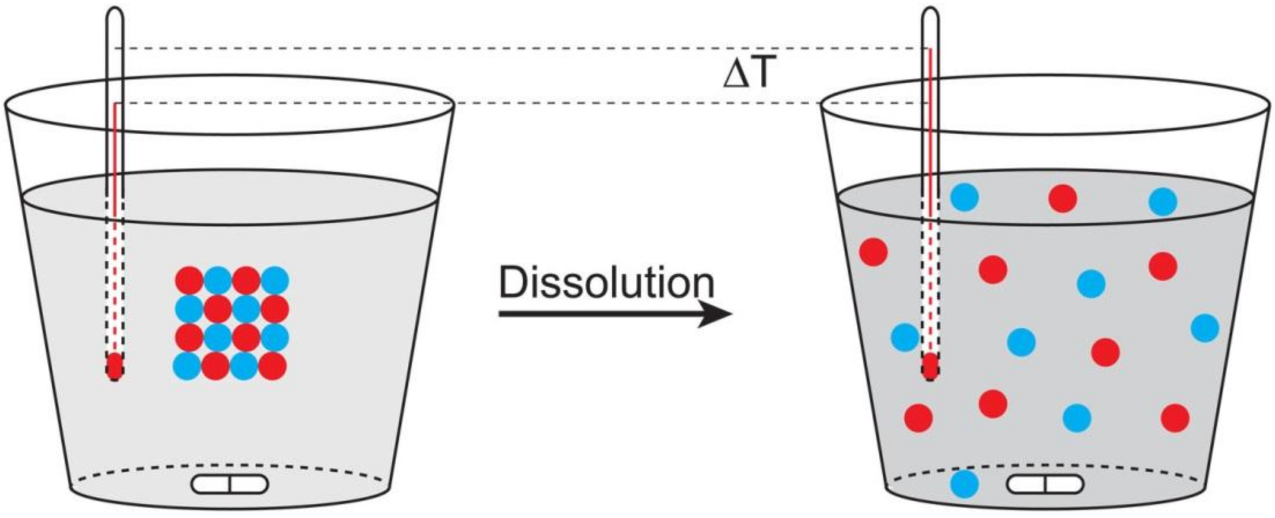
Background

Chemicals can store energy in a number of ways. One of these forms of stored energy occurs when two oppositely charged molecules interact – if the interaction forms a solid, this is commonly referred to as a salt molecule. This type of interaction is favorable due to a process called ion pairing as represented in the image below. When two molecules come together in this way, energy is stored in the form of potential energy.



This energy can be released if the bond is broken. The law of **Conservation of Energy (Standard 6.5)** tells us that the energy that was stored when the bond was formed must be exactly equal and opposite to the energy released upon bond breaking.

This experiment will exploit dissolution chemistry (dissolving a salt in water) to determine the amount of energy stored in the ionic bonds of various salts. To do this, we will monitor the temperature change of water upon dissolving NaCl, KOH, NH_4Cl, and NaOH. This change in temperature will allow us to approximate the stored energy using the equation discussed below.



To introduce the principles necessary to understand this laboratory experiment, consider holding a 100 gram brass rod to a flame for 30 seconds. What will happen to your hand if you pick up the rod? It will burn, of course. However, holding the same mass of water over a flame for 30 seconds will not boil the water; in fact, it will not even heat the water enough to make your finger uncomfortable if you submerge it. This phenomenon can be explained physically by the simple mathematical relationship (**Standard P-10**)

$$E = mC\Delta T \tag{1}$$

In this equation, *E* is the total amount of energy that is transferred from the flame, *m* is the mass of the object that is absorbing the heat (100g for our example), ΔT is the change in temperature that will occur due to absorbing the energy, and *C* is known as the specific heat (or heat capacity). This value is completely dependent on the substance that is absorbing the energy. Brass has a specific heat of 0.092 calories per gram Kelvin (cal g^{-1} ºC $^{-1}$ or $^{cal}/_{g\ ^{\circ}C}$) while the value for water is 1.00 cal g^{-1} ºC $^{-1}$.

Using Equation 1, we can easily justify why the brass burns us but the water does not. Assuming that a total of 1,000 calories of energy (E) are generated by the flame over 30 seconds, calculate the change in temperature for the brass and the water.

	Energy (E)	Mass (m)	Specific Heat (C) cal g^{-1} ºC^{-1}	Change in Temp (ΔT) ºC
Brass	*1,000 cal*	*100 g*	*0.092*	**108.7**
Water	*1,000 cal*	*100 g*	*1.00*	**10**

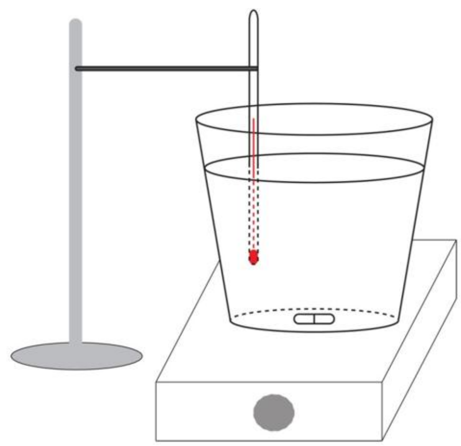
Hint for students: In this table, all italicized values can be filled in from the information provided, while the boldfaced value is calculated from Equation 1.

Test your understanding: *How much energy is stored in 25 grams of iron (C = 0.108 cal g^{-1} ºC^{-1}) when it is heated from 25 ºC to 70 ºC? How much energy is stored in the same mass of water undergoing the same change in temperature?*

In general, the physical relationship between specific heat and molecular properties can be attributed to how molecules interact. Of fundamental importance, students should understand that **transfer of energy can ONLY occur when molecules physically interact**. It then follows that the phase of matter influences the transfer of energy. Molecules in the gas phase are separated by large distances, so it is less likely that they will interact and heat will not be transferred efficiently. In condensed phases (liquids and solids), molecules are interacting very regularly and the molecular structure becomes much more important. Water is composed of a very complex matrix of intermolecular forces that allow it to store energy. On the other hand, the rigidity of the brass on the atomic level inhibits its ability to absorb energy. Students that choose to pursue science in college will learn about the physics behind the relationship between atomic structure and specific heat at a much more sophisticated level.

Returning to the experiment at hand, the change in temperature for of 50 mL of water (50g) will be monitored when 5g of the each of the above listed salt is dissolved. The total energy of dissolution will be calculated using Equation 1.

Experimental Preparation



Materials:

- NaCl = sodium chloride
- KCl = potassium chloride
- NaOH = sodium hydroxide (Handle with care – caustic)
- NH_4Cl = Ammonium chloride
- Water (tap water will suffice, but distilled is better)
- Thermometer (needs to be readable in the 10-40 ºC range)
- Styrofoam cup (smaller volumes are better since only 50mL will be used)
- Graduated Cylinder
- Balance
- Weight boat or paper

Optional Materials:

- Magnetic stir bar and magnetic stir plate
- Ring Stand and Clamp

Procedure:

1. Set up a calorimeter (instrument to measure heat) as shown in the figure above. Using a Styrofoam cup will minimize the amount of heat transferred out of the water during the course of the experiment. Place a magnetic stir bar in the cup and place on a magnetic stir plate.
2. Measure 50 mL of water (50 grams) in the graduated cylinder and transfer it to the calorimeter.
3. Submerge the thermometer in the water. If a stir bar and stir plate are being used, make sure to suspend the thermometer above the stir bar to avoid collisions that may break the thermometer.
4. Allow the calorimeter 5-10 minutes to equilibrate. Depending on availability of time, you may opt to omit this step.
5. Determine the temperature of the water.
6. Weigh out approximately 5 grams of NaCl, NaOH, NH_4Cl or KCl. Note the exact mass in the table below.
7. Completely add the salt to the water and ensure complete dissolution.
8. Monitor the thermometer. The temperature should change rather rapidly. Note the temperature when the change is maximized.
9. Rinse out the calorimeter and repeat for the other salts.
10. Calculate the total energy of dissolution using equation 1.

Data

Salt	Mass	Initial Temperature	Final Temperature	ΔT	Energy	Energy per gram
NaCl						
KCl						
NaOH						
NH_4Cl						

Questions:

Using the information you learned in the background material, propose a reason that thermoses (or ice chests) are good insulators.

Why is Styrofoam an effective insulator?

Which of the salts have the potential to be used as a cold pack? A hot pack?

Using your knowledge of conservation of energy, describe why dropping an ice cube into a glass of water results in a change in temperature.

Advanced Exercise:
Calculate the total change in temperature if a 10 gram piece of ice is dropped into 100 grams of water.

Hint: Since energy MUST be conserved, the energy gained by the ice is equal and opposite of the energy lost by the water $E_{ice} = -E_{water}$.