*Lab Handout*

# Lab 1. Thermal Energy and Matter

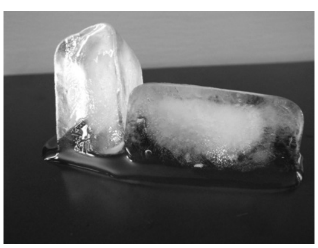
## What Happens at the Molecular Level When Thermal Energy Is Added to a Substance?

### Introduction

Every substance in the universe is made up of matter. A substance can exist in three different states: solid, liquid, or gas. A substance such as water can easily transition from one state of matter to the other. For example, water transitions from a solid state to a liquid state when an ice cube melts (Figure L1.1). The ice cube is able to melt and transition from a solid to a liquid because it absorbs thermal energy. Thermal energy is a type of energy that is transferred between two objects because they have different temperatures. In the example of an ice cube melting, thermal energy is transferred to the ice cube from the warm air surrounding it. Thermal energy always moves from the warmer object to the colder object. Think about another example, such as a cold can of soda in your hand. In that case, thermal energy is transferring from your hand to the soda; eventually the cold soda will gain enough thermal energy that it becomes the same temperature as its surroundings.

FIGURE L1.1

**Water undergoes a phase change from solid to liquid when ice melts.**



All substances, regardless of whether they are a solid, a liquid, or a gas, are made up of atoms and molecules. Atoms and molecules are submicroscopic, meaning they are too small to be seen with our eyes and even too small to be seen with most microscopes. The atoms or molecules that make up a substance are constantly in motion. The composition of a substance will always be the same even though the substance can transition from one state to a different state. Water, for example, is always made of $H_2O$ molecules even when it is in a solid (ice), liquid, or gaseous (steam) state.

The difference between the solid, liquid, and gas states of a substance is due to the amount of kinetic energy the atoms or molecules have and how these particles are moving relative to each other. Kinetic energy is the energy of motion. Atoms or molecules that are moving quickly have more kinetic energy than atoms or molecules that move more slowly. For example, the molecules found within a sample of gaseous water move around quickly. These molecules therefore have a lot of kinetic energy. The molecules that are found in a sample of solid water, in contrast, move around slower and have less kinetic energy than the molecules in a sample of gaseous water. You can therefore measure the temperature of a substance to learn about the average kinetic energy of the molecules within that substance.

At this point, we have established several key ideas about the nature of matter. For example, we know that all matter can exist in three different states and all matter is composed of atoms or molecules that are really small. We also know that a substance has the same composition regardless of its state and that the atoms or molecule of a substance will have different amounts of kinetic energy at different temperatures. These ideas, when taken together, can serve as a foundation for the development of an explanatory model that can be used to illustrate what happens at the molecular level when thermal energy is added to a substance. This type of model is important to develop because explanatory models can help us predict the behavior of matter under different conditions. For example, we could use an explanatory model to help us predict how long it will take a substance to boil when it is heated on a hot plate or a stove. Your goal for this investigation will be to collect data about the behavior of a substance when thermal energy is added to it and then use what you learn to develop an explanatory model that describes what happens to the molecules that make up a substance when they are exposed to thermal energy.

## Your Task

Develop a model that helps you explain what happens at the molecular level as thermal energy is added to a substance. The substance you will work with during this investigation is water. Your model should account for the mass of the substance, its temperature, and the amount of time that thermal energy is being added to the substance so that you can explain the relationship between the amount of water in a sample, the temperature at which the sample boils, and how long it takes to reach the boiling temperature. Your model, once fully developed, should enable you to make accurate predictions about the amount of time it will take for a particular sample of water to boil. Once you have developed your model, you will need to test it to determine if it leads to accurate predictions or not.

The guiding question of this investigation is, **What happens at the molecular level when thermal energy is added to a substance?**

## Materials

You may use any of the following materials during your investigation:

**Consumable**
- Water

**Equipment**
- Beakers (various sizes)
- Graduated cylinders (various sizes)
- Electronic or triple beam balance
- Hot plate
- Thermometer or temperature probe
- Stopwatch
- Safety glasses or goggles
- Chemical-resistant apron
- Nonlatex gloves

## Safety Precautions

Follow all normal lab safety rules. In addition, take the following safety precautions:

1. Wear sanitized indirectly vented chemical-splash goggles and chemical-resistant nonlatex gloves and aprons during lab setup, hands-on activity, and takedown.

2. Never put consumables in your mouth.
3. Use caution when working with hot plates, because they can burn skin and cause fires.
4. Hot plates also need to be kept away from water and other liquids.
5. Use only GFCI-protected electrical receptacles for hot plates.
6. Clean up any spilled water immediately to avoid a slip or fall hazard.
7. Be careful when working with hot water, because it can burn skin.
8. Handle all glassware with care.
9. Handle glass thermometers with care. They are fragile and can break, causing a sharp hazard that can cut or puncture skin.
10. Never return the consumables to stock bottles.
11. Wash hands with soap and water after completing the lab activity.

**Investigation Proposal Required?** ☐ Yes ☐ No

FIGURE L1.2

A sample of water can be heated on a hot plate.

### Getting Started

The first step in developing your model is to design and carry out an investigation to determine how long it takes for different samples of water to boil and the temperature at which each sample boils. To accomplish this task, you can heat a sample of water in a beaker on a hot plate (see Figure L1.2). Before you begin to heat different samples of water, you must determine what type of data you need to collect, how you will collect it, and how you will analyze it.

To determine *what type of data you need to collect,* think about the following questions:

- What information do you need to make your model?
- What measurements will you take during your investigation?
- How will you know how much thermal energy has been transferred to your samples of water?

To determine *how you will collect the data,* think about the following questions:

- What equipment will you use to collect the data you need?
- How will you make sure that your data are of high quality (i.e., how will you reduce error)?
- How will you keep track of the data you collect?

- How will you organize your data?

To determine *how you will analyze the data,* think about the following questions:

- What type of calculations will you need to make?
- What type of table or graph could you create to help make sense of your data?

Once you have carried out your investigations, your group will need to develop a model that can be used to help explain what is happening at the molecular level when thermal energy is added to water. Your model must include the relationship between the amount of water being heated, the temperature at which that sample of water boils, and how long it takes the sample to reach the boiling temperature. Your model should also be able to account for any differences in the mass of water, differences in initial temperature between samples, and the amount of time that thermal energy is added to the substance.

The last step in this investigation is to test your model. To accomplish this goal, you can heat different amounts of water that you did not investigate to determine if your model leads to accurate predictions about the time it takes for each particular sample of water to boil. If you are able to use your model to make accurate predictions about the time it takes for different amounts of water to boil, then you will be able to generate the evidence you need to convince others that the model you developed is valid.

## Connections to Crosscutting Concepts, the Nature of Science, and the Nature of Scientific Inquiry

As you work through your investigation, be sure to think about

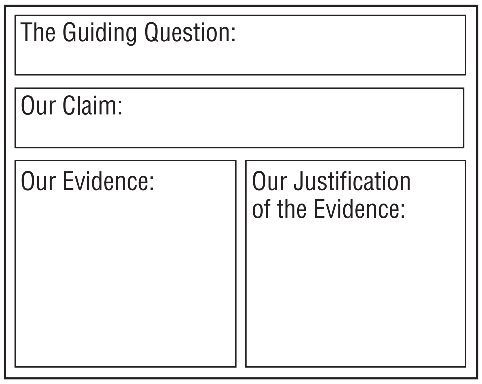
- how scientists need to be able to recognize what is relevant at different scales;
- how scientists often need to track how energy moves into, out of, and within a system;
- the difference between laws and theories in science; and
- how scientists must use imagination and creativity when developing models and explanations.

## Initial Argument

Once your group has finished collecting and analyzing your data, your group will need to develop an initial argument. Your argument needs to include a *claim*, *evidence* to support your claim, and a *justification* of the evidence. The claim is your group's answer to the guiding question. The evidence is an analysis and interpretation of your data. Finally, the justification of the evidence is why your group thinks the evidence matters. The justification of the evidence is important because scientists can use different kinds of evidence to support their claims. Your group will create your initial argument on a whiteboard.

**FIGURE L1.3**

**Argument presentation on a whiteboard**




Your whiteboard should include all the information shown in Figure L1.3.

## Argumentation Session

The argumentation session allows all of the groups to share their arguments. One member of each group will stay at the lab station to share that group's argument, while the other members of the group go to the other lab stations to listen to and critique the arguments developed by their classmates. This is similar to how scientists present their arguments to other scientists at conferences. If you are responsible for critiquing your classmates' arguments, your goal is to look for mistakes so these mistakes can be fixed and they can make their argument better. The argumentation session is also a good time to think about ways you can make your initial argument better. Scientists must share and critique arguments like this to develop new ideas.

To critique an argument, you might need more information than what is included on the whiteboard. You will therefore need to ask the presenter lots of questions. Here are some good questions to ask:

- How did you collect your data? Why did you use that method? Why did you collect those data?
- What did you do to make sure the data you collected are reliable? What did you do to decrease measurement error?
- How did your group analyze the data? Why did you decide to do it that way? Did you check your calculations?
- Is that the only way to interpret the results of your analysis? How do you know that your interpretation of your analysis is appropriate?
- Why did your group decide to present your evidence in that way?
- What other claims did your group discuss before you decided on that one? Why did your group abandon those alternative ideas?
- How confident are you that your claim is valid? What could you do to increase your confidence?

Once the argumentation session is complete, you will have a chance to meet with your group and revise your initial argument. Your group might need to gather more data or design a way to test one or more alternative claims as part of this process. Remember, your goal at this stage of the investigation is to develop the most acceptable and valid answer to the research question!

## Report

Once you have completed your research, you will need to prepare an *investigation report* that consists of three sections. Each section should provide an answer to the following questions:

1. What question were you trying to answer and why?
2. What did you do to answer your question and why?
3. What is your argument?

Your report should answer these questions in two pages or less. The report must be typed, and any diagrams, figures, or tables should be embedded into the document. Be sure to write in a persuasive style; you are trying to convince others that your claim is acceptable or valid!