Thermal Energy and Heat Transfer

You will explore thermal energy, thermal equilibrium, and three different modes of heat transfer through five hands-on activities aided by the **thermal vision** provided by a cutting-edge infrared (IR) camera (that only a few years ago was an expensive tool for seeing bad guys in the dark!). In each activity, you will be guided to learn basic science concepts from doing a series of experiments following the inquiry process illustrated in Figure 1. You will set up an experiment, predict what will happen, conduct the experiment, observe what happens using an IR camera, and then explain the observed results. In the case where what you predict does not agree with what you observe, you can redo the experiment to check the results. At the end of each activity, you will apply what you have learned to answer some questions.

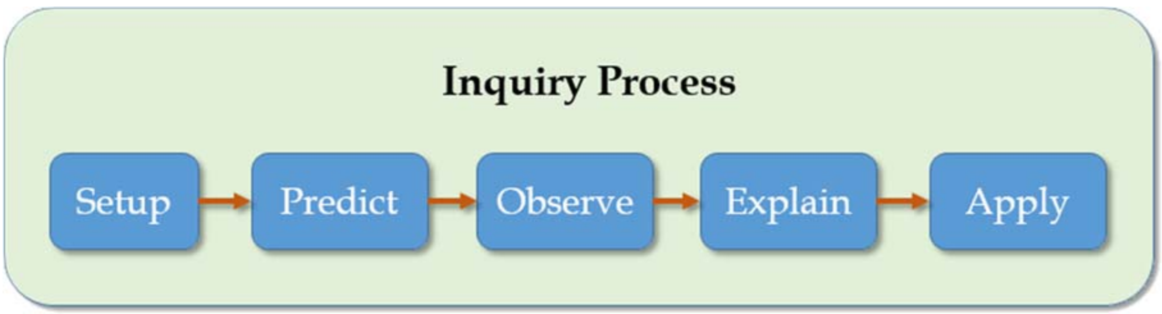

Figure 1

About the IR Camera

The IR camera that you will use is actually a combination of a conventional digital camera that sees the visible light and a special camera that sees the invisible IR light. You can switch back and forth between them and take both a conventional image and an IR image. However, you should only use the IR part as this is what makes this device interesting. The following are a few things that you should know about this camera before getting started:

- Make sure that you use the menus on the touch screen of the camera to disable the MSX mode as this mode can sometimes affect the quality of the IR image. To access the menus, tap on the screen of the camera.
- The camera automatically resets the colors based on the highest and lowest temperatures that it detects in the view for maximal color contrast (every time you hear a click sound from the camera, it is doing so). The downside is that the thermal phenomena you want to observe may be “dimmed down” by much hotter or colder objects that are irrelevant to the experiment but happen to be in the view scope.
- The IR camera can also be used as an IR thermometer that reads the temperature of a single point. This is represented by the aim cursor on the screen of the camera. You may use this functionality to take some data.

1. Thermal Energy Activity: Warm up with the IR Camera!

Any object at finite temperature has thermal energy. The amount of thermal energy stored in an object depends on its temperature and heat capacity.

Materials and Tools

Make sure that you have the following lab supplies:

- An IR camera
- A small petri dish (e.g., 3.5 cm)
- A large petri dish (e.g., 9 cm)
- A graduated cylinder
- A graduated dropper
- Hot water (>80 °C)
- Ice water (<5 °C)
- Tap water
- A timer (using your phone)

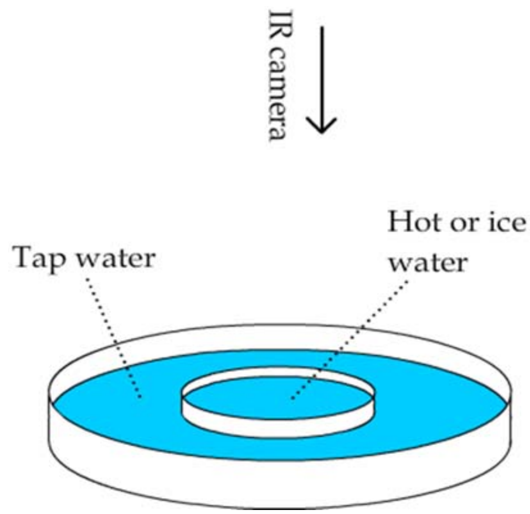

Figure 2

Prediction

In this activity, you will put a dish of hot or ice water into a dish of tap water (as illustrated in Figure 2) and observe what happens under an IR camera. Through this simple activity, you will also familiarize yourself with the operations of the IR camera, the meaning of the color IR images, and the inquiry process. Before you do anything, answer the following questions:

1. What will happen to the temperatures of the water in the two petri dishes? Explain why.

2. What will be the final temperatures of the two dishes? Explain why.

Observation

Follow these steps to conduct the experiment and observe the change of thermal pattern of the water in the two petri dishes over time through the IR camera:

1. Pour 20 ml of tap water into the large petri dish.
2. Carefully place the small dish into the large dish and make sure that no water from the large dish enters the small one.
3. Add a small amount of hot or ice water (e.g., 3 ml) to the small petri dish using the dropper and make sure that the water does not mix with the water in the large dish.
4. Take an IR image from the top and pay attention to the colors in the IR image and how they correspond to different temperatures. Point the aim cursor to the water in each dish to read its temperature. Fill the temperature readings in the following table.
5. Take an IR image every minute and observe the color changes over time.

Time elapsed (minutes)	Temperature of the water in the small dish (°C)	Temperature of the water in the large dish (°C)
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		

Optional: Time elapsed (minutes)	Temperature of the water in the small dish (°C)	Temperature of the water in the large dish (°C)
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		

Write anything that has interested you during the observation:

Explanation

Collect the IR images that you have taken and use them as evidence to check your prediction. Whether your prediction is correct or not, explain your observation based on the concepts of **thermal energy**, **heat capacity**, and **thermal equilibrium**. Back your explanation with your IR images.

1. What happened to the temperatures of the water in the two petri dishes? Explain why.

2. What were the final temperatures of the two dishes? Explain why.

Optional Experiments

1. Repeat the experiment with water of a different temperature in the small dish. If you have used hot water, try ice water this time, or vice versa.

2. Repeat the experiment with doubled or tripled volume of hot or ice water in the small dish.

Questions

Based on what you have learned from this activity, answer the following questions:

1. What can you do with the water in the small petri dish to increase the final temperature of the water in the large one? List all the possible methods and explain why they can work.

2. Suppose you are choosing an air conditioner to cool a room. What factors should you consider?

2. Conduction Activity: Two Thumbs Up!

Thermal conduction is the diffusion of thermal energy through a material. Thermal energy diffuses at different rates in different materials. The ability of a material to diffuse thermal energy is known as the thermal conductivity.

Materials and Tools

Make sure that you have the following lab supplies:

- An IR camera
- A book
- A metal ruler (with paint)
- A wood ruler

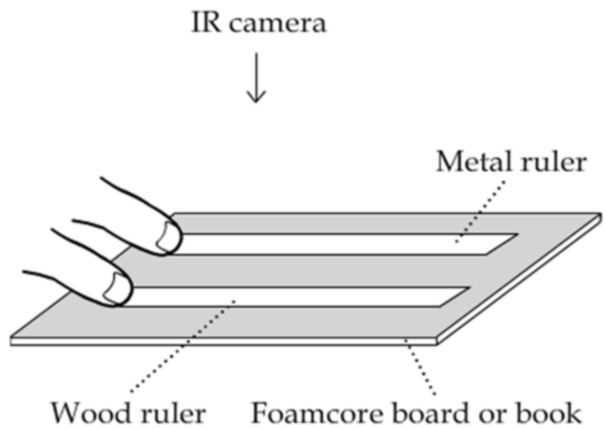

Figure 3

Prediction

Before you do anything, answer the following questions:

1. When you touch the two rulers, which one will feel colder? Explain why.

2. What will happen to the temperature patterns of the two rulers after you touch them for a while (Figure 3)? Explain why.

3. What will happen to the temperature patterns of your two fingers right after you move them away from the rulers? Explain why.

Observation

Follow these steps to conduct the experiment and observe the changes of thermal patterns of the rulers and the thumbs through the IR camera:

1. Make sure both of your hands are warm.
2. Find a table that has no hot or cold objects on it.
3. Put a book on the table.
4. Place the two rulers on a book so they are parallel to each other (Figure 3).
5. Observe the two rulers through the IR camera to make sure that they are both at room temperature (on the screen of the IR camera, the colors of the rulers should be approximately the same with those of the book and the table -- to the point that you cannot see them on the screen if you turn off the MSX mode of the camera). If you have grabbed the rulers, your hands will give them some thermal energy, which can be seen through the IR camera. The residual heat may take a minute to dissipate. Wait until they disappear from the view of the IR camera or find parts of the rulers that your hands have not touched.
6. Take an IR image to record the initial temperature patterns of the rulers.
7. Firmly touch the two rulers with your two thumbs -- one on each -- for about 60 seconds.
8. While your thumbs press on the rulers, have your partner observe the two rulers closely through the IR camera and take an IR image of the rulers every 10 seconds.
9. Move your thumbs away from the rulers and immediately observe the rulers through the IR camera. Your partner should take an IR image right away.
10. Immediately after that, ask your partner to quickly take a close-up IR image of your two thumbs. Make sure that both thumbs are in the view scope and near each other.

Explanation

Collect the IR images that you and your partner have taken and use them as evidence to check your prediction. Whether your prediction is correct or not, explain your observation based on the concepts of **thermal conduction** and **thermal conductivity**. Back your explanation with your IR images.

1. When you touched the two rulers, which one felt colder? Explain why.

2. What happened to the temperature patterns of the two rulers after you touched them for a while (Figure 3)? Explain why.

3. What happened to the temperature patterns of your two fingers right after you moved them away from the rulers? Explain why.

Questions

Based on what you have learned from this activity, answer the following questions:

1. Suppose you are in a very hot place and the room temperature is 10 °C above your body temperature. Which ruler will feel relatively cooler, the metal one or the wood one? Explain your answer.

2. Suppose you are making a door for your house and you would like to save energy for the house, which material should you use for the door, metal or wood? Explain your choice. Is your choice wise for both winter and summer conditions? Explain why or why not.

3. Radiation Activity: Catch Invisible Light!

Any object at finite temperature emits thermal radiation -- invisible light that can travel through space. The radiated energy can be absorbed by another object, resulting in an increase of its temperature. This is called radiative heat transfer. Radiative heat transfer happens very fast as thermal radiation moves at the speed of light.

Materials and Tools

Make sure that you have the following lab supplies:

- An IR camera
- A few pieces of paper
- A few binder clips
- A ruler
- A timer (using your phone)
- A closed jar of hot water (> 80 °C)
- A closed jar of ice water (<5 °C)

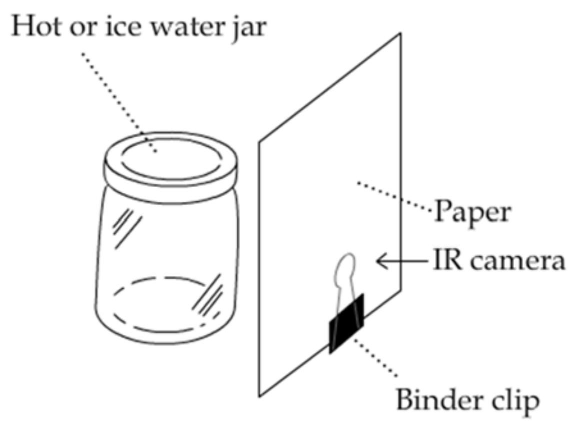

Figure 4

Prediction

Before you do anything, answer the following questions:

1. What will happen to the temperature pattern of a piece of paper when it faces a jar of hot or ice water from the side (Figure 4)? Explain why.

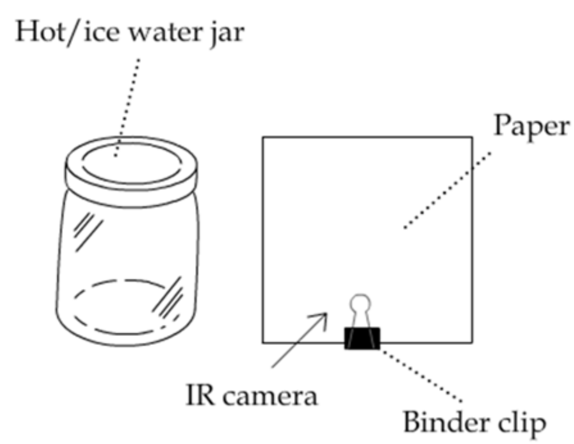

Figure 5

2. What will happen to the temperature pattern of the paper when it is further away from the hot or ice water jar? Explain why.

3. What will happen to the temperature pattern of the paper when it does not face the jar (Figure 5)? Explain why.

Observation

1. Put a jar of hot or ice water on a table where there is no other hot or cold objects on it.
2. Attach one or two binder clips to a piece of *dry* paper so that it stands on the table.
3. Move the paper close to the hot or cold jar (about 1″ away), facing the jar.
4. Keep the paper in place for one minute. Take an IR image of the side of the paper facing away from the jar every 10 or 20 seconds and record the highest temperature of the paper in Table 3A below. To ensure consistent color contrast across IR images, make sure that the jar does not show up in the IR view when you take images.
5. Do not touch the paper or move your hands too close to it when taking images, or else the result might be affected.
6. Once the temperature of the paper stabilizes, move the paper 1″ further away from the jar (but still facing the jar). Take an IR image and record the highest temperature of the paper in Table 3B below. Repeat this procedure for two or three more times.
7. Repeat 1-6 with the paper not facing the jar (Figure 5). Record your data in Table 3C and Table 3D below.

Experiment 1: Paper facing the jar

Initial temperature of the jar: __________°C   Initial temperature of the paper: ___________ °C

Table 3A. Highest temperature on the paper over time

Time elapsed	Temperature (°C)
10 seconds	
20 seconds	
40 seconds	
60 seconds	

Table 3B. Highest temperatures on the paper at different distances from the jar

Distance	Temperature (°C)
1″	
2″	
3″	
4″	

Experiment 2: Paper not facing the jar

Initial temperature of the jar: ___________°C   Initial temperature of the paper: ___________°C

Table 3C. Highest temperature on the paper over time

Time elapsed	Temperature (°C)
10 seconds	
20 seconds	
30 seconds	
60 seconds	

Table 3D. Highest temperatures on the paper at different distances from the jar

Distance	Temperature (°C)
1″	
2″	
3″	
4″	

Explanation

Collect the IR images that you and your partner have taken and use them as evidence to check your prediction. Whether your prediction is correct or not, explain your observation based on the concepts of **thermal radiation** and **light absorption** (perhaps geometric optics, too, if you have learned it before). Back your explanation with your IR images.

1. What happened to the temperature pattern of a piece of paper when it faced a jar of hot or ice water from the side (Figure 4)? Explain why.

2. What happened to the temperature pattern of the paper when it was further away from the hot or ice water jar? Explain why.

3. What happened to the temperature pattern of the paper when it did not face the jar (Figure 5)? Explain why.

Optional Experiment

Repeat the experiment with a jar of a different temperature. If you have used a jar of hot water, try a jar of ice water this time, or vice versa.

Questions

Based on what you have learned from this activity, answer the following questions:

1. Suppose you put a hot water jar at 100 °C on the left side of a piece of paper and an ice water jar at 0 °C on the right side (Figure 6). The distances from the jar to the paper are equal and the paper faces both jars. What will the thermal pattern on the paper look like? Explain your answer.

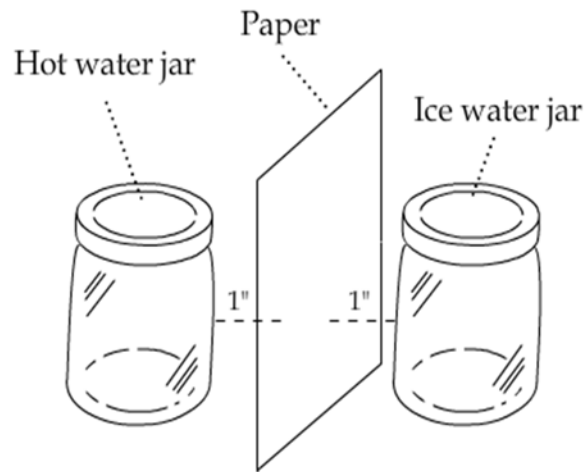

Figure 6

2. Describe how a house gains and loses energy through radiative heat transfer from its windows in the day and at night.

4. Natural Convection Activity: Track Invisible Flow!

Natural convection is the flow of thermal energy along with fluid motion that occurs without any external force. Any temperature difference in a fluid on the Earth will cause natural convection and result in redistribution of thermal energy.

Materials and Tools

Make sure that you have the following lab supplies:

- An IR camera
- A few pieces of paper
- A closed jar of hot water (> 80 °C)
- A closed jar of ice water (< 5 °C)

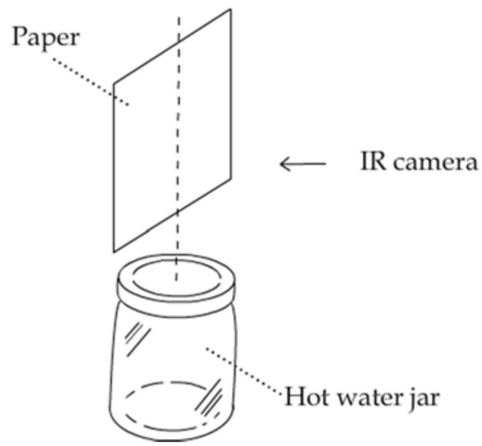

Figure 7

Prediction

Before you do anything, answer the following questions:

1. What will happen to the temperature pattern of a piece of paper when you hang it above a hot water jar in the vertical (Figure 7) and horizontal (Figure 8) directions?

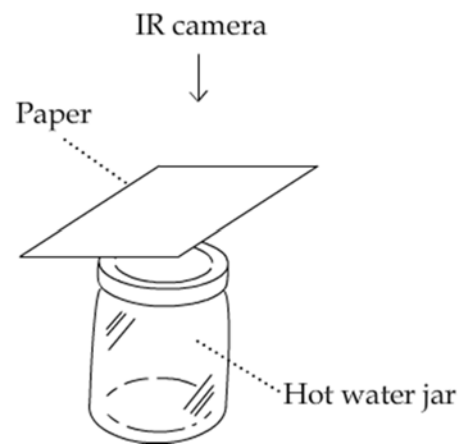

Figure 8

2. What will happen to the temperature pattern of a piece of paper when you hang it above a cold water jar in the vertical and horizontal directions?

Observation

Follow these steps to conduct the experiment and observe the convective heat flow that naturally occurs in the air through the IR camera:

1. Put a jar of hot water on a table where there is no other hot or cold objects.
2. Have your partner steadily hold the top edge of a piece of *dry* paper and carefully place it above the jar in the vertical direction (Figure 7). Make sure that the paper is close to the top of the jar but does not touch it.
3. Ask your partner to keep the paper in that position for at least 30 seconds and observe it through the IR camera. Make sure that the hot water jar does not show up in the IR view. Take an IR image every 10 seconds.
4. Get another piece of paper and hold it in the horizontal position above the jar (Figure 8). Repeat the observation. *You and your partner should switch roles whenever repeating an observation or redoing an experiment so both of you get a chance to take actions.*
5. Repeat step 1 to 4 with a jar of ice water.

Explanation

Collect the IR images that you and your partner have taken and use them as evidence to check your prediction. Whether your prediction is correct or not, explain your observation based on the concepts of **natural convection**, **thermal conduction** (between air and the jar and between air and the paper), and **thermal radiation** (between the paper and the jar). Back your explanation with your IR images.

1. What happened to the temperature pattern of a piece of paper when you hung it above a hot water jar in the vertical (Figure 7) and horizontal (Figure 8) directions?

2. What happened to the temperature pattern of a piece of paper when you hung it above a cold water jar in the vertical and horizontal directions?

Questions

Based on what you have learned from this activity, answer the following questions:

1. How can you distinguish the effects of heat transfer on a piece of paper from a hot water jar through radiation and convection? Suppose the paper faces the hot water jar from the above position (Figure 8).

2. Which part of a heated room tends to be warmer, near the ceiling or near the floor? Explain your answer.

5. Forced Convection Activity: Blow Heat Away!

Unlike natural convection, forced convection is the flow of thermal energy along with fluid motion driven by an external force such as wind.

Materials and Tools

Make sure that you have the following lab supplies:

- An IR camera
- A few pieces of paper
- A few binder clips
- A closed jar of hot water
- A closed jar of ice water
- A hand-held fan

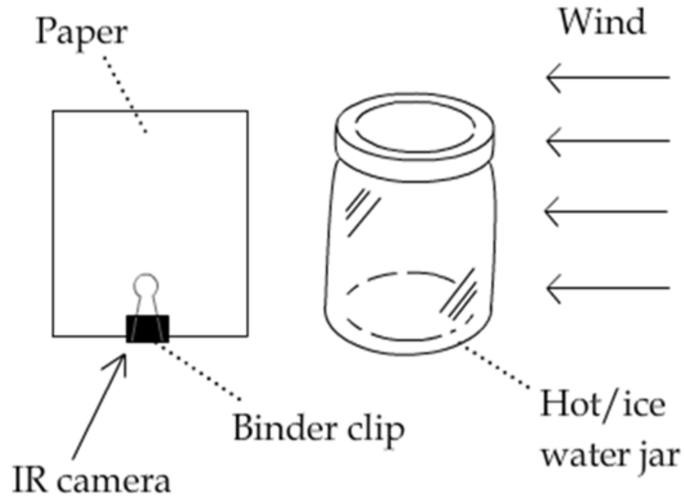

Figure 9

Prediction

Before you do anything, answer the following questions:

1. What will happen to the temperature pattern of a piece of paper next to a hot water jar when wind is blowing towards them (Figure 9)?

2. What will happen to the temperature pattern of a piece of paper next to an ice water jar when wind is blowing towards them (Figure 9)?

Observation

Follow these steps to conduct the experiment and observe forced convection caused by blowing air through the IR camera:

1. Put a jar of hot water on a table where there is no other hot or cold objects.
2. Attach one or two binder clips to a piece of *dry* paper so that it stands on the table.
3. Place the paper about 1" away from the jar. Make sure that the paper does not touch or face the jar (Figure 9).
4. Keep the paper in that position for at least 30 seconds while you use the hand-held fan to blow air towards the jar. Observe the paper through the IR camera. Make sure that the hot water jar does not show up in the IR view. Take an IR image every 10 seconds.
5. Repeat the experiment with the ice water jar. *You and your partner should switch roles whenever repeating an observation or redoing an experiment so both of you get a chance to take actions.*

Explanation

Collect the IR images that you and your partner have taken and use them as evidence to check your prediction. Whether your prediction is correct or not, explain your observation based on the concepts of **forced convection**, **fluid flow**, and **thermal conduction** (between air and the paper and between air and the jar). Back your explanation with your IR images.

1. What happened to the temperature pattern of a piece of paper next to a hot water jar when wind was blowing towards them?

2. What happened to the temperature pattern of a piece of paper next to an ice water jar when wind was blowing towards them?

Questions

Based on what you have learned from this activity, answer the following questions:

1. What can you do to increase the heat transfer from the hot water jar to the paper through forced convection? List all possible methods and explain them.

2. Why do people turn on the ceiling fan in a heated room *in the winter* when there is no need to cool? Explain your answer.