Infrared Experiments of Thermal Energy and Heat Transfer

You will explore thermal energy, thermal equilibrium, heat transfer, and latent heat in a series of hands-on activities augmented by the **thermal vision** through an infrared (IR) camera. Each activity will guide you to learn basic science concepts by doing experiments following the Predict-Observe-Explain 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 explain the observed results. In the case where your prediction does not agree with your observation, you can redo the experiment to double-check the results. If the results are still not what you expected, you should resolve the conflict: Is your result or your prediction wrong? At the end of each activity, you will apply what you have learned to answer some questions that help generalize your understanding to other situations.

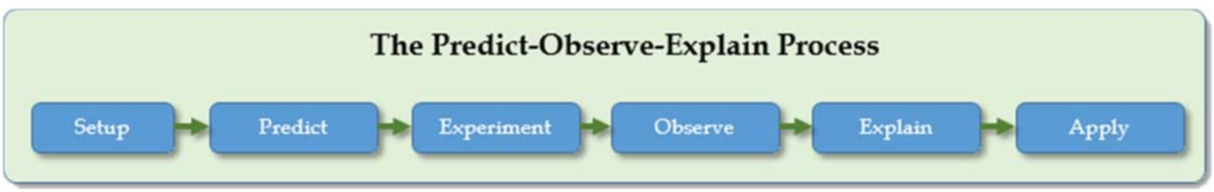


Figure 1

About IR Cameras

Two different types of IR cameras may be used in these activities. One is the FLIR ONE that can be attached to a smartphone (in which case you also need to install the FLIR ONE app on your smartphone). The other is the C2 or C3 standalone IR camera. Both types are actually a combination of a conventional digital camera that detects the visible light and a special camera that detects the invisible IR light (you can see two lenses side by side on the cameras). You can switch back and forth between them or take both a conventional image and an IR image. However, it is the IR part that makes this device interesting. The following are a few things that you should know about these IR cameras 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 make the IR image hard to see. You can always re-enable the MSX mode if needed.
- 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 recalibrating). The downside is that the phenomena you want to observe may be “dimmed down” by much warmer or cooler objects that are irrelevant to the experiment but unavoidable 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 (for C2/C3) or the smartphone (for FLIR ONE). You may use this tool 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 diameter)
- A large petri dish (e.g., 9 cm diameter)
- A graduated cylinder
- A graduated dropper
- Hot water (>80 °C)
- Ice water (<5 °C)
- Tap water
- A timer (using your phone)

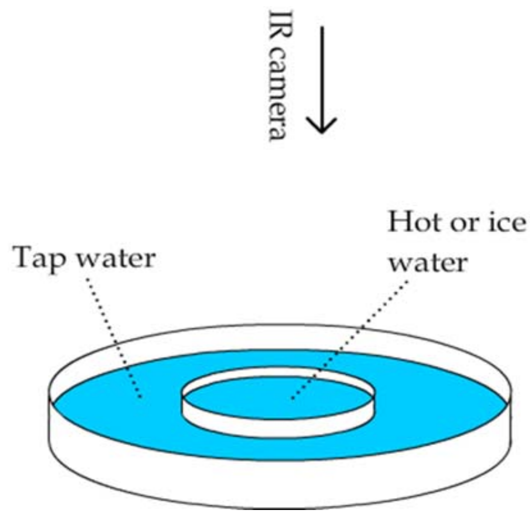


Figure 2

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 color representations in 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 approximately 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 30 ml of tap water into the large petri dish. If water does not cover the bottom surface of the large dish completely, gently shake the dish to make sure it does.
2. Carefully place the small dish *in the middle of* the large dish as shown in Figure 2. Don't let the water in the large dish flow into the small one.
3. Add a small amount of hot or ice water (e.g., 3-5 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 and the hot or ice water covers the bottom surface of the small dish completely.
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.
5. Point the aim cursor to the water in each dish to read its temperature. *You should aim at the same locations in the two dishes every time you read the temperatures.* Fill the temperature readings in the following table.
6. Observe the color changes over time and take an IR image every two minutes. While keeping the large dish completely in the view of the IR camera, move the IR camera as close to the dishes as possible.

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		

Fill the IR images of the initial state, an intermediate state, and the final state of your observation in the following table:

Initial IR image	Intermediate IR image	Final IR image

Explanation

Use the IR images that you have taken 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 approximately 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 high emissivity surface coating)
- A wood ruler

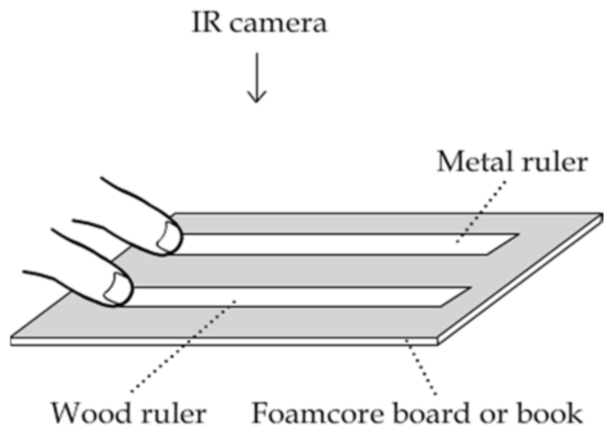


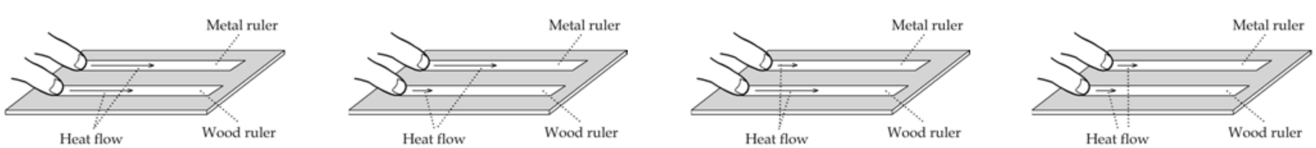
Figure 3

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 heat flow patterns of the two rulers after you touch them for a while? Select one from the following pictures and explain why.



(a) (b) (c) (d)

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. Move your IR camera as close to the rulers as possible so that you have a large and clear IR view of only the contact area between the thumbs and 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 (Figure 4). Make sure that both thumbs are in the view scope and near each other.

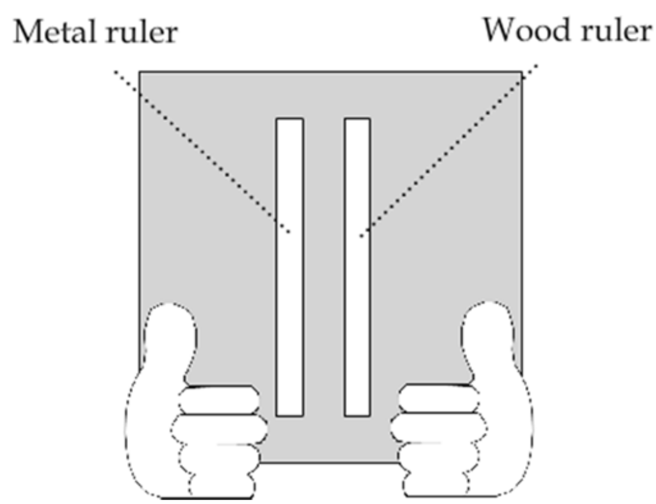


Figure 4

In the following table, fill the IR images that represent different states:

(a) Initial state of rulers	(b) State of rulers after thumbs press for 60 seconds
(c) State of rulers immediately after thumbs move away	(d) State of thumbs immediately after they move away from rulers

Explanation

Use the IR images that you and your partner have taken 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 (Figure 4)? 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)

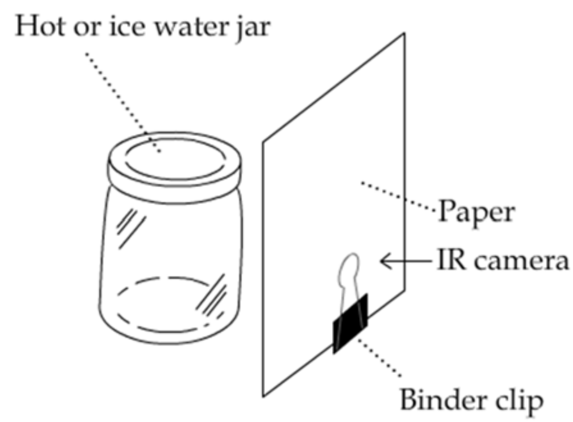


Figure 5

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 5)? Explain why.

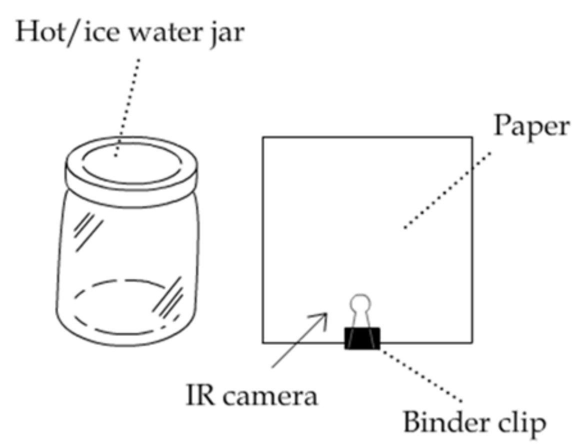


Figure 6

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 6)? 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 6). 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″	

In the following table, fill IR images that represent different states:

(a) Paper facing jar from 1″ away after 60 seconds	(b) Paper facing jar from 2″ away after 60 seconds
(c) Paper not facing jar from 1″ away after 60 seconds	(d) Paper not facing jar from 2″ away after 60 seconds

Explanation

Use the IR images that you and your partner have taken 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 5)? 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 6)? 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 7). 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.

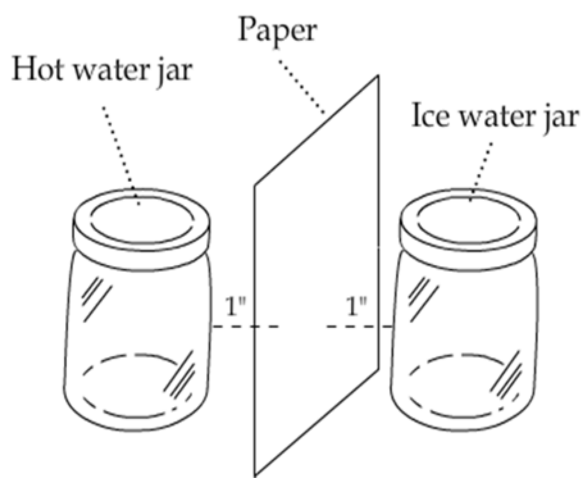


Figure 7

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

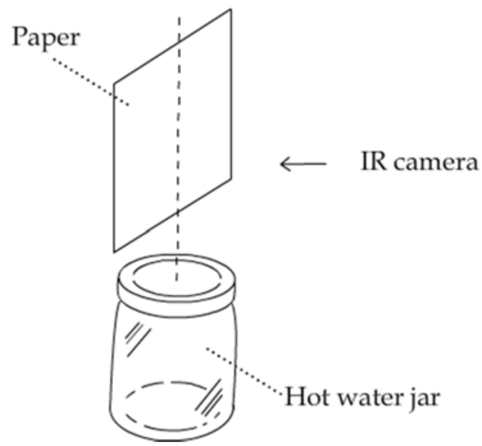


Figure 8

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)

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 8) and horizontal (Figure 9) directions?

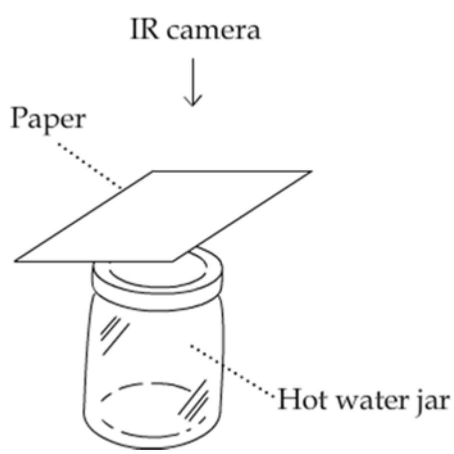


Figure 9

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 8). 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 9). 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.

In the following table, fill IR images that represent different states:

(a) Vertical paper above the hot jar after 30 seconds	(b) Horizontal paper above the hot jar after 30 seconds
(c) Vertical paper above the cold jar after 30 seconds	(d) Horizontal paper above the cold jar after 30 seconds

Explanation

Use the IR images that you and your partner have taken 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 8) and horizontal (Figure 9) 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 9).

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

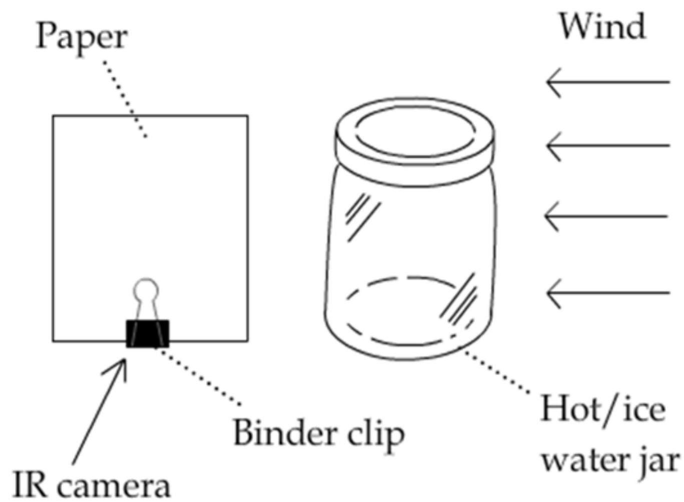


Figure 10

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 10)?

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 10)?

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 10).
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.*

In the following table, fill the IR images that represent different states:

(a) Paper next to the hot jar before fan blows	(b) Paper next to the hot jar after fan blows for 30 seconds
(c) Paper next to the cold jar before fan blows	(d) Paper next to the cold jar after fan blows for 30 seconds

Explanation

Use the IR images that you and your partner have taken 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.

6. Latent Heat Activity: Heat Out of Thin Air?

In the previous activities, you have seen how thermal energy can transfer from a hot object to a cold one through conduction, radiation, convection, or a combination of them. In order for heat to transfer, you had to create a temperature difference using a hot or cold object. But there are some cases in which the transfer of thermal energy can take place without using a hot or cold source. In this activity, you will discover this kind of phenomena through a very simple experiment.

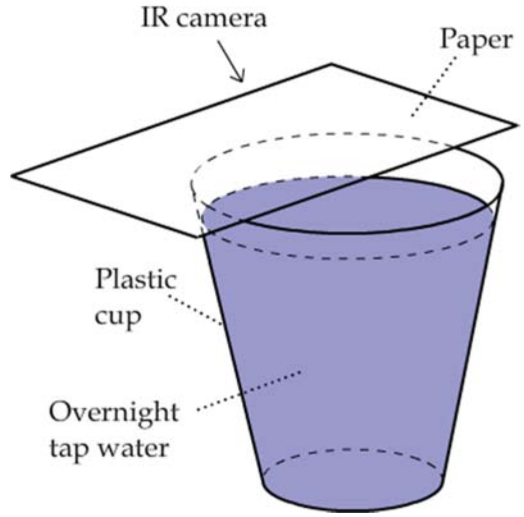


Figure 11

Materials and Tools

Make sure that you have the following lab supplies:

- An IR camera
- A few pieces of dry paper
- A few plastic or paper cups
- Tap water in an open cup (80% filled) prepared the day before in the classroom

Prediction

Before you do anything, answer the following questions:

1. If you leave some tap water in an open cup in the classroom for a night and check its temperature the next day, what will you find? If the temperature is different from the room temperature, what do you think has caused it?

2. If you cover the cup with a piece of dry paper and observe its temperature change for a few minutes, what will you find? If the temperature changes, what do you think has caused it?

Observation

Follow these steps to conduct the experiment and observe the changes of temperature patterns of the subjects through the IR camera:

1. Put the cup of tap water on a table where there is no hot or cold objects around.
2. Observe the cup with the IR camera, take an IR image of it, and record its temperature using the crosshair cursor.
3. Place a piece of dry paper on the table, take an IR image of it, and record its temperature.
4. Cover half of the cup with a piece of dry paper as shown in Figure 11. Make sure that the paper does not get wet. Even you accidentally wet the paper with a water droplet, just use another piece of dry paper.
5. Keep the paper in that position for at least 60 seconds and observe it through the IR camera from the top position. Take an IR image and record the temperature of the paper every 10 seconds.

In the following table, fill the IR images that represent different states:

(a) An open cup of water	(b) A piece of dry paper
(c) An IR image of the paper and the cup taken from the top position, immediately after the cup is half-covered by a piece of dry paper	(d) An IR image of the paper and the cup taken from the top position, 10-20 seconds after the cup is half-covered by a piece of dry paper

Explanation

Use the IR images that you and your partner have taken as evidence to check your prediction. Whether your prediction is correct or not, explain your observation based on the concepts of phase change, in particular evaporation and condensation of water. Back your explanation with your IR images.

1. What do you think has caused the temperature difference between an open cup of water and the surrounding environment?

2. What do you think has caused the temperature change of the paper above the cup of water shortly after it was placed above the cup?

Questions

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

1. Someone in the lab needs a cup of water that is exactly at the same temperature as the room temperature. What can you do to help? Explain your idea.

2. If you remove the paper on top of the cup after it is placed there for a while and then observe the paper using the IR camera, what would you see? Explain your answer.

3. If you keep observing the paper after it is placed above the cup for a long time (say, more than 10 minutes), what would you see about the paper through the IR camera?