SPACE SCHOOL

ASTRONAUT TRAINING...UNDERWATER

Heat Transfer and Cooling
A *Space School* Lesson Plan

by Bill Andrake, Swampscott Middle School
Swampscott, Massachusetts

Science Lesson: Heat Transfer and Cooling - Based on *Space School* Fulldome Film
Grade Level: 6-8
Time: Five to Six (45-50 minute) class periods

Introduction

One might imagine that dealing with the extreme cold of outer space might be the biggest problem to solve in maintaining a safe temperature inside the International Space Station (ISS), however it is actually just the opposite. Keeping the ISS cool from the sun's radiant energy and the heat of the equipment inside the ISS requires an ammonia cooling system. If this system malfunctions, as it did in 2013, the astronauts need to make an emergency space walk to replace it or the ISS will overheat.

This lesson explores the concepts of heat transfer and refrigeration with hands-on activities, experiments and vocabulary activities.

Next Generation Science Standards

Disciplinary Core Ideas:

- ***Definitions of Energy***
- ***Conservation of Energy and Energy Transfer***
- ***Relationship between Energy and forces***
- ***Structure and Properties of Matter***

Objectives

- To understand the nature of heat and how it is transferred.
- To understand that coldness can't be transferred, that it is a condition caused by an absence or loss of heat.
- To see and explain changes to materials involved in the transfer of heat.
- To reinforce the concept of conservation of energy.
- To better understand physical changes to substances, evaporation and condensation at the molecular level.

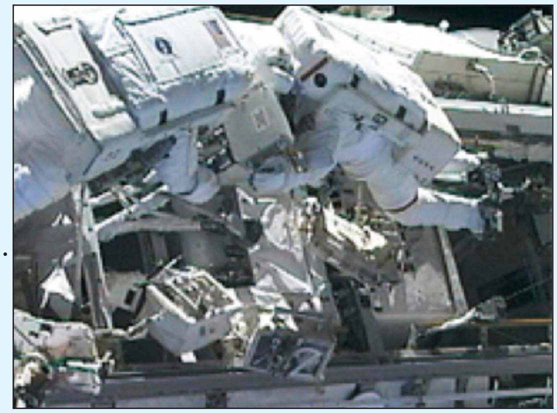
Contents

Partial support for this work was provided by the Guy Harvey Ocean Foundation
http://www.guyharvey.com/our-mission/

Heat Transfer and Cooling: Background

In May 2013, a 5-1/2 hour space walk by Astronauts Chris Cassidy and Tom Marshburn was required to replace a failed ammonia pump in one of the cooling loops of the International Space Station. It's just this sort of situation that astronauts train for in NASA's Neutral Buoyancy Lab and whose story is a focus of *Space School*.

The International Space Station (ISS) is an orbiting laboratory with an international crew of up to six astronauts who live and work in microgravity for 5 to 6 months. At 260 miles above the Earth's surface, the ISS is engineered to protect its occupants from the Sun's harmful radiation and the solar wind while maintaining a safe mixture of pressurized air in a space the size of a six-bedroom house.



Flight Engineers remove a failed ammonia pump August 7, 2010. Photo credit: NASA TV

Additionally, orbiting the Earth every 92 minutes exposes the crew to large variations in temperature over a short period of time. Temperatures in space range from 200 ºF / 93ºC in sunlight to -200 ºF / -129º C when flying through Earth's shadow. Thus, maintaining a safe and consistent temperature is a major challenge aboard the ISS. Temperature control is not only essential for the comfort and safety of the crew, but it ensures that equipment aboard the station will operate correctly and is protected from extreme changes in temperature.

One might imagine that dealing with the extreme cold of outer space might be the biggest problem to solve in maintaining a safe temperature inside the ISS, however, it is actually just the opposite. ***The major challenge is to keep the station cool*** and to keep it from over heating. Interestingly enough it's not the heat from the Sun that's the problem, it's the radiation.

In the vacuum of outer space, there are no molecules to transfer heat through **conduction** or **convection** so the only way that heat can get to the space station is through the **radiant heat** from the Sun, which can drastically raise the temperature of the ISS. The key to controlling the temperature in the ISS is to shield the station from the **electromagnetic waves** of the Sun. By blocking this solar radiation, the station stays cool.

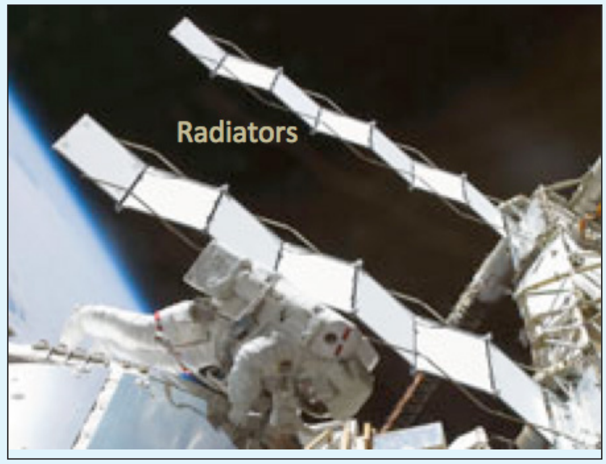
Blankets made of Mylar are used to prevent hyperthermia by reflecting 80% of radiated body heat. Photo: Bill Andrake

To accomplish this, the vehicle is covered with special Mylar insulation. Mylar is a very thin film (0.3 mm in thickness) coated with aluminum, which acts as a highly reflective barrier to solar radiation, preventing the transfer of **radiant heat** to the space station. During exposure to the Sun's rays, the Mylar will heat up. To keep that heat from being transferred by **conduction** into the station, there are several layers of Mylar separated by Dacron material. This Mylar insulation is so good at blocking heat transfer that this creates another problem for life aboard the ISS; *it gets too warm inside the station*.

Heat Transfer and Cooling: Background (continued)

There are many computers and electronic systems throughout the ISS that release heat as electricity passes through the miles of wiring and components. This heat builds up inside the space station and must be released.

Waste heat inside the ISS is removed by various devices, which transfer heat from components to loops of circulating cold water warming up the water. The heat in this water must be released into space to keep the ISS cool. However, water can't be circulated in any heat exchanger outside the ISS, as it would quickly freeze. The solution is ammonia.



Pictured here are two of the many 6' x 12' radiators deployed from the ISS. Photo from NASA.

Anhydrous ammonia is a clear liquid that boils at a temperature of -28°F and freezes at -107°F. Inside the ISS, the pipes of heated water are paired with pipes of liquid ammonia and the heat from the water is transferred to the ammonia. These ammonia pipes then continue outside the ISS in external loops, releasing the heat and cooling off before re-entering the ISS.

The engineering challenges associated with heat transfer, or lack of it, aboard the International Space Station provide an opportunity to bring the science of heat and energy transfer into the classroom. Connections can be made to our daily lives by examining many questions around this concept.

- How can we heat or cool buildings efficiently?
- How can we keep heat from escaping or entering our buildings, drink bottles, and even our bodies?
- What would our world be like without refrigeration?

The following pages offer a few activities that may serve as a springboard into this very relevant topic.

References:

Steve Price, Dr. Tony Phillips, Gil Knier. NASA Science. Science News. *Staying Cool on the ISS*. March 21, 2001.http://science.nasa.gov/science-news/science-at-nasa/2001/ast21mar_1/

NASA. *Cooling System Keeps Space Station Safe, Productive*. Dec. 11, 2013 Last Updated: May 30, 2015. Editor: Jerry Wright http://www.nasa.gov/content/cooling-system-keeps-space-station-safe-productive

Astronauts Complete Spacewalk to Repair Ammonia Leak, Station Changes Command 05.12.13 http://www.nasa.gov/mission_pages/station/expeditions/expedition35/e35_051113_eva.html

SPACE SCHOOL

Heat Transfer and Cooling

Vocabulary

Ammonia: A chemical compound whose molecules consist of one atom of Nitrogen bonded to three Hydrogen atoms. Its chemical formula is NH_3. Ammonia has been used as a refrigerant since the mid 19th Century.

Atoms: The tiniest particles of an element that still retain the properties of that element.

Condensation: A physical change in which a gas or vapor becomes a liquid. Separated molecules release heat in this process, **lose kinetic energy,** and form loose bonds between them to reach the liquid state.

Convection: Heat transfer when heated molecules in a fluid, such as water or air, move from one place to another, taking the heat with them. Convection happens in the atmosphere, our oceans, and in the Earth's interior.
Fluids are heated, become less dense and rise, whereas cooler more dense material sinks, creating circulation and heat transfer.
***Heat cannot be transferred in this manner within the International Space Station as there is a lack of gravity. Gases can't rise or sink in the microgravity of the ISS.*

Conduction: The transfer of heat through a material.

Evaporation: The process in which a substance changes from a liquid to a gas or vapor.
Molecules of the substance absorb heat, **gain kinetic energy**, and then separate in this process.

Heat: A form of energy associated with the motion of atoms or molecules and capable of being transmitted through matter by **conduction**, carried by fluids by **convection**, and through empty space by **radiation**.

Hypothermia: A medical emergency that occurs when the body loses heat faster than it is able to produce it, causing a dangerously low body temperature.

Kinetic Energy: The motion of a body or of the particles in a system

Molecules: Particles formed from two or more atoms chemically combined in a specific ratio. They are the tiniest particles of any chemical compound that still retain the properties of that compound.

Radiant Heat: Heat transferred in the form of electromagnetic radiation rather than by conduction or convection; infrared radiation

Radiator: A device, usually series of pipes or tubes, used to release the heat absorbed by a fluid. Radiators in automobiles release heat from an engine to keep it at the proper operating temperature. Radiators carrying hot water or steam are used to heat rooms.

Temperature: A measurement of the average **kinetic energy** of the molecules in an object or system.

SPACE SCHOOL

Science Activity: Heat Transfer and Conduction: Does "cold" really exist?

In this activity students will see that heat can be transferred through materials in a process called "conduction." In addition, there is a direction that heat always travels which will help us to understand why materials become cold.

Materials:

- Foam cups, ceramic mugs, or Pyrex beakers.
- 10 cm metal strips of copper or aluminum (good conductors)
- Ice and ice water as well as a source for boiling hot water

Procedure:

1. Fill one container with very hot water and the other with ice water.
2. Place one end of a metal strip (preferably copper or aluminum) about 3-4 cm into the cup with hot water and hold on to the other end with your finger tips.
3. Hold the metal strip for a minute or two.

What do you feel happening? ______________________________

____

What can you infer from this observation? ______________________________

____

In what direction is the heat from the hot water traveling? ______________________________

____

4. Next, repeat this procedure by placing the metal strip in a cup of ice water.
5. Hold the metal strip for a minute or two.

What do you feel happening? ______________________________

____

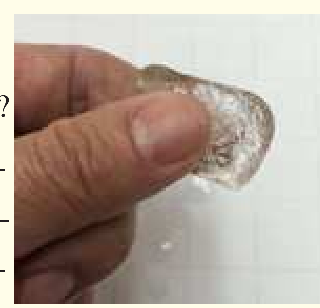
We might infer that "coldness" is moving toward your fingers.

What might be another explanation for what you were feeling? ______________________________

____

Let's try another simple activity to explain our observations.

6. Hold an ice cube in your hand. It feels cold and at the same time the ice cube is melting.



Is the "coldness" of the ice cube **<u>going into</u>** your hand or is **<u>heat leaving</u>** your hand?

____

What is your evidence for this conclusion? ______________________________

____

Science Activity: Heat Transfer and Conduction: Does "cold" really exist? (cont'd)

Discussion:

When the metal strip was placed in hot water, the metal began to heat up in your fingers.

This demonstrates the transfer of heat by conduction, or through a material. Heat travels from the hot water through the metal to your fingers. Heat appears to travel from an area with a higher temperature to an area of lower temperature.

When the metal strip was placed in ice water the strip felt cold between your fingers.

This may be perceived as "coldness" traveling from the ice water to your fingers, but the correct explanation is that heat was being conducted from your fingers and the metal strip to the ice water. This second explanation is validated by holding an ice cube in your hands.

Since the ice cube is melting and becoming liquid water, the ice must be gaining energy, thus heat is leaving your hand and going into the ice cube.

We learn from this lesson something very important: *that heat travels from a higher to a lower temperature; the "First Law of Thermodynamics."*

We also realize that "coldness" does not exist. Things become colder as they lose heat. We can define cold as the lack or absence of heat.

Activity: The Nature of Heat - Heat and the Motion of Molecules

In this activity students will see how heat affects water as it is heated and cooled in order to gain an understanding of the nature of heat, that is energy associated with the movement or kinetic energy of atoms or molecules.

Materials:

- Test tube with colored water.
- A rubber stopper that is sized correctly for the test tube.
- Plastic or glass tubing with the right diameter to fit tightly into the hole of the rubber stopper.
- Foam cups, ceramic mugs, or Pyrex beakers.
- Ice water as well as a source for boiling hot water

Procedure:

- Insert a 5 to 10 cm rigid plastic or glass tube into the rubber stopper. It must be a tight seal.
- Then push the stopper with its tube into a test tube filled with colored water.
- Flick water out of the tube so that the water level in the tube is a cm or so above the top of the rubber stopper.
- See the set-up below:

Test tube with colored water fitted with a stopper and tube. The tube inserted the stopper shown here, was cut from a plastic disposable pipette. Be sure that it is a tight fit.

Next, fill a foam cup or mug ¾ full with hot water.
Place the test tube into this hot water.
Observe what happens to the water level in the small tube as the test tube becomes heated.

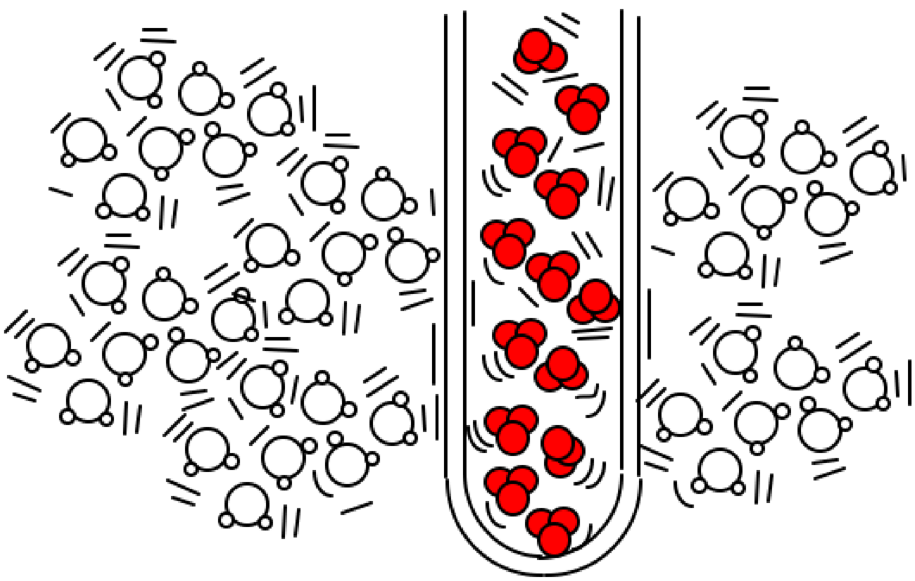
Now fill a foam cup or mug ¾ full with ICE water.
Place the now warm test tube into this cold water.
Observe what happens to the water level in the small tube as the test tube becomes chilled.

Activity: The Nature of Heat - Heat and the Motion of Molecules (continued)

Discussion:

When placed in hot water, the colored water in the test tube rose. Heat energy was *transferred* from hot water molecules to the molecules in the test tube. This energy is the movement or vibration of molecules or **"kinetic energy"** of the molecules.

When the tube was placed in hot water, where molecules were really vibrating and colliding, they get the glass of the tube vibrating and that gets molecules of the water in the test tube to vibrate. With this kinetic energy the molecules spread out, causing the volume of the colored water to expand and climb up the tube. In this way the energy (motion) of the molecules in the hot water is transferred to the molecules of the colored water inside the test tube.



Vibrating water molecules outside the test tube collide with the test tube and transfer this vibration to the water molecules in the tube. As these molecules inside the tube vibrate, they spread out and move up the tube.

When placed in colder water, the molecules in the warm test tube were vibrating more than those in the surrounding ice water. They transferred their kinetic energy to the molecules in the cold water.

With less energy now in the water molecules in the test tube there are fewer collisions and they condense, resulting in the volume of the water to shrink and the water level drops in the tube. This also provides an explanation for how a liquid filled thermometer measures temperature.

SPACE SCHOOL

Classroom Demonstration: Radiant Heat and Mylar

In the vacuum of space there are no molecules to transfer heat through conduction, so energy is transferred from the Sun as radiant heat. When exposed to the Sun's energy during their orbits, vehicles in space are exposed to temperatures over 200 ºF / 93 ºC!

In the 1950's NASA developed a material called Mylar to protect spacecraft from the Sun's heat. Mylar is a very thin film (0.3 mm in thickness) coated with aluminum and is a highly reflective barrier to solar radiation. Mylar has been used on every manned space flight and protects thousands of satellites, space telescopes, and the International Space Station.

Back on Earth the heat blocking ability of Mylar has been utilized in emergency blankets to ward off hypothermia. The Mylar blanket can be wrapped around a victim to prevent the transfer of radiant heat out of the body.

We can demonstrate the heat blocking ability of Mylar by observing the temperature change in a thermometer exposed to the radiant energy from a heat lamp with and without a Mylar shield.

Materials:

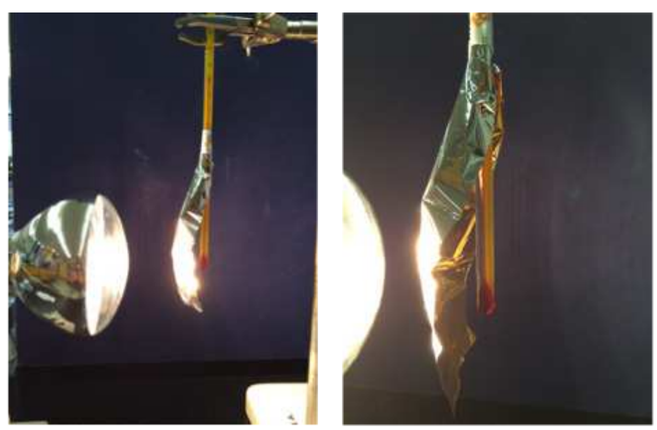
- Heat lamp with clamp and stand
- Thermometer, preferably with a clamp and stand
- 10 cm x 5 cm piece of Mylar cut out from emergency blanket. Mylar emergency blankets are inexpensive and found in many stores (outdoor, camping, department, home centers) as well as on-line.

Procedure:

1. Place or hold a thermometer with its bulb 10cm from the center of a stationary heat lamp.
2. Record the starting temperature.
3. Turn on the heat lamp and measure and record the temperature change after two minutes.
4. Loosely, tape a 10 cm x 5 cm piece of Mylar around the thermometer to shield the bulb from the radiant heat of the lamp. Leave a 2-3 cm space between the sheet and the thermometer bulb. (See Photo)

Thermometer WITHOUT Mylar shield

Thermometer WITH Mylar shield



Classroom Demonstration: Radiant Heat and Mylar (continued)

Sample Results:

Temperature of thermometer (48ºC / 118ºF) without a Mylar shield after 2 minutes.

This is a 23ºC / 41ºF increase from a starting temperature of 25ºC / 77ºF.

Temperature of thermometer (26ºC / 79ºF) with a Mylar shield after 2 minutes.

This is only an increase of 1ºC/ 2ºF from the starting temperature of 25ºC/ 77ºF.

**After 10 minutes the temperature increased only 3ºC / 8ºF.*

Questions to stimulate discussion.

- If Mylar blocks the radiant heat from the lamp, then why did the temperature of the thermometer rise at all with a Mylar shield?
- Did the Mylar only block some of the radiant energy or is there another explanation?
- How might we test this with another experiment?
- What happens to the temperature of the Mylar sheet when exposed to the heat lamp?
- How might heat from a warm Mylar sheet get transferred to the thermometer?

Extensions to this Demonstration.

Hopefully, this demonstration will lead to student questions and ideas for a variety of experiments to test the effectiveness of Mylar to block radiant heat transfer.

For example:

- Repeat this demonstration with multiple layers of Mylar.
- Use a combination of Mylar and insulation to keep a beverage hot or cold.
- Describe what you feel when wrapped in an emergency blanket.
- Compare Mylar and Aluminum foil for blocking radiant heat transfer.

SPACE SCHOOL

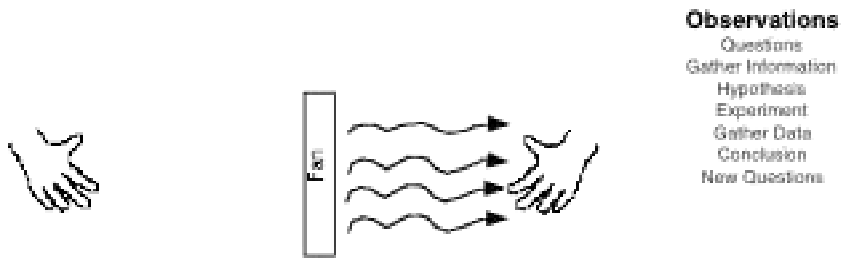
Classroom Activity: Evaporative Cooling and the Scientific Method

In this activity we will use the scientific method to understand the process of heat transfer through evaporative cooling which is the principle behind refrigeration.

Materials: One thermometer and a fan per lab group.

Science begins with **OBSERVATION**...information using our senses.

Using your senses, compare the <u>temperature</u> of the air **blowing** in front of a fan as compared to the **still** air behind the fan.

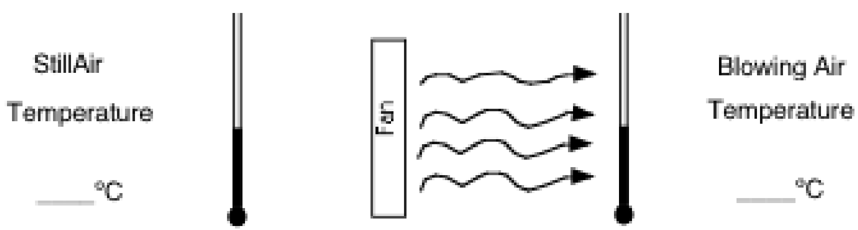


The blowing air in front of the fan feels ____________

The still air behind the fan feels ________

Do you think that the air in front of the fan is cooler than the air behind it? __________

Using <u>one</u> thermometer, now compare the <u>temperature</u> of the air **blowing** in front of a fan as compared to the **still** air behind the fan.



How did the temperatures from the thermometer differ from your first observation? ______________________

____

Why do you think it was important to use only one thermometer to get this information? __________________

____

Classroom Activity: Evaporative Cooling and the Scientific Method (continued)

Our CURIOSITY leads to QUESTIONS from our observations.

From this activity, what questions do you have?

____

____

Observations
Questions
Gather Information
Hypothesis
Experiment
Gather Data
Conclusion
New Questions

Science is the way we discover answers to these questions. So let's GATHER INFORMATION by listing what we know about these questions.

____

____

____

Observations
Questions
Gather Information
Hypothesis
Experiment
Gather Data
Conclusion
New Questions

Form a HYPOTHESIS. A hypothesis is a possible answer to a question based on prior information... a good hypothesis can be tested with an EXPERIMENT.

What might be a possible answer to our question?

____

____

____

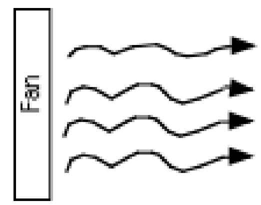
Observations
Questions
Gather Information
Hypothesis
Experiment
Gather Data
Conclusion
New Questions

An EXPERIMENT is a procedure used to test a hypothesis. A good experiment will either prove or disprove a hypothesis, without leaving any doubt.

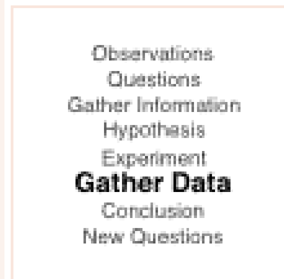
Observations
Questions
Gather Information
Hypothesis
Experiment
Gather Data
Conclusion
New Questions

Classroom Activity: Evaporative Cooling and the Scientific Method (continued)

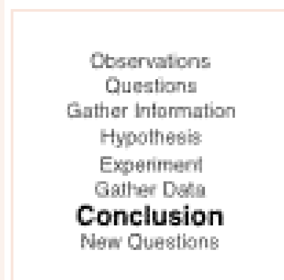
In the space below describe a test that you performed to prove or disprove the hypothesis to our science question. You may use neat, clear drawing(s) along with your written description.



What happened in your experiment? Write the results or DATA from your experiment below. Be clear... be specific.



Forming a CONCLUSION: Interpreting your results or data.
What did the results of your experiment show or tell us?



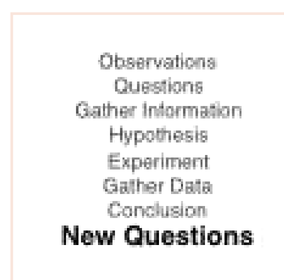
Were you able to prove or disprove our hypothesis? ___________

Do you feel that you have an answer to our original question? _______

If so...what is your answer ? ___________________________________

If not... what would you do next? ________________________________

... because we are CURIOUS ...



In science whenever we answer a question this leads to NEW QUESTIONS; science doesn't end. ***From this experiment what new questions do you have?***

SPACE SCHOOL

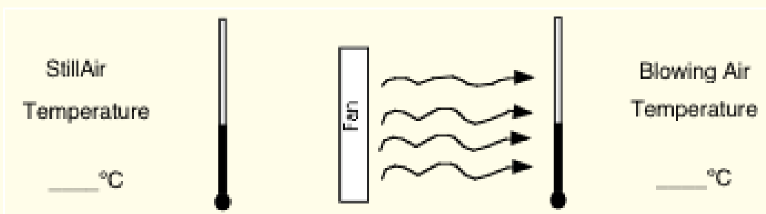
Lesson Notes: Classroom Activity - Evaporative Cooling and the Scientific Method

In this activity we will use the scientific method to understand the process of heat transfer through evaporative cooling which is the principle behind refrigeration. The first part of this activity is best done on a warm day, in a warm humid classroom.

***OBSERVATION*:** *"Using your senses, compare the temperature of the air blowing in front of a fan as compared to the still air behind the fan."*

Students usually feel cooler in front of the fan and warmer behind the fan.

Using one thermometer, now compare the temperature of the air blowing in front of a fan as compared to the still air behind the fan.



Students are quite surprised to find out that the air in front of the blowing fan is actually the same temperature as the air behind the fan. This sparks curiosity.

Using only one thermometer to get this information is important, as different classroom thermometers may not react to a change in temperature in the same way.

"Our CURIOSITY leads to QUESTIONS from our observations."

" From this activity, what questions do you have?"

- Students often wonder why it feels cooler in front of a blowing fan even though the temperature is the same as the air behind the fan.
- What is it about blowing air that gives it a cooler sensation than still air?
- What's different about the blowing air hitting our skin as opposed to the thermometer?

Next, we try to answer these questions by eliciting any prior knowledge and GATHERING INFORMATION.

- *"Science is the way we discover answers to these questions. So let's start by listing what we already know about them?"*
- As students think about this, they analyze how they cool themselves with a fan and how we cool our bodies.
  - We perspire to cool us off.
  - Our perspiration **evaporates** from our skin and this takes away heat.

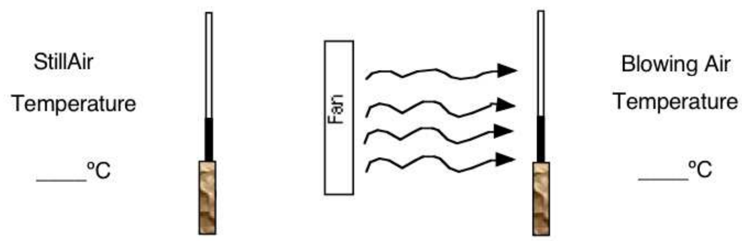
Lesson Notes: Classroom Activity-Evaporative Cooling and the Scientific Method (cont'd)

"Form a __HYPOTHESIS__. A hypothesis is a possible answer to a question based on prior information... a good hypothesis can be tested with an EXPERIMENT. What might be a possible answer to our question?"

- Students often wonder why it *feels* cooler in front of a blowing fan even though the temperature is the same as the air behind the fan.
- Possible answer: Moving air would speed the evaporation of sweat off of our skin, cooling us faster.

"__EXPERIMENT__ is a procedure used to test a hypothesis. A good experiment will either prove or disprove a hypothesis, without leaving any doubt."

- "Describe a test that you performed to prove or disprove the hypothesis to our science question. You may use neat, clear drawing(s) along with your written description."
- An example of what students may come up with might be placing a thermometer with a wet piece of cloth or paper towel wrapped around its bulb and record the temperature in front of a blowing fan vs. behind the fan. We know that there is no difference with a dry thermometer.



Thermometer wrapped with a wet piece of paper towel around the bulb, placed behind the fan and then in front of a blowing fan.

"What happened in your experiment? Write the results or DATA from your experiment below. Be clear... be specific."

- Students would observe a colder temperature in the "wet thermometer" in front of the blowing fan. In addition (and this is important) as the cooling takes place, the paper towel dries and temperature does not continue to drop.

"Forming a __CONCLUSION__: Interpreting your results or data. What did the results of your experiment show or tell us?"

- The reason that the air in front of a blowing fan feels cooler is that it is evaporating the moisture from our skin at a faster rate than behind the fan. We can infer that evaporating water produces a "cooling effect" because when the towel dried, the temperature no longer fell.

"... because we are CURIOUS ...In science whenever we answer a question this leads to __NEW QUESTIONS__; science doesn't end. From this experiment what new questions do you have?" Students may ask:

- Why would evaporation cause a cooling effect? The process must absorb heat.
- What would happen if we evaporated a different liquid such as alcohol which evaporates very quickly?
- When students understand that evaporation of a liquid can cause cooling, this process can be applied to refrigeration and can lead to lessons that explore the two processes of condensation and evaporation at the molecular level.

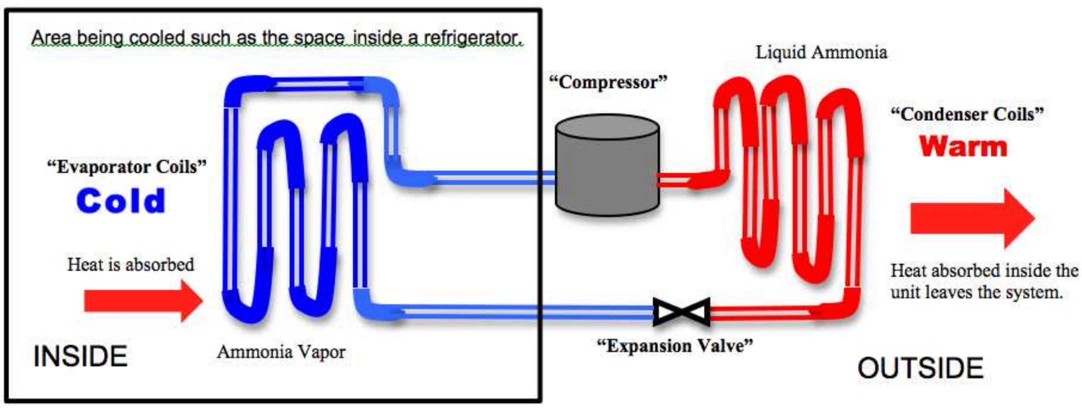
SPACE SCHOOL

Follow Up Discussion: How Refrigeration Works

Wipe some rubbing alcohol on your skin. You will feel a cold sensation as the alcohol quickly evaporates. The molecules of alcohol absorb heat from your skin, increasing their kinetic energy and becoming a gas. This loss of heat from your skin feels cold and this process is called **evaporative cooling**.

Refrigeration uses the principle of evaporative cooling in a closed system, in order to remove heat from an area being cooled such as the space inside a refrigerator and release that heat outside of the refrigerator.

Below is a diagram showing the basic components of a refrigeration system along with a description of how it works using ammonia as the refrigerant.



The **compressor** compresses the ammonia gas condensing it into a liquid. As this happens, the molecules release their energy gained during the evaporation phase of the cycle. **Condensation** (gas to liquid) releases heat. The **condenser coils** are located on the outside of the system and let the hot ammonia release its heat.

The high-pressure ammonia liquid flows through the **expansion valve**. You can think of the expansion valve as a small opening. The liquid ammonia, now under high pressure, passes through the valve to an area of much lower pressure, where the molecules of the liquid immediately expand and the ammonia becomes a gas.

The molecules absorb heat as the ammonia evaporates. **Evaporation** (liquid to gas) absorbs heat. This **evaporative cooling** chills the freezer compartment and space in a refrigerator by **evaporator coils** filled with heat absorbing ammonia gas. The gas is pulled into the **compressor**, and the cycle repeats.

Question: If you leave the door of the refrigerator open, could you chill the room?

Answer: ***No*** *because the heat that you remove from the room would simply be returned from outside of the refrigerator; you would need to get the heat released out of the room... that's what an air conditioner does. An air conditioner has its condenser coils outside the building.*

SPACE SCHOOL

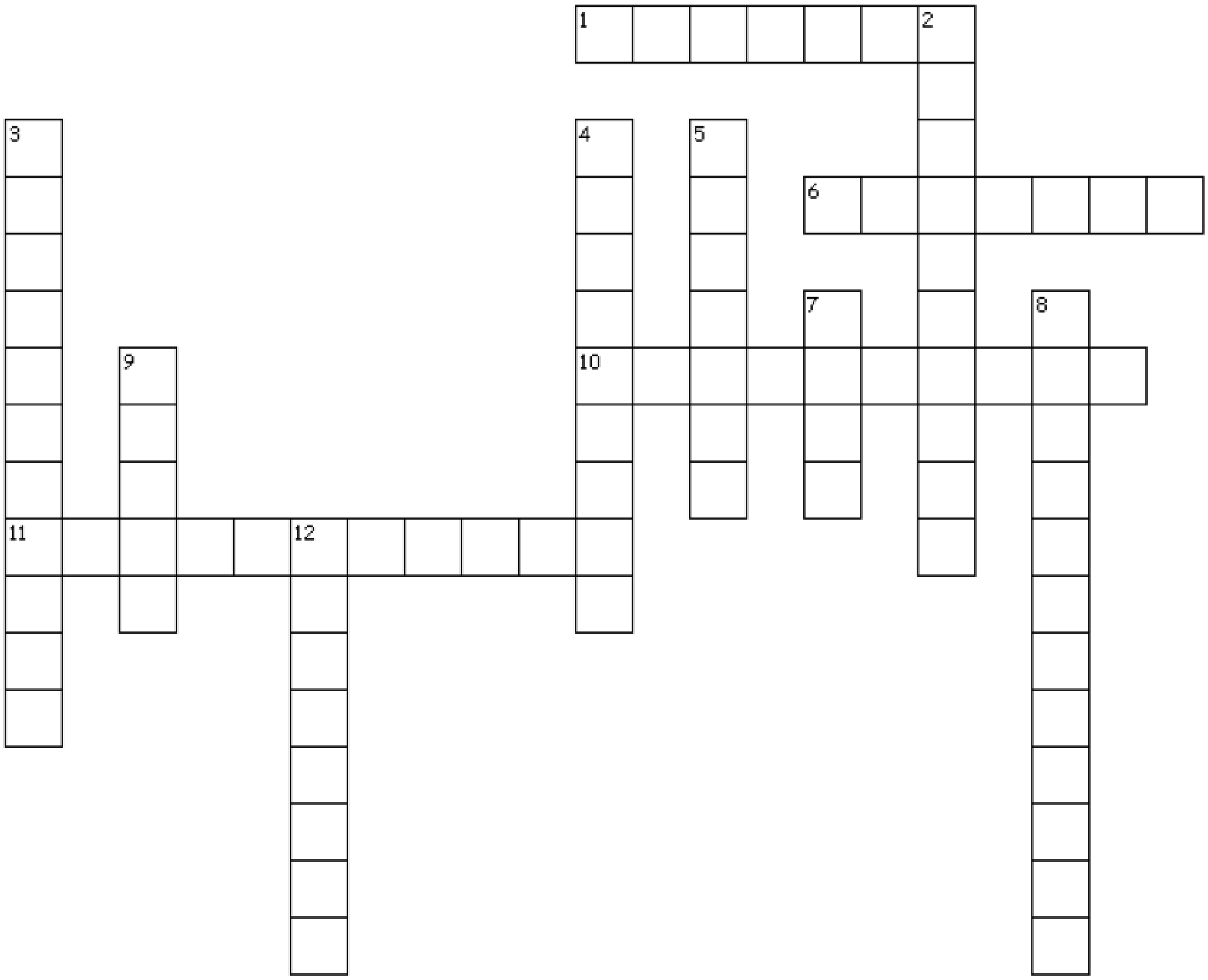
Word Search: Heat Transfer and Cooling

C	E	J	D	H	X	S	A	I	N	I	E	R	B	D
T	O	K	F	T	E	I	D	O	Y	H	V	O	R	H
E	S	N	S	G	N	A	I	J	Y	L	A	T	A	Y
R	R	P	D	O	M	T	T	P	C	B	P	A	K	T
R	G	U	M	E	C	X	O	U	Z	M	O	I	L	E
G	O	M	T	E	N	T	T	U	Y	A	R	D	Y	S
Z	A	Y	V	A	H	S	I	G	I	G	A	A	S	N
U	H	N	Q	E	R	Y	A	D	M	I	T	R	E	N
K	O	P	R	T	A	E	H	T	N	A	I	D	A	R
C	G	M	U	D	Y	A	P	Q	I	Q	O	Z	R	J
M	I	K	U	N	C	O	G	M	F	O	N	W	B	Y
A	T	O	M	S	C	O	V	B	E	M	N	J	D	I
S	E	L	U	C	E	L	O	M	K	T	Q	J	W	O
K	I	N	E	T	I	C	E	N	E	R	G	Y	I	G
R	C	O	N	D	U	C	T	I	O	N	V	K	J	K

AMMONIA
ATOMS
CONDENSATION
CONDUCTION
CONVECTION
EVAPORATION
HEAT
HYPOTHERMIA
KINETIC ENERGY
MOLECULES
RADIANT HEAT
RADIATOR
TEMPERATURE

SPACE SCHOOL

Crossword Puzzle: Heat Transfer and Cooling



Across

1. The motion of a body or of the particles in a system.
6. Heat transferred in the form of electromagnetic radiation; infrared radiation
10. The transfer of heat by heated molecules in a fluid as they move from one place to another.
11. A measurement of the average kinetic energy of the molecules in an object or system.

Down

2. The transfer of heat through a material.
3. The process in which a substance changes from a liquid to a gas or vapor from an increase in kinetic energy.
4. Particles formed from two or more atoms that retain the properties of a compound.
5. A chemical compound with formula NH_3.
7. A form of energy associated with the movement of molecules and transmitted through conduction, convection and radiation.
8. A physical change in which gas or vapor becomes liquid.
9. The tiniest particles of an element that still retain the properties of that element.
12. A device, usually series of pipes or tubes, used to release the heat absorbed by a fluid.