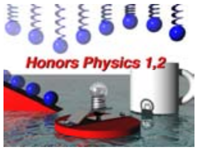



# *Thermodynamics Temperature, Heat, and Entropy*

## CONCEPT EXPLORATION

Thermodynamics is the branch of physics that explores the relationships between certain properties of matter, especially those that are affected by changes in temperature. It also involves a description of the conversion of energy from one form to another.

### Engagement Questions

**1. What is the Celsius temperature scale based on? For example, what does "0" Celsius and what does "100" Celsius correspond to?**

**2. Why does the liquid inside of a thermometer give a different reading when the thermometer is immersed in liquids or gasses at different temperatures? What does the liquid inside of the thermometer do when the thermometer is placed inside a higher temperature substance?**

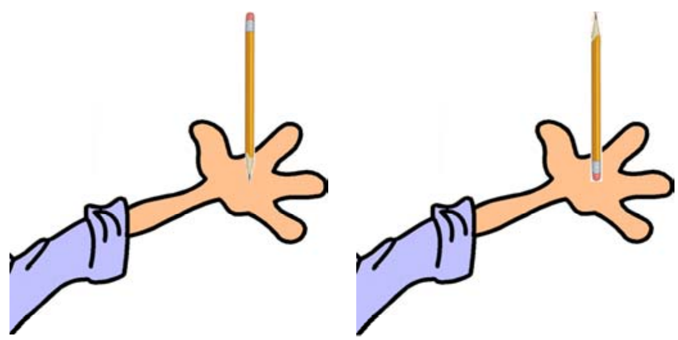
### *The Challenge*

You will investigate how the molecules of substances behave when they are at different temperatures.

### *Your Ideas about the Challenge*

Your "friend" exerts a 10 Newton force on the palm of your hand with a pencil. **Do not actually try this.**

**3. Would you rather have this force exerted on your palm with the lead end of the pencil or the eraser end? Explain your answer.**



Even though the force exerted on your palm would be the same in each situation, the force in each situation would be exerted over a different surface area. To understand why one force is more painful than the other you must consider the concept of pressure.

**Pressure** is force per unit area.

$$\text{Pressure} = \frac{\text{Force}}{\text{area}}$$

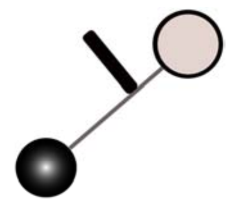
When a contact force is applied to a body, it is usually distributed over a particular area.

A force is exerted on a body.

**4. Describe two different ways that the force could be applied so that there would be an increase in pressure. What could you do to the force to increase the pressure <u>and</u> what could you do to the surface area, over which the force is distributed, in order to increase the pressure?**

| | |
|---|---|
| **Situation 1: change the force** | |
| **Situation 2: change the surface area** | |

Your teacher will use a constant-volume pressure gauge in order to investigate how pressure is affected by temperature.



### *The Investigation*

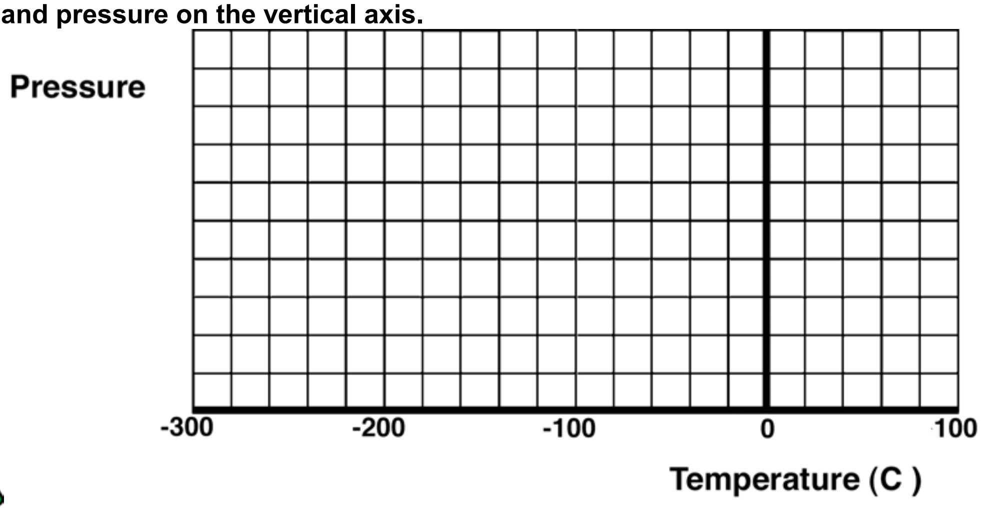
a. Your teacher will immerse the large bulb of the constant-volume pressure gauge into various liquid baths that are at different temperatures. The pressure reading on the gauge will be announced for each temperature.

b. Record both of the corresponding temperatures and pressures in the table seen below.

**<u>Data Table</u>**

| Data set | Temperature ($C^o$) | Pressure |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |

**5. Plot the data points that you have on the grid that you see below. Graph temperature on the horizontal axis and pressure on the vertical axis.**



**6. Using a straight edge, draw a "best-fit" line that passes through the trend of the points that you have on your grid. Make sure that you "extrapolate" your line so that it intersects the horizontal (temperature) axis on the grid.**

**7. What temperature does zero pressure correspond to on your grid?**

Recall that pressure is force per unit area. In order for the pressure to change either the force applied to the walls of the constant-volume pressure gauge was changing or the area over which this force was applied was changing.

**8. Did the area, over which the force was applied, change as the pressure changed? Explain how you know.**

**9. Was the force applied to the inner wall of the constant-volume pressure gauge changing as the pressure changed? Explain how you know.**

**10. Evaluate the following student statement about the questions that you have just answered. Identify ideas that are consistent with your ideas and others that are not consistent with your ideas.**

*"The force applied to the inside of the bulb on the pressure gauge must have decreased as the bulb was put into colder temperature baths. The area of the inside surface of the bulb didn't change because the size of the bulb didn't change."*

**Check your work with your teacher**

**11. What was exerting the force on the inside of the bulb on the constant-volume pressure gauge?**

**12. Why do you think that the gas molecules that were colliding with the inside wall of the bulb, exerted a smaller force as the temperature dropped?**

**13. How fast would the gas molecules have been moving if the pressure gauge read zero pressure units?**

**14. Evaluate the following student statement about the questions that you have just answered. Identify ideas that are consistent with your ideas and others that are not consistent with your ideas.**

*"Gas molecules move faster when they are at a higher temperature. They have more kinetic energy when they move faster so they can exert larger forces when they are at a higher temperature."*

**Check your work with your teacher**

## *Thermodynamics Temperature, Heat, and Entropy*

**CONCEPT DEVELOPMENT**

The lowest theoretical temperature possible would be the temperature at which all motion would cease. This temperature is referred to as absolute zero. **Absolute zero** is –273.15 $^oC$.. This temperature is the basis for the **Kelvin temperature scale.** Zero Kelvin (0 K) is equal to –273.15 $^oC$. The conversion between the Celsius temperature scale and the Kelvin temperature scale is relatively easy since it simply involves the addition or subtraction of 273.15 degrees. For practical matters we will round this value off and either add or subtract 273 degrees.

Kelvin temperature = Celsius temperature + 273

$$T_K = T_c + 273$$

Celsius temperature = Kelvin temperature – 273

$$T_C = T_K - 273$$

### Engagement Question

**1. Calculate both the freezing point and the boiling point of water using the Kelvin temperature scale.**

### *The Challenge*

You will determine which way heat is transferred between two bodies. Does heat go from a body with more internal energy to one with less internal energy, or does heat go from a body at a higher temperature to one that is at a lower temperature?

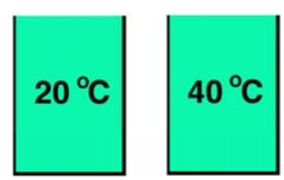
The **temperature** of a body or substance is defined as the average kinetic energy of all of the molecules that make up a body or substance. Recall that kinetic energy is the energy of motion. If a molecule is moving faster then it has more kinetic energy.

The **internal energy** of a body is the sum total of all of the different kinds of kinetic energies of all of the molecules that make up that body.

**Heat** is a form of energy. It is sometimes referred to as thermal energy. Heat can be transferred from one body to another.

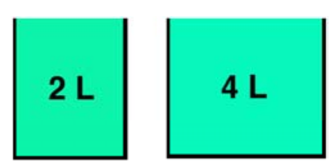
### *Your Ideas about the Challenge*

Two equal-volume containers are full of water. One of the containers has a temperature of 20$^0$C while the other container has a temperature of 40 $^O$C.



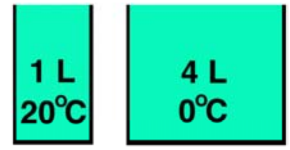

**2. Which container would have the most internal energy? Explain your answer.**

Two containers are full of water at the same temperature (20 $^O$C). One of the containers has a volume of 2 liters while the other container has a volume of 4 liters.



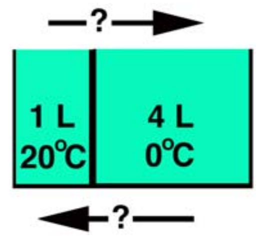

**3. Which of these containers would have the most internal energy? Explain your answer.**

Two different-size containers are full of water at different temperatures. One of the containers has a volume of 1 liter at a temperature of 20 $^{O}$C. The other container has a volume of 4 liters at a temperature of 0 $^{O}$C.




**4. Which of these containers would have the most internal energy? Explain your answer.**

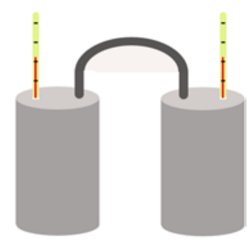
The two containers, described above in question 4, are brought into direct physical contact with one another. Thermal energy, heat, is transferred from one container to the other.




**5. Which way does the heat flow? Does the heat flow from the large container into the smaller container or does it flow from the higher temperature container into the lower temperature container? Explain your answer.**

**6. Describe how you could detect which way the heat flows in the situation described in question 5. What materials or devices would you need to tell which body gained the heat and which body lost the heat?**

At each lab station you should find the following materials:
a heat transfer kit along with thermometers, a source of 0$^{o}$C water and a source of 20$^{o}$C water.



### *The Investigation*

a. Pour 100 ml of the 20 $^{o}$C water into one of the containers.
b. Pour 400 ml of the 0 $^{o}$C water into the other container.
c. Close the lids on both containers and make sure that a thermometer is reading the temperature of the water in each container.
d. Make sure that the aluminum conductor bar is positioned properly so that heat can be transferred from one container to the other.
e. Observe the temperatures of the water in each container for a few minutes. Be sure to keep track of which container originally contained the 0 $^{o}$C water and which container originally contained the 20 $^{o}$C water.

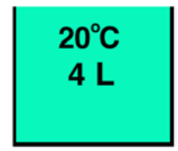
**7. Which container gained heat and which container lost heat? Explain how you know.**

**8. If you allowed the two containers to remain in physical contact with one another for a long period of time, how do you think that the temperatures of the two containers would compare? Would one container always be at a higher temperature than the other container or would they eventually be at the same temperature? Explain your answer.**

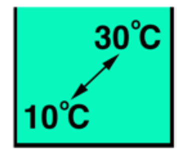
**9. Evaluate the following student statement about the questions that you have just answered. Identify ideas that are consistent with your ideas and others that are not consistent with your ideas.**
*"I think that the two containers would eventually be at the same temperature because the faster moving molecules in the hotter water would lose their energy when they collided with the slower moving molecules in the cooler water. The cooler molecules would begin to move faster as they gained the energy lost by the faster moving molecules. Eventually all of the molecules would pretty much be moving the same speed which would give them all about the same average kinetic energy and temperature. Temperature is simply a measure of average kinetic energy."*

**Check your work with your teacher**

A 4-liter container is full of water at 20°C.




**10. Do you think that it could be possible for the slower moving molecules in the water to spontaneously go to one part of the container so that the water in one part of the container would be cool while the water in the other part of the container was warm? Explain your answer.**




A container of water that had pockets of water at different temperatures would be more "ordered" than a container of water that had a uniform temperature. The measure of the "disorder" of a system is referred to as **entropy**. The second law of thermodynamics states that the entropy of an isolated system always increases.

The **second law of thermodynamics** can be stated in many ways. One of the ways that it can be stated is summarized below:

*Heat will never spontaneously flow from a cold object to a hot object.*

Another way to state the second law of thermodynamics is seen below:

*It is impossible to construct a heat engine that is 100% efficient.*
*Some of the energy is always wasted in a form that is no longer useful.*

The wasted energy degenerates into disorganized energy. The entropy of the system increases.
The second law of thermodynamics is a law that involves probability. It is possible that the air in this room could suddenly organize itself so that all of the fastest moving molecules moved to one corner of the room. This corner would be much warmer than the rest of the room. It is just not probable that this would happen.

You pour a container full of hot water into a container of cold water.
**11. If the entropy of this system increased, describe what would happen to the temperature of the water in the container. How would the final temperature of this mixture compare to the initial temperature of the hot water and to the initial temperature of the cold water?**

**12. Did the entropy of the "system" increase or decrease? Explain your answer.**

A Bunsen burner is positioned beneath a flask half full of a fluid. The top of this flask contains a movable piston that supports a 200 g mass.


**13. Where will the heat go that is produced by the Bunsen burner? What objects or substances will receive this heat?**

**14. What will happen to the pressure inside of the flask? Will it increase or decrease? Explain your answer.**

**15. As heat is added to the flask what do you think will happen to the level of the piston in the flask? Explain your answer.**

Your teacher will perform a demonstration similar to the arrangement described during questions 13 – 15.

**16. Describe what happened to the piston when your teacher exposed the chamber below the piston to a higher temperature.**

In order for the piston to move the heat added to the chamber below the piston must have been exerting a force over a distance on the bottom surface of the piston.

**17. What physics terms do we use to describe what happens when a force is exerted over a distance on a body?**

**18. Evaluate the following student statements about the questions that you have just answered. Identify ideas that are consistent with your ideas and others that are not consistent with your ideas.**

**<u>Student A</u>**

*"Heat must be a form of energy since it can do work on a body. Adding heat to a body from another body must be one way to transfer energy between them."*

**<u>Student B</u>**

*"If you do work on a body you can also give the body energy. Doing work on a body is another way to transfer energy."*

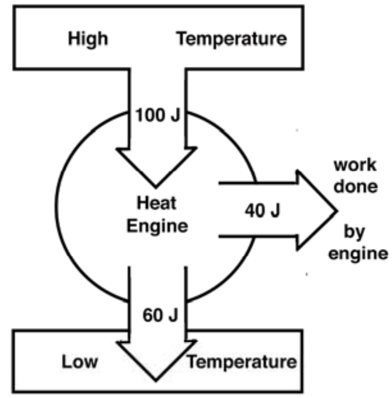
**Check your work with your teacher**

# Thermodynamics Temperature, Heat, and Entropy

## CONCEPT REFINEMENT

***Review***

Heat can be transferred from a high temperature object to one that has a lower temperature. This heat can also produce an increase in pressure. This increase in pressure can exert a force over a distance and do work.




The diagram, shown to the right, represents a heat engine undergoing a single cycle. The heat engine receives 100 Joules of thermal energy from a high temperature reservoir. Of this 100 Joules of energy, only 40 Joules represents work done by the heat engine while 60 Joules of thermal energy is expelled from the heat engine to a low temperature reservoir.

In order to calculate the efficiency of this heat engine you would make use of the idea that the thermal energy from the high temperature reservoir ($Q_h$) is equal to the thermal energy that is expelled to the low temperature reservoir ($Q_l$) plus the work that is done by the heat engine ($W_{eng}$). This is the **first law of thermodynamics.**

$$Q_h = Q_l + W_{eng}$$

The work done by the engine is equal to the difference between the thermal energy received from the high temperature reservoir and the thermal energy expelled to the low temperature reservoir.

$$W_{eng} = Q_h - Q_l$$

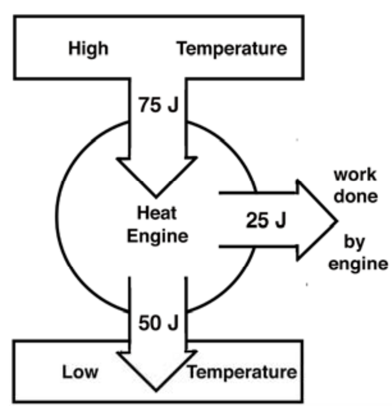
The efficiency of this heat engine can be considered as a ratio between the useful work that is done ($W_{eng}$) to the amount of thermal energy that was originally available to the heat engine ($Q_h$).

$$\text{efficiency} = \frac{W_{eng}}{Q_h}$$

The efficiency can also be expressed in terms of the difference between the thermal energy from the high temperature reservoir, ($Q_h$), and the thermal energy expelled to the low temperature reservoir, ($Q_l$).

$$\text{efficiency} = \frac{Q_h - Q_l}{Q_h}$$

**1. Calculate the efficiency of the heat engine described above. Be sure to show all of your work. Express your answer as a percentage.**

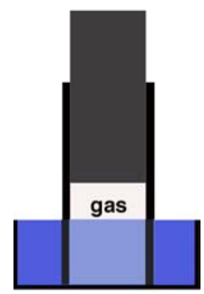


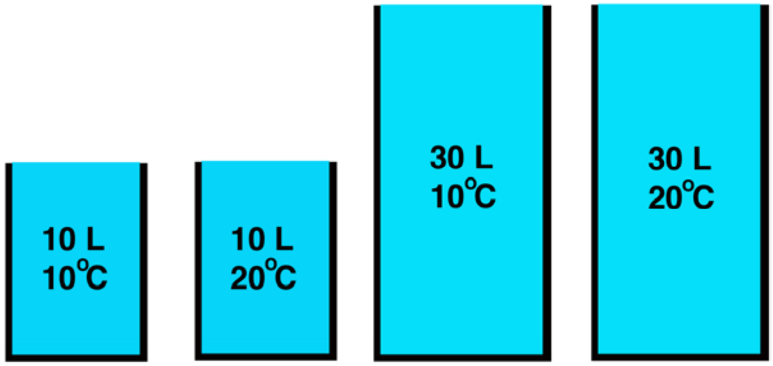

**2. Calculate the efficiency of the heat engine seen to the right.**

Each of the situations described below involves a sample of gas enclosed within the chamber beneath an adjustable piston.

**3. For each situation indicate whether the action taken would result in an increase or a decrease in pressure.**

**For each situation explain why the action would result in this increase or decrease.**

| Situation | Increase or decrease in pressure? | Explanation for the increase or decrease in pressure | |
|---|---|---|---|
| **A. The size of the piston chamber is kept constant while heat is added to the chamber.** | | |  |
| **B. The size of the piston chamber is kept constant while heat is removed by a cold-water bath.** | | |  |
| **C. No heat is added. The size of the chamber in the piston is increased.** | | |  |
| **D. No heat is added. The size of the chamber in the piston is decreased.** | | |  |




The four containers shown above are each full of water.  Two of the containers have a volume of 10 L while the other two have a volume of 30 L.  The water in two of the containers are at a temperature of 10 °C while the water in the other two containers are at a temperature of 20 °C.

**4.  Which of the containers shown above has the most internal energy?  Which of the containers has the least amount of internal energy?**

**5.  Indicate which way the heat would flow if the large container with the 10 °C water was placed in direct physical contact with the smaller container with the 20 °C water.  Explain your answer.**