

Period 6a Activity Solutions: Entropy

6.1 Conservation of Energy and the First Law of Thermodynamics

Your instructor will discuss how molecular motion and the changes in internal energy DU relate to energy conservation and the first law of thermodynamics.

1) Internal Energy

Your instructor will demonstrate two rolling carts colliding with a barrier. Both carts have the same mass and the same frictional force with the table top.

- a) Which cart has more kinetic energy after it hits the barrier – the cart that rolls a shorter distance or a longer distance? **_longer distance_** How do you know?

The cart that rolls a longer distance also bounced off of the barrier with a faster velocity. This cart has more kinetic energy because kinetic energy is proportional to the velocity squared. $E_{kin} = \frac{1}{2} M v^2$

- b) Now watch the carts, without their outer covers, collide with the barrier. How can you explain the difference in the kinetic energy of the carts after they hit the barrier?

More of the kinetic energy of motion of the elastic band cart is used to vibrate the washers. This kinetic energy goes into increasing the internal energy of the cart. Since the elastic band cart has less kinetic energy after the collision, it does not move as far away from the wall. The cart with rigid rods rolls farther away from the wall because less of its initial kinetic energy went into vibrating its washers.

- c) Explain how energy was conserved when each cart collided with the barrier.

If each cart is pushed with the same force, both carts start with the same amount of kinetic energy. Their kinetic energy goes into moving against the force of friction with the table top and into vibrating the washers. Since after the collision the elastic band cart uses more energy vibrating the washers, it does not roll as far after the collision.

- d) How does this demonstration illustrate an increase in the internal energy of an object?

The carts demonstrate what happens inside of a solid when kinetic energy is converted into the thermal energy of vibrating atoms and molecules. The greater the internal energy of an object, the faster its atoms and molecules vibrate.

2) Work Obtained from a Thermodynamic System

Your instructor will explain the electric drill activity. Be sure to hold the cardboard tube over the end of the drill while you perform this activity.

- a) How was heat Q added to the system of the drill and the stopper?

Friction between the moving drill tube and the wooden clamp produced thermal energy.

- b) What evidence do you have that the internal energy of this system increased?

The water in the tube became steam.

- c) How was work done by this system?

As the stopper flew up, work was done against the force of gravity and the force of friction holding the stopper into the tube.

- d) How much work was done on the stopper by the drill if 505 joules of heat transferred to the water resulted in a 500 joule increase in the internal energy of the system?

$$W = Q - \Delta U = 505 \text{ J} - 500 \text{ J} = 5 \text{ J}$$

3) Conservation of Energy

When we say that energy is wasted as friction, what has happened to that energy?

Energy wasted by friction is not lost, but has increased the internal energy of objects. An increase in internal energy means that the object's molecules move more rapidly.

6.2 Order, Disorder, and Entropy

4) Ordered and Disordered Checkers

- a) Turn the checkerboard on your table so that a red square is at the bottom right hand corner. Select one red or black checker **at random** from the beaker. (Before you remove the checker, the number of red and black checkers is the same.) Place the selected checker on the bottom right checkerboard square. Since there are two colors of checkers, what is the probability that the color of the checker you drew at random matches the color of the checkerboard square?

Since there are two colors of checkers, the probability that you selected the correct color at random is 1 in 2 or $\frac{1}{2}$.

- b) Draw a second checker at random from the beaker and place it directly on the square above the first checker. (In this activity, we assume that each time a checker is drawn, another checker of that color is added to the beaker. This means that the number of red and black checkers in the beaker is always the same.) What is the probability that the color of the second checker you drew matches the color of the second square?

Again, the probability that you selected the correct color at random is 1 in 2 or $\frac{1}{2}$.

- c) What is the probability that the color of **each** of the checkers you have drawn at random matches the color of the checkerboard square?

The total probability is the product of the individual probabilities:

$$\frac{1}{2} \times \frac{1}{2} = \frac{1}{2^2} = \frac{1}{4}$$

- d) Draw two more checkers at random and place them on the two checkerboard squares to the left of the two checkers already on the board. (You now have the four lower right checkerboard squares filled.)

What is the probability that the color of all four checkers matches the color of their checkerboard squares?

The total probability is the product of the individual probabilities:

$$\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{2^4} = \frac{1}{16}$$

- e) You can verify your results using the 16 four x four boxes shown below. Fill in all possible arrangements of checkers by writing an R for a red checker and B for a black. The first five boxes have been filled in for you. You fill in the rest.

R	R	R	B	R	R	R	R
R	R	R	R	B	R	R	B
R	R						
B	B						

- f) You can see that there are 16 different arrangements of four checkers drawn at random. Circle the box or boxes that match your first four checkerboard squares. How many boxes have you circled? 1 What is the probability that the color of all four checkers pulled at random matches the color of their checkerboard squares? Does this probability agree with the probability calculated in part d)?

The arrangement of the randomly selected checkers must match one of the 16 arrangements above. Therefore, the probability of getting the ordered arrangement must be 1/16. Yes, comparing with part d) we see

$$\frac{1}{16} = \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{2^4}$$

- g) Of the 16 possible arrangements of four checkers on four checkerboard squares, how many arrangements are disordered by color? 15 What is the probability that the color of four randomly selected checkers is a disorderly pattern?

Since 15 of the 16 arrangements are disorderly, the probability of getting a disordered arrangement is 15/16.

- h) The total probability of all the arrangements must be equal to one. Make your own equation for the probability that the arrangement will be disorderly by color.

$$1 - \frac{1}{16} = \frac{15}{16}$$

- i) What is the probability of filling an ordered arrangement of the whole checkerboard by this procedure? $\frac{1}{2^{64}}$
- j) Group Discussion Question: Are orderly or disorderly patterns more common in nature? Why?

Disorderly patterns are more common because there are many more disorderly patterns in nature than orderly patterns.

5) Entropy Examples

- a) Does entropy naturally increase or decrease over time? Why?

Entropy is a measure of the disorder of a system. Entropy naturally increases because systems, when left to themselves, become less ordered over time.

- b) Try to arrange the sets of photographs in chronological order. In which sets of photos is there a noticeable change in entropy?

The sets of photographs that show a noticeable change, such as the burning toast or the melting ice cream man, can be arranged in chronological order. But the photos that do not show a noticeable change are difficult to order. The ice cream man illustrates increase in entropy because the ice cream would not likely go from a puddle of ice cream back to the ice cream man, regardless of the conditions in the room.

- c) What happens to the entropy of an ice cube when it melts into water?

The entropy of the ice increases when it melts because the orderly crystal structure of the ice molecules has become a disordered arrangement of liquid water molecules.

- d) How many calories of heat are required to melt 250 grams of ice at 0 °C into 250 grams of water at 0 °C? The latent heat of melting of ice is 80 cal/gram.

$$Q = L_{heat} \times M = 80 \text{ cal/g} \times 250 \text{ g} = 20,000 \text{ cal}$$

- e) What is the change in entropy when the 250 grams of ice at 0 °C melt into 250 grams of water at 0 °C?

$$DS = \frac{DQ}{T} = \frac{20,000 \text{ cal}}{273 \text{ K}} = 73.3 \text{ cal/K}$$

Period 6b Activity Solutions: The Laws of Thermodynamics

6.3 Equilibrium and the Second Law of Thermodynamics

Your instructor will discuss equilibrium, which is a system or object that does not change over time.

6) Equilibrium Examples

- a) List of examples of objects or systems in equilibrium.

Water at room temperature, floating magnets, uncharged capacitor

- b) Which sets of photographs illustrate systems going toward equilibrium?

Sets of photos that show noticeable changes over time are going toward equilibrium.

7) Equilibrium and Entropy

Explain how equilibrium is related to entropy.

As systems come to equilibrium with their surroundings, the entropy of the systems increases. Objects that are at the same temperature or the same pressure as the room are in equilibrium. Objects that are not tipping over or falling are at equilibrium.

8) The Second Law of Thermodynamics

Your instructor will discuss several statements of the second law of thermodynamics. Give examples from the classroom to illustrate each statement.

- a) The entropy of a physical system left to itself will increase or, if the system is already at its maximum entropy, the entropy will remain the same.

an ice cube melts and the water warms to room temperature

- b) Any system, when left to itself, tends toward equilibrium with its surroundings.

an inflated balloon deflates

- c) The entropy of a system that is in equilibrium with its surroundings remains constant.

There is no noticeable change to any object at equilibrium with its surroundings.

Your instructor will discuss the relationship between irreversible processes and perpetual motion machines. Another version of the second law is shown below. Give examples to illustrate it.

- d) All physical processes are irreversible.

Examples showing work done as systems go to equilibrium: door closer, a capacitor or battery connected to a fan turns the fan blades, water at different temperatures in two beakers turns a fan

- e) Group Discussion Question: What happens to entropy of the dorm room of a typical college student over the course of the academic year? What must be done to the room to decrease its entropy?

6.4 Reversible Processes and Perpetual Motion

9) **Sand** Mix together the two different colors of sand.

a) Will the mixed colors of sand naturally go back to its unmixed state? No

b) What must be done to separate the two colors of sand?

Work must be done on the system of the mixed sand to separate it.

c) Is the process of mixing the sand a reversible or irreversible process?

It is an irreversible process. It is possible to separate the colors of sand, but only if work is done on the system of the mixed sand.

10) The Dippy Duck revisited

Is the Dippy Duck a perpetual motion machine? If not, what is its source of energy?

It is not a perpetual motion machine. The dippy duck will stop when the water evaporates from the cup. The dippy duck draws water from a cup that requires someone to do work to fill the cup.

11) Perpetual Motion Machines?

Your instructor will show you examples of “perpetual motion” machines.

Can a machine run on its own forever without some kind of energy input? Why or why not?

No, perpetual motion machines do not work. Since some energy is wasted in every process, that energy must be replaced to keep the machine working. Perpetual motion would violate the second law of thermodynamics. A perpetual motion machine, from which you could take energy as it runs, violates the 1st law and the 2nd laws of thermodynamics.

6.5 Efficiency and Irreversible Processes

7) **Engines** Your instructor will discuss and demonstrate several types of engines, heat engines and motors.

a) What is the difference between a heat engine and an electric motor?

Both devices convert energy into mechanical energy of motion. Heat engines convert thermal energy, which is produced by combustion of some type of fuel, into mechanical energy. Electric motors convert electrical energy directly into mechanical energy with some energy wasted as heat.

b) How is work related to equilibrium?

Work or energy is required to change a system from an equilibrium state. That energy can be given off or work can be done by a system if it is moving back toward equilibrium. For example, the electric motor runs only if there is difference in voltage, and a steam engine runs only

if there is a difference in temperature. These devices will only run as long as a nonequilibrium situation exists.

- c) Can a system ever return to a non-equilibrium state?

Yes, a system can return to a non-equilibrium state, but work must be done on that system or energy put into the system. Two examples are the compressed air tank and charging of the capacitor.

- 8) **Air Conditioners** Your instructor will demonstrate an air conditioner.

- a) How does the palm glass filled with freon apply to an air conditioner (or a refrigerator)?

Freon has such a low boiling point that heating the glass bulb in your palm can cause some freon molecules to change phase from liquid to gas. This phase change increases the pressure in the palm glass.

- b) What is the cooling mechanism in an air conditioner (or refrigerator)?

Cooling occurs in the air conditioner coils when the pressure on the freon (or other liquid) is quickly reduced as the freon is allowed to expand through a small opening. As the liquid freon expands, it becomes a gas. To change phase from a liquid to a gas, heat must have been added. That heat comes from the surroundings, and the surroundings are cooled.

- 9) **Calculations with Heat Engines, Heat Pumps, and Refrigerators**

- a) What is the maximum efficiency of a heat engine that has 100 °C at the high temperature region and 20 °C in the low temperature region?

First, convert the temperatures from Celsius to Kelvin by adding 273 K.

$$Eff = \frac{T_H - T_L}{T_H} = \frac{373 \text{ K} - 293 \text{ K}}{373 \text{ K}} = \frac{80 \text{ K}}{373 \text{ K}} = 0.21 = 21\%$$

- b) You use a heat pump to warm your house. If the air temperature outside of the house is - 10 °C and the temperature inside is 23 °C, what is the maximum coefficient of performance for this heat pump?

First, convert the Celsius temperatures to Kelvin by adding 273 degrees. Then use equation 6.7.

$$COP = \frac{Q_H}{W} = \frac{T_H}{T_H - T_C} = \frac{273 + 23}{(273 + 23) - (273 - 10)} = \frac{296}{296 - 263} = 9.0$$

- c) Group Discussion Question: What is the difference between a heat pump and a refrigerator?