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Activity Sheet 7: Applications of the Laws of Thermodynamics

7.1 Conservation of Energy

Your instructor will discuss how changes in internal energy ΔU relate to energy conservation.

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 back a shorter distance or a longer distance? ________________________

How do you know?

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?

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

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

7.2 Pressure, Temperature, Volume and the Ideal Gas Law

2) Crushing Cans

Your instructor will illustrate the relationship between pressure and volume by changing the internal energy and the phase of water molecules inside cans.

a) What happens to the internal energy and the motion of the water molecules in the can as the water is heated into steam?

b) Pressure in the can is caused by the collisions of molecules of steam with the can walls. When the water is heated, what happens to the pressure inside the can?

c) What happens to the motion of the water molecules and the pressure inside the can when the steam is quickly cooled and condenses into liquid water?

d) Why do the walls of the can collapse?

3) The Ideal Gas Law

Next we consider the relationship among pressure, temperature, volume, and number of molecules of a gas and discuss the Ideal Gas Law. We will find that ratio reasoning is useful and can be based on proportionalities.

a) The previous demonstration discussed the relationship between the temperature of a gas and the pressure the gas exerts on the walls of a container. At a fixed volume of gas, pressure and temperature are directly proportional. Write a proportionality to show this relationship. ___________________

Write a ratio of the initial pressure of a gas $\mathbf{P_{initial}}$ (or $\mathbf{P_i}$) to the final pressure $\mathbf{P_{final}}$ (or $\mathbf{P}_f$) and a second ratio of the initial gas temperature $\mathbf{T_i}$ to the final temperature $\mathbf{T_f}$. Based on your proportionality above, relate these two ratios by an equation.

b) We showed that the pressure inside the can resulted from steam molecules hitting the can walls. Suppose that you could change the volume of a container of gas without changing the temperature of the gas. As you decrease the gas volume, what happens to the number of times that gas molecules hit the can walls?

At a fixed temperature and number of molecules, write a proportionality to show how the pressure of a gas is related to its volume. _____________________

Write a ratio of the initial pressure of a gas $\mathbf{P_i}$ to the final pressure $\mathbf{P}_f$ and a second ratio of the initial volume $\mathbf{V_i}$ to the final volume $\mathbf{V_f}$. Based on your proportionality above, relate these two ratios by an equation.

c) Combine your equations from parts a) and b) into an equation that relates the pressure, the volume, and the temperature of a gas.

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d) Your instructor will demonstrate the relationships between pressure, temperature, volume, and the number of gas molecules.

If the volume and temperature of a gas are held constant and the number of gas molecules is increased, how will the gas pressure change? ________________

At a fixed volume and temperature, write a proportionality to show how the pressure of a gas is related to the number **N** of molecules of gas. ___________

Write a ratio of the initial pressure of a gas $\mathbf{P_i}$ to the final pressure $\mathbf{P_f}$ and a second ratio of the initial number of gas molecules $\mathbf{N_i}$ to the final number of gas molecules $\mathbf{N_f}$. Based on your proportionality above, relate these two ratios by an equation.

e) Now combine all four variables – pressure, volume, temperature, and number of molecules – into a single equation.

f) Write this equation as a proportionality between **P**, **V**, **N**, and **T**.

g) You can illustrate this relationship with a pump and a liter bottle. Note the temperature on the thermometer inside the bottle. Then pump air into the bottle.

Which of the four variables **P**, **V**, **N**, and **T** changed as you pumped air into the bottle? Indicate below the change in variables.

Pressure:

Volume:

Temperature:

Number of molecules:

h) Introducing the constant **k** into the proportionality obtained in part f) gives the equation for the Ideal Gas Law:

$$\mathbf{P\,V = N\,k\,T}$$

A car tire has a pressure of 30 pounds/in^2 or 2.07 x 10^5 newtons/m^2. The volume of air in the tire is 0.05 meters^3. The tire temperature is 27 ^{o}C or 300 K. The constant **k** = 1.38 x 10^{-23} J/K degree. How many molecules of air does the tire contain?

i) The owner's manual of your new car indicates two tire pressures: a maximum pressure of 36 pounds/in^2 and a recommended pressure of 28 pounds/in^2. To which pressure should you inflate your tires? Why?

7.3 Work from Thermodynamic Systems

Your instructor will discuss how changes in internal energy $\Delta \boldsymbol{U}$ relate to energy conservation and the first law of thermodynamics.

4) The Dippy Duck Does Work

The dippy duck contains liquid freon, which changes phase easily at room temperature. Wet the head of the duck and place the cup of water in front of the duck's head. How does evaporation from the duck's head do work on the freon in the duck?

5) The Electric Drill Popper

The electric drill activity illustrates work done by an electric motor (the drill) and a thermodynamic system (the steam in the tube). 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 $\boldsymbol{Q}$ added to the system of the drill and the stopper?

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

c) How was work done by this system?

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?

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6) Thermodynamic Systems Doing Work

a) How is work related to equilibrium?

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

c) In the next section, you will see how different types of engines work. What is the one necessary condition for any engine or machine to do work?

7.4 Engines and Work

7) Electric Motors

Electric motors convert electrical energy into mechanical energy of motion. An example is the electric motor in a drill that turns the drill shaft. Electricity to run a motor can be generated by a thermodynamic system as shown below.

a) Attach the thermocouple to the ammeter. Place the thermocouple on the table and warm one side with your hand. What happens?

b) What is the energy source of this current?

c) Your instructor will demonstrate a fan that uses energy from thermocouples. How does this thermodynamic system do work?

8) Internal Combustion Engines

Internal combustion engines also use thermodynamics systems to do work. Your instructor will demonstrate models of internal combustion engines.

a) What causes the pistons in an engine to move?

b) What is the energy source for an internal combustion engine?

9) External Combustion Engines

Your instructor will discuss and demonstrate external combustion engines.

a) What causes the pistons in the steam engines engine to move?

b) What is the energy source for an external combustion engine?

c) What happens to the temperature of the steam as the steam does work?

d) You instructor will demonstrate an engine that runs on liquid nitrogen. What does this engine have in common with a steam engine?

e) Why are internal and external combustion engines known as heat engines?

10)Heat Engines using Nitinol Wire

a) Place a piece of nitinol wire into a beaker of hot water. What happens to the wire?

b) A mass is hung from a piece of nitinol wire. What happens when you close the switch?

c) Your instructor will help you make a heat engine that uses nitinol wire. What happens when the wire is dipped into beakers of hot and cold water?

d) Why must the nitinol wire be dipped in different temperatures of water?

e) Group Discussion Question: What is the difference between a heat engine and an electric motor?

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11) Heat Engine Efficiency

a) What is the maximum efficiency of a heat engine for which the high temperature is at 100 ^{o}C and the low temperature is at 20 ^{o}C?

(Hint: First, convert the temperatures from Celius to Kelvin by adding 273 K.)

7.5 Refrigerators, Air Conditioners, and Heat Pumps

12) *Air Conditioners*

a) In Activity 3.f), you found that increasing the pressure on the gas in a liter bottle increased the temperature of the gas. What do you think happens to the temperature of a gas when it is allowed to expand? ________________

b) Hold the palm glass upright and warm one bulb with your palm. What happens to the freon in the glass tube? Why are liquids with low boiling points, such as freon, good coolants for air conditioners?

c) What does an air conditioner do?

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

13) Heat Pumps

a) What is a heat pump?

b) How is a heat pump similar to an air conditioner? How does a heat pump differ from an air conditioner?

c) Group Discussion Question: Do you think heat pumps could be used as the only source of central heating for homes? What benefit could a heat pump produce?

14) Coefficient of Performance of Heat Pumps

You use a heat pump to warm your house. If the air temperature outside of the house is – 10 ^{o}C and the temperature inside is 23 ^{o}C, what is the maximum coefficient of performance for this heat pump?

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

15) Coefficient of Performance of Air Conditioners or Refrigerators

The temperature inside your refrigerator is 40 ^{o}F (4 ^{o}C) and the temperature in your kitchen is 78 ^{o}F (26 ^{o}C). What is the maximum coefficient of performance of your refrigerator?