Gas Laws and Thermochemistry Review Packet

Gas Laws

Introduction to Gas Laws

Earlier in your science education you learned to describe the gas state as the state of matter with no definite shape, no definite volume, and highly compressible. Now you have added the kinetic molecular theory to your understanding of gas behavior. We will review several of the major laws that describe the physical nature of gases.

The gas state of matter is described by what we call "The Molecular Theory of Gases". The bolded parts of the description of the gas state are the basis for our understanding on the physical behavior of gases:

Kinetic Molecular Theory of Gases

1. **Gases are composed of tiny particles called molecules** which are in rapid, random, straight-line motion, colliding with each other and the walls of the container they are in.

2. **Gases exert pressure by these collisions** with the walls of their container.

3. Ga**ses are mainly empty space**; only about $1/1000^{th}$ of the total volume is actually filled by the molecules. The gas occupies the rest of the volume by moving through it.

The physical behavior of the gaseous state of matter differs from that of the solid and liquid states of matter due to its lack of the definite volume. Therefore, **when you discuss a gas it is necessary to specify the conditions of the gas you are considering; these conditions are described by four variables.**

Gas State Variables			
Pressure (P)	**Volume (V)**	**Temperature (T)**	**Number of moles (n)**

Pressure is defined as the force exerted per unit of surface area (force/area) and the SI unit for pressure is the pascal (Pa). Atmospheric pressure is commonly measured using a barometer. The mercury barometer was invented by Torricelli in 1643; the atmospheric pressure is directly proportional to the height of a column of mercury in a glass tube that is inverted in a pan of mercury. Because of this **gas pressure has commonly been expressed in units of inches of mercury (in Hg), centimeters of mercury (cm Hg), or millimeters of mercury (mm Hg) which is also called the torr in honor of Torricelli.** A second type of barometer is the aneroid barometer which is based upon a sealed vacuum chamber with a flexible metal wall. This wall moves in or out as the atmospheric pressure changes and a spring and needle connected to this moving wall indicates the pressure on a dial. This barometer is commonly used in our modern society as we try to remove mercury from our environment. A monometer is a modified version of the mercury barometer that is frequently used to measure the pressure of gas samples in a laboratory. **Very often gas pressure is measured in industry and in our daily lives with a device called a pressure gauge and units of pounds per square inch (psi).**

When dealing with gases **there is a reference pressure called standard pressure which is defined as the normal pressure of the atmosphere at sea level on a fair weather day. Standard pressure can be expressed in all of the units listed** above plus the unit atmosphere (atm). **These values are: 29.9 in Hg, 76.0 mm Hg, 760 mm Hg, 760 torr, 101,325 Pa, 14.7 psi, and 1.00 atm.** For now we will only use three of these values to use in our problems.

Standard Pressure Values		
1.00 atmosphere (atm)	**760 torr**	**14.7 lbs/in^2 or 14.7 psi**

Temperature is a measure of the average kinetic energy and is measured in units called degrees. The temperature scale most commonly used in our daily like is the Fahrenheit scale but in chemistry and other scientific laboratories the Celsius scale is the most common. **In our laboratory work we will always record our temperature readings in Celsius degrees. However, when we study gases we find we must use the Absolute or Kelvin scale** which was developed to correspond to the physical behavior of gases. **This scale starts at absolute zero, the coldest temperature possible, where there is no motion of the gas molecules. There are no negative values on the Absolute or Kelvin**, it cannot be colder that 0 A or 0 K. Whenever you do a calculation involving gas temperature you must use the Kelvin scales you frequently need to convert Celsius to Kelvin and Kelvin to Celsius.

Conversions between Celsius and Kelvin Temperatures

$K = {}^0C + 273$ **${}^0C = K – 273$**

(By scientific convention no degree sign is used with the Kelvin scale and the values are just called Kelvin, no Kelvin degrees.)

Just as there is a reference pressure called standard pressure, **there is a reference temperature called standard temperature. This value is the normal freezing point of water at standard pressure** and you need to memorize the value of the standard temperature.

Standard Temperature Values to Memorize		
0^0C	**273 K or 273 A**	**32^0F**

Chemists and physicists frequently combine the concepts of standard temperature and standard pressure into a single abbreviation, **STP** which means **standard temperature and standard pressure.**

STP
(Standard Temperature and Pressure)

The following are the values we will commonly use for STP but, of course, any of the units for standard temperature or standard pressure can be used.

0^0C or 273 K	AND	1.00 atm or 760 torr or 14.7 psi

Intro to Gas Laws Questions

1. In the boxes below, draw pictures to represent the molecules of a solid, liquid and gas:

2. What are three characteristics of particles in a gas? ______________________________
____
____

3. Gases exert ____________________ by ____________________ with the walls of their containers.

4. Imagine a gas at room temperature and normal pressure, such as the air in the classroom. Of all the space the gas fills in the room, about how much of that space contains gas molecules rather than empty space?

5. If most of the space a gas occupies is empty space, how does it "fill" the rest of the space in its container?

6. Gases are different from solids and liquids because of they have low densities and can respond to changing pressure and temperature by expanding (getting bigger) and contracting (getting smaller). Therefore, when you describe a sample of gas there are four variables you commonly mention. Give the letter and name for each of these variables.

   ____________________ ____________________ ____________________ ____________________

7. The ____________________was invented by ________________ in the year _________. There are two types the ___________________ barometer and the ___________________ barometer.

8. In industry and in our daily lives we frequently need to measure gas pressure. Give the name of the device and the units most commonly used.

   ____________________________ ______________________

9. Define "standard pressure" and then give its values expressed in the three standard units.

   ____
   ____

   _________atmospheres (atm) ___________ torr _________ lbs/in^2 (psi)

10. In scientific terms, temperature is actually a measure of ____________________________________

11. Give the value of standard temperature in Celsius, Fahrenheit, and Kelvin. (Note that there is no degree sign for Kelvin.)

_____________ ^0C ____________ ^0F _______________ K

12. What do the letters STP stand for?

________________________ ________________________ and ______________________________

13. What is happening to the molecules when you heat a sample of gas? (Don't say "they get hot" but instead explain it in terms of the kinetic molecular theory picture of gases.)

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14. Gases are very compressible; that is, you can squeeze a sample of gas down into a much smaller volume. When you compress a gas what is it that is actually decreasing? (Don't say "the volume" but instead explain it in terms of the kinetic molecular theory picture of gases.)

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FOR THE FOLLOWING QUESTIONS IMAGINE A SAMPLE OF GAS IN A CONTAINER WITH FLEXIBLE WALLS SO IT CAN EXPAND AND CONTRACT. IN OTHER WORDS, IMAGINE A GAS THAT CAN CHANGE ITS VOLUME.

15. If you have a 10 liter sample of gas at room temperature and you apply pressure to squeeze the gas down to a volume of 5 liters, at constant temperature, what will happen to the number of collisions between the gas molecules and the walls of the container?

____

16. In the case above, the volume got smaller and the pressure got ____________________ at constant temperature.

17. If you have a 10 liter sample of gas at room temperature and you reduce the pressure to allow the gas to expand to a volume of 20 liters, at constant temperature, what will happen to the number of collisions between the gas molecules and the walls of the container?

____

18. In the above case, the volume got larger and the pressure got _______________________ at constant temperature.

Boyle's Law (Constant Temperature Problems)

In 1650 Sir Robert Boyle summed up a series of experiments on gases with the statement that is now known as **Boyle's Law**. He said *"The volume and pressure of a sample of gas are inversely proportional at constant temperature."* That is, **when the pressure gets bigger the volume gets smaller and vice versa as long as you keep the same temperature and the same number of molecules** (that is what we mean by "the sample"). We can represent this law with an equation:

Boyle's Law
at constant temperature:

$$\frac{V_1}{V_2} = \frac{P_2}{P_1} \quad \text{or} \quad P_1 V_1 = P_2 V_2$$

Our strategy for solving these problems will be:

(1) Read the problem and underline information about volume, temperature and pressure (always assume the temperature is not changing).
(2) Determine if you are solving for volume or for pressure.
(3) Use algebra to put the equation in the correct format.
(4) Plug the numbers into the equation and solve it.
(5) Round to two decimals, add a label, and box the final answer.

EXAMPLE PROBLEM #1:
A <u>5.00 L</u> sample of a gas had a pressure of <u>380.0 torr</u> at a temperature of <u>25.0^{0}C.</u> Calculate the volume this sample of gas would occupy at <u>standard pressure</u>. *Hint: we know standard pressure in many units, but for this problem it makes sense to use 760 torr since that is the unit used in the problem.*

$V_1 = 5.00$ L $\qquad T_1 = 25.0^0$C $\qquad P1 = 380.0$ torr

$V_2 = ?$ $\qquad T_2 = 25.0^0$C $\qquad P2 = 760.0$ torr

$$V_2 = \frac{P_1V_1}{P_2} \qquad V_2 = \frac{5.00 \text{ L x } 380.0 \text{ torr}}{760.0 \text{ torr}} = 2.5 = 2.50 \text{ L}$$

EXAMPLE PROBLEM #2
A <u>14.00 L</u> sample of gas has a pressure of <u>3.00 atm</u> at a temperature of <u>25.0^{0}C</u>. The volume of the sample of gas increased to <u>42.0 L</u> while the temperature remained constant. What was the final pressure of the gas?

$V_1 = 14.00$ L $\qquad T_1 = 25.0^0$C $\qquad P1 = 3.00$ atm

$V_2 = 42.0$ L $\qquad T_2 = 25.0^0$C $\qquad P2 = ?$

$$P_2 = \frac{P_1V_1}{V_2} \qquad P_2 = \frac{3.00 \text{ atm x } 14.0 \text{ L}}{42.0 \text{ L}} = 1 = 1.00 \text{ atm}$$

Boyle's Law Problems

Most commonly we find our gas law problems presented in "story problem" format. Before attempting to solve the problem you first organize the information and then set up the calculation.

1. A sample of gas had a volume of 20.0 liters at 0^{0}C and 1520 torr. What would be the volume of this gas sample at 0^{0}C and 760 torr?

   $V_1 =$ $\qquad T_1 =$ $\qquad P_1 =$

   $V_2 = ?$ $\qquad T_2 =$ $\qquad P_2 =$

   $V_2 =$

2. If a sample of gas has a volume of 12.0 liter at 25.0^{0}C and 0.500 atmospheres pressure, what volume would it occupy at 25.0^{0}C and 2.00 atm pressure?

$V_1 =$ $T_1 =$ $P_1 =$

$V_2 =$? $T_2 =$ $P_2 =$

$V_2 =$

3. A 60.0 mL sample of gas at 40.0 lbs/in^2 pressure suddenly experiences a pressure drop to a standard pressure while the temperature remains constant at 25.0^0 C . What is the new volume?

$V_1 =$ $T_1 =$ $P_1 =$

$V_2 =$? $T_2 =$ $P_2 =$

$V_2 =$

4. A sample of gas has a pressure of 2.00 atm and a volume of 400 mL at 40^{0}C. What volume would this sample occupy at 40^{0}C and 5.00 atm?

$V_1 =$ $T_1 =$ $P_1 =$

$V_2 =$? $T_2 =$ $P_2 =$

$V_2 =$

5. A sample of gas at 25.0^{0}C and 750 torr had a volume of 80.0 mL. The volume was changed to 120.0 mL while the temperature remained constant. What was the new pressure?

$V_1 =$ $T_1 =$ $P_1 =$

$V_2 =$ $T_2 =$ $P_2 =$?

$P_2 =$

6. A gas sample was held at a pressure of 30.0 psi and 100^{0}C. The temperature was held constant while the pressure was increased to 120 psi and the volume changed to 8.0 cubic feet. What was the original volume?

$V_1 =$? $T_1 =$ $P_1 =$

$V_2 =$ $T_2 =$ $P_2 =$

$V_1 =$

7. A student collected 88.0 mL of carbon dioxide at 28.0^0C and 730 torr. What volume of carbon dioxide would the student have at 28.0^0C and 760 torr?

V_1 = T_1 = P_1 =

V_2 = ? T_2 = P_2 =

V_2 =

Graphing Boyle's Law (Pressure vs. Volume)

An important concept you must consider when you study gases is the relationship between pressure and the volume of a sample of gas at constant temperature.

Make a graph of the following data of pressure versus volume for a 3.00 mole sample of gas at 25.0^0C. Rotate the paper so the x-axis is along the long dimension of the paper. Graph the pressure as the independent variable and volume the dependent variable. Be sure to label the axes and include a title.

Pressure (atm)	Volume (L)	Pressure (atm)	Volume (L)	Pressure (atm)	Volume (L)
1.00	73.35	4.50	16.30	8.00	9.17
1.50	48.90	5.00	14.67	8.50	8.63
2.00	36.68	5.50	13.34	9.00	8.15
2.50	29.34	6.00	12.22	9.50	7.72
3.00	24.45	6.50	11.29	10.00	7.34
3.50	20.96	7.00	10.48		
4.00	18.34	7.50	9.78		

Answer the following questions directly on this sheet.

1. Define pressure.

2. Describe the motion of the molecules in a sample of gas and explain how the moving gas molecules create pressure inside their container.

3. Look at your graph and see what happens to the volume of a gas as its pressure increases at constant temperature. Is this relationship as directly proportional or inversely proportional? Explain your answer.

4. We commonly talk about standard pressure when we are working with gases. Complete the following table that expresses standard pressure in several common units.

atm	torr	760. mm Hg	101,325 Pa
psi	29.9 in Hg	76.0 cm Hg	101.325 kPa

Charles' Law (Constant Pressure Problems)

So far we have studied the relationship between gas pressure and volume. **Now we will look at the relationship of temperature and volume for a sample of gas at constant pressure.** This relationship was first determined in 1787 by Jacques Charles and so it is called Charles' Law. Charles' Law states that *"the volume and temperature of a sample are directly proportional at a constant pressure"*. In other words, **when the temperature increases, so does the volume and visa versa as long as you keep the temperature the same**. We can represent this law with an equation:

Charles' Law
at constant pressure:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad \text{or} \quad V_1 T_2 = V_2 T_1$$

When we work with gas law problems that involve a temperature change we must work with the Kelvin temperature scale. We saw on the last sheet that gas volume varies in 1:1 ratio with the Kelvin temperature; that is, **if you double the Kelvin temperature you double the volume, triple the Kelvin temperature the gas volume triples, etc.** The Kelvin scale begins at absolute zero and is equal to 273 K at 00C, so you **add 273 to the Celsius temperature to convert it to Kelvin.**

Convert 25.0^{0}C to Kelvin ______________________ Convert 332 K to ^{0}C ___________________

Problem 1: A sample of gas has a volume of 55.8 mL at 25.0^{0}C and 760 torr. What volume would this gas sample occupy at STP?

V_1= T$_1$= + 273 = K P$_1$=

V_2= ? T$_2$= + 273 = K P$_2$=

V_2 =

Problem 2: A gas sample had a volume of 25.0 L at 100.0^{0}C. What volume would this gas occupy at 200.0^{0}C, assuming the pressure remains constant at 760 torr?

V_1= T$_1$= + 273 = K P$_1$=

V_2= ? T$_2$= + 273 = K P$_2$=

V_2 =

Problem 3: A gas had a volume of <u>75.0 mL</u> at <u>40.0^{0}C</u> and <u>755 torr</u>. The volume increased to <u>145 mL</u> while the pressure remained constant. What was the final **Celsius** temperature?

V_1= T_1= + 273 = K P_1=

V_2= T_2= ? + 273 = K P_2=

T_2 =

Problem 4: A gas had a volume of 25.0 liters at 400.0^{0}C and standard pressure. The gas was cooled until the volume was 12.5 L at standard pressure. What was the final Celsius temperature of the gas?

V_1= T_1= + 273 = K P_1=

V_2= T_2= ? + 273 = K P_2=

T_2 =

More Charles' Law Problems

Solve the following problems directly on this sheet. You must use the technique shown in class: organize the information and set up the correct equation. Give your final, boxed answer rounded to two decimals.

1. A sample of gas has a volume of 425 mL at 25^{0}C and 760 torr. What volume would this gas sample have at STP?

2. A sample of gas occupied 250.0 mL at 30.0^{0}C. What volume will it have at 60.0^{0}C, assuming the pressure remains constant?

3. A 5.76 liter sample of a gas at 22.0^{0}C and 748 torr pressure was heated to a final volume of 17.28 liters, with the pressure remaining constant. What was the final Celsius temperature?

Graphing Charles' Law (Temperature vs. Volume)

Directions:

1. Graph the data in the first two columns of the table below.
2. The data in the table represents the change in volume of an enclosed sample of gas as it cooled with the pressure remaining constant. Ignore the last column in the table for now.
3. Plot the temperature as the independent (x) variable. Rotate the sheet of graph paper so you can make the temperature scale longer. The temperature scale must range from -300^{0}C to 100^{0}C. This means you will show first and second quadrants of the graph but the majority of your graph paper will be in the second quadrant.
4. Make your graph large enough to fill most of the sheet of graph paper.
5. Because it will be very difficult to accurately plot the volume, plot points but then draw a circle around each point so that you will be able to at least connect the circles for a straight line.

Temperature (^{0}C)	Volume (L)	Temperature (K)
100	10.00	
75	9.33	
50	8.66	
25	7.66	
0	7.32	
-25	6.65	
-50	5.98	
-75	5.31	
-100	4.64	
-125	3.97	
-150	3.30	
-175	2.63	
-200	1.96	

6. When the student continued cooling the gas he found that at just below -200^{0}C the gas sample became a liquid so he could no longer gather data for us to graph. HOWEVER, we can predict what this line would look like. This prediction is called *extrapolation*. Use a dotted line for your extrapolation and extend the line until it crosses the x-axis. Where on the x-axis does it cross?

    ____

7. Look at your graph and complete the statement: As the Celsius temperature of a sample of gas increases the volume __________________, at constant pressure. This means volume and temperature of a sample of gas are _____________________ proportional at constant pressure.

8. According to the graph, what would be the apparent volume, in liters, of this sample of gas at the x-intercept? ______________________ Why would this never happen in the real world?

    ____

9. Complete the last column of the table by filling in the Kelvin temperatures using the relationship K = ^{0}C + 273

Combination Gas Law Problems

It is very common to have **both the temperature and the pressure change** in a sample of gas. A problem like **this involves applying both Charles' law and Boyle's law in the same problem**; that is called the **Combination Gas Law**. We can represent this law with an equation that combines the previous two we have used:

Combination Gas Law
with changing temperature AND pressure:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_1}{T_2}$$

Problem 1: A sample of gas has a volume of 46.5 mL at 28.0^0C and 785 torr pressure. What volume would this gas occupy at STP?

V_1=	T_1=	+ 273 =	K	P_1=
V_2= ?	T_2=	+ 273 =	K	P_2=

V_2 =

Problem 2: A sample of gas has a volume of 72.8 mL at 735 torr and -40.0^0C. What volume would this gas sample occupy at STP?

V_1=	T_1=	+ 273 =	K	P_1=
V_2= ?	T_2=	+ 273 =	K	P_2=

V_2 =

More Combination Gas Law Problems

Solve the following problems directly on this sheet. You must use the technique shown in class: organize the information and set up the correct equation. Give your final, boxed answer rounded to two decimals.

1. A student collected a 46.0 mL sample of gas at 28.0^0C and 748 torr. What volume would this gas sample occupy at STP?

2. A sample of gas had a volume of 15.0 liters at 20.0^{0}C and 0.875 atm. What volume would this gas sample occupy if it was heated to 40.0^{0}C and the pressure dropped to 0.500 atm.

3. A 44.0 mL sample of gas at -40.0^{0}C and 12.0 psi was brought to standard conditions; that it, STP. What was the new volume of the sample?

Gas Law Review Worksheet #1: Boyle's, Charles', and Combination Gas Law Problems

Solve the following problems directly on this sheet. You must use the technique shown in class: organize the information and set up the correct equation. Give your final, boxed answer rounded to two decimals.

1. A 15.0 liter sample of gas at 35.0^{0}C was heated to 70.0^{0}C while the pressure was held constant. What was the final volume of this gas sample at the new temperature?

2. A sample of gas occupies 4.00 liters at 0.0^{0}C and 2.50 atm. What volume would this sample occupy at standard conditions?

3. A sample of gas had a volume of 15.0 liters at 20.0^{0}C and 0.875 atm. What volume would this sample occupy if it was heated to 40.0^{0}C and the pressure dropped to 0.500 atm?

4. A 6.50 liter sample of gas at STP was heated until its volume was 24.0 liters at a constant pressure of 14.7 psi. What was the final Celsius temperature?

5. If a sample of gas has a volume of 22.4 liters at 28.0^0C, to what Celsius temperature must it be cooled to decrease the volume to 20.0 liters, assuming constant pressure?

6. A student collected a 46.0 mL sample of gas at 26.0^0C and 748 torr. What volume would this sample fill at STP?

7. What pressure would be needed to compress 5.00 x 103 ft^3 of methane (natural gas) at 30.0^0C and 0.985 at, to a volume of 2.50 x 103 ft^3, assuming constant temperature?

8. A gas sample with a volume of 1275 mL of 220.0^0C and 1.00 atm was cooled to standard conditions. What was the new volume?

9. A 44.0 mL sample of gas at -40.0^0C and 12.0 psi was allowed to warm and expand until it reached STP. What was the final volume of this gas sample?

10. If a gas sample has a volume of 175 mL at STP, what volume would it fill at 14.7 psi and 25.0^0C?

Gas Laws Review Sheet #2: Conceptual Gas Laws Questions

1. What does temperature measure?

2. What is the lowest temperature possible, expressed in Celsius and Kelvin?

3. What is the volume of an "ideal gas" at absolute zero?

4. How would you define pressure and how do gases create pressure?

5. If you graph two variables and get a straight line are the variables directly proportional or inversely proportional?

6. If you graph two variables get a curved line are the variables directly proportional or inversely proportional?

7. Describe the motion of gas particles at STP.

8. Describe the motion of "ideal gas" particles at absolute zero.

UNIVERSAL GAS LAW OR IDEAL GAS LAW

The universal gas law is an equation which relates all four variable for a single sample of gas. We don't use this equation when we are dealing with changes in volume or temperature or pressure. We use this equation when we know any three of the variables (P,V,T and n) describing a gas sample and we want to solve for the fourth.

1. Give the other name for the universal gas law:____

____

The universal gas law is: $PV = nRT$

where P = pressure, V = volume, n = number of moles, T = temperature (again, it must be in Kelvin), and R is a proportionality constant called the universal gas constant. R = 0.0821 L atm/K mole

We can solve the equation to find P, $P = nRT/V$

We can solve the equation to find V, $V = nRT/P$

We can solve the equation to find n, $n = PV/RT$

We can solve the equation to find T, $T = PV/nR$

Because the value of R is given in liters and atmospheres we must factor-label any other volume or pressure units to agree with R.

2. What would be the volume, in liters, of 3.00 moles of gas at 30.0^0C and 2.75 atm pressure?

3. What would be the pressure, in atmospheres, if an 8.25 liter container holds 2.64 moles of argon at 28.0^0C?

4. How many moles of gas are there in a 0.750 liter container with a pressure of 2.25 atmosphere at 225.0^0C?

5. How many moles of gas are there in an 875 mL container with a pressure of 925 torr at 25.0^0C? (Note: substitute the mL and torr in the equation, then add factor-label terms at the end to convert the mL to liters and torr to atm.)

6. What is the temperature, in Celsius degrees, of an 8.40 liter sample of gas with a pressure of 752 torr and a total of 0.333 moles of gas? (You solve for Kelvin, then find Celsius.)

8. A 6.00 liter container held 3.00 moles of oxygen, 11.1 moles of nitrogen and 0.143 moles of argon at a temperature of 20.0^0C. What was the total pressure, in atmospheres, in the container? (Note: find the total moles of gas, then solve for pressure.)

Thermochemistry

Thermochemistry is the application of the laws of thermodynamics to chemical processes. In this unit, we will be concerned with the First Law of Thermodynamics and its applications. You are probably already familiar with the First Law, because it is the same as the Law of Conservation of Energy: Energy can be neither created nor destroyed; it can only be converted among different forms.

System and Surroundings

When we perform an experiment designed to test a hypothesis related to a thermochemical process, or when we think about thermochemistry, we divide the universe into two parts called the system and the surroundings. The *system* is the part of the universe under consideration. The *surroundings* are the remainder of the universe. In a general chemistry laboratory, thermochemical experiments are often conducted in water in a Styrofoam cup. The heat released from the physical or chemical change is absorbed by the water and the cup. In many thermochemical experiments, it is desirable to minimize the amount of heat energy that can transfer between the system and the surroundings. As coffee drinkers know, Styrofoam cups do a good job of keeping the heat energy transfer relatively low when compared with other containers such as paper cups. In more sophisticated research settings, more expensive instruments are used which provide better insulation and further reduce heat energy transfer.

Enthalpy

Another important state function is *enthalpy*, H. It is defined as $H \equiv E + PV$
where E is internal energy, P is pressure, and V is volume.

The change in enthalpy is given by the enthalpy in the final state minus the enthalpy in the initial state, which for a chemical reaction is products minus reactants:

$$\Delta H = H_{products} - H_{reactants}$$

If $H_{products}$ is greater than $H_{reactants}$, the change in enthalpy is positive, and the process is endothermic. If $H_{products}$ is less than $H_{reactants}$, the change in enthalpy is negative, and the process is exothermic.

Sign of Enthalpy	Direction of heat flow (into or out of the system/rxn)	Is heat a reactant or product	Is reaction endothermic or exothermic
ΔH is negative -	**out of system**	**product**	**exothermic**
ΔH is positive +	**Into system**	**reactant**	**endothermic**

Exothermic reactions

Energy (heat) is released as the products of the reaction have less potential energy than reactants. ($HC + O_2 \rightarrow CO_2 + H_2O$).

Burning — Condensation
Rusting of iron — Freezing

Endothermic reactions

Energy (heat) is absorbed as the products of the reaction have more potential energy than reactants.

Photosynthesis
Melting and evaporation

Thermochemical Equations

A *thermochemical equation* is a balanced chemical equation that includes the enthalpy change for the reaction. The physical state, gas, liquid, solid, or aqueous, must be included for each chemical species in the reaction because enthalpy varies for the same species in different physical states. As an example, consider the combustion of liquid ethanol:

$$C_2H_5OH(\ell) + 3\,O_2(g) \rightarrow 2\,CO_2(g) + 3\,H_2O(\ell) \quad \Delta H = -1367\text{ kJ}$$

The enthalpy change is –1367 kJ per 1 mole of ethanol or per 3 moles of oxygen that react. There are 1367 kJ of energy released per 2 moles of carbon dioxide or per 3 moles of water that form as products.

If 2 moles of ethanol react with excess oxygen, the enthalpy released is

$$2\text{ mol } C_2H_5OH \times \frac{1367\text{ kJ}}{1\text{ mol } C_2H_5OH} = 2734\text{ kJ}$$

Calorimeter is a tool used to measure heat of a chemical process (ΔH); heat flows into a substance with known c_p (specific heat) and the temperature change is recorded. A calorimeter usually contains a carefully measured mass of a substance of known specific heat, such as water. As the reaction absorbs or releases energy, the temperature of the water will change. From that temperature change, the energy that the water absorbed or released can be calculated.

Definition Questions: you should be able to use or apply the following terms. Be able to **write** complete definitions for,

energy	temperature	standard state
potential energy	heat	standard heat of formation
kinetic energy	specific heat capacity	exothermic
enthalpy	endothermic	Law of conservation of Energy
thermal	Hess's Law	isolated, closed, open system

1. How many Joules of heat energy would be required to raise the temperature of 16.0g of lead from 25˚C to its melting point of 327˚C for a length of time long enough to completely melt the lead. Given: The specific heat capacity of lead is 0.159J/gK and the molar enthalpy of fusion is 24.7J/g.

Specific heat is in Kelvin. Must convert C to Kelvin.

$Q=mc\Delta T$

2. The specific heat capacity of diamond is 0.5050 J/gºC. How much energy is required to heat 25.0 g of diamond from 10.5ºC to 15.6ºC?

$Q=mc\Delta T$

3. A piece of aluminum with a mass of 50g and an initial temperature of 90^{oC} is placed into 100mL of water at a temperature of 25°C. The temperature of water rises to 31.3^{0}C. Determine the specific heat capacity of aluminum.

Q lost (Al) = Q gained (Water)

$-(mc\Delta t) = +mc\ \Delta t$

4. What is the molar enthalpy of the formation of 1mol $H_2SO_{4(l)}$ given the following information?

$H_2O_{(g)} + SO_{3(g)} \rightarrow H_2SO_{4(l)}$ $\Delta H_{rxn} = xkJ$

Flip and divide by 2 $2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(g)}$ $\Delta H_{rxn} = -484kJ = +242$

Flip and divide by 2 $S_{(s)} + 3O_{2(g)} \rightarrow 2SO_{3(g)}$ $\Delta H_{rxn} = -890kJ = +445$

$\underline{H_{2(g)} + 2O_{2(g)} + S_{(s)} \rightarrow H_2SO_{4(l)}}$ $\underline{\Delta H_{rxn} = -814kJ = -814}$

$\underline{\Delta H_{rxn}}$ $= -127$ kJ

a. 4. What is the molar enthalpy of the formation of 1mol C_2H_6 gas given the following information? $C_2H_{4(g)} + H_{2(g)} \rightarrow C_2H_{6(g)}$ $\Delta H_{rxn} = xkJ$

$C_2H_{4(g)} + 3O_{2(g)} \rightarrow 2CO_{2(g)} + 2H_2O_{(l)}$ $\Delta H_{rxn} = -1401kJ$

$2C_2H_{6(g)} + 7O_{2(g)} \rightarrow 4CO_{2(g)} + 6H_2O_{(l)}$ $\Delta H_{rxn} = -3100kJ$

$\underline{2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(l)}}$ $\underline{\Delta H_{rxn} = -572kJ}$

Using the following reaction $Fe_3O_4(s) + CO(g) \rightarrow 3\ FeO(s) + CO_2(g)$

b. Using standard enthalpies of formation, determine ΔH_{rxn} . Use table given in class. The of heat of formation for FeO is -272 kJ.

c. Is this reaction endothermic or exothermic? Explain in terms of bonds breaking/forming.