Name

# Gas Chemistry

## How to do well on the Gas Chem Celebration…

- You will be able to understand all points of the KMT, including being able to describe the difference between real and ideal gases.
- You will be able to draw graphs that show the relationships between:
  Pressure + Volume, Pressure + Temperature, and Volume + Temperature.
- You will know which of these are directly proportional, and which is inversely proportional.
  Your graphs will match the titles to the axis labels as well.
- You will be memorize and explain Avogadro's Hypothesis
- You will be able to calculate any pressure conversions (atm, kPa, psi, and mm of Hg)
- You will be able to calculate any type of combined gas law problems
- You will read the BASICS.
- You will re-read the BASICS.

# Gas BASICS


Gases are the most interesting phase because mostly they are invisible and you have to use your measuring and wits to grasp how perfect they are. You already know that gases follow the Kinetic Molecular Theory, which is covered again just below. Some of the theory is perfectly true but sometimes the theory "fibs" to help you grasp how gases are gases, and how they stay gases.

Nearly all substances can be phase changed into gases, but for many this happens only at very high temperatures passed their boiling point. $H_2O$ boils into a gas at 373 K at standard pressure. Iron gas forms at 3023 K, and that is remarkably hot! For an example that doesn't, think about wood, or certain plastics. They might catch fire, or decompose before they can change into the gas phase.

There's also the idea of "ideal gases" which are the theoretical perfection of gases, but they are not real. They are like super heroes. We know that super heroes are fake - but we accept them because it makes for a good movie, or in this case, makes it easier to understand gases in general.

Ideal gases: are perfect, make believe, super hero gases. They are the idea of gases, but there are no examples of ideal gases, none actually exist. Real gases are real, they exist on the periodic table and in the air. Ideal gases are used to help explain what gases are. They are the gases of the KMT (below). They are a "model" of gases, not actual gases.

## Ideal gases are models, or conceptualizations of gases. Real gases can turn into liquids, because they are real. Ideal gases are perfect gases and can't ever become liquid or solid.

A real gas acts most ideally when it is at high temperature, and it is at low pressure. This is because at high temperatures, any particle collisions are strong enough that the gas particles bounce off of each other rather than stick to form a liquid. At low pressure they collide less frequently, and have a much less chance of forming into a liquid. The biggest flaw a gas can have is to become a liquid! That means a real gas most closely follows the Kinetic Molecular Theory when it's at high temp & low pressure.

When comparing two real gases at the same conditions, the one with the smaller particles is more ideal.

Helium is the most ideal of the real gases, because they are the smallest particles

Carbon dioxide is "more ideal" than octane, when both are at the same temperature and pressure, because the $CO_2$ particles are smaller than the $C_8H_{18}$ particles.

There are some gases that are atomic— they exist as single atoms, which are the noble gases.
Other gases are diatomic, or paired, like the HONClBrIF twins: $H_2$, $O_2$, $N_2$, $Cl_2$, $Br_2$, $I_2$, and $F_2$ . Bromine is a liquid at room temperature, and iodine is a solid, but both become gases are relatively low temperatures.

Some gases are compounds, like $CO_2$, $SO_3$, methane $CH_4$, etc.

And there are a few odd gases that we'll learn about like: ozone $O_3$.

Try to remember the formula for laughing gas: He, He, He!

## The Kinetic Molecular Theory of Gases

We covered this already, but it's worth repeating now because it's so important. It's the Kinetic Molecular Theory that allows us to think about, discuss, and understand gases. It tells us how gases normally act, why they are gases, and what's different about gases than the other 2 phases of matter (solids and liquids).

### The Kinetic Molecular Theory (KMT) of gases states that gases...

1. Gases are made up of small particles such as atoms or molecules.
   *The volume of gas particles is considered to be negligible.*
2. Gas particles will act as if they are small, hard spheres.
   *They aren't really, they do have shapes, and are not spheres, but they act as if this is true.*
3. Gas particles have no attraction for or any repulsion for any other gas particles.
   *This is not quite true either, but the attraction and repulsion they have for one another is small, and unless the temperature is crazy cold, this attraction has almost no real effect on gases.*
4. Gas particles move fast, and only in straight lines. They are in random, constant, straight line motion
   *The particles of a gas cannot spiral, make loops, or hover in place either.*
5. All particle collisions are elastic; when the gas particles hit each other all of their energy is transferred, none is lost. In theory, when the particles have collisions that will transfer energy between particles, and the total energy of the gas system will remain constant.
   *This is not true, but the loss of energy is small, and the addition of energy all the time from the Sun, and the Earth more than makes up for it. Gases do stay gases usually.*
6. Collisions between particles result in pressures being exerted.
   *The more collisions the higher the pressure. The stronger the collisions, the higher the gas pressure too.*
7. Gas particles are separated by vast distances from each other relative to the size of the gas particles. In theory, they can be compressed indefinitely, the gas will remain a gas.
   *Gases are mostly empty space, and particle size is insignificant. The particles do take up some space, but it's tiny. In theory, the particles act as if they take up no space at all, like points in mathematics, but that's silly.*

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# Measuring Gases

We will measure gases 4 ways in our class, the gas pressure, the gas volume, the gas temperature, and the number of moles of gas.

1. <u>Volume</u>: Volume is measured in liters of space, or milliliters of space (mL) Converting from these units means knowing that 1 Liter = 1000 milliliters
2. <u>Temperature</u>: Gases will be measured in Kelvin only, because when we use our formulas, a temperature of zero (as in 0°C) or a negative number (such as -4.5°C) will collapse the math.
   Zero Kelvin means absolute zero.
3. <u>Number of Moles</u>: Just what is says, how many moles of gas are present.
4. <u>Pressure</u>: Pressure is measured in 4 different units that you know. All of these have unlimited SF.
   101.3 kilo-Pascals (kPa) has been decided to be standard pressure in metric units.
   This is equal to pressure in other units, such as:
   - 1 atmosphere (atm),
   - 760 millimeters of mercury (mm Hg) measured in an old style barometer, or
   - 14.7 pounds per square inch (psi)

# The relationship between Pressure, Volume and Temperature of gases.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Gases three main measures, pressure and volume and temperature are all in different relationships with each other at the same time. We will explore the three of these now.

The combined gas law, at right, connects all three of these variables. The starting conditions of pressure multiplied by the volume, which is then divided by the Kelvin Temperature is equal to the new conditions of the gas, pressure X volume, then divided by the Kelvin Temperature.

We always use Kelvin because having a negative number, or a zero as a denominator will wreck our math. Units for pressure or volume can be which ever you choose, as long as they are the same on both sides of the equal sign.

Gas math problems have a lot of words, there are six variables and you need to be told five of them. Sometimes the letters STP are used for two at once, standard temperature and standard pressure. They are in your reference tables, any units will work, but read the problem, if you start or end at STP, but there are psi or have mm Hg on the other side, use the same units.

Example problem one…

Your balloon holds 15.6 liters of helium gas at STP, when it rises into the night air, the temperature drops down to just 255 Kelvin, and the volume shrinks to 12. 3 Liters. What is the new pressure? (note, you are given five of six variables, you solve for the last one, make sure you put the numbers and units in the right place, and then it's just a simple cross multiply and divide to solve for the missing variable.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{(1\text{ atm})(15.6\text{ L})}{273\text{ Kelvin}} = \frac{(P_2)(12.3\text{ L})}{255\text{ Kelvin}}$$

$$(1\text{ atm})(15.6\text{ L})(255\text{ K}) = (P_2)(12.3\text{ L})(273\text{ K})$$

$$\frac{(1\text{ atm})(15.6\text{ L})(255\text{ K})}{(12.3\text{ L})(273\text{ K})} = P_2$$

$$1.18\text{ atm} = P_2$$

That is as hard as these problems might get, which is not bad. What is important to see is what might happen if the problem says, for example, pressure temperature remains constant. Or one of the other variables remains constant.

You can always choose the same number with unit to use on both sides of the = sign, these will cancel each other out, or you can cancel part of the combined gas law formula out, which is what you will see on the next page. Either way, the same answers come out.

Always use the same units on both sides of the = sign, and always use Kelvin, never centigrade, or worse, the "F" word (Fahrenheit!).

Mathematically we can look at this formula in parts as well. Algebra allows us to have, for example, constant temperature. That changes the math to just $P_1V_1 = P_2V_2$ (the temperature cancels out). .

The pressure and the volume of a gas are in what is called an INVERSELY PROPORTIONAL relationship. As one variable increases, the other decreases.

A problem might read like this… A gas held at constant temperature is 35.5 Liters and at 1.45 atm. If the pressure is increased to 2.78 atm what is the new volume?

Cancelling out the temperature (it's constant), we can use this formula: $P_1V_1 = P_2V_2$

$P_1V_1 = P_2V_2$ becomes (1.45 atm)(33.5 L) = (2.78 atm)($V_2$) solve for $V_2$. → → 17.5 Liters = $V_2$.

The math would give us the exact same answer if we used the "whole" combined gas law and inserted (say) 305 Kelvin for $T_1$ and also for $T_2$, since temperature is constant. Either way, the answer is 17.5 Liters.

If Pressure were constant, we could omit $P_1$ and $P_2$ from the formula in the same way.

If Volume were constant, we could omit the $V_1$ and the $V_2$ from the formula as well.

Or, you could use (say) 1 atm as $P_1$ and $P_2$, or 22.4 Liters for $V_1$ and $V_2$, the math the same works either way.

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Separating the parts of the combined gas law into it's "component parts", there are three gas laws inside of it. You do not have to know them by name, but they are real gas laws that have been mathematically combined into just one big equation.

$$P_1V_1 = P_2V_2$$

is called Boyle's Law. (that's a name you do not have to remember)

This law shows that Pressure and volume are inversely proportional. That means that as one variable increases, the other must decrease proportionally to keep the equality.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

This is the Gay-Lussac Law of Gases (another name you don't need to remember)

This law established that the pressure and temperature of a sample of gas are DIRECTLY PROPORTIONAL. As one variable increases, so does the other. Or, as one variable decreases, so does the other.

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

This is known as Charles' Law (the third name that is not necessary to memorize)

This law established that the volume and temperature of a sample of gas are DIRECTLY PROPORTIONAL. As one variable increases, so does the other. Or, as one variable decreases, so does the other.

All gas problems can be solved with the combined gas law formula. But, if one variable is a constant, you can omit it prior to the math, or insert the same value on both sides of the equal sign. Remember, you must use Kelvin temperature only, that prevents you from getting a negative number or a zero as a denominator.

Example problems….

1. At constant pressure, a sample of gas of 22.4 Liters and standard temperature is warmed up to 365 Kelvin. What is the new volume of this gas?

You could decide to use 1 atm pressure on both sides of the equal sign, or use the smaller formula that omits the pressure before the math.

$$\boxed{\frac{V_1}{T_1} = \frac{V_2}{T_2}} \rightarrow \frac{22.4\text{ L}}{273\text{ K}} = \frac{V_2}{365\text{ K}} \rightarrow (V_2)(273\text{ K}) = (22.4\text{ L})(365\text{ K})$$

$V_2 =$ 29.9 Liters

2. At constant volume, a gas sample at standard pressure and 303 Kelvin is cooled to just 245 Kelvin. What is the new pressure on this gas?

$$\boxed{\frac{P_1}{T_1} = \frac{P_2}{T_2}} \rightarrow \frac{101.3\text{ kPa}}{303\text{ K}} = \frac{P_2}{245\text{ K}} \rightarrow (P_2)(303\text{ K}) = (101.3\text{ kPa L})(245\text{ K})$$

$P_2 =$ 81.9 kPa

All combined gas law problems can be solved with the combined gas law, or one of the smaller laws that combine together to form it. The math works out exactly the same either way.

# Avogadro's Hypothesis

Amedo Avogadro has that famous number named after him (6.02 x $10^{23}$ particles per mole). He studied gases and came up with one of the best "one liners" in chemistry history, called Avogadro's Hypothesis. It would be a law but no one can count to his number. Here's what it is, and here's what to memorize;

> **"Equal volumes of different gases at the same temperature & pressure have the same number of particles, and the same number of moles."**

Go slowly through the diagram and figure this out.

In each of these three containers of 22.4 Liters in volume, with 3 different gases in them. Each is at STP. Remember that 22.4 Liters of any gas at STP is ONE MOLE of gas. Therefore, each container has ONE MOLE, or 6.02 x $10^{23}$ particles of gas, the same in each container.


| | | | | |
|---|---|---|---|---|
| Equal volumes | volume in L | 22.4 | 22.4 | 22.4 |
| of Different gases | Type of gas | argon | oxygen | nitrogen |
| at same temp and pressure | Pressure in kPa | 101.3 | 101.3 | 101.3 |
| | Temp in Kelvin | 273 K | 273 K | 273 K |
| have same number of moles, and particles. | # of moles | 1.0 mole | 1.0 mole | 1.0 mole |
| | # of particles | 6.02 x $10^{23}$ | 6.02 x $10^{23}$ | 6.02 x $10^{23}$ |

Memorizing this will save you from doing tedious math problems. You can memorize it, or grunt out all of the math to figure out questions like this

Which sample has the same number of molecules as 3.69 Liters of carbon dioxide at 125 kPa and 305 Kelvin?

A. 1.23 Liters of $N_2$ at 125 kPa and 305 Kelvin
B. 3.69 Liters of $CH_4$ at 125 kPa and 305 Kelvin
C. 7. 38 Liters of CO at 125 kPa and 305 Kelvin
D. 1.00 liters of $C_8H_{18}$ at 125 kPa and 305 Kelvin

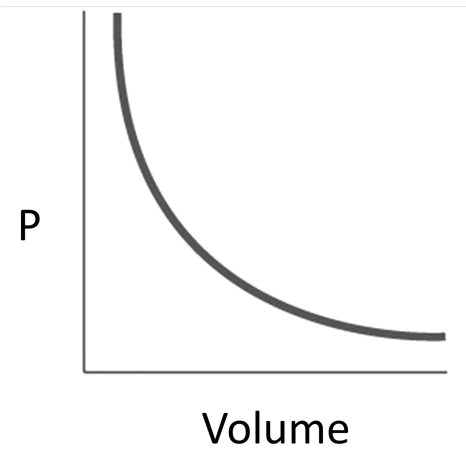
The answer is B, equal volumes of DIFFERENT GASES at the same temp and pressure have the same number of particles (or moles).
The type of gas does not matter, Avogadro does.

# The Graphs showing the relationships of Pressure—Volume—Temperature of Gases.

You will have to recognize and draw graphs showing the inversely proportional relationship of P and V.

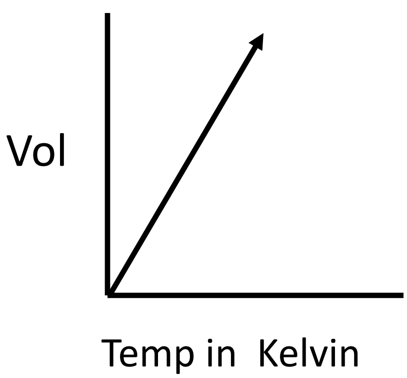
Also you will have to recognize and draw graphs showing the directly proportional relationships between P and T, and between V and T.

There are only 2 different shaped graphs to show these three relationships, that is because one shows inversely proportional, and the other directly proportional. Watch axis labels and you're good.




For Pressure + Volume, as one variable increases, the other decreases.

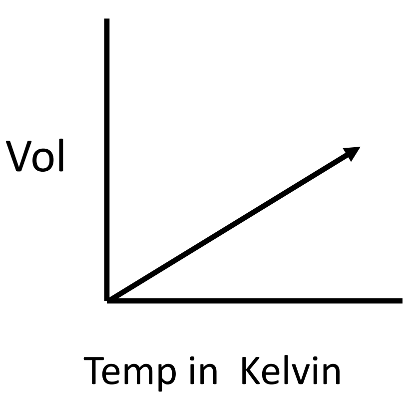
Or, as one variable decreases, the other increases.




For Pressure + Temperature, as one variable increases, the other increases as well.

Or, as one variable decreases, the other does the same.

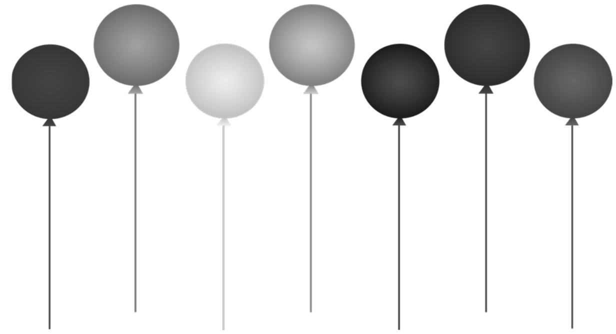
Temperature MUST be in KELVIN.




For Volume + Temperature, as one variable increases, the other increases as well.

Or, as one variable decreases, the other does the same.
Temperature MUST be in KELVIN.

# Gas Notes



1. Write the Combined Gas Law Formula

=

2. Which we say like this:

_______________________________________________________________________________

3. And THAT MEANS: that if you know the ORIGINAL CONDITIONS of _____________,

   _______________, and __________________________, you can…

4. The pressure units I could use are:_______________________________________________________

5. The volume units I could use are:_____________________________________________________

6. Units for temperature are always __________________________ (no matter what)

7. Your balloon is filled on the ground. It's 45.6 liters in size, it is filled with helium gas to a pressure of 1.20 atm, and the temperature of the gas is 293 K (20.0°C). The balloon rises into the atmosphere, and the temperature drops to 278 K (5.00°C); the pressure drops to 1.05 atm. What's the new volume of your balloon?

8. A weather balloon has been filled with helium to a volume of 65.5 liters, at 1.50 atm, and the gas temperature is 295 K. At a height of twelve hundred meters, the balloon cools to 265 K, and the volume drops to 62.0 Liters. What is the pressure in this balloon under these new conditions?

9. At constant temperature, a sample of ($H_2S$) dihydrogen monosulfide *(stink gas)* of 50.0 $cm^3$ and 125 kPa is put into a much larger container and it expands to 595 $cm^3$. What is the new pressure of this gas?

10. At constant pressure, a 12.0 liter sample of $CO_2$ gas is at 24.0°C. If the sample is cooled to -15.0°C, what's the new gas volume?

11. At a constant volume of 450.0 mL, a sample of carbon dioxide gas is at 165 kPa, and standard temperature. If it is heated up to 349 Kelvin, what is the new pressure on this gas?

| FILL IN<br>Review Guide | formula | Show a simple graph of this relationship | Name this relationship as ***inversely or directly*** *proportional. Or both.* |
|---|---|---|---|
| The combined gas law: | | | |
| The combined gas law with constant temp: | | | |
| The combined gas law with constant pressure: | | | |
| The combined gas law with constant volume: | | | |

The combined gas law is the starting point for every single gas problem in our course.
Sometimes one of the three variables is a constant, and we can cancel it out before the math.

The temperature MUST BE KELVIN. WHY?

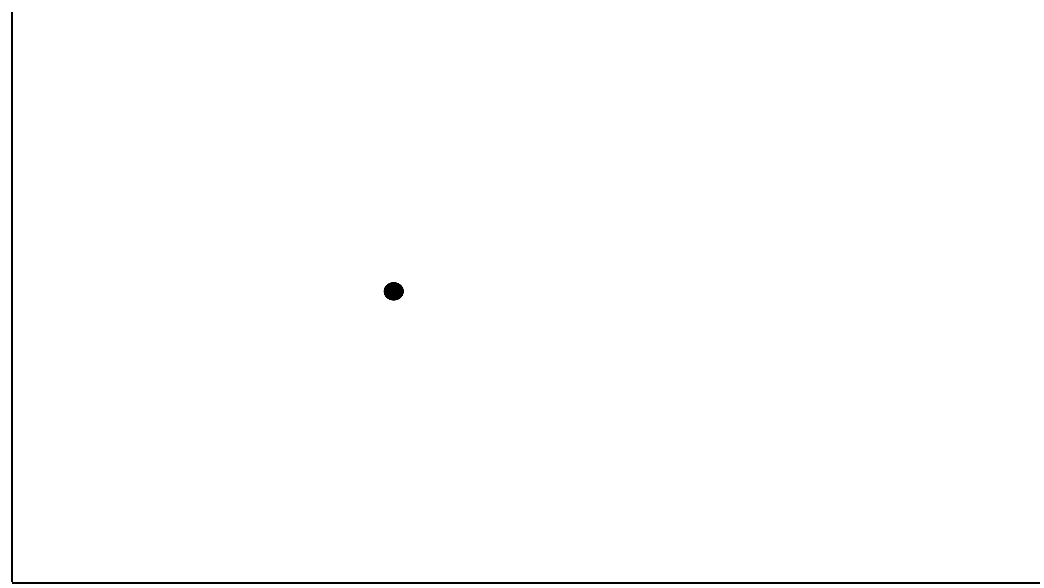
14. With CONSTANT TEMPERATURE we can change this formula to… (Boyle's Law)

| 15. DRAW Charlie's $CO_2$ Balloon | 16. Draw squished balloon with smaller volume. |
|---|---|
| P and Vol for this balloon? __________ ___________ | 17. As volume decreased, __________________________ |

18. The Pressure and Volume ___________________________________________________________

19. If the balloon was stretched into a LARGER VOLUME? Volume __________ and Pressure ___________

20. Draw this graph…



Fill in the rest of the dots. Use both of the balloons in the slide show to "show" you why the first and last dot are where they are.

21. __________________________________________________________________________

22. P x V = C, that means that the _______________ X _________________ = _________________________

23. For this gas sample, every single point, every P x V = ______________________________________

24. *Your* $N_{2(G)}$ sample has volume of 3.75 L, and pressure of 125 kPa. What is the gas constant for this gas?

25. What if we change the conditions of your nitrogen gas sample, to 9.75 Liters. Calculate the new volume?

26. For any sample of gas, the pressure and volume are inversely proportional and equal to a constant, so…

27. Boyle's Law: For any sample of gas, pressure + volume are inversely proportional and PxV = C, so…

28. A sample of neon gas is at standard pressure and 45.8 liters volume. If you double the pressure, what is the new volume?

Do the math with kPa here

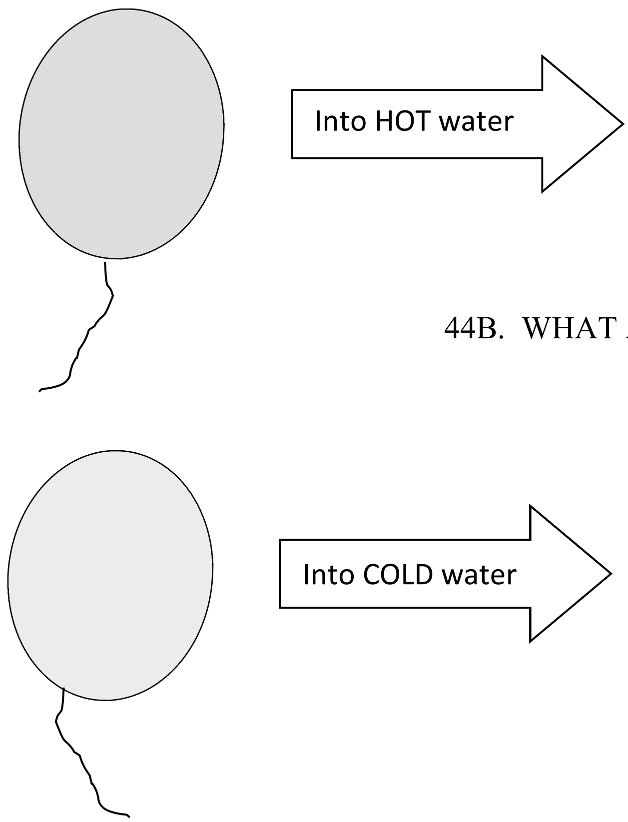
Do the math with atm here

29. A thick rubber balloon has 16.3 liters of oxygen gas inside at 1.25 atm. If the balloon can be squished (when some boys stand on it) to a volume of just 12.8 L, what's the new balloon pressure?

30. There are 4 variables in which to measure gases. (you already know these) They are:

________________ ___________________ ____________________ _____________________

31. Let's imagine what happens to the balloon size (volume) when we put these 2 balloons into hot water, and into cold water. What do you think? ________________________________




44B. WHAT ACTUALLY HAPPENED?

32. When both variables move in the same direction (both increase, or both decrease) this is called:

__________________________________________________________

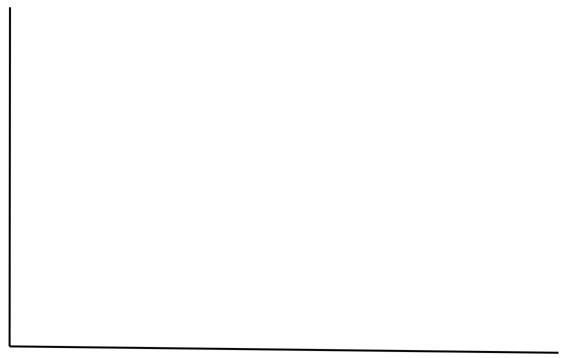
Draw this graph.
(title, axis labels)

Time for a story about little girls and balloons and the Oakdale mall and being a stay home father.

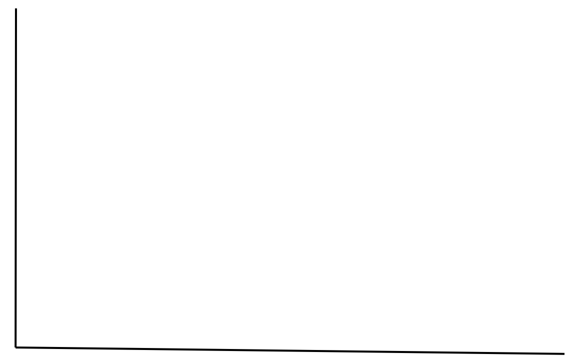
33. Volume and Temperature of a gas are ___________________________________________________

34. Draw these 2 graphs carefully - Note the TITLE wording and the axis labels. (Y is a function of X)

Temperature as a function of Volume



Volume as a function of Temperature



35. Directly proportional does not mean that the slope have to be 1, it can slope any direction… like these

# Ideal vs. Real Gases

This will be out there, but you are smart enough to grasp this. To teach we discuss “ideal gases”, which are not real. They are the theoretical concept of gases. There are NO examples of ideal gases, any more than there is a Superman or Wonder Woman. We understand them, but we know they are fake.

They are used to help kids learn what gases are, how gases remain gases, etc. There are NO examples of ideal gases. There are many examples of real gases, and you know lots of them, like: oxygen, nitrogen, carbon dioxide, helium, etc.

36. Ideal vs. Real Gases

A.

B.

C.

D.

E

37. Real gases act most ideally under these two conditions:

Because:

38.

39.

40. Fill in the chart.

| Name | Symbol | Number of atoms | ranking |
| --- | --- | --- | --- |
| Neon | | | |
| Carbon Dioxide | | | |
| Propane | | | |

41. If you had 2.45 liters of neon, of carbon dioxide, and propane ($C_3H_8$) gases, all at STP, which gas would act the MOST IDEAL ?

___

42. Convert 1.06 atm into millimeters of mercury

43. Change 844 mm of Hg into kilopascals

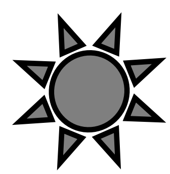
44. When a rigid cylinder containing methane gas at 273 Kelvin and is at 125 kPa is warmed up to 295 K, the pressure changes. What is the new pressure of this gas? VOLUME IS CONSTANT HERE

45. Avogadro's Hypothesis (this is really important)

| 46. Fill in | He | $CO_2$ | $NH_3$ | ANY GAS |
|---|---|---|---|---|
| volume | | | | |
| Temp | | | | |
| Pressure | | | | |
| moles | | | | |
| particles | | | | |

If you have 5.48 liters of $He_{(G)}$, $CO_{2(G)}$ and $NH_{3(G)}$ all at STP, how many moles of each gas, and how many particles of each gas are present? You could do the math, or write it out in words.

# Ideal vs. Real Gases…



All gases are real, there are no ideal gases, but we still TALK about ideal gases to help understand what gases are, and how gases stay gases. Under cold conditions, real gases condense into liquids (or worse, solids!). Under high enough pressure you can squeeze gases into the solid phase too.

Ideal gases are "perfect" in that they can never become liquid or solid.
Ideal gases are like super heroes, we can aspire to be perfect but we are just humans.

**How will you remember how to decide what gases are acting "ideally" compared to other gases?**

1. Smaller particles of gas are more ideal than larger particles at the same conditions. $He_{(G)}$ is more ideal than $CH_{4(G)}$.

2. Hot gases with high kinetic energy slam into each other with a lot of force, they are unlikely to form into liquids, so hot gases are more ideal than cold ones (that will condense). Gases at lower pressure are less likely to even collide together and less likely to condense than gases at higher pressures.

**Today, the temperature out side is cold, and**
**you are in a higher pressure moment of your school year to perform academically.**

**In the summer, the it's is HOTTER and you're in a lower pressure situation in your life.**
**Summer is more ideal — gases are more ideal in the summer too: Hotter & Lower Pressure = MORE IDEAL**

47. Under which conditions of temperature + pressure does carbon dioxide gas behave most like an ideal gas?
1. low temperature + low pressure
2. low temperature + high pressure
3. high temperature + low pressure
4. high temperature + high pressure

48. Which gas sample at STP has the same total number of molecules as 2.0 liters of $CO_{2(G)}$ at STP?
1. 5.0 L of $CO_{2(G)}$
2. 2.0 L of $Cl_{2(G)}$
3. 3.0 L of $H_2S_{(G)}$
4. 6.0 L of $He_{(G)}$

Time for another demo, this one is about Pressure and Temperature (the can crush)

Pressure as a function of Temperature

49. As temperature _______ pressure ________

Temperature + Pressure are

_____________________________________________

*Does the can "suck in" or does air pressure crush it from the outside?*

*CHEM NEVER* ________________________

| | |
|---|---|
| 50 | 51, 52, 53 |
| 54, 55, 56 | 57, 58, 59 |

| 60. The KINETIC MOLECULAR THEORY AKA ________________ (make flash cards, or else) | |
|---|---|
| A | |
| B | |
| C | |
| D | |
| E | |
| F | |
| G | |

61. Draw these three graphs (careful title to axis label placement!) (PxV) (PxT) (VxT)

62. According to the kinetic molecular theory, the particles of an ideal gas

1. have no potential energy
2. are separated by great distances, compared to their size
3. have strong intermolecular forces
4. are arranged in a regular, repeated geometric pattern

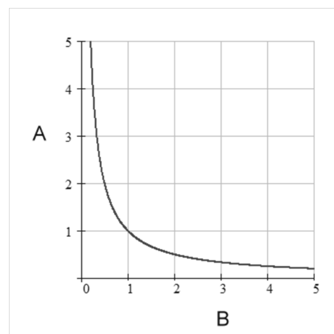
63. Which temperature change would cause a sample of an ideal gas to double in volume while the pressure is held constant? From

1. 400. K to 200. K
2. 200. K to 400. K
3. 400.°C to 200.°C
4. 200.°C to 400.°C

64. A sample of gas confined in a cylinder with a movable piston is kept at constant pressure. The volume of the gas doubles when the temperature of the gas is changed from

1. 400. K to 200. K
2. 200. K to 400. K
3. 400.°C to 200.°C
4. 200.°C to 400.°C

65. Under which conditions of temperature and pressure would a 1-liter sample of a real gas behave most like an ideal gas? 1. 100 K + 0.1 atm 2. 100 K + 10 atm 3. 500 K + 0.1 atm 4. 500 K + 10 atm




66. Here is a graph from gas chemistry. What relationship can it represent?

1. Pressure as a function of Volume
2. Pressure as a function of Temperature
3. Volume as a function of Temperature
4. Temperature as a function of Kinetic Energy

67. What's the volume of a gas at 2.00 atm & 360. K, if it's original conditions were 307 L, 385 K, 0.250 atm?

68. Under which conditions of temperature and pressure would a 1-liter sample of a real gas behave LEAST like an ideal gas?

1. 356 K & 1.2 atm
2. 356 K & 4.0 atm
3. 459 K & 1.2 atm
4. 500 K & 4.0 atm