

The basic gas laws: Boyle, Charles, Gay-Lussac, and combined

If you're reading this page, you probably need help understanding the gas laws. Not to worry – we'll get you up and running in no time. However, before we do *anything*, we need to do a couple of things:

Thing 1: Visit the kinetic molecular theory page.

In order to really understand why the gas laws are what they are, you need to understand how gases work in the first place. Though it's not a requirement, I strongly recommend that you read [this tutorial](#) before you go too much further.

Thing 2: Learn the terminology used when talking about gases.

If you want any hope of figuring out the gas laws, you have to understand the terms that are used to describe them. Some of these you'll know, some you won't, but you really need to review all of them:

Pressure (P): Pressure is the force that something exerts on something else. Just as I can exert pressure on you by pushing you, gas molecules exert pressure on things by bouncing off of them. Sure, each gas molecule doesn't exert much pressure, but when you've got a ton of them, the force adds up. Units of pressure include:

- atmospheres (atm): The average air pressure at sea level. This unit has historically been used to measure gas pressure.
- Pascals (Pa): 101.325 kPa (kilopascal) is equal to 1 atm. Pascals are the SI unit of pressure, though atm and mmHg are still commonly used.
- mmHg: Millimeters of mercury, where exactly 760 mm Hg are equal to 1 atm. This makes reference to the fact that a column of liquid mercury 760 mm tall exerts 1 atm of pressure at its bottom. The unit "torr" is basically equal to mmHg, though it's much less commonly used.¹
- Bar: We don't actually see it all that often in chemistry, but 1 Bar is equal to 100 kPa, or just under 1 atm.
- psi: Pounds per square inch are used mainly for tires. 14.7 psi = 1 atm. Don't use them for chemistry.

Volume (V): Volume is a measure of how big something is. The typical units of volume are either liters (L) or milliliters (mL).

Temperature (T): Temperature is an indirect measurement of how much kinetic energy the molecules of a substance has. In other words, hot things have more energy than cold ones. The only units of temperature used in gas laws are Kelvin (K), where: 1 Kelvin = 273 degrees Celsius.² If somebody gives you degrees Celsius instead, just add 273 to get the temperature you want.

Standard temperature and pressure (STP): Standard temperature is 0 degrees Celsius and standard pressure is 100.00 kPa. (Note: The standard pressure for a very long time was 1.00 atm, so if that's what you hear, don't worry too much about it).

Let's get going!

Avogadro's law:

A long time ago, there was a guy named Avogadro. He did a lot of scientific stuff, and then he became a superhero.



A true hero.

Before becoming a hero, however, he said something that's actually relevant to this tutorial. His law, known as Avogadro's law, states that all gases behave the same way under the same conditions. In other words, if you have 1 L of helium and 1 L of hydrogen, they'll behave the same ways when you heat them, squish them, etc.³

Boyle's, Charles's, and Gay-Lussac's laws:

The laws named for each of these three guys describes how gases behave when you do something to them. You've probably heard these in your chemistry class and probably aren't too thrilled about all that equation stuff. Don't get too concerned: It's easier than it sounds.

Boyle's law:

Did you know that when you sit on a balloon it will get smaller? If you did, then you already understand Boyle's law:

$$P_1V_1 = P_2V_2$$

In this equation, the little "1" refers to the pressure and volume of the gas before you sit on it, and the little "2" refers to the pressure and volume after you sit on it. It really is as simple as I mentioned before: If you add pressure to a gas it gets small, and if you release the pressure it gets big again.⁴ The reason this works is because there's a lot of empty space between gas molecules, and pressing on the container squishes them together into this empty space.

Sample problem: At 1.00 atm of pressure, your idiot brother's empty head has a volume of 1.50 liters. If you hire a fat guy to sit on his head with a pressure of 4.50 atm, what will the volume of his head become?

Answer: In this problem, the initial pressure is 1.00 atm, the initial volume is 1.50 L, and the final pressure is 4.50 atm. Solving for the V_2 term, we find that:

$$(1.00 \text{ atm})(1.50 \text{ L}) = (4.50 \text{ atm}) V_2$$

$$V_2 = 0.333 \text{ L}$$

Which means that his head will now fit into a soda can!

Charles's law:

Did you know that if you heat up a balloon, the balloon will get bigger? If you did, then you already understand Charles's law:

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

In this equation the little "1" refers to the volume and the temperature of the gas before you heat it and the little "2" refers to the volume and temperature of the gas after you heat it. And, as the equation shows, if you heat up a gas it gets big, and if you cool it the gas gets small.⁵ The reason this works is that if you heat up a gas the molecules have more kinetic energy, which makes them hit the sides of their container harder, which makes the container expand.

Sample problem: Having had his head squished, your brother's head now expands and contracts when the outside conditions change. If your brother's head has a volume of 1.50 L at a temperature of 15 degrees Celsius, what volume will his head have if he goes to Riyadh, Saudi Arabia when the temperature is 43 degrees Celsius?

Answer: The biggest problem people have with this equation is that they forget to convert temperature to Kelvin. As a result, the initial volume is 1.50 L, the initial temperature is 288 K, and the final temperature is 316 K. Solving, we find that:

$$\frac{1.50 \text{ L}}{288 \text{ K}} = \frac{V_2}{316 \text{ K}}$$

and that the final volume of your brother's head is 1.65 L.

Gay-Lussac's law:

Despite the stupid name, Joseph Louis Gay-Lussac was kind of a badass. Not only was he one of the first people to go hot air ballooning in 1804, but he also came up with an awesome gas law.



I'm willing to admit, however, that he didn't look like much of a badass.

His gas law said that if you've got a gas in a sealed container, heating it up will make the pressure inside the container increase. This law is one of the reasons that you don't want to hang around [if somebody sets an acetylene tank on fire.](#)

In equation form, we would phrase this like so:

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

Where the little “1”s and “2”s mean the same thing they did for the other two equations. In this case, pressure and temperature are said to be directly proportional because as the temperature increases, the pressure also increases correspondingly.

Sample problem: Let’s say your brother went and got surgery so that his head wouldn’t change its size anymore. If his head had an internal pressure of 1.00 atm in your living room (where the temperature is 25 degrees Celsius), what will the pressure inside his head be if he takes a trip to Vladivostok, Russia, where the temperature is -18 degrees Celsius?

Answer: You do this problem the same way as the one before, except that you’re solving for P_2 . Doing the math (and remembering to convert 25 degrees Celsius to 298 K and -18 degrees Celsius to 255 K), you find that the pressure in his head is 1.28 atm.

Save 67% of your memorization with the combined gas law!

If you don’t want to remember those three laws, I don’t much blame you – memorizing things is boring. Fortunately, you can get away with not memorizing these laws by combining them. This equation is, not surprisingly, called the combined gas law:

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

Where all the variables are the same as in the other equations.

The simplest way to make this equation work for you is to just ignore whatever variables you don’t need. For example, if you’re given a problem in which temperature is never mentioned, just leave off the two T terms to get Boyle’s law. If you ignore P, you get Charles’s law and so on.

Sample problem: I’ve got a tank of acetylene gas in my storage shed. The temperature outside right now is 5 degrees Celsius and the pressure in the tank is 15.3 atm, what will the pressure in the tank become if my enemies come in the night and set my shed on fire, causing the temperature of the tank to rise to 1165 degrees Celsius?

Because volume is never mentioned, we can ignore this term, which gives us:

$$\frac{P_1 \overset{\text{nope}}{\cancel{V_1}}}{T_1} = \frac{P_2 \overset{\text{nope}}{\cancel{V_2}}}{T_2} \longrightarrow \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

It’s Gay-Lussac again!

And, when we plug the numbers in (again remembering to convert degrees Celsius to Kelvin), we find that the tank has an internal pressure of 79.1 atm. Which is probably why [it’s suggested](#) that you shouldn’t ever heat an acetylene tank much past 50 degrees Celsius.

Footnotes:

1. Though 1 Torr and 1 mmHg are usually treated the same, they're actually very slightly different. Namely, 1 Torr is equal to 0.9999999 mmHg (which is so small that we ignore the difference).
 2. Actually, $1.00\text{ K} = 273.15^\circ\text{ C}$. However, this is a small enough difference that we don't bother with it.
 3. Of course, he phrased things a little differently, using words other than "squish." Specifically, he stated that if you have 1 mole of helium and 1 mole of hydrogen, they'll have the same volume under the same conditions. Which, if you go to Wikipedia and see it through, are basically the same thing as what I said before.
 4. In fancy talk, this means that the pressure and volume of a gas are inversely proportional. Which means what when one gets big, the other gets small.
 5. When one thing gets bigger when the other gets big, the values are said to be proportional to one another.
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- Avocado soldier: This handy little icon was put together by curtana at <http://iconsbycurtana.livejournal.com/>. By the way, if you've never seen Axe Cop, [you really ought to check it out](#).
- Gay-Lussac in a balloon: Public domain via Wikimedia Commons.