Gas Laws

It's not all rescuing kittens from trees.
Firefighters need physics, too.

Introduction

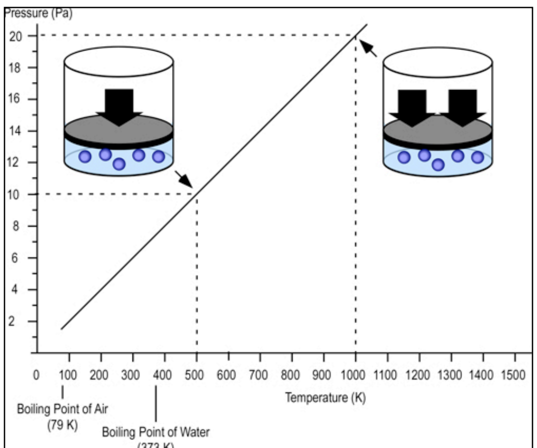
You might be surprised at how much physics a firefighter needs to know. There's a lot more to fighting fire than simply hosing down whatever is burning with water. But why is water so effective at putting out fire? Because it's wet? Well, not actually (gasoline is just as wet). Because water has such a high specific heat and latent heat of fusion, it's an excellent material for absorbing a large amount of energy in a short amount of time. And the faster you cool down the fuel (whatever is burning), the faster that fire is out. But the flames are not the only danger firefighters face; in a closed compartment (like a room in a burning building), the smoke and trapped hot air present considerable danger. Being able to quickly cool these gases can be life saving. Knowing how to quickly cool these gases requires physics. Specifically, you need to know the gas laws: how a gas in a closed container will respond to changes in volume, temperature, and pressure. Firefighters have developed a technique known as gas cooling by which they inject a burst of fine water droplets (a fog) into a compartment, which rapidly cools the contained smoke (500°C gas can be cooled to about 100°C very quickly), decreases its pressure and volume, and makes the room safer for the firefighters to enter.

Objectives

- Examine Gay-Lussac's Law for constant volume
- Demonstrate Boyle's Law for constant temperature
- Derive Charles' Law for constant pressure
- Combine these laws to formulate the Ideal Gas Law

Equipment

- Two Lab Quest units
- Gas Pressure Sensor and accessories
- Barometer
- Test tube, ring stand, burner, clamps



Gay-Lussac's Law: $P_1 / T_1 = P_2 / T_2$

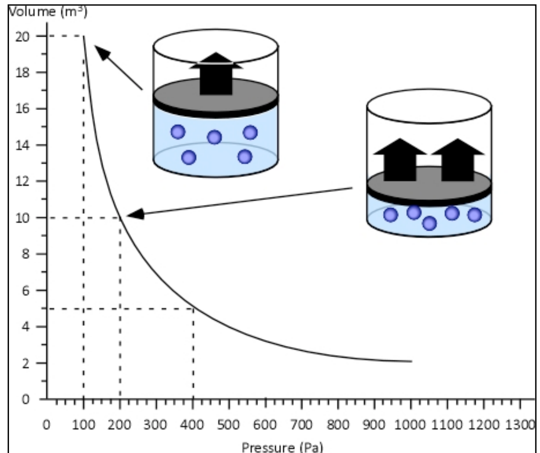
Gay-Lussac's Law: Procedure & Analysis

- Connect the gas pressure sensor and temperature probe to the LabQuest. Attach one end of the clear tubing to the pressure sensor, and the other end to the fitting on the rubber stopper. With the blue release valve open, insert the stopper into the test tube. Close the stopper valve by turning the blue toggle 90°.
- Place the stoppered tube and the temperature probe into the metal beaker. Fill the beaker with room-temperature water (do not completely submerge the test tube), and place it on the ring stand over the burner. Use a clamp to elevate the plastic tubing and keep it from contact with the metal beaker.
- Under the **Sensor** menu of the **Meter** tab, choose **Data Collection**. Set the time interval to **20 minutes**, with a collection rate of **6 samples per minute**. Tap **OK**.
- Under the **Graph** menu of the **Graph tab**, choose **Show Graph** and select only **Graph 1**. Under the **Graph Options** menu, set the **x-axis** to **Temperature** and the **y-axis** to **Pressure** and tap **OK**.
- Light the burner and start data collection. Keep an eye on the temperature; you might not need the entire 20 minutes to collect the data. Stop data collection early if the temperature in the beaker reaches about 90°C. If the stopper pops out of the tube, stop the data collection. If the temperature is over 80°C, do not restart the experiment. You have enough data.
- Tap the **File Cabinet** to save the data run.
- If you have not already, record the following data in a neat table in your lab notebook. Note that you may not have the same precise temperatures. Record the actual temperature and pressure for the data pair which comes the closest. You may not have data all the way up to 90°C.

Make sure the blue release valve on the stopper is closed before you begin data collection.

TEMPERATURE (°C)	PRESSURE (kPa)	TEMPERATURE (°C)	PRESSURE (kPa)	TEMPERATURE (°C)	PRESSURE (kPa)
20		45		70	
25		50		75	
30		55		80	
35		60		85	
40		65		90	

1. Examine the graph of Pressure vs Temperature and carefully sketch it in your notebook. Carefully note the shape of the curve.
2. Under the **Analyze** menu of the **Graph** tab, select **Curve Fit**. Choose the **Linear** fit and record the equation of the best fit line in your lab notebook.



Boyle's Law: $P_1V_1 = P_2V_2$

BOYLE'S LAW: PROCEDURE & ANALYSIS

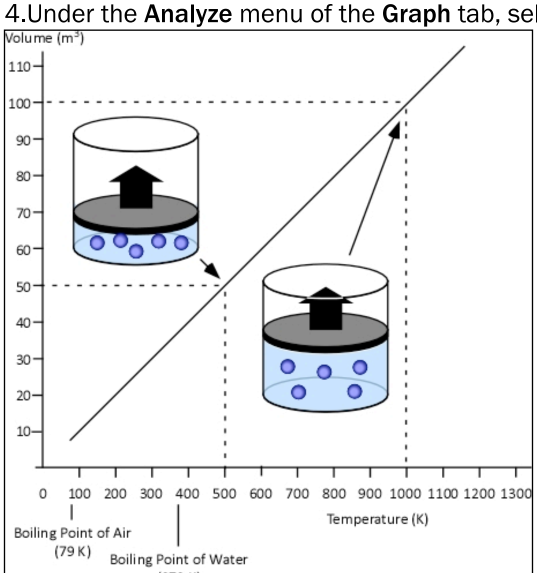
- While you are collecting the Gay-Lussac data, connect the gas pressure sensor to the second LabQuest and switch it on. Pull the plunger of the syringe out to the 20ml mark and screw it into the input valve of the sensor.
- Under the **Sensor** menu of the **Meter** tab, choose the **Data Collection** option. Select **Events with Entry** as the data collection mode. The **Number of Columns** should be **1**. Give it the name **Volume**, with units of **ml** (or milliliters). Tap **OK** to continue.
- To begin data collection, tap the **GO** button. You should notice a small **KEEP** icon appear directly next to it. To record data, tap the **KEEP** icon. When you are asked for the event name, type in 20 (for the volume of the syringe) and tap **OK**. Data collection continues, and you can change the volume of the syringe. Depress the plunger slowly until the volume is 18 ml. Tap **KEEP** to record the data, enter 18 for the volume, and tap **OK**.
- Continue to decrease the volume of the syringe, recording the pressure at 2 ml intervals, until the volume is 8 ml. When the last data is recorded, click the **STOP** button to end data collection. Tap the **File Cabinet** to save the run.
- If you have not already, disconnect the syringe and record the data in your lab notebook:

VOLUME (ml)	PRESSURE (kPa)	VOLUME (ml)	PRESSURE (kPa)	VOLUME (ml)	PRESSURE (kPa)
20		16		12	
18		15		11	
16		14		10	
14		13		8	

3. Examine the graph of Pressure vs Volume and sketch it in your notebook. Carefully note the shape of the curve.

4. Under the **Analyze** menu of the **Graph** tab, select **Curve Fit**. Choose the **Linear** fit (*don't click OK yet*). Compare this fit with the **Power** fit. Which is a better fit for the data (Hint: A lower RMSE value is a more exact fit)?

5. Record the equation of the best fit in your lab notebook. If the volume and pressure are inversely related, the exponent of your power fit should be –1. Is your exponent close to this?



Write the relationship for Charles' Law.

CHARLES' LAW: ANALYSIS

6. Derive Charles' Law conceptually. Boyle's Law keeps the temperature constant, and Gay-Lussac's Law keeps the volume constant. What would happen if you kept the pressure constant? Think about volume as a function of temperature, and what that relationship would look like. Write the equation.
7. Combine all three gas laws into a single mathematical statement.
8. Think about the firefighter's problem. Combine what you know about heat transfer (specific heat and latent heat of fusion for water), plus what you have just learned about the behavior of gases. Briefly explain how gas cooling works using these ideas.