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Measuring the Atomic or Molecular Mass of a Gas with a Tire Gauge and a Butane Lighter Fluid Can

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In the course of compiling a collection of more than 100 gas law demonstrations,[1] we have developed a simple, inexpensive apparatus based on a butane lighter fluid can and a standard tire pressure gauge that can be used for several lecture or laboratory experiments, including the measurement of the atomic or molecular mass of a gas.

The Mass of Air or the Dependence of Pressure on the Mass of a Gas

Hopkins has shown how to demonstrate the mass of air[2] and/or the dependence of the pressure of air on the mass of the sample[3] using a tire pressure gauge and an empty aerosol can to which a tire valve stem has been soldered. Our experience with gas-law experiments based on butane lighter fluid cans[4] suggested that there would be several advantages to using a butane can for these demonstrations.

1) Butane cans already contain a valve.
2) These cans are built to sustain reasonably large pressures because the vapor pressure of butane approaches 5 atm at temperatures as low as 35°C.
3) The self-sealing valve on the butane can allows one to evacuate the can and then fill the can with gas from a compressed gas cylinder. These demonstrations are therefore no longer restricted to just "air."

To demonstrate the mass of air, connect the stem of an *empty* butane lighter fluid can to a vacuum pump with thick-wall rubber tubing. Turn on the pump and depress the valve stem, thereby opening the can to the vacuum pump. Once the valve stem is released and the can automatically seals itself, the "empty" can is weighed to the nearest ±0.001 g with an analytical balance. The valve stem is then depressed, allowing air to enter the can, and the weight of the can filled with air is measured.

In order to demonstrate the dependence of the pressure of a gas on the mass of the sample, one of the plastic adapters that come with butane lighter fluid cans must be modified so that it fits snugly inside a standard tire pressure gauge as shown in Figure 1. This can be done by cutting off the tip of the adapter with a hacksaw, and then shaping the adapter with a file.

The can is then evacuated, and the weight of the empty can plus adapter is measured. A short length of rubber tubing is attached to a two-stage pressure regulator on a compressed gas cylinder, and the regulator is adjusted to a pressure of 45–60 psi. The cylinder is opened to purge the rubber tubing, the evacuated butane can is connected to the rubber tubing, and the valve stem on the can is depressed, thereby filling the can at a gauge pressure of 30–45 psi.

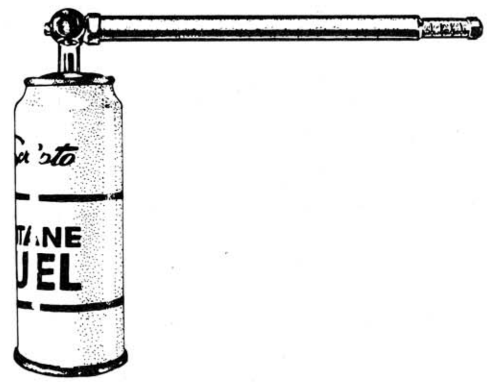

Figure 1. The pressure of the gas in a butane lighter fluid can be measured experimentally by modifying one of the plastic adaptors that come with these cans so that it fits snugly into a tire pressure gauge.

The can is then weighed to ±0.001 g and the pressure is measured to ±1 psi with a tire pressure gauge as shown in Figure 1. The valve stem is depressed for 1 or 2 s to allow a small amount of gas to escape, and the pressure and weight measurements are repeated. This process is repeated until the pressure falls below the 10–12 psi minimum of the tire pressure gauge. (We have obtained as many as 35 measurements of pressure and weight in a single trial.) The valve stem is then depressed for at least 30 s, to allow the pressure inside the can to reach atmospheric pressure, and the can is weighed once more.

If a compressed gas cylinder is not available, this demonstration can be done by connecting the evacuated butane can to a second can filled with butane, and simultaneously depressing both valve stems. (Be sure to hold the empty butane can upside down so that no liquid butane is transferred.)

Typical results for argon are given in the table. These data, as well as results for samples of helium, oxygen, and "butane,"[5] are shown in Figure 2. A least-squares analysis was used to fit these data to a straight line. The linear regression correlation

New lectures and laboratory experiments and directions in teaching chemistry through the use of the laboratory are provided in this feature. Experiments will be fully detailed and will be field tested before they are published. Contributions should be sent to the feature editor.

[1] Bodner, G. M., Magginnis, L. J., and Greenbowe, T. J., *in* "Chemical Demonstrations," Volume II, (*Editor:* Shakhashiri, B.S.), University of Wisconsin Press, Madison, WI, **1985,** Chaps. 5 and 6.
[2] Hopkins, D. E., J. CHEM. EDUC., **51,** 425 (1974).
[3] Hopkins, D. E., J. CHEM. EDUC., **53,** 718 (1976).
[4] Davenport, D. A., J. CHEM. EDUC., **53,** 306 (1976).
[5] "Butane" lighter fluid is a mixture of volatile hydrocarbons containing roughly 94% isobutane, 5% *n*-butane, and 1% propane.

The Dependence of the Pressure of a Gas on the Mass of the Gas in a Butane Lighter Fluid Can

Compound	Mass of Can	Mass of Gas [a]	Gauge Pressure [b]	Least Squares Equation [c]	Atomic Mass [d]
argon	34.299 g	1.028 g	52 psi	$P = -12.81 + 64.33m$	42 g/mol
	34.227	0.956	49		
	34.151	0.880	44		
	34.064	0.793	39		
	33.996	0.725	34		
	33.916	0.645	29		
	33.864	0.593	25		
	33.797	0.526	21		
	33.771	0.500	19		
	33.713	0.442	19		
	33.644	0.373	11		
	33.481	0.210	"0"		
	33.271	0	evacuated		

[a] At 27°C and 0.9826 atmosphere pressure.
[b] The gauge pressure of the gas is zero when the gas reaches atmospheric pressure.
[c] Least-squares linear correlation coefficient, $r = 0.9994$.
[d] Obtained by extrapolating these data to estimate the mass of gas at zero gauge pressure and then dividing this mass by the number of moles of an ideal gas that would occupy a volume of exactly 4 fl oz (0.1183 L) at the conditions (27°C and 0.9826 atm) under which this experiment was done.

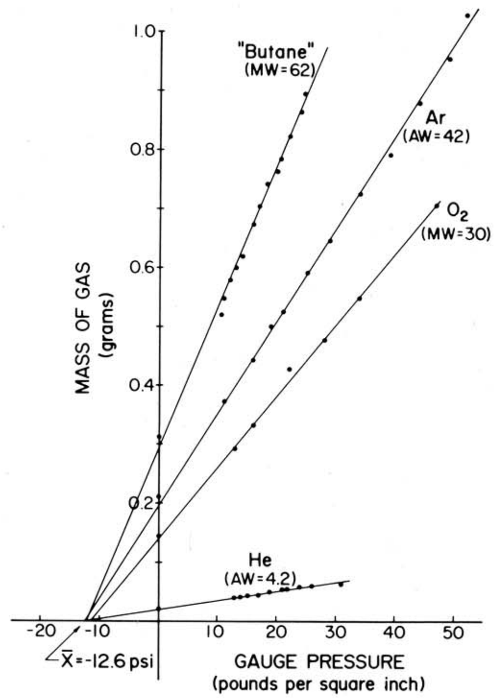

Figure 2. A plot of the mass of the gas in the butane can versus the gauge pressure for samples of helium, oxygen, argon, and "butane." The average of the x intercepts for these four lines is -12.6 psi. The atomic/molecular weights shown in this figure were obtained by extrapolating these data to estimate the mass of each gas present at 0 gauge pressure, and then dividing this mass by the number of moles of gas calculated from ideal gas behavior.

coefficient was 0.997 for butane and 0.999 for the other three gases.

Since gauge pressure is zero when the pressure of the gas is equal to atmospheric pressure, these data should extrapolate to zero grams of gas at a gauge pressure of -14.6 lb/in^2. Experimentally, we find that these data extrapolate to an average gauge pressure of -12.6 psi, which suggests a small systematic error in these measurements, probably associated with the tire pressure gauge.

Measuring the Atomic or Molecular Mass of an Unknown Gas

The most important advantage of using butane lighter fluid cans for this experiment is the ease with which data can be collected using such an apparatus and then analyzed to determine the atomic or molecular mass of the gas. The key to this measurement is determining the number of moles of gas in a sample of known mass. The experimental atomic or molecular masses given in Figure 2 were determined by extrapolating the experimental data to estimate the mass of each gas that would be present at atmospheric pressure (0 gauge pressure), and then dividing this mass by the number of moles of gas in the sample assuming ideal gas behavior and a volume for the butane lighter fluid can of exactly 4 fl oz.