An important topic in the study of thermodynamics is the ideal gas law, \( PV = nRT \), and experiments that test this law are common in student laboratories.\(^1\) Usually in classroom experiments, the number of moles \( n \) in the sample is held fixed. Then, two of the other three variables \( P, V, \) and \( T \) are varied, holding the third one constant. However, with very simple equipment it is possible to vary \( n \), keeping \( V \) and \( T \) constant, thus allowing the student to investigate all the variables in the ideal gas law.

The apparatus is described in Ref. 2 and consists of a plastic soda bottle, a bicycle pump, automobile tire valve, and tire pressure gauge. One pumps up the bottle and measures how much the mass increases, \( \Delta m \), as well as the increased pressure. We used a two-liter soda bottle, although a football makes a more interesting container.\(^3\)

Similar equipment can be used to determine the molar mass,\(^2,4\) density of the gas for different pressures,\(^2\) or the mass or volume of the container.\(^2,3\)

In physics, we are also interested in verifying the gas law. One starts with the theory under investigation: \( P = \frac{nRT}{V} \). Substituting \( n = \frac{(m_0 + \Delta m)}{M} \) gives

\[
P = \frac{RTm_0}{VM} + \left( \frac{RT}{VM} \right) \Delta m,
\]

where \( m_0 \) is the mass of the air in the bottle just after the cap is put on without any extra air being pumped in. \( M \) is the molar mass of air. Thus, if a graph of \( P \) versus \( \Delta m \) produces a straight line, the dependence of \( P \) on \( n \) for the ideal gas law is verified. The slope of the line is equal to \( RT/(VM) \). Since \( R, T, \) and \( V \) can be measured, one can determine the molar mass of air from the slope. The \( \Delta m \) intercept is equal to \(-m_0\). Since \( V \) is known, the density of air \( (m_0/V) \) at laboratory pressure and temperature can also be determined.

In Fig. 1 we show a graph of \( P \) versus \( \Delta m \) for our data, with \( V = 2.075 \) L, \( T = 296 \) K, and the atmospheric pressure \( P_0 = 741.5 \) mm Hg = 0.988 \( \times \) \( 10^5 \) Pa. The data lie in a straight line, confirming \( P \propto n \). From the slope we calculate the molar mass of air to be \( M = 27.4 \) g. In Ref. 2 a value of \( M = 27.8 \) g was obtained from data taken from a single point. The horizontal intercept gives \( m_0 = 2.15 \) g, resulting in 1.04 kg/m\(^3\) for the density of air. This is to be compared with 1.17 kg/m\(^3\) for the density of moist air at 296 K and 742 mm Hg pressure.\(^5\)

It is advantageous to graph the absolute pressure, \( P = P_0 + P_{\text{gauge}} \), inside the bottle instead of the gauge pressure so the student uses both types of pressures, and because it demonstrates to the

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**Fig. 1.** A graph of \( P \) vs \( \Delta m \) for air in a 2-L bottle. The line drawn is the best-fit line using linear regression. The slope is \( 4.31 \times 10^7 \) J/(m\(^3\)kg), and the horizontal intercept is \(-2.15 \) g.
student the large range of validity of the gas law. In Fig. 1, one can see that the linearity holds while the absolute pressure, and consequently $n$, is increased by a factor of 4. This is a large variation in comparison to other "gas law" experiments. For example, in experiments in which the temperature $T$ is varied while keeping $P$ or $V$ constant, the relative change of the variables is smaller. Usually the students vary $T$ from ice water, 273 K, to boiling water, 373 K, and the relative change is only $100/273 = 0.37$ or 37%.

Adding $n$ to $P$, $V$, and $T$ completes the list of the experimental variables the students can analyze with the gas law. Since the experiment is simple and portable, it makes a good lecture demonstration and helps get the students “pumped up” on the ideal gas law.

References