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Experiments with Disposable Hypodermic Syringes

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ypodermic syringes have been used previously in simple physics and physical science experiments.[1] We have made several extensions of the ideas in courses taught for students preparing to be elementary and secondary science teachers and for in-service teachers working on physical science certification.[2] Listed below are a few experiments and demonstrations involving hypodermic syringes. Typical data are shown where appropriate.

Experiment 1: Boyle's Law

The hypodermic syringe may be used to demonstrate Boyle's law. First, take a 60 cc plastic veterinary syringe and seal the needle end of the barrel with glue or by melting it shut with heated pliers. Next, place the syringe plunger into the barrel to the 60 cc mark. It will be necessary to place a thin wire beside the plunger as you insert it into the barrel to allow the air to escape. After the plunger is inserted, remove the thin wire. Mount the syringe in a wooden frame and compress the trapped air by pushing the plunger against a set of bathroom scales (see Fig. 1).

Fig. 1. Boyle's law apparatus.

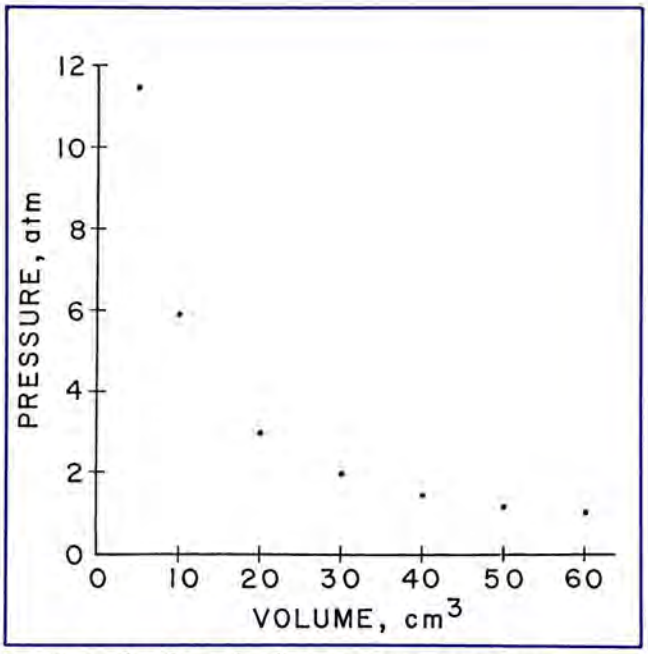

Fig. 2. Boyle's law: absolute pressure vs. volume.

Take a series of pairs of volume and scale readings. To aid in eliminating friction between the plunger and syringe barrel, take the average of the minimum and maximum scale readings required to maintain each volume measurement. If this is not done, friction could cause errors of approximately 1% in the highest bathroom scale readings to approximately 100% in the lowest scale readings. (Table III lists a typical value for the frictional force between the plunger and barrel.)

Fig. 2 shows a typical plot of the pressure vs. volume (note the inverse relation depicted). Fig. 3 shows the same data plotted with pressure vs. (volume)$^{-1}$. (The data for Fig. 2 and 3 appear in Table I.) Fig. 3 clearly shows Boyle's law ($P_1V_1 = P_2V_2$). An approximate value of the universal gas constant R can be obtained by dividing the slope of the curve in Fig. 3 by (nT) where n is the number of moles of gas in the syringe and T is the ambient temperature in kelvins. (n is determined from the density of air[3] at the ambient temperature and the molecular weight of air.[4])

For this particular experiment the slope is 5.81 J, n is 0.0025 moles, and T is 295 K. This gives a value for R of 7.88 J/(mole·k). This differs 5% from the accepted value of 8.314 J/(mole·K).[5] This version of demonstrating Boyle's law is slightly different from that appearing in *College Introductory Physical Science*.[6] It is less cumbersome, does not require a set of masses, and the results are quantitative.

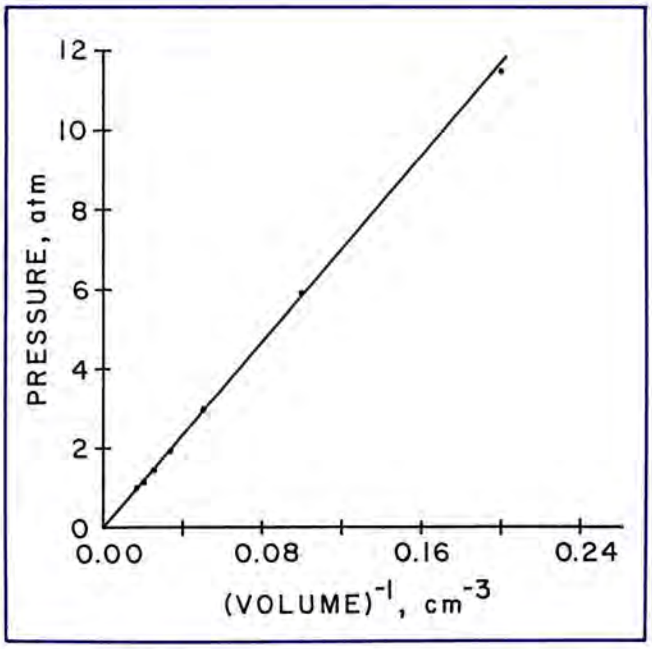

Fig. 3. Boyle's law: absolute pressure vs. (volume)$^{-1}$.

Experiment 2: Charles' Law and the Concept of Absolute Zero

A study of Charles' law and a determination of absolute zero temperature also can be performed using a hypodermic syringe. Following the procedure mentioned in Experiment 1, insert the plunger into the barrel of a 60 cc veterinary syringe so that a volume of about 20 cc of air remains in the syringe. Remove the wire. Place the syringe, needle nose down, in a beaker of water.

Heat the system slowly using an alcohol burner. Make temperature and volume readings as the mixture is warmed. Continue this until the temperature is near the boiling point of water. It is suggested that the plunger be jiggled within the barrel prior to each reading since friction tends to hamper the motion of the plunger.

An example plot of volume vs. temperature for such an experiment is depicted in Fig. 4. (The data plotted in this graph appear in Table II.) The curve in Fig. 4 illustrates Charles' law. If this graph is extrapolated to zero volume, an approximate value of $-236°C$ is obtained for absolute zero. This can be done by several members of a class and an average value for absolute zero determined. (We agree with the IPS Instructor's Guide that "the apparatus is temperamental and the experiment is time-consuming, with a high probability of irregular results."[7] However, it could be done as a demonstration by the instructor using the procedure above. The IPS Instructor's Guide suggests a much better way to demonstrate Charles' law without the use of a syringe.[8])

Experiment 3: Atmospheric Pressure

The pressure of the atmosphere can be measured to within 5% of 1.01×10^5 N/m^2 by using a plastic 60 cc veterinary syringe. First, attach a string to the plunger of the syringe so that weights can be suspended from it. With the needle end of the syringe barrel open and pointed upward, attach a weight, W_1, sufficient to extract the plunger at constant speed. (To achieve constant speed be sure that the plunger passes by the divisions on the barrel at a uniform rate.) This weight approximates the frictional force between the plunger and the barrel. Next, place the plunger fully into the barrel, cap the needle end of the barrel, and proceed to add enough weight, W_2, to extract the plunger from the barrel at constant speed.

The atmospheric pressure is determined by taking W_2 minus W_1 and dividing by the cross-sectional area of the syringe barrel. Values are typically within 5–8% of one atmosphere. Table III contains a sample calculation. The primary source of error is the crude determination of the frictional force. We feel that increased accuracy in the measurement of the atmospheric pressure is not worth the extra effort required to determine more accurately the force of friction.

Experiment 4: Expansion of Gases

Place a miniature marshmallow in the 60 cc syringe used in Experiment 1. Insert the plunger as in Experiment 1 until the marshmallow is on the verge of being compressed. Remove the thin wire. Slowly pull back on the plunger. Because the marshmallow contains trapped gases, it expands in the presence of the reduced pressure. Extract the plunger completely from the barrel and observe that the marshmallow has out-gassed, for it does not return to its original shape when exposed to atmospheric pressure. Grade school children are fascinated by this demonstration, especially when they are allowed to participate.

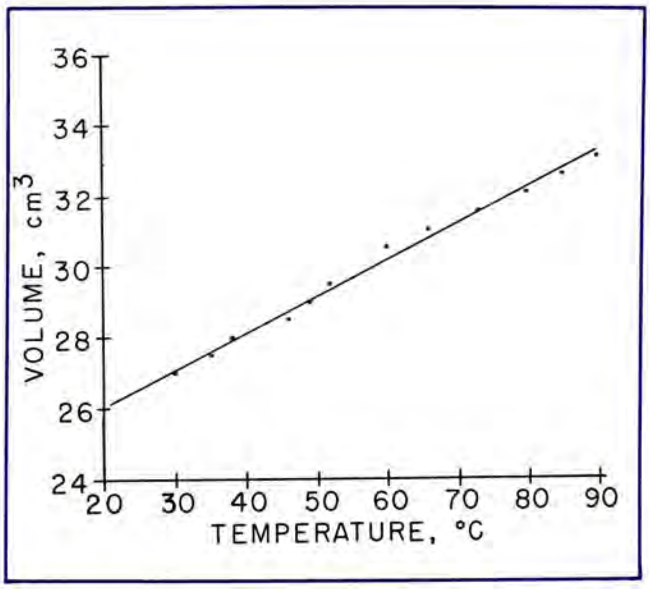

Fig. 4. Charles' law: volume vs. temperature.

Table I. Boyle's law data.[a,b]

Scale reading (lb)	Volume (cm^3)	Pressure (gauge) (lb/in^2)	Pressure (absolute) (atm)	$(\text{Volume})^{-1}$ (cm^{-3})
0.0	60	0.00	1.00	0.017
1.5	50	1.87	1.13	0.020
5.0	40	6.24	1.43	0.025
11.5	30	14.36	1.98	0.033
23.5	20	29.3	3.00	0.050
57.5	10	71.8	5.88	0.100
123.0	5	154.0	11.48	0.200

[a]Diameter of syringe barrel, d = 1.01 in.
[b]Area of syringe barrel, $A = \pi d^2/4 = 0.801\ in.^2$.

Table II. Charles' law data.

Volume (cm^3)	Temperature (°C)
25.0	23
27.0	30
27.5	35
28.0	38
28.5	46
29.0	49
29.5	52
30.5	60
31.0	66
31.5	73
32.0	80
32.5	85
33.0	90

Table III. Measurement of atmospheric pressure.

Diameter of syringe barrel, d = 2.64 cm
Area of syringe barrel, $A = 5.47 \times 10^{-4}\ m^2$
Frictional force $W_1 = (0.70\ kg)\ (9.81\ m/s^2) = 6.9\ N$
$W_2 = (6.30\ kg)\ (9.81\ m/s^2) = 61.8\ N$
$P_a = (W_2 - W_1)/A = 1.004 \times 10^5\ N/m^2$

Experiment 5: Boiling at Reduced Pressure

Place about 20 cc of warm water in a 60 cc syringe. Insert the plunger as in Experiment 1 until all of the air is removed. Remove the thin wire. Without extracting the plunger fully from the syringe, pull back rapidly on the plunger. Notice that many small bubbles are formed. This is boiling that occurs because of reduced pressure. A boiling chip in the water will yield significantly more boiling.

These experiments are just a few of the many interesting experiments that can be done with a simple hypodermic syringe. Since some of the experiments are quantitative and the equipment is inexpensive, these experiments can readily be integrated into a physical science laboratory program.□

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