AN APPARATUS FOR BOTH BOYLE'S AND CHARLES'S LAW.

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The apparatus consists of an open and a closed manometer, both straight and vertical, and made of glass of ordinary size, with their lower ends dipping into mercury contained in a vessel connected with an air compressor. To vary the temperature of the air within the closed manometer, this may be surrounded by a jacketing tube (not shown in the figure) through which liquids at different temperatures or the vapors of boiling liquids,

such as water, ether, acetne, carbon tetrachloride, alcohol, etc., may be passed.

The open manometer is about 110 cm. long and passes through one of the holes of a thrice perforated stopper. The closed manometer is about 60 cm. in length and passes through a second hole, while the third hole is provided with an L-tube. The lower ends of the manometers should be rotated in a flame until they fuse nearly together, leaving an opening about a millimeter in diameter; this will prevent undue surging of the mercury when forced up into the tubes. The upper end of the closed manometer should be as nearly flat as it is possible to make it so that no correction need be applied to the volume (actually measured as a length on the assumption that the bore of the tube is uniform) on account of the convexity of the end. It is well to have the upper end of the open ma-

nometer flared out like a funnel, or fitted with a cork over which is fixed a broken test tube, such an arrangement preventing the overflow of mercury, which may otherwise happen should the air in the vessel be compressed too rapidly.

The stopper is fitted to a screw cap bottle, and a circle punched out of the cap just large enough to accommodate the three tubes. To fill the closed manometer with dry air, connect it with a chloride of calcium tube and pass a Bunsen flame along it until its entire length is heated nearly to redness. Let it cool to the temperature of the room, disconnect from the drying tube, and, before any considerable amount of the dried air can escape, dip the open end of the tube into vaseline. The short plug of vaseline that will enter the tube effectually seals the dried air unless it is heated too much by handling.

Fill the bottle to a depth of about three centimeters with clean and dry mercury, cover the mercury with a thick layer of calcium chloride¹, insert the stopper into the neck of the bottle, and push the ends of the manometers down nearly to the bottom. Screw on the cap and, connecting a bicycle valve and pump to the L-tube by means of rubber tubing, pump air into the bottle until the stopper is forced up snugly against the cap. It may be found necessary to bind the rubber tubing by wire or string both to the L-tube and to the bicycle valve.

Remove the bicycle valve and pump and substitute an exhaust pump. Close the upper end of the open tube with a tiny lump of beeswax. Exhaust the air in the bottle a little, and then disconnect; the mercury will rise in the tubes. Continue the exhaustion by degrees until the mercury rises to a distance above the stopper equal to about a fourth of the length of the closed manometer. Replace the rubber tubing connecting the L-tube to the bicycle valve, interposing a screw cock and binding the rubber tubing to the valve and L-tube.

The jacketing tube is a piece of wide and thin glass tubing with its ends flared a little for the reception of stoppers, and is a little longer than the portion of the closed manometer extending above the screw cap. Its ends are closed with two-hole stoppers, one hole of each of which is fitted with an L-tube, while the closed manometer is thrust through the other hole of the lower stopper, and a thermometer through the remaining hole of the upper stopper.

¹To prepare perfectly dry calcium chloride in thin cakes or plates, proceed as follows: Heat a lump of the chloride held by crucible tongs in a large blast flame. The chloride will fuse and the drops that fall from the lump are caught upon a plate or a piece of sheet metal.

The apparatus may be supported on a retort stand, one ring encircling the bottle and a smaller ring or a burette clamp near the top of the rod holding the tubes. Special metal stands are also made to hold the apparatus. A meter stick is secured alongside the tubes by a clamp or by means of cord or rubber bands, one end of it resting upon the screw cap.

The apparatus when assembled may be used season after season at a moment's notice except for the occasional replacing of the rubber tubing due to its deterioration and of the calcium chloride because of its deliquescence. The support, meter stick and pump can be detached, of course, and made available in other experiments. The principle of the operation of the apparatus is readily understood by students, its action is rapid and its results are reliable. A dozen pieces of the apparatus have been used in the writer's laboratory for several years, and have proved perfectly satisfactory both to pupils and instructor.

The apparatus is used (1) to find the relationship between the pressure and the volume of a mass of gas at constant temperature (Boyle's Law); (2) to determine the coefficient of expansion of a gas kept under constant pressure (volume coefficient of expansion); and (3) to find the coefficient of expansion of a gas maintained at a constant volume (pressure coefficient of expansion). It is also utilizable in demonstrating the principle of pressure transmission and of manometers. The manner of employing the apparatus for these purposes as well as the kind of results that may be obtained are considered in what follows.

BOYLE'S LAW.

The apparatus is arranged as shown in the figure. The jacketing tube is hardly necessary, inasmuch as the temperature of the laboratory may usually be considered as remaining uniform during the brief time required for the performance of the experiment. Still it is but little trouble to run water from a large supply kept well stirred so as to maintain constancy of temperature up through the jacketing tube, or to pass steam from a boiler down through it. The data will then not be influenced by any variations in the temperature of the room.

The meter stick is read at a point on a level with the inner surface of the upper end of the closed tube. The pump is then worked until the mercury in the open tube is forced a little above that in the closed tube. Usually the apparatus leaks a little so that the mercury levels fall slowly. The rubber tubing

can be pinched together either with the screw cock or between the thumb and finger so that it is possible to prevent the movement of the mercury long enough to make a reading when it is at the same level in both tubes. If, however, the apparatus is tight, and the mercury remains stationary or falls too slowly, disconnect the pump, and open the valve by sticking a pencil point into it.

When the mercury stands at the same level in both tubes, the pressure of the confined air is equal to that of the atmosphere as read on a barometer. When the mercury in the open tube is higher than in the closed tube, the pressure on the confined air is greater than that of the atmosphere; and when it is lower, the air is under a pressure less than that of the atmosphere. The apparatus therefore permits of studying Boyle's Law at pressures both greater and less than atmospheric.

Air is now pumped into the bottle until mercury is forced up to nearly the top of the open tube. By pinching the rubber tubing, the mercury can be prevented from sinking, and readings of the mercury levels in both tubes are made. Two students can work to advantage here, one reading the mercury level in the open tube at the same instant that the other reads the mercury level in the closed tube. Enough air is allowed to escape from the bottle to let the mercury sink about ten centimeters in the open manometer. The motion of the mercury is then checked and readings of both levels taken. In similar fashion additional readings are taken until the mercury in the open tube sinks below the stopper.

The following tabulation taken from a student's notebook shows what results the apparatus can yield. It is not too much to require that the products of P and V do not differ by more than two per cent.

TABULATION FOR BOYLE'S LAW.

A. Barometer reading, 75.9 cm. **B.** Reading at top of closed tube, 82.0 cm.

C Readings on open tube	D Readings on closed tube	C-D Pressure above at- mospheric	D-C Pressure below at- mospheric	A+(C-D) Pressures P greater than at- mospheric	A-(D-C) Pressures P less than at- mospheric	B-D Volumes V	P×V
75.5 cm.	52.8 cm.	22.7 cm.		96.5 cm.		27.3 cm.	264 × 10
66.8	50.7	16.1		89.9		29.4	264
60.4	48.9	11.5		85.3		31.2	266
49.5	45.9	3.6		77.4		34.2	265
42.1	43.5		1.4 cm.		72.4 cm.	36.6	265
37.0	41.7		4.7		69.1	38.4	265
31.4	39.7		8.3		65.5	40.4	262
27.8	38.3		10.5		63.3	41.8	264

VOLUME COEFFICIENT OF EXPANSION.

The temperature of the air within the closed manometer is reduced to 0° by running a weak salt or alcoholic solution through the jacketing tube, previously cooled to about -2° by putting plenty of snow or cracked ice into it. By regulating the speed of flow by means of a screw cock compressing the rubber tubing leading the solution to the jacketing tube, the temperature of the confined air can be maintained at 0° . Air is pumped into the bottle until the mercury stands at the same height in both manometers. The difference between the readings on the meter stick at points on a level (1) with the inner surface of the upper extremity of the closed tube and (2) with the mercury gives the volume of the air at 0° .

After the solution is run out of the jacketing tube, steam from a boiler is passed through it. The temperature of the imprisoned air is thereby raised to that of the boiling point of water under the prevailing pressure of the atmosphere. It is easy to increase the pressure of the steam by compressing the rubber tubing somewhat so that its temperature may be raised to 100° , but that is unnecessary for the purpose of this experiment. When enough air is pumped into the bottle to raise the mercury in both tubes to the same level, a reading on the meter stick is made. The difference between it and the reading at the top of the closed manometer gives the volume at the higher temperature. From these data the volume coefficient may be computed as shown in the annexed tabulation. Determinations usually give values differing by less than three per cent from the accepted value of .00367².

PRESSURE COEFFICIENT OF EXPANSION.

While the steam is still being passed through the apparatus, the pump is worked until the mercury in the closed tube is forced up to the same level that it occupied when the volume of the enclosed air was read at 0° and under atmospheric pressure. The level of the mercury in the open tube is read at the same time, and the increase of pressure needed to keep the air at a constant volume ascertained. The pressure coefficient is calculated as shown in the tabulation.

TABULATION FOR CHARLES'S LAW.

	1st trial	2nd trial
A. Barometer reading	74.5 cm.	74.5 cm.
B. Reading at the top of the air column	67.6 cm.	67.6 cm.

²Students' directions for performing the experiments with this apparatus are given in the writer's *Laboratory Manual of Physics* (D. C. Heath & Co.)

C. Reading of the mercury level in			
both tubes when the air is at 0°..1st adjustment			
	42.4 cm.	42.3 cm.	
	2nd "	42.3	42.4
	3rd "	42.3	42.3
	Average	42.3	42.3
z. Temperature when steam is passed.....			
	99.4°	99.4°	
D. Reading of the mercury level in			
both tubes when the air is at t°..1st adjustment			
	33.4 cm.	33.3 cm.	
	2nd "	33.3	33.3
	3rd "	33.4	33.3
	Average	33.4	33.3
E. Reading on the open tube when the			
temperature of the air is t° and			
the reading on the closed tube is			
the same as in C.....1st adjustment			
	68.7 cm.	69.0 cm.	
	2nd "	68.9	68.6
	3rd "	68.5	68.5
	Average	68.7	68.7
F. Volume of the air at 0° and A cm. [B — C]			
	25.3 cm.	25.3 cm.	
G. Volume of the air at t° and A cm. [B — D]			
	34.2 cm.	34.3 cm.	
Increase in volume under pressure of A cm. [G — F]			
	8.9 cm.	9.0 cm.	
Coefficient of expansion under constant pressure $\left[\frac{G-F}{Ft^\circ}\right]$			
	.00355	.00361	
Per cent of error			
	3%	2%	
H. Pressure of the air with volume constant at t°			
[E — C + A]			
	100.9 cm.	101.1 cm.	
Increase in pressure with constant volume [E — C]			
	26.4 cm.	26.5 cm.	
Coefficient of expansion with constant volume $\left[\frac{H-A}{At^\circ}\right]$			
	.00356	.00357	
Per cent of error			
	3%	3%	

Good values for the expansion coefficients cannot be obtained unless the imprisoned air is kept perfectly dry. The common procedure of putting a drop of strong sulphuric acid within the tube cannot, of course, be employed with a vertical tube, and it has been pointed out that "sulphuric acid does not serve the purpose for which it is intended" (Hennings, this Journal, Vol. XII, p. 9). The experience of the writer has been similar to that of the authority just quoted. Freshly prepared closed manometers were found to give results with small error, but after standing for a year they yielded values for the coefficients that were much too large. The use of calcium chloride, however, relieved the situation satisfactorily. One closed manometer was made of tubing of about six millimeters bore, and a couple of tiny lumps of freshly fused calcium chloride introduced into

it so as to float upon the surface of the mercury within the tube. The volume of the chloride was regarded as negligible, and the apparatus has given excellent results for four seasons. The use of calcium chloride within the bottle prevents moisture from getting into the air within the closed tube. Since the outlet of the bottle is provided with a bicycle valve, one filling of the chloride lasts some time before it deliquesces enough to seriously impair its drying power.

A CONVENIENT GASOMETER.

BY N. F. SMITH.

Many interesting physical experiments—such, for example, as those with the sensitive flame—require for their execution a gas pressure in excess of that supplied by the ordinary city gas works.

Since few elementary laboratories are supplied with gas tanks containing compressed hydrogen or coal gas, these instructive experiments are commonly omitted. For the performance of such experiments, the following extremely simple device has been found effective and convenient.

An empty carboy, gasoline can or other air-tight receptacle holding from three to five gallons is fitted with a two-hole rubber stopper through which pass a siphon, DE, and an inlet tube, C. The container is first filled with water, after which C is connected to the gas-cock and the water displaced by gas. C is then connected to the burner where gas at high pressure is desired. E is connected to the water tap and the faucet opened until the desired pressure is obtained. By regulating the rate at which water is supplied, any desired gas pressure can be secured. A five gallon container will supply gas for a sensitive flame for one or two hours without refilling.