mass action, nor—dare I say it?—at phase relations—the research spirit pervading every part of the work.

Once or twice a year, perhaps, in presenting a subject, the teacher will draw his material from the original papers themselves. The pupils will at every stage of progress instinctively feel that chemistry is not a dead mass of laws and formulæ and equations, but a science, fairly throbbing with life, whose marvelous growth has been due to just those lines of thought which they, themselves, have been pursuing.

DEVICES USEFUL FOR DEMONSTRATION PURPOSES.*

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I have often urged at these meetings the desirability of devoting a portion of our time to the consideration of practical physics, and it is for that reason, perhaps, that I have been asked to set the example today.

The devices to be described are not altogether new, and they are of a very simple nature. For their simplicity I have no apology to offer, it being a first principle of experimental demonstration that the apparatus should be shorn of every unnecessary feature which might distract the mind from the contemplation of the phenomenon to be exhibited or bewilder the student in his attempt to grasp the principle to be illustrated.

I.

An apparatus for showing in a semi-quantitative way the expansion of air at constant pressure.

In exhibiting the phenomenon of the expansion of gases by heat it is desirable to afford the most direct possible ocular demonstration, not only that expansion occurs, but likewise to show approximately how great that expansion is. The ordinary form of air thermometer fails in the latter respect, because we are un-

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able to estimate even approximately by inspection the relation of the total content, including bulb and neck, to the volume of the mercury displaced in the process of expansion. In a cylindrical vessel the volume is, however, directly proportional to the length of the cylinder and the change of the volume between the ice point and the steam point ($\frac{100}{273}$ of the volume at zero) is so great that it can be estimated with the unaided eye. In the apparatus which I have adopted for the purpose after trying a variety of forms, the very ingenious and simple device employed in the usual experiment for demonstrating Boyle's law is used. A tube 100 cm. long and about 5 cm. in diameter is closed at the lower end and two-thirds filled with mercury. (See Fig. 1.)

FIG. 1.

A small tube, likewise closed at one end, and graduated in cubic centimeters from the bottom upward, is inverted in this mercury cistern as in the usual Mariotte apparatus. It is convenient to select for this purpose a tube the total contents of which are 100 cubic centimeters. Such tubes already graduated may be purchased of any dealer in chemical apparatus. If the amount of air entrapped in the upper end of this inner tube be such that, when the tube is pushed down so that the height of the inner column of mercury is at the level of mercury in the outer cistern, its volume is 27.3 cc. At zero, the apparatus becomes direct reading. To adjust the pressure of the enclosed gas to exactly one atmosphere, a rubber cork is fitted to the open mouth of the larger tube. Through a hole in this cork a tube slides with sufficient friction to hold it in position at whatever point it may be released. The lower

end of this sliding tube is enlarged in the blowpipe flame into the form of a small inverted cup. Within the hollow of this little cup the top of the tube, which floats in the mercury, is placed. The floating tube will then stand vertically in the center of the cistern and its height can be adjusted with ease so that, whatever may be the temperature, the mercury columns inside and outside of the tube will co-

inside. I know of no more simple or satisfactory method of maintaining the enclosed gas at a constant pressure of one atmosphere. To bring the enclosed volume of air to the temperatures of zero C. and 100 degrees C. an ordinary lamp chimney of the largest size is mounted so as to surround the entire upper portion of the outer tube as shown in Fig 1. The space between this lamp chimney and the outer tube may then be filled with water and crushed ice, or a jet of steam may be introduced to bring the enclosed parts to a higher temperature.

In using the apparatus for class room or lecture demonstration it is well to start at the steam point. The apparatus having been previously set up and steam introduced for some little time before the beginning of the hour, the inner tube will have already attained the proper temperature when attention is first called to the subject. The inner tube is raised so that all may see the mercury column above the level in the mercury in the outer cistern. It is then lowered by pushing down the sliding tube until the pressure is exactly one atmosphere and the height of the column is read upon the graduated scale. The steam jet is now removed and the space between the outer tube and the chimney is filled with ice water. The mercury column within the inverted tube will soon be seen to begin to rise above the outer level. The apparatus is left standing while other topics to be presented to the class are considered, and just before the end of the period the final adjustment is undertaken. The diminution of volume due to fall of temperature having been pointed out, the sliding tube is then pushed down until the pressure is restored to normal, when the reading upon the graduated scale is again made. For the purpose of drawing off the condensed steam, and likewise the water from the bath, it is convenient to insert through the collar upon which the glass chimney is mounted a small tube with stop-cock, as shown in the figure. A siphon may, however, be employed for this purpose. Another convenient addition to the apparatus is a thermometer inserted through a hole in the upper cork, by means of which one can ascertain when the change of temperature is completed. Successful working of this apparatus depends, of course, upon the uses of dry mercury and a perfectly dry inner tube. To secure the very best results the graduated tube should

be completely filled with mercury before inverting in the cistern and air dried by passing through strong sulphuric acid or through drying tubes with potassium oxide or phosphorous pentoxide should be introduced by means of an inverted siphon. If these precautions be taken the apparatus will serve very well for quantitative laboratory work on the coefficient of expansion of air, although of course it is not possible to make readings to the degree of exactitude that may be obtained with more refined apparatus.

II.

Floats adjusted to show the phenomenon of the maximum density of water.

The fact that water reaches its maximum density at 4 degrees C. is of course touched upon even in our most elementary courses of experimental physics, and various forms of apparatus have

Fig. 2.

Fig. 3.

been suggested for the purpose of showing this phenomenon. The simplest of these consists of a float, like that suggested by Preston in his well-known work on the Theory of Heat (p. 177), so adjusted that it will float in water at 4 degrees and sink in water

at zero. Such floats may be given various forms, one of which is shown in Fig. 2-a. This consists of a short piece of light glass tubing, preferably the bottom of an ordinary test tube, to which a cork is fitted. This cork should be of such size that it can be pushed down into the tube by slight pressure. The first approximate adjustment is made by pouring mercury into the tube until it will float nearly submerged in water with the cork inserted. A long, thin stem consisting of a fiber of glass not more than one-half a millimeter in diameter is now inserted vertically through the center of the cork and the tube is sealed by the application of a layer of cement (bicycle tire cement or ordinary sealing wax). Upon placing the float thus prepared in water at 10 degrees it will be found either too heavily or too lightly loaded. In the latter case further adjustment is possible by pushing the cork more deeply into the tube, thus decreasing its displacement, until it will sink. The final adjustment, which consists in lightening the tube as far as is possible without actually enabling it to float is performed by melting the tip of the glass fiber in a Bunsen flame and removing small portions of the melted glass. If too much is removed a still smaller amount may be restored in a similar manner. If this float be adjusted so that it will sink very slowly in water at 10 degrees it will do the same at zero because the density of water at these two temperatures is almost identical. It only remains to determine whether the adjustment is close enough to admit of its rising at the intermediate temperature of 4 degrees. When we consider how small the change of density is between these two temperatures, a unit of volume of water at zero diminishing to 0.99988 at 4 degrees and increasing again to 1.000125 at 10 degrees, it would seem at first hopeless to attempt to make such an adjustment. A little practice will show, however, that by successive alternate additions to and curtailment of the length of the glass fiber, the float may be brought to fulfill these delicate requirements. It will stand at the bottom of a cylinder of ice cold water, will rise slowly as the temperature approaches 4 degrees, and if care be taken to see that it is not permanently retained at the surface by the action of the surface film, it will sink again before 10 degrees has been reached.

Another plan likewise easily carried out consists in so adjust-

ing this simple instrument that it will float with a portion of the slender stem projecting through the surface volume at 10 degrees (Fig. 2-b). In this form the instrument becomes an extremely sensitive hydrometer of variable immersion, and its upward and downward movement between zero and 4 degrees and between 4 and 10 degrees will frequently amount to two or three centimeters. In this form the apparatus lends itself to the actual measurements of the change of density of the liquid.

To both of these forms the following objections may be urged: In the first place, they are exceedingly fragile, and in the second place, one never feels sure that the closing of the tube by means of the cemented cork is complete. The slightest leakage or the soaking of water into the cork through a layer of cement would speedily destroy the delicate balance of the instrument. On this account a float entirely constructed of glass and containing no mercury is to be preferred. A piece of ordinary glass tubing having a bore of about two millimeters is sealed at one end and is blown into a bulb about six or eight millimeters in diameter. The tube is then drawn out in the flame of the blast lamp at a point about 5 cm. from the bulb and sealed off. (Fig. 3.) This closed tube is now placed in water at 10 degrees. If it floats, more glass is added at the closed end until it sinks, and successive adjustments are made by adding to or subtracting from the amount of glass at the heavy end until it sinks very slowly indeed at that temperature. In order to save time it is best to make two of these floats, adjusting the one in the flame while the other is cooling. It is not a long nor particularly difficult operation to adjust such floats, and they have the advantage of being permanent. After adjustment they may be placed in a bottle and will serve for a lifetime. For the purpose of demonstration it is only necessary to place the bottle in a bath of crushed ice or melting snow long enough to bring the contents into the neighborhood of the ice point and then to place the bottle upon the lecture table and allow it to warm up gradually in the atmosphere of the classroom. The bulbs which at the beginning of the experiment are at the bottom of the bottle will then rise and after the liquid has passed the temperature of 4 degrees will sink slowly again to their original position.

III.

The Torsion Balance Electrometer.

The Gold Leaf Electroscope is an instrument of such simple construction and of such delicacy that it answers the purpose of indicating the presence of static charges of electricity and likewise of determining their sign, in an admirable manner. There is, however, nothing quantitative about the action of such electroscopes in the ordinary form, and when we come to the question of measuring differences of electrical potential, the usual forms of electrometer are somewhat expensive to construct and difficult to handle. In the instrument now to be described I have endeavored to apply a principle already used by Threlfall for the measurement of the force of gravitation. Consider the case of a short rod mounted with freedom of rotation about the horizontal axis A B. (Fig. 4.) Its position of unstable equilibrium will be that in which the longer end of the rod is vertically above the axis of support. If now such a rod be fastened, at the point where the axis in the figure lies, to a horizontal fiber of quartz or to a fine wire, one end of which is fixed while the other is capable of be-

Fig. 4.

Fig. 5.

ing twisted by means of a micrometer screw, the twisting of the fiber will gradually lift the suspended bar with a motion of rotation out of its vertical position of stable equilibrium. The position of unstable equilibrium will no longer be vertical, but will make some angle with the vertical plane depending upon the stiffness of the fiber and the mass and adjustment of the rod. Finally, as the torque increases, the angle of instability is reached and the equilibrium of the rod is converted from the stable to the unstable type. As the position at which this change is approached the sensibility of the rod to forces tending to turn it upon its axis

increases indefinitely, so that by means of this device a torsion balance may be constructed, the sensitiveness of which, like that of the ordinary balance, may be increased at will up to the point where it is no longer possible to make it return to its zero position. By a suitable adjustment of the bar this position of maximum sensibility may be made to occur when the bar is in a horizontal plane (Fig. 5), and if the longer end of the bar be given a metallic coating and be charged, we have an instrument which may be used as an electroscope. By attaching to the short end of the bar a mirror, so that its angular movement can be carefully observed, and by using the micrometer screw at the torsion head to bring the bar back to its zero position, the instrument becomes an electrometer. The degree of sensitiveness to which an instrument of this type can be brought may be readily imagined. Threlfall found that with the form which he gave to it he could measure variations in the force of gravitation which did not amount to more than one part in a million. I am experimenting at present to see whether it were not possible to construct a manageable balance of this kind which will show the gravitational traction of bodies for one another. An apparatus which will do this, and which is easily handled in the classroom, would be, of course, a desirable addition to our equipment for demonstration. The principal fault which torsion balances of this type possess consists in the lack of sufficient damping. Whenever they are drawn out of the position of equilibrium they oscillate for a considerable time before coming to rest. Even if we are not able to overcome this fault, such balances will be useful in many ways. With them we may exhibit and compare magnetic attractions and repulsions by substituting for the charged body at the end of the rod a thin disk of iron. By placing vertically beneath this disk a coil of wire one may readily convert the apparatus into a sensitive ammeter.

In seeking to increase our means in illustrating the principles of physics, it is often better to endeavor to find new applications of existing apparatus, with such modifications as may be necessary, rather than to attempt to devise something entirely novel. This is the method of procedure which I have followed in the present paper, and the examples might be indefinitely extended. Take, for instance, the revolving mirror devised by Koe-

nig for the study of the manometric flame. This may be used in a large number of other striking experiments, by means of which the complex character of the electric spark may be shown, curves obtained from the composition of two vibrations either parallel or making any desired angle with one another may be exhibited, the periodical extinction of the alternating arc or the movements of such an arc in the magnetic field may be studied, etc. With another well-known and very simple instrument, the revolving disk with open sectors, innumerable fleeting phenomena may be exhibited. Prof. Boys, for example, used this device for showing the nature of the action of sound waves upon sensitive water jets. It is equally applicable to the observation of the changes of form of falling drops, the study of vibrating rods and strings or the mapping of the paths of projectiles. In all such work the aim should be to secure the greatest simplicity of construction compatible with the satisfactory operation of the instrument.

A CHEAP SUBSTITUTE FOR A PICHNOMETER.

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The adoption of the common forms of pichnometers for class use in secondary schools is open to objection on two grounds—first, they are expensive, and second, the manipulation required is beyond the ability of the average pupil.

The substitute I suggest gives results accurate to the third decimal, is easy to clean and dry, is made in one piece (i. e. no stoppers to lose or break), and is cheap.

The specifications furnished to the dealer who made those in use in my school were: "One ounce flat-bottomed Florence flasks, with a ring around the neck, numbered consecutively." This is practically a small volumetric flask for self graduation. I have previously used graduated volumetric flasks. These may be obtained of twenty-five cubic centimeters capacity, but I think it is good for each pupil to calibrate his own. The numbering affords the easiest method of keeping a record of the (different) capacities of the flasks. The flasks cost fifteen cents apiece.