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A SPECIFIC GRAVITY BALANCE FOR GASES

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By Junius David Edwards

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1. PURPOSE OF INVESTIGATION

An accurate method of determining gas densities is needed in many lines of technical and scientific work. This need, which has been especially urgent in the natural-gas industry, where the measurement of gas by means of orifice meters requires a knowledge of the density of the gas, was presented to the Bureau by S. S. Wyer on behalf of several natural gas companies, who requested recommendations as to apparatus and methods. The effusion type of apparatus, which has been generally used for this purpose, was first investigated, but has proven unreliable in practice. The investigation of that method by this Bureau has shown the character and magnitude of the errors involved; a full description of this investigation will be published in another paper.

The need of a more precise method being apparent, an investigation of other available methods was undertaken. The method selected, the apparatus and its operation, and laboratory and field tests made with it form the subject of this paper. The first balance was constructed in the instrument shops of the Bureau, and this, with slight changes, forms the laboratory type of apparatus recommended. To make the method applicable for field work with natural gas, a portable type of balance was also desired, and T. H. Kerr, of the Ohio Fuel Supply Co., Columbus, Ohio, undertook the construction of this model. The author is indebted to T. H. Kerr and E. F. Schmidt for their generous assistance in perfecting the mechanical details and constructing the balance shown in Fig. 6, several of which have already been placed in service.

2. PRINCIPLE OF THE METHOD

The principle of the method to be described is based upon the laws of the compressibility and the buoyant effect of gas. According to Boyle's law the density of a gas is proportional to its pressure; and the buoyant force exerted upon a body suspended in a gas is proportional to the density of the gas and therefore to its pressure. Therefore, if the bouyant force exerted upon a body is made the same when suspended successively in two gases, then the densities of the two gases must be the same at these pressures; or the densities of the two gases at normal pressure are in inverse ratio to the pressures when of equal buoyant force.

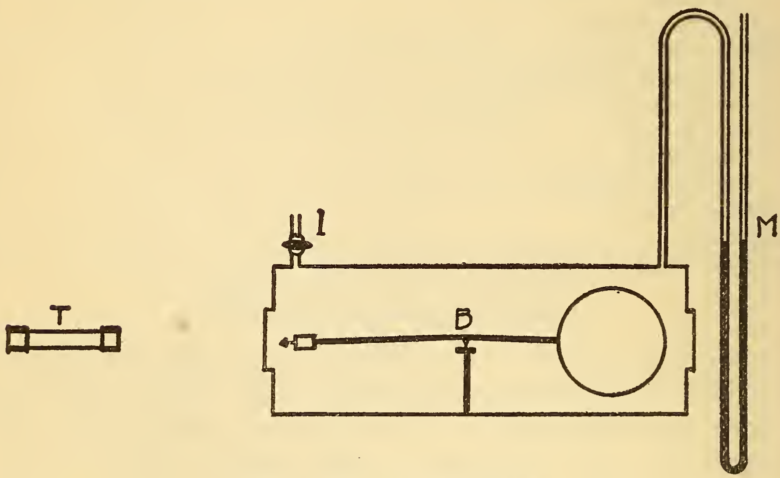

Fig. 1.—*Diagram of apparatus*

In this connection it may be well to define density and specific gravity. The density of a gas is the mass of a unit volume measured under specified conditions of temperature and pressure. It is usually expressed as the mass in grams of a normal liter. The term "specific gravity," as used in this paper, means the ratio of the weight of a given volume of gas to the weight of an equal volume of dry air, free from carbon dioxide, measured at the same temperature and pressure.

The apparatus used, shown diagrammatically in Fig. 1, consists of a balance beam carrying a sealed globe on one end and a counterweight upon the other. The balance beam (*B*) with its support is mounted in a gas-tight chamber to which is attached a mercury manometer (*M*). In operation, the balance case and manometer connections are filled with dry air through the inlet (*I*), and the pressure adjusted until the beam is balanced as judged by observation through the telescope (*T*). Then the balance case is filled with the gas to be tested and the pressure adjusted until the beam again balances at the same zero point. The derivation of the formula used is as follows:

Let d_a be the density of air at some standard pressure, p_0, and d_g the density of the gas to be tested at the same pressure, p_0.

Also let p_1 be the pressure at which the beam balances in air and p_2 the pressure at which it balances in the gas.

Then the buoyant effect of the air displaced by the globe equals $kd_a\frac{p_1}{p_0}$ and the buoyant effect of the gas displaced equals $kd_g\frac{p_2}{p_0}$, k being a constant which depends upon the difference in external volume of the balance globe and of its counterweight. These forces are equal, since the buoyant force must have been the same in the two cases to bring the beam to the same position.

Therefore:

$$kd_g\frac{p_2}{p_0}=kd_a\frac{p_1}{p_0}$$

And:

$$\frac{d_g}{d_a}\text{ (or the specific gravity) }=\frac{p_1}{p_2}$$

3. WORK OF PREVIOUS INVESTIGATORS

A. W. Gray [1] was one of the first to employ this principle, viz, using the pressure of the gas as a measure of its density. His apparatus consisted of a silica beam with globe and counterpoise of the same material, balanced on a quartz fiber. A small mirror was mounted at the center of the balance beam and readings of its position were made by means of a beam of light reflected by the mirror and a right-angle prism mounted above it on the balance case.

[1] Communication Leyden Lab., No. 94a; 1905.

F. W. Aston [2] designed a similar balance, using a knife-edge of quartz. It was used only as a null point apparatus, since the beam was brought to the same zero point each time by adjusting the gas pressure; readings were made by observing a line on the end of the beam with a microscope. Less than 1 cc of gas was required for a determination and an accuracy of 1 part in 1000 was secured.

Gray and Ramsay [3] in their determination of the density of radium emanation employed a microbalance, which was adjusted by changing the pressure of the gas in the balance case, thus modifying the buoyant force on a small globe on one arm of the balance.

W. C. Baxter [4] has constructed a balance using this method. The beam carries a metal knife-edge and a globe having a volume of about 600 cc. Because of its low sensibility it is not well adapted for precise work.

W. R. Whitney, of the General Electric Co., has furnished the Bureau with the description of a balance utilizing the same principle, designed in his laboratories for determining the density of argon mixtures. The beam and globe, which are made of glass, are supported by a metal knife-edge; a large leveling bottle is used in adjusting the pressure. In use, the balance is calibrated to read zero with a gas of known density at a certain definite temperature and pressure. The density of any other gas is calculated at any time from the pressure required to balance the beam in that gas, the temperature of the gas and the data secured in the preliminary calibration.

4. DESCRIPTION OF APPARATUS

In the design of the apparatus the difference in the requirements for field and laboratory use were borne in mind. In the field, portability and simplicity are almost as important as accuracy; whereas in the laboratory, accuracy is of prime importance. The advantages and disadvantages of the various forms of construction will be discussed in connection with the description of the apparatus.

The Balance.—A simple form of apparatus is illustrated in Fig. 2. It can be constructed from materials readily available and the glass blowing required is of the simplest kind. The balance case is made of a piece of glass tubing about 40 mm in diameter. One end is sealed off as shown and the other is slightly flared to receive a rubber stopper. The rubber stopper must be firmly held in place,

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[2] Proc. Royal Society, A, 89, p. 439; 1914.
[3] Proc. Roy. Soc., 84, p. 539; 1910.
[4] J. Am. Soc. M. Eng., 38, p. 688; 1916.

since it must be gas tight under a difference of pressure of one atmosphere. This can be accomplished by means of the collar and clamp shown in the drawing. The collar, made of fiber, is kept from slipping off the case by means of the small glass lip left on the tube when it was flared to receive the stopper. The ends of a small screw clamp are held in this collar and the necessary pressure can be applied to the stopper by means of the thumbscrew. Inserted through the stopper are two tubes, one bearing a two-way cock to connect with the vacuum pump and to admit the gas, and the other connecting with the mercury-filled U gage. The pressure required for equilibrium is reached by carefully

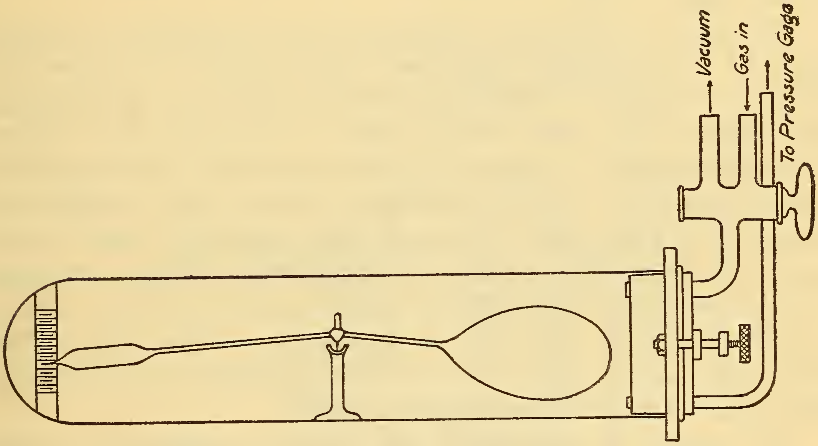

Fig. 2.—*Simple balance with glass case*

regulating by means of the stopcock the amount of gas admitted or withdrawn; or if this regulation is not fine enough, a screw pinchcock in addition can be used to constrict the rubber tube leading to the vacuum pump.

It is usually advisable to water-jacket the apparatus in order to reduce temperature changes to a minimum. This can be done by placing the balance inside another glass tube, or it can be set in a rectangular jar with plane glass sides. A pair of laboratory clamps can be used to hold it in place, or a wooden frame suitably weighted can be used for that purpose. It is important to have it resting on a firm base whenever in use; and the arrangement should be such that the position of the pointer can be accurately observed.

The beam is made from a piece of glass rod 1.5 to 2 mm in diameter. To one end is sealed a glass globe and to the other a short, thick piece of glass to serve as a counterweight. It will be necessary to bend the beam a little to bring the center of gravity below the point of support. To aid in adjusting the sensibility of the beam a short vertical piece of glass rod is sealed to it at the center.

The "knife-edge" consists of two very sharp needle points set at an angle and firmly attached to the beam by means of Khotinsky cement. The needle points rest in a cylindrical glass trough made from a short piece of tubing by grinding on a flat plate with emery. This support is attached to a vertical glass pillar by means of Khotinsky cement, and the pillar is attached in the same manner to the case.

The center of gravity of the beam may be adjusted by adding glass to or removing it from the counterweight, by bending the beam, by raising or lowering the needle points, and by changing the weight of the small vertical post at the center of the beam. The beam should be adjusted in the above ways until it approximately balances in air and has the requisite high sensibility as shown by a long period of swing. The sensibility should correspond to the accuracy desired, but in general a change in pressure of a few tenths of a millimeter of mercury should produce a measurable change in the point of equilibrium of the beam. The adjustment of this beam may be tedious at first, but is comparatively easy after a little experience is gained.

The position of equilibrium can be read by means of a small scale placed next to the pointed end of the counterweight or it may be observed by reference to the cross hair of a reading telescope focused on it.

The design of a more satisfactory, but more expensive, balance suitable for laboratory or field use is shown in Fig. 3. The balance case and its water jacket are made up of brass tubing and cast metal end pieces or may be cast in one piece as shown in the figure. Aluminum may be used in the construction in order to make the apparatus as light as possible if this is desired, but a heavier form has the advantage of greater stability. Lining the casting with a thin piece of drawn metal tubing may be necessary in order to eliminate any leakage due to microscopic holes in the case casting. The ends of the gas chamber are closed by brass screw caps which have glass windows fastened in with Khotinsky cement. A small, soft rubber washer set in an annular ring in the cap enables one to screw it on to form a gas-tight joint without the

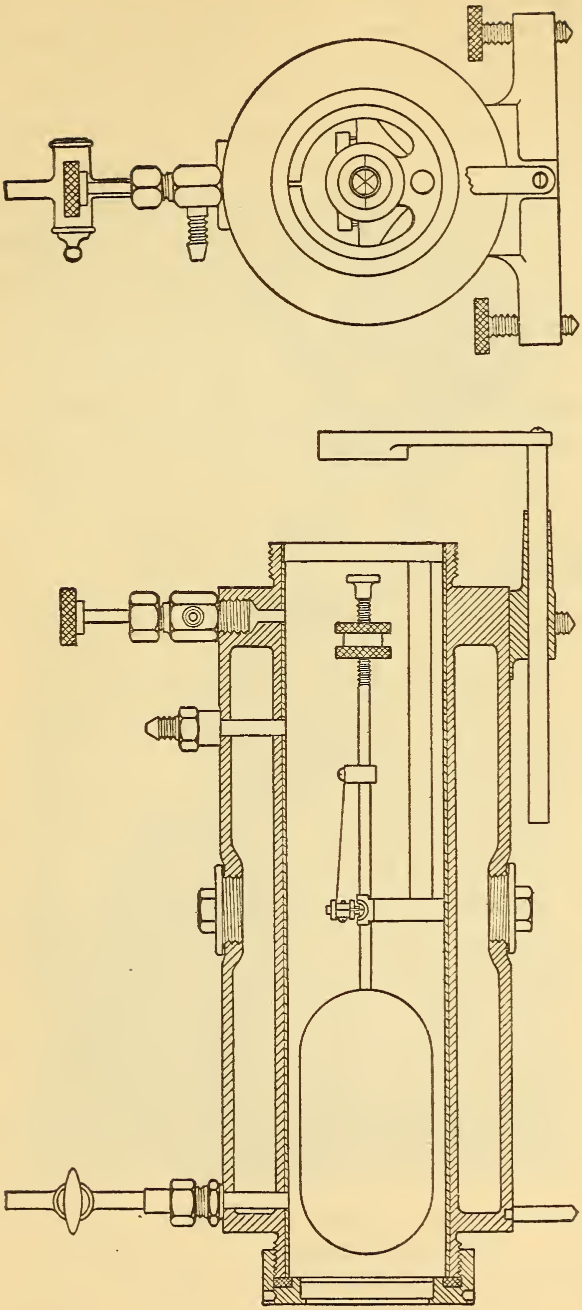

FIG. 3.—*Details of balance construction*

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use of tools. The water jacket is filled or drained through the openings in the top or bottom which are closed by screw plugs.

The glass stopcock (shown at the left end of Fig. 3) cemented into a metal union provides means for introducing gas and air. A small drying tube can be attached to this by means of rubber tubing. At the other end of the balance is shown a needle valve which is used for the fine adjustment of pressures. With this needle valve, which is capable of fine adjustment, any gas in excess of the required pressure can be let out gradually. This eliminates the use of a bulky and inconvenient leveling bottle. Adjacent to the valve is shown a connecter to which is attached by means of a union a small copper tube leading to the U gage. In Fig. 3 the arrangement of these three connections to the gas chamber conforms with that on the portable apparatus illustrated in Fig. 6; but it is preferable that they all be placed at the end of

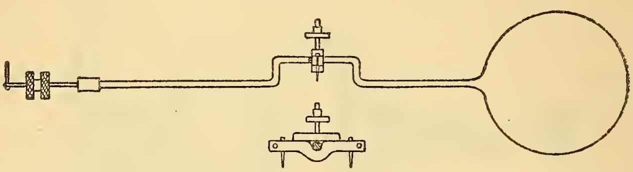

FIG. 5.—*Balance beam, glass and metal form*

the case away from the bulb and made in the same manner as illustrated for the needle valve.

The beam and globe may be made entirely of metal in order to give them the strength desirable for field work, as shown in Figs. 3 and 4, or the weight of the beam can be reduced and its sensibility greatly increased by the use of glass in its construction. Such a beam is shown in Fig. 5. Where careful treatment can be accorded the balance, as in the laboratory, this form has a decided advantage. The beam is made from a glass rod 1.5 to 2 mm in diameter. To one end is sealed a closed glass globe; to the other is cemented a small screw carrying two lock nuts and a slender pointer which turns up to permit observation of the tip against a lighted background. The cross arm is made in two pieces and clamped to the beam. It is necessary with this construction to bend the beam in order to bring the center of gravity below the line of support. The fine adjustment of the sensibility is made by raising or lowering the nut attached to the post at the center of the cross arm. In the all-metal form (see Fig. 4) the globe, which is made of spun brass, is soldered to a bronze tube, the other end

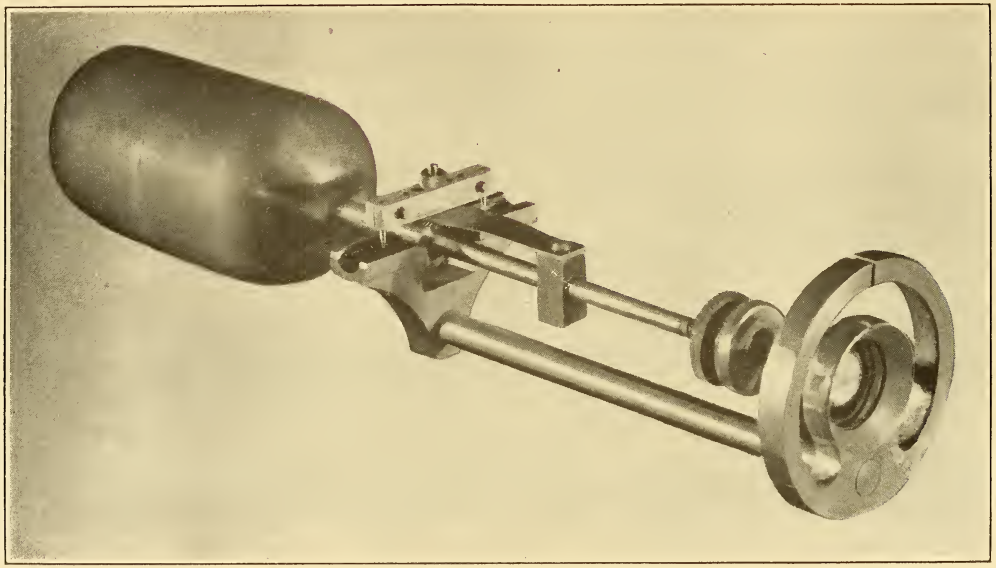

Fig. 4.—*Balance beam, all metal form*

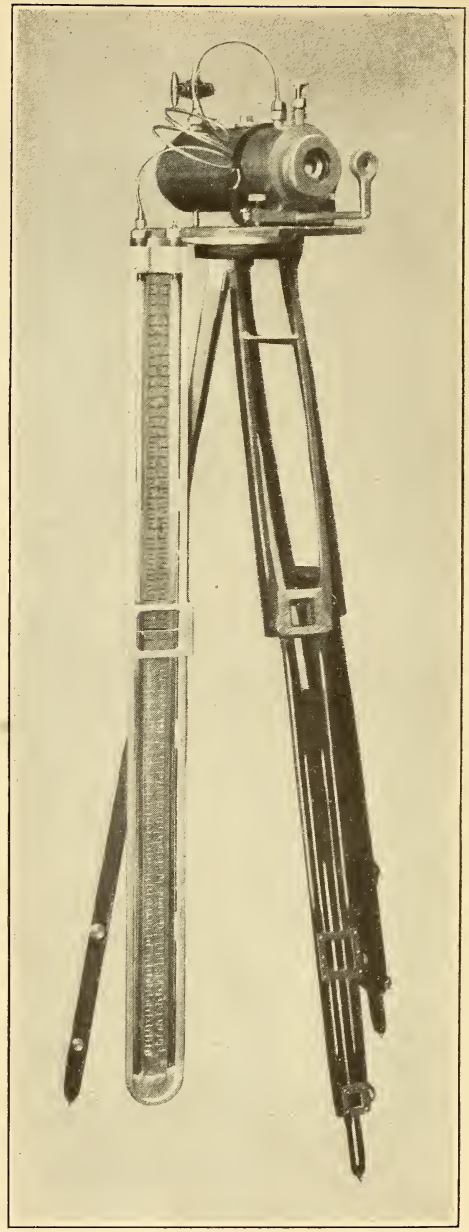

FIG. 6.—*Edwards gas density balance (as developed at the Bureau of Standards)*

of which is threaded to carry the lock nuts used as counterweights. The cross arm is carried on a vertical pillar which is rigidly attached to the beam. A pair of lock nuts hold it rigidly to the pillar and permit changing the center of gravity (and therefore the sensibility) of the beam by raising or lowering the needle points. Any turning of the beam on the pillar is prevented by a strip of metal fastened to both cross arm and beam, which keeps the needles in a plane at right angles with the axis of the beam.

The needles forming the "knife-edge" of the beam are carried on a small metal cross arm and rest in a half cylinder of glass which serves as a bearing surface. The use of a small glass hemisphere as the bearing support for one of the needles was not entirely satisfactory in practice. Although it kept the beam centered in the case, there was a tendency for the needle to bear on the side of the hemisphere unless the bearing support was exactly horizontal, and any imperfection in the bearing surface tended to increase in effect since the needles continually bore on the same small area. With the cylindrical bearing on both sides, no difficulty was experienced in keeping the beam centered except where there was excessive vibration from machinery in which case it might be necessary for the sake of expedience to use the hemispherical bearing. The needles can be removed or their length adjusted by loosening the set screws near the ends of the cross arm. Any sewing needle with a fine sharp point can be used. Phonograph needles are not satisfactory for this purpose unless they are first hardened and sharpened by polishing them in a lathe with an oil stone.

The bearings are cemented into a support, which is held rigidly in place either by cement, as shown in Fig. 2, or by means of a rod attached to a split ring which fits tightly into the end of the case, as shown in Figs. 3 and 4. This ring carries at its center a small glass window across which a line is ruled to serve as a reference line in balancing the beam. A nut on the end of the beam is faced with celluloid and bears a pair of cross lines. A small magnifying glass is mounted in the vertical arm, shown at the end of the apparatus in the side view, but not shown in the end view. The glass can be focused on the reference line and the crossed lines on the end of the beam, making their adjustment to coincidence accurate and convenient. This arrangement is very satisfactory for ordinary work, but in very accurate work a reading telescope permits closer adjustment.

When used in the laboratory, the apparatus is set directly on a table and is leveled by means of two screw feet on the base and the gage is supported by a laboratory stand. For field use the balance has been provided with a tripod support which also carries the U gage. The balance is strapped to a baseboard which screws firmly on the head of the tripod. The balance as set up is shown in Fig. 6. The whole outfit, except the gage, can be packed into a small carrying case (about 17 by 11 by 6 inches over all); a separate case is provided for the gage.

Accessory Apparatus.—The accessory apparatus required for the operation of the balance includes a pressure gage, barometer, vacuum pump, and means of drying the gases.

An ordinary U gage filled with mercury, used in conjunction with a barometer, is the most convenient method of measuring the pressure. This gage should have tubes of at least 5 mm internal diameter in order to reduce errors due to capillarity. The introduction of a short piece of capillary tubing at the bend of the U serves to damp the motion of the mercury column and prevent unnecessary oscillation. This is important because it is highly undesirable to get small globules of mercury into the balance case. For use with the portable outfit the gage shown in Fig. 6 was designed. The glass U is mounted in an aluminum casing and the upper ends are connected to steel caps by cement. These caps are threaded so that the gage can be connected to the balance through a small copper tube attached by means of a union. During transportation the ends of the gage are closed by tightly fitting screw caps, thus making it unnecessary to remove the mercury.

The reading of the position of the mercury meniscus is facilitated by means of a slide bearing a cross line similar to that used on slide rules. A scale ruled on a strip of glass, silvered on the back, and placed behind the gage tubes is very convenient for reading the height of the mercury column. For most work, particularly in the field, a wooden meter stick, carefully graduated, will prove sufficiently accurate. In the laboratory a good mercurial barometer should be used for obtaining the atmospheric pressure, but for field work an aneroid barometer [5] is more convenient. When using an aneroid barometer, it should be noted that the readings are given in millimeters (or inches) of mercury at 0° C, whereas the mercury in the pressure gage

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[5] Information concerning the construction of aneroid barometers, their accuracy, and precautions to be observed in their use, is contained in Bureau of Standards Circular No. 46.

attached to the balance is at the prevailing temperature. For precise work these pressures should be reduced to the same basis before calculating the total pressure.

Filling the apparatus by sweeping the air out with a stream of gas is slow and uncertain; some means of evacuation is therefore necessary. The better the vacuum produced the fewer times the apparatus must be filled and evacuated to insure an uncontaminated sample. For field work a small hand pump is very useful. The pump which has been used with the portable apparatus produces a residual pressure of 160 mm of mercury, making it necessary to fill and empty the apparatus five to six times to insure a satisfactory sample. If a laboratory water-jet pump is available which will reduce the pressure as low as 25 mm, then three evacuations are ample. With a pump reducing to 5 mm or lower, two evacuations serve.

For precise work the use of phosphorus pentoxide in drying the gases is most satisfactory. For most commercial work, however, granulated calcium chloride will give satisfactory drying, and it is much easier to preserve and handle. The carbon dioxide in the air should be removed for very precise work to insure greater uniformity in the density of the standard gas. Sodium hydroxide or soda lime can be used for this purpose.

5. EXPERIMENTAL RESULTS

Standard of Comparison.—As a check upon the accuracy of the specific-gravity balance the densities of several gases were determined by an independent direct-weighing method. The gas to be weighed, after careful drying over phosphorus pentoxide, was introduced into a weighing globe and its pressure and temperature ascertained with the necessary precautions. The weighing globe had a capacity of approximately 1 liter and was closed with a carefully ground stopcock. The temperature of the gas in the globe was regulated by means of a constant temperature water bath and the pressure determined by means of a standardized barometer adjacent to the globe. The pressure of the gas was adjusted to that of the atmosphere through a long tube just before closing the globe. The globe, after careful wiping with a damp cloth, was placed in the balance case and allowed to come to equilibrium with its surroundings. The balance and case were inclosed in a tight copper box and the latter was surrounded by a thin board case so that uniformity of temperature conditions throughout the balance case was assured. Weighings were made, using a counterpoise of the same volume and shape as the weighing globe. The method of swings was employed in weighing and the balance case was not opened after the globe had been placed in it until the globe had reached constant weight.

Knowing the volume of the globe, its weight evacuated, and its weight filled, the weight of a liter of the gas could be calculated. Corrections were applied for the change in volume of the globe upon evacuation and for the buoyancy of the weights. The specific gravity was calculated from the weight so obtained and the weight of a liter of air determined in the same manner.

Results of Tests.—The specific gravities of a number of gases as determined with the laboratory type of balance and with the portable balance are given in the table following. For comparative purposes the specific gravities of these gases as determined by the method of weighing previously described are also given.

Specific Gravity as Determined with Various Balances

Apparatus	Natural gas A	Natural gas B	Carbon dioxide (commercial)	Argon-air mixture
Direct-weighing method	0.644	0.748	1.528	1.168
Beam No. 1, glass with needles set in cement, like Fig. 2, in laboratory-type apparatus	.644		[a] 1.522	1.166
	.645		1.522	
Beam No. 2, like Fig. 5, in laboratory-type apparatus	.644	.747	1.523	1.167
	.644	.747	1.522	1.167
Beam No. 3, all metal, like Fig. 4, in portable-type apparatus	.643	.748		
		.749		
Beam No. 4, duplicate of beam No. 3, in portable-type apparatus	.643	.749		
	.644	.748		

[a] See p. 17.

The accuracy of the results is mainly dependent on the operation of the balance beams. Beam No. 1 was similar to that shown in Fig. 2, and beam No. 2 was equipped with a metal support for the needles and a metal counterweight, as shown in Fig. 5. The operation of beam No. 2 was very satisfactory; it could be adjusted rapidly and it was very sensitive and regular in its swings. In eight trials, during which time the atmospheric pressure was changing slowly, the total pressure at which the beam balanced did not vary more than 1 or 2 parts in 7500. No difficulty was experienced in securing close agreement between duplicates. In these tests the position of the beam was determined by reference to the cross hair of a telescope focused on the pointer at the counterweight end of the beam. In each test the beam was balanced in air at approximately atmospheric pressure.

The results shown for beams Nos. 3 and 4 were obtained with the portable balance, set up on its tripod, as shown in Fig. 6. This support introduced no difficulties that were due to lack of stability. The metal beams were not quite as sensitive and regular in their operation as the glass beams, but they gave results of a satisfactory degree of precision. Because of their greater weight the needles were more likely to lose the fine points necessary for high sensitivity.

Sources of Error.—The possible sources of error in the method are due to the deviations of the gases from Boyle's law, the compressibility of the globe, condensation upon the beam, solid particles adhering to the beam, errors in the pressure reading, and errors due to incomplete purging of the apparatus.

It is evident that if the air and the gas tested do not change in density to the same extent with the same change in pressure, then an error is introduced in the results. The deviations from Boyle's law are in most cases small and can be made neglible for most work by proper choice of the conditions of operation. Where the expansion coefficient of the gas changes considerably with change in pressure, it is better to adjust the beam so that it balances at about atmospheric pressure in the gas instead of in the air. The result will then correspond more closely to the specific gravity at one atmosphere. When required for more accurate work, the necessary correction for variation from Boyle's law can be calculated if the data required are available for the gas in question.[6]

Errors due to change in volume of the globe with change in pressure can not be corrected for and must be prevented by having the globe sufficiently rigid. For changes in pressure of only one-half an atmosphere small glass globes can easily be made satisfactory in this respect without adding excessive weight. The construction of metal globes should be such as to give the greatest rigidity compatible with light weight.

The condensation of gas upon the beam would be of importance only in case easily condensible gases, such as water or hydrocarbon vapor, were present or results of highest possible accuracy were desired. By measuring such gases at atmospheric pressure or less, trouble from this source will be reduced to a minimum. The possibility of error from this source may be eliminated by so constructing the beam that the surface exposed on each arm shall be the same. A. W. Gray [7] accomplished this by attaching as a

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[6] A brief table showing the deviation of certain gases from Boyle's law is found in the Principles of Physical Chemistry by E W. Washburn, p. 31; 1915.

[7] Loc. cit.

counterweight a hollow glass hemisphere of the same diameter as the globe and therefore having the same total surface, internal and external, as the external surface of the globe. For technical work with natural gas it has not been necessary to adopt this refinement of construction.

Care should be taken in purging the apparatus to make sure that the gas chamber contains an uncontaminated sample of gas or air when making a reading. When a gas carrying water vapor is being tested, its compression should be avoided to prevent the possible deposition of water in the balance and connections. In such cases it may be desirable to balance the beam in the gas only when at atmospheric pressure or less as previously explained. Gases carrying water vapor may show considerable deviation from Boyle's law. Only dry air or other pure dry gas should be used for comparison purposes.

Gas introduced into the apparatus should be absolutely free from dust or suspended particles of any kind which might adhere to the globe. Because of the high sensitivity of the balance this is especially important and should be guarded against by filtering the gas through a plug of cotton. When running a series of determinations, the zero point should be checked frequently to make sure that it has not changed because of this or any other cause. For accurate work the points of equilibrium in gas and air should be determined alternately.

The balance might be adjusted so that it balanced at the zero point of its scale in air or some pure gas at a definite pressure and temperature. After this preliminary calibration the specific gravity of any gas could be determined at any time by observing the pressure of the gas required to bring the beam to the same point. From this pressure and the temperature of the gas the specific gravity could be calculated. This procedure is not recommended, however, for the beam being unsymmetrical is likely to have its point of equilibrium changed by temperature changes, or fine particles of dust may adhere to the globe and introduce large errors. Experience has shown that such changes do occur, and this fact casts serious doubt upon the accuracy of results obtained when the apparatus is used in this manner.

Standard Gas.—The specific gravity of a gas is usually referred to dry air free from carbon dioxide, as unity. (See p. 4.) For very precise scientific work this practice is open to the objection that air is not a pure gas and its composition is subject to small changes from time to time and place to place. Where an accuracy no greater than 1 part in 1000 is desired, air is suitable for such use and gives a standard gas of remarkably uniform density, universally available in unlimited quantities.

The researches of Guye, Kovacs, and Wourtzel[8] on the density of air have shown maximum variations of only 7 to 8 parts in 10 000; the maximum deviation from the mean was considerably less. Even the use of air without removing the carbon dioxide does not introduce a large error. The normal carbon dioxide content of the atmosphere is only 3 to 4 parts per 10 000, sometimes rising to 6 to 8 parts in poorly ventilated rooms. The effect of this amount of carbon dioxide can be neglected where an accuracy of only 2 or 3 parts per 1000 is needed.

Where the highest accuracy is desired, pure oxygen or other pure gas can be used as a standard of comparison. Great care, however, should be taken to establish the purity of the standard gas, so that the results obtained may merit the confidence placed in them. Unless the purity of the standard gas is established beyond question there is no advantage in the use of that gas over air, except where a direct comparison is desired with that gas.

Accuracy of Method.—Theoretically the only limits imposed upon the method, provided the balance is sufficiently sensitive, are those due to the deviations of the gases from Boyle's law. These errors can be reduced to a minimum by the method of operation above described, and, generally speaking, they may be neglected where an accuracy of only 1 or 2 parts per 1000 is needed. The laboratory balance tested gave results agreeing with the weighing method within 0.2 per cent, except when used with the carbon dioxide. The estimated correction for the deviations from Boyle's law would bring this result within 0.2 per cent of that by the weighing method. The portable outfit with the metal beam gives results of the same order of accuracy when operated under the most favorable conditions. Obviously, the treatment accorded the balance and the care exercised in its operation will determine largely the accuracy obtained in its use, but it is capable of giving results of sufficient accuracy for most purposes.

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[8] J. de Chim. Phys., **10**, p. 332; 1912.

6. OPERATING DIRECTIONS

The method of operation, together with precautions to be observed, are summarized in the following paragraphs.

The apparatus should be firmly set up so that the beam support is horizontal. This can be determined by tapping the balance case and observing whether or not there is a tendency for the beam to slide to either side. Adjustment of the sensitivity of the beam should be made as described above, if necessary.

The water jacket should be filled with water at room temperature or sufficient time be allowed for the water to come to equilibrium with its surroundings before making a test.

A test for leaks should then be made by reducing the pressure to 200 mm or less and nothing whether the gage shows an appreciable change during a period of five minutes.

The balance case is then filled with dry air by first evacuating and then allowing air to enter through a drying tube attached to the glass stopcock provided for that purpose. If the balance contains gas from a previous determination, this should be flushed out by evacuating and refilling the requisite number of times. Air should be allowed to enter until the pressure is slightly in excess of that necessary to secure a balance. The exact adjustment of the pressure can then be made by withdrawing air through the needle valve, which enables one to change the pressure very gradually or in steps of a few tenths of a millimeter at a time. When equilibrium is reached, the pressure on the U gage is read and the atmospheric pressure is determined from the barometer. The balance case is then filled with the gas whose specific gravity is to be determined. After proper purging the pressure is adjusted in the same manner as with air.

The balance case may be gently tapped in order to start the beam swinging when there is a tendency to stick. If this sticking is serious, the needles should be sharpened and the glass bearing examined for imperfections. If found to be scratched, it should be replaced. Failure to secure constant readings with air or gas is usually due to an imperfection in the needles or bearings. The gage should always be tapped just before reading in order to eliminate the effect of the mercury clinging to the glass.

When it is desired to transport the apparatus, the beam should be removed from the apparatus, but it can remain in position on its support when set up in the laboratory.

The data and calculations obtained in two determinations with the same gas are given below.

	I		II	
Barometric pressure (millimeters)		756.4		756.2
Gage readings with air (millimeters)	396.7 390.3		396.7 390.3	
Pressure (millimeters)		−6.4		−6.4
Total pressure (millimeters)		750.0		749.8
Gage readings with gas (millimeters)	189.3 597.4		189.2 597.7	
Pressure (millimeters)		+408.1		+408.5
Total pressure (millimeters)		1164.5		1164.7
Specific gravity	$\frac{750.0}{1164.5}=0.6441$		$\frac{749.8}{1164.7}=0.6438$	

7. SUMMARY

The apparatus described provides a quick and accurate means of determining gas density. A form of balance-beam support has been devised which gives high sensibility. The needles which replace the knife-edge are easily adjustable and, in contrast with the metal or quartz knife-edge usually used, can be obtained almost anywhere, are inexpensive, and can be replaced as often as necessary. The success obtained in the use of this apparatus is mainly due to the high sensibility afforded by this means of support. It is necessary to remove the beam from the case only when it is desired to transport it. No leveling bottle is necessary in adjusting the gas pressure within the balance, this being accomplished by means of a needle valve which affords precise control. The portable outfit combines lightness of weight, convenience in use, and durability without any great sacrifice of accuracy. No preliminary calibration of the apparatus is necessary.

WASHINGTON, November 8, 1916.

APPENDIX

WEIGHT OF A NORMAL LITER OF SOME GASES

The normal liter of a gas is that quantity having a volume of 1 liter when measured at a temperature of 0° C and 760 mm pressure of mercury at standard gravity.

Gas	Formula	Weight of normal liter
		Grams
Hydrogen [a]	H_2	0.08987
Oxygen [b]	O_2	1.42905
Nitrogen [c]	N_2	1.2507
Argon [c]	A	1.7809
Carbon monoxide [c]	CO	1.2504
Carbon dioxide [c]	CO_2	1.9768
Methane [d]	CH_4	.7168
Ethane [d]	C_2H_6	1.3562
Propane [e]	C_3H_8	2.0196
Acetylene [f]	C_2H_2	1.1791
Ethylene [f]	C_2H_4	1.2609
Nitrous oxide [c]	N_2O	1.9777
Ammonia [c]	NH_3	.7708
Sulphur dioxide [c]	SO_2	2.9266
Air [g]	....	1.2930

[a] Morley, Smithsonian Contributions to Knowledge, 1895.
[b] Germann, Jour. of Phys. Chem., 19, p. 437; 1915.
[c] Guye, Jour. Chim. phys., 5, p. 203; 1907. (Contains a review of the best density determinations summarized on the basis of the normal liter. Most probable value for each gas indicated.)
[d] Baume and Perrot, Jour. Chim. phys., 7, p. 369; 1909.
[e] Timmermans, Compt. rend., 158, p. 789; 1914.
[f] Stahrfoss, Arch. Sc. phys. et nat., IV, 28, p. 384; 1909.
[g] Guye, Kovacs, Wourtzel, Jour. Chim. phys., 10. p. 332; 1912.