PRACTICAL TESTING OF GAS AND GAS METERS

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PREFACE.

The author has received a large number of requests, at different times and from various men connected with the gas industry, for information regarding the methods, apparatus and chemicals used in the testing of gas. The first thought was, naturally, to refer the inquirer to some standard work where he would find answers to all of his questions. Careful investigation, however, failed to reveal such a work. The nearest approach was Abady's Gas Analyst's Manual; but this was written several years ago, and deals with the subject from the English standpoint. There are very many points of difference between the procedure on this side of the water and that abroad, and, so far as the writer knows, no book, written by an American and dealing purely with American methods of gas manufacture and testing and thoroughly up to date, is available to-day. It is hoped that this volume may fulfill these requirements.

No attempt has been made to write a treatise on the manufacture and distribution of gas; these topics have been widely and ably covered by such experts as King, Newbigging, Butterfield, Latta, and many others. Only where the methods of manufacture were intimately connected with the interpretation of chemical or other tests have the former been touched upon. The writer's chief aim has been to explain clearly, simply and fully such tests as would be of practical service to the gas manager, chemist or photometrist, and to make such comments and suggestions as might guide him in his choice of apparatus or process and assist him to secure accurate and useful results therewith. For this reason all chemical processes, reactions and calculations have been explained at a length which may seem wearisome to the expert chemist. It is hoped, however, that even he will find in this book a compilation of processes and forms of apparatus which may save much tiresome searching of journals and text-books. Many of the later forms of calorimeters, for example, have been described in different technical journals during 1908, and a brief account of these, together with the original reference, is given in the chapter on calorimetry.

To the state or municipal inspector we trust that the work will appeal by giving him a broader view of what is being done in the field of inspection in other states. As the writer knows from his own experience, too often is an inspector so tied down by restrictions, so hampered by routine work, and so near-sighted by reason of the limited field of his vision, that he not only makes no personal progress toward broad-mindedness, but becomes an actual drag on the wheels of progress.

To the student, whether in the college or commencing work for a gas company, it is trusted that this book may prove a help by leading him by easy journeys over the rather troublesome roads of photometry, calorimetry and the chemical analysis of gas.

Finally, at the risk of repetition, let it be said that the chief aim of the writer has been to put before managers and others who have had no chemical training and to whom the words "calorimetry" and "photometry" mean nought save routine tests but little understood; whose principal ambition is to manage their plants economically, and at the same time satisfactorily in other ways; the aim, I say, is to put before these men the subjects connected with gas testing so plainly that what has heretofore been but dry bones to them may become a living reality, which shall aid them in their present positions and at the same time open up greater possibilities for the future.

It seems necessary for the writer to state that he alone is responsible for the opinions expressed in this volume, and that they are not in any sense to be taken as an index of the ideas or policy of the Public Service Commission, by which he is employed. Neither is it to be necessarily assumed that the writer will recommend his beliefs for the Commission to put into practice, since many things are both possible and desirable in the scientific and business world which could not, at least in the present age, be carried out by governmental bodies.

The author is indebted to D. McDonald & Company for the excellent cut of the standard cubic foot, and to the American Meter Company for their kind loan of cuts of the Siphon Pressure Gauge, the Arch Gauge, and meter prover.

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ERRATA.

p. 86. Symbol H_2O_2 should be H_2O.

p. 89, line 17. After word "flask" add "add barium chloride in excess and filter."

p. 146, line 14. After words "2.14 grains hydrochloric acid" add "per liter."

p. 273, line 20. After word "inches" insert "barometric."

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PART I.

PHOTOMETRY.

PRACTICAL TESTING OF GAS AND GAS METERS

PART I.

PHOTOMETRY.

CHAPTER I.

PHOTOMETER AND ACCESSORIES.

THE selection of a suitable location for the photometer room and the proper construction and equipment of the latter are matters of primary and vital importance. It is the custom with a large number of gas companies to locate the photometer at the works in order that constant watch may be kept over the output of the plant. The works foreman, or some competent man, is detailed to take the candlepower at stated intervals, or, in specific cases, at certain points in each run; and from his results the superintendent is able to determine whether the heats have been right, whether the run has been too long or short, and in general whether the make has been conducted to the best advantage. Moreover, the gasmaker himself is thus informed of the quality of the product, and consequently works with more intelligence and certainty.

There are reasons, however, which in certain cases would point to some location for the photometer room other than at the works. In the first place it is not always well to have the candlepower taken by a man who is directly interested in the result, as is the case with nearly all men at the works. However honest the employee may be, if he has formed an opinion that the gas is of a certain quality, he is liable to allow his judgment to influence the test, and only those who are familiar with such work know how easy it is to move the sight box a fraction of an inch one way or the other and believe that it makes no practical difference with the results.

Moreover, the candlepower determination involves certain refinements in execution and calculation which are more in the province of an educated man, and many companies prefer for this reason to intrust the test to some member of their office force.

Again, the gas at the works is not of the same quality as that delivered to the consumer. This is especially true in the winter time, when it is not uncommon to find a loss of from one to three candlepower between the works and a point at a distance of a mile therefrom. This is of peculiar significance in states and cities where the company is under some form of governmental supervision, for in all such cases the test of the inspector will be made at a distance varying from one-quarter of a mile to one and one-half miles from the works of the company. The one-mile limit so frequently set has its origin in the fact that experiments have shown that as a rule after the gas has traveled one mile in the mains the loss in candlepower has practically attained a maximum.

It has been suggested that allowance be made for this by assuming a definite loss of candlepower and then making the gas at the works sufficiently rich to compensate for such loss. The objections to such procedure are twofold. First, it is impossible to assume any definite loss, since the latter depends not only on the temperature in the mains, but also on other factors connected with the composition of the gas which it is not feasible to accurately regulate; and second, that a sudden rise in external temperature might leave the gas so rich as to be a menace to Welsbach mantles and to ceilings.

A more satisfactory way to overcome these difficulties would seem to be to locate the photometer at the office of the company, when such office is over a quarter of a mile from the works; to instruct some one of the office force in the science of photometry, and then from time to time notify the works by telephone of the quality of gas which is being delivered at the office.

Having determined upon the site for the photometer room, the next step is to see that the latter is properly constructed and equipped. As in most cases it is impracticable to build a room especially for photometric work, the problem becomes one of alterations in existing conditions; and to understand what these should be, it is only necessary to enumerate the qualifications desirable in such a room.

The ventilation may be said to be the first and most important feature, since neither gas, candles nor standard lamp will burn properly or at their maximum efficiency without an abundant supply of pure air. To this end a room should be selected which is not less than 15 feet long, 9 feet wide, and 12 feet high. The best ventilation is secured by an opening near the floor for the admission of the fresh air, and one in or near the ceiling for the exit of the impure air. The inlets should have a total area of 10 square feet for a room of the size above mentioned; they should extend around the entire room, and should be so constructed as to allow of a free inrush of air without occasioning drafts. The importance of proper ventilation cannot be overestimated; those who have had experience with the use of candles in a close and impure atmosphere will appreciate this fact, for the effect on the candles is visible to the naked eye. With other standards and with gas flames the result is similar, though less marked, and in the appendix will be found formulæ for correcting for the amount of moisture, carbonic acid, etc., in the atmosphere. These corrections are, of course, not absolute, and it must not be assumed that, by the use of them, the necessity of proper ventilation is obviated.

It is well, whenever possible, to select a room which has no wall exposed to the outside air, or to conditions which will make its temperature different from that of the other walls, since such conditions give rise to drafts. Some arrangement should be made whereby the temperature of the room may be kept constant at, say, 70 degrees, throughout the entire year. This is of vital importance for two reasons. In the first place, it has been shown by Jenkins and others that the candlepower of a gas increases with increase of temperature, and a table illustrating this fact will be found in the appendix. This will seem perfectly natural if we remember the effect produced in a burner by preheating the air supply thereof. The second reason is still more important, but somewhat less easy of comprehension. The illuminating value of gas is largely derived from certain hydrocarbon vapors which are more or less condensible. If a gas carrying such vapors passes through a cold pipe, condensation takes place, and the hydrocarbons are deposited in the pipe and thus lost to the gas. If now the temperature of this same pipe should suddenly rise, the condensed vapors will be picked up by the gas in passing, and thus cause a temporary increase in candlepower. These statements apply with equal truth to the photometer meter, because the ability of the water in that meter to absorb vapors decreases with increase of temperature. Thus it is apparent that an even temperature is a necessity for accurate work, and this can be secured if the photometer room is built entirely within a second and larger room which is itself heated by hot air and kept at as uniform a temperature as possible. It is perhaps needless to say that no heating apparatus of any kind should be placed near the photometer.

It has been the general custom, where an open-bar photometer was to be used, to paint the room black. Recent experiments by the National Bureau of Standards show that such procedure is not essential; but it will doubtless make the photometric work easier to the average operator if as much external light and reflection as possible are excluded from the eye.

Piping. The gas to be tested should come as directly as possible from the main through a pipe of not less than one-half inch diameter, and should not be allowed to pass through any meter before reaching the photometer. It is well to cover the pipe with some non-conducting material, such as magnesia pipe covering, in order to prevent changes of temperature therein.

If the gas is not to be burned continuously, it will be found advantageous to provide a blow-off whereby the gas which has

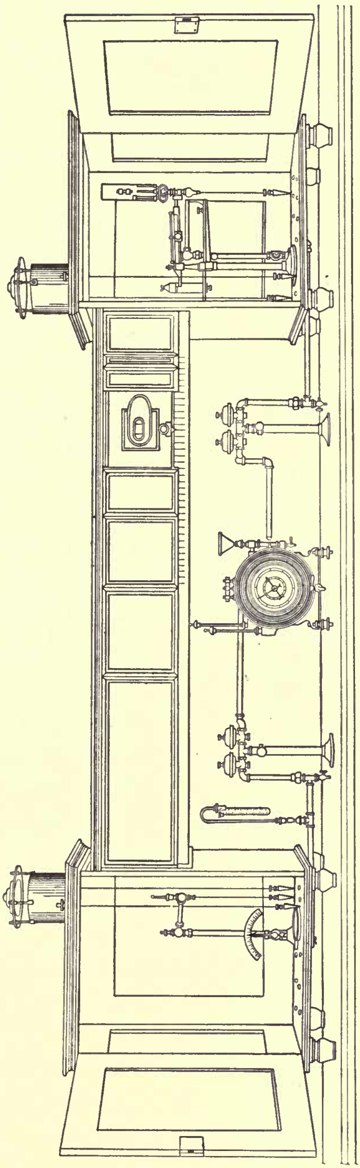

Fig. 1. Closed-bar Photometer.

been standing in the pipe may be quickly exhausted. This may be accomplished by tapping the pipe just before the photometer meter, inserting a T and running a pipe therefrom through the outer wall of the building, proper precautions being taken to see that the gas escaping from this blow-off causes no injury or inconvenience to anyone. By this simple expedient, gas fresh from the main can be obtained in five minutes, while to secure the same result by burning the gas in the photometer might take half an hour.

Stationary Photometers. For practical use in this country there are but two general styles of stationary photometer, the open and the closed bar. Each has its strong points and its defects, its advocates and its enemies. The closed-bar photometer as manufactured by the American Meter Company (Fig. 1) consists essentially of a rectangular tube or gallery 5 feet 10 inches long, $13\frac{1}{4}$ inches wide by 12 inches deep, which at either end is bolted to a cabinet 2 feet $9\frac{1}{2}$ inches high, 24 inches wide and 18 inches deep. The front of the gallery is composed of overlapping, interchangeable panels, thus excluding all light from the interior, and at the same time permitting the use of the sight box in different parts of the gallery. In one of the cabinets is placed the standard and in the other the gas pillar and burner. Ventilation is secured through 15 holes, 1½ inches in diameter, in the bottom of each chamber, and the products of combustion and impure air are conveyed away through brass chimneys 6 inches in diameter and 4½ inches high. On the lower front edge of the gallery is placed a graduated scale so constructed that a direct reading of candlepower is possible. The sight box runs on a track within the gallery, and to the front of it is attached a wooden shield which passes behind the gallery panels. The interior of the gallery is painted a dull black and fitted with shields to prevent reflection. The whole apparatus stands on a table in the center of which is placed the meter and to the left of the latter the governor and pressure gauge.

The advantages claimed for this style of photometer are that it is somewhat cheaper than the open bar; that it does not require an entirely dark room for its use, and that the flames of the gas and standard are less subject to drafts. On the other hand, it is urged that the ventilation is not as satisfactory as with the open bar, that there is danger of incorrect results due to reflections in the interior of the gallery, and that there is liable to be a considerable change in temperature within the chambers after long continued burning of the gas or standard.

The open-bar photometer, known as the Suggs-Letheby, differs from the above in that neither gas, standard nor bar is inclosed. It consists in its essential features of a bar (Fig. 2), extending from the gas to the standard, on which the sight box runs. The scale on this bar is graduated in a manner similar to the one on the closed bar, and screens are set at definite intervals to protect against reflections. From the fact that both the gas and the standard are uninclosed, and burn in the open air, it will be seen that the ventilation is better than with the closed bar, and the distance of the sight box from the table and wall prevents in large measure the reflection, which is one of the objectionable features of the latter instrument. The cost of the Letheby is slightly greater than that of the closed-bar photometer of similar size, and the former requires a separate and special room for its use; but if the purchaser is not compelled to consider the financial side of the question, an open-bar photometer should be installed. For smaller companies which cannot easily secure the necessary room, however, the closed-bar photometer will be found to give excellent satisfaction, and the results obtained therefrom will be more than sufficiently accurate for all practical purposes. The Improved Letheby photometer may be secured as a 60-inch, 80-inch, or 100-inch bar, but the 60-inch form is recommended by the Committee of the American Gas Institute[1] both because "being shorter it requires less space, and because the two light sources usually compared in plain gas photometry are at such relative distances from the disc as to give it the best theoretical illumination for easily comparing the star or other figure on the disc." The divisions on the 60-inch scale are, however, necessarily smaller than those of the 80-inch or 100-inch bars, and consequently more difficult to read accurately. Moreover, a slight movement of the sight box on the 60-inch bar causes the pointer to cover

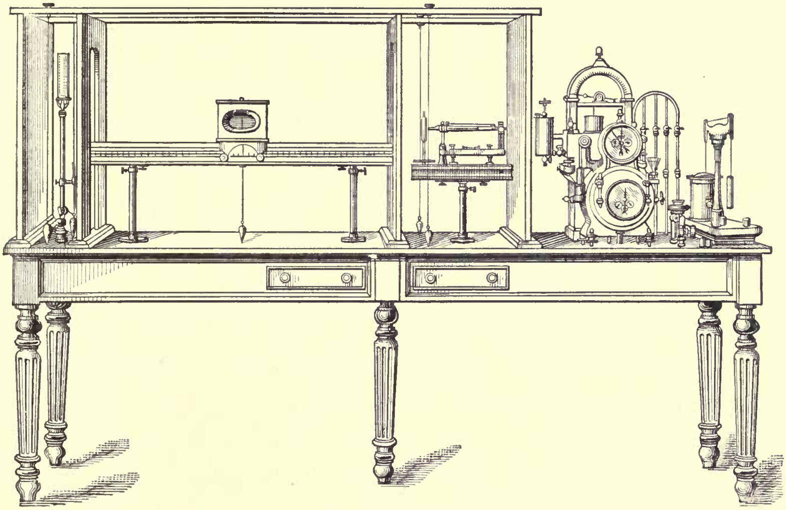

Fig. 2. Suggs-Letheby Photometer.

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[1] Proceedings of American Gas Institute, October, 1907.

more spaces than a similar movement would cause with the longer bars, and, therefore, a small error of reading makes less difference with the latter form. With closed-bar photometers the author believes that the 80-inch type is the one most generally used.

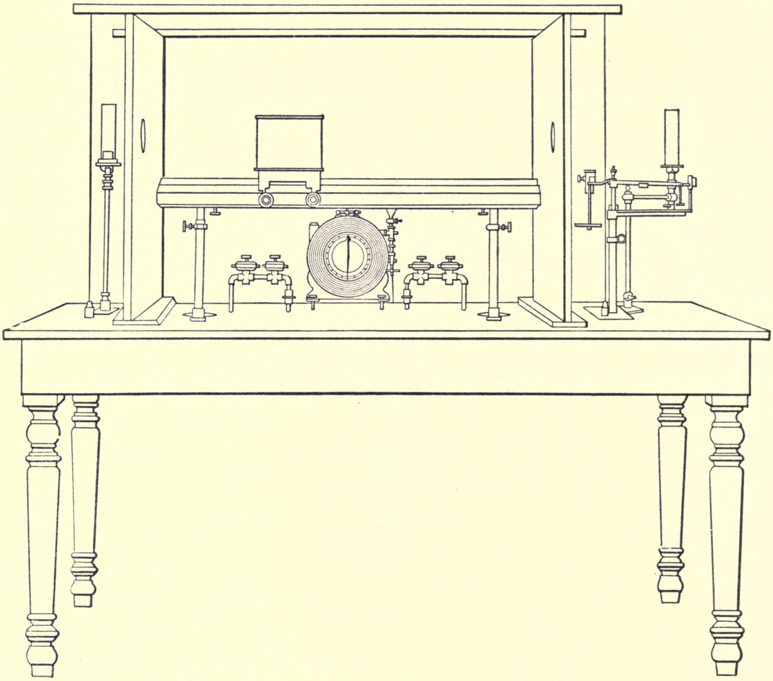

Fig. 3. Standard Bar Photometer, Style B.

The cost of a photometer is always a matter of interest to a prospective purchaser, and for the benefit of such the prices offered by the American Meter Company of New York City are herewith given as samples:

80-in. closed-bar mahogany photometer complete	$260.00 net
60-in. open-bar (style B) photometer complete	275.00 net
100-in. open-bar (style B) photometer complete	300.00 net
60-in. Sugg-Letheby photometer complete	550.00 net
100-in. Sugg-Letheby photometer complete	600.00 net

A word as to the table photometer in use in London may not be out of place at this time. One objection to all forms of bar photometers is that the standard is used at varying distances from the disc, and the nearer the standard is to the latter, the greater is the light area of its flame at the disc. Now, in securing a value for the standard, the disc was in a certain definite position which is almost certain to be different from that at which it stands when the candlepower of the gas is measured. This objection has been overcome with the Table Photometer by adopting fixed positions for standard, disc and light to be tested, and gaining equality of illumination by varying the rate of flow of the gas. This method, however, was found to be unsatisfactory, because it could not be applied to gases which differed widely in candlepower, nor to both Argand and flat-flame burners; so the Notification of the Gas Referees for 1907 recommends moving the flame under test. This does not seem desirable, because one of the first principles of photometry is that all flames should be kept as quiet as possible. The Table Photometer has been carefully tested in this country, and the consensus of opinion seems to be that, in its present form, it is not the equal of the bar photometer in accuracy and ease of manipulation.

Portable Photometer. For the use of inspectors who are obliged to test gas in places where there is no stationary photometer, and for the convenience of gas companies operating plants in more than one locality, it has been found necessary to devise some form of photometer which could be easily transported from place to place and which should be sufficiently accurate for practical purposes. Such instruments are now in use in New York and Massachusetts, as well as with some of the larger gas companies, and for the benefit of others who may feel the need of these, a somewhat detailed description of the one in use by the Public Service Commission, Second District, of New York, with the directions for its use, is now given.

The photometer in question was constructed by the American Meter Company of New York, and cost complete about $275.00. It consists of an outside box or trunk in which is packed the bar, the meter, tubing and all accessories. The trunk is a rectangular box of $\frac{3}{4}$-inch birch, 44 inches long by $10\frac{3}{4}$ inches wide by $16\frac{3}{4}$ inches deep on the outside. It is constructed of three-ply material to prevent warping and is surrounded by four bands of wood screwed to the sides and 9½ inches apart.

The corners are protected by steel pieces which are riveted, and one end is strengthened inside and out by a sheet of aluminum which is also riveted on. This end, which when the photometer is set up, is to be uppermost, is pierced by a hole 4 inches in diameter, which when the trunk is packed for shipment is closed by a hinged door opening inwards and which is also reënforced by an aluminum plate.

The lid is held in place by four trunk locks, two on either side and near the ends, and by two hasps in the center. On the outside of the lid, and 6⅛ inches from one end, an aluminum plate 8¼ inches by 6⅞ inches is set in, which contains four keyhole-shaped openings or sockets; these engage with four brass projections on the end of the bar and serve to support the latter while in operation. A similar plate is set into the bottom of the trunk, and immediately behind this is a door opening inwards.

In the interior the trunk is divided into two compartments by a wooden partition 1 inch thick which is held in place by angle irons. The smaller of these divisions, 9½ inches by 9 inches, serves as packing space for the meter, and is therefore well cushioned on sides and bottom with rubber, while a large rubber pad on the inside of the lid rests on top of the meter and holds it in place. In the corners around the meter, or coiled on top thereof, are packed the tubing and the curtain for the gas end. The other compartment, occupying the remainder of the interior, contains the bar, which fits tightly enough to need no further protection. This bar is of ⅜-inch material, is 60¼ inches by 8 inches by 7 inches outside dimensions, and is hinged at the center so that one-half may be folded over on the other.

When extended to its full length the parts are held together by a brass pin passing through a narrow but heavy strip of brass, which projects from the one-half, and then into a metallic socket in the other half. The ends of the bar are protected by aluminum plates on which set the locks which engage with the trunk and cover. The edges are bound with aluminum, and plates of the same metal strengthen the portion of the bar around the center joint and surround each end for a space of 4 inches.

Ten inches from one end are two circular holes 4 inches in diameter, one in the bottom and the other directly above it in the top of the bar; these serve for the ventilation of the candles and supply room for the swing of the balance. On the side of the bar between these openings is a door 8 inches by 4 inches through which the balance and candles are reached and attended to.

Within the bar are packed the chimney, balance, trumpet tube, sight box, and burner board. The chimney is contained in a light metal case, from one end of which projects a pin and from the other a strip of metal perforated by a screw hole. The pin engages in a socket at the end of the bar and just behind the candle balance, while the strip is firmly screwed down with a thumb nut.

The base of the balance is permanently fastened in place in the center of the bar and just beyond the circular holes. The beam is perforated in the center of the semicircle formed by the arms carrying the knife edges, and through this opening a thumb nut fastens the end to the top of the bar while the tines of the pointer pass, one on either side of a stationary pin. The balance pan and candle holder are secured in position above the chimney holder by a thumb nut with a very broad surface which passes through a hole in the pan and into a socket in the woodwork.

The burner board is fastened by thumb nuts to the bottom of the bar underneath the beam of the balance. The top of the sight box is formed of a long plate of tin which projects some six inches beyond the working parts of the box. Through each of these projections a hole is bored three-quarters of an inch in diameter, and nuts with very broad bearing surfaces pass through these and fasten the sight box to the top of the bar. The trumpet tube is pierced by a small hole near the rim, and a thumb nut holds this in place near the center of the bar. The interior of the entire gallery is lined with black velvet, and the exterior, the trunk, meter, burner board, balance and all metallic parts are painted a dull, non-reflecting black.

The meter is a dry one and is classed as a two-light; it is cylindrical in form and has three diaphragms. The inlet and outlet are provided with valves especially adapted for making connections with rubber tubing. The top is not soldered but is closed by a large plate which is screwed on, the joint being made tight by a rubber gasket. This is a great convenience, as it is often necessary to clean the valves and occasionally to adjust the meter. The dial is 4 inches in diameter and is divided into thousandths of a foot. The inlet and outlet tubes are within the case, thus obviating the danger of damage during transit. An opening in the top of the meter 5 inches deep, and of course not connecting with the interior, permits the insertion of a thermometer.

The balance is of the type commonly used in this country with stationary photometers, the upright being omitted, and the piece bearing the sockets for the knife edges being shortened to meet the requirements of its position.

The sight box is of the customary variety, and is provided with a bevel gear for rotating the disc. The trumpet tube has a broad base, in the corners of which are four holes which slip over nuts on the top plate of the sight box; the tightening of these nuts then holds the tube in position.

The burner board is a piece of wood 8 inches by 3 inches on which three burners may be screwed. The central one has a broad base and an arm for connecting with the gas supply; the others are merely for the transportation of other burners. The entire apparatus weighs 125 pounds, and may be packed or unpacked and set up in three minutes.

In preparing the photometer for use the lid is first removed and set up, with aluminum plate out, against some solid object, as a desk or the wall of a room. The bar is then lifted from the trunk, which is set on end at a distance from the lid about equal to the total length of the bar. The balance, chimney and other accessories are unscrewed and removed from the interior. The sight box is placed in position and the trumpet tube attached thereto; the halves of the bar are now swung together and clamped in place. The proper end is then fastened to the plate on the lid by means of the socket joint already mentioned, and the other end is similarly secured to the trunk. (Fig. 4.)

The burner board is next set up within the trunk; the constant position of this is secured by two pins on either side of the inside walls, which engage with holes in two small brass plates projecting on either side of the burner board. These pins are placed at such a point that, with the board in position and the burner thereon, the center of the flame will be 60 inches from the center of the candle flames.

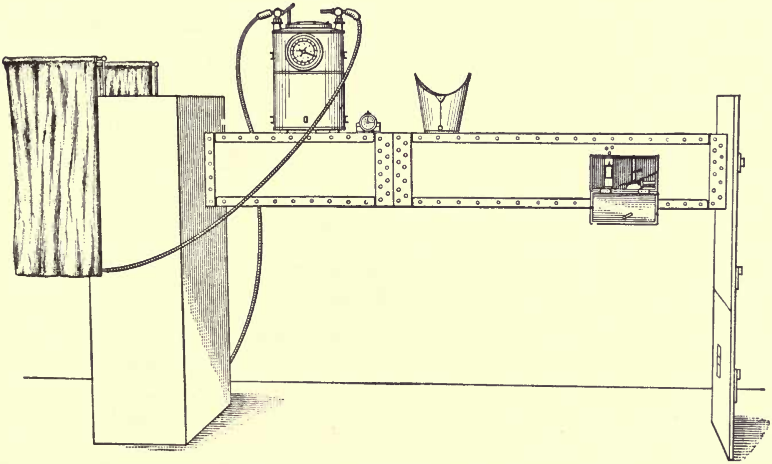

Fig. 4. Portable Photometer.

The meter is now placed on top of the bar and connected with the gas supply and to the burner by flexible metallic tubing, The chimney is removed from its case, cleaned and placed on the burner. The doors in the top of the trunk and the one leading to the bar are opened. Then light the gas and allow it to burn while finishing the preparation of the rest of the photometer.

Insert the thermometer in the meter, and if an aneroid barometer is used, open and place it on the bar near the meter. The balance is next to be set up within the photometer and adjusted, and the candles lighted. The alignment of the latter is accomplished by means of two marks fixed on the sides of the bar, one in front of and one behind the candles. As the beam of the balance projects far within the bar and consequently the scale is hidden from view, some other arrangement had to be made for noting the swing of the balance. This was very satisfactorily settled by the use of a pointer about 5 inches long fastened perpendicularly to the balance at a point above the knife edges. As the balance swings, this pointer passes a thin line across a small open space joining the ventilation hole, and thus not only may the end point be very accurately read, but also the movements of the balance may be watched without stooping. While making readings the door in front of the candles is closed to prevent drafts, and a black velvet curtain is hung behind the gas flame to exclude external light and prevent reflection.

The actual operation of testing is performed in exactly the same manner as with a stationary photometer, but in making the corrections there are one or two changes. The correction for temperature is, with a dry meter, 1 per cent for every 5 degrees, instead of 1 per cent for 4 degrees, as with the wet meter; and a correction must be made for the error of the meter. The latter should be tested as often as possible against a standard wet meter, and the percentage error thus found carried into the candlepower calculations. Thus, if the meter is found to be slow, it means that it is registering less gas than is actually passing. Then the candlepower as found is higher than it should be, since it is obtained by burning more gas than is shown by the dial of the meter. Hence for a slow meter the percentage correction for error of the meter will be minus, and for a fast meter, plus. The reason for the change in the temperature correction is that with a dry meter the tension of aqueous vapor does not enter into the question as it does with a wet meter.

There are several unsatisfactory features connected with the instrument just described, most of which may, however, be easily eliminated. In the first place the base on which the photometer rests while in use is too narrow, rendering it unstable and peculiarly susceptible to jarring. The apparatus is rather heavy to manage, and because of this and of the narrowness of the ends of the trunk, it is severely handled by baggagemen. The outside of the box is thus often in need of repairs, while the contents, with the exception of the meter, are very seldom seriously injured.

The sight box is of necessity set close to the bottom of the bar, and thus the readings are liable to be affected by reflection from dust along the bed of the photometer. Moreover, the bar is so constructed that it is somewhat difficult to keep the interior clean, although this may and should be done. There is no governor or pressure gauge provided, and these, of course, are desirable, although not absolutely essential.

The above objections, together with three others, are applied by the American Gas Institute to portable photometers in general. The three additional reasons for complaint are as follows: (1) The photometer is closed and is thus supplied with vitiated air; also under this condition such air as the flames get is supplied through small crevices and accompanied by drafts. (2) Rubber tubing is often used which reduces the candlepower. (3) The photometer is usually set up in any place that comes handy, and hence has no proper ventilation, temperature or protection against drafts.

With the portable instrument above described there is no rubber tubing used, its place being taken by a flexible metallic tubing made of iron and so packed with rubber that the latter never comes in contact with the gas. This is a very essential point, as experiments by the writer have shown a loss of candlepower reaching as high as 14 per cent, due to the use of rubber tubing. Such loss is by no means confined to old samples of tubing, for several lengths of new and expensive rubber hose showed a similar loss. The metallic tubing may be coiled in about the same space that would be occupied by the rubber, and thus far has given excellent satisfaction. It may be obtained of the New York Flexible Metallic Hose and Tubing Company of New York City, at a price of about nine cents a foot.

Objection No. 1, regarding vitiated air, does not seem to apply to the instrument described, as the air supply is more than sufficient for both gas and candles; and considering the size of the openings for entering air and escaping products of combustion, it can hardly be said that the air is supplied through small crevices and consequently accompanied by drafts. Objection No. 3 would seem to be more a fault of the operator than of the instrument, but it remains a serious charge against the use of portable photometers in general, and one which will not be easily corrected.

Mr. Charles D. Jenkins, State Gas Inspector of Massachusetts, who has used and studied the portable photometer for twenty-five years, has recently devised a new one which, while following the same general lines as the old type, has many improvements which tend to diminish error and to render the operation and transportation more easy and safe.

The outer trunk is of leatheroid, well reënforced by steel. Inside of this, and of nearly the same size, is a box of one-half-inch material in which are packed the bar, meter and accessories.

The system of retaining the smaller articles in place is by straps, rather than by thumb nuts, but there is some question whether this is any improvement. The inner box is 34 inches by 16¾ inches by 12¾ inches, thus affording a much broader and more stable base for the photometer when set up. The purpose of the leatheroid case is to protect the apparatus from jarring during shipment and to save repairs on the external part. At the same time, and because of this added protection, it has been possible to reduce the weight of the whole apparatus considerably, by using thinner stock and little or no steel, or other reënforcements.

The burner board, instead of setting within the trunk, is held by two steel arms, which project a fixed distance beyond the trunk. This tends to improve the ventilation, as does also a circular hole, which is cut in the interior box below its junction with the bar, and less than a foot above the floor. It is quite possible that this opening may give rise to drafts, but thus far such an effect has not been noticed. The ventilator above the candles is covered by a cap exactly similar to those placed on closed-bar stationary photometers. While the air supply for the flames is not at all diminished by this device, any possibility of external light entering the bar at this point is precluded.

The bar, instead of breaking in the center, does so at a point about 2 feet and 8 inches from the end supported by the cover. This is a distinct improvement, as it removes the joint beyond reach of the sight box, and in the older forms the sliding of the sight box over the joint gave rise to a jar which invariably caused flickering of the candles.

A similar instrument is being constructed for use in New York State, and while the cost is about $25 greater than that of the preceding form, it is believed that both time and money will be saved in the long run, while the accuracy and efficiency are doubtless somewhat increased.

Various other forms of photometers have been devised, some of which are in use to-day; and a few types are briefly described below, for while most of these instruments are intended more for scientific than for practical use, the principles involved may at any time be applied to the manufacture of a photometer which shall fulfill all requirements and be satisfactory for general use.

The Wild Flicker photometer differs from the ordinary photometer in that the disc, which is thin, circular, and made of some white material, one-half being opaque and reflecting, while the other half is translucent and diffusing, revolves on its center and is viewed by the agency of a mirror and telescope. As the disc revolves an unequal illumination of the two halves will cause a distinct flicker to be seen every time the line separating the halves crosses the field of vision, and this flicker will totally disappear when the halves are equally illuminated. The disc is made to revolve by the use of a small motor.

Selenium photometers depend for their action on the fact that selenium conducts electricity to a degree dependent on the intensity of the illumination thrown upon it. An instrument embodying this principle is manufactured at the Elektromechanische Werkstätte of Mainz. The selenium cell is placed between the two sources of light which are being compared, and is connected in series with a battery and a milli-ampere meter. When both sides of the cell are equally illuminated there is no current.[1] Whether

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[1] Journal of the American Chemical Society Abstracts, March 20, 1908.

this is the best of the selenium photometers or not, the author is unable to say, as these instruments are as yet rare; but it will serve to give some idea of their general action. It is doubtful whether they will ever become of practical importance, for the sensitiveness of selenium to light seems to be variable and uncertain, and the cells subject to deterioration.[1]

A type of grating photometer has recently been devised which is claimed to be extremely accurate. The object used to cast a shadow is a grating of narrow mesh, the wires of which are inclined at angles of 45 degrees to the vertical. The two sources of light to be compared are disposed on the same horizontal plane on the one side of the vertically supported grating, while on the other side is a screen of matt glass. The lights therefore cast a pair of images of the grating on the screen, and the distance between screen and grating is so arranged that the individual bars of shadow are at the same distance apart. The angles at which the light rays impinge on the grating and the screen are also so arranged that the right eye of the observer is in the axis of the rays proceeding from the left-hand light, and the left eye in the axis of those from the right-hand light. This causes each eye to see only one set of shadows distinctly, a stereoscopic effect being produced. When the two images coalesce the observer seems to see a single set of bars in space, the components of which appear to lie in different planes until the two lights have been so adjusted as to cast equal illumination on the grating. By the employment of suitable reflecting mirrors or prisms, the whole optical system can be erected on a bar photometer.[2] It is rather curious in this connection to note how this, one of the most recent of photometers, goes back in principle to one of the earliest instruments, that devised by Count Rumford in 1792, in which the illuminating power was determined by casting the shadow of a slender rod upon a screen and comparing the distances of standard and gas from the screen when the shadows cast by the two were of equal intensity.

The Jet photometer is not a photometer in the strict sense of

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[1] Gooch and Walker, Outlines of Inorganic Chemistry, Pt. 2, p. 279.

[2] Journal of Gas Lighting, April 14, 1908.

the word; it may be considered as a specific gravity instrument, and will therefore be described in a later chapter.

Many other photometers have appeared, in print at least, during recent months, but as these have not as yet proved their practical value, they will not be described here. The reader who is interested in them, however, should consult the Journal of Gas Lighting for May 7, 1907, and June 2, 1908, the American Gas Light Journal, June 29, 1908, the Progressive Age, Feb. 1, 1908, etc.

Meter. The Committee of the American Gas Institute recommends[1] the use of a wet photometer meter, having a capacity of one-twelfth of a cubic foot per revolution, and from the author's experience in New York State this would seem to be the meter which is coming most generally into use in connection with photometric work. The only advantage of this meter over the one making one-tenth of a cubic foot per revolution, is that it somewhat simplifies the calculations; since, if the meter makes one revolution of one-twelfth of a cubic foot per minute, the gas is being consumed at the rate of 5 feet per hour. Such a meter, if bought separately, will cost $50 and will, if properly cared for, render accurate and lasting service. The care of the meter and apparatus in general will be described in a succeeding chapter.

Governor. The use of two governors is an aid to accurate work; these should be placed, the one on the inlet and the other on the outlet of the photometer meter. The inlet governor is for the purpose of securing a uniform pressure on the gas in the inside of the meter drum, while the outlet governor serves to still further reduce the pressure of the gas before it reaches the burner and also to compensate for fluctuations in pressure produced as the meter partitions dip into the water. Two kinds of governors, the wet and the dry, are in common use. The latter, while not quite as delicate as the former, is recommended for general use for three reasons: First, it requires less care; second, it does not call for the use of water, which must be added to the wet governor from time to time, and which after each such addition must be saturated with the gas under test before correct results can be obtained; third,

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[1] Proceedings of American Gas Institute, October, 1907.

the dry governor allows changes in candlepower to be more quickly noted because the water in the wet governor may absorb or give off illuminants if conditions are varied.

Disc. A good disc is one of the photometrist's most important allies, and a large measure of his success and accuracy will depend on his choice of this feature. There are three types on the market which seem to have met with considerable favor, — the Lummer Brodhun, the Leeson contrast disc, or the disappearing star, and the Bunsen disc. Of these the first is accurate but fatiguing to the eye; the second is said to be equally accurate and less tiresome; the third, if well made, is very easy to read and is simple and cheap. The author has had a rather wide experience with discs of the disappearing star type, and as a result feels that he can recommend them for general use. There has been considerable difficulty, however, in securing a star disc which would read the same on both sides, and very many of the discs inspected were incapable of furnishing accurate results, even in expert hands. The committee of the American Gas Institute (whose report is quoted so often in this volume for the simple reason that in the author's mind it is the ablest and most thorough utterance on the science of photometry which has been delivered in this country) recommends the Leeson contrast disc, and thus confirms the author's opinion; but the Bunsen disc is very highly regarded by such authorities as Mr. Jenkins, of Massachusetts, and will, if carefully chosen, give most satisfactory results.

Candle Balance. The candle balance used in a photometer should be set firm and level in the proper chamber. It is well to have its position permanently fixed; this may be accomplished by having a circular socket let into the floor of the chamber into which the base of the balance fits tightly. There should be some means provided for raising or lowering the beam and pan, which should also be capable of being moved a little backward or forward in order to align the candles. The knife edges and bearings must be accurately made and fitted; the balance should swing freely and quickly and respond readily to a one-grain weight. The candle holder should be so constructed that candles may be easily inserted or removed without their being gouged or otherwise damaged, and at the same time the candles must be firmly held in place. Both a rough and a fine adjustment should be provided.

Sight Box. The sight box must slide in the gallery easily and without jar. It must be easy to open, so that mirrors and disc may be kept clean; this purpose is served if the entire top of the box is hinged. The disc should give a sharp end point and should be reversible. A pair of good mirrors will greatly facilitate the work.

CHAPTER II.

STANDARDS AND BURNERS.

On no part of the photometric outfit have so much time and research been expended as on the invention and testing of standards, and up to the present time only one has been produced which is not subject to adverse criticism. The author has before him descriptions of some fifty different types of proposed standards, only about fifteen of which, however, have ever seen really active service. It is not within the scope of this work to describe or even mention all of these various types, since most of them are either obsolete, inaccurate, or impracticable for general use. Likewise we shall not go into the question of theoretical or of primary standards, however interesting and important the subject may be, for it could be of no service to the practical gas man or photometrist. It seems advisable, however, to treat rather fully of the history, manufacture and use of such standards as are in practical service to-day, in order that the reader may understand the advantages and disadvantages of each. There are but six of these, — the 10-candle Pentane lamp, the Hefner, Carcel, and Elliott lamps, the Edgerton slit and candles.

Candles. The founder of the gas industry, Murdoch, seems also to have been a pioneer in the field of standards, for in 1808 he noted that the light from tallow candles varied, and therefore specified that the latter should weigh six to the pound and should burn at the rate of 175 grains per hour. This tended to produce uniformity, but the tallow candle was not adapted to accurate work, and was succeeded by the wax candles. These latter were used as early as 1824, but not until 1849 were they made a legal standard in England by act of Parliament. Undoubtedly improvement had been made over the tallow, but wax candles proved unsatisfactory, as Dr. Letheby, then chemist of the city of London, reports that the consumption of wax was irregular and that it was impossible to determine when they were burning properly. Attempts were made to introduce paraffin for the manufacture of standard candles in 1852, when Lewis Thompson declares it to be superior to wax or sperm because it is readily tested as to purity, and its composition is easily fixed and determined the world over.[1] This plea, however, never brought paraffin to the front in England, although in Germany it was adopted as standard in 1872, and definite specifications issued regarding its use. Tests of these candles by Lummer and Brodhun showed them to be unsatisfactory in that the top of the flame split into three parts and that the flame smoked. The directions for using these candles required that the readings should be made when the flame was 50 mm. high. This evidently assumed a fixed relation between flame height and intensity, and when it was proved that such a relation did not exist, the accuracy of the method was seriously impugned.

Stearine candles have been tried in two forms, one the Munich candle, and the other the French Bougie de l'Etoile. The former had a short and rather uneventful life, going out of use in 1860, while of the latter the *Journal of Gas Lighting*, in 1859, says: "For uniformity and steadiness of light the stearine candle sold in France under the name of Bougie de l'Etoile far surpasses the ordinary sperm candle." The Bougie was for some time standard in France, and Durand states that the Carcel lamp, the recognized standard in that country to-day, should always be tested against the stearine candle before using.

Sperm candles as standards were first used as a substitute for wax in 1852, and in 1860 were legalized by the Metropolis Gas Act. Under this act very careful specifications were issued for the manufacture of these candles; the wick was to consist of three strands, each of 18 threads; there were to be 32 to 34 plaits in 4 inches of the wick when extended by a pull just sufficient to straighten it out. The wick after steeping and drying was to weigh not less than 6 nor more than 6½ grains for each 12 inches.

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[1] Journal of Gas Lighting, June 23, 1908.

The weight of the ash from 10 wicks after treatment with water was to be 0.025 grain. The spermaceti used must have a melting point of from 112 to 115° F., while that of the finished material would be slightly higher on account of the 3 to 4¼ per cent of beeswax which was added to prevent crystallization of the sperm. If a 40-grain brass weight were attached to the wick, and the candle floated in water at 60° F., taper end down, it should float with a 2-grain weight placed on top and sink with a 4-grain weight. It seems that the manufacturers found it impossible to comply with these directions, and Dr. Love, of New York, after a careful investigation, found that with the candles which he tested not one of the above specifications was fulfilled. This may, in some measure, account for the disfavor into which these candles have fallen, for there is no disguising of the fact that candles to-day are not satisfactory as standards, although they are used more frequently than any other form. The bare fact is apparent to anyone who has used candles extensively, but the reasons may not be quite as clear. Hornby in his *Gas Manufacture* says: "Slight variations in the quality of the sperm and in the method of admixture (for 4 to 5 per cent of beeswax is added to keep the sperm from crystallizing), and changes in process of manufacture, will sometimes tend to slightly alter the results obtained with such candles.

"The weak point of the candle, however, is the wick, the roughness or smoothness of which, and its curvature during burning causing extraordinary variations in the light emitted by it, even supposing that the wicks could be made absolutely uniform, the twist of the thread kept constant, and the same amount of strain placed upon them during the making of the candle."

Even this does not include all of the charges brought against candles. They are said to be unreliable even when made according to the most exacting specifications; they are very strongly influenced by changes in atmospheric conditions, such as heat, moisture, and the presence of carbonic acid; and any correction for these factors is extremely difficult if not at the present day impossible in the case of the average gasworks.

That the light emitted by candles is affected by altitude is proven by the experiment, in 1859, of Frankland and Tyndal, who burned a candle on the summit of Mont Blanc, where the atmospheric pressure was only 16.4 inches, and found that the sperm was being consumed at the normal rate, but that the flame was entirely non-luminous. To illustrate the amount of the error introduced by one of the above causes, a table will be found in the appendix showing the effect of temperature on candle-power.

Now, while admitting all of the weaknesses mentioned above, and without being desirous of being regarded as an advocate of the candle as the best standard (which it most assuredly is not), the author feels that a very considerable part of the curse which rests upon candles is due to the improper use of them; and that while they are not accurate enough to serve as an unchangeable standard, their cheapness, simplicity, availability and adaptability recommend them in many cases where a more accurate standard would be impracticable.

These opinions are based on long-continued observations of the use of candles by a very large number of gas companies, as well as by many of the inspectors appointed by various state and local governments, and it is only fair to admit that if the Pentane lamp or any other standard were used with the same calm disregard for the most vital principles governing their operation, as is shown in the daily use of the candle, its accuracy would be utterly unreliable.

Moreover, the candle is the only standard which can be used with a portable photometer, and this fact alone will compel its employment in some cases, and more especially in the work of government supervision, until some equally portable and more accurate substitute is found. The precautions necessary to be observed in the use of candles will be fully dealt with in a later chapter, but before leaving the subject, there are two definitions which should be placed before the reader, and which would seem to belong under this heading.

The unit of light for gas is "the average light, measured in a horizontal direction, given by Parliamentary sperm candles prescribed by the British Metropolis Gas Act of 1860, said candles to be six to the pound and burning 120 grains per hour. If custom is to be followed, the unit of light as understood to-day by the illuminating-gas industries of the United States is one-tenth of the Harcourt 10-candle Pentane lamp."[1]

Mr. Grafton gives the following definition of the light of a candle which it is well to bear in mind: "The light of one English candle is the amount of light emitted and maintained for at least one hour after maturing, from the combustion of 120 grains of sperm fed by a definite sized wick in a quiet but pure atmosphere."

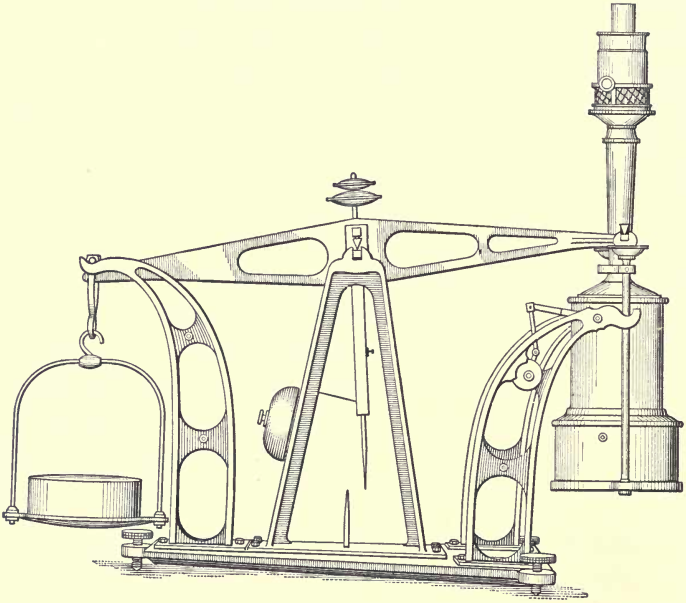

Fig. 5. Carcel Lamp.

The Carcel lamp is the oldest candlepower standard which is in use to-day, having been invented by Carcel some 110 years ago. It is official in Paris and is accepted throughout France, although not widely used outside of that country, and very rarely seen in the United States. It consists[2] of an Argand burner (Fig. 5), with

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[1] Journal of the Franklin Institute, March, 1908.

[2] Journal of Gas Lighting, June 23, 1908.

wick and chimney, the oil being forced by pumps through the central pipe to the burner above. These pumps, of which there are three, empty into a common space and are operated by clockwork in the base. An overflow of the surplus oil is always maintained, so that the wick draws its supply from a constant head, thus insuring uniform conditions. Colza, or rape-seed oil is used, and the rate of consumption maintained at 42 grams per hour, regardless of the height of the flame, as at that rate there is the least variation in candlepower for a given variation in oil consumed. The wick is the delicate part of the lamp and should be frequently changed, the rules for official testing in Paris requiring a new wick for each test. While opinions vary greatly as to the accuracy of this lamp, there is no question but that it is sufficiently exact for practical work. It is not to be recommended for the latter purpose, however, for several reasons, of which it will be necessary to give but one, namely, that simpler, cheaper, sufficiently accurate instruments are on the market, which can be put in the hands of a works foreman or a clerk in the office, and trustworthy results secured thereby.

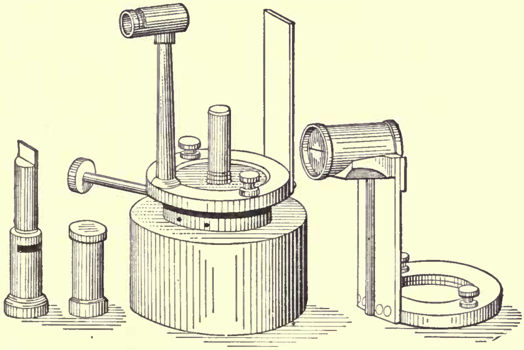

Fig. 6. Hefner Lamp.

The Hefner lamp was brought out in 1884. It consists[1] of a small lamp (Fig. 6), with a wick made of cotton threads (15 to 20 in number) laid straight until the total size of the wick is just sufficient to fill the wick tube, which is 8 mm. in diameter, without

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[1] Journal of Gas Lighting, July 7, 1908.

squeezing. The lamp is of brass throughout, with the exception of the wick tube, which is made of German silver to avoid corrosion. For the same reason the walls and interior should be well plated.

The wick is operated by a worm gear which actuates two spur wheels. When not in use the wick tube is kept covered by a cap. The height of the flame should be 40 mm. and must be exactly adjusted.

The fuel consumed is amyl acetate, a colorless, chemical compound, prepared commercially by the distillation of amyl alcohol with a mixture of common or ethyl alcohol, sulphuric acid and potassium acetate. The finished product is liable to contain small quantities of water and alcohol, but these, in the amounts in which they ordinarily occur, have no appreciable effect on the luminous intensity of the flame, although they do seriously influence its stability.

Amyl acetate may be readily obtained for about $6.00 per gallon, and the cost of a certified Hefner lamp is $27.00.

This lamp is largely used in Germany and in a few cases in the United States, and for constancy and reproducibility it is said to be the equal of the best flame standards.[1] As a working standard, however, it has serious defects. In the first place the flame is of reddish color and consequently difficult to compare with a gas flame.

Second, the value of the Hefner is only 0.88 candle, and this fact likewise tends to increase the difficulty of reading and to render the results less accurate.

Third, the flame must be maintained at an exact height of 40 mm. during the test, and this can hardly be done without the presence of two observers, one to make readings and the other to watch the flame.

Fourth, the lamp must be operated in a perfectly quiet atmosphere, since the flame flickers at the slightest jar or draft, such as might be caused by the walking about of the observer, the moving of the sight box, the opening or closing of a door in another part of the building, etc.

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[1] Proceedings of American Gas Institute, October, 1907.

Fifth, the setting of the height of the flame at 40 mm. is not as simple as it sounds, on account of the very pointed character of the flame tip; and an error of 1 mm. (or 0.04 inch) in setting will cause an error of 2.5 per cent in the light emitted.

From a consideration of all these facts it will be seen that, however satisfactory the Hefner lamp may be in theoretical work and in the hands of skilled observers, it is not to be recommended as a standard for works use, or as a rule for purposes of governmental supervision.

It is to be noted that all of the standards previously described, together with the Pentane lamp, have been the invention of foreigners. This is not surprising, if we remember the length of time during which gas has been in service and under supervision abroad, and that only since 1860 has there been any attempt at such regulation in the United States. It is all the more gratifying, therefore, to turn to the discovery of a standard by an American.

It has been known for a long time that the light emitted by a kerosene lamp was remarkably uniform, and numerous attempts have been made to devise a standard which should use kerosene as a fuel. None of these was entirely successful, however, until in 1906, Dr. A. H. Elliott, of the Consolidated Gas Company of New York City, placed his standard kerosene lamp on the market.

This is of the student-lamp form (Fig. 7), with a flat cotton wick 1½ inches wide. The reservoir is of sufficient capacity to furnish oil for 12 hours' continuous service, and is supplied with the usual valve feed, thus insuring a constant level of oil at all times.

The chimney used is the No. 40 Macbeth pearl glass, which is 10 inches height, 1.75 inches inside diameter at the top, 3 inches wide outside at the bottom, and about 4 inches at the widest part. An adjustable brass screen covering the upper part of the flame is supported on two uprights which are riveted to the burner shell. This screen opening is made seven-eighths inch over the crown of the cap, and 1½ inches between the side wings.

The wick in use is trimmed to 1 inch in width, the corners being cut off equally on each side from one-quarter inch on the top edge to one-half inch on the side; this is done to prevent the ends from throwing out long, smoky tails which might crack or smoke the chimney. The consumption of fuel is 40 grams per hour, and the oil recommended is known as Pratt's Astral oil, though other grades may be used.

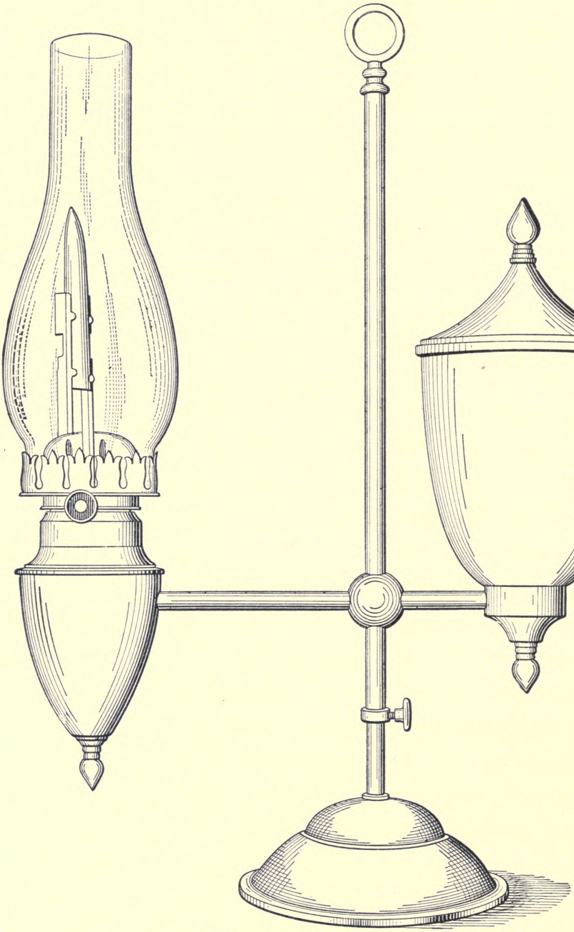

Fig. 7. Elliott Lamp.

The lamp gives under the most favorable conditions a light equal to 10 candlepower, although in many cases which have come under the author's personal notice it has been impossible to obtain quite this figure.

The advantages of this lamp as a working standard are many. It is cheap, costing only $25. The fuel used may be obtained anywhere, is very uniform in quality, is safe, and costs but 15 to 18 cents per gallon. The glass of the chimney is relatively distant from the flame, and thus is less liable to fouling. The parts are easily replaceable in any locality; the light emitted is easy to compare with gas, the flame is readily adjusted and very constant when once lit, and the candlepower of the lamp is high, thus reducing the errors of observation.

Tests made by a New York photometrist at the request of Dr. Elliott gave a remarkable series of figures in which the readings with the lamp did not vary by 0.01 candlepower during a period of 4 hours. The author was not able to duplicate these figures, but secured results which seemed to show conclusively that after the lamp was once lighted it would remain sufficiently constant for practical work over a period of 8 hours. The tests in the following table were made by three different assistants, each trimming the lamp according to his idea of the directions.

TEST OF ELLIOTT LAMP.[1]

Date.	Time.	C. P.
May 24	9.40	8.74
Do	10.40	8.82
Do	11.40	8.76
Do	1.40	8.66
Do	2.40	8.76
Do	3.40	8.67
May 25	9.40	8.63
Do	10.40	8.70
Do	11.40	8.67
Do	12.40	8.70
May 27	11.50	8.63
Do	1.50	8.61
Do	4.30	8.58
July 16	10.30	8.29
Do	11.45	8.52
Do	12.30	8.13
Do	1.30	8.51
Do	2.40	8.38
Do	3.30	8.35
Do	4.45	8.22
July 17	10.30	8.12
July 17	2.00	8.64
Do	2.45	8.53
Do	4.00	8.69
Do	4.45	8.45
July 19	10.15	8.37
Do	11.30	8.33
Do	2.00	8.38
Do	3.15	8.60
Do	4.00	8.56
July 22	11.30	7.90
Do	1.15	7.84
Do	2.00	7.90
Do	4.30	7.94
July 23	9.45	7.89
Do	10.30	7.80
Do	11.30	8.11
Do	1.20	8.19
Do	2.30	7.68
Do	3.20	8.02
Do	4.30	8.02

During the last two days of the above tests the wick was old and the candlepower of the lamp consequently fell off to a marked extent. Its constancy also seems to have been somewhat influenced by that factor.

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[1] For results with the five-candle Elliott lamp, see Tables XI and XII in the Appendix.

From these figures it will be seen that it has proved difficult to so trim the wick that the lamp shall give the same candlepower on different days, and this has been found to be the experience of various gas companies which have used the lamp. This trouble seems to arise largely from the fact that the opening in the screen has been made so large as to take in the greater part of the flame, and consequently slight variations in trimming have either caused some of the blue portion of the flame to show through the screen slit, or else the upper corners of the opening were not completely filled by the flame. This defect has been remedied by the inventor, who has now reduced the candlepower of the lamp to 5, and the writer is assured by Dr. Elliott that this change has resulted in even greater constancy and accuracy than is exhibited by the 10-candle standard.

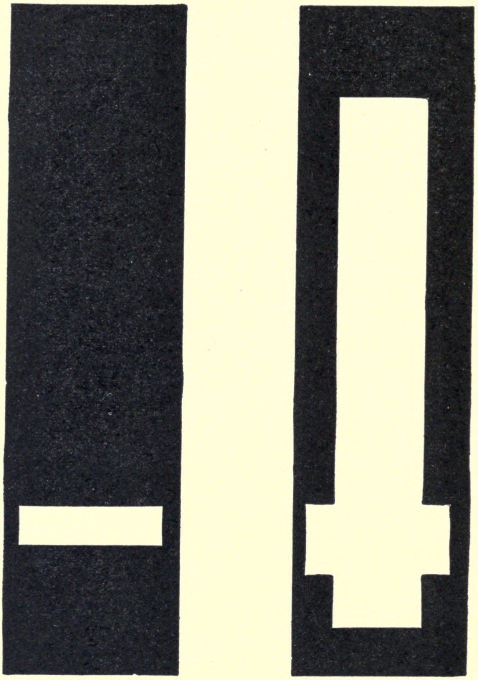

Fig. 8. Edgerton Sleeve.

Based upon a principle entirely different from the foregoing, the Edgerton standard, which uses coal or water gas as a fuel, consists of a Suggs D Argand burner, and a glass chimney, 7 inches by 1¾ inches, with a blackened brass sleeve surrounding it. In the front of this sleeve there is a horizontal slot $\frac{13}{32}$ of an inch high and of sufficient width to include the entire diameter of the flame. The lower edge of the slot is seven-eighths inch above the steatite ring of the burner, and if the flame is maintained at a height of 3 inches the most luminous zone will be included in the slot. The portion of the sleeve directly opposite to the slot is cut away to avoid reflections, and there are also windows in the sides to enable the observer to properly adjust the flame. The radiant center is nine-tenths inch in front of the geometric center, and this fact should be borne in mind when standardizing the instrument.

The initial cost is but $3.75, and this, together with its reliability, ease of operation and the fact that the fuel costs almost nothing and is always at hand, renders the Edgerton a most useful and satisfactory standard for works use, or for any employment where absolute accuracy is not required.

There are, however, certain disadvantages attendant upon its use. Mr. F. N. Morton, in his superb paper on the History of Photometric Standards, read before the Illuminating Engineering Society in February, 1908, shows the wide divergence of opinion which exists as to the accuracy of this standard, and states that in his judgment it should be frequently compared with candles, Pentane, Hefner or some other form of standard. The general view to-day seems to be that if the gas used as fuel does not vary by more than 2 candlepower, and if certain simple rules are strictly complied with, the standard will be accurate within 0.2 to 0.4 candlepower. To accomplish this the chimney must be kept clean and the calibrated section of it must always be turned towards the slot; the flame height must be maintained nearly uniform, and the factor for the instrument, which lies between 4 and 7 candlepower, must be frequently verified and always redetermined when a new chimney is employed.

The author believes that this and the Elliott lamp are to be strongly recommended for works use, and especially in cases of small plants which cannot afford to employ a chemist to test and purify pentane, etc.; for while they are not as accurate as the Hefner, Carcel or Harcourt lamps, they are much cheaper and more easily operated, and results obtained with them are sufficiently near to the truth to guide the manager in his manufacture of gas.

This standard must not be confused with the Methven screen, which, while in many particulars similar to the Edgerton, is for certain fundamental reasons less accurate than the latter.

The Pentane lamp has reached a pinnacle never attained by any other standard, namely, it is to-day without an opponent. For this reason it seems advisable to devote some space to a careful explanation of its construction, and no clearer view can be obtained than is given by the following, which is quoted from Butterfield's Extract of the Referees' method. "Air is saturated with pentane vapor by passage through a saturator which is about two-thirds filled with pentane, and the air gas so formed descends by its gravity to a steatite ring burner. The saturator is 184 mm. square and 38 mm. deep, and contains seven partitions soldered to its top, and alternately meeting either side, and stopping 25 mm. short of the opposite side. The air is thus compelled to pass eight times across the saturator.

"A piece of India rubber tube 13 mm. wide internally, conveys the air gas from the saturator to the burner. The air inlet pipe to the saturator and the air gas outlet are provided with stopcocks, and the height of the flame is controlled by the outlet cock.

"A brass chimney 431 mm. long, 30 mm. inner and 32 mm. outer diameter, is placed so that its lower end when cold is 47 mm. above the steatite burner. This chimney tube draws the flame to a definite form and hides the top of it from view.

"A mica window in the tube allows the tip of the flame to be seen and the height to be regulated, so that the tip is somewhere between the bottom of the window and a crossbar. A tube 290 mm. long, and 50 mm. inner and 52 mm. outer diameter, surrounds the chimney tube and draws in air at its base.

"The chimney tube projects 65 mm. below and 76 mm. above this outer tube. The heated air passes from the top of the outer tube to another tube 529½ mm. long, and of 23 mm. inside and 25 mm. outside diameter, which is placed parallel to the first tube, and with its axis 67 mm. distant from the axis of the latter. From the bottom of this tube the air passes to the center of the steatite ring of the burner. The outer diameter of this ring is 24 mm., the inner diameter 14 mm., and there are 30 holes, each one 1.25 mm. in diameter.

"A conical shade 102 mm. wide at the base, 55 mm. wide at top, and 57 mm. high, having an opening 34 mm. wide, is placed around the flame. The light which serves as the 10-candle standard passes through the opening in this shade. Leveling screws are provided by which the lamp is adjusted until it is vertical, and the height of the steatite ring (when using the table photometer) is 353 mm. from the table."

The Pentane lamp made in the United States differs from the above only in minor details, the most important being that the saturator is connected with the burner by brass tubing, which would seem to be a distinct improvement over the rubber hose employed with the English model. The total weight of the apparatus is 25 pounds, and the price $75.

The fuel used consists principally of a hydrocarbon, pentane, (C_5H_{12}), belonging to the same series as methane and ethane, and obtained by the distillation of gasoline. From the nature of its origin it will be readily seen that it cannot be made (at least commercially) absolutely pure, but always contains small quantities of other hydrocarbons. Since the presence of these latter in any considerable amount will seriously affect the value of the standard, it is necessary that every fresh batch of pentane should be prepared and tested by a chemist, and for this reason, among others, the standard is not as available for the smaller companies. (An illustration of the lamp is seen in Fig. 9.)

The accuracy of the lamp is unquestionable, and at the present time it is the most highly esteemed standard in the United States.

The author does not believe, however, that the last word has been spoken on this question, for there are several imperfections and disadvantages still to be overcome. First, the lamp is too expensive, and the cost of its fuel ($3 per gallon) too great. Second, the fuel is inflammable and greatly increases insurance risk and difficulty of transportation. Third, the pentane employed must be carefully tested by a chemist, and this requires special facilities. Fourth, it is believed that the simplicity and ease of operation could be somewhat increased, if we remember that these standards are being considered purely from the standpoint of the practical man, and not at all in the line of theoretical or primary standards.

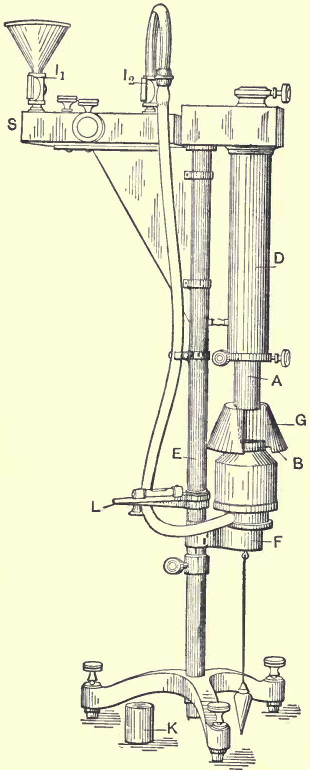

Fig. 9. Pentane Lamp.

Before concluding this subject a word should be said regarding electric standards. The convenience of these in certain places, and their accuracy are unquestioned, but they are unsuited for use in the photometry of gas flames, because the electric lamp is entirely unaffected by atmospheric conditions. Mr. Gartley says: "To compare a gas flame against an electric lamp, normal atmospheric conditions are imperative, otherwise an error of as much as 10 per cent may be introduced, generally against the gas flame." [1]

Burners. The burner question has, like that of standards, had a long and interesting history, and were there time it would be profitable to trace the evolution of the burner from its remote ancestor, the lava tip, down to its present magnificence in the form of the

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[1] Proceedings of American Gas Institute, October, 1907.

Metropolitan No. 2, or Carpenter burner. Without going into this in detail, however, it suffices to say that one fact stands out clearly: the end and aim of all the research along this line has been to produce a burner which should do justice to the actual candlepower of the gas; and up to recent years no burner has been found which could accomplish this, principally because no device had been discovered which properly regulated the air supply according to the quality of the gas.

Hornby, in his *Gas Manufacture*, says: "In batswing or fishtail burners the size and angle of the apertures determine the amount of air, while in the Argand, the chief regulating agency is the chimney by which the amount of air admitted is under perfect control. With a poor gas little air is needed, and the best burners for such a gas are those with large holes. Here the directive force with which the gas issues is small in proportion to the quantity passing, and so the supply of air is likewise correspondingly small. The reverse is true for rich gases."

While it is somewhat difficult to admit that the air supply is perfectly controlled by the chimney, it is true that the latter serves a twofold purpose of shielding the flame from drafts and of drawing upon its surface the air needed for combustion. With flat-flame burners the proper air supply is secured by the pressure at which the gas issues from the burner forcing the white-hot carbon particles into intimate and rapid contact with the air.

The only burner, however, which accurately controls the air supply is the Metropolitan No. 2, or Carpenter burner, which in its essential features is an Argand burner fitted with an air shutter for regulating the amount of air admitted to the interior of the flame. Because of this regulator the burner gives with low candle gas a higher result than any other.

And now the question immediately arises, Why should not this burner be employed in every case, at least for coal gas? The answer to this will be found in the consideration of two or three facts. In Massachusetts the law requires that the gas shall be tested with the burner best adapted to it, which is at the same time practical for use by the consumer, and the authorities in that state

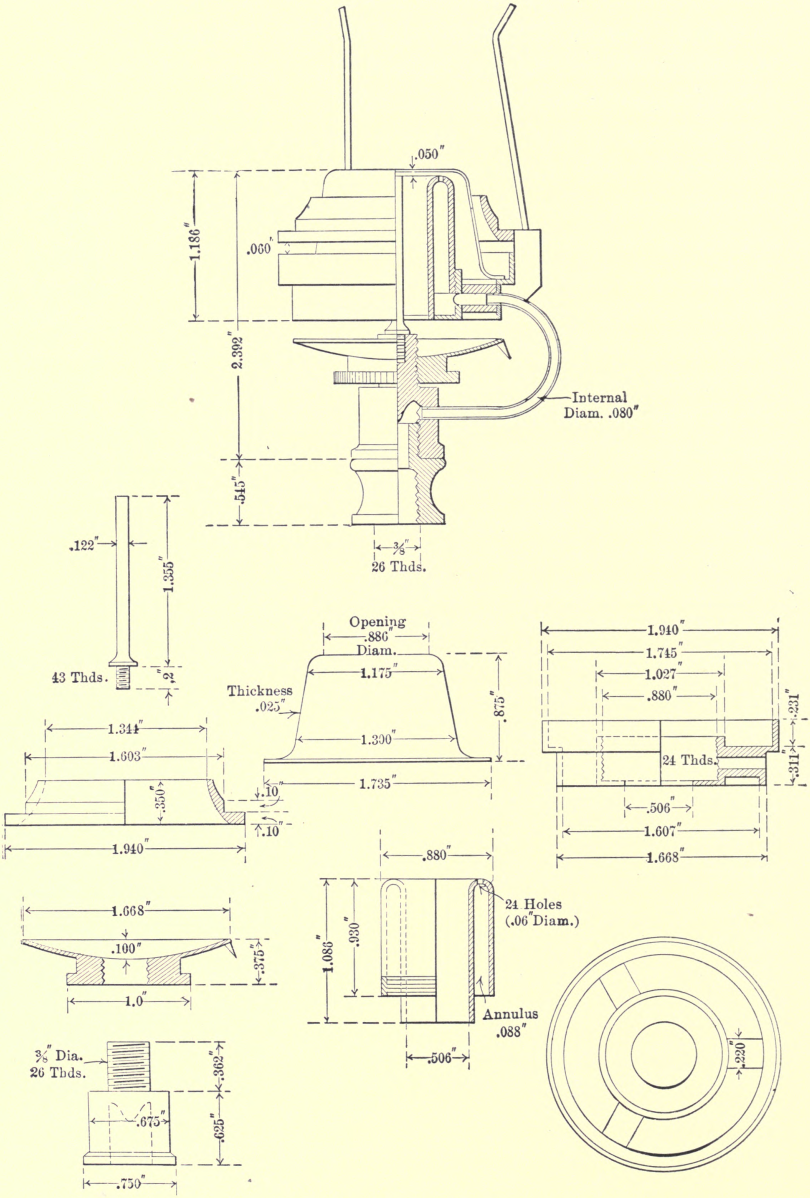

Fig. 10. Metropolitan No. 2, or Carpenter Burner.

have interpreted this to mean a burner which is not only satisfactory in its mechanical details, but which in cost is within the reach of everyone. The price of the Metropolitan No. 2 is $25, and this would seem to place it beyond the reach of most consumers. In London a similar regulation is in force, but is interpreted differently.

Again, in certain localities the choice of a burner must be governed by local considerations; thus, in New York, the Second-Class Cities Law specifically calls for the use of the Suggs New F and Old D Argand burners and of the No. 7 Slit Union Bray burner, dependent upon the nature of the gas to be tested; and the order of the former Commission of Gas and Electricity of that state, which has thus far been continued by the Public Service Commission of the Second District, requires the use of the above burners in all cities and towns under its jurisdiction where coal or water gas is made.

Now, without defending the wisdom of these regulations, it would seem advisable for gas companies to conform to local laws and customs in the manner of testing their gas in order that they may the more carefully comply with the regulations laid down for their control.

In cases where the above conditions do not apply, the use of the Carpenter burner is to be recommended for coal gas, and the No. 7 Slit Union Bray burner for water gas. In the appendix will be found a table compiled from data secured by the author and his assistants which will illustrate the results to be expected with the two Argand and the Bray burners. These tests were obtained in the course of routine work in a large number of places throughout the state of New York, and no two are from the same sample of gas. These figures will serve to show that no hard and fast rule can be laid down regarding the proper burner to be used in individual cases, and that the photometrist who honestly seeks for the correct result will try more than one burner in all cases of reasonable doubt.

In the instances cited above, Argands of the types known as New Style F and Old Style D are to be employed. The Old D which is furnished with photometers is not a standard burner, and tests by the writer and others have shown that it is not to be recommended. The standard Old D burner will as a general thing give the better result with a gas of less than 16 candlepower, and the New F is almost invariably the better burner for candlepowers between 17 and 20. The rules issued by the New York Public Service Commission of the Second District cover this point well, and are in substance the same as the above.

The writer wishes to be very distinctly understood with regard to this matter of burners. The Carpenter burner comes nearer to bringing out the actual candlepower of a coal gas than does any other burner; it is therefore unquestionably, from a scientific or theoretical standpoint, to be recommended for adoption. It is only on the grounds of expediency and in deference to local conditions that other burners are recommended for special cases.

For a straight oil gas a 3-foot steel tip burner may be used; and for acetylene, a Perfection No. 3, which is made especially for this gas. Gasolene gas is tested with a Tirrill, and for oil-air gas either a Suggs Table Top tip or an F Argand may be used.

As a rule, a chimney 7 inches by 1¾ inches should be used, although in the case of certain low candlepower gases a 6-inch chimney will be found to give better results simply because it more nearly adjusts the air supply to the quality of the gas.

The New F and Old D Argand burners cost at the time of writing $5.50 apiece, and are made to order in England. The Bray burner costs about 25 cents, and may be procured of nearly any of the large dealers of gas appliances. The chimneys are $3.00 a dozen, and as a rule can be obtained only in the larger cities.

CHAPTER III.

CANDLEPOWER TESTS WITH COAL AND WATER GAS.

Before commencing the actual operations for taking the candlepower, there are two very important points to be attended to. First, the photometer bar must be measured; second, the meter must be tested. With regard to the latter, little need be said here, as the subject will be fully treated in the chapter on meter testing. We shall, therefore, assume that the gauge glass of the meter bears a mark at which the lowest edge of the meniscus must rest if the meter is to register correctly.

The measurement of the photometer is most essential and must be done with extreme care, since on the accuracy of this depends the correctness of all future work. A method of procedure is here suggested which is simple and yet sufficiently accurate if carefully followed out. Let us assume the bar to be of the 60-inch type. Then the distance between the plumb bobs, defining the position of gas and standard, is to be just 60 inches. If this proves to be incorrect, it can be rectified by moving the bob at one end, but the question of which bob to adjust must await its answer until further measurements have been taken. Now drop a plumb line from the 16-candle mark on the scale to the photometer table. As the point thus found will lie somewhat in the rear of the line connecting the two plumb bobs, it is necessary to use draftsman's triangles or some similar device for drawing a line, through the point and perpendicular to the axis of the photometer. Next measure the distance of this point (in a straight line parallel to the photometer bar) from the bob at the gas or standard end.

If the bar was calibrated for use with a one-candle standard, the square of the distance to the gas divided by the square of the distance to the standard should equal 16, and consequently with the 60-inch bar the standard will be 12 inches and the gas 48 inches from the 16-candle mark. In a similar manner the observer may check as many of the marks as may seem desirable.

If the bar was graduated with a view to reading the candle-power direct with a 2-candle standard, as is often the case, it is evident that the 16-candle mark will stand where the 8-candle mark would be were the standard of only one-candle value. In case the location of the point is incorrect, move either the gas or standard until the error is rectified.

For example, on a 60-inch bar the 16-candlepower mark is found to be $11\frac{1}{2}$ inches from the standard and 48 inches from the gas. This, of course, means that the bar is too short, and the standard bob should be set one-half inch farther away from the gas end. It frequently happens, especially with closed-bar photometers, that the wood used in their construction was not perfectly seasoned, or else the photometer may have been set up in a locality where the conditions of temperature, moisture, etc., may have caused it to expand or shrink. It is, therefore, advisable to remeasure the bar occasionally; and if the marks of the original measurement have been preserved on the photometer table this may be done with great ease and rapidity.

In some instances it may be found that the total length of the bar is correct, but that the position of the marks on the scale is in error; in such cases it will be necessary to move the scale itself. Another method of measuring is to determine the position of one mark on the scale with extreme accuracy, and then measure the distances, on the scale itself, of the other marks from this.

A formula for calculating the proper position of any mark on the scale has been worked out by the author, and as he has never seen it in this form in print, it is thought to be worthy of insertion here.

$$(Px^2 - x^2) + 2\,Lx = L^2$$

where x = distance from the standard to the desired mark,
L = the total length of the bar,
P = the point chosen (as 10-candlepower mark).

To illustrate, suppose it is desired to know the location of the 10-candle mark on a 60-inch bar, then

$$(10\,x^2 - x^2) + 120\,x = 3600.$$

Solving this we find $x = 14.41$, so the 10-candle mark should be 14.41 inches from the standard where the value of the latter is one candle.

Preparations for the Test. It is always well to spend a few minutes in looking over the apparatus to see that everything is in proper order. If a closed-bar photometer is used, see that it is level, and that the interior of the bar is free from dust and contains no obstruction to the passage of light to the disc. The precaution against dust is necessary because while the dead black of the bar when clean affords but small chance for reflection, a layer of dust on the bottom of the gallery, which is only slightly lower than the disc, makes a most excellent reflecting surface.

It may seem an absurdity to have added a warning against obstructions in the bar, but on several occasions the writer has found that company employees have considered the bar a most desirable substitute for a closet, and bottles, Welsbach mantles, chimneys, and other things have had to be removed before a test could be made.

The ventilation holes in the bottom of the gas and candle chambers must be clear, and nothing should be placed over these to obstruct the free passage of air.

The mirrors and sight box must be kept clean and especial care exercised to see that a coating of dust has not settled on the disc. A recent experience of the writer's well illustrates the latter point. A disc which had been in use by one of his assistants for several months, with perfectly satisfactory results, suddenly changed so that the readings from its two sides differed from each other by as much as 3 candlepower, and there seemed to be no reasonable explanation of the phenomenon, save that dust had collected on one or both of the surfaces. Moreover, not only does cleanliness promote accuracy, but it greatly eases the strain on the operator, as anyone who has tried to read a poor disc reflected in dirty mirrors can affirm. It occasionally happens, and more especially with portable photometers, that the disc becomes perforated; this renders it unfit for use, and a new one should be immediately substituted.

See that the burner is free from dirt, and has not been chipped or otherwise injured, and that, in the case of the Argand, it is provided with a clean and perfectly dry chimney. Test the governor and pressure gauge to see that they are working freely. Ascertain that the meter is level and is not subject to any strain due to improper height of the pipes leading to the inlet or outlet. The water in the meter should be changed occasionally, and for this reason both the funnel and the outlet water cock should be easily accessible. Whenever this change is made the fresh water must be thoroughly saturated with gas before the meter can be used. Such saturation is best accomplished by burning gas through the meter for at least one hour.

The candle balance should be examined with great care, as this offers one of the most fruitful sources of error. Rust, sperm and dirt are continually collecting on knife edges and bearings, and the fact that the balance was cleaned yesterday offers no assurance that it will work properly to-day. It is always a source of surprise to those unaccustomed to the use of a balance to note how wide a variation in results may be caused by a seemingly infinitesimal particle of sperm. If we remember, however, that the whole success of the balance depends on the practical absence of friction, and on the bearing surfaces being as thin as possible, the matter does not seem at all strange.

The moisture and oxygen in the atmosphere are continually attacking the steel of the knife edges and forming small particles of rust which, coming between the knife edge and bearing, act as a brake on the action of the balance. Spatterings of sperm from the candles also fall on the bearings and attract and hold dust, and this causes the balance to swing more slowly than it should and give totally incorrect weights. Unless the working parts of the balance be clean, and the knife edges sharp and smooth, it will matter little how fine a disc, burner and meter one has, or how accurately one can read; the results will be utterly inaccurate. Never, therefore, start to make a candlepower test without first cleaning every knife edge and bearing on the balance.

This, of course, applies only to that type of balance where the bearings are exposed; in other forms, such as the Becker, the above precautions are largely unnecessary, but to compensate for this the balance must be adjusted before every test, and the beam carefully dusted. It is an excellent plan to keep a small box of the size of a cigar box near the balance and to place all waste sperm, candles, matches and cleanings of the balance in this.

The 10 or 20-grain weight to be used should have been standardized on some delicate analytical balance, and must be incessantly watched, as it is extremely easy for a slight film of sperm to gather in spots or in the grooves formed by the lines of the numbers with which it is stamped. Always clean the weight before each test, but in doing so, use only a soft rag, as any harsher substance will readily remove fine metallic particles and thus destroy its accuracy.

Having now made the general preparations, the first step in specific tests is to clear the stale gas from the service, and be certain that the supply is fresh from the main. If a blow-off has been provided this may be accomplished in from 5 to 10 minutes, and this is the most satisfactory method of procedure. If there is no blow-off the pipes may be cleared by burning the gas for a period of time dependent on the size and length of the service. In almost every case from 20 minutes to half an hour will be sufficient, but it is to be remembered that during this time the air in the photometer room is being heated and fouled by the products of combustion, and this is one reason for the desirability of installing a blow-off.

The next point to be considered is the meter. The accuracy of this depends upon the degree of care with which the water level is adjusted, and, remembering this fact, it is astounding to see the number of companies where this detail is practically ignored. The writer has met man after man who has argued with him regarding the terrible errors of candles and who would not use a closed-bar photometer because of its supposed inaccuracy, and yet whose meter was in error from 1 to 10 per cent, because of neglect to adjust the water line.

It is estimated that with a 6-foot wet meter a difference of one-sixteenth of an inch in the water level makes a difference of about 1 per cent; thus, it will be readily admitted that the level should be corrected before every test, since the gas in passing picks up some of the water, and since a change in temperature will seriously affect the water volume.

The meter is generally standardized to be correct when the lowest edge of the meniscus just touches the scratch or other calibration mark on the gauge glass *when there is no pressure whatsoever on the meter.* Hence, to adjust the latter, while connected to the photometer, it is necessary that both inlet and outlet be opened to the air. This is accomplished by removing the plug from the dry well at the back of the meter and opening the burner cock of the photometer, the gas being shut off from the meter.

Before proceeding with the operation it is customary at this point to ascertain whether any water has collected in the dry well, and if so, to expel it. This may be done by placing one finger over the outlet to the dry well and turning the gas partly on. By removing and replacing the finger the operator can tell by the sound whether water be present, and if it is found, can blow it out by means of the gas pressure. This test serves also to show whether the meter is working properly, since if there is a stoppage when the finger is placed over the dry well and the gas turned on (the burner cock being closed for this test), the water in the gauge will not move freely as it should do.

Now the water level is examined, and if the lowest edge of the meniscus does not just touch the standard mark on the gauge, water is added through the funnel or removed by the outlet cock until the proper level is attained. It will often be found well to hold a sheet of white paper or a lighted match behind the gauge glass in order to facilitate the reading of the meniscus. When the water level is correct, close the funnel valve and replace the plug in the dry well. Test for a leak by turning on the gas, closing the burner orifice with the finger, or, better, with a rubber cap closed at one end, and then watching the hand of the meter. If this does not move, the meter and connections are tight, and the gas may now be lighted in the test burner.

If a blow-off has been employed, it will be but 5 or 10 minutes before the gas itself is ready for a test, but the latter must not be commenced immediately for several reasons. In the first place, whatever water has been added to the meter must be saturated with gas. Second, the meter and pipes leading from it to the burner must be cleaned of stale gas. Third, time must be allowed for equalization of temperatures between the water in the meter and the incoming gas.

While waiting for these things to be accomplished, the observer should see that the burner is accurately aligned and should regulate the flow of the gas. The rate is supposed to be 5 feet per hour, but only under standard conditions, namely, 60° F. and 760 mm. or 30 inches pressure. When such conditions do not prevail, it is necessary to calculate what rate under the existing circumstances would be equivalent to 5 feet per hour under standard conditions. For this calculation the writer always employs a method derived from Mr. Jenkins, the State Inspector of Massachusetts, which will be explained in detail in the paragraph on candlepower corrections. In brief, 1 per cent is added for every 4 degrees over 60 degrees, and 1 per cent for every three-tenths of an inch under 30 inches. Thus, if the temperature in the meter is 68 degrees and the barometer stands at 30.15, the correction would be made as follows:

$$(68 - 60) \div 4 = 2 \text{ per cent } +$$
$$(30.15 - 30.00) \div 0.3 = 0.5 \text{ per cent } -$$

Combining these, 2 per cent – 0.5 per cent = 1.5 per cent +

$$5.0 \text{ feet} \div 0.985 \text{ (or } 1.00 - .015) = 5.08.$$

Consequently, under the assumed conditions, the meter must register 5.08 feet per hour in order to be actually passing 5 feet measured under standard conditions. If the meter dial is divided into one hundred spaces of $\frac{1}{1000}$ foot each, in order to be passing 5.08 feet per hour, the large hand must pass over 84.7 divisions per minute, or 0.0847 foot (that is, 5.08 ÷ 60). If the divisions are $\frac{1}{1200}$ foot, the hand must pass over 101.6 marks or $0.0847 \div \frac{1}{1200}$. All of this calculation may be easily carried out in the head with sufficient accuracy; the only difficult part, the division of 5 feet by 985, may be obviated by multiplying the 5 feet by 1.5 per cent and adding the product to the 5 feet. It is necessary to perform this rating with considerable care, since it is usually done by one-minute observations, and any error at this point will be magnified tenfold when the regular test is made.

The next point is to regulate the outlet governor so that the pressure at the burner shall be 1 inch. Many photometers are not equipped with governors and consequently the gas is tested at the street pressure. There are two important objections to such a course of procedure. First, the fact that the pressure in the mains is seldom absolutely uniform, and second, that experiments have shown that the candlepower varies with the pressure to a certain extent.

The writer made a number of tests of burners under varying conditions of pressure and rate, and a few of these will be found in a table in the appendix. From the figures there given it will be evident that it is necessary to prescribe a pressure that shall not only make for uniformity, but shall also give the highest efficiency with the burner employed.

While the gas is being cleared from the pipes, the candles should be lighted, as these must burn from 15 to 20 minutes before being ready for the test. The candles to be used are what are known as sixes, that is, weighing six to the pound. There is a form on the market which is half the size of the above and known as twelves, but these are not to be recommended, since in a number of instances they have been shown to vary considerably from the sixes which are the official candles and hence used in nearly all the state and municipal inspections.

Assuming then that sixes are to be used, if the candle to be employed be a fresh one, it must first be cut in two. The general method of effecting this is to roll the candle on a table under a knife blade until cut through. Then the operator has the choice of two ways of proceeding. First, he can burn the candle from the middle towards the ends, or, second, he can burn only the lower half in that manner and the upper half from the end towards the middle. The first method is recommended by many writers because of the fact that the candle increases slightly in size from the upper to the lower end, and by burning from the middle towards the ends, one-half of the candle is decreasing in diameter as the consumption progresses, while the other half is increasing. This is supposed to render the light more uniform throughout the life of the candle.

On the other hand, Mr. Hartley of England, after careful investigation, is satisfied that this advantage is more theoretical than real. There are two points in favor of the second method: one is, that by a certain procedure in preparation a saving of about 10 per cent can be secured in the expense for candles; and the other reason will appear more clearly in what follows, but is along the line of economy and a better condition of the wick.

If the candle is to be burned by the second method, the above economy is secured by the following procedure: Do not cut the candle in the center, but at that point insert a fine, sharp blade, making as small a hole as possible, and cut the wick (Fig. 11). Then, about an inch below the incision cut carefully around the entire candle nearly into the wick, taking pains, however, not to damage the latter.

Now by taking one-half of the candle in either hand, a slow, steady, straight pull will separate the two halves, leaving the wick of the lower part ready to light. By this means the inch of sperm, which is usually pared or burned off, is left at the bottom of the upper half, and while this portion is wickless, that fact is of no consequence, since it is never possible to consume the last inch or two in any case.

If the candle is entirely severed in the middle a portion of sperm about one inch from the end to be lighted must be removed, and this may be done either by paring the end to a conical shape and burning off the sperm, or by cutting in nearly to the wick, as described above, and pulling off the piece thus severed, leaving the projecting wick intact.

The former procedure is recommended by the American Gas Institute and has the advantage that there is no liability of injuring the wick. The latter method is used by the state inspectors in Massachusetts and New York, and prepares the candle more quickly for use, while with a little practice and due care there is no danger of spoiling the wick. The upper end of the candle may be burned off or the sperm surrounding the wick may be cut away, but cannot be pulled off as with the lower half.

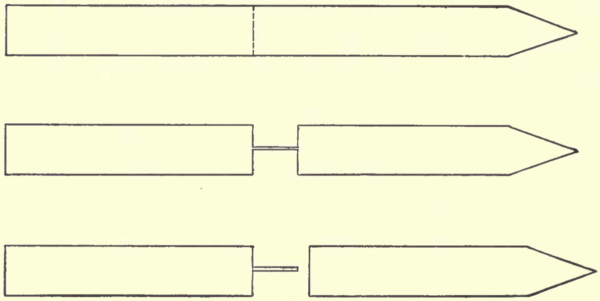

Fig. 11. Method of Cutting Candles.

It is the writer's practice to cut off a small portion of this end of the wick with a sharp knife, as it is nearly always frayed and does not give a clear-cut glowing end.

The halves being in the condition shown in Fig. 12, are now ready for use. Bring the flame of the match in contact with the end of the wick, and when the latter is ignited, invert the candle over the waste box, holding it at a slight angle to the perpendicular. Revolve slowly in the fingers until the sperm at the base of the wick melts and drops off and a cup-shaped depression is formed. Then reinvert and insert in the candle holder. After a short period the wick will begin to curve at the end, and the point thereof to glow.

The glowing end of one wick should point towards the disc and that of the other towards the observer; thus the two wicks form a right angle with each other. The reason for this position is simple; if both ends pointed towards the disc, the smaller areas of the flames would be towards the latter and the results would be too favorable to the gas; while if both wicks were parallel to the disc, the converse would be true.

In lighting candles which are in the holder and which have already been used, it is only necessary to apply a flame to the wick, and as soon as it is ignited, place a drop of sperm in the cup at the base. This latter precaution is observed because when first lighted the sperm of the candle is hard and does not soften immediately, and so the wick has difficulty in drawing up the fuel necessary for combustion. The drop placed in the cup relieves this strain until such time as the sperm around the wick shall have become softened. *In no case* touch the wick with any hard object, or it is extremely liable to be injured.

When burning properly the wick should curve at nearly a right angle to the length of the candle, and the end should be small and glow with a clean red heat. The cup at the base of the wick should extend the full diameter of the candle and should be fairly dry. The outlines of the cup should be regular, and all sides should be of approximately the same height. There should be no loose strands to the wick, which should be perfectly smooth from base to end.

The flame tip should be smooth, rounded and without smoke. The height of the flame will furnish indication as to whether the candle will burn faster or slower than the standard time. The candles should project from one inch to 1½ inches above the holder, and care should be taken to see that they are vertical.

One of the greatest troubles with candles is the fact that so often they cannot be made to burn within the required limits, and consequently the test has to be discarded. Candles that persistently err in this respect should be unhesitatingly discarded, but the cause is sometimes due to a local condition and may be remedied.

A hot, ill ventilated room will generally cause the candles to burn slow, and after airing out they will often assume their normal rate. If the cup is too full of sperm the candle will be slow. This may sometimes be remedied by drawing out some of the liquid with a piece of blotting paper. If, however, the cup persists in filling, the candle should be discarded.

If the rate of consumption is too great it may occasionally be lowered by taking the candle from the holder and inverting over the waste box while still lighted, as in the case of preparing a fresh candle for use. If the end of the wick refuses to glow, as is often the case after it has been touched or improperly extinguished, let a drop of sperm carefully fall on the very tip and wait 15 or 20 minutes; the glow will generally reappear after such treatment.

If there are loose fibers projecting from the wick, or if it does not curve properly, the only thing to do is to cut it off close to the candle and prepare the latter afresh, as if it had not been used. In case the wick is not very nearly in the center of the candle, the latter should be at once discarded.

The candle should be allowed to burn from 15 to 20 minutes before a test is commenced, in order that they may assume their normal rate. It will mean a very considerable saving of time if the operator will study the candle flames and learn to tell when they are approximately normal. This judgment can be acquired with some practice, and its employment is vastly superior to the custom of making a test at whatever rate the candles may be burning and then being obliged to discard the results because the rate of sperm consumption was abnormal.

It is always well to see that the flames of both candles and gas are opposite the center of the disc, and this may be easily accomplished by holding a pocket mirror before the disc and inclined at a slight angle thereto. The reflection in this mirror will serve to show whether all of the light from the flames is reaching the disc, and whether either gas or standard is too high or too low.

Assuming now that the above details have been attended to, the actual operations of the test may be taken up. Darken the room and shut off all drafts. If a closed-bar photometer is being used the door of the gas end should be closed, or nearly so. It does no harm in a darkened room to leave this door ajar, and it has the advantage of improving the ventilation. Adjust the balance so that the candle end is slightly the heavier, and with stop watch in hand watch for the swing. As the pointer passes the center of the scale start the watch, drop the 20-grain weight gently into the pan, and close the door, if there be one. In case of a 10-minute test with two candles, a 40-grain weight should be used, and with a 5-minute test and but one candle the weight should be only 10 grains.

At the expiration of exactly 30 seconds from the starting of the watch, read the meter and record the result. In making readings of the disc, set the latter where the two sides have a nearly equal illumination, and then move so that first one side and then the other seems brighter by distinct but decreasing amounts, until the point is reached where the illumination of both sides is exactly the same. Record the reading of the pointer on the scale and repeat the operation from 10 to 20 times at regular intervals throughout the period of test, reversing the disc for the last half of the time.

This reading is the most difficult part of the operation to the unexperienced, and nothing but practice will develop an expert. There are, however, a few suggestions to be made which may prove of service. In the first place, never look at any strong light just prior to making readings. The retina of the eye is extremely sensitive and will retain the impression of the light to such an extent that any accurate comparison of intensities is impossible. The writer makes it a practice to discard his first reading, since, even if no strong light has been viewed, the eye requires a moment or two to accommodate itself to the comparative darkness of the sight box.

Again, it is well to make the readings rather rapidly, for the eye soon becomes fatigued with the strain of comparing intensities; for this reason the observer who takes a long time for each reading in the hope of making it absolutely correct is liable to obtain poorer results than the one who reads more rapidly.

In moving the sight box care must be taken, especially with the closed-bar photometer, that its motion is not fast enough to cause a draft and thus produce flickering of the candles.

The observer is cautioned not to mistake difference in color for difference in intensity, since the color of the gas flame is different from that of any of the standards used. He should not try to observe both sides of the disc at once; the best comparison is made by viewing one side and then the other as rapidly as possible and mentally comparing the impressions.

At the end of exactly 4 minutes and 30 seconds the reading of the meter is again taken, and then the balance must be constantly watched until the pointer again passes the center of the scale, when the watch is stopped and its reading recorded. If on looking over the figures it is found that the gas has not burned very close to the five-foot rate, that the readings with a two-candle balance have varied by more than 0.5 candle, or that the rate of the candles is more than 15 seconds from the normal, the test should be repeated. With a two-candle standard there should be no difficulty in obtaining consecutive tests which check within 0.3 to 0.4 candlepower, and very much better than this can usually be done by a skilled observer.

In extinguishing the candles, let fall a drop of sperm on the glowing end of each wick and immediately blow out the flame. This is very important and will leave the candle in such condition that on relighting it will soon reach its normal rate.

Calculations. There are two or three methods of making the calculations; in one, factors for the various corrections are found by consulting tables prepared for the purpose and similar to the one in the appendix; another uses the candlepower computer, on which it is only necessary to set various results against each other on the two scales and the corrected candlepower may at once be read off; while a third method consists in the use of percentages entirely. The first two processes are in far more general use than the third, and the only claims against them are that they are not especially easy to understand and manipulate and that to use them in more than one place means the necessity of carrying tables or computer always on the person. The percentage method, while theoretically not quite as accurate, is far simpler, requires no tables or other paraphernalia, and gives results which are far more accurate than many of the factors in the candlepower determination. As the first two methods have been described many times, they will not be dealt with here, but the third method will be explained and used throughout this volume.

There are four corrections to be applied to the average of the disc readings before the corrected result can be obtained: (1) for the temperature; (2) for the barometer; (3) for the rate of the gas; (4) for the rate of the candles. The standard conditions of temperature and pressure are 60° F. and 30 inches pressure, and if we measure the gas under any other conditions, it is clear that we are not getting the actual volume.

Thus, consider for a moment 1 cubic foot of gas A B C D under standard conditions. Suppose now that keeping the pressure constant we increase the temperature from 60 to 70° F. The result will be that the gas will expand and that the original cubic foot will now occupy a greater volume, as A B E F. The result would have been the same if, keeping the temperature constant, the pressure had been reduced a certain amount. Now, when the gas volume is read on the meter at 70 degrees, the result is A B E F, or, for example, 5.13 feet, whereas, really, but 5 feet of gas have been consumed. If the corrections are made on the assumption that 5.13 feet has been the rate, we are obviously doing the gas an injustice, and must add to our result an amount sufficient to counterbalance this.

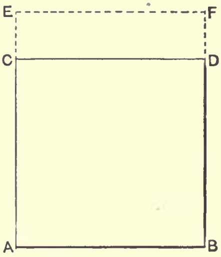

Fig. 12. Illustrating Expansion of Gases.

It has been found by calculation and experiment that with gas saturated with moisture, as is practically the case after passing the wet meter, a correction of 1 per cent must be made for every 0.3 inch variation of the pressure from 30 inches, and also 1 per cent for every 4 degrees variation of the temperature from 60 degrees. From what has been said above, it will be clear that these corrections are to be added if the temperature is above

60 degrees or if the barometer is below 30 inches; and *vice versa*, they are to be subtracted if the temperature is below 60 degrees or the barometer above 30 inches. The correction of 1 per cent for every 4 degrees of temperature does not strictly hold above 77° F., but as gas is seldom tested at temperatures greater than that, and as the error only reaches tenths of a per cent, the result is well within the general limits of accuracy of the process.

With the candles a correction of 1 per cent for every 3 seconds above or below the standard of 5 minutes for burning 10 grains is customary. This is derived as follows: One candle should burn 120 grains per hour, or 10 grains in 5 minutes; 5 minutes equals 300 seconds, and 1 per cent of 300 seconds is 3 seconds. If the candles are fast, that is, if they consume 20 grains in less than 5 minutes, they are evidently giving out more light than they should, and consequently making the readings lower than they would be with normal candles; therefore, for fast candles, the correction should be added, and for slow ones it should be subtracted.

If the gas burns faster than 5 feet per hour, it is giving out more light than it would under standard conditions, therefore a minus correction is necessary, and this is figured out in the following way: Subtract 5 feet from the number of feet consumed per hour, multiply the difference by 100, divide by 5, and the result will be the percentage to be subtracted.

A concrete illustration will make the above remarks clearer. The following figures represent the data secured in an actual test.

Temperature of gas, 70° F.
Barometer, 30.12 inches.
Two candles burned 20 gr. in 4 minutes 48 seconds.
Average reading on the bar, 8.50.
Reading of meter at end of 4 minutes, 0.502
Reading of meter at start, 0.166
Difference, 0.336 foot.

If the gas consumed in 4 minutes was 0.336 foot, in one hour the rate would be 0.336 times 15, or 5.04 feet; (5.04 minus 5.00) times 100 divided by 5 equals 0.8 per cent minus. The temperature is 10 degrees over 60; 10 divided by 4 equals 2.5 per cent plus. The candles burned in 12 seconds less than 5 minutes; 12 divided by 3 equals 4 per cent plus. The barometer is 0.12 inch over 30 inches; .12 divided by .3 equals .4 per cent minus. The corrections for rate of gas and for barometric pressure are minus, while those for temperature and candles are plus. Combining these we get 5.3 per cent plus, and dividing the average readings by 1.00 minus .053, the corrected reading is found to be 8.98; and since a two-candle standard was used, the true candlepower is 8.98 times 2, or 17.96.

In this example it has been assumed that the meter read in thousandths of a foot, that a two-candle balance was used, that the scale read direct in candlepower for a one-candle standard, and that a 5-minute test was made. If only one candle had been employed, a 10-grain weight would have been used instead of the 20-grain, and the readings would have been twice as great. Occasionally a scale reads direct in candlepower for a two-candle standard, and in such cases the multiplication of the corrected reading by 2 is, of course, omitted.

If a leak is discovered at the close of the test, allowance must be made for it in the calculations. This is done by finding the amount of the leak as read from the meter in 4 minutes, and deducting it from the gas consumed during the 4-minute test, since this leakage gas did not help in any way to increase the candlepower, and yet was included in the calculation of the amount of gas burned per hour.

The figures which are likely to be met in a 10-minute test, with the meter divided into twelve hundredths of a foot, and a two-candle standard, can best be seen from the following:

Temperature, 56° F.
Barometer, 29.73 inches.
Average readings on bar, 10.17.
Time to burn 40 grains of sperm, 10 minutes 12 seconds.

Reading of meter at end of 9 minutes,	1.555
Reading of meter at start,	0.637
Difference,	0.918

Rate of gas equals 918/1200 times 60/9 equals 5.1 feet per hour. Correction for gas, (5.1 minus 5) times 100 divided by 5 equals 2.0 per cent minus. Correction for the candles (1 per cent for 6 seconds on a 10-minute test), 2 per cent minus. Correction for temperature, 1 per cent minus and for barometer 0.9 per cent plus. Combined correction, 4.1 per cent minus. The corrected candle-power equals (10.17 times 2) divided by (1.00 plus .041) equals 19.54.

The 10-minute test is very generally employed and has certain supposed advantages as to accuracy; the 5-minute test is the one employed by the state inspectors in New York and Massachusetts and in many municipalities, and has the advantage of economy of time (which is especially important to a traveling inspector) and also of decreasing somewhat the difficulties encountered in the use of candles.

CHAPTER IV.

PHOTOMETRIC WORK WITH OTHER STANDARDS AND GASES.

Pentane Lamp. The Pentane lamp has been described in an earlier chapter, and it is now only necessary to study its preparation for, and use during a test. The first thing is to see that the pentane to be employed is of the proper quality. The preparation and testing of this compound cannot be better described than by quoting from the "Notification of the Metropolitan Gas Referees" for 1907.

"*Preparation.* — Light American petroleum such as is known as gasoline and used for making air gas, is to be further rectified by three distillations, at 55° C., 50 and 45 degrees in succession. The distillate at 45 degrees is to be shaken up from time to time during two periods of not less than three hours each with one-tenth of its bulk of (1) strong sulphuric acid; (2) solution of caustic soda. After these treatments it is to be again distilled, and that portion is to be collected for use which comes over between the temperatures of 25 and 40 degrees. It will consist chiefly of pentane, together with small quantities of lower and higher homologues whose presence does not affect the light of the lamp.

"*Testing.* — The density of the liquid pentane at 15° C. should not be less than 0.6235, nor more than 0.626, as compared with that of water of maximum density. The density of the pentane when gaseous as compared with that of hydrogen of the same temperature and under the same pressure, may be taken. This is done most readily and exactly by Gay-Lussac's method under a pressure of about half an atmosphere and at temperatures between 25 and 35 degrees. The density of gaseous pentane should lie between 36 and 38.

"Any admixture with pentane of hydrocarbons belonging to other groups and having a higher photogenic value, such as benzene or amylene, must be avoided. Their presence may be detected by the following test. Bring into a stoppered 4-ounce bottle of white glass 10 c.c. of nitric acid, specific gravity 1.32 (made by diluting pure nitric acid with one-half its bulk of water); add 1 c.c. of a dilute solution of potassium permanganate containing 0.1 gram of permanganate in 200 c.c.

"Pour into the bottle 50 c.c. of the sample of pentane, shake strongly during 5 successive periods of 20 seconds. If no hydrocarbons other than paraffins are present, the pink color, though somewhat paler, will still be distinct; if there is an admixture of as much as one-half per cent of benzene or amylene, the color will have disappeared."

If the lamp to be used has been standardized by responsible parties, it will have a value assigned to it which may be used in all calculations; if it has not been authoritatively standardized, its value should be determined by testing the lamp against candles. Since the latter are liable to vary, it is best to make a large number of determinations, using many different candles in order to arrive at a correct result. The standardization is accomplished by placing the lamp in the position usually occupied by the gas pillar, with the flame opposite the center of the disc and with the plumb bob suspended from the burner at exactly the correct distance from the center of the scale. The determination is then made in the manner described above for gas, save that the only correction to be applied is for the rate of the candles. The factor thus derived will be very close to 10, and should hold good for a year, provided no change is made in any of the parts of the lamp.

The latter should now be so set up at the end of the bar opposite to the gas that the bob hanging below the burner shall be exactly in line with those which we have already seen employed for the alignment of the candles. The center of the flame when properly adjusted should be at the same height as the center of the disc. Next the instrument is to be leveled by means of the screw legs of the tripod; this is in order that the burner and chimney may be vertical. After the leveling it will doubtless be found that the plumb bobs are no longer in line; if so, this must be rectified. When the lamp is lighted the plumb line should bisect the flame, and this should be carefully observed.

In filling the lamp remember first of all that pentane is extremely inflammable, and see that all flames are excluded from the room. Open both inlet and outlet cocks to the saturator box, and also the drip cock at the bottom of the vapor tube. Fill the saturator two-thirds full of pentane and close all cocks. The height of the liquid against the window in the side of the saturator should never be less than $\frac{1}{8}$ inch. The lower end of the chimney tube is next set exactly above the steatite ring burner, and 47 mm. distant therefrom. This is easily accomplished by means of the boxwood gauge, which is furnished with the lamp, but before using this gauge the conical shade about the burner must be removed. If the chimney is not centrally over the burner, it may be brought to this position by means of the three adjusting screws in the base of the outer chimney. These screws should be tightened only enough to maintain the chimney tube in its central position. This adjustment being made, the conical shade is replaced with the opening so located that all of the flame below the chimney may be seen from the position of the disc.

In lighting and regulating the lamp the following instructions are taken from the "Proceedings of the American Gas Institute" for October, 1907:

Lighting. — The regulating cock being closed, open first the outlet cock on the saturator box; then open the drip cock. At or above 60° F., it is likely that vapor pressure will have accumulated in the saturator. The drip cock will permit its release and fill the tube with vapor ready for the siphon action upon which the supply of fuel depends; and furthermore, discharge the excess vapor below the position of the flame.

The inlet cock is then opened to establish atmospheric pressure in the saturator, and the drip cock is closed. Light a match and hold over, but not touching, the steatite burner. Gradually open the regulating cock, when the vapor will ignite gently if feeding properly.

Should there at first be an excess of air in the burner, the flame will burn with a greenish center, and as the proper proportion of the mixture is obtained, a small explosion will take place, extinguishing it. Relight at once without changing the regulating cock, when the flame will burn normally.

Its shape at first will be purely conical, but as the hot air inner feed increases, the cone will be bulged, and its top will open into a ring.

Regulating. — During the 15 minutes while the flame is maturing, or the lamp reaching a thermal equilibrium, the flame should be, from time to time, regulated to the height of the crossbar. If it be too low, it will take longer to mature; if it be too high, it will smoke the chimney. When the flame remains steady and it is time for the reading, set its height as follows: Move the disc box near to the lamp; stand in rear of the lamp, looking first at the mica window and then past it at the reflection of the flame front in the disc glass. Lower the flame top below the chimney. When it is perfectly quiet, slowly raise it until its reflected image shows wholly luminous at the base of the chimney. This is the position of maximum intensity of the flame. A further rise of one-fourth inch will not materially affect the value of the lamp. The flame top draws to three luminous points. If the lamp is free from drafts and the air is pure, the flame height will be approximately correct when these points are at the height of the crossbar in the American lamp. The lamp is now ready for use.

Now, having aligned the gas burner, and rated the flow of gas to 5 feet per hour, start the watch as the long hand of the meter passes some particular point on the dial and record the reading. Make from 10 to 20 readings of the disc, reversing the latter for the last half of them. Note and record the reading of the meter after exactly 5 minutes have elapsed. The corrections for barometer, temperature and rate of gas are now applied to the average readings in exactly the same manner as when the candles are used as a standard; but the corrected reading thus obtained must then be multiplied by the value of the lamp, and this result will be the true candlepower of the gas.

Example. Value of the lamp, 9.95 candles; average readings on the bar, 1.84; temperature, 62 degrees; barometer, 30.24 inches; gas burned in 5 minutes, 5.12 revolutions of the large hand, or $\frac{512}{1200}$ of a foot. The corrections are: Temperature, 0.5 per cent plus; barometer, 0.8 per cent minus; gas, 2.4 per cent minus; total, 2.7 per cent minus. $(1.84 \div 1.027) \times 9.95 = 17.81$, the corrected candlepower. In extinguishing the lamp simply close all of the cocks, commencing with the inlet cock to the burner.

Elliott Lamp. The fuel recommended for use with this lamp is Pratt's astral oil, a variety of kerosene which does not need to be tested, both because of its general uniformity and because any variation in the oil would make but little difference, since the lamp is filled and standardized each day. The filling is accomplished in the same manner as with the old-fashioned student lamp. The chimney must be thoroughly cleaned each time before use, and it is well to select a certain side which shall always be presented towards the disc. If a fresh wick is to be used, place the sheet brass pattern which comes with the lamp over the wick and trim to conform to this pattern. Singe the top of the wick to free it from fluff and to secure a smooth, even surface. If the wick has been used before, trim the top very carefully with a pair of sharp shears, taking great pains to remove only the soft carbon and not to cut into the wick itself. The wick should be changed at least once a week, as experiments made by the writer show that the lamp depreciates in value and loses its constancy even over a period of 12 hours where the wick is old. Place the lamp at the standard end of the photometer; light the same and let it burn quietly for 10 minutes. Bring the flame in line with the plumb lines, opposite the center of the disc and perpendicular to the axis of the photometer. Then adjust the flame so that the top thereof is not over one-quarter of an inch above and parallel with the upper edge of the diaphragm.

If properly trimmed and set, nothing but the luminous part of the flame should be visible through the diaphragm; it usually happens, however, that the blue portion rises slightly above the lower edge of the opening, and this cannot be prevented. If the center of the flame rises too high, it may be remedied by trimming the top of the wick a trifle concave. After the flame is properly adjusted, allow the lamp to burn 20 minutes before commencing the test, which is conducted in exactly the manner described for the Pentane lamp, and the calculations are the same, so that these need not be repeated here.

Edgerton Standard. The most important factors in connection with the use of this standard are to see that it is properly and frequently standardized and that the chimney is kept clean. If convenient, it is desirable that the gas used in the standard should not vary; this may be accomplished by filling a small holder with gas of uniform quality. Either water gas or coal gas may be used, but it must be remembered that the value of the standard will not be the same for the two. In standardizing, place a definite portion of the chimney towards the disc, and in all future work keep the same portion in that position. The flame is to be 3 inches high, though a slight variation from this will not materially affect the results. The work of ascertaining the value of the Edgerton, together with its use as a standard, is so similar in principle to the methods described for the Pentane and Elliott lamps, that it does not seem necessary to go into detail regarding them.

Hefner Lamp. The fuel used in this is a chemical compound known as amyl acetate and will as a rule be purchased ready for use, since its preparation and purification at the works or laboratory of the inspector would in the end prove costly. Amyl acetate has the formula $C_5H_{11}.C_2H_3O$, and may be called the amyl ether of acetic acid. It boils at 148° C., and consequently is very much less inflammable than pentane. Its specific gravity is 0.874; it is soluble in alcohol and ether, but not in water. It should be possible to secure this chemical in a perfectly pure condition, but if there is any doubt on this point it may be settled by testing its gravity and boiling point, and if impurities be present, they may be eliminated by fractional distillation.

In addition to the above tests the "Physikalische Technische Reichsanstalt" recommends the following: When distilled in a glass retort at least 90 per cent should pass over between the temperature limits of 137 and 143° C. Its reaction should be practically neutral, and blue litmus paper should not be sensibly reddened by it. It should mix, bulk for bulk, with ether, benzine or carbon bisulphide without becoming milky. A drop placed on white filter or blotting paper should evaporate without leaving a greasy spot. It should be kept in a glass-stoppered bottle and in a dark place, as it has a tendency to decompose in a strong light.

Stine, in his "Photometrical Measurements," gives the following description of the proper method of operating the Hefner lamp: The character of the wick is practically without influence on the illuminating power of the lamp if it does not fill the tube tightly. The wick should be washed in distilled water, then soaked for a time in a 1 or 2 per cent solution concentrated ammonia, and finally thoroughly washed in distilled water.

To prepare the lamp for use, insert the wick in the wick tube and test the adjusting wheel train, which must move the wick easily and smoothly without catching in its threads or sticking. Then the top of the wick should be trimmed off straight and smooth with the top of the tube, using sharp scissors and avoiding irregularity of surface or stray thread ends. The top of the lamp is unscrewed, and the amyl acetate is poured into the lamp until it is nearly filled, leaving sufficient space so that the addition of the wick will not cause an overflow. Screw the top in place, and after the wick has become thoroughly wet, light it, adjust the flame to the normal height, and place the lamp in position on the photometer bench. Allow it to burn for 20 to 30 minutes in order to become constant. The vent holes on the top plate near the wick tube must be watched and kept open.

As soon as the determination is completed, the lamp should be emptied and cleaned, for the metallic parts are liable to corrosion from the action of decomposition products of the amyl acetate. The wick should be removed and the lamp and wick tube well rinsed with ordinary alcohol. The wick itself is to be thoroughly washed in clean alcohol, dried and stored in a tightly stoppered test tube. The amyl acetate which is poured from the lamp after a determination should be thrown away and not used for another test. This does not mean a great waste, for unless the lamp is to be used over a long period it need not be completely filled at the start, as Dr. Stine's procedure would indicate. If but one test is to be made, a very small amount of amyl acetate will answer, since so long as the ends of the wick all rest in the fluid, the supply is sufficient for the flame. Repetition must also be made of two of the precautions already mentioned, as they are extremely important: (1) See that the flame height is *exactly* correct. (2) Allow no draft or jar to affect the test.

Candlepower Tests of Other Gases. While the general procedure for taking the candlepower of acetylene, oil, gasolene and natural gases is the same as has already been described for coal and water gas, there are certain points of difference, especially with respect to the burners employed, which it may be well to note here. With a straight oil gas whose candlepower will be from 45 to 60, none of the burners hitherto mentioned will give satisfactory results, due doubtless to the fact that not one of them provides the proper amount of air for combustion. A 3-foot iron tip burner has been found by the writer to give excellent results, and is therefore recommended for this quality of gas. It is clear that the rate of consumption in such a burner cannot even approximate 5 feet per hour, and it has been demonstrated by experiment that the highest results are obtained when the gas is burning at a rate of from 0.75 to 1 foot per hour. It will often be found desirable to try more than one rate in order to be certain of securing the maximum results, although a practiced observer can generally judge by his eye when the flame has reached its point of greatest efficiency. The correction for this consumption of gas may be applied in exactly the same manner as previously described; or the average readings, corrected for candles, barometer and temperature, may be multiplied by 5 and divided by the rate per hour.

In testing acetylene great precautions must be taken to guard against leaks or escape of gas, since it is an extremely explosive substance. Like oil gas, it requires a special burner consuming about 1 foot per hour, and on account of the wide limits of its explosibility with air, peculiar provisions have to be made to insure the presence of only the requisite amount of air. There are several burners on the market which have solved these problems, and of these either the Perfection No. 3 or the Bray burner will give very good results, although the former yields slightly the higher candlepower. The Perfection burner, however, must not be turned down or it will carbonize, while the other may be regulated without this objection. The burners are very delicate, and should be watched to see that the lava is not chipped and that the holes do not become plugged. If the latter occurs, use great care in cleaning them in order not to enlarge the aperture or chip the edge. The rate to be employed with these burners is 1 foot per hour, and the correction is made as in the case of the oil gas.

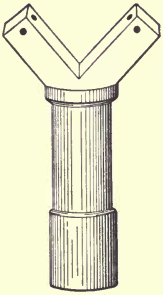
Fig. 13.
Acetylene Burner.

With gasoline gas the Tirrill burner seems to give the best results, and the rate of consumption with this should be about 6 feet per hour.

Natural gas is seldom tested for illuminating power, since it is almost entirely used in Welsbach mantles and heating appliances. The writer has, however, made a few tests of such gas for candlepower and secured very satisfactory results with the new F Argand burner. It was impossible, however, to make the tests at the 5-foot rate, and the gas was turned down so as to fill about half the chimney, and the proper correction made for this reduction of rate. The gas as tested burned 3.2 feet per hour, and the blue part of the flame was unusually high.

CHAPTER V.

INTERPRETATION OF RESULTS AND LEGAL REQUIREMENTS.

WHILE this work is in no sense intended as a treatise on the manufacture of gas, it cannot entirely ignore that subject. The mere figures denoting the candlepower are valueless unless deductions can be drawn therefrom which will result in increased efficiency and economy at the works. It would seem, therefore, that no apology was necessary for discussing some of the more important factors affecting candlepower, in order that the photometer may prove to the manager a true and useful friend.

Taking first the question of coal gas, the coal used is of course one of the most important factors. Where the laboratory facilities permit, it is very desirable that every fresh shipment of coal should be analyzed, and if possible some contract made with the coal company which should bind the latter to certain specifications. If such analysis is made, the principal attention should be devoted to the fixed carbon, volatile matter, moisture and sulphur, since the first three of these affect the quantity and quality of gas and coke, while the last appears as a very objectionable impurity in both gas and by-products. The coal as charged into the retorts should contain as little moisture as possible, as this has a powerful effect in lowering the temperature of the retort, by reason of the large amount of heat absorbed in converting the water into steam, or to speak technically, by reason of the high latent heat of steam.

The next point to be considered is with regard to the yield. Ten years ago it was not difficult to make 5 feet or even 5.25 feet of gas per pound of coal and still maintain a satisfactory candlepower; but to-day such a result seems to be almost impossible, unless the plant is equipped with modern apparatus, the best of gas coal is purchased and the entire operation of gas making is conducted with the greatest skill. Otherwise the best practice would indicate 4.75 to 4.9 feet per pound as the maximum safe yield.

If the gas is to be enriched, however, a much larger yield may be obtained, yet a not inconsiderable portion of candlepower difficulties arises from this very fact of enrichment, which was intended to abolish them. It is an old story familiar to every inspector of wide experience; the manager will state that he has enriched his gas and that therefore it must be satisfactory. Let us examine this statement a moment.

The enrichers most commonly employed are cannel coal, benzol and oil. Cannel gives off a very rich gas, and if this be burned at the proper heats and well mixed with the gas to be enriched, it will serve its purpose admirably. It is possible, however, by lack of attention to the above points, to use cannel and not secure the desired results. This is also true of oil enrichment, while with benzol the increase of candlepower depends on two factors, (1) whether the benzol is so cracked up and mixed with the gas to be enriched as to form a permanent gas; (2) whether the gas from the retorts is of the right quality to carry the benzol. The writer has seen tests of benzol-enriched gas where the finished product was of no higher candlepower than the unenriched gas, due to the fact that nearly all of the enriching material was dropped from the gas before reaching the place of test.

The treatment which the gas receives in the retorts, washers, etc., is perhaps the most important factor governing the quality of the finished product. If the heats in the retorts are low and the charge is not left in too long, a gas high in candlepower may be secured, but the yield will be too small. If the heats are high and the exhauster is pulling strongly, a large yield will be obtained, but the higher hydrocarbons, which are the light-giving factors, will be decomposed into the lower forms; hydrogen will be liberated in large amounts and the candlepower will suffer.

Hornby, in his "Gas Manufacture," says: "As the gas passes down the heated retort on the way to the ascension pipe, it comes in contact with the heated sides of the retort, and this and the radiant heat in the retort cause the following reactions: Ethane splits up into ethylene and hydrogen, while ethylene decomposes to methane and acetylene, and the latter at once polymerizes to benzene, styrolene, retene, etc. A portion also condenses and at the same time losing some hydrogen, becomes naphthalene; and the compounds formed by interactions among themselves build up the remainder of the hydrocarbons present in the coal tar, while the organic substances containing oxygen in the coal break down and cause the formation of the phenols in the tar. . . . At comparatively low temperatures you get plenty of tar and little gas, the latter, however, of high candlepower. As the heat is increased the liquid hydrocarbons decrease and gaseous products increase; that is, you get more gas and less tar. At still higher heats the gaseous products are richer in hydrogen and poorer in carbon, and methane is formed abundantly. Finally at still higher heats free hydrogen is given off, this always occurring towards the end of the operation of gas making."

In the advanced course of "Self Instruction for Students of Gas Manufacture" by Mentor, the following table is given to show the effect of temperature on the composition of the gas.

Temperature.	Hydrogen.	Methane.	Olefines.	Carbon Monoxide.	Nitrogen.
	%	%	%	%	%
Dull red	38.09	42.72	7.55	8.72	2.92
Hotter	43.77	34.50	5.83	12.50	3.40
Bright orange	48.02	30.70	4.51	13.96	2.81

Now by considering the value of each of these constituents for illuminating purposes, the influence of the temperature in the retorts may readily be seen. In Latta's "Hand Book of Gas Engineering Practice" the candlepowers of four of the principal illuminants are given as follows: benzene, 349.0; ethane, 35.0; ethylene, 68.5; methane, 5.0.

The Massachusetts State Gas Inspector in his report of February, 1885, says: "80 to 90 per cent of each gas is composed of diluents or light bearers. These are hydrogen, methane and carbon monoxide. None of these give any light when burned alone, but do give considerable heat. Equal volumes of hydrogen and carbon monoxide give about equal quantities of heat when burned; but methane gives about three times as much heat as either. The heat furnished by these gases in burning helps to raise the temperature of the particles of carbon set free from the illuminants when these are decomposed by the heat of the flame. Small quantities of carbon monoxide up to 12 per cent can be added to coal gas and the light will be increased thereby. But if as much as 20 per cent of carbon monoxide is added, the light is considerably diminished. Hydrogen may be advantageously present in coal gas up to 40 per cent of the entire mixture." The effect of carbonic acid in gas has likewise been investigated by the Massachusetts inspector, and is shown in tables in the appendix.

The value of the gas as an illuminant also depends upon the length of time which it takes to carbonize the charge. Butterfield, in his "Chemistry of Gas Manufacture," says: "The gas evolved shortly after coal is placed in a retort at an ordinary carbonizing temperature contains the gases occluded in the coal. These are mainly nitrogen and methane, with small quantities of oxygen, carbonic acid and other gases; consequently the illuminating power of the gas coming from the retort during the first half hour after charging is very low. Then it rises rapidly and the gas evolved during the next hour is the best obtained from the charge. If the heat of the retort is low, this period is prolonged, and the gas is even richer. But from the middle or end of the second hour to the end of the third hour it may be taken that the gas will be considerably poorer, and thence to the end of the distillation that it will be very poor indeed. The period at which the richest gas is produced is also that of the most rapid production, though the rate of evolution does not fall off markedly during the ensuing period."

The tendency of a considerable vacuum within the retorts is to draw in air and furnace gases through cracks in the walls of the retort, or through imperfectly sealed lids. The effect of carbonic acid on candlepower has already been mentioned, and that of air may be gathered from experiments of the Massachusetts inspectors, made in 1893, which are summarized in a table given in the appendix. Experiments by Wurtz gave even greater losses of candlepower than are shown in this table, running from 15.69 per cent loss of light for an addition of 3 per cent of air up to 84 per cent loss for 25 per cent of air.

The gas coming from the hydraulic main is at a temperature of about 130 to 150° F., and if this were suddenly chilled it is certain to drop a large share of its illuminants, and even after leaving the purifiers a sudden drop in temperature will cause a loss of candlepower which is in inverse ratio to the degree of fixation of the gas. That is to say, a gas in which the hydrocarbons are poorly cracked up will lose far more in candlepower than one where they are well fixed. The amount of water used in the scrubbers also has an influence on the candlepower. If in the desire to remove all traces of ammonia a large amount of fresh water is used, the candlepower is liable to suffer; the remedy is to repeatedly run the same water through the scrubber. This will naturally be done in any case where the ammonia liquor is to be sold, and the suggestion is made for such of the smaller plants as do not recover their ammonia.

Water gas is made by passing steam through a bed of incandescent carbon and enriching the product by means of oil. The factors which in this process tend to decrease the illuminating value of the yield are: (1) the admission of too large an amount of steam; (2) insufficient heat in the generator; (3) fires not clean or fuel bed too low; (4) incorrect relation between blows and runs, or wrong lengths of either; (5) poor carburation. The reactions concerned in the manufacture of water gas are, generally speaking, 4 in number.

$$\begin{aligned}
&(1)\quad C + 2H_2O = CO_2 + 2H_2.\\
&(2)\quad C + H_2O = CO + H_2.\\
&(3)\quad C + CO_2 = 2\,CO.\\
&(4)\quad CO + H_2O = CO_2 + H_2.
\end{aligned}$$

The first commences at about 600° C., the second at 1000 degrees, while the other two are liable to take place, to varying extents, between 700 or 800 degrees and 1200° C. It is evident that the first and fourth reactions must be prevented if possible; the one is caused by a lack of heat in the generator and the other by the presence of too much steam or too little fuel. As the steam passes up through the lower layers of the fuel, the temperature at that point is reduced and reaction one takes place.

The carbonic acid formed, passing upward through hotter and hotter layers, reacts with the carbon according to equation three, and thus the objectionable carbonic acid is largely excluded from the finished product. Now, if too much steam is supplied, it means the cooling of larger areas of the generator; the steam rises intact to the upper layers of fuel, reactions two and three are prohibited, while numbers one and four are carried out, and as a result large quantities of carbonic acid pass over into the carburettor. If on the contrary the admission of steam be too slow the yield will be small; so that a happy medium must be struck and this can best be found by experiment in each individual case.

If the fuel bed be too low the carbonic acid formed at the bottom passes out at the top without having been reduced to carbon monoxide, and the same effect is produced by insufficient heat in the generator.

If the length of the blow is too great, there is a waste of fuel; while if it is too short, the generator and its contents are not raised to the temperature necessary for the vital reactions.

If the run be too long the fuel bed becomes cooled below the point at which carbon monoxide is formed and retained, and again carbonic acid passes off in the product.

Thus it will be seen that most of these difficulties sum themselves up in the words "carbonic acid"; consequently the gas should be constantly tested for this substance, and when it is found to be present to the extent of over 3 or 4 per cent the indications are that some of the above-mentioned factors are at work. The determination of carbonic acid is easily and quickly made and the various methods and details will be thoroughly given in the chapter on chemical tests.

Air or nitrogen is nearly always present in water gas to some extent and is due to the amount left in the generator at the end of a blow and to the nitrogen in the coal. Its percentage is usually small, however, unless entering from some other source, in which case the effect on the candlepower will be marked, as has been already demonstrated for coal gas.

In the superheater care must be taken to see that the heat is sufficient to insure the permanency of the oil gas, otherwise there will be a considerable loss of candlepower, due to condensation of the oily vapors. If the generator, carburettor and superheater are in one, as is the case with some of the older types of apparatus, there is danger not only of not properly fixing the oil gas, but also of maintaining so high a temperature that the oil will break down and deposit carbon.

Chilling of the gas in the holder or mains will often cause a seemingly disproportionate loss of candlepower, and this can generally be traced to improper fixation of the oil gas.

With oil and acetylene gases the candlepower is usually so high that it seems needless to consider any possible causes of loss in that respect, save as they are related to the calorific value, so that the subject will be dismissed for the present with a few words. With acetylene the principal cause of diminution in candlepower is overheating in the generator; this frequently happens in the water-to-carbide type of machines and results in polymerization of the acetylene and formation of benzene, styrolene, etc. Not only is the yield thus reduced and the candlepower lowered, but the tarry products formed by overheating cause carbonization of the burners, which become choked and smoky. The evidence of such overheating will also be found on the lime left after generation, for whereas it should be comparatively white, if overheating has occurred, it will be of a dirty yellow or brown color and may contain deposits of tarry matter.

In the case of oil gases it is a not infrequent practice to mix them with air. This in itself is perfectly proper since it serves a useful purpose in diluting a gas which is too rich in ordinary burners and in supplying oxygen to assist in the combustion of the heavy hydrocarbons; but it is always possible that more air will be admitted than can be handled by the gas, in which case the candlepower will of course drop to a marked extent. The writer has tested a gas of this type, which under ordinary circumstances would be of about 35 candlepower, and which in this case had dropped to 16 candlepower, presumably for the above reason.

It may be interesting to note some of the results which may be expected, or which may be unexpectedly found in the determination of the candlepower of the various gases. Of necessity these will depend considerably on the locality and the presence or absence of governmental regulations, so that no single set figure can be given in any case.

In the United States a good unenriched coal gas, with a yield of 4.75 to 4.90 feet per pound should run from 14 to 16 candlepower.[1] If only the best gas from the run is accepted, the yield will be much lower but the candlepower may reach as high as 19 or 20.[1] This is not an economical method of manufacture, and there is positive harm in so high a candlepower for coal gas, since mantles and ceilings will be quickly disfigured by the smoke or by deposited carbon. The writer has seen a coal gas of only 8 candlepower[1] supplied for municipal use in open burners, and has also in mind a city where the candlepower is generally below 13;[1] but such gases are not to be commended and there is clearly some serious error in the management of the plants.

If properly enriched, coal gas can easily be made the year round of 16 to 17 candlepower,[1] and this is an excellent quality of gas, considered both from the side of its heating and of its illuminating value. Whether such a gas is the most economical for the consumer, when the cost of enrichment is considered, is a different question, and it is more than probable that if the price of the gas were reduced to correspond with the decrease in candlepower, a lower figure for the latter would be more satisfactory to all concerned, particularly when it is remembered that the greater

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[1] Taken with burner best adapted to gas (Metropolitan No. 2 excepted).

part of the gas used to-day is burned in appliances where its calorific value is of far more importance than its illuminating power.

A blue or unenriched water gas, as its name implies, burns with a blue flame and thus is of no value for lighting if used in open burners. A good carburetted water gas, as made in this country, yields from 20 to 28 candlepower. The general practice to-day is to maintain this figure as near 20 as possible, save where local regulations compel different results. As examples of the extremes, however, the writer has tested a water gas of less than 9 candlepower and another of 28 candlepower, both supplied for use in open burners. The former is undoubtedly evidence of faulty manufacture, while the latter is far richer than is desirable, not only from the standpoint of economy, but also because it is a menace to mantles and ceilings.

A mixed gas, or a mixture of coal and water gas, may naturally be of almost any candlepower, dependent upon the value of the components of the mixture and their proportion. As a rule, the candlepower of mixed gas is from 17 to 20. The Rochester Railway & Light Company, of Rochester, N. Y., voluntarily offered to maintain its gas at 20 candlepower, and almost without exception has lived up to this agreement, thus showing the possibilities of making a mixed gas of that candlepower with a reasonable profit.

A straight oil gas, well made, will give a candlepower of 45 to 60; gasolene, 12 to 17; an oil-air gas should be from 30 to 35, and acetylene from 170 to 200 candlepower. For the last-mentioned gas many claims are made for illuminating values ranging from 200 to 240 candlepower, but it is doubtful if such figures are ever reached in practical work. Certainly they have never been approached in the tests made by inspectors in the states of New York and Massachusetts.

The candlepower of natural gas will vary greatly according to the field from which it is drawn, and any result from 4 to 16 may be expected.

In Australia the standard illuminating power in Melbourne and Perth is 15; at Adelaide, 17.5, and at Ballarat, 18. In Bombay, India, it is 14 candlepower; in Tokio, Japan, the company supplies 16-candle coal and 18-candle water gas. Colombo has 10-candle gas, and the same is true of Berlin. Scotland has always maintained an unnecessarily high illuminating value; in January, 1907, there were only two authorized gas undertakings supplying under 20-candlepower gas. This has not been due, however, to legal restrictions, for out of the 50 authorized concerns supplying gas, 22 have their required illuminating power prescribed as 14, yet the gas supplied by them severally is at a figure between 20 and 29 candles.[1] In England the tendency of late years has been to reduce the requirements and to increase the accuracy and efficiency of the instruments employed; so that in London to-day there are two standards of 14 and 16 candlepower respectively, and the tests are made with the Carpenter burner, which gives about 2 candlepower higher results than are obtained with the Suggs Argand burner.

Such being the figures at which gas is supplied in various parts of the world, a moment's attention may well be given to some of the legal requirements regarding candlepower in different places. In England, the birthplace and training school of the gas industry, the first act for the regulation of gas companies was passed in 1833. This was entitled the Lighting and Watching Act, but contained no mention of illuminating value. In 1847, another act concerning gas was passed, and still there was no mention of candlepower requirements. By the Great Central Gas Act of 1850, however, wax candles, weighing six to the pound and burning at the rate of 120 grains per hour, were specified as standards for photometric work. From this time on there has always been governmental regulation of the gas industry, and the standard of candlepower has been set at 16, until 1905, when by the London Gas Act it was reduced to 14 for the South Metropolitan and Commercial Gas Companies.

In Berlin and Colombo, as has been stated, the law requires only 10 candlepower; Dublin, Ireland, and Ontario, Canada, have

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[1] Journal of Gas Lighting, January 15, 1907.

16 candlepower, and in general it may be said that the requirements are much less stringent abroad than in this country.

Turning now to the United States, the pioneer in matters of gas regulation is Massachusetts, where a state inspector has been steadily employed for over 45 years. The standard for candlepower in this state started at the surprising figure of 12. This was afterwards raised to 15, and in March, 1892, on the recommendation of the state inspector, it was again raised, this time to 16, at which figure it has continued ever since.

In the State of New York various standards have been set; thus by an act of the Legislature of 1905 the gas in New York City was required to be of at least 22 candlepower. In 1907, an act to set the same standard in Albany was enacted, but this was superseded during the same year by the Second-Class Cities Law, which demands that the minimum candlepower of coal gas shall be 16, of water gas, 20, and of a mixture of coal and water gas, 18. These last are likewise the figures set for all coal and water gas plants throughout the state by an order of the former Commission of Gas and Electricity, issued in 1907, and by a separate act for the city of Syracuse, known as the Hammond Bill.

In Auburn an agreement between the gas company and the city calls for 18 candlepower; in Rochester the company has agreed to furnish 20 candlepower, and in Buffalo, by a contract recently expired, the candlepower was to be maintained at 18. The gas company at Plattsburgh is likewise under agreement to furnish 18-candle gas.

In Wisconsin the subject of candlepower requirements has received careful consideration, and the Board of Railroad Commissioners, which has supervision of the gas companies, has decided that it is not desirable to set any standard whatever for candlepower, for the reason that most of the gas used in the state is employed in such a manner that its heating value and not its illuminating power is the vital point to be considered.

In the District of Columbia the standard is 22 candlepower, and even though at least one of the companies there manufactures largely coal gas, the law is generally complied with. Various cities throughout the country have standards of their own, and in general public opinion has prevented these from falling below 16, but it is to be expected that with the increasing cost of manufacture, the difficulty in securing good coal and enriching materials at reasonable prices, and the tendency to abolish the flat-flame burner, these candlepower requirements will in the near future be done away with and a standard of heating value substituted therefor.

PART II.

CHEMICAL TESTS.

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CHAPTER I.

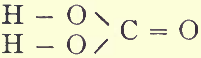
CARBONIC ACID AND SULPHURETTED HYDROGEN.

THE chemical tests which may be profitably employed in connection with the manufacture of gas are very numerous and would of themselves fill a large volume. As the purpose of this work, however, is to treat of the finished product only, no mention will be made of the analysis of coal, oil, tar, coke, carbide, benzole, etc. Many thorough studies have been made and published regarding each of these, and it is believed that these books devoted to a single line of thought should serve as the basis for analytical work rather than such hasty and incomplete discussion of the subjects as would be necessary in the limited space of this work. Neither is it feasible nor desirable to attempt to give all of the methods which have been proposed for the estimation of the various impurities, such as sulphur, ammonia, etc., for many of these have proved themselves to be inaccurate and others are not adapted to a gas works laboratory, being either too tedious, unnecessarily exact, or requiring peculiar and costly apparatus.

While quoting, therefore, one or two methods for the determination of each substance, the intention will be to lay more stress on the principles underlying each process and to give a detailed account of the procedure, reactions, and calculations involved in one reliable, rapid, and accurate method. Consideration will be given to the following impurities, all of which are generally present, to a greater or less extent, in the gas as it is delivered to the holder: carbonic acid, sulphuretted hydrogen, total sulphur, carbon bisulphide, ammonia, naphthalene, cyanogen, arsenic, silicon, and phosphorus. The last three are as a rule found only in acetylene, while the latter gas may also contain all the rest of the impurities mentioned with the possible exception of naphthalene. Carbon monoxide is not mentioned in this list for two reasons: first, it is a normal and necessary constituent of water gas and so cannot be considered as an impurity; second, the methods for its determination will be given so fully in a succeeding chapter that they need not be inserted here.

Carbonic Acid. The importance of this compound has already been dwelt upon in connection with the candlepower of water gas. In a purified coal gas it should not be present to the extent of over 1 to 2 per cent; in carburetted water gas the limit may be set at 3 per cent, while in gasolene and acetylene gases the amount present is almost always so small as to be unimportant. The general procedure in all processes for the determination of carbonic acid is to bring a measured quantity of the gas to be tested in contact with a solution of caustic potash, caustic soda or barium hydrate and after shaking the reagent and gas together for a short time to either measure the gas remaining or to ascertain the amount of alkali unacted on. The reactions which take place are as follows:

$$KOH + H_2CO_3 = KHCO_3 + H_2O_2$$
$$KOH + KHCO_3 = K_2CO_3 + H_2O.$$

The symbol usually given for carbonic acid is CO_2. Strictly speaking this is incorrect, as CO_2 represents the anhydride of carbonic acid, that is, the latter with one molecule of water extracted. The correct symbol then is H_2CO_3, or it may be written  $\begin{matrix} H - O \searrow \\ H - O \nearrow \end{matrix} C = O$ which is called the graphic symbol. This compound H_2CO_3 is assumed to be formed whenever the anhydride CO_2, which is gaseous, is dissolved in water; and while it has never been isolated, it is reasonably certain that it is the form which enters into reactions.

The first effect of the caustic potash on this substance is to form potassium bicarbonate ($KHCO_3$) and to liberate one molecule of water. The reaction does not, however, end here. The potassium bicarbonate reacts with more of the caustic potash to form neutral potassium carbonate, K_2CO_3, and another molecule of water is thrown off. As the affinity of carbonic acid for caustic potash is very great, all of the former in the gaseous mixture is speedily extracted and the volume of the gas is of course lessened by the volume of carbonic acid which it has lost. Now by dividing the loss in volume by the original volume the percentage of carbonic acid is easily obtained. Thus, if a gaseous mixture of 100 c.c. was subjected to treatment with caustic potash and 10 c.c. were lost by such action, the carbonic acid evidently formed $\frac{10}{100}$ of the mixture, or 10 per cent.

Unfortunately carbonic acid is not the only body present in illuminating gas which reacts with caustic potash. If a gas containing both carbonic acid and sulphuretted hydrogen be subjected to the action of caustic potash, both of the ingredients mentioned will be absorbed, the reaction with the sulphuretted hydrogen being exactly similar to the one already shown for carbonic acid. Thus,

$$\begin{aligned} KOH + H_2S &= KHS + H_2O \\ KOH + KHS &= K_2S + H_2O. \end{aligned}$$

Now in cases where sulphuretted hydrogen is present it will readily be seen that we cannot simply shake the gas with caustic potash, note the diminution in volume and call that loss the amount of carbonic acid present; for the loss also includes the sulphuretted hydrogen. It is therefore necessary to remove the latter before making the test for carbonic acid, and this may be done by passing the gas through a solution which has the power of absorbing the sulphuretted hydrogen and not the carbonic acid. Such a solution may contain copper sulphate, cupric phosphate, cadmium chloride, manganese binoxide with phosphoric acid, etc. The last named was recommended by Bunsen and is not dissolved, but the manganese binoxide is made into the form of a ball and soaked several times in syrupy phosphoric acid. It is also possible to remove the sulphuretted hydrogen by means of a small oxide purifier, and in works use this would seem to be the most satisfactory plan. Ammonia must also be removed, or in the volumetric processes it may increase the alkalinity of the solution and thus render the carbonic acid results too low. As a rule, however, ammonia and free carbonic acid do not exist long in the same solution.

And now two general methods are available for the determination of the carbonic acid, the gravimetric and the volumetric. By the first, a measured volume of gas is bubbled slowly through a solution of barium hydrate, the precipitate of barium carbonate which forms is collected on a filter, washed, dried, ignited, and weighed. From the weight of barium carbonate formed and the amount of gas used, the percentage of carbonic acid can be readily obtained. For example, if one cubic foot of gas was passed through the solution and the barium carbonate formed weighed 4.2864 grams, the calculation would proceed thus:

$$\underset{197}{BaCO_3} : \underset{44}{CO_2} :: 4.2864 : x.$$

$x = 0.9574$ gram of carbonic acid from 1 cubic foot of gas. To change this to grains per hundred cubic feet it is only necessary to multiply by 100×15.432, since 1 gram equals 15.432 grains. So $0.9574 \times 100 \times 15.432 = 1477$ grains per hundred cubic feet. If it is desired to express the result in per cent, 1 grain $CO_2 = 0.001231$ cubic foot. Then 1477 grains $= 1477 \times 0.001231 = 1.82$ cubic feet CO_2 per 100 cubic feet of gas, or 1.82 per cent by volume. These calculations are of course based on the assumption that the volume of gas used, 1 cubic foot, has been corrected for temperature and pressure. The only solution needed for this method is one of barium hydrate, which is made by dissolving 50 grams of pure $Ba(OH)_2 \cdot 8\,H_2O$ in one liter of distilled water. This solution should be protected from contact with the air with the especial view of excluding carbonic acid. The method is fairly accurate, but cumbersome and not as rapid as the volumetric processes.

Another gravimetric method consists in passing the gas through a series of U tubes containing soda-lime, which has the power of absorbing carbonic acid. By weighing these tubes before and after the passage of the gas, the weight of carbonic acid in a given volume of gas is found directly.

All of the volumetric methods are essentially the same: the carbonic acid in a known quantity of gas is absorbed in an excess of a solution of caustic potash or barium hydrate of known strength and the amount of alkali unacted on by the carbonic acid is determined by titration with a standard acid solution. The method of procedure may be as follows: measure from a burette three portions of 20 c.c. each of the standard alkali and place one portion in each of three bulbs, bottles, or other receptacles connected together. Connect the inlet of the series with the source of the gas to be tested and the outlet to a fourth bulb containing caustic potash, which in turn is connected with a meter. The object of the fourth bulb is to exclude air from the apparatus.

Now cause a known amount of gas to bubble through the potash, empty the contents of the first three bulbs into a flask, add two drops of methyl orange or of cochineal and run in the standard acid from a burette until the color just changes from a yellow (in the case of methyl orange) or a violet (in the case of cochineal) to a pink or yellow respectively. The methyl orange is the better indicator, although it takes a little more practice to judge of the end-point accurately than is the case with cochineal.

The solutions necessary for this method are prepared as follows:

Cochineal: grind three grams of whole cochineal in 250 c.c. of a mixture of 3 to 4 volumes of water and 1 volume of alcohol and decant the clear solution.[1]

Methyl orange: the powder may be purchased under the name of Poirriers orange III, Tropæolin D or Helianthine; one gram dissolved in a liter of water is a convenient strength.

Standard solution of caustic potash: this substance can now be obtained in a state of great purity; the solution should contain about 12 grams to the liter, and it is only necessary to weigh out this amount and dissolve it in one liter of distilled water. The exact weight of the caustic potash used is not required, since the

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Cohn, Indicators and Test Papers. [1]

strength of the solution must later be determined in any case by titration with standard acid.

Tenth normal hydrochloric acid: the chemically pure hydrochloric acid of commerce, of specific gravity 1.10, contains 20.2 per cent by weight of hydrochloric acid. Now a tenth normal solution of this acid contains 3.645 grams of the gas in each liter. Therefore, $3.645 \times 100 \div 20.2$ or approximately 18.1 c.c. of hydrochloric acid (sp. gr. 1.1) diluted to one liter will give a solution which is approximately tenth normal.

Having made the reagents it is now necessary to determine their exact strength. To standardize the hydrochloric acid, first make a tenth normal solution of sodium carbonate by dissolving exactly 5.3 grams of the pure dry salt in one liter of water. If a guaranteed quality of this substance cannot be purchased, it may be prepared by igniting a platinum crucible half full of very pure sodium bicarbonate at a dull red heat for an hour followed by cooling in a desiccator. Now fill a burette with the standard carbonate solution and another with the acid to be tested. Run 25 c.c. of the former into a small flask, add two or three drops of methyl orange and then add acid from the second burette with continual stirring or shaking, until the yellow color of the solution just changes to a faint pink. Read the acid burette and repeat the titration with fresh portions of alkali and acid until check results have been secured. The calculation is then made as follows:

Assume 25 c.c. N/10 sodium carbonate = 27.2 c.c. hydrochloric acid, 1 c.c. hydrochloric acid = 0.919 c.c. N/10 sodium carbonate, but since the sodium carbonate = 5.3 grams to the liter, 1 c.c. hydrochloric acid = (0.919×0.0053), or 0.00487 gram sodium carbonate,

$$\underset{73}{2\,HCl} : \underset{106}{Na_2CO_3} :: x : 0.00487.$$

$x = 0.00335$, therefore 1 c.c. of the hydrochloric acid contains 0.00335 gram of that gas. This result could have been obtained without any of this figuring by remembering the properties of normal solutions. Thus, since the sodium carbonate is N/10 and 1 c.c. of hydrochloric acid = 0.919 c.c. sodium carbonate, the hydrochloric acid must be 919/1000 of N/10. A N/10 solution of hydrochloric acid contains 0.00365 gram hydrochloric acid per c.c., so the solution in question would contain 0.00365 × 0.919, or 0.00335 gram of hydrochloric acid per c.c.

Having obtained this factor, it is now easy to ascertain the strength of the caustic potash. The titration of this against the acid proceeds exactly as described above for the standardization of the acid. Let us assume that 25 c.c. of acid require 13.4 c.c. of caustic potash. Then 1 c.c. or 0.00335 gram hydrochloric acid = 0.536 c.c. caustic potash.

$$\underset{56}{\mathrm{KOH}} : \underset{36.5}{\mathrm{HCl}} : : x : 0.00335.$$

$x = 0.00514$. If 0.536 c.c. caustic potash = 0.00514 gram, 1 c.c. contains 0.00959 gram of caustic potash. Or, using normal solutions, the caustic potash is 25/13.4 × 0.0919 normal. One c.c. of normal caustic potash contains 0.056 gram. 25 × 0.0919 × 0.056 ÷ 13.4 = 0.00959 gram of caustic potash per c.c. of solution. It is now convenient to transform this result into such a form that it will be available for use in each determination with as little calculation as possible. To do this it is only necessary to find the value of 1 c.c. of the caustic potash in terms of carbonic acid.

$$\underset{112}{2\,\mathrm{KOH}} : \underset{44}{\mathrm{CO_2}} : : 0.00959 : x.$$

$x = 0.00377$ gram of carbonic acid which will be neutralized by 1 c.c. of the caustic potash.

To consider an actual determination with the above solutions: 60 c.c. of caustic potash were used in the bulbs; 1 cubic foot of gas was passed through, and it then required 90 c.c. of the hydrochloric acid to neutralize the remaining potash.

90 c.c. HCl = (90 × 0.536) c.c. KOH = 48.24 c.c.
60 − 48.24 = 11.76 c.c. KOH used up by the CO_2.
11.76 × 0.00377 = 0.0443 gram CO_2 in 1 cubic foot of gas,
or 0.0443 × 100 × 15.43 = 68.35 grains CO_2 per 100 cubic feet of gas.

It may have been noticed that the gas is measured after it has passed through the potash solution and not before. This is done for the reason that the water in a wet meter will dissolve carbonic acid and under certain circumstances give it up again to a passing current of gas; consequently the experimenter would never be certain of his results. The volume of the gas as determined after passing the caustic potash bulbs is of course less than the original volume by the amount of carbonic acid absorbed, and if great accuracy is desired, a correction must be made for this. In the example cited, however, the carbonic acid absorbed is only equal to 0.0008 cubic feet, so that in this case the error is decidedly negligible.

Hempel recommends, for the determination of small quantities of carbonic acid, a solution of barium hydrate and titration with oxalic acid. The objection to oxalic acid in this connection is that it is not stable and must be carefully standardized before each determination; while a N/10 solution of hydrochloric acid will retain its strength almost indefinitely. The barium hydrate will work perfectly well if it is kept without access of air; but if it comes in contact with carbonic acid a turbidity of barium carbonate will form, and the solution must be filtered before using.

Hempel also gives a very excellent method for the rapid and accurate estimation of carbonic acid in illuminating gas which is so well described that the author's words are quoted verbatim: "The carbonic acid can be determined with great exactness with the apparatus devised by Rüdorff. This consists of a three-necked bottle *A* (Fig. 14); in one neck the manometer *B* filled with a solution of indigo is inserted; in the second neck the glass stopcock pipette *C* graduated in tenths; and in the third neck either a single glass stopcock or a double bore stopper carrying two tubes, one of which reaches to the bottom of the bottle, while the other ends just below the stopper.

"The exact contents of the bottle must be known. In making the determination illuminating gas is led into the bottle until all of the air is driven out, the lighter gas being introduced at the top of the bottle and the heavier air passing out below. The stopcocks are now closed, and the manometer is brought to zero by carefully allowing some of the gas which is in the bottle, and which is under pressure, to escape. If now a solution of caustic potash be allowed to drop from the pipette into the bottle, the carbonic acid will be absorbed. The volume of the carbonic acid present can be read off directly from the pipette, if, after the absorption, the manometer is again brought to zero by admitting more caustic potash.

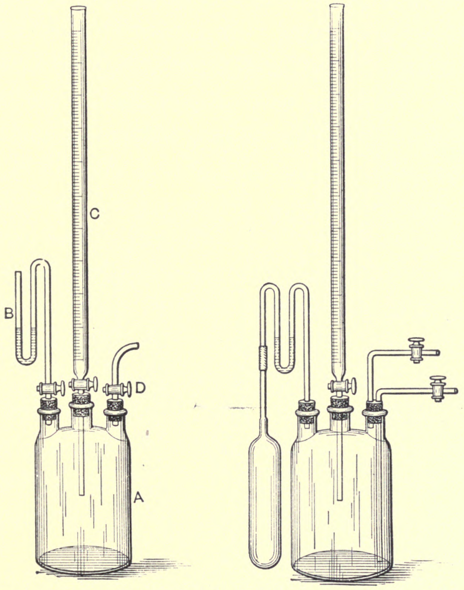

Fig. 14. Rüdorff's Apparatus for Carbonic Acid.

"In this determination the gas must, of course, be free from sulphuretted hydrogen. If this is not the case, the gas is passed through manganese binoxide before entering the apparatus. To avoid changes of temperature it is advisable to place the apparatus in a vessel of water during the experiment.

"It is self evident that the apparatus in this form is influenced by changes of temperature and pressure of the atmosphere. It can be made independent of these by attaching a Pettersson compensating tube to the manometer as in Fig. 14." This is a most excellent method and highly to be recommended.

Only one other method need be mentioned, and that because of its difference in character from all of those hitherto described. This is by use of the Harcourt apparatus, which consists in its essential features of two glass cylinders (Fig. 16), a large tank or aspirator and a graduated vessel. One of the cylinders contains a liquid in which is suspended a definite amount of barium carbonate; the other is charged with a saturated solution of barium hydrate. By means of the aspirator, gas is sucked through the barium hydrate until the turbidity in that cylinder is equal to that in the one containing the known amount of barium carbonate. The water running from the aspirator is caught in the graduate, and thus the quantity of gas necessary to precipitate a known weight of barium carbonate is ascertained. The method is rapid, but not accurate; the principle involved has been tested many times in connection with water analysis, and no method founded on it has as yet proved satisfactory. It will serve, however, as a convenient means of securing approximate results.

Thus far all of the methods mentioned have been quantitative; if a qualitative test for carbonic acid is desired, it is only necessary to allow some of the gas to bubble through a clear solution of barium hydrate, when, if carbonic acid be present, the liquid takes on a milky appearance.

An apparatus for the continuous determination of carbonic acid is manufactured by Alexander Wright & Co., under the name of Simmance & Abady's Patent Automatic Combustion Recorder (Fig. 15). With this instrument a charge of gas is bubbled through a caustic potash solution every so often, and the unabsorbed gas is passed on to a small bell, the rise of which indicates on a scale the percentage of the carbonic acid. A mark is also made at the same time on a chart showing whether the carbonic acid be high or low; this chart will furnish a continuous record for 60 days. The cost of the instrument is $250, and while doubtless a handy thing to possess, it is primarily intended as an aid to the securing of proper combustion of coal in boilers, etc., and would seem to be more of a luxury than a necessity for a gas works.

Acetylene rarely if ever contains carbonic acid; if it be present, it is in such small amounts as to be unworthy of attention. In natural gas, the carbonic acid content is generally under 1 per cent; out of 42 analyses before the writer, but one shows over 1 per cent carbonic acid. In crude coal gas after condensation but prior to washing the carbonic acid will be from 1.1 to 1.8 per cent by volume, or 980 to 1470 grains per 100 cubic feet; after passing the scrubbers it is reduced to 700 to 1100 grains per 100

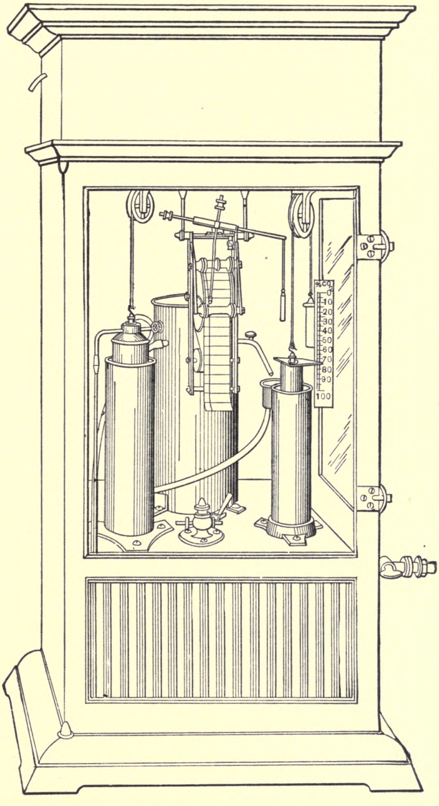

Fig. 15. Recording Apparatus for Carbonic Acid.

cubic feet. Out of 142 analyses of purified coal gas made by the state inspectors of Massachusetts between 1883 and 1906, only 18 showed over 1.5 per cent of carbonic acid, and most of them were far below this figure. With water gas, as has been stated, the percentage of carbonic acid will vary greatly according to the conditions of generation. The unpurified gas *should* contain a little less than 3 per cent by volume of carbonic acid. As a matter of fact it may vary between wide limits, and it is with water gas that the test for this substance is of the greatest value. In the Massachusetts report above referred to there are some 109 analyses of water gases, and of these 34 have between 2 and 3 per cent of carbonic acid; 22 between 3 and 4 per cent; 9 between 4 and 5 per cent; 6 between 5 and 6 per cent, and 7 between 6 and 9 per cent, while 31 are under 2 per cent.

Sulphuretted Hydrogen. The fact that sulphur is found in illuminating gas is due to its presence in coal, oil and carbide; the amount and form in which it occurs are due in part to the conditions prevailing in retort or generator and in part to the manner in which it is combined in the coal. A good gas coal will have from 0.5 to 2.0 per cent of sulphur; it may even be used with as much as 2.5 per cent, but this amount should never be exceeded, and it is far better to employ a coal with less than 1.5 per cent of sulphur. This sulphur may be present in the coal in three forms: (1) as sulphates, (2) as sulphides, (3) in combination with organic matter. The sulphate, which is generally present as a lime salt, is not volatile, and remains with the coke in the retort. The sulphides and organic compounds, however, when heated in the reducing atmosphere of the retort or generator, give off the greater part of their sulphur in the form of sulphuretted hydrogen, and most of the remainder as carbon bisulphide.

Butterfield found by experiment that the crude gas taken from the hydraulic main contained on an average 1.2 per cent of its volume of sulphuretted hydrogen, when coal containing 1.1 per cent of sulphur was being carbonized. This ratio is, of course, not a fixed one, and it has been found that the higher the temperatures of distillation, the greater the amount of sulphur, and especially in forms other than sulphuretted hydrogen, which passes into the gaseous product. After leaving the retort various reactions may take place between the components of the gas. Hornby states that the ammonia unites with a part of the sulphuretted hydrogen, carbonic acid, sulphurous acid and cyanogen to form the sulphydrate, carbonate, sulphite and cyanide of ammonium, while other reactions produce ammonium sulphocyanate, ammonium thiosulphate, etc.

Carburetted water gas before purification contains from 100 to 150 grains of sulphuretted hydrogen per 100 cubic feet (0.15 to 0.25 per cent by volume) and small amounts of sulphur in other forms. Butterfield states that he has never seen the sulphur (exclusive of sulphuretted hydrogen) in purified water gas exceed 10 grains per 100 cubic feet, but the writer has analyzed 52 samples for sulphur, taken from water gases supplied in New York State during 1908, where the total sulphur was in excess of 10 grains; ten of these had over 15 grains and 2 over 20 grains per 100 cubic feet of gas, and no sulphuretted hydrogen was present.

In acetylene, if properly made, there should be little or no sulphuretted hydrogen. If the gas comes from a hot generator, however, and if there is aluminum sulphide or calcium sulphide in the carbide, sulphuretted hydrogen will be found in the acetylene in amounts varying from 0.01 up to 1.34 per cent. The gas is also liable to contain small quantities of organic sulphur compounds which Caro contends, and probably with justice, are mustard oils and mercaptans.

Now the presence of sulphuretted hydrogen in illuminating gas is objectionable for several reasons. In the first place, it is of itself poisonous, and from its odor extremely offensive. Moreover, it acts powerfully on most of the metals, as may be seen by exposing for a moment a moistened silver coin to a current of gas containing sulphuretted hydrogen, when a black metallic film of silver sulphide will be formed. Furthermore, its products of combustion contain sulphurous and sulphuric acids which act upon metals and leather and have an injurious effect upon the respiratory tract. There seems to be no difference of opinion as to the necessity of removing sulphuretted hydrogen from the gas. Hornby has well put the case when he says: "In the case of sulphuretted hydrogen, however, there can be no choice; every trace of this impurity must be removed or the gas is unfit for consumption." The tests for this obnoxious constituent become then of prime importance; but since no trace of sulphuretted hydrogen is to be allowed in the finished product, a qualitative test of the latter is usually all that is necessary. It is often desirable, however, to determine the efficiency of the purifiers, or to ascertain the amount of sulphuretted hydrogen in the crude gas, and therefore one or two quantitative methods for its determination will be given.

The mere detection of the presence of hydrogen sulphide is extremely simple. With a little practice, the sense of smell alone will tell the observer all that he needs to know. The familiar odor of rotten eggs will overcome that of the gas itself, even when the sulphuretted hydrogen is present in minute quantities only. There is one precaution to be noted in this connection. In the case of a carburetted water gas, the oil used for enrichment sometimes imparts to the gas an odor which might be mistaken for that of sulphuretted hydrogen. The test, moreover, is not sufficiently delicate to meet all requirements, and while, if the odor of sulphuretted hydrogen is really detected, there can be no doubt as to the presence of that impurity, it does not follow that if the odor is not detected the sulphuretted hydrogen is entirely absent.

A qualitative test, which is simple and infallible, consists in moistening a strip of white paper with a solution of acetate of lead (sugar of lead) and exposing it to a current of the gas to be tested. If sulphuretted hydrogen be present, the paper will become covered with a metallic, brownish-black layer of lead sulphide. The reaction is,

$$Pb(C_2H_3O_2)_2 + H_2S = PbS + 2C_2H_3O_2.$$

The length of time necessary to produce this discoloration will also give some idea as to the amount of the sulphuretted hydrogen present. There is but one point to be guarded against; it sometimes happens that particles of oil or dust from the burner are blown onto the paper and color it a dirty brown. This color has no metallic luster and is not spread evenly over the paper, and consequently will afford no trouble to a practiced observer. In many companies in the United States it is the custom to make a continuous test, and this is done by suspending strips of paper, which have been soaked in lead acetate solution and dried, in a bell jar through which the gas continually flows. The dried paper, however, does not respond as quickly to the action of the sulphuretted hydrogen as does the moist paper, and since the latter takes but a moment to prepare, it would seem to be preferable to make a number of tests, of, say, 1 minute each, with the moist paper in preference to a continuous one with the dry paper. To prepare the necessary solution, all that is required is to dissolve the requisite amount of lead acetate in water. The proper strength for this solution seems to be a matter of opinion. The Metropolitan Gas Referees of London direct that 6.5 grams of crystallized lead acetate be dissolved in 100 c.c. of water. In July, 1908, an article appeared in one of the gas journals stating that the proper strength was 120 grams to the liter. Dr. A. A. Noyes, in his "Qualitative Analysis," suggests that as a reagent lead acetate should be prepared by dissolving 100 grams $Pb(C_2H_3O_2)_2 \cdot 3\,H_2O$ in 1 liter of water. It is doubtless true that any of these solutions will give perfect satisfaction if made from pure chemicals and kept from access to the air, as lead acetate reacts readily with carbonic acid to form a white precipitate of lead carbonate, and the writer has met with solutions which had become so exhausted in this way that the clear liquid would not react with sulphuretted hydrogen. It should be needless to remark that the test for sulphuretted hydrogen, as well as all tests, chemical, photometrical or calorimetric, should be made with gas fresh from the main, holder or other source of supply.

In testing acetylene for sulphuretted hydrogen, use of the moist paper is not recommended; it is better to bubble the gas through a solution of lead acetate and then ignite it at a burner. The appearance of a brownish-black precipitate or color in the lead acetate will indicate the presence of sulphuretted hydrogen.

For the quantitative estimation of sulphuretted hydrogen in gas, Sutton recommends the method and apparatus devised by Mohr.[1] This is based on the fact that when sulphuretted hydrogen is brought into contact with an excess of arsenious acid in hydrochloric acid solution, arsenious sulphide is formed, thus:

$$As_2O_3 + 3\,H_2S = As_2S_3 + 3\,H_2O.$$

The arsenious sulphide settles out as a yellow precipitate, and the excess of arsenious acid is determined by titration with N/10 iodine solution and starch. The process is carried out as follows: The gas is led into two successive small wash-bottles containing a dilute solution of caustic soda or potash; from the last of these it is led into a large Woulff's bottle filled with water. The bottle has two necks and a tap at the bottom; one of the necks contains the cork through which the tube carrying the glass is led; the other a cork through which a good sized funnel with a tube reaching to the bottom of the bottle is passed. When the gas begins to bubble through the flask, the tap is opened so as to allow the water to drop rapidly; if the pressure of gas is strong, the funnel tube acts as a safety valve and allows the water to rise up into the cup of the funnel. When a sufficient quantity of gas has passed into the bottle, say 6 or 8 pints, the water which has issued from the tap into some convenient vessel is measured in cubic inches or liters and gives the quantity of gas which has displaced it. In order to insure accurate measurement all parts of the apparatus must be tight.

The flasks are then separated, and in the second, 5 c.c. of arsenious solution are placed, and acidified slightly with hydrochloric acid. If any traces of a precipitate occur, it is set aside for titration with the contents of the first flask, to which 10 c.c. or so of arsenious solution are added, acidified as before, both mixed together, diluted to a given measure, filtered, and a measured quantity titrated with N/10 iodine solution, using starch as an

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[1] Sutton's Volumetric Analysis.

indicator. This method does not answer for very crude gas containing large quantities of sulphuretted hydrogen, unless the absorbing surface is largely increased.

The arsenious solution is a N/10 solution of sodium arsenite, and is made by dissolving 4.95 grams of the purest sublimed arsenious oxide reduced to powder in about 250 c.c. of distilled water in a flask with about 20 grams of pure sodium carbonate. Warm and shake for some time until solution is complete, then dilute, cool and make up to one liter. The N/10 solution of iodine is prepared in the following manner: Weigh out exactly 12.7 grams of the purest iodine and about 18 grams of C.P. potassium iodide (free from iodate), and dissolve the two together in about 250 c.c. of water and dilute to 1 liter. This solution must not be heated, as iodine is volatile, and some may be lost as a vapor. Keep in a glass-stoppered bottle in a cool and dark place; if possible keep the bottle completely filled.

The starch indicator must be prepared with care, as upon it depends the delicacy of the end point. If Kahlbaum's soluble starch can be obtained, it is only necessary to dissolve 0.5 gram in 25 c.c. of boiling water, allow it to cool and bottle it. If this is not obtainable, take one part of clean potato starch, mix it with just enough cold water to form a smooth emulsion, and then gradually pour this into 200 times its weight of boiling water, stirring constantly. Continue to boil the mixture for three or four minutes, then let it stand till the suspended matter has thoroughly settled out, and decant the clear solution into a bottle. This solution should be made fresh at least every three or four days, as it deteriorates rapidly on standing.

The value of the iodine solution is found by titration, as follows:[1] Weigh out, into two No. 4 beakers, two portions of 0.175 to 0.200 gram each of pure arsenious acid. Dissolve in 10 c.c. of caustic soda solution with stirring. Dilute the solutions to 150 c.c. and add hydrochloric acid until the solution contains a few drops in excess, and finally add a concentrated solution of 5 grams of sodium bicarbonate. Cover the beakers to avoid loss. Add the starch solu-

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[1] Talbot's Introductory Course of Quantitative Chemical Analysis.

tion (5 c.c. if made from potato starch, 1 to 2 c.c. if from soluble starch), and titrate with the iodine to the appearance of the blue of the iodo-starch, taking care not to pass the end point. Arsenious acid dissolves more readily in caustic alkali than in alkali carbonates, but the presence of the former during titration is not admissible, because it interferes with the color of the blue iodide of starch. The addition of hydrochloric acid destroys this caustic, and the solution is then made alkaline with a bicarbonate. Normal carbonates cannot be used for the same reason given for the caustic alkali.

Assume that 0.200 gram of As_2O_3 required 41.2 c.c. of the iodine solution. The reaction is

$$As_2O_3 + 2\ I_2 + 2\ H_2O = As_2O_5 + 4\ HI.$$

Therefore $198 : 508 :: 0.2 : x.$

$x = 0.513$ gram of iodine in 41.2 c.c. Then 1 c.c. of the iodine solution contains 0.01245 gram of iodine, and the solution is 0.098 normal. Knowing the strength of this, it is easy to determine the value of the arsenious solution used in the analysis. From a glass-stoppered burette[1] run 25 c.c. of the iodine solution into a flask, and then from a second burette add the arsenious solution until the iodine color is nearly removed. Then add the starch indicator and continue the addition of the arsenious solution drop by drop until the blue color just disappears. If the titrated solution is allowed to stand for a short time exposed to the air, the blue color will return, due to the oxidation of the hydriodic acid by the oxygen of the air. If 25 c.c. of the iodine solution require 23.8 c.c. of the arsenious solution, 1 c.c. of the latter equals 1.0504 c.c. of iodine. It also equals $(25 \times 0.01245) \div 23.8$, or 0.01308 gram of iodine.

Then

$$\underset{198}{As_2O_3} : \underset{508}{2\ I_2} :: x : 0.01308$$

$$x = 0.005098 \text{ gram } As_2O_3 \text{ to 1 c.c.}$$

Now

$$As_2O_3 : 3\ H_2S :: 0.005098 : x. \qquad x = 0.002626.$$

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[1] Iodine solutions act upon rubber, hence only burettes with glass stopcocks should be used.

So 1 c.c. of the arsenious solution is equivalent to 0.002626 gram of hydrogen sulphide. If now in an actual determination 15 c.c. of arsenious solution were used, 0.5 cubic foot of gas corrected was passed and 10.2 c.c. of iodine required to oxidize the excess of arsenious oxide, then the calculation will proceed thus: 1 c.c. iodine equals $23.8 \div 25 = 0.952$ c.c. of the arsenious solution. $15 - (10.2 \times 0.952) = 5.29$ = number of cubic centimeters of arsenious solution used up by the sulphuretted hydrogen in the gas. But 1 c.c. of arsenious solution = 0.002626 gram of hydrogen sulphide, therefore,

$5.29 \times 0.002626 = 0.01389$ gram of hydrogen sulphide in 0.5 cubic foot of gas.

$0.01389 \times 15.43 \times 200 = 42.86$ grains of sulphuretted hydrogen per 100 cubic feet of gas.

This method is stated by Sutton, one of the greatest authorities on volumetric analysis, to be far superior to the direct titration of hydrogen sulphide by iodine, as is done in the Tutweiler or U. G. I. test. This latter method, however, is simpler, more rapid and fairly accurate, and is therefore well adapted to gasworks use. With this process a measured sample of gas is taken, and into this is run a standard solution of iodine. At first the iodine will be decolorized by the sulphuretted hydrogen, but when the latter is exhausted, the iodine color will begin to appear. The burette is graduated to read direct in grains of sulphuretted hydrogen per 100 cubic feet of gas. This is practically the same as the method of Dupasquier, who draws a measured quantity of gas through a solution of iodine in potassium iodide, to which some starch paste has been added.

The operation is stopped at the moment when the solution becomes colorless; from the volume of gas used to decolorize a known weight of iodine, the quantity of sulphuretted hydrogen present in the gas may be easily calculated. The reaction is

$$H_2S + I_2 = 2\,HI + S$$

if the solutions are very dilute and direct sunlight is excluded.

If a gravimetric method is desired, proceed exactly as in the volumetric method, using the arsenious solution until the latter has been added. Then filter off the arsenious sulphide, wash it well with hot water, dry at 100° C. and weigh. 39.02 per cent of the weight of arsenious sulphide is sulphur, and hydrogen sulphide equals 34/32 times the weight of sulphur. Now assume 10 cubic feet of gas corrected were taken and the weight of arsenious sulphide was 3.7284 grams.

$3.7284 \times 0.3902 \times 15.43 \times 100/10 \times 34/32 = 238.5$ grains hydrogen sulphide per 100 cubic feet.

Since the factors 0.3902, 15.43, 34/32 and 100 are constant and occur in every calculation, they may be combined into one factor, thus: $100 \times 0.3902 \times 15.43 \times 34/32 = 639.7$.

Therefore, to find the grains of sulphuretted hydrogen per 100 cubic feet of gas, multiply the weight of arsenious sulphide by 639.7 and divide by the volume of gas used.

The Harcourt method for sulphuretted hydrogen is conducted in the same general manner as his test for carbonic acid, save that the solution through which the gas is drawn is made of lead acetate, and the standard cylinder contains a similar solution having a color equal to that produced by the action of a definite amount of sulphuretted hydrogen on lead acetate. The gas is passed through the first cylinder until the color therein matches the standard color, and from the volume of gas required to accomplish this the quantity of sulphuretted hydrogen in the gas is easily calculated. This is rapid and much more accurate than the similar test for carbonic acid, principally because colors or intensity of colors and not turbidities are compared.

To determine sulphuretted hydrogen in acetylene, Harcourt's color tubes may be employed, or the gas may be passed through a solution of lead acetate in one or more flasks or wash-bottles, the precipitate of lead sulphide filtered off, washed with hot water, dissolved in dilute nitric acid, and the solution evaporated nearly to dryness. Then 5 c.c. of concentrated sulphuric acid are added and the evaporation continued until the white fumes of sulphuric acid are freely given off. After cooling, dilute carefully with cold water and add double the volume of common alcohol. Let stand until all of the lead sulphate has settled out; filter, and wash the precipitate with common alcohol. This precipitate may then be dried, ignited and weighed; or it may be dissolved in ammonium acetate, made up to 100 c.c. in a long narrow tube, sulphuretted hydrogen added and the color compared with that of known amounts of lead in similar tubes which have been also treated with sulphuretted hydrogen.

Many other methods have been devised, such as Wanklyn's, Leicester Greville's, Folkard's, L. T. Wright's, and Marshall's, but for the details of these the reader should consult Abady's "Gas Analysts' Manual."

An excess of sulphuretted hydrogen in the purified gas is due to one of five causes: (1) Insufficient purifying capacity. Newbigging says that with four boxes, three of which are in continual use, the maximum output per day expressed in thousands, multiplied by 0.6 will give the superficial area of purifying surface necessary. If only two boxes are used at a time, the first must always be changed as soon as foul gas appears at the outlet. (2) Exhausted oxide. This is easily discovered, if after revivifying, the oxide fails to remove the sulphuretted hydrogen. The remedy is apparent. (3) Poor quality of oxide. (4) Too rapid passage of the gas through the purifiers. (5) Channels in the oxide. In the case of lime purification, if the lime box is not followed by one of clean oxide, sulphuretted hydrogen, which has been regenerated in the lime box by the action of carbonic acid on calcium sulphydrate (the product of the reaction between sulphuretted hydrogen and slaked lime), may pass on to the holder.

CHAPTER II.

TOTAL SULPHUR.

As has already been stated, the sulphur in gas exists principally as sulphuretted hydrogen, but also to some extent as carbon bisulphide and other organic compounds. These latter are present in coal gas, as it leaves the condensers to the extent of about 0.024 to 0.042 per cent by volume, or 34 to 59 grains per 100 cubic feet, about four-fifths of this being carbon bisulphide. According to Hornby, the scrubbers remove about 2 grains of carbon bisulphide per 100 cubic feet of gas, and another writer states that after leaving the washers the gas will contain on an average 30 to 40 grains of sulphur compounds, exclusive of sulphuretted hydrogen, per 100 cubic feet. This amount is too great to be allowed to remain in the finished product, and in many places a law is in force limiting the amount of total sulphur which may be permitted.

The reason for such legislation will be clear after a moment's consideration of the facts. The product of combustion of the sulphur in the gas is sulphurous acid. This of itself would be disagreeable and dangerous to have in the air were it present in sufficient quantity, but even this is only an intermediate product in many cases. In the presence of oxygen and moisture sulphurous acid oxidizes to sulphuric acid, and there can be no question as to the danger to health from this substance; the only discussion is as to whether there can be enough of it formed in a room with the ordinary means of ventilation, to render its presence a menace. One or two opinions of eminent authorities are quoted here to throw light on the subject.

Major C. W. Hinman away back in 1878 said: "I am of the opinion that when gas containing the ordinary amount of sulphur (less than 20 grains) is burned, and the ventilation is moderately effective, the damage done is inconsiderable; but when the amount of sulphur much exceeds the common limit, or the ventilation is ineffective, that the effect on persons of delicate organization is unpleasant and certain objects may be injured."[1]

Mr. H. Leicester Greville says, referring to the fact that the standard for sulphur in London has been abolished: "The only rational excuse for the abrogation of the proportion of sulphur compounds must have been the introduction of the incandescent burner. Consumers who use a flat flame or Argand burner would suffer the penalty of polluting the atmosphere of their living rooms with the amount of increased sulphur in the gas. Those, on the other hand, who use the incandescent would not have any increased vitiation or pollution owing to the decreased consumption. Thus: with a flat-flame burner consuming 8 feet per hour and sulphur at 20 grains per 100 cubic feet, the illuminating power is 14 candlepower and the sulphur per hour 1.6 grains. With an incandescent burner at 2 cubic feet per hour and sulphur at (say) 50 grains per 100 cubic feet, the illuminating power is 50 candlepower and the sulphur per hour, one grain."[2]

The Public Control Committee of the London County Council, in a report to that body says: "The Council will probably remember that we were not in favor of legislation for removing the restrictions with regard to the presence of sulphur compounds in gas; but the companies maintained that there was no method by which these compounds could be removed without creating a nuisance in the process of purification."[2] They go on to say that before the Act of 1905 the Referees prescribed the maximum for sulphur as 17 and 22 grains for summer and winter respectively. For 1907, the average sulphur in gas of the three companies in London was above the 35 grains which the companies said would be the probable average after the passage of the Act of 1905, and in one company it was very considerably above it. They conclude as follows: "We regard the question as one which very seriously affects the

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[1] Massachusetts State Gas Inspector's Report, 1878.

[2] Journal of Gas Lighting, June 11, 1907.

interests of gas consumers generally, and we therefore propose to ask the gas companies for an explanation of the large proportion of sulphur compounds present in the gas supplied by them and for an assurance that the proportion shall be reduced in the near future."[1]

The *Lancet*, the leading British medical journal, on February 8, 1908, presented evidence of the presence of sulphuric acid in the products of combustion of coal gas: "Over the ordinary gas light the ceiling paper shows always more or less discoloration and after a time becomes charred, crumbles and drops off; this is commonly attributed to the deposition of soot, when often it is really the effect of sulphuric acid formed in the combustion of the gas and deposited on the ceiling." The *Lancet* states that an examination of such paper shows it to be sour to the taste and distinctly acid in reaction, and analysis showed as much as 16 grains of sulphuric acid per square foot of paper.

The article continues: "It seems probable that the presence of sulphuric acid from this source, in the course of time, may be a source of injury to the respiratory tract, manifesting itself particularly in catarrhal inflammations and non-resistance to infection."[2]

To state the other side of the case, the British Act of 1905, above referred to, abolished the limit for sulphur compounds other than sulphuretted hydrogen, and as the English have always been leaders in careful and painstaking investigations of gas matters, this fact is of great weight.

Again, in the hearing before the New York State Commission of Gas and Electricity on the matter of fixing standards of illuminating power and purity of the gas supplied throughout New York State, the opinion of most of the managers of gas companies present seemed to be that a standard for total sulphur was unnecessary. The observations of the writer in New York State would tend to make him of this opinion also, *provided* that the gas companies would not take advantage of such removal of restrictions

[1] Journal of Gas Lighting, May 26, 1908.

[2] Journal American Medical Association, March 28, 1908.

to allow the total sulphur to mount up as it has done in London since 1906.

During the year 1908 (to December 1st) some 677 tests were made of the gas supplied by the various coal and water gas companies doing business in the state of New York outside of New York City. Of this number only 28 showed over 20 grains of sulphur per 100 cubic feet, and but 5 of them were over 25 grains, the highest amount being 29 grains.

On the other hand, in Massachusetts the writer has seen sulphurs of over 40 grains per 100 cubic feet, and there seems to be little question but that such an amount may be a menace to health and property.

Aside from all these considerations, however, two facts affect powerfully the question of a limit for sulphur. First, in very many, if not most of the cases in this country where legislation has been enacted to regulate the gas industry, the amount of sulphur which may be present in gas is limited to a definite amount. Second, the policy of practically all of the gas companies to-day is to give the most satisfactory service possible, and since the people, rightly or wrongly, regard sulphur as deleterious, it must be kept within bounds.

Although lime purification is becoming scarce in this country, it may be well to say just a word as to the manner in which the sulphur is removed by this process. Carbon bisulphide is not acted on by either calcium hydrate or by the calcium carbonate which is formed by the reaction of the carbonic acid in the gas with the lime. It does react, however, with the calcium sulphydrate (CaSH) which has already been mentioned as the product of the action of sulphuretted hydrogen on slaked lime, and calcium sulphocarbonate is formed. Hence the lime must be foul for the removal of carbon bisulphide; but it must not be forgotten that if carbonic acid reaches this foul lime, sulphuretted hydrogen will be liberated and therefore a clean box of oxide must follow the last lime box.

Oxide of iron is an excellent material for the removal of sulphuretted hydrogen, but its powers of retention for carbon bisulphide are small. Newbigging says: "As oxide of iron pure and simple, it has no affinity for carbon bisulphide and other sulphocarbon compounds, but from the observations made at the several Metropolitan Gas Works Mr. R. H. Patterson (one of the Referees) deduced the interesting fact that the sulphur which is present in a state of minute division in the oxide of iron after the latter has been in use for some time and frequently revivified, possesses the power of arresting a portion of the carbon bisulphide." Dr. H. B. Harrop, in his "Gas Works Chemistry," is inclined to disagree with this opinion. He concludes as the result of some very thorough experiments, that "the sulphur compounds other than sulphuretted hydrogen dropped in the boxes may be absorbed by some unidentified organic substances deposited there from the gas."

Because of these facts, and especially because the amount of sulphur which may be present in gas is in many localities restricted by law, it becomes of importance to learn what methods have been devised for the estimation of carbon bisulphide and total sulphur. With one exception these methods all follow the same general idea of burning the gas, collecting the products of combustion, oxidizing the sulphurous acid to sulphuric acid, and determining the latter by some volumetric or gravimetric method.

The single exception is Harcourt's color test, the apparatus for which is shown in Fig. 16. *a* is a burner supporting the chimney, *b*, inside of which is suspended the bulb, *c*. This bulb is filled with platinized pumice and is held in place by the clamp, *d*, on an iron ring stand, *e*, in such a manner that it is about 1 inch above the burner and in the center of the chimney. The tube, *f*, connects with the gas supply and passes through the stopper of the bulb down into the pumice. On the side of the neck is an outlet, *g*, which is connected with a capillary tube leading through the rubber stopper and nearly to the bottom of the glass cylinder, *h*. One end of a short tube, *i*, bent at right angles passes through the second hole in the rubber stopper and projects a half-inch into the cylinder; the other end is connected with the aspirator, *j*, which is entirely filled with water before commencing a test. *k* is a graduated cylinder, the divisions on which may express cubic centimeters or fractions of a cubic foot. The cylinder, *m*, contains the standard solution, and *n* is a sheet of white cardboard.

The principle on which the apparatus works is that in passing over the heated platinized pumice the carbon bisulphide in the gas becomes converted into sulphuretted hydrogen which is absorbed in a solution of lead acetate contained in the cylinder, *h*, and the color of such solution becomes thereby darker and darker. When its intensity matches that of a solution in *m* containing a known amount of sulphuretted hydrogen, the flow of gas is cut off, and the amount used is determined by the quantity of water which has passed into the graduated cylinder, *k*.

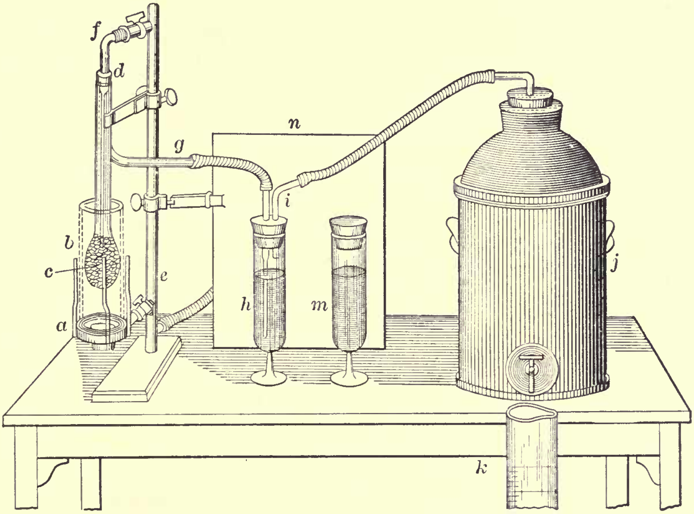

Fig. 16. Apparatus for Harcourt's Color Test.

The detailed procedure to be followed with this apparatus is as follows:[1] "To use the apparatus turn on first the upper stopcock, sending gas through the bulb at the rate of about one-half cubic foot per hour, as may be judged by lighting the gas for a moment at the end of the horizontal arm, when a flame about an inch in length should be produced. Light the burner and

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[1] Abady's Gas Analyst Manual.

turn down the flame till it forms a *blue non-luminous ring*, then place the small clay pieces upon the top of the chimney round the neck of the bulb. A testing may be made five minutes after the burner is lit, except when the apparatus is first used, when the gas should be allowed to flow through the bulb for a quarter of an hour or a little longer, and any number of testings may be made, one after another, as long as the heat is continued.

"The mode of testing is as follows: Place the piece of opal glass in the back of the comparison box. (The figure shows a sheet of cardboard, but a small box which takes the Standard Color and the Test Tube and which has an opal back, is now used.) Put the Standard Color Tube in one of the holes in the box. Now dilute some of the lead syrup solution with about 20 times its volume of distilled water, and fill the test glass up to the mark with the solution thus prepared. Insert the caoutchouc plug with capillary tube (which should descend very nearly to the bottom of the glass, but must not press upon the bottom, or it will probably be broken) and elbow tube, and connect, as shown in the figure, with the bulb and aspirator, placing the two glasses side by side in the comparison box.

"There are two color standards, one for daylight and the other for gaslight, which are sent out in sealed glasses. When using the gaslight standard, the gaslight employed should be a flat flame or Argand, emitting yellow rays; the incandescent (white mantle) will not do. The glass containing the standard solution should always be shaken before commencing a test.

"The aspirator must be quite full of water at starting, and the measuring cylinder empty. Turn the tap of the aspirator gradually; a stream of bubbles will rise through the solution of lead. Turn off the tap for a minute and observe the liquid at the bottom of the capillary tube. If it gradually rises, the India rubber connections are not air tight and must be made so before proceeding. Avoid pressing the plugs into the glass or the aspirator while they are connected, which would drive up the lead solution into the inlet tube.

"When the connections are air tight, let the water run into the measuring cylinder in a *slender stream* until the lead solution has become as dark as the standard. As the ascending bubbles interfere somewhat with the observation of the tint, it is best to turn off the tap when the color seems almost deep enough; compare the two; turn on the tap, if necessary, for a few moments, then compare again and so on until the color of the two liquids is the same. The volume of water which the measuring cylinder now contains is equal to the volume of gas which has passed through the lead solution."

The calculations involved in computing the result will be made clearer by a concrete illustration. Assume that the standard solution contains 0.0121 gram or 0.187 grain of lead sulphide, that the measuring cylinder is divided into cubic centimeters, and that 2492 c.c. of water have passed from the aspirator to this cylinder:

$$\underset{239}{PbS} : \underset{32}{S} :: 0.187 : x$$

$x = 0.025$ grain. So the standard solution contains 0.025 grain of sulphur, and since the test solution has been made to match the standard in color, enough sulphuretted hydrogen must have passed into it so that it too contains 0.025 grain of sulphur. Then 2492 c.c. which are equal to 0.088 cubic foot, contain 0.025 grain of sulphur as carbon bisulphide.

$0.025 \times 100 \div .088 = 28.4$ grains of sulphur as carbon bisulphide per 100 cubic feet of gas.

This does not give the total sulphur in the gas, for the reason that carbon bisulphide is not the only form in which sulphur exists in the gas, and the other varieties are not converted to sulphuretted hydrogen by the action of heat. Abady states that these other compounds contain sulphur which ordinarily amounts to 7 or 8 grains per 100 cubic feet, and this quantity must therefore be added to that found by the analysis in order to arrive at the total sulphur in the gas. Thus it is clear that the method is only an approximation at best.

Moreover, as will be readily seen, the test cannot be conducted upon gas containing sulphuretted hydrogen; in such cases the latter must be removed by an oxide purifier before the gas reaches the apparatus. There are one or two other precautions which should be noted. For each separate experiment the test cylinder must be emptied, rinsed and recharged. The solutions must not be allowed to become heated, as thereby the color is intensified. It is a little difficult to see how this can be avoided, since hot gas is passed into one of the tubes, and this fact would seem to detract from the value of the results. The test solution may be used again and again, provided it is exposed, after each determination, to the action of light for a few hours, whereby it again becomes colorless. Air must, however, be excluded during the process, as otherwise carbonic acid acts on the lead acetate, forming lead carbonate, and the strength of the solution is thereby diminished.

The platinized pumice will serve for 100 tests; after that its action is weakened by the deposition of carbon on its surface. It may be revivified, however, by heating it rather hotter than is customary during a test, and drawing air over its surface. The carbon is oxidized to carbonic acid and passes off into the aspirator; the process is complete when the air which has been drawn through is passed through a solution of barium hydrate and creates no cloudiness, thus proving that carbonic acid is no longer being formed.

This process of determining total sulphur has not been adopted to any extent in this country, and does not, in the writer's opinion, compare favorably with either the Referees' method, or another which will be described shortly and which was devised by Major C. W. Hinman and perfected by Mr. C. D. Jenkins. Before coming to these most important methods, however, a short description must be given of two other processes which are recommended by high authorities.

The method of Wildenstein consists in burning the gas in a Referees' apparatus in the manner prescribed in the Referees' test, collecting the products of combustion and making them up to a definite volume. A portion of this representing a known volume of gas is then placed in a beaker or porcelain dish and acidified slightly with hydrochloric acid. The solution is heated to boiling, and a known volume of a standard solution of barium chloride is added, in amount more than sufficient to unite with all of the sulphuric acid present. Ammonia is then cautiously added until the solution is just neutral and the excess of barium chloride titrated with a standard solution of potassium chromate. This method is both convenient and accurate, but the directions must be followed in detail, or the reliability of the results is lost. The sulphur from the gas is present in the solution as sulphuric acid; the barium chloride unites with this to form barium sulphate, thus:

$$BaCl_2 + H_2SO_4 = BaSO_4 + 2\,HCl.$$

This barium sulphate is a heavy white precipitate very insoluble in water and dilute hydrochloric acid; the boiling facilitates both the formation of this precipitate and its settling out. As has been seen from the reaction, hydrochloric acid is formed, and this must be neutralized because barium chromate is soluble in dilute hydrochloric acid, producing a solution with a yellowish to reddish color which would obscure the end-point of the titration. As the potassium chromate is added, it unites with the excess of barium chloride, thus:

$$K_2CrO_4 + BaCl_2 = BaCrO_4 + 2\,KCl.$$

The barium chromate is a heavy yellow precipitate insoluble in neutral or alkaline solutions and settling out readily from the boiling liquid. As long as the barium chloride remains in the solution, the supernatant liquid will be colorless; but the moment enough potassium chromate has been added to unite with all of the barium chloride, the solution will be colored yellow, and this is the desired end-point.

The barium chloride and potassium chromate are made by dissolving 52 grams of the former and 48.5 grams of the latter in water and making the volume of each solution up to 1 liter, thus making both N/2. One cubic centimeter of either is then equal to 1 c.c. of the other and to 0.02 gram of SO_3; therefore in making the calculation it is only necessary to deduct the number of cubic centimeters of potassium chromate used from the number of cubic centimeters of barium chloride added and multiply the difference by 0.02 to get the grams of SO_3 in the amount of liquid tested; and as .4 of SO_3 is sulphur, the result is readily calculated to grains per 100 cubic feet of gas.

Example. Ten cubic feet of gas were burned and the products of combustion made up to 200 c.c. Fifty c.c. of these were taken for analysis, 10 c.c. of the barium chloride added and 5.8 c.c. of the potassium chromate required to combine with the excess of barium chloride.

$$10.0 - 5.8 = 4.2 \text{ c.c.}$$
$$4.2 \times 0.02 = 0.084 \text{ gram } SO_3 \text{ in the 50 c.c.}$$
$$\text{but } S = 0.4 \text{ of } SO_3 \text{ and 1 gram} = 15.43 \text{ grains,}$$

therefore $0.084 \times 0.4 \times 15.43 = 0.5184$ grain sulphur in 50 c.c. The total volume of the sample was 200 c.c. and represented 10 feet of gas, so $0.5184 \times 200/50 \times 100/10 = 20.7$ grains of sulphur per 100 cubic feet. Or, if one-fourth of the total solution is always taken for analysis, we can combine the various factors and deduce the following formula for finding the grains of sulphur per 100 cubic feet of gas:

$$\frac{(B - K) \times 49.36}{G}$$

where B equals the number of cubic centimeters of barium chloride added, K equals the number of cubic centimeters of potassium chromate, and G the cubic feet of gas burned.

If the method is to be employed only for water gas, it will be better to use the entire sample for analysis, or else to make the standard solutions much weaker, say 20.8 grams of barium chloride and 19.4 grams of potassium chromate to the liter respectively, in either of which cases the above formula would have to be modified.

Mr. W. C. Young takes an aliquot part of the liquor given by the Referees' apparatus, adds sufficient acetic acid to decompose any ammonium carbonate which may be present, and then a measured excess of a standard solution of barium chloride. The solution is next evaporated to dryness in a platinum dish and heated to low redness; the contents are cooled and washed out into a beaker, an excess of potassium chromate added and a standard solution of silver nitrate run in from a burette until the red color of the silver chromate remains permanent.

The idea of the process is to precipitate the sulphuric acid with an excess of barium chloride, and then by expelling all hydrochloric acid and ammonium chloride from the solution, to determine the amount of barium chloride which has not been needed to combine with the sulphuric acid by titration with silver nitrate. Since hydrochloric acid and ammonium chloride are both volatile, their expulsion is for the most part easily accomplished; but to remove traces which are held within the solid residue, it is necessary to heat to low redness. Silver nitrate reacts with barium chloride and potassium chromate as follows:

$$2\,AgNO_3 + BaCl_2 = 2\,AgCl + Ba(NO_3)_2,$$
$$2\,AgNO_3 + K_2CrO_4 = Ag_2CrO_4 + 2\,KNO_3.$$

The first of these reactions is the one which will take place so long as there is any barium chloride left in the solution, but the moment it is exhausted the second reaction sets in. The silver chloride is a heavy white precipitate, while the silver chromate is deep red; consequently the end-point is very sharp. The amount of silver nitrate used in the titration is equivalent to the excess of barium chloride added, or, in other words, to the amount of barium chloride left over after all of the sulphuric acid has been converted to barium sulphate. Now the solutions may be made up so that 1 c.c. of the barium chloride equals 5 c.c. of the silver nitrate, and the latter should be N/20 and contain 8.499 grams to the liter. The potassium chromate is a 10 per cent solution; that is, 100 grams to the liter.

Now, assuming that the products of combustion from 10 cubic feet of gas were made up to 100 c.c. and 10 c.c. taken for analysis; 15 c.c. of barium chloride were added, and it required 37.5 c.c. of silver nitrate to react with the excess. 37.5 c.c. of silver nitrate equals 7.5 c.c. of barium chloride. 15 − 7.5 = 7.5 c.c. of barium chloride used in uniting with the sulphuric acid. 7.5×0.026 (the weight of barium chloride in 1 c.c.) = 0.195 gram barium chloride.

$$\begin{array}{ll} BaCl_2 : S : : 0.195 : x \\ 208 \quad\quad 32 \end{array}$$

$x = 0.03$ gram of sulphur in the 10 c.c. analyzed. $0.03 \times 10 \times 10 \times 15.43 = 46.29$ grains of sulphur per 100 cubic feet of gas. The principal advantage of this test is its rapidity, one complete determination (after securing the products of condensation) requiring only about 20 minutes. Its accuracy is sufficient for practical purposes, but it is believed that one of the methods already given, or that of Mr. Jenkins which follows, will be found to be more satisfactory in the long run.

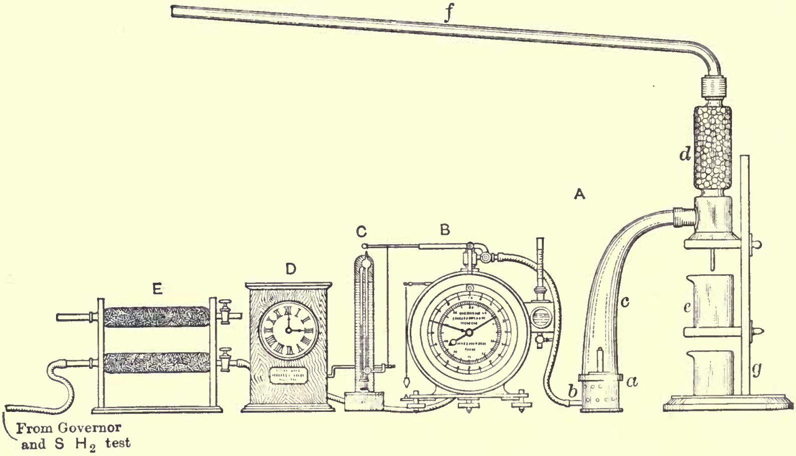

Fig. 17. Referees' Sulphur and Ammonia Apparatus.

The Referees' method is the one officially used in London, and has been adopted by many gas companies in the United States. The apparatus necessary is seen in Fig. 17. *a* is a small Bunsen burner with a steatite tip which projects upward through a cylindrical metallic stand, *b*. This stand has a gutter-like depression running round the upper and inner edge, in which rests the large end of the glass trumpet tube, *c*. The stand is perforated, in both sides and top, with 14 circular holes of about 5 mm. diameter;

these serve to admit the air required for combustion of the gas. The burner pillar is surrounded, when the apparatus is in use, by about 2 ounces of commercial sesquicarbonate of ammonia, in small lumps; these rest on the cylinder and lie between the burner and the trumpet tube. *d* is a glass cylinder or bead glass with a tubulure at the bottom and a constriction between this and the upper part of the cylinder. This bead glass is filled with marbles or balls of glass, each about 15 mm. in diameter, which serve to expose a large surface to the current of combustion products and thus promote condensation.

At the bottom of the bead glass is a small outlet tube of glass, through which the condensate runs into the beaker, *e*. A long glass tube, *f*, is connected to the top of the cylinder and serves a threefold purpose, first as an outlet for the uncondensed gases, second as a regulator for the draft, third as a condenser for any condensible substances which may have passed through the cylinder. The wooden stand, *g*, serves to support the beaker and bead glass. The manner of using this apparatus is prescribed with great exactness by the Metropolitan Gas Referees: "It is to be set up in a room or closet where no other gas is burning. The gas shall pass through a meter by reference to which the rate of flow can be adjusted, and which is provided with a self-acting movement for shutting off the gas when 10 cubic feet have passed.

"Pieces of sesquicarbonate of ammonia, from the surface of which any efflorescence has been removed, are to be placed round the stem of the burner. The index of the meter is to be then turned forward to the point at which the catch falls and will again support the lever-tap in the horizontal position. The lever is made to rest against the catch so as to turn on the gas. The index is turned back to a little short of zero and the burner lighted. When the index is close to zero the trumpet tube is placed in position on the stand and its narrow end connected with the tubulure of the condenser. At the same time the long chimney tube is attached to the top of the condenser.

"As soon as the testing has been started a first reading of the aerorthometer is to be made and recorded, and a second reading as near as may be to the time at which the gas is shut off. The rate of burning, which with practice can be judged very nearly by the height of the flame, is to be adjusted, by timing the index of the meter, to about half a cubic foot of gas per hour.

" After each testing, the flask or beaker, which has received the liquid products of the combustion of the 10 cubic feet of gas, is to be emptied into a measuring cylinder and then replaced to receive the washings of the condenser. Next the trumpet tube is to be removed and well washed out into the measuring cylinder. The condenser is then to be flushed twice or thrice by pouring quickly into the mouth of it 40 or 50 c.c. of distilled water. These washings are brought into the measuring cylinder, whose contents are to be well mixed and divided into two equal parts.

"One-half of the liquid so obtained is to be set aside, in case it should be desirable to repeat the determination of the amount of sulphur which the liquid contains.

" The other half of the liquid is to be brought into a flask, or beaker covered with a large watch-glass, treated with hydrochloric acid sufficient in quantity to leave an excess of acid in the solution, and then raised to the boiling point. An excess of a solution of barium chloride is now to be added, and the boiling continued for 5 minutes. The vessel and its contents are to be allowed to stand till the barium sulphate has settled at the bottom of the vessel, after which the clear liquid is to be as far as possible poured off through a paper filter. The remaining liquid and barium sulphate are then to be brought on to the filter, and the latter is to be well washed with hot distilled water. (In order to ascertain whether every trace of barium chloride and ammonium chloride has been removed, a small quantity of the washings from the filter should be placed in a test tube, and a drop of a solution of silver nitrate added; should the liquid, instead of remaining perfectly clear, become cloudy, the washing must be continued until on repeating the test no cloudiness is produced.)

" Dry the filter with its contents, and transfer it into a weighed platinum crucible. Heat the crucible over a lamp, increasing the temperature gradually, from the point at which the paper begins to char, up to bright redness.[1] When no black particles remain, allow the crucible to cool; place it when nearly cold in a desiccator over strong sulphuric acid, and again weigh it. The difference between the first and second weighings of the crucible will give the number of grains of barium sulphate. Multiply this number by 11 and divide by 4; the result is the number of grains of sulphur in 100 cubic feet of the gas.

"This number is to be corrected for the variations of temperature and atmospheric pressure in the manner indicated under the head of Illuminating Power, with this difference, that the mean of the first and second aerorthometer readings shall be taken as the reading."

The aerorthometer (Fig. 18) is an instrument for correcting the volume of a gas measured over water, at any ordinary temperature and pressure, to that which the gas would have if measured over water under a pressure of 30 inches of mercury, and at a temperature of 60° F. Thus its reading corresponds to the figure derivable from a reading of the barometer and the thermometer and a reference to a table giving the tension of aqueous vapor at different temperatures. The instrument consists of a bulb and vertical stem in which sufficient water is present to insure that the air is saturated.

The measuring tube, which terminates in a closed bulb, and a companion tube of the same calibre, which is open to the air, dip into a reservoir of mercury in the base, the capacity of which can be adjusted by a regulating screw pressing on a leather cover. The relative volume of the bulb and tube down to any division is represented by the number belonging to that division. The capillary tube above the bulb is closed by a very small amount of sealing wax.

In order to adjust the instrument, the sealing wax is softened by heat and a small hole made through it. When the bulb has acquired the temperature of the air, the regulating screw is to be turned until the two columns of mercury stand level at the calcu-

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[1] "An equally good and more expeditious method is to drop the filter with its contents, drained but not dried, into the red-hot crucible."

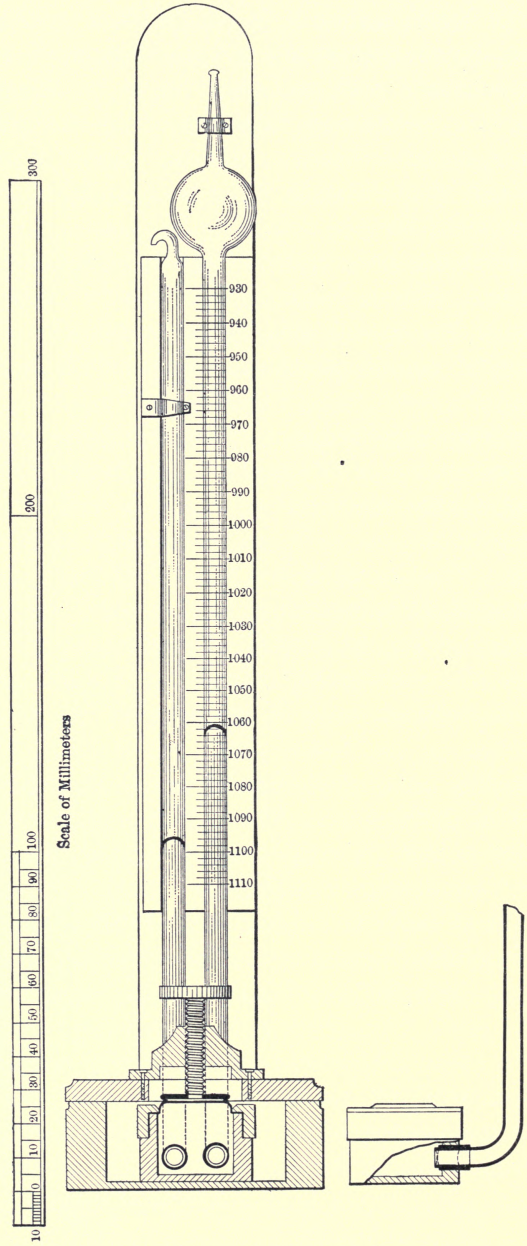

Fig. 18. Aerorthometer.

lated aerorthometer reading. Then the sealing wax stopping is again melted where it was perforated, by being touched from above with a heated wire while the base of the tube and the bulb are protected from heat by a wrapping of cotton wool.

In using the aerorthometer, turn the screw up until the level of the mercury in the open tube is some distance below that of the mercury in the bulb tube; then turn the screw slowly down until the mercury stands at the same level in both tubes. The division at which the mercury now stands is the aerorthometer reading. This instrument is not in much use in this country. It costs about $12.50 in England, which would probably mean $15 or $16 in the United States.

Alexander Wright & Co., who manufacture and sell all of the apparatus recommended by the Referees, say in their catalogue: ". . . We consider it an unreliable instrument for general use." The correction which the aerorthometer affords may be arrived at equally well by consulting the table of corrections for temperature and pressure and tension of aqueous vapor, which is given in the appendix, or it may be reached by the percentage method, as has been explained under the candlepower calculations.

The theory involved in the Referees' method for total sulphur is as follows: A definite volume of gas is burned, and the sulphur is converted to SO_3. This passes up through the condenser and draws with it ammonia vapor from the ammonium carbonate around the burner tube. In the presence of water the ammonia and sulphuric anhydride unite to form ammonium sulphate. Thus,

$$2\,NH_3 + SO_3 + H_2O = (NH_4)_2SO_4.$$

The carbon in the gas burns to carbonic acid, which unites with the water and ammonia vapor to form ammonium carbonate. The hydrogen of the gas burns to water vapor, which furnishes part of the water necessary for the above reaction. On passing over the enormous condensing surface offered by the glass marbles, the carbonate and sulphate of ammonium and the aqueous vapor condense and run back into the beaker.

This condensate is made up to a definite volume and one-half taken for analysis. To this half hydrochloric acid is added for two reasons: first, to break up the ammonium carbonate present, which would otherwise react with the barium chloride to form barium carbonate, a heavy white precipitate, which would then be weighed with the barium sulphate and thus give too high results for the sulphur; second, because barium sulphate must be precipitated in a solution slightly acid with hydrochloric acid.

Heating the solution to boiling drives off the carbonic acid, which is thus eliminated from further consideration. It also renders the formation of barium sulphate more complete and rapid. The continued boiling after addition of barium chloride brings the precipitate together in a form in which it will settle rapidly. The solution is then allowed to stand until the precipitate has settled; this renders filtration more rapid, and also diminishes the possibility of any barium sulphate passing through the filter, as sometimes happens.

The precipitate always contains small amounts of barium chloride and ammonium chloride mechanically inclosed, and these are removed by washing with hot water. If cold water were used, not only would it require a longer time to dissolve out the impurities, but also the water would be almost certain to carry some of the barium sulphate through the filter. The washings are tested for chlorine with silver nitrate, and when a precipitate or cloudiness no longer occurs on the addition of the reagent, it is clear that, if the washing has been conscientiously performed, the precipitate no longer contains any chlorides.

The platinum crucible must be ignited when empty and cooled in a desiccator before weighing; this is to drive off the film of moisture and dust which settles on the surface of the crucible. In igniting the precipitate care must be taken that the burning carbon does not reduce the barium sulphate to barium sulphide; the best method to prevent this is to ignite the filter and precipitate separately. This as a rule, however, cannot be done in the analysis of gas for sulphur, because the barium sulphate precipitate will be too small, and will not separate readily from the filter.

The next best method is to place the uncovered crucible on the ring stand at an angle to the vertical, and apply a small flame well back on the side and bottom of the crucible, so that there may be the freest possible access of air. The weights in this country will usually be expressed in grams; the calculation is then explained thus: Assume barium sulphate found to equal 0.8275 gram from one-half of the sample obtained by burning 10 cubic feet of gas corrected for temperature, pressure and tension of aqueous vapor.

0.8275 × 2 × 10 = 16.55 grams of barium sulphate per 100 cubic feet of gas. To change this to grains multiply by 15.43 and we get 255.37 grains of barium sulphate from 100 cubic feet of gas. Now every grain of barium sulphate contains 32/233 grains of sulphur; this is obtained from the relation of the atomic weight of sulphur, 32, to the molecular weight of barium sulphate, 233. 255.37 × 32/233 = 35.07 grains of sulphur per 100 cubic feet of gas. Or, to combine all of these factors into a rule: When 10 cubic feet of gas (corrected) are burned, and one-half of the sample is taken for analysis, multiply the weight of barium sulphate in grams by 42.38, and the result will be grains of sulphur per 100 cubic feet.

This method is accurate provided the gravimetric analysis is carried out with great care and by one accustomed to chemical manipulation. It is, however, very slow, as considerable time is consumed in waiting for the barium sulphate to settle, in filtering, drying, igniting, waiting for the crucible to cool and in weighing. Also much of the sesquicarbonate of ammonia on the market contains ammonium bicarbonate, and the excessive carbonic acid from this is said to materially interfere with the condensation of the sulphurous and sulphuric acids.

Again, a considerable amount of gas is required, in order to secure a precipitate of barium sulphate sufficiently large to handle, and the burning of 10 cubic feet of gas at a rate of 0.5 cubic foot per hour is a long and tedious process.

Moreover, where a large number of tests are to be made, a number of platinum crucibles are required, and these cost from

$20 apiece upward. Certain of the volumetric processes have been proven to be just as accurate, far more rapid, and requiring no expensive apparatus; hence it would seem the wisest policy to adopt one of these. Such a method has been used by the writer for many years, and has given perfect satisfaction. For the sake of brevity, it will be alluded to as the Hinman-Jenkins method.

The apparatus needed for this method is described in the *Journal of the American Chemical Society* for April, 1906, and is illustrated in Fig. 19. *a* is a bead glass 12 inches long and 2.4 inches in diameter. This is filled with large cut glass beads about three-sixteenths inch in diameter, which are kept from dropping through the lower opening by a flower-shaped piece of glass (see Fig. 20), or by a watch-glass with a number of V-shaped openings cut in its circumference. This bead glass offers a large condensing surface to the products of combustion, and at the same time the draft is not interrupted. *b* is a glass adapter 16.4 inches long, 2 inches in diameter at the larger end and three-fourths inch diameter at the upper. This is connected to the bead glass by a short piece of heavy rubber tubing wired to the constricted part of the bead glass. *c* is a connecting piece joining the upper to the lower adapter, *d*, which is 16 inches long, 1.6 inches in diameter at the large end and one-half inch diameter at the small end. This connecting piece is composed of a glass piece, *e*, in shape similar to the adapters but only 5 inches long, thirteen-sixteenths inch diameter at the top, and three-eighths inch diameter at the bottom. This passes through a rubber stopper 2 inches in diameter at the smaller end, and projects nearly one-half inch above the stopper into the upper adapter.

The upper end of the glass piece is roofed over by a watch-glass $1\frac{5}{8}$ inches in diameter supported on platinum wires and one-eighth to three-sixteenths inch above the end of the glass piece; this serves to deflect the products of condensation and keep them from running down into the lower adapter. An overflow tube, *f*, passes just through the stopper and leads to a 100 c.c. Erlenmeyer flask, *g*, in which the condensate collects. The overflow tube is enough above the level of the stopper so that a little water always remains on the latter and thus keeps it cool. The bottom of the glass piece is fitted into a cork bound by a brass band, and the lower adapter fits into the other end of this cork.

The Bunsen burner, *h*, carries a lava tip with an opening 0.2 inch in diameter, while near the base for the pillar are two other holes for the admission of air. Surrounding the pillar is a glass tube 0.8 inch in diameter and 1½ inches long which fits into the center of a section of a large rubber stopper. This stopper itself fits tightly into a glass cylinder 2 inches in diameter and 2 inches long, and rests upon and within a cylindrical iron base, *i*.

Around the top of the bead glass a brass ring one-half inch wide is sweated on, which serves as support for the cord by which the entire apparatus (save the burner) is suspended. The complete outfit costs $20. It may be readily set up or taken apart in three minutes, and the individual pieces packed in a small space for transportation.

The method of procedure with this apparatus is as follows: The bead glass is suspended by its cord from a gas fixture, hook or nail; the rubber stopper is inserted in the upper adapter, and the small end of the latter is forced into the rubber connection so as to make a tight joint with the bead glass. The lower adapter is then fastened into the cork connector, the Erlenmeyer suspended from a hook in the stopper, and over the mouth of the overflow tube, and the apparatus is ready for use. Care must be taken to see that the whole column is vertical, and that

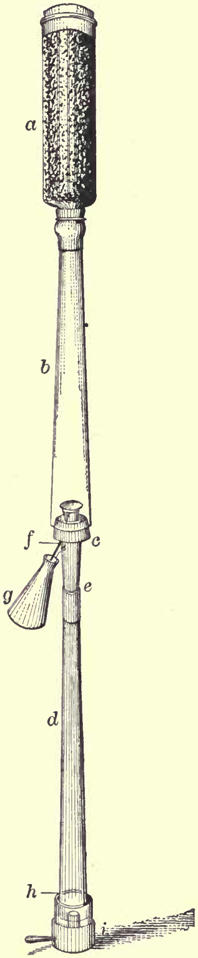

Fig. 19. Hinman-Jenkins Sulphur Apparatus.

the connections are tight. The bottom of the lower adapter should be at such a height above the floor that when the lamp is inserted the adapter will project about one-fourth to one-half inch within the outer glass ring of the burner.

The gas to be tested is connected with a meter and then with the burner. The latter is lighted, and 3 to 4 c.c. of a 10 per cent solution of ammonia are placed in the chamber formed by the inner and outer glass rings. As the hand of the meter passes zero, the burner is inserted under the adapter by pulling the latter slightly from the vertical, pushing in the lamp, and then returning it to the vertical position.

Record the reading of the meter at the start. 0.8 cubic foot of gas is to be burned at a rate not exceeding 0.6 foot per hour, and after each 0.2 foot has passed, 2 c.c. to 3 c.c. of ammonia are added to the burner chamber, without disturbing its position. All of the air which is supplied to the burner must pass over this ammonia, consequently the SO_2 and SO_3 formed from the sulphur in the gas meet everywhere throughout the apparatus an ammoniacal atmosphere, and so condense as ammonium sulphate and ammonium sulphite and run back with the water formed by the combustion into the Erlenmeyer flask.

To avoid labor in calculation, it is well at the start to note the temperature and pressure, and ascertain how much gas must be registered on the meter in order to have used 0.8 foot at normal temperature and pressure. Thus, if the temperature is 72 degrees and the barometer 30.12 inches and the meter is 2.4 per cent slow, the corrections are: temperature (dry meter) 2.4 per cent plus, barometer 0.4 per cent minus, and meter 2.4 per cent minus. Combining these we get 0.4 per cent minus. $0.8 \div 1.004 = 0.797$. Consequently, if the reading on the meter shows 0.797 foot, 0.8 foot corrected will have been used.

Of course any dry meter may be used; a wet meter is not recommended because of the solvent action of the water and because the latter will give up to the gas, and take from it, certain substances, such as ammonia, sulphuretted hydrogen, etc., the seemingly contradictory action depending on changes of temperature and quality of the gas. A small 3-diaphragm meter, known as an "O" light, is in use by the writer and his assistants, and has given very fair satisfaction. The dial is horizontal, thus enabling one to read it without stooping over. The top is fastened in place by screws and so may be easily removed to adjust the meter or clean the valves. This meter should be tested as often as practicable, and its error included in the calculations, as was done above. Its cost is $40, and it may be procured of the American Meter Company.

When the 0.8 foot of gas has been consumed, shut off the gas and allow the apparatus to cool. Disconnect the lower adapter and pour distilled water through one end, holding the other end over the bead glass. When the entire inner surface has been touched by the running water, the adapter is laid aside, and water poured through the bead glass, in small quantities at a time, until about 150 c.c. have been used. As the Erlenmeyer flask will not hold this amount, it may be emptied at any time into a numbered 200 c.c. sample bottle, and replaced in position. This can easily be done without loss, if the bottle is held under the overflow tube while the flask is being emptied. Allow a minute or two for the bead glass to drain, then disconnect the upper adapter, with the rubber stopper still in place, from the bead glass, and wash out the connecting piece. All of the washings are transferred to the bottle, and the sample is ready for analysis. The latter is performed in a manner different from any of those methods already described. The reagents employed and their preparation will now be given.

(*a*) Bromine water. This is made by covering the bottom of a 250 c.c. bottle with pure bromine, filling the bottle with distilled water and shaking. When sufficient of the bromine has been dissolved, the supernatant liquid will be of a deep-red color. This must be kept in a glass-stoppered bottle, and should not be exposed to direct sunlight or to heat.

(*b*) A solution of barium chromate in hydrochloric acid, containing 92 grams of pure barium chromate dissolved in a mixture of 120 c.c. strong hydrochloric acid (Sp. Gr. 1.2) and 880 c.c. of water. As in most laboratories 250 c.c. of this reagent will last for months, the following directions cover the preparation of this amount. It is difficult to secure barium chromate of the requisite purity, and the best results are obtained by making it on the spot.

Take 22.2 grams of pure $BaCl_2 . 2 H_2O$ and dissolve, in a 750 c.c. beaker, in about 250 c.c. of distilled water. In another beaker dissolve 14 grams of pure potassium bichromate in 250 c.c. of water. Heat both solutions to boiling and pour one into the other, stirring all the while.[1] Cover the beaker with a watch-glass and let stand several hours, or, better, over night, in a warm place.

Decant the supernatant liquid through a filter; wash the precipitate by decantation two or three times with hot water, and finally bring it on the filter and continue the washing until the wash water shows no trace of chlorine or chromium. To determine this, take 10 c.c. of the wash water in each of two test-tubes; to one add nitric acid and silver nitrate, when if chlorine be present a white turbidity or opalescence will appear. To the other add acetic acid and lead acetate, and if a yellow precipitate is formed, or a yellow color appears, it is a sign that the chromium has not been completely washed from the precipitate. If a 9 cm. filter is used, it will be difficult to perform the washing satisfactorily, because of the bulk of the precipitate; hence it is better to divide the latter between three filters.

When chlorine and chromium no longer appear in the filtrate, the barium chromate is ready for use. Dissolve it in a mixture of 30 c.c. of hydrochloric acid and 220 c.c. of water, heated to boiling, and if the solution is not clear, filter it.

In the finished product there must not be an excess of either barium or chromate, even in trifling amount, and it is therefore always advisable to test the solution for these substances. This may be done by taking 10 c.c. of the barium chromate in a test

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[1] As the reaction sets free hydrochloric acid, in which barium chromate is soluble, it is well to just neutralize the acid formed with ammonia, thus increasing the yield of barium chromate.

tube, adding ammonia until just alkaline, and filtering. The barium chromate is insoluble in alkaline solution, and so precipitates out; while if the solution contains any barium chloride or potassium bichromate, they will pass into the filtrate, which is to be divided into two equal parts.

To one-half add a few drops of hydrochloric acid and then dilute sulphuric acid, when, if barium be present, a white precipitate will be formed. To the other half add acetic acid and lead acetate, and a yellow precipitate or color will indicate the presence of chromium. In case the test for barium gives positive results, enough potassium bichromate must be added to the main solution to exactly react with this barium, and another test made to see that this has been accomplished. Conversely, if chromium is found to be present, barium chloride must be added until the excess is entirely neutralized.

(*c*) A solution of ammonia made by diluting one part of strong ammonia with 8 to 10 parts of water.

(*d*) Stannous chloride solution, containing about 13 grams of tin to the liter. It is well to make up a stock of, say, 4 liters of this reagent, as it is somewhat troublesome to prepare and may, with proper precautions, be kept for a long time. 13 grams of pure tin are placed in each of four 100-c.c. Erlenmeyer flasks, 50 c.c. of hydrochloric acid (1.2) added to each, and a piece of platinum to aid in the solution. By heating and allowing to stand, as much of the tin as possible is brought into solution; this will require a long time if the tin is pure, but need not take up the entire attention of the operator. Filter the contents of all four flasks through one filter, receiving the filtrate in a 750 c.c. beaker. Add 200 c.c. of strong hydrochloric acid to this filtrate, pour into a large bottle and make up to 4 liters.

(*e*) Starch solution, the manufacture of which has already been described under Mohr's method for sulphuretted hydrogen.

(*f*) Potassium iodide solution. — Dissolve 3 or 4 crystals of pure potassium iodide in 25 c.c. of water.

(*g*) Solution of potassium ferricyanide. — 1 gram in 10 c.c. is sufficient, as it should be made up afresh every time it is needed.

(*h*) Standard solution of potassium bichromate, containing about 20 grams to the liter. It is necessary to know the exact strength of this solution, as it is used to determine the value of the stannous chloride each time the latter is used. To standardize, weigh out very accurately about 0.5 gram of purest iron wire, dissolve in a little hydrochloric acid, dilute to about 50 to 75 c.c., and place this solution in a Florence flask provided with a Bunsen valve. The latter is made up of a rubber stopper through which projects a piece of glass tubing about 3 inches long. To the upper end of the tube is connected a piece of rubber tubing 1½ inches long, closed at the top by a glass rod. This rubber has a slit one-fourth inch long, cut through one wall midway between the rod and the glass tubing which serves as outlet for the steam, but which, when the heat is removed from the flask and the contents begin to cool and condense, closes automatically and prevents the entrance of air, thus producing a partial vacuum in the flask.

Now to the solution of iron wire in the glass, add 1 gram of very pure zinc (free from iron), insert the valve and heat gently until *all* of the zinc is dissolved; by this time the air will have been expelled and replaced by hydrogen and steam. Remove the lamp and allow the flask and contents to cool. Open the slit in the valve and take out the stopper. Add the potassium bichromate to be tested from a burette until a small drop of the liquid from the flask, placed on a white porcelain tile in contact with a drop of the potassium ferricyanide, no longer produces a blue or greenish-blue color. The end-point is somewhat difficult to read, and a little time spent in practice with this will be well employed.

The process is based on the fact that potassium bichromate will oxidize a solution of ferrous chloride, in presence of hydrochloric acid, to ferric chloride; and the moment when sufficient has been added is shown by the test with the potassium ferricyanide, which gives a blue precipitate or coloration with ferrous salts and a colorless solution with ferric salts. The reactions involved are:

$$Fe + 2\,HCl = FeCl_2 + H_2$$

$$6\,FeCl_2 + K_2Cr_2O_7 + 14\,HCl = 6\,FeCl_3 + 2\,KCl + 2\,CrCl_3 + 7\,H_2O$$

$$2\,K_3Fe(CN)_6 + 3\,FeCl_2 = Fe_3(Fe(CN)_6)_2 + 6\,KCl.$$

The iron wire sold for standardizing purposes generally contains 99.8 per cent of iron, and allowance is made for this and for the amount of iron in the zinc used. This latter item can be easily ascertained by buying chemicals whose analysis is furnished by the manufacturer. To cite a specific case: 0.5082 gram of iron wire was taken, 1 gram of zinc containing 0.015 per cent of iron was used for reduction of the iron, and 21.60 c.c. of the potassium bichromate were required. $(0.5082 \times 0.998) + 0.00015 = 0.5073$ grams of iron, which reacted with the potassium bichromate.

$0.5073 \div 21.6 = 0.02349$ gram of iron per cubic centimeter of bichromate.

$$\begin{array}{ll} 6\,\mathrm{Fe} : & K_2Cr_2O_7 :: 0.02349 : x \\ 336 & 294 \end{array}$$

$x = 0.02055$ gram of potassium bichromate per cubic centimeter or 20.55 grams per liter.

In standardizing the stannous chloride, which is done each time before using, 5 c.c. of the potassium bichromate are placed in a Florence flask, slightly acidified with hydrochloric acid, and the stannous chloride run in from a burette until nearly the proper amount has been added. This quantity may be estimated, if necessary, by a preliminary titration. Then two drops of the potassium iodide are added and two drops of starch solution and the titration continued, adding the stannous chloride drop by drop, until the muddy, greenish appearance of the liquid suddenly changes to a clear peacock-blue green. This end-point is extremely sharp, is brought about by less than one drop of stannous chloride, and when once seen can never be mistaken. It is unnecessary to figure the value of the stannous chloride at this stage, as will be seen when the final calculation is considered.

In carrying out the process, the sample of 200 c.c. is emptied into a shallow porcelain dish, which is then marked with the same number as that borne by the sample bottle. Enough bromine water is added to color the solution decidedly reddish; this is to oxidize to sulphuric acid any sulphurous acid which may have been formed. The dish is now placed over a small Rose burner and the contents evaporated to about 25 c.c. Care must be taken that the flame does not play upon the dish above the surface of the liquid, or ammonium sulphate will be lost by volatilization. Allow the liquid to cool, add 2 c.c. of the barium chromate, and wash down the sides of the dish with a stream from a wash-bottle.

Heat the solution to boiling and then add enough of the ammonia solution so that a faint smell of ammonia remains; this will require only a few c.c. An insufficient amount will result in too high a figure for the sulphur, while too much will interfere with the future work. It is better, however, to add too much rather than too little, since the excess may be easily removed by boiling. Boil the solution for a minute or two after adding the ammonia, let the precipitate settle, filter, wash twice by decantation and once on the filter.

Place the filtrate in a numbered Florence flask of 125 c.c. capacity, insert a rubber stopper bearing a Bunsen valve, and boil the solution until all air in the flask has been expelled and steam has issued freely for some minutes from the orifice in the valve. Place the flask in cold water and leave there until the contents have attained the room temperature. Then remove the stopper, add hydrochloric acid to distinctly acid reaction, and run in the stannous chloride until the yellow color of the solution has nearly disappeared. Now add two drops of potassium iodide and a few c.c. of starch (if made from soluble starch) and continue the titration until the solution becomes colorless. Read and record the number of the sample and the number of c.c. of stannous chloride used.

The principles upon which this process rests are as follows: When the barium chromate is added in excess, it reacts with the ammonium sulphate formed from the combustion of the gas in an ammoniacal atmosphere, in the following manner:

$$(NH_4)_2SO_4 + BaCrO_4 = BaSO_4 + (NH_4)_2CrO_4.$$

The excess of barium chromate is precipitated by ammonia and filtered out, and the filtrate then contains an amount of ammonium chromate equivalent to the quantity of ammonium sulphate originally present. The boiling is to remove the air dissolved or mechanically contained in the liquid, which would otherwise oxidize the stannous chloride. The latter reacts with the ammonium bichromate (formed by action of hydrochloric acid on ammonium chromate) to form stannic chloride and chlorides of ammonium and chromium:

$$3\ SnCl_2 + (NH_4)_2Cr_2O_7 + 14\ HCl = 3\ SnCl_4 + 2\ NH_4Cl \\ + 2\ CrCl_3 + 7\ H_2O.$$

As the value of the stannous chloride will vary from day to day, especially if air is not rigorously excluded, it is desirable to work out a factor which shall take this into consideration and which shall simplify the calculation of results. How this factor is reached will be made clearer by a specific illustration. The potassium bichromate contains, say, 20.55 grams to the liter, and 5 c.c. of this are equal to 10 c.c. of the stannous chloride. In titrating the sulphur, 4.75 c.c. of stannous chloride were used.

$$K_2Cr_2O_7 : 3\ SnCl_2 : : (5 \times 0.02055) : x$$

$$x = 0.1992 \text{ gram of stannous chloride in 10 c.c.}$$

$0.1992 \times 0.475 = 0.0946$ gram of stannous chloride used in titrating the sulphur sample.

Now $3\ SnCl_2 = 1\ (NH_4)_2Cr_2O_7 = 2\ (NH_4)_2SO_4$

because $(NH_4)_2SO_4 + BaCrO_4 = BaSO_4 + (NH_4)_2CrO_4$

and $2\ (NH_4)_2CrO_4 + 2\ HCl = (NH_4)_2Cr_2O_7 + 2\ NH_4Cl + H_2O$;

therefore $\underset{570}{3\ SnCl_2} : \underset{64}{2\ S} : : 0.0946 : x$

$$x = 0.01062 \text{ gram of sulphur in 0.8 foot of gas.}$$

$\frac{0.01062 \times 15.43 \times 100}{0.8} = 20.48$ grains of sulphur in 100 cubic feet of gas.

Now to combine these equations we have

$$\frac{5 \times 0.02055 \times 570 \times 4.75 \times 64 \times 15.43 \times 100}{294 \times 10 \times 570 \times 0.8},$$

of which the 570 in numerator and denominator cancel, and of the rest all are constant quantities, save the 4.75, the 10 and the 0.02055. Eliminating these we have

$$\frac{5 \times 64 \times 15.43 \times 100}{0.8 \times 294} = 2099.3.$$

Hence, when 0.8 foot of gas is burned, to find the sulphur in grains per hundred cubic feet, multiply the grams of potassium bichromate in 1 c.c. by 2099.3 and the product by the number of centimeters of stannous chloride used in titrating the sample, and divide by the number of cubic centimeters of the stannous chloride equivalent to 5 c.c. of the potassium bichromate. If a number of analyses are to be calculated at once, it will save time if a slide rule or logarithm table be used.

This method has been repeatedly checked by Major Hinman, Mr. Jenkins and the writer, against the standard gravimetric process, and it has been proved beyond a doubt to be accurate within two or three tenths of one per cent. If only one sample is to be done at a time, it is no more rapid than some of the methods already mentioned; but if a number of analyses are to be made, the saving of time over the gravimetric method used by the Referees is very great, as by the Hinman-Jenkins method from 40 to 50 determinations can be made in a day by one man.

One of the greatest difficulties formerly encountered with this process, was in keeping up the strength of the stannous chloride, since any contact with the oxygen of the air causes oxidation to set in. This has been entirely overcome by the use of an apparatus devised by Mr. Jenkins and copied by the writer in his laboratory. The bottle of stannous chloride is set on a shelf 27 inches from the bench. A 2-hole rubber stopper is wired into the mouth of this bottle, and through one of these holes a glass tube passes to within one-half inch of the bottom of the bottle, and above the stopper it curves and passes downward to connect with the side outlet of a Gavalowski burette. Through the other hole another glass tube passes, reaching one inch below the stopper, and connected above to the outlet of the carbonic acid generator. The top of the burette is closed by a rubber stopper with one hole through which a tube projects one-half inch into the burette and connects above with the tube leading from the carbonic acid generator to the stannous chloride bottle.

The generator is home-made and consists of a Mason fruit jar, filled half full of commercial hydrochloric acid. Into the mouth of this jar sets a large rubber stopper, through which passes a piece of an adapter 12 inches long, 3 inches in diameter at the bottom, and 1¼ inches at the top. The tube from the stannous chloride passes through a rubber stopper tightly fitted into the upper and smaller end, while the lower end is closed by another stopper pierced by a hole three-sixteenths of an inch in diameter. Within this adapter are placed small lumps of marble, filling it to a height of about 3 to 4 inches. All connections are wired and the greatest precautions taken to see that the whole apparatus is air tight.

When the cock is opened, stannous chloride runs into the burette and in so doing creates a vacuum in the adapter. This causes the acid to rise through the hole in the stopper and to come in contact with the marble, generating carbonic acid. As soon as the burette is full the cock is closed, and the pressure of the carbonic acid generated soon forces the acid back into the Mason jar. Thus the entire outfit is filled with carbonic acid, and air never comes in contact with the stannous chloride. The Gavalowski burette costs about $3.50, but aside from this the entire apparatus can be made in the laboratory.

It is sometimes desired to determine the carbon bisulphide in gas by itself. For this the method of Harding and Doran, described in the *Journal of the American Chemical Society Abstracts* for January 10, 1908, may be used. Briefly described, the gas is passed from the meter through a solution of caustic potash and then through concentrated sulphuric acid to remove the carbonic acid and water vapor. It is then bubbled through a solution of caustic potash in absolute alcohol, which absorbs carbon bisulphide, forming potassium xanthate $CS(OC_2H_5)SK$. The xanthate solution is heated to expel all gases and acidified with acetic acid. An excess of a standard solution of cupric acetate is added, resulting in the formation of cupric xanthate, which is filtered off and washed with cold water. The excess of cupric acetate in the filtrate is determined by adding potassium iodide and titrating the liberated iodine with standard sodium thiosulphate, using fresh starch solution as indicator. This method has been successfully tried on the gas supplied in Minneapolis, and showed the presence of from 12.60 to 14.16 grains of carbon bisulphide per 100 cubic feet of gas.

With acetylene the determination of total sulphur is of little importance, since under the improved conditions of carbide manufacture of the present day, impurities have been largely excluded from the acetylene. Should it be desired, however, to make such a determination, it is believed that the Hinman-Jenkins apparatus will serve admirably for the collection of the sample in liquid form, if two changes are made. First, the orifices of the burner and the air-ports must be adapted to acetylene gas. Second, as acetylene produces but little water on combustion, it is well to have a small continuous stream of water and dilute ammonia playing upon the surface of the beads. As this liquid runs through, it may be collected in a large flask and used over and over, so that the total volume of the sample need not exceed 500 c.c. The analysis must be carried out by a different process, and as this same process will include the determination of phosphorus, arsenic and silicon, it will be now described for all of these substances at once.

The solution of the products of combustion is evaporated twice to dryness with nitric acid, the residue taken up in water and nitric acid, and the silica filtered off, ignited and weighed. The filtrate is evaporated to 25 c.c., made just ammoniacal, an excess of magnesia mixture is added, and then ammonia, drop by drop, with constant stirring until one-third of the total solution is ammonia. This will precipitate the phosphorus and arsenic as magnesium ammonium phosphate and magnesium ammonium arsenate. Let stand for some hours, filter off the precipitate and wash it with a cold mixture of one part ammonia, one part alcohol and three parts water. Evaporate the filtrate to dryness, acidify with hydrochloric acid, evaporate again to dryness and heat until the ammonium salts are expelled. Take up in water and hydrochloric acid, heat to boiling, add a hot solution of barium chloride, allow the precipitate to settle, filter off the barium sulphate and ignite and weigh it. The precipitate of magnesium ammonium phosphate and arsenate is to be dissolved in hydrochloric acid, and sulphuretted hydrogen passed into the hot solution until all of the arsenic is precipitated as arsenious sulphide. Filter, and wash well with boiling water. This precipitate will always contain sulphur; to convert it to pure arsenious sulphide extract the washed and still moist precipitate on the filter with ammonia, wash the residual sulphur, precipitate the solution with hydrochloric acid without heat, filter, dry, extract with carbon bisulphide, dry at 100° C. and weigh.

The filtrate from the arsenious sulphide is to be heated to expel the sulphuretted hydrogen, the phosphorus precipitated with magnesia mixture and the precipitate washed as before. Dry the filter and contents, ignite in a porcelain crucible, and weigh as magnesium pyrophosphate. Great care must be taken not to reduce the magnesium pyrophosphate during the ignition; to this end employ a low heat until the filter paper is all consumed, and then gradually raise the temperature, using finally the whole heat of a Tirrill burner. The magnesia mixture employed is made by dissolving 11 parts of crystallized magnesium chloride and 28 parts of ammonium chloride in 130 parts of water and adding 70 parts of dilute ammonia (Sp. Gr. 0.96). Allow the solution to stand one or two days and filter. 10 c.c. of this is sufficient for 0.1 gram of phosphoric anhydride.

On account of the small percentage of these impurities usually present in acetylene, it is necessary to burn a large volume of the gas in securing the sample, and even then the precipitates will be small and will require great care in manipulation. If 10 cubic feet of gas, corrected for temperature and pressure, are taken, the calculations will be somewhat as follows: Assume weight of barium sulphate 0.2205 gram; weight $Mg_2P_2O_7$, 0.0527 gram; SiO_2, 0.0172 gram; As_2S_3, 0.0052 gram.

$$\underset{233}{BaSO_4} : \underset{32}{S} : : 0.2205 : x$$

$x = 0.0303$ gram of sulphur in 10 cubic feet of gas.

$0.0303 \times 15.43 \times 10 = 4.68$ grains of sulphur per 100 cubic feet.

$$\begin{array}{l}Mg_2P_2O_7 : P_2 :: 0.0527 : x\\ 222 \qquad\quad 62\end{array}$$

$x = 0.0147$ gram of phosphorus in 10 cubic feet of gas, or 2.27 grains per 100 cubic feet.

$$\begin{array}{l}SiO_2 : Si :: 0.0172 : x\\ 60 \qquad 28\end{array}$$

$x = 0.0080$ gram of silicon in 10 cubic feet of gas, or 1.23 grains per 100 cubic feet.

$$\begin{array}{l}As_2S_3 : As_2 :: 0.0052 : x\\ 246 \qquad 150\end{array}$$

$x = 0.0032$ gram of arsenic in 10 cubic feet of gas, or 0.49 grain per 100 cubic feet.

The value of the silicon determination by this method is doubtful. Glass contains silicon as one of its most important constituents, and the passage of the water and salts from the combustion over the glass beads and through glass vessels will doubtless dissolve a small amount of silica therefrom. It is therefore better, if silicon alone is to be determined, to bubble a known volume of the gas through a solution of some suitable absorbent, such as caustic potash, and then separate the silica from this by the usual method of dehydration.

Eitner and Keppeler burn the gas at the rate of 10 liters per hour (0.35 cubic foot) and collect the products of combustion in a glass hood, from which they are aspirated through absorption bulbs. The first ten of these bulbs contain water; a second set of ten contains sodium hypobromite, and these are followed by an empty bulb to catch any spray that may be carried over. All of the phosphoric acid is retained in the glass hood and first set of bulbs, while the sodium hypobromite insures the retention of all of the sulphuric acid.

At the end of the operation the glass hood is inverted and filled with hot water containing hydrochloric acid, and this is left standing over night. The contents are then concentrated in a porcelain dish and ammonium carbonate added. Filter off the silica and so forth, and add the filtrate to the contents and washings of the absorption apparatus after they have been boiled with hydrochloric acid to destroy the hypobromite, made ammoniacal and filtered. After cooling, the phosphoric acid is determined by precipitation with magnesia mixture, and the sulphuric acid in the acidified filtrate from this determination by precipitation with barium chloride.

This is one of the best methods for sulphur and phosphorus in acetylene, but the apparatus is so cumbersome that it will not find favor in any but well-equipped laboratories. It also takes no account of the silicon and arsenic, and the latter, if present, would probably be precipitated with the phosphorus and thus render the results for that substance too high.

In the *Journal of Gas Lighting*, for June 9, 1908, the following method is given: "The method of analysis is an adaptation of the Referees' sulphur method, modifying the burner and letting water drop through the column while the gas is burning. The water solution of the products of combustion is titrated with N/10 soda solution, using phenolphthalein as an indicator. The silica is then dehydrated and weighed. The phosphoric acid is precipitated from the silica filtrate with magnesia mixture, and the sulphuric acid in the filtrate from the phosphoric acid by barium chloride."

As a rule, however, the quantitative estimation of silicon, phosphorus or arsenic is not necessary, since undoubtedly they should not be allowed in the gas in more than the merest traces, and a qualitative test will therefore give all the information necessary. Such tests have already been given for sulphuretted hydrogen and for phosphorus. For arsenic a modification of the Marsh test may be used, provided the greatest care is exercised to prevent explosion.

Lewes states the amount of the above impurities in acetylene to be about as follows:

Symbol.	Maximum.	Minimum.
	%	%
H_2S	1.34	0.00
PH_3	1.70	0.03
SiH_4	0.80	0.00
AsH_3	0.004	0.00

The silicon and phosphorus are objectionable for three reasons. First, they are poisonous; second, they are spontaneously inflammable, and if present in sufficient amount will ignite the acetylene; third, their products of combustion clog the fine orifices of the acetylene burners. Arsenic is of course dangerous as a very violent poison. Lest these statements should produce undue apprehension, they should be qualified somewhat. The highest proportion of phosphoretted hydrogen ever met with in acetylene was 2.3 per cent (that is, in acetylene from ordinary carbide), and this gas was not spontaneously inflammable.[1] Only one case of spontaneous inflammation has ever been recorded, and that was in the earliest years of carbide manufacture.[1]

Keppeler says: "When generated by the drip system, the gas coming from a carbide containing 1 per cent of calcium phosphide catches fire of itself, whereas if the carbide-to-water system be adopted, 25 per cent of calcium phosphide is needed to produce the same effect." [1] It should also be stated that Wolff could find no siliciuretted hydrogen or arseniuretted hydrogen in acetylene. The arsenic, phosphorus and silicon, if present at all, exist in the gas as AsH_3, PH_3 and SiH_4 respectively, and burn to arsenious oxide and arsenic oxide, phosphorus pentoxide and silica. Arsenic oxide and phosphorus pentoxide are the anhydrides of arsenic and phosphoric acids; that is, if they combine with water they form the above mentioned acids, thus:

$$As_2O_5 + 3\ H_2O = 2\ H_3AsO_4$$

This will make more apparent the danger resulting from their presence in gas.

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[1] Scientific American Supplement, August 8, 1903

CHAPTER III.

OTHER IMPURITIES.

Ammonia. In coal and water gases, ammonia, if present, is due to the presence of nitrogen in the coal and the union of this nitrogen with hydrogen. William Foster, after studying the distribution of the nitrogen of coal among the several products of destructive distillation, concluded that in ordinary gas manufacture, of the total nitrogen in the coal, 14.5 per cent is evolved as ammonia. The coal on which he conducted his experiments contained 1.73 per cent of nitrogen, and as a general thing the amount of nitrogen in gas coals lies between 1 and 2 per cent.[1] E. Schilling reports that 14 per cent of the total nitrogen is the average yield as ammonia, and 20 per cent the maximum in a number of experiments. In coke ovens C. Winckler found that nearly 20 per cent of the nitrogen of coal was obtained as ammonia, while Lewis T. Wright, experimenting with Yorkshire and Derbyshire coals, gives the percentage of nitrogen recovered as ammonia as from 22.3 to 23.6.

These figures show a considerable variation, which is doubtless due in part to the temperatures of distillation. Wright states that the yield of ammonia is greater at a medium than at a high or low heat, and cites figures to prove the point. With water gas, the amount of ammonia formed is small, due to the fact that the temperature at which ammonia is decomposed is below that at which carbon decomposes steam.

Now this ammonia is generally removed from the gas for two reasons: first, it is a marketable by-product, and the revenue from this source aids in reducing the cost of manufacture of the gas; second, ammonia is objectionable in the finished product because (*a*) it acts injuriously on the meters and fixtures, (*b*) the products of its combustion may become deleterious to health and property,

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[1] Butterfield's Chemistry of Gas Manufacture.

and (*c*) in many cases there is a legal requirement that the gas as distributed shall not contain over a certain quantity of ammonia.

The removal of the ammonia takes place first, in the hydraulic main; second, in the condensers; and third, in the washers and scrubbers. When the gas leaves the retort, it contains, among other constituents, ammonia, carbonic acid, sulphuretted hydrogen, and certain other sulphur compounds of an acid character, such as thiosulphuric acid, sulphocyanogen and so forth. The ammonia, being basic in character, unites to some extent with these acid radicals and is partly carried away in the liquor of the hydraulic main. A further portion is taken out in the condensers, where the aqueous vapor, in condensing, carries down with it some of the ammonia, sulphuretted hydrogen and carbonic acid of the crude gas. Butterfield considers that the gas from common coal, after condensation, but prior to washing, contains between 0.5 and 0.95 per cent of ammonia by volume. Practically all of this is removed in a well-managed scrubber, owing to the great solubility of ammonia in water.

It not infrequently happens, however, that ammonia, and to a considerable amount, is found in the gas after it has passed the washer. This may be due to several causes. First, the quantity of water used may be insufficient; second, the apparatus may be so arranged that the water does not have a fair chance to extract the ammonia; third, the water may have taken up all the ammonia that it can hold; fourth, on passing a gas practically free from ammonia through or over water which is saturated with that impurity, the water, far from taking up more ammonia, will give off some of its original content to the gas, and this process will be continued until an equilibrium is reached. This is also true when small quantities of ammonia are involved. As soon as water dissolves any ammonia it becomes a solution, and is ready to give up ammonia to any gas containing less of that substance than it carries in solution.

For this reason it is practically impossible to furnish coal gas absolutely free from ammonia, although the amount of the latter in the finished product may be cut down to 0.5 grain or less per 100 cubic feet of gas.

Another point that is worthy of attention is that when ammonia has once been carried beyond the washers and absorbed in purifiers, holder, meters or drips, it will be given up again when a gas free from ammonia and at the proper temperature passes over these storage points. The writer has recently met with a curious illustration of this, which seems worthy of repetition in the light of an object lesson. A plant which had been making coal gas in which ammonia was occasionally allowed to pass the scrubbers, suddenly changed over and manufactured water gas. Some time after, ammonia was found in the gas as it reached the consumer. Knowing that water gas contains little or no ammonia, the manager could not account for this phenomenon and was inclined to lay the blame on inaccuracy in testing or impurity of reagents. As the proofs of ammonia multiplied, however, he commenced an investigation, and soon found that the ammonia was really present in the gas and was coming from the purifiers which had formerly been used for coal gas.

The detection and estimation of ammonia in gas is of great simplicity and should be carried out in every coal-gas works. It is not necessary that a chemist should be employed, as the necessary reagents can be purchased ready for use, and with a few simple precautions the test may be made with sufficient accuracy by any intelligent and careful employee. Three methods which are typical, accurate and in general use will be described in detail; these may be designated as the Massachusetts, the Referees' and Lacey method.

The Massachusetts method is the one employed by the state inspectors of Massachusetts and New York, and by many of the gas companies in those districts. The apparatus needed consists simply of a 10 c.c. pipette, a rubber stopper with a glass tube projecting about 1 inch on either side, slightly bent and drawn out to a small opening on the lower end, and a bulb similar to the one shown in Fig. 20. There are but two reagents employed in the actual test, a solution of cochineal and a standard solution of hydrochloric acid; while to standardize the latter, a solution of sodium carbonate and one of methyl orange are needed.

The cochineal solution is made up as follows: 3 grams of the whole cochineal are ground in a porcelain mortar, transferred to a flask, 200 c.c. of water and 50 c.c. of alcohol are added, and the whole allowed to stand for 48 hours with frequent shakings. At the end of this time filter off the residue and preserve the liquid in a glass-stoppered bottle. This solution will keep almost indefinitely, and as only 2 to 3 drops are needed for each determination, the 250 c.c. as prepared above will answer for about 1000 tests.

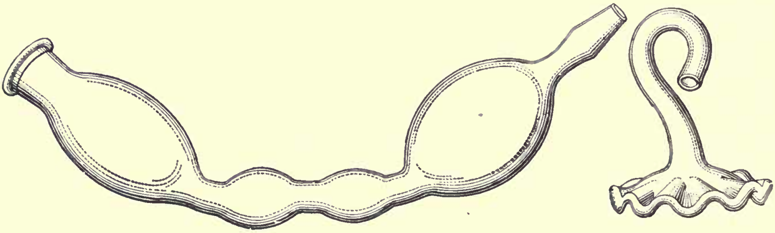

Fig. 20. Ammonia Bulb and Glass Flower.

The standard solution of hydrochloric acid is made of such a strength that 1 c.c. equals 0.001 grain of ammonia. Other strengths may of course be used, but the above figures are desirable because of the ease of calculation. Now

$$NH_3 : HCl :: 17 : 36.37 :: 1 : 2.14;$$

therefore, if 1 c.c. of the standard acid is to equal 0.001 grain of ammonia, it must contain 2.14 grains of hydrochloric acid. One c.c. of N/10 hydrochloric acid contains 0.0561 grain of the acid. 2.14 divided by 0.0561 equals 38.2. Therefore for the desired acid it is only necessary to take 38.2 c.c. of a solution of N/10 hydrochloric acid and dilute them to 1 liter. The preparation of a N/10 acid solution has already been described and need not be repeated here. It only remains then to standardize the acid used for the ammonia test.

Make up a solution of pure sodium carbonate prepared as before described, and containing 0.2035 gram to the liter. Place this solution in one 25 c.c. burette, and the acid to be tested in another. Run 20 c.c. of the alkali into a porcelain dish, add two drops of methyl orange, and then add the acid from the burette until the color of the solution just changes from yellow to red. The end-point is a trifle hard to judge, owing to the extreme dilution of the solutions, and check determinations should be made until the operator is satisfied with the accuracy of his results.

Now assume that 20 c.c. of sodium carbonate have required 22.14 c.c. of the hydrochloric acid for neutralization,

$$Na_2CO_3 : 2\ HCl :: (20 \times 0.0002035) : x$$

$x = 0.00280$ gram of hydrochloric acid in 22.14 c.c. Then 1 c.c. of HCl = 0.0001265 grams HCl. But the acid desired should contain 0.00214 grain, or 0.00014 gram to 1 c.c. Consequently, to make the acid of the desired strength, it is necessary to add to each c.c. (0.000140 − 0.0001265) or 0.000013 gram HCl. For 977.86 c.c. (the amount remaining after the first titration) 0.0127 gram HCl must be added. The N/10 HCl contains 0.00364 gram HCl per c.c. 0.0127 divided by 0.00364 equals 3.49 c.c. This amount of N/10 HCl is then added to the 977.86 c.c., the mixture well shaken and the titration repeated. In this way an acid is speedily obtained which is near enough to the theoretical strength to be well within the limits of error of the process.

To conduct a test, the bulb and pipette are first washed out with distilled water and well drained. Suck up 3 to 4 c.c. of the standard acid in the pipette, and shake until the latter has been well rinsed, then allow the pipette to drain into the sink. Now measure out exactly 10 c.c. of acid with the pipette and let it run into the bulb. Add two to three drops of the cochineal and insert the stopper. Connect the glass tube with the gas supply, and the outlet of the bulb with the inlet of a meter on whose outlet a burner may be placed to consume the passing gas.

It is well to insert a small glass bulb filled with cotton wool between the acid solution and the meter, in order to prevent any moisture being carried over into the latter. The cotton must be very loosely packed, or it will interfere with the flow of the gas.

Now pass gas through the solution at the rate of 0.6 to 0.8 cubic foot per hour, and note the reading of the meter at the start. As soon as the ammonia in the gas has neutralized the acid in the bulb, the color of the latter will change from a yellow or orange to a deep purple. At the moment when this change of color has affected the entire solution, read the meter, and the test is finished. The acid is of such a strength that if this change of color occurs after the passage of 1 cubic foot of gas (corrected as usual), the latter contains exactly one grain of ammonia per 100 cubic feet; consequently the calculation of results consists simply in correcting the volume of gas burned for temperature and pressure, and dividing the results so obtained into one; the quotient will be the grains of ammonia per 100 cubic feet of gas.

Two or three precautions and suggestions regarding this process should be noted. The standard acid is very dilute and thus extremely susceptible to change if improperly cared for. It must never be left exposed to the air for even a few moments; it should never be opened in a room where the fumes of ammonia have recently been present; none of the acid should ever be returned to the bottle after once having been taken therefrom, and the part of the stopper which enters the neck of the bottle should never be touched or placed in contact with any object.

In case the gas contains much sulphuretted hydrogen, the latter will dissolve in the acid and so interfere with the test for ammonia. To prevent this, Hempel uses a bulb containing a solution of sugar of lead, neutralized with acetic acid, and inserted between the gas supply and the acid solution. If there is much tar in the gas, a small bulb filled with cotton and inserted in front of the standard acid will catch this. The meter is placed beyond the absorption bulb, as otherwise ammonia might be taken up or given off during the passage of the gas through the meter.

The change of color when the acid is neutralized is so marked that it cannot be mistaken; only once has the writer seen a case where the end-point might have caused trouble. In this instance, the characteristic color change took place, and soon after the solution lost all of its color and took on the appearance of water. Addition of more cochineal reproduced the purple color, but this was again decolorized after the passage of a little more of the gas. The only explanation of this phenomenon which the writer can offer is that the gas contained sulphurous acid or hydrocyanic acid which acted on the cochineal and destroyed the color. It should be added that the gas did not contain any sulphuretted hydrogen. As has been said, however, this effect has been seen but once out of many thousands of tests conducted by the writer and his assistants, and if the acid solution is watched carefully from start to finish, no inaccuracy or trouble need result even if a repetition of this occurrence should be noted.

This process is usually run in conjunction with the determination of total sulphur by the Hinman-Jenkins method, the acid bulb being inserted in the series between the gas supply and the meter; thus the two operations are carried out at one and the same time and on the same sample of gas. The method is simple, accurate and rapid, and the cost of apparatus and reagents is small. The bulb for the standard acid costs about 75 cents, the pipette, 25 cents, the cochineal solution not over 25 cents, and the standard acid may be purchased of any reliable chemist at a price varying with the amount bought. It is probable that enough could be purchased for $5 to last a year, since it costs no more in time or material to make up 10 liters than it does 1 liter.

The London Gas Referees no longer require a test for ammonia, but their former directions for this determination are as follows: "Take 50 septems (1 septem equals 0.0001 imperial gallon or 7 grains weight of pure water at 62° F.) of the test acid (which is greatly in excess of any quantity of ammonia likely to be found in the gas) and pour it into the glass cylinder or saturator, so as to well wet the whole interior surface and also the glass beads. Connect 1 terminal tube of the cylinder with the gas supply and the other with the meter, and make the gas pass at the rate of not more than two-thirds of a cubic foot per hour. Any ammonia that is in the gas will be arrested by the sulphuric acid, and a portion of the acid (varying with the quantity of ammonia in the gas) will be neutralized thereby.

" At the end of each period of testing wash out the glass cylinder and its contents with distilled water, and collect the washings in a glass vessel. Transfer one-half of this liquid to a separate glass vessel, and add a quantity of a neutral solution of litmus or other indicator in ordinary use, just sufficient to color the liquid. Then pour into the burette 100 septems of the test alkali, and gradually drop this solution into the measured quantity of the washings, stirring constantly. As soon as the color changes (indicating that the whole of the sulphuric acid has been neutralized), read off the quantity of liquid remaining in the burette.

"To find the number of grains of ammonia in 100 cubic feet of the gas, multiply by 2 the number of septems of test alkali remaining in the burette, and move the decimal point one place to the left.[1] It should be stated that this test was always carried out in conjunction with the test for total sulphur, and consequently 10 cubic feet of gas were always used. The Referees' apparatus for these two tests is seen in Fig. 17, *A* being the sulphur apparatus, *B* the meter, *C* the aerorthometer, *D* the clock, and *E* the ammonia cylinder or saturator.

The explanation of the calculations is as follows: The sulphuric acid is made of such a strength that 25 septems contain enough acid (2.88 grains) to exactly neutralize 1 grain of ammonia. The standard alkali contains 1 grain of ammonia in each 100 septems. Now assume that 26.0 septems of alkali remain in the burette after the titration, then 74.0 septems were exhausted in neutralizing the excess of sulphuric acid. But 25 septems of the acid equal 100 septems of the alkali; therefore $\frac{74}{100}$ of 25 septems of acid, or 18.5 septems, were neutralized by the ammonia in the gas, and 6.5 septems remained for reaction with the standard alkali. Then since only one-half of the sample from 10 cubic feet of gas was titrated, $\frac{6.5 \times 2 \times 100}{25 \times 10} = 5.2$ grains of ammonia per 100 cubic feet of gas. This is the same result as would have been reached by following the rule given above; for $26 \times 2 = 52$, and by moving the point one place to the left we get 5.2.

Since the septem as a unit is practically unknown in the scientific work of the United States, and since nearly if not quite all burettes and pipettes employed here are graduated in cubic centimeters, it has been thought advisable to state the values of the solutions

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[1] Abady's Gas Analyst Manual.

used in terms of the metric system. The ammonia standard should contain 1.4286 grams of ammonia per liter, and the sulphuric acid 16.471 grams per liter. 25 c.c. of acid should be taken at the start, and 100 c.c. of ammonia used in the burette. The above calculations will not be altered by this change of nomenclature, since 1 c.c. of the acid will equal 4 c.c. of the alkali, and will also equal 0.04 grain of ammonia, exactly the same as before. To make up the standard acid, proceed as follows: pure sulphuric acid of specific gravity 1.839 is practically 100 per cent H_2SO_4; therefore 16.471 grams would be (16.471 ÷ 1.839), or 8.96 c.c. So dilute 8.96 c.c. of the pure acid to 1 liter. To standardize, precipitate a known amount, say 50 c.c. or 100 c.c., with barium chloride, and weigh the barium sulphate formed. If the solution is not exactly correct, calculate the amount of water or acid to add in order to make it so, after the manner shown under the Massachusetts method. The ammonia solution is made by diluting 5.6 c.c. of pure ammonia (Sp. Gr. 0.90) to 1 liter and standardizing against the acid of known strength.

It is hard to see why litmus is mentioned as an indicator. It is a difficult solution to prepare; it does not keep well and it is strongly affected by carbonic acid gas, which causes the red color to persist even though the liquid be alkaline, and thus proves a source of error. If, however, litmus is to be used, the reader should consult Cohn's Indicators and Test Papers for the method of preparation, the precautions to be observed, the accuracy of results, etc.

The method is very slow, but accurate if ordinary care is observed. The price of the saturator is about $2.50.

Lacey's method is especially applicable to cases where it is necessary to learn as quickly as possible the amount of ammonia in the gas. The apparatus employed is shown in Fig. 21. *a* is a modified form of Wanklyn's gas bottle, arranged so that the hand can be inserted for drying, and having a capacity of one-tenth cubic foot, the hollow stopper being made with a flat top to facilitate handling. *b* is a 25-septem pipette, and *c* an alkalimeter for measuring the ammonia solution during the titration of excess acid.

Two solutions are used, standard sulphuric acid and a corresponding solution of ammonia of known value. The former may be made by diluting one part of the ordinary standard acid solution of the Referees' test with 99 parts of water; 25 septems of this solution are equivalent to 0.01 grain of ammonia. In a similar manner the Referees' ammonia solution is diluted, one part to 99 parts of water, to make the standard ammonia used in the Lacey test; 100 septems of this diluted solution equal 0.01 grain of ammonia.

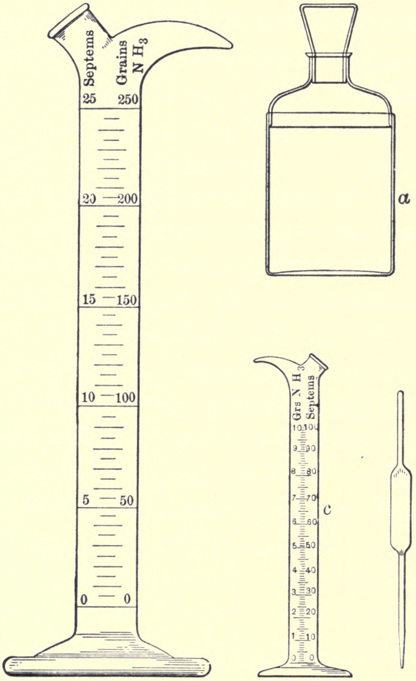

Fig. 21. Lacey's Apparatus for Ammonia.

In making a test the gas bottle is first cleaned and thoroughly dried; it is then inverted and filled with the gas to be tested by downward displacement of the air. 25 septems of the acid solution are measured out with the pipette and placed in the hollow stopper, together with two drops of cochineal solution. With the bottle still inverted insert the stopper and shake so that all of the inclosed gas shall come in contact with the reagents. After about two to three minutes empty the liquid into a beaker and wash out the bottle and stopper with a little distilled water, adding the washings to the contents of the beaker.

Fill the alkalimeter to the top mark with the ammonia solution, place the thumb over the larger opening, and through the smaller one allow the alkali to fall, a few drops at a time, into the beaker, stirring well the contents of the latter. Continue the addition of the alkali until the orange color of the solution changes to a purple or violet; when this stage is reached, set the alkalimeter on the table, allow it to drain well, and from the quantity of alkali remaining may be read off direct the grains of ammonia per 100 cubic feet of gas. Thus, if 18 septems remain, since each of these is equivalent to 0.1 grain ammonia per 100 cubic feet of gas, the gas tested contained 1.8 grains of ammonia per 100 cubic feet.

Since the total content of the alkalimeter is only 100 septems, it is clear that, with these solutions, determinations cannot be made when the ammonia in the gas is in excess of 10 grains per 100 cubic feet; for such cases either the solutions may be made stronger, or 50 c.c of acid may be used. In titrating the excess of acid, when 50 c.c. have been used, it must be remembered that 10 grains or the equivalent of 25 c.c. of acid must be added to the result when calculated in the ordinary way. In unpurified gas, it is better to make the solutions of greater strength; Abady recommends diluting the Referees' ordinary acid solution to one-fourth its strength, and using the same ammonia solution as is used by the Referees for their test of ammonia in purified gas.

This method is an excellent one for works use, being rapid, fairly accurate, and easy to handle. It is unfortunate that the apparatus is not graduated in the metric system, since few Americans are familiar with septems and decigallons. Still, it must be admitted that the calculations are simple and clear, so that it may be considered that the practical advantages more than outweigh the theoretical objections. The apparatus necessary for this process costs, in this country, approximately $20.

So much has been said and written regarding the need, or needlessness, of a government standard for sulphur, ammonia and sulphuretted hydrogen, that a few more words on the subject may not be out of place at this time. The opinion seems to be unanimous that hydrogen sulphide should practically be excluded from all illuminating gas. In some cases, as in New York City and the State of Wisconsin, the requirements are that only a trace shall be permitted, but the great objection to this is that no one has yet given a definition of a trace of sulphuretted hydrogen which would enable the authorities to enforce the law by an appeal to the courts, if necessary. The writer has tested gas which would turn lead acetate paper black in two seconds, and yet the officers of the company supplying said gas insisted that only a trace was present. It seems to be the better practice to-day not to permit even a trace of this impurity in the gas as delivered to the consumers, and as a rule there is very little complaint against this regulation.

With regard to ammonia, the case is quite different. While it is true that its presence to any extent in the gas as consumed would be deleterious to health and property, it is also true that it practically never occurs to such an amount in purified gas. Out of 677 tests made in the State of New York during the year 1908, prior to December 1, only 9 showed the presence of more than 10 grains of ammonia per 100 cubic feet of gas, and it is questionable whether even this amount would be dangerous. The limiting of the quantity of ammonia which may be present in gas is really of more benefit to the gas company than to the consumer, since this ammonia has a commercial value, and whatever goes into the gas is lost to the company; also since one of the principal evils of ammonia is the effect it has upon the meters, which are as a rule the property of the gas company.

It seems probable for these reasons that the gas companies will never allow much ammonia to get beyond the washers, and consequently it is difficult to perceive the need of any governmental regulation of this impurity. The test for ammonia has already been abandoned by the London Gas Referees, and the Railroad Commission of Wisconsin has recently decided that such a test is unnecessary. With these examples to follow, it is possible that restrictions as to ammonia will form an unimportant part of the gas regulations of the future.

The question of a limit for total sulphur is still more complicated. As has been already intimated, the restrictions in London have been removed, and now there is considerable complaint that the action was unwise, as the gas companies have taken advantage thereof to furnish gas containing 30 and even 40 grains of sulphur per 100 cubic feet. Massachusetts still holds to her old standard of 20 grains per 100 cubic feet, although there is an agitation in that state at the present time for a more liberal allowance. New York likewise holds to 20 grains, while Wisconsin has set its limit as 30 grains.

It seems to be the consensus of opinion in the best informed circles that over 20 grains of sulphur may be present in a gas without rendering it dangerous; but on the other hand, if all restrictions are removed, and gas containing 35 and 40 grains of sulphur per 100 cubic feet is distributed, there is liable to be damage to health and property. Moreover, the supply of good gas coal is steadily diminishing, and as poorer qualities are substituted, the percentage of sulphur is likely to increase rather than decrease. Before sulphur regulation is condemned as obsolete, it is believed that further investigations are needed to prove definitely whether or not serious damage would result from the presence in the gas of 30, 40, or 50 grains of total sulphur.

Naphthalene. Naphthalene can hardly be classed as an impurity, since in some cases it is employed for the enrichment of gas near the burners; but it is nevertheless often one of the disturbing factors in the process of gas manufacture and distribution. It is formed in the retort, along with, but not from, benzene, by the breaking down of the hydrocarbons of the paraffin series, and the polymerization of the products of such decomposition. Thus, at a red heat, most methane derivatives will yield certain amounts of benzene, naphthalene, anthracene, etc., while the higher the heats, the higher will be the yield of naphthalene.

Butterfield says:[1] "Actually, naphthalene in a state of vapor and of finely divided solid is usually present in quantity more

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[1] Chemistry of Gas Manufacture.

than sufficient to saturate the gas with naphthalene vapor at the prevailing temperature."

Newbigging says:[1] "It is generally believed that the presence of naphthalene in gas is due, principally, to the high heats necessarily used in the carbonization of the coal, owing to the partial distillation of a portion of the tar," and goes on to prove this by saying that in the days of iron retorts, when the heats were necessarily less than they are to-day with clay retorts, naphthalene as now found in the mains in the solid state was almost unknown.

Now, under certain conditions, depending on various factors such as the richness of the gas, the amount of aqueous vapor which it carries, the speed at which it is cooled, etc., this naphthalene is not taken out in condensers and scrubbers, but is carried along into the mains and distributing pipes and there deposited, causing serious trouble through the obstruction which it offers to the passage of the gas. Such deposition is in general due to three causes: (1) Sudden changes of temperature of the gas; (2) friction in the pipes, or even sharp bends in the latter; (3) condensation of aqueous vapor from the gas causes deposition of naphthalene.

The importance of the first cause may readily be seen from the following table, showing the vapor pressure of naphthalene and the proportion of naphthalene vapor which gas can retain at varying temperatures.[2]

Temperature, Degrees Fahr.	Vapor Press., mm. of Mercury.	Vol. Vapor retained by 100 vols. Gas.
32	0.022	0.0029
50	.047	.0062
59	.062	.0082
68	.080	.0105
86	.135	.0178
104	.320	.0421
140	1.830	.2410
176	7.400	.9740
212	18.500	2.4300

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[1] Handbook for Gas Engineers and Manufacturers.

[2] J. Soc. Chem. Ind., 1900, 209, by R. W. Allen.

Thus if 100 volumes of gas at 212° F., containing 2.43 volumes of naphthalene, were suddenly cooled to 32° F., 2.427 volumes of the naphthalene would be dropped out. As to the third cause, Hornby states that[1] . . . "gas absolutely deprived, as far as possible, of aqueous vapor does not deposit naphthalene under the ordinary conditions of temperature and pressure," and this statement is repeated and emphasized in Newbigging's Handbook. Dr. Harrop, in his excellent little work on "Gas Works Chemistry," says: "The amount of naphthalene made is a question of coal and retorting, and it is there that the remedy should be sought, but a high naphthalene gas *may* be taken care of in the condensing system.

. . . If the gas is always cooled to 60° F. the washers and scrubbers will take care of the solid flakes, and it is safe to rely on 25 grams (or actually somewhat less) as the greatest amount that can go out into the street. If this is seen to, and supposing the rest of the condensing operation is moderately well managed so that the finished gas carries a fair amount of condensible hydrocarbons that will come down in liquid form in case the gas happens to be chilled in the mains or service pipes, naphthalene troubles will be rare."

In another part of his work, under the head of Removal of Tar, he says: "The problem is to effect a cooling that will make it possible to extract the gaseous ammonia, to remove the bulk of the naphthalene vapor, and yet to leave in the finished product as much as may be of the illuminant vapors of those hydrocarbons like benzene, which condense to liquids at the ordinary temperatures of the street. To accomplish this it is believed by most engineers that a cooling by successive and gradual stages to 70°, or perhaps 60° F., is the proper course."

Experiments of White and Barnes, reviewed in the *Journal of American Chemical Society Abstracts*, January 1, 1907, show that incomplete removal of tar before the gas reaches the scrubbers is responsible for most of the naphthalene troubles in the city mains; that the tar is the most powerful agent in the removal of

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[1] Hornby, Gas Manufacture.

naphthalene, and that if the former is removed from the gas by the P. & A. tar extractor at the proper temperature, little or no trouble will be experienced from naphthalene.

From all this it would seem that prevention is a far better and cheaper policy than cure; but if the evil has occurred, there are various methods of removing it which do not enter into the scope of this work, but which may be said in general to depend on the extraction of the naphthalene by various solvents, among which naphtha seems to have played the most important part.

There is only one test of any importance for the presence and amount of naphthalene in gas. This is known as Colman and Smith's test, and is based upon the fact that naphthalene reacts with picric acid to form naphthalene picrate, $C_{10}H_8O . C_6H_2(NO_2)_3$, which is almost insoluble in aqueous picric acid. For a qualitative test, it is only necessary to bubble a few feet of the gas to be examined through a practically saturated solution of picric acid, and if no precipitate forms, the absence of naphthalene in appreciable amount may be asserted, since 1 milligram of the latter will give a perceptible precipitate.

For the quantitative determination, 3 reagents are required: (1) a standard solution of picric acid, approximately N/20 (*i.e.*, containing about 22.9 grams to the liter); (2) a N/10 solution of barium hydrate; (3) a solution of lacmoid. The picric acid is standardized by means of the barium hydrate, using the lacmoid as an indicator. The color of the solution will change from brownish yellow to green when the picric acid has all been neutralized and the alkali is in excess.

According to Sutton the barium hydrate is made up as follows: "Shake up in a stoppered bottle powdered crystals of barium hydrate with distilled water and allow it to stand a day or two until quite clear; there should be an excess of the hydrate, in which case the clear solution, when poured off into a stock bottle . . . will be nearly twice the required strength. It is better to dilute still further (after taking its approximate strength with N/10 hydrochloric acid and phenolphthalein) with freshly boiled and cooled distilled water; the actual working strength may be checked by evaporating 20 to 25 c.c. to dryness with a slight excess of sulphuric acid, then igniting over a Bunsen flame and weighing the barium sulphate."

To prepare a satisfactory lacmoid solution, the commercial lacmoid must be purified. To accomplish this, treat the fine powder with boiling water, acidulate the blue solution, after cooling and filtering, with hydrochloric acid, collect the precipitate after a few hours, wash it with a little cold water, and dry at not too high a temperature. To prepare the indicator solution, take 3 grams of the purified lacmoid and 5 grams of naphthol green and dissolve them together in a mixture of 700 c.c. of water and 300 c.c. of alcohol.[1] The naphthol green is added to counteract the violet tinge which is generally found in lacmoid solutions, however carefully they may have been prepared, and which is very liable to deceive the observer.

For the apparatus, 5 bottles are connected in series; the first is of 4 ounces capacity and contains a solution of citric acid to remove any ammonia there may be in the gas; the second holds 10 ounces, and contains 100 c.c. of the picric acid. The third and fourth contain 50 c.c. each of the same solution, while the fifth serves to retain any of the picric acid which may have been mechanically carried over from the other bottles. This last bottle is connected with the meter inlet. The bottles are connected one with the other by means of rubber tubing, as close a joint as possible being made, and the pipe from the first bottle to the gas supply being of glass (Fig. 22).

The ordinary gas pressure is not sufficient to force the gas through the series of bottles used for the test, and so, unless the full gas-holder pressure is available, it will be necessary to increase the pressure by means of either a water jet pump, or, better, by Colman and Smith's special device, which is shown in the above cut, and which is described as follows:

"The method consists in enclosing the meter[2] in a stout case of galvanized iron, the top of which can be closed air-tight by means of suitable clamps and packing and having a piece of plate glass

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[1] Cohn, Indicators and Test Papers.

[2] Abady, Gas Analysis Manual.

fixed in the front to allow of the meter index being read off. The inlet of the meter is connected by means of a union to tube passing outside the meter case, which is connected by a flexible tube to the testing apparatus, the outlet of the meter remaining open. On the cover are 3 tubes, *a*, *b*, *c*, and a fourth, not shown in the figure, which is connected to the mercury pressure gauge. The tube, *a*, is connected to a small steam or water jet vacuum pump, and *b* and *c* to the pressure regulator. When the pump is started, and the air drawn from the meter case, the mercury level rises in the right hand limb of the U tube, *B*, and falls in the left limb, thus continuing until the level in the latter is below the bottom of the tube, *C*. As soon as this occurs air is drawn into the meter-case through the side tube, *D*, and the vertical tube, *C*, so that the vacuum cannot then rise higher.

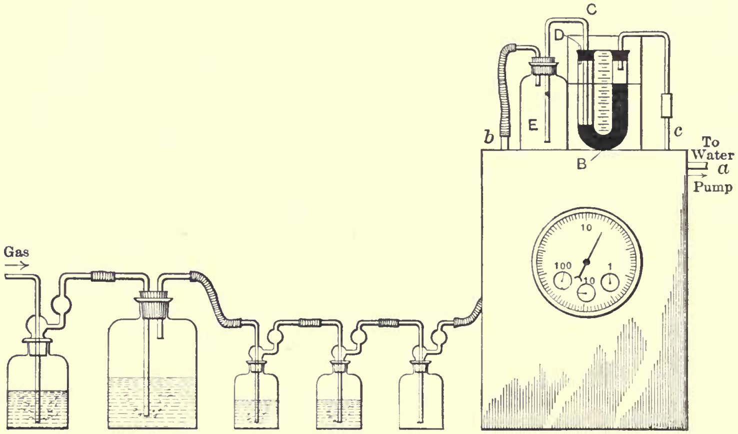

Fig. 22. Colman and Smith's Naphthalene Apparatus.

Any desired amount of vacuum can be obtained by simply regulating the height of tube, *C*, and so long as the pump exhausts gas more quickly than it passes in through the meter or through any leaks in the case, this vacuum is constantly maintained. The bottle, *E*, is interposed to catch any globules of mercury which may be carried over with the current of air.

With this apparatus, therefore, the pressure around the meter can readily be regulated to any desired amount below that of the atmosphere, and a vacuum of 2 inches of mercury (27 in. water) is amply sufficient to draw the gas through any testing apparatus, even if the gas itself is under the vacuum of 12 inches of water."

In making the usual correction of the volume of gas registered by the meter for temperature and pressure, the amount of vacuum shown on the mercury pressure gauge must be deducted from the reading of the barometer, as this represents the difference between the atmospheric pressure and that within the meter case. The price of the apparatus delivered in this country will be in the neighborhood of $65.

In carrying out the process, 10 to 15 cubic feet of gas are bubbled through the five bottles at a rate of from 0.5 to 1 cubic foot per hour. When the necessary quantity of gas has passed, the contents of the three bottles containing picric acid are combined in the first of these bottles, as little water as possible being used for rinsing.

The bottle holding the solution is now closed by a rubber stopper, through which passes a glass tube which is sealed at the lower end, but having a small hole in the side about one inch from the bottom. This tube is inserted so that the hole is just below the bottom of the stopper, and the air removed from the bottle as completely as possible by means of a water jet pump. While the latter is still working, raise the tube so that the hole shall be closed by the stopper; the bottle is thus sealed against access of air.

The bottle is next placed in a water bath containing sufficient water to cover it, and the temperature in the bath raised to the boiling-point and maintained thus until the liquid in the bottle becomes quite clear. Then remove the bottle, allow it to cool, shaking occasionally to wash down any naphthalene which may solidify in the upper part of the bottle. Allow the solution to stand for some hours, in order that the naphthalene picrate may separate out completely; then filter with aid of a suction and wash the precipitate with a *small* amount of cold water.

Make the filtrate and washings up to 500 c.c. and take 100 c.c. of this for titration with the N/10 barium hydrate. The washing of the precipitate must be done with as little water as may be, for the naphthalene picrate, while almost insoluble in picric acid, dissolves to a very appreciable extent in water.

The calculations will be best understood by citing a concrete instance. 10 cubic feet of gas were used for the test and 40 c.c. of the N/10 barium hydrate were required to neutralize the excess of picric acid, 1 c.c. of which equals 0.52 c.c. barium hydrate.

$$\underset{171}{Ba(OH)_2} : \underset{458}{2\,C_6H_2(NO_2)_3OH} : : 0.00855 : x.$$

$x = 0.0229$ grams picric acid equivalent to 1 c.c. of the N/10 $Ba(OH)_2$.

$0.0229 \times 0.52 = 0.01191$ gram picric acid per cubic centimeter of that solution.

$40 \times 0.0229 = 0.9160$ gram picric acid uncombined with naphthalene.

$(0.01191 \times 200) - 0.9160 = 1.466$ grams picric acid combined with naphthalene.

$$\underset{458}{C_6H_2(NO_2)_3OH} : \underset{128}{C_{10}H_8} : : 1.466 : x.$$

$x = 0.4097$ gram naphthalene per 10 feet gas.

$0.4097 \times 15.43 \times 10 = 63.2$ grams naphthalene per 100 feet.

This test is long, cumbersome and inaccurate if the details are not strictly followed, or if there be in the gas any hydrocarbon with a higher boiling-point than that of naphthalene, which at the same time forms stable picrates. It is, however, the only test in practical use, and in experienced hands will give valuable information.

Hitherto, tests for cyanogen have rarely been made, but with the increase of plants for the recovery of the cyanides in gas, this substance becomes of importance and should receive brief consideration. Foster states that 1.56 per cent of the nitrogen in coal is converted into cyanogen in ordinary gas manufacture. Butterfield considers that gas from common coal after condensation, but prior to washing, contains from 0.05 to 0.12 per cent by volume of cyanogen. He believes that the amount of cyanogen will depend chiefly on the proportion of its elements in the coal carbonized, while Hornby states that high heats will produce ten times as much cyanogen as low ones, and this statement is borne out in general by Newbigging.

The cyanogen exists in the gas principally as ammonium cyanide, and this is absorbed to a considerable extent in the washers and scrubbers. Indeed, it may be entirely removed by special solutions, such as those of ferrous salts, placed preferably before the washers. Whatever cyanide passes the washers is partially removed by the purifiers, whether of lime or oxide, with this difference between the two, however; the lime absorbs the cyanogen more completely, but the latter cannot be recovered therefrom; while the oxide, acting with less efficiency as an absorbent, yields its cyanogen to proper treatment.

The determination of cyanogen may be made, as recommended by Hempel, by absorbing it in a solution of caustic potash, adding silver nitrate, which forms the insoluble silver cyanide, and then acidifying slightly with nitric acid. The silver nitrate forms a heavy white precipitate, which may be filtered off and ignited in a porcelain crucible, until only metallic silver remains. From the weight of the latter the cyanogen is easily calculated; thus, if 10 cubic feet gas were used and the metallic silver weighed 1.3600 grams,

$$\underset{108}{\mathrm{Ag}} : \underset{26}{\mathrm{CN}} :: 1.36 : x.$$

$x = 0.3274$ gram cyanogen in 10 cubic feet gas.

$0.3274 \times 15.43 \times 10 = 50.52$ grains cyanogen per 100 cubic feet gas.

In former years it has been the practice in some localities to place a restriction on the amount of carbon monoxide which should be furnished in the finished product. This was done because of the undisputedly poisonous character of this gas. Of late years, however, it has come to be generally accepted that no gas is made to breathe, and the growing importance of the water gas plants in this country shows how little attention is paid at the present time to the amount of carbon monoxide in gas. Should it be necessary, however, to test for this substance, a regular gas analysis outfit should be employed, such as will be referred to in the following chapter, where this determination will be alluded to more in detail.

CHAPTER IV.

THE ANALYSIS OF GAS.

To cover properly the subject of gas analysis would require a volume by itself. Many excellent treatises on this subject are available, notably, Hempel's Gas Analysis, and for detailed information the reader is referred to these. It is not the purpose of this chapter to go into the subject exhaustively, but merely to refer to the general principles involved and to a few of the more common types of apparatus. It is assumed that the analyses are to be made by a trained chemist, and consequently the subject will be treated in a more technical manner than has been adopted for the preceding tests, which in many cases may be carried out by persons not possessing a thorough chemical education.

In general, the analysis of a gas consists in absorbing the constituents one by one in appropriate reagents, and measuring the decrease in volume caused by such absorption. Certain substances, such as hydrogen and methane, cannot be readily treated in this manner, and these are determined by exploding with oxygen and determining the volume of the products of explosion or the diminution in volume of the original mixture.

The first requisite for a satisfactory analysis is a thoroughly representative sample, from which all air shall have been excluded. A simple, accurate and economical method which has been in use for many years by the Massachusetts inspectors is recommended as satisfying every requirement. The sample tube (Fig. 23) is a glass bulb, 1¾ inches diameter and 2¼ inches long, with the ends drawn out into two tubes containing capillaries and terminating in two short ends one-fourth inch in diameter. One end is connected to the gas supply by means of a piece of pressure tubing; the gas is turned on, and lighted at the other end of the sample tube. If the flame is not over 1½ inches long there will be no danger of melting the glass, and the bulb may be purged of air by continuing the combustion for any necessary period. As a rule, one-half to three-quarters of an hour will be ample.

When the sample is ready for sealing, place a Mohr pinch cock on the inlet tubing and turn down the gas until the flame is only one-fourth to three-eighths inch long. With a blowpipe seal the capillary nearest the outlet first; this is readily done by holding the sample bulb in one hand and the end of the tube in a pair of gas pliers held in the other hand; as soon as the capillary is white-hot pull the two hands gently apart, keeping the blowpipe flame playing on the sealed end. With the gas pressure still on, seal the other capillary in a similar manner.

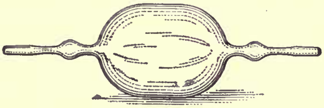

Fig. 23. Sample Tube.

To transfer the sample from the tube to a eudiometer or pipette it is only necessary to connect the two with a piece of pressure tubing of glass or rubber, filled with mercury, and join the other end of the sample tube with a mercury reservoir. By breaking the sealed capillaries the gas may be readily forced from the sample tube into the pipette. The sample tubes cost but fifty cents, and may be used over and over by having the ends again drawn out by a glass blower.

Having secured the sample, it will be well to consider, first, the various absorptions and explosions, with the reagents required, and then the different forms of apparatus. For the absorption of carbonic acid, caustic potash is almost universally used, either in the form of balls, or as a saturated solution. The balls are made by pouring the fused caustic into a bullet mold, and must be moistened before being used for the absorption of carbonic acid. This method is very tedious, and is not to be recommended, as the use of solutions is fully as accurate and requires only three to four minutes. The potash for such solution should be pure, but the variety known as "purified by alcohol" must not be used. The reagent must be kept from contact with the air, or it will deteriorate rapidly.

Dr. Harrop suggests the use of caustic soda in place of caustic potash, but it is a little difficult to see the reason for this. The former is cheaper, it is true, but the latter is the better reagent, and is recommended by Hempel, Sutton, Crookes, Fresenius, Hinman, Jenkins and others. According to Hempel 1 c.c. of caustic potash (1 part caustic potash to 2 parts of water) has an analytical absorbing power of 40 c.c. carbonic acid. He also shows that when the percentage of carbonic acid is not too high, it can be completely absorbed by simply passing the gas once into the pipette, the entire manipulation taking less than one minute.

In case there is any doubt whether all of the carbonic acid has been removed, the gas should be passed two or more times into the absorption pipette, until there is no further diminution in the volume of the sample. For very small amounts of carbonic acid, it is better to absorb in a solution of barium hydrate and titrate the excess of the latter with standard oxalic acid solution.

Four reagents have been extensively used for the absorption of oxygen, namely, phosphorus, pyrogallic acid, chromous chloride, and metallic copper. The first is employed in the form of a long, moist stick, and removes the oxygen through formation of phosphorous acid, which dissolves in the water. The absorption takes about an hour, according to Crookes, and it is supposed to be complete when white fumes no longer appear on the stick of phosphorus. Hempel considers that after three minutes, at the longest, the absorption is complete, and the end point is sharply shown by the disappearance of the glow which normally attends the reaction; this glow can best be observed in a dark room. At 10° C., or lower, the reaction will not be complete in a half-hour's time.

This process, known as the Lindeman, is one of the finest methods of gas analysis, but is only applicable under certain conditions. Schönbein has shown that the reaction is wholly or partly prevented by the presence of ethylene and other hydrocarbons or ethereal oils, by traces of ammonia, etc.; and as these compounds are always liable to be present in illuminating gas, the results obtained by the use of phosphorus in the analysis of such gases are of doubtful value. In addition to this, it is difficult to free the gas from phosphorous acid; the latter exerts some tension and so vitiates the results. If phosphorus is employed, however, it must be kept from the light, in which case it is capable of absorbing an enormous quantity of oxygen.

An alkaline solution of pyrogallic acid is the favorite reagent to-day for the absorption of oxygen. Dr. Harrop recommends that 15 grams of pyrogallol be dissolved in a small quantity of water and introduced into the pipette, which is then filled with a solution of caustic soda of the same strength as that used in the carbonic acid pipette. Hempel prepares the solution by dissolving 5 grams of pyrogallol in 15 c.c. of water, and adding, after this is in the pipette, 120 grams of caustic potash dissolved in 80 c.c. of water. Sutton saturates a ball of papier-maché with the solution, and uses this ball in the absorbing vessel, but this is not as satisfactory as the use of the solution itself, on account of the smaller surface exposed to the action of the gas, and the lesser amount of reagent present.

At a temperature of 15° C., or higher, the last trace of oxygen can be removed with certainty in the space of three minutes by shaking with the solution of alkaline pyrogallol;[1] it will be found safer, however, to allow the gas to stand in contact with the reagent for 15 to 20 minutes, with frequent shakings. The solution must be kept strictly from contact with the air, or it will deteriorate rapidly; 1 c.c. of fresh reagent will absorb from 8 to 9 c.c. oxygen. When first made the solution should be light yellow, and should turn red on contact with oxygen.

The advantage of chromous chloride as an absorbent for oxygen lies in the fact that it may be used in the presence of carbonic acid or sulphuretted hydrogen, being the only reagent that will absorb oxygen alone from a mixture of oxygen and sulphuretted hydrogen.

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[1] Hempel, Gas Analysis.

Moissan's method for the preparation of chromous chloride is as follows:[1] A green solution of chromium chloride free from chlorine is made by heating chromic acid with concentrated hydrochloric acid, and this solution is then reduced with zinc and hydrochloric acid. Since spongy particles always separate from the zinc used in the reduction, the solution must be filtered. For this purpose the reduction is carried on in a flask fitted with a long and a short tube, as is a wash bottle. The longer tube is bent downward above the flask and is here supplied with a small bulb tube, which is filled with glass wool or asbestos.

The hydrogen given off during the reduction is allowed to pass out through the longer tube for some time; then after closing its outer end the tube is pushed down into the solution. The hydrogen is thus obliged to pass out through the shorter tube, which carries a rubber valve.

Carbonic acid is then passed into the flask through the short tube, and the chromous chloride solution is driven over into a beaker containing a saturated solution of sodium acetate. A red precipitate of chromium acetate is formed which is washed by decantation with water containing carbonic acid. The red chromium acetate is, relatively speaking, quite unchangeable, and in moist condition it may be kept for an unlimited time in closed bottles filled with carbonic acid.

In washing the red precipitate, some free acetic acid is added in the beginning, to dissolve any basic zinc carbonate which may have been thrown down. In this way a preparation completely free from zinc is obtained.

To absorb oxygen, the chromium acetate is decomposed by the addition of hydrochloric acid, the air being excluded. It is advisable to use an excess of chromium acetate in order to avoid the presence of free hydrochloric acid. This reagent seems to be but little used, probably because of the difficulty of its preparation, and because it is seldom required to determine oxygen in the presence of sulphuretted hydrogen or carbonic acid; it is not as highly recommended as either the phosphorus or the alkaline pyrogallol.

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[1] Hempel, Gas Analysis.

Copper is practically never used for the determination of oxygen in illuminating gas, for the reason that, in the form in which it is employed, namely, little rolls of wire gauze immersed in a solution of ammonia and ammonium carbonate, basic ammonium cuprous carbonate is formed, which absorbs carbon monoxide. If the latter gas be absent, as is sometimes the case with petroleum and naphtha gases, and is indeed very often true of natural gas, this method would seem to be excellent. The copper has a much greater absorbing power for oxygen than alkaline pyrogallol, while it has the advantage over phosphorus of absorbing equally well at all temperatures.

Of the four reagents mentioned, the alkaline pyrogallol is the most satisfactory for use with illuminating gas. Attention must, however, be paid to the fact that it deteriorates rapidly, and fresh portions should be employed at frequent intervals.

In the *Journal of the American Chemical Society*, March, 1908, Franzen proposed the use of sodium hydrosulphite for absorption of oxygen, one gram of reagent absorbing 64 c.c. of the gas, $Na_2S_2O_4 + H_2O + O = 2\ NaHSO_3$. Fifty grams of the hydrosulphite are dissolved in 250 c.c. water and 40 c.c. caustic soda solution (500 grams in 700 c.c. water), and the solution used in a Hempel pipette for solid substances filled with iron wire gauze. One cubic centimeter of this solution absorbs 10.7 c.c. oxygen. It is cheaper than pyrogallol, it may be used in weakly alkaline solution, and has the same absorptive power at various temperatures; it may be used with gases containing carbon monoxide, and at lower temperatures and in presence of substances that hinder the oxidation of phosphorus. This reagent has not yet been sufficiently tried to recommend its adoption, but in view of the advantages above stated, it is certainly worthy of careful consideration.

Carbon Monoxide. If carbon monoxide is to be determined by absorption, but two reagents need to be considered; a hydrochloric acid solution of cuprous chloride, or an ammoniacal solution of the same. Abady considers that the action of the latter is sharper, but that the former is less troublesome to make. There are several points to be noted in connection with the use of either of these reagents. If, after the absorption of carbon monoxide, the hydrogen is to be determined with palladium, the ammoniacal solution must be used.

The solutions of cuprous chloride are absorbents not only for carbon monoxide, but also for acetylene and ethylene; if this fact is not remembered, the results may be entirely valueless. Moreover, certain gases not absorbable by cuprous chloride are much more soluble in this than in other absorbing liquids; therefore, to obtain accurate results a cuprous chloride solution which has been saturated with the gases but slightly soluble in it must unquestionably be used.[1]

Experiments have also shown that even when the heavy hydrocarbons are not to be determined, they must be removed before the carbon monoxide is absorbed by the cuprous chloride. Last, but not least, Drehschmidt has demonstrated that the union of carbon monoxide with cuprous chloride is so feeble that upon shaking a solution that has taken up any considerable quantity of carbon monoxide, this latter is again given up in an atmosphere free from that gas. It is therefore necessary to employ two pipettes, the first containing a solution of cuprous chloride that has been used many times, and the other a solution that is practically fresh.

If, in spite of these facts, it is desired to use the cuprous chloride solution, it may be prepared, according to Dr. Harrop, in the following manner: "A liberal supply of copper wire is put into a pint stoppered bottle, one part water is added to two parts concentrated hydrochloric acid, and in this diluted acid crystallized cuprous chloride is dissolved to saturation. The solution is poured into the bottle and allowed to stand for several days, or until the solution is reduced, as shown by becoming almost colorless. The pipette may then be filled with the clear solution. The absorption of carbon monoxide is not very active, and the charge in the pipette must be frequently renewed."

Sandmeyer prepared the hydrochloric acid solution thus: "25 parts of crystallized copper sulphate and 12 parts of dry

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[1] Hempel, Gas Analysis.

sodium chloride are placed in 50 parts water and heated until the copper sulphate dissolves. Some sodium sulphate may separate out at this point, but the preparation is continued without the removal of this salt. One hundred parts of concentrated hydrochloric acid and 13 parts of copper turnings are then added, and the whole is boiled in a flask until decolorized. To avoid excessive evaporation it is desirable to insert in the neck of the flask a tall condensing tube or an upright condenser. The addition of platinum foil to the contents of the flask will facilitate reduction. The solution should be kept in bottles, which are filled up to the neck and are closed by rubber stoppers." [1]

For the preparation of the ammoniacal cuprous chloride, Hempel recommends the following procedure: 1500 c.c. of the Sandmeyer solution is poured into about 5 liters of water, and the resulting precipitate is transferred to a stoppered measuring cylinder containing about 320 c.c., and upon which there has been previously marked the height at which 62 c.c. of liquid would stand. After about two hours the precipitate and liquid which are above this 62 c.c. mark are drawn off by means of a syphon, and 7.5 per cent ammonia is added up to 320 c.c. mark, that is, to the top of the cylinder. The stopper is inserted, the cylinder is well shaken, and it is then allowed to stand for several hours. A solution prepared in this manner has so slight a tension that the latter may in nearly every case be neglected.

In view of the difficulties attending the absorption of carbon monoxide by cuprous chloride, it has become the custom with many analysts to determine this constituent by explosion with oxygen, and this method would seem to be both easier and more accurate. Gautier and Clausman, however, in a recent article state that in a mixture of nitrogen or air and carbon monoxide, or of nitrogen with different combustible gases and carbon monoxide, the latter cannot be accurately determined either by explosion with oxygen or by treatment with cuprous chloride; but if the gas after the explosion or after treating with cuprous chloride is passed over iodine pentoxide heated to 70 degrees,

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[1] Berichte der deutschen chemischen Gesellschaft 17, 1633.

the last trace of carbon monoxide will be oxidized. The writer has been unable to verify this and merely gives the statement in order that it may be thoroughly investigated.

Illuminants. Sutton states that the hydrocarbons $(C_nH_{2n+1})_2$ and C_nH_{2n+2} may be absorbed by absolute alcohol. The method, however, gives but approximate results and can be employed only in the presence of gases very slightly soluble in alcohol. Hempel states that Bunsen made use of absolute alcohol to determine the gaseous hydrocarbons that are not properly gases in purified illuminating gas, and found that the hydrocarbons thus absorbed consisted chiefly of benzene.

While bromine has in the past been used for the absorption of the illuminants in gas, the reagent most frequently employed for that purpose to-day is Nordhausen, or fuming sulphuric acid. This does not absorb methane but takes up principally ethylene, propylene and benzene.

The use of Nordhausen acid naturally forbids the presence of water, and the absorption pipette must be thoroughly dried before use. If mercury is to be the confining fluid, some trouble may be experienced through the fact that fuming sulphuric acid acts quite energetically on that element, in presence of minute traces of water vapor, and forms a solid mass which obstructs the passage of the gas. This may be prevented by diluting one part of the Nordhausen acid with one part of concentrated sulphuric acid, specific gravity 1.84, and cooling the mixture before use. The absorption of the illuminants is rather slow, and at least an hour should elapse before the action is considered complete. It is then always necessary to pass the gas into a caustic potash pipette in order to absorb any sulphurous acid which may have been carried over by the gas.

Benzene. In the absorption of this constituent Dr. Harrop employs an ammoniacal solution of nickel hydrate. This method was severely attacked by D. A. Morton in the *Journal of American Chemical Society* for December, 1906. He concludes that the use of the ammoniacal solution is useless, as plain ammoniacal water absorbs benzene equally well, and recommends the use of concentrated sulphuric acid for absorption of benzene vapor. He states that the absorption of ethylene by the sulphuric acid is slight and may readily be corrected for; that traces of the higher olefines may give a slightly too high result for the benzene, but that this error must be small, if not inappreciable.

Dennis and McCarthy, in the *Journal of American Chemical Society*, February, 1908, declare that Morton's method does not give constant results, even when conditions are the same; that from mixtures of ethylene and benzene it does not quantitatively remove the latter, and that it does remove an indeterminate amount of the former. They also claim to have located the trouble with the ammoniacal nickel nitrate method. If the latter solution has taken up some cyanogen it is able to quantitatively absorb fairly large amounts of benzene vapor; therefore if cyanogen compounds are present in the gas to be tested, this method will give accurate results. They find that ammoniacal solutions of nickel cyanide, prepared as they direct, will quantitatively absorb benzene from ordinary coal gas and will not absorb measurable quantities of ethylene or of the other constituents, except those absorbable in caustic potash.

Hydrogen. Sodium and potassium have been experimented with to a considerable extent to see if their common property of absorbing hydrogen could not be utilized in separating that gas from a mixture containing also methane and ethylene. These investigations have led to the conclusion that neither potassium nor sodium is suitable for the absorption of hydrogen in ordinary forms of apparatus, largely because of the difficulty of finding any suitable confining fluid.

The only absorption method for hydrogen, then, which can be recommended is the one using palladium. This substance may be employed in either of two forms, palladium sponge or palladium black, the latter being the more active. The former is prepared by heating the palladium, in portions of about one gram at a time, nearly to redness on platinum foil and allowing it to cool not too rapidly. By these means the palladium becomes covered with a quantity of the oxide, which is able to burn hydrogen at ordinary temperatures with evolution of heat, and this heat raises the temperature of the reduced metallic palladium to the point at which it can absorb large quantities of hydrogen by occlusion. The palladium black, which is either an oxygen compound of palladium or a mixture of metallic palladium and palladious oxide, is prepared in exactly the same manner as platinum black, that is, palladious chloride is reduced with alcohol in a strongly alkaline solution.

In view of the simplicity and accuracy of the explosion methods for hydrogen, carbon monoxide, etc., the absorption of these gases cannot be recommended; the only reagents needed for explosions are pure hydrogen and oxygen gases. The latter may be bought in cylinders under pressure, and if each cylinder is subjected to analysis before use, accurate results may be secured. A cylinder of oxygen costs $2.75 and may be purchased through any leading drug or chemical firm. The hydrogen is best made in the laboratory, and a very convenient apparatus for this purpose will be described in connection with Hinman's analysis outfit.

No convenient and accurate method is available for the determination of nitrogen. It has been, and still is, the practice to estimate this gas by difference. This is inaccurate, it is true, for two reasons: First, it piles upon nitrogen the errors accumulated in other determinations; second, it takes no account of the rarer gases, such as helium, argon, neon, etc., which would be found with the nitrogen. In spite of these facts, the accuracy is probably amply sufficient for practical purposes, provided the remainder of the analysis has been properly carried out.

In the analysis of acetylene an entirely different procedure must be followed, because of the activity of acetylene itself as a chemical reagent, and because of its interference with the absorption of the gases. Hempel recommends that the acetylene be first absorbed by fuming sulphuric acid, passing the gas repeatedly into the pipette until no further diminution in volume occurs, and removing the acid fumes with caustic potash before making the final measurements.

It is probable that small amounts of acetylene will still remain in the gas, as it is extremely difficult to remove the last traces by this method, since the rapidity of absorption diminishes with the dilution of the gas; the danger of dissolving acetylene in the absorbents is nevertheless greatly minimized.

The oxygen is next absorbed with alkaline pyrogallol: Phosphorus must not be used on account of the strong influence exerted by even small amounts of acetylene on the absorption of oxygen by phosphorus, thus rendering the results entirely useless. Hempel then directs the removal of the last traces of acetylene with ammoniacal cuprous chloride solution; but if this be used, there can be no determination of carbon monoxide by this method. It is therefore suggested that the last traces of acetylene be removed by some reagent which is indifferent to carbon monoxide, and then that the methane, hydrogen and carbon monoxide be determined by explosion. The method for phosphoretted hydrogen, silicon hydride and arseniuretted hydrogen has already been given.

Apparatus. There are a number of forms of gas analysis apparatus on the market, several of which are excellent; others are meant for rough work only, while still others are especially adapted to the analysis of some peculiar kind of gas. As of interest to those connected with the illuminating-gas industry, four types will be considered briefly, the Hempel, the Elliott, the Orsat-Lunge and the Hinman. The last named will be discussed in detail, since it is the only one of the four which has not been accurately and frequently described and illustrated in various standard works.

Hempel's apparatus is the best known of the more accurate instruments, and in experienced hands gives excellent results. It is seen in Fig. 24, and consists of an iron trough, *A*, for holding mercury, a glass tube, *D*, graduated in millimeters and 76 to 80 cm. long; a water reservoir, *E*, a leveling bottle, *H*, a measuring bulb, *C*, and a number of gas pipettes of the form, *B*, the explosion pipette differing from these in that it has a glass stopcock between the two bulbs, and two platinum wires entering the lower bulb near its top. In measuring the sample of gas, the measuring bulb, *C*, is brought into the position shown in the figure and pressed down tightly upon the rubber stopper, *a*, by means of the clamp, *f*. Mercury is then drawn out through *m* until the meniscus of the mercury in the measuring bulb is nearly tangent to the horizontal hair of a magnifying glass, which is fastened to the apparatus opposite *l*. The stopcock at *m* is then closed, and by turning a screw on *m*, the mercury at *l* is adjusted to exactly the correct height. By reading accurately the

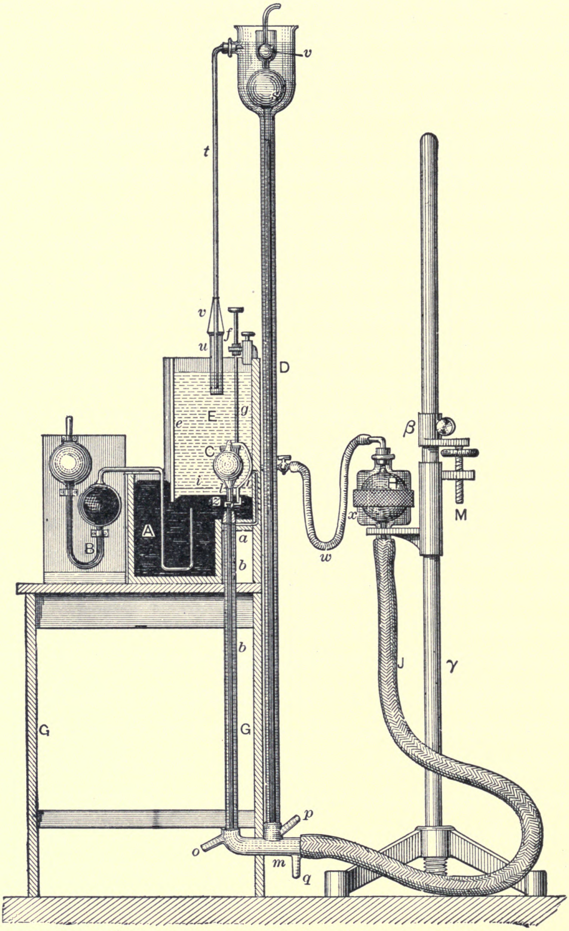

Fig. 24. Hempel's Apparatus for Gas Analysis.

height of the mercury in the manometer, *D*, the pressure of the gas in the bulb is determined. After first introducing corrections for variations in the temperature, the pressure of the surrounding atmosphere is ascertained by means of the correction tube seen in

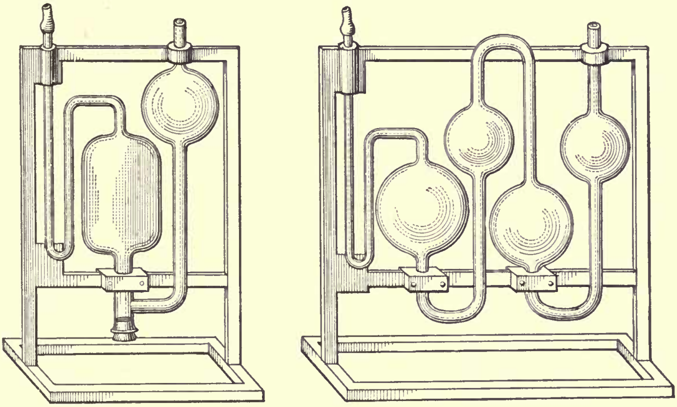

Fig. 24A. Hempel's Pipette.

Fig. 24A. In using this a very small amount of water is introduced into *A* through *b*, followed by mercury until the level of the latter is at the zero mark of the scale tube, *B*, and at *a* on *A*. By sliding the glass rod, *D*, up and down in the adjusting tube, *c*, the sharp adjustment of the height of the mercury is made. The small end of *b* is rapidly sealed with a small blowpipe flame; the seal should occur just above the level of the water in the mercury trough.

If now the temperature or pressure change during the analysis, a correction may easily be found by replacing the correction tube in the mercury trough, and again bringing the mercury to the mark by the use of the adjusting rod, *c*. The reading of *B* will then give the volume to be added to or subtracted from the values found in the analysis in order to make all the results comparable.

In using the apparatus, the capillary stem of a pipette is introduced into the mercury trough, and the end of the stem brought into the measuring bulb. The gas can then be forced over into the pipette, the absorption made, and the gas returned to the measuring bulb. In the case of the absorbent for illuminants it is necessary to completely fill the absorption pipette with the fuming sulphuric acid, so that the latter shall only come in contact with the mercury in the capillary. Taplay has made improvements on this apparatus which are in general intended to simplify the manipulation of the burette and pipettes without the introduction of air, a difficult matter in the ordinary forms. This apparatus is seen in Fig. 25, and its manufacture and use are described in Abady's "Gas Analysts' Manual." The cost of the Hempel apparatus complete is about $35.

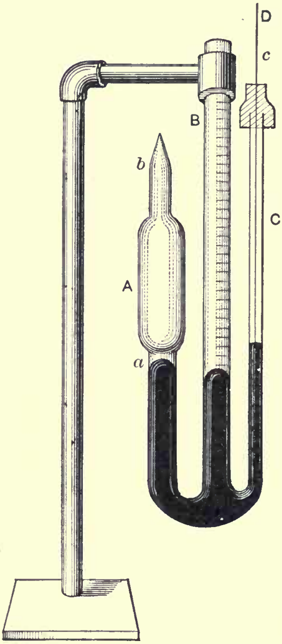

Fig. 24B. Hempel's Correction Tube.

The Elliott apparatus, designed by Dr. A. H. Elliott of New York, is intended for the rapid analysis of coal or flue gases, and was formerly used to a considerable extent. It is not as accurate as Hempel's, but is much more rapid and less delicate, and, therefore, more suitable for rough work. The apparatus in its old and improved forms is shown in Figs. 26 and 27. In Fig. 26, *A* is the laboratory tube, which holds about 125 c.c.; *B* is the measuring tube with a capacity of 100 c.c. from the zero mark to the scratch, *c*, on the capillary tube; the graduations are tenths of a cubic centimeter. *I* is a three-way cock opening into *A*, to the leveling bottle and through its stem. *A* and *B* are connected by capillary glass tubes, a tight joint being made by means of pressure tubing. *M* is a funnel of about 60 c.c. capacity, and between it and *A* is a glass stopcock, *F*, the end of the latter being ground to fit tightly into the end of *M*. In using this apparatus the air is first expelled by water, the gas sample is admitted through *F*, the water being drawn off through *I*. The gas is then measured in *B*, 100 c.c. being taken. The reagents are introduced into *A*, and the absorptions made in that tube, the gas being returned to *B* for measurement, after each absorption. After the use of each reagent, *A* must be washed out with water. The explosions are made in a special burette. This apparatus complete costs in the neighborhood of $25.

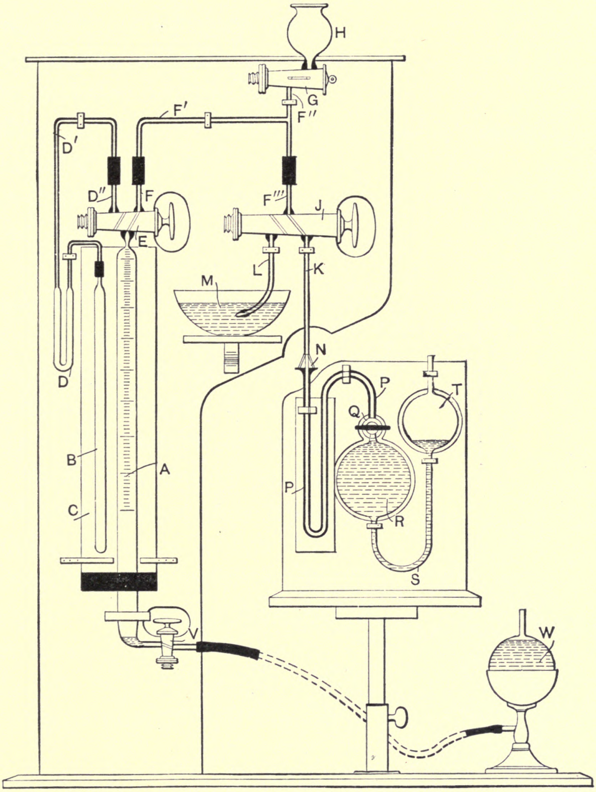

Fig. 25. Taplay's Modification of Hempel's Apparatus.

The Orsat-Lunge is a most convenient form of apparatus for the rapid and partial analysis of gas. It is put up in a wooden box, with removable front and back, and having a handle on the top; thus it may readily be transported and the analysis made on the spot. It consists of a measuring tube, *A*, Fig. 28, of 100 c.c. capacity, which is surrounded by a water jacket for the purpose of keeping the temperature constant. At its base this tube is connected with the leveling bottle, *B*, which is filled with water, brine or mercury. At its top the measuring tube is joined by means of capillary tubing of small bore with three absorption vessels, *C*, *D*, and *E*, which may be connected with or shut off from the measuring tube by means of glass stopcocks. The outlet of each of these vessels is connected with a similar vessel in the rear furnished with a tubulated exit, which in turn is attached to a rubber bag, whereby air is excluded and the reagent may be driven back, if necessary.

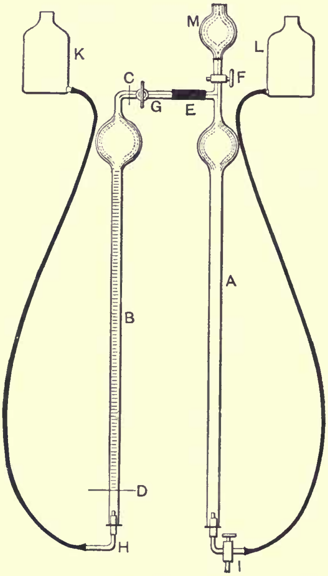

Fig. 26. Elliott's Analysis Outfit, Old Style.

The first vessel contains caustic potash, the second, alkaline pyrogallol, and the third, acid cuprous chloride solution. In order to increase the surface exposed to the gas, each tube is filled with narrow glass tubes set vertically; while in addition to these the cuprous chloride vessel contains pieces of copper wire which keep the solution reduced. In some forms of this apparatus there is a fourth vessel containing palladium sponge for the absorption of the hydrogen.

The gas is measured and forced over into the vessel, *C*, for absorption of carbonic acid; back to the burette for measurement; then into *D* and back to the burette; then into *D*, from here into *C* for the removal of acid vapors, and thence to the burette. The entire analysis may be performed with great rapidity, and, especially if mercury be the confining fluid, with considerable accuracy. It does not admit of the determination of methane, illuminants and nitrogen, but it does furnish information of great value

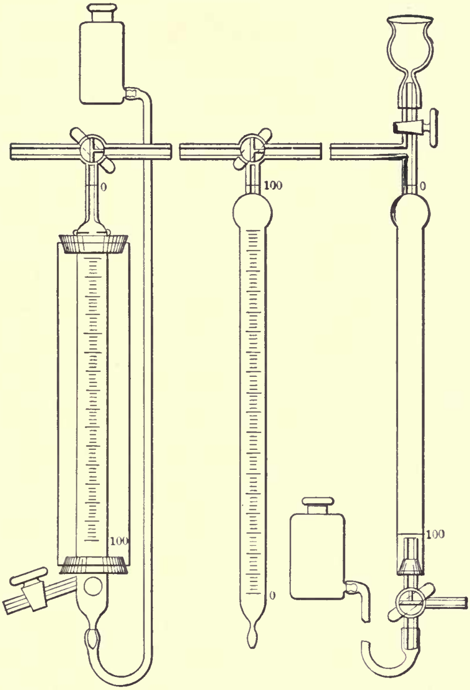

Fig. 27. Elliott's Analysis Outfit, New Style.

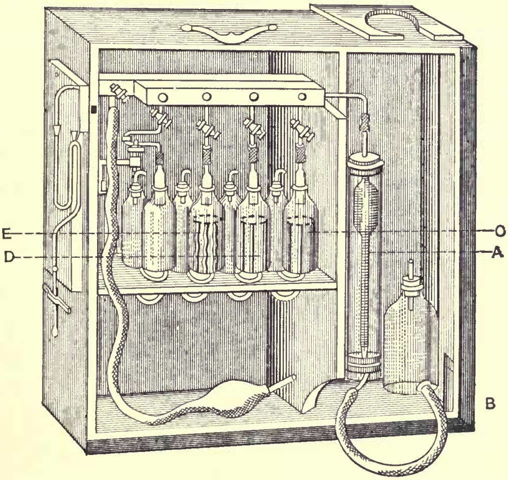

Fig. 28. Orsat-Lunge Analysis Apparatus.

to a gas maker, and especially to the manager of a water gas set. The outfit costs, with three pipettes, but $20.

Hinman's apparatus is the least known of the four, and yet is probably the most accurate. So far as the writer knows, but one printed description has ever been given of it, and as this is to-day rarely available, it seems desirable to insert it at this point. Major Hinman says: "An apparatus was desired which should be as far as possible free from fragile or costly parts, and which without being too complicated should require no corrections to be made for variations in the pressure, temperature or aqueous vapor; reliable results rather than minute accuracy being desired."

"The apparatus finally adopted operates on the same principles as Williamson and Russell's, except that in my apparatus the gas is not exploded in the measuring tube but in a bulb for that special purpose. The trough is nearly the same as that of Devere, and pipettes are also used."

"The apparatus as made consists of a measuring tube, *a*, Fig. 29, about 230 mm. long and about 20 mm. in diameter, divided into one-fortieth of an inch and calibrated with mercury as described by Bunsen. The tube is firmly held by a clamp on the end of the rod, *b*, which rod slides up and down *c* and is clamped in any position by the screw, *d*. A slow motion is given to *c* and thus to the measuring tube by means of the milled-headed nut, *e*, which works along a thread cut on the rod, *f*, which is firmly secured to the body of the apparatus. The screw, *g*, can be turned in so that its end just fits into a longitudinal slot in the rod, *f*. By this means *c* is prevented from turning around *f*, and the measuring tube can thus be kept exactly over its well; or *g* can be used to clamp *c* in any position.

"The pressure tube, *h*, is about 200 mm. long, and has a diameter of only 6 mm. A mass of lead covered with sealing wax is attached to the lower part of *h*, so that when it is filled with air, it will keep upright when it is suspended from an eye at the top. The pressure tube is hung by a wire from the end of the arm, *i*, which slides with friction along the rod, *f*.

"The mercurial trough is of cast iron, and consists of the plate, *l*, which is about 130 mm. square, 15 mm. thick, and has a groove in its upper surface 10 mm. wide, 6 mm. deep and 5 mm. from the edge; the well, *k*, which is about 240 mm. deep and 30 mm. in inside diameter; and the side well, *m*, for the pipette, which is of the same depth as *k*, but part of it extends 40 mm. above the top of *l*; *m* is 10 mm. wide and 90 mm. broad. The wells, *m* and *k*, have walls 6 mm. thick. Of course *k*, *l* and *m* are all cast in one piece.

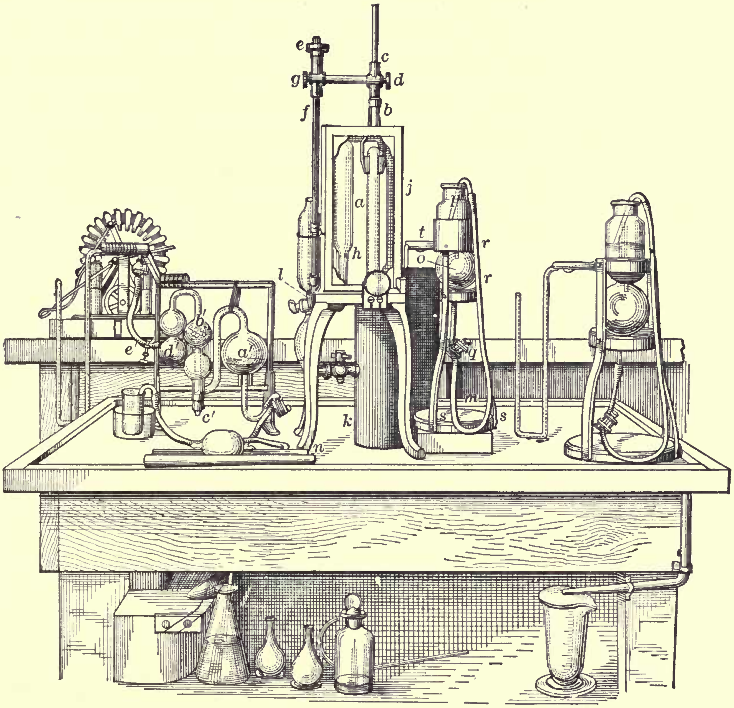

Fig. 29. Hinman's Analysis Apparatus.

"The groove in *l* has cemented into it, by means of a cement composed of beeswax and rosin, a rectangular trough of plate glass 5 mm. thick, cemented with the same cement into a sheet-iron frame, *j*, which is made by bending a sheet of the right size into a box without ends, and then cutting out the sides so as to leave only a strip 12 mm. wide on each edge. The legs, *n*, are secured onto the plate, *l*.

"The pipettes consist of a bulb, *o*, of a little larger capacity than the measuring tube, open at one end and at the other melted to a tube about 5 mm. in diameter, having a bore of 1 mm., bent so that when it is put into the side well, *m*, the point of the pipette can be brought directly under the measuring tube. The other end of the bulb is joined to the end of a piece of good rubber tubing, about 300 mm. long, with rather thick walls and small bore, and the other end of which is connected with a small syphon which dips to the bottom of a strong glass bottle, *p*, of rather larger capacity than the bulb, *o*. Immediately below the bulb is a screw clip, *q*.

"The pipette is held in a stand devised by my assistant, Mr. Lewis. It consists of two discs of wood, *rr* (Fig. 29) (cut away so as to fit the bulb), to which are screwed three rods of iron, *ss*, so as to hold the bulb between the discs and at the same time form a tripod to support the pipette. The pipette tube is supported by being attached to a semi-cylindrical piece of metal, *t*, which is fastened into the upper disc, *r*. This style of pipette is to hold reagents for absorption.

"I have invented another sort of pipette in which to explode gases. The bulb is of the same capacity as the former one, but the sides are 12–15 mm. thick, and instead of the pipette tube being melted onto the bulb, it is ground into the top with emery and then cemented in with shellac containing a little Venice turpentine. Two grooves are made in opposite sides of the end of the pipette tube, where it is ground into the bulb, in which are platinum wires, the ends of which approach within 1 mm. of each other. Care is taken to have the form of the pipette such that all the gas will be expelled from the bulb when the mercury rises.

"The apparatus is used in the following manner: Clean mercury is poured into the well until it is about 8 mm. deep above the top of *l*. A drop of water is put in the end of the pressure tube, which is suspended so that the bottom nearly touches *l*, and water of the temperature of the room is poured in until the glass vessel is nearly full. Air is then taken out of or added to the pressure tube until the mercury in the lower part of the tube is just on a level with the top of a straight-edged piece of glass, *v*, which is fixed just behind the pressure tube and measuring tube, so that its top edge is parallel to and about 15 mm. above the top of *l*.

"The measuring tube being thoroughly cleaned, and a drop of water spread over the sides, is fixed in the clamp, a thin slice of cork being placed between each side of the clamp and the tube. The tube is then placed upright in a small, long-handled cup of mercury, like that used by Doyere, and is lowered through the water into the mercury well. The piece, *c*, is then put over *b* and fixed into position on the rod, *f*.

"A clean pipette, full of mercury, is then lowered into the trough, and the point brought directly under the measuring tube, which is then lowered, so that the pipette touches the top of the measuring tube. The bottle is placed on the table, the screw clip, *q*, loosened, and the air is forced over into the bulb, *o*, of the pipette.

"When the pipette tube has become filled with mercury, the measuring tube is raised, and the pipette withdrawn. The air in the pipette is then displaced by mercury, and if the gas to be analyzed can be taken from a rubber tube, the end of this is slipped over the pipette tube, and the gas then drawn in.

"The pipette is put into the well, placed under the measuring tube, which is lowered a little, and the gas forced into it by raising the bottle, *p*, to the position, *p′*, and opening the clip, *q*. If desirable, the gas can be bubbled directly into the measuring tube by means of a properly bent tube.

"When as much gas as is desired is in the measuring tube, the pipette or other tube is withdrawn, the measuring tube raised or lowered until the top of the mercury in it is on a level with the top of the glass, *v*, and if the mercury in *h* is not at the same height, it is adjusted by altering the height of the mercury in the trough, or by adding hot or cold water to that surrounding the tubes, care being taken to thoroughly mix the water by agitation with a stirrer. The gases in the measuring and pressure tubes are thus kept at the same pressure and temperature, and are saturated with moisture. The reading of the measuring tube is effected by a telescope fixed at some distance from the apparatus. As the mercury is always at the same height, the telescope is always in the same position.

"When it is desired to subject the gas to the action of any reagent, a pipette containing a few drops of the reagent (the rest of the pipette being filled with mercury) is introduced into the trough, and the gas drawn over as before described, and is then shaken up with the reagent.

"When the gas is to be transferred back to the measuring tube, mercury is drawn through the tube to remove any traces of the reagent, as it is essential that none of the reagent should be transferred with the gas. The point of the pipette being under the measuring tube, the bottle, *p*, is raised, the clip, *q*, opened, and the gas is forced into the measuring tube. When the gas is nearly over, the clip, *q*, is nearly closed, so that the gas passes quite slowly; the pipette is raised by a block of wood under its base, so that its point is 40 to 50 mm. above the surface of the mercury in the measuring tube. The progress of the liquid in the pipette tube must be watched carefully, and when it is about 20 mm. from the end, the clip, *q*, is closed, and by carefully pinching the rubber tube above the clip, the liquid is forced within 1 or 2 mm. of the point of the pipette tube; the point of the pipette is then brought under the surface of the mercury by raising the measuring tube, and the pipette withdrawn. The quantity of gas left in the pipette tube would be quite unmeasurable if it were five times larger."

One or two changes have been made in the apparatus since this description was written, which make for greater accuracy and ease of manipulation. The pressure tube rests with its open end in a groove, while the upper end fits into a cup-shaped depression in a flexible steel spring, whose ends are held under projections on either side of the top of the framework which holds the glass sides. This eliminates the necessity of the mass of lead, the arm, *i*, and the wire used for suspension. The narrow neck of the pressure tube bears three scratches corresponding in height to three similar marks on the glass window in the rear; the mercury in the tube is set level with two of these marks at the start, and brought to the same position before each measurement.

The writer has also made a slight change in the pipette which has proved very satisfactory. The screws holding the legs to the top plate are removed, and a circular strip of brass with the ends soldered together, is placed around the plate. This strip is punctured by three holes through which the screws pass and fasten it securely to the top. The brass projects about 1¼ inches above the top surface, thus making a shallow cup in which the bottle, *p*, rests. It is often necessary in the course of an analysis to place the bottle on top of the pipette, and then change the position of the latter. The brass ring prevents the bottle from sliding off or tipping over, a thing very liable to happen; it thus enables the operator to move the pipette more quickly and with less need of care.

The trough, *k*, is tapped about one-half way down and a steel tube bearing a three-way cock inserted, the other end of this tube connected with a rubber bulb whose upper end is joined to a glass tube 1⅜ inches in diameter and open at the top; the opening, however, is only five-sixteenths of an inch in diameter. This tube is held vertically against the side of the trough by wire. By means of the three-way cock, mercury may be drawn off from the trough into a bottle; or, by opening the cock and squeezing the bulb, it may be forced into the vertical glass tube or allowed to flow from the latter into the trough. This enables rapid adjustment of the height of mercury in the trough, and consequently rapid and accurate alignment of the mercury in the pressure tube.

A hydrogen generator has been devised which works admirably and is seen in Fig. 29. The acid is introduced into the bulb, *a′*, and is raised or lowered by mercury from the bottle. The zinc is in bulb, *b′*, and is held in place by a glass rod flattened at the end and passing through the rubber stopper, *c′*, which is wired securely on. In the bulb, *d′*, is placed a little caustic potash solution, for the purpose of catching any acid fumes. The end, *e′*, may be connected to a specially bent tube which is readily inserted under the measuring tube or eudiometer, and thus the hydrogen passes directly into the latter.

The apparatus is mounted on a table 39 inches by 27 inches, covered with oilcloth and having a small hole in one corner by which any mercury which has been spilled on the table may be drawn off. Twenty inches from the floor is a shelf which serves to hold the stirrer, caustic potash, and sulphuric acid bottles, waste mercury bottle, the cup used in lowering the eudiometer and pressure tube into place, filters, etc. These filters are used for drying the eudiometer; the most convenient method is to fold two of them double and insert in the cleft end of a stick. By rolling the filter around the stick a most effective drier is secured.

From one corner of the shelf projects a small board pierced by a 2-inch hole, in which is placed the neck of a liter bottle used for purifying the mercury. The mouth of the bottle is closed by a rubber stopper bearing an iron tube and stopcock, while there is a hole in the bottom of the bottle directly opposite the neck, through which the impure mercury and the sulphuric acid are poured in.

The pipettes and hydrogen generator, when not in use, are kept in a glass case, the bottles being left on top of the pipettes so that the pressure is always outward.

For the explosion, the writer uses a Wimshurst machine, which sets on an adjoining bench, and from which wires pass to the analysis table. This has proved most satisfactory; the machine occupies but little room, and by means of the wires the spark can be passed while the explosion pipette is still in position under the eudiometer. The entire apparatus costs $300. The Wimshurst machine and mercury are extra; the former costs $12, while about 75 pounds of the latter are required.

A few of the minor precautions to be observed in the use of this apparatus may be of service to those using it for the first time. The eudiometer should be moistened with a very small amount of water before being filled with mercury, and the pressure tube should likewise receive a small drop of water only; if more is used it will obscure the reading of the mercury meniscus.

All pipettes should be tested for a leak by placing the moistened finger tip over the end of the capillary, and observing whether the mercury in the latter recedes continuously when the bottle is lowered.

Wash out the Nordhausen acid as soon as the absorption is complete and the sample returned to the eudiometer; use ordinary sulphuric acid for the first washings, diluting it towards the end. The mercury must then be drawn off and the pipette dried by aspirating.

It is well to leave the pipettes under the eudiometer while the absorptions are going on, since in this case if any pressure or vacuum is created there will be no loss of the sample. In removing a pipette from under the eudiometer the latter should be lowered a trifle to prevent water from being sucked in.

When adding oxygen for the explosion, draw over at first only one-half of the total quantity of oxygen to be used, and explode; then draw over the rest and explode again; this will prevent burning the nitrogen.

For purification of the mercury, the author uses strong sulphuric acid and mercurous sulphate, allowing the mercury to stand under the reagents until needed, when it is drawn off by the cock at the bottom of the purification bottle. The oxygen used should always be analyzed; this is easily and accurately done by the explosion with hydrogen.

The advantages and disadvantages of this form of apparatus as compared with others may now be briefly considered. Major Hinman made a number of experiments to compare it with the Hempel under varying conditions. The results showed that while Hempel's was equally reliable for absorptions, the determinations of hydrogen and nitrogen were far more accurate with the Hinman. The latter is very costly; parts of it, notably the pipette stems, are fragile and easily broken, and it is distinctly not intended for rapid work.

On the other hand, it gives very accurate results; the carbon monoxide is determined by explosion, eliminating the errors attendant upon the use of cuprous chloride; there is no need of corrections for temperature, pressure or tension of aqueous vapor; the absorptions are complete in a short time; mercury is the confining fluid, so there is no chance for loss due to the solubility of certain constituents of the gas in water; there are no glass stopcocks to become stuck or to leak; the explosions are made without danger of burning the nitrogen, while the readings may be made with extreme accuracy.

On the whole this apparatus seems to be the most satisfactory where absolutely trustworthy results are desired; it will of course never be employed for rapid approximate work, and should never be placed in the hands of any but a skilful and competent manipulator.

The calculations involved in the use of Hinman's apparatus may best be explained by two concrete instances.

Divisions.*	Vol. in c.c.	
147.3	22.90	Gas taken.
146.7	22.82	Vol. after absorption of carbonic acid.
146.5	22.79	Vol. after absorption of oxygen.
138.2	21.58	Vol. after absorption of illuminants.
326.4	48.91	Vol. after adding oxygen.
84.9	13.72	Vol. after explosion with oxygen
8.8	2.49	Vol. after absorbing carbonic acid from explosion.
64.0	10.65	Vol. after adding hydrogen.
23.0	4.59	Vol. after explosion with hydrogen.

* *American Journal of Science and Arts*, September, 1874.

Vols. in c.c.		Vol. in c.c.	Per cent.	
0.47 N_2	(A) $CH_4+CO+H_2=21.11$	22.90	100.00	Gas taken.
6.06 H_2O formed 2.02 O_2 left	(B) $CH_4+CO=11.23$	.08 .03	.35 .13	CO_2 O_2
27.33 O_2 added 25.31 O_2 used	(C) $2CH_4+\frac{1}{2}CO+\frac{1}{2}H_2=25.31$	1.21	5.29	hydro-carbons
11.23 CO_2 formed 21.11 combustible gas	$2(C)-(A)=3CH_4=29.51$	9.84 1.39	42.97 6.06	CH_4 CO
	$(A)-(B)=H_2 = 9.88$	9.88	43.15	H_2
	$(B)-CH_4=CO = 1.39$	.47	2.05	N

Divisions.	Vol. in c.c.	
149.7	23.26	Gas taken.
149.2	23.19	Vol. after absorption of carbonic acid.
149.0	23.16	Vol. after absorption of oxygen.
140.3	21.88	Vol. after absorption of illuminants.
328.0	49.14	Vol. after adding oxygen.
82.8	13.41	Vol. after explosion with oxygen.
5.9	2.06	Vol. after absorbing carbonic acid from explosion.
45.3	7.88	Vol. after adding hydrogen.
14.2	3.28	Vol. after explosion with hydrogen.

Vols. in c.c.		Vol. in c.c.	Per cent.	
0.53 nitrogen	(A) $CH_4+CO+H=21.35$	23.26	100.00	Gas taken.
4.60 H_2O formed	(B) $CH_4+CO=11.35$	.07	.30	CO_2
1.53 O_2 left	(C) $2CH_4+\frac{1}{2}CO+\frac{1}{2}H=25.73$	.3	.13	O_2
27.26 O_2 added	$2\,(C)-(A)=3CH_4=30.11$	1.28	5.50	hydrocarbons
25.73 O_2 used	$(A)-(B)=H=10.00$	10.04	43.16	CH_4
11.35 CO_2 formed	$(B)-CH_4=CO=\ 1.31$	1.31	5.63	CO
21.35 combustible gas		10.00	42.99	H_2
		.53	2.28	N

As has already been said, no other forms of apparatus will be described here, but if the reader is interested in some of those more recently proposed, he should consult the *Journal of American Chemical Society Abstracts* for December 5, 1907, and March 5, 1907; the *Journal of Gas Lighting*, January 21, 1908, and September 17, 1907; and the *Progressive Age* for December 2, 1907, etc. In order that some idea may be given of the results of gas analysis, two or three tables are inserted in the appendix giving data taken from various sources, but, with the exception of the natural gas figures, principally from the reports of the Massachusetts State Gas Inspectors.

If properly interpreted, there is nothing which will give a manager so much information as to the running of his plant as an accurate chemical analysis. From it he can readily calculate the heating value of the gas, in the manner which will be shown in the discussion of calorimetry; he can determine whether air is being admitted; whether heats are too high or too low; whether a greater yield may safely be secured, and many other factors of prime importance. The writer is indebted to Mr. C. D. Jenkins, State Gas Inspector of Massachusetts, one of the most experienced and competent gas analysts in the United States, for the following clear and concise statements on the interpretation of gas analyses.

"**Coal Gas.** The diluents should not exceed 5 per cent in the purified gas. High nitrogen, especially with much carbonic acid, would indicate that furnace gases had been drawn in through a leaky retort. High nitrogen with oxygen would indicate air leaks. Both of these conditions depend on the exhauster carrying a vacuum on the generating plant. High carbonic acid with normal nitrogen (and no oxygen) would point to the use of a wet coal or to a large per cent of oxygen in the coal. The three diluents affect the candlepower directly, as well as volumetrically; their action on the heating value, however, is simply to reduce the latter by the volume of the inert gases introduced. The amount of illuminants does not of itself furnish a criterion of the candlepower of the gas, but must be considered in conjunction with the amount of the other gases. An average per cent of illuminants, high methane, low hydrogen and average carbon monoxide, should indicate a good candlepower gas with high heating value; while with the same amount of illuminants, low methane, high hydrogen and average to high carbon monoxide, the candlepower and heating value both suffer, but the latter in not as great proportion as the former.

"The methane is a valuable constituent from the standpoint of both heating and lighting power. It is an indicator of heats and yields, high heats and large yields giving a low methane content, with an excess of hydrogen.

"**Water Gas.** The diluents are liable to vary more than is the case with coal gas, on account of the carbonic acid which may be allowed to remain in the gas. A large amount of carbonic acid would indicate too long a run, too low a heat in the generator or too thin a fire.

"Nitrogen would come from gases left in the apparatus during the 'blow,' and should therefore be low. The illuminants are more nearly uniform than in coal gas, and their proportion will give a better idea of the candlepower. The illuminants and methane coming from the oil gas, made in carburetting the blue water gas, should be in the same relation as in oil gas; a large proportion of methane would indicate a breaking down of the illuminants with consequent loss of candlepower.

"In mixed coal and water gas the amount of carbon monoxide would indicate the relative proportion of each gas; by assuming a normal analysis for one, the other can be calculated."

PART III.

CALORIMETRY, SPECIFIC GRAVITY AND PRESSURE.

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CALORIMETRY, SPECIFIC GRAVITY AND PRESSURE.

CHAPTER I.

THE JUNKER AND BOYS CALORIMETERS.

THE subject of calorimetry is every year becoming of greater interest and importance, and is destined, in the very near future, to occupy the foremost position among methods of gas testing. Indeed, it seems essential and just that this should be so, if the history of the modern gas industry be considered. It is coming to be accepted as a fact that, as a general rule, from 75 to 90 per cent of the gas burned is consumed in Welsbach burners and in stoves or other heating appliances. Now if this be true, the heating value of the gas is clearly the factor to be reckoned with, and it is predicted that before long, governmental regulations will require a certain heating value, rather than a candlepower limit, as a standard for gas. Indeed, to continue the candlepower standard is simply to place a premium on inefficiency and to protect the few at the expense of the many; for a high candlepower *per se* benefits only those who use flat-flame burners, and may prove a real injury to the consumers who use Welsbachs. Already candlepower tests have been abandoned in Wisconsin, and the Public Service Commission of the Second District of New York State is conducting extensive researches tending in this direction. There is no doubt that photometric work will persist in many localities and for varied reasons for a long time to come; but the writer is firmly of the opinion that the calorimetric test should be brought more and more to the fore, and should wherever possible be substituted for candlepower requirements.

The calorimetry of gas is the science of determining the number of heat units given off by the perfect combustion of a unit volume of the gas under standard conditions. Before proceeding further, it may be well to insert a few definitions which will assist in the comprehension of what follows. A British Thermal Unit, or a B.T.U., as it is commonly abbreviated, is the amount of heat required to raise the temperature of one pound of water at its maximum density (*i.e.*, 39.1° F.) through 1° F. A large Calorie or Kg.-calorie is the quantity of heat necessary to raise the temperature of 1 Kg. of water at its maximum density, 1° C. A small calorie or g.-calorie is the same as the above, save that the amount of water to be heated is 1 g.[1]

In France and some other countries the heating value of a gas is expressed in Calories per cubic meter; this means the number of Kgs. of water which can be raised in temperature from 0° to 1° C. by the consumption of 1 cubic meter of the gas.

The latent heat of steam may be explained thus: when water passes from a liquid state to that of a vapor, it requires a large amount of heat to bring about the transition, and this heat does not at all raise the temperature of the substance, but is all expended in converting the water at 212° F. into steam at the same temperature. This particular amount is called the latent heat of steam, and is equal to 536 calories. Conversely, when steam at 212° F. condenses to water at the same temperature, 536 calories are given off, and it is this factor which will be considered under the head of "net" calorific values.

Gas calorimeters, or instruments for determining heating values, may be divided into two broad classes, according as (1) they do or (2) do not measure the rise in temperature of a known quantity of water, caused by the combustion of a measured volume of gas.

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[1] The Kg.-calorie is usually written with a capital C, thus, Calorie, while the gram-calorie is written with a small c. The latter is also sometimes referred to as the small calorie, while the Kg.-calorie is known as the large calorie.

Class 2 is mostly composed of recent inventions which have not been carefully tested, while class 1 contains the more accurate and reliable instruments, and the ones which are recommended for general use. Of these there are but four which are worthy of attention, the Junker, the Simmance-Abady, the Sargent, and the Boys.

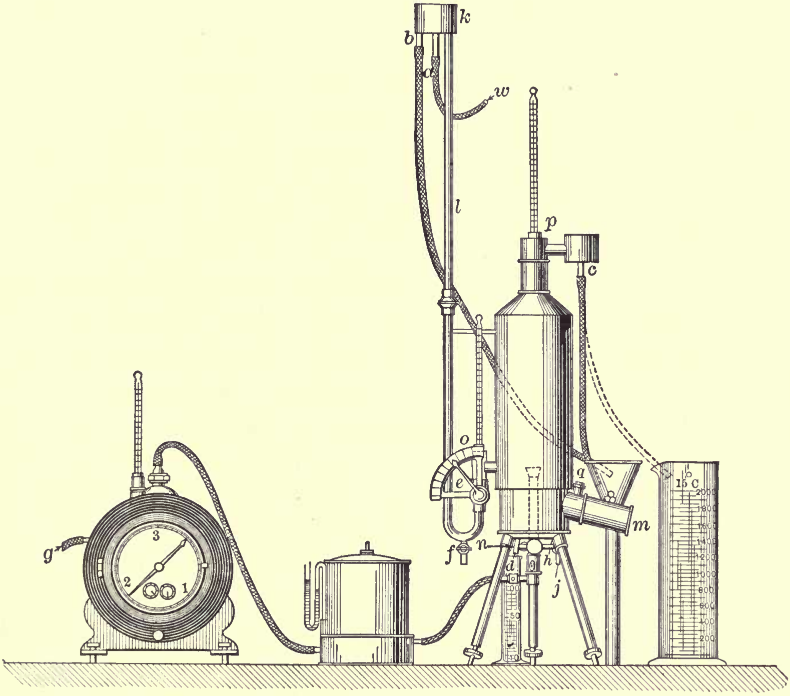

Fig. 30. Junker Calorimeter.

The Junker calorimeter (Fig. 30) consists of a combustion chamber surrounded by an annular copper vessel filled with a large number of copper tubes. The gas is burned in a long-tube Bunsen burner, *h*, which projects well into the combustion chamber and is secured in place by the clamp, *i*, fastened to the metal rod, *j*. The burner is provided with a spreader on top, an adjustable air mixer, and a stopcock for regulation of the gas. Both the air and gas regulators are easily accessible when the burner is in place. The cold water enters at *a*, and overflowing into the cup, *k*, passes down through the metallic tube, *l*, to the regulator, *e*, where the rate of flow is controlled. From here it flows upward around the copper tubes and escapes through the outlet, *c*, into the sink or the receiving vessel.

The products of combustion pass downwards through the copper pipes and escape at *m*, where there is a regulating damper. Since these copper tubes are always surrounded by water, the heat developed by combustion is removed by the latter, and the gases escape at the room temperature, while the outlet water has received all of the heat generated by the burning of the gas. *N* is a tube for the escape of the water of condensation.

The entire instrument is nickel-plated and mounted on three legs provided with leveling screws. Thermometers are inserted, by means of rubber stoppers, at *o*, *p* and *q*, and thus the temperature of the inlet and outlet water and of the outlet gases may be taken. As accessories, the following pieces of apparatus are needed: a wet meter, a governor, a vessel of known capacity and holding 1 to 2 liters, and a 50 c.c. graduated glass cylinder.

The cost of the meter, governor and calorimeter is $200; these may be procured of Eimer & Amend of New York; but the meter which they furnish is unsatisfactory. The author has used a small wet meter made to order by the American Meter Company and having a dial divided into thousandths of a cubic foot. This meter costs $30, and has given excellent satisfaction. Readings are made to within a few ten thousandths of a foot, and a table of corrections has been drawn up for all rates between three and four feet per hour. It is not accurate, however, at higher rates, and where a calorimeter is to be set up permanently in one place, a 6-foot wet meter registering 1/10 cubic foot per revolution is to be recommended; the cost of such is $50. Whatever style of meter is adopted, it must be carefully tested and the water line marked with great accuracy. If a governor is used, one of the wet style should be employed, and it should be placed between the meter and the burner.

Rubber tubing is not suitable for the transmission of the gas on account of the absorption of illuminants which it causes; the writer has, however, found by experiment, that such absorption has a far less effect on the calorific determinations than it does on the candlepower. Flexible metallic tubing may be obtained for about 9 cents per foot, and this will give excellent satisfaction.

The thermometers used should register degrees Fahrenheit and should be of the greatest accuracy. Whenever possible it is well to purchase those which have been certified by the National Bureau of Standards. If, for any reason, such certification cannot be procured, the thermometers should be tested by the operator, to see that they register exactly the same under similar conditions. If a complete calibration is impossible, they should at least be immersed in ice water and in boiling water, and observed to see if they register 32 degrees and 212 degrees respectively. It is also easy to compare their readings on a few intermediate points by heating water to a definite temperature, say 90 degrees, immersing the thermometers therein and observing whether their readings are the same. Small reading glasses are provided with the thermometers measuring the temperature of the inlet and outlet water; with these it is comparatively easy to read to hundredths of a degree.

A 2-liter cylinder is usually supplied for catching and measuring the outlet water during a determination. This is open to criticism along several lines; the main objection, however, is that it is impossible to accurately determine the end point, because of the large cross-section exposed. The writer at first employed a 2 L. flask, with the calibration mark on the neck. This enabled one to make a very accurate reading, since in the narrow neck of the flask a difference of 2 c.c. was readily perceptible; but the flask was fragile, and after one or two had been broken, a 2-liter bottle of clear white glass was substituted, a scratch made on the neck, and the contents of the bottle up to this point accurately determined. This has proven most satisfactory; the bottle is strong, cheap, can be readily replaced in almost any drug store, and enables readings to be made which are easily accurate to less than 0.1 per cent.

The Junker calorimeter in use by the Public Service Commission of New York must of necessity be so packed that it can be readily and safely transported; to this end the legs are unscrewed and done up in canvas to keep them from rolling about; the thermometers in their cases are thrust into pockets in a canvas bag which in turn is rolled up and tied; the long inlet tube and overflow is unscrewed and fastened to the side of a suit case by straps. The body of the calorimeter is laid on a padded bed in the bottom of the case, and held in place by three straps. Another strap surrounds the meter, and still another holds the burner in place. All of the other accessories, such as heating coil, bottle, graduate, etc., are carried in a second case.

In setting up the instrument, the legs are first screwed in place and the inlet tube and waste-gas pipe connected. The calorimeter is then leveled by means of the screws at the base of the legs, a small iron level being always carried with the outfit. Next the meter is set up, leveled and filled with water to a point slightly above the mark on the gauge glass. The gas is connected to the inlet of the meter, the outlet being connected through the governor with the burner, the latter being stood upon the bench.

The gas is turned on and lighted at the burner, and allowed to burn for at least two hours in order to thoroughly saturate the tubing and the water in the meter with gas. In case the small wet meter is used, three-quarters of an hour to an hour will be sufficient for this. If the meter is to be used again and again with the same gas, this long period of saturation will only be necessary when fresh water is used in the meter; even in such cases, however, it is desirable to burn the gas for some time before making the test, in order that the water may acquire the temperature of the gas, and so that, if the gas is different in composition from that which last passed the meter, time may be allowed for the rectification of this difference.

During this preliminary run, the thermometers are placed in position, the water supply connected to the inlet of the calorimeter, and rubber tubes connected to the overflows of the inlet and outlet water. The temperature of the inlet water must be as nearly as possible the same as that of the room; for if the air were the warmer of the two, it would impart some of its heat to the colder water, and thus the rise in temperature as shown by the outlet thermometer would not be wholly due to the heat generated by the combustion of the gas. Therefore, if the inlet water be cold, some means must be provided for raising its temperature to that of the surrounding air.

Three methods adapt themselves to this purpose: 1. If the calorimeter is to be permanently set up in one place, a permanent water-supply tank with a large horizontal area may be affixed to the upper wall of the room above the calorimeter. Such a tank, by virtue of the large surface exposed, will allow the water to speedily assume the temperature of the room; the tank should contain sufficient water to supply the calorimeter for one day's tests. This is the best of the three methods, and should be adopted wherever possible.

2. If both hot and cold water are constantly available, they may be connected together by means of a brass T, and the faucets regulated until the temperature of the joint stream is that of the room. This plan is open to the objection (1) that the pressure is liable to be variable, due to the varying consumption by other consumers on the line, thus causing both the temperature and the flow of the inlet water to vary, and (2) that the temperature of the water is liable to vary, resulting in a similar difficulty. It may happen that several tests will be necessary before normal conditions are obtained, but by the exercise of patience and judgment very satisfactory results may be obtained by this method of procedure.

(3) If only a cold water supply is available, a heating coil may be inserted between the faucet and the inlet of the calorimeter. Such a coil may be purchased for about $2, and consists of a coil of copper pipe surrounded by an iron jacket to prevent radiation. The coil is set upon an iron tripod and is heated by means of a

Bunsen or Tirrill burner. By careful regulation of the latter and of the faucet, water of any desired temperature may be supplied to the calorimeter.

This method, crude as it appears, has many advantages, and may be made to operate with great success. If the calorimeter is to be used as a portable instrument and set up in various localities, the heating coil often furnishes the only feasible method of securing a constant supply of water of a given temperature. It is, of course, subject to draughts and to fluctuations in the water pressure, and for these reasons does not compare in efficiency with the overhead water tank; but for a cheap device, and especially where portability is an essential feature, it will give good satisfaction, and, with care, furnish results which are more than sufficiently accurate for practical work.

Having secured water of the desired temperature, it is now turned into the calorimeter, and the flow regulated so that the water overflows in both inlet and outlet cups, and passes off from the latter at a rate approximating 100 liters per hour. Before proceeding further, it is necessary to test for a leak. This is done by shutting off the gas at the burner and watching the meter hand. If the latter moves, a leak is indicated, and this must be stopped before continuing with the test.

If the water in the meter is now saturated, the burner is regulated to pass from 4 to 7 feet per hour, according to the gas to be tested, and the air mixer adjusted to give the most efficient flame. This latter point is reached when the tip of the flame alone shows a very faint luminosity. This adjustment must be made with some care, since an excess of air will cool down the flame, while a deficiency will result in incomplete combustion. Certain experiments of the writer, however, have seemed to indicate that the inaccuracy caused by improper regulation (within reasonable limits) of the air supply is smaller than is commonly supposed.

The burner is now inserted in the combustion chamber and screwed firmly in place. It is always well to hold a mirror beneath the burner after it is in position to see that the gas is still burning and that the flame has the same appearance as when in the open air. The burner tube should project some 5 inches up into the chamber, and it is well to so fix the clamp that this distance may always be maintained.

After a few minutes again regulate the water so that there shall be a difference of about 15 degrees between the temperatures of the inlet and outlet. Allow the gas to burn in the calorimeter for from 20 to 30 minutes before commencing a test. If the condensation is to be determined, wait until the condensate drops regularly from the outlet at the base, then as the meter hand passes 0, place the 50 c.c. graduate under the outlet tube and record the reading of the meter. Allow at least 1 to 2 feet of gas to be consumed before removing the graduate and again reading the meter. From the number of c.c. in the graduate and the amount of gas consumed, the heat represented by the water of condensation may be calculated in the manner shown later.

The apparatus is now ready for a regular test, the writer's procedure being as follows: Record first the temperature of the room and of the gas in the meter, the barometric reading, and if desired the humidity. Insert the tube from the outlet overflow into the neck of the 2 L. bottle and at the same instant read the meter and start the stop watch.

Make as many readings as possible of the water thermometers, and at least one or two of the outlet gases. At the instant when the water in the bottle reaches the scratch on the neck, stop the watch and read the meter simultaneously.

Before proceeding with the calculations, a few precautions must be noted, and if some of these seem to be repetitions of what has preceded, it must be set down to their great importance. 1. The calorimeter should be set up in a quiet, light, well-ventilated room, free from draughts and with a constant temperature between 60 and 80 degrees. 2. Sunshine must not be allowed to strike on or near the instrument, and proximity to windows, electric lights, burning gas, steam radiators and hot-water pipes must be strictly avoided. 3. The calorimeter should be so placed that the overflows may be easily led into the sink, and adjustment of the gas, water, etc., may be readily made without disturbing the connections.

4. The thermometers should be in a good light and in such a position that reading is facilitated, since any unnecessary movement during the period of test means a draught upon the instrument and corresponding inaccuracy of results. 5. The meter must be adjusted and leveled *with the utmost precision;* this is one of the most essential requirements for accurate work. 6. The water in the meter and the tubing must be thoroughly saturated with the gas. 7. The gas must be allowed to burn in the calorimeter at least 20 minutes before commencing the test. 8. The water must be overflowing from *both* inlet and outlet weirs; if this is not the case, it will be found that the temperature of the outlet water will fluctuate badly. 9. Always test for leaks. 10. Always have the temperatures of the inlet water, outlet gas and room as nearly as possible the same. 11. Be careful not to spatter water on the sides of the calorimeter, and if this has been done, wipe it off as quickly and completely as possible. 12. Keep the metallic surfaces polished, and entirely free from dirt and dust. 13. Never place the lighted burner in the calorimeter when the water is not running through the latter, and never turn off the water while the burner is lighted and in place. A recollection of this will save many thermometers and much time.

For the calculation of results the following simple formulæ may be employed:

$$\text{B.T.U. per cubic foot gas} = \frac{\begin{array}{c}\text{L. of water heated} \times \text{degrees C.}\\ \text{rise in temperature} \times 3.968\end{array}}{\text{cubic feet of gas burned (corrected)}}$$

$$\begin{array}{r}\text{Heat of condensation}\\ \text{in B.T.U. per cu. ft.}\end{array} = \frac{2.381 \times \text{cubic centimeter condensate}}{\text{cu. ft. gas burned (corrected)}}$$

To illustrate this by a concrete instance: Content of bottle = 2 L.; average temperature of inlet water 20.25° C.; of outlet water 34.75° C.; of inlet gas 69° F.; of outlet gases 22° C.; of room 70° F.; barometer 30.27 inches. Length of test 3 minutes 5 seconds; reading of meter at start 2.7274; at end 2.9189; gas burned (uncorrected) 0.1915 foot; condensation 35.4 c.c. for 2 feet of gas (uncorrected). Meter error for rate used 3.2 per cent fast. Corrections: Barometer 0.9 per cent + ; temperature 2.3 per cent – ; meter 3.2 per cent –; total 4.6 per cent –.

$0.1915 \div 1.046 = 0.1831$ foot of gas burned for B.T.U. test.

$2.0 \div 1.046 = 1.9120$ feet of gas burned for condensation test.

34.75 degrees – 20.25 degrees = 14.5 degrees.

$\frac{2 \times 14.5 \times 3.968}{.1831} = 628.5$ gross B.T.U. per cubic foot.

$\frac{2.381 \times 35.4}{1.912} = 44.1$ B.T.U. in condensation.

$628.5 - 44.1 = 584.4$ net B.T.U. per cubic foot of gas.

There has been considerable discussion and disagreement over the term "net" heating value, and the following explanation is offered in order that the issues at stake may be more clearly set forth. When a gas containing hydrogen is burned, water vapor or steam is formed, and this in condensing to a liquid gives off heat to the amount of 536 calories per gram. Now in the calorimeter this heat goes towards raising the temperature of the water, while in industrial appliances such as Welsbach mantles, gas engines, gas stoves, etc., the products of combustion pass off at a temperature above that at which steam condenses, and consequently the latent heat is not available.

For this reason it is argued by many that in order to arrive at the true heating value of the gas, considered from a practical standpoint, this heat of condensation should be deducted from the total or gross heating value. On the other hand, it is being more and more strongly urged to-day that the true heating power of a gas is all the heat that can be extracted from its combustion, cooling the products to the original temperature of the gas and air; that the energy that a gas engine, for example, is receiving from the combustion of a quantity of gas is diminished several times as much by the sensible heat carried away in the exhaust at 1000 to 1500° F., as it is by the heat loss involved in the vaporization or condensation of the water formed; that all other fuels are rated according to their total heating value, and that there is no justice in discrimination against gas.

To quote from the very able and scholarly committee of the American Gas Institute, "If the latent heat and sensible heat of the condensed water from the products of combustion are deducted, there is just as much reason for deducting the sensible heat of the uncondensed portion of the products of combustion, since it is necessarily lost at the same time; and if the temperature of the exhaust products leaving the apparatus is very high, this sensible heat may be several times that deducted in obtaining the so-called 'net' value. In other words, there would be a different true 'net' value for each change in conditions of the utilization of the gas, and none of them determinable by a direct test by a calorimeter or any other known instrument.

"Therefore the committee are of the opinion that the heating value of a gas should be expressed only in that which is determinable as the 'gross' or total heating value, the value of the gas as given by the calorimeter. . . . The argument for a correction is based on the claim that all of the heat developed cannot be utilized, but that varies widely with the appliance. With some appliances a great loss is experienced through sensible heat of waste products and latent heat of water vapors. With other appliances this loss is reduced to very small magnitude, and water heaters, or similar types of appliances, can be made, as in the calorimeter itself, to utilize it all. In what an absurd position we would find ourselves if, advocating the use of 'net' values, we tried to figure the efficiency of such an appliance."

Regarding the situation purely from a scientific standpoint, the writer considers that it is no more fair to state the "net" as the true heating value of the gas than it would be to give the candle-power taken with an imperfect lava tip burner as the true candle-power of the gas. The "net" results are sometimes interesting and valuable from a practical standpoint, but even here it would seem advisable to base all calculations on the gross or true heating value of the gas, making due allowance when necessary for the heat of condensation.

The Junker calorimeter is probably the most perfect instrument of its kind on the market. Experiments at the University of Wisconsin show that the average efficiency of this instrument is over 99½ per cent, a truly remarkable result. The merits of the Junker are: 1. A polished metallic surface, with an air chamber within; this arrangement practically prevents radiation. 2. The water circulates in the opposite direction from the products of combustion, and thus the colder water meets the cooler gases. 3. The water content is only about 1½ pounds; while this is large enough for the efficient absorption of the heat from gases of high calorific values, it is also small enough to insure accuracy with gases of low heating power. 4. A constant head of water is always maintained by means of weirs. 5. The water regulator is an arm swinging on a quadrant, allowing delicate and accurate adjustment of the flow. 6. The temperature of inlet and outlet water is easily and correctly determined. 7. The instrument is portable. 8. The air and gas supplies are easy to regulate when the burner is in position. 9. The condensate drains readily and regularly. 10. The waste-gas damper allows of the regulation of the air supply through the calorimeter. 11. The whole apparatus is well made and easy to take apart and clean.

There are one or two defects to the calorimeter as it is commonly supplied. The meter which is furnished is entirely unsatisfactory, principally because it has a fixed overflow *within* the meter, and when the latter registers incorrectly it cannot be adjusted without taking it apart. The thermometers in the inlet and outlet water are not on the same level; this renders it difficult to read them both, and the movement of the operator in making readings is liable to cause a draught. The water is measured instead of being weighed, and the latter method is regarded by many as the more accurate and satisfactory.

The Committee of the American Gas Institute considers that the mounting of the instrument on three legs makes it somewhat unstable, and that it is rather difficult to insert the lighted burner when the instrument is set up; but the writer has experienced no trouble in either of these directions. The thermometers are of the centigrade type, and the water is measured in cubic centimeters; in order to express the results in B.T.U. as is customary in this country, it is necessary to make an extra calculation.

Most if not quite all of these difficulties may be easily remedied. Scales sensitive to 0.01 of a pound may be procured and used in conjunction with a copper pail to replace the graduate or bottle for measuring the water. It should be noted, however, that while the limit of accuracy of the scales is 4.5 g., experiments with the bottle mentioned have shown that an error of 4 g. is almost impossible, and the average error is about 1 to 2 g.

In purchasing the instrument, it should be distinctly specified that Fahrenheit thermometers are desired, and that the meter will be purchased separately. The thermometers may be brought to the same level by a very simple device in use in the laboratory of the Milwaukee Gas Company and shown so clearly in Fig. 31[1] that no further description seems necessary. With these changes it will be difficult to find fault with the instrument along any line.

The Boys Calorimeter is the official instrument in London, and the following description thereof is taken from "The Notification of the Metropolitan Gas Referees for the year 1908." This calorimeter, which has been designed by Mr. Boys, is shown in vertical section (Fig. 32). "It consists of three parts, which may be separated, or which, if in position, may be turned relatively to one another about their common axis. The parts are (1) the base, *A*, carrying a pair of burners, *B*, and a regulating tap. The upper surface of the base is covered with a bright metal plate held in place by three centering and lifting blocks, *C*. The blocks are so placed as to carry (2) the vessel, *D*, which is provided with a central copper chimney, *E*, and a condensed water outlet, *F*.

"Resting upon the rim of the vessel, *D*, is (3) the water-circulating system of the calorimeter attached to the lid, *G*. Beginning at the center where the outflow is situated, there is a brass box which acts as a temperature-equalizing chamber for the outlet water. Two dished plates of thin brass, *KK*, are held in place by three scrolls of thin brass, *LLL*. These are simply strips bent

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[1] American Gas Institute.

round like unwound clock springs, so as to guide the water in a spiral direction inwards, then outwards and then inwards again to the outlet.

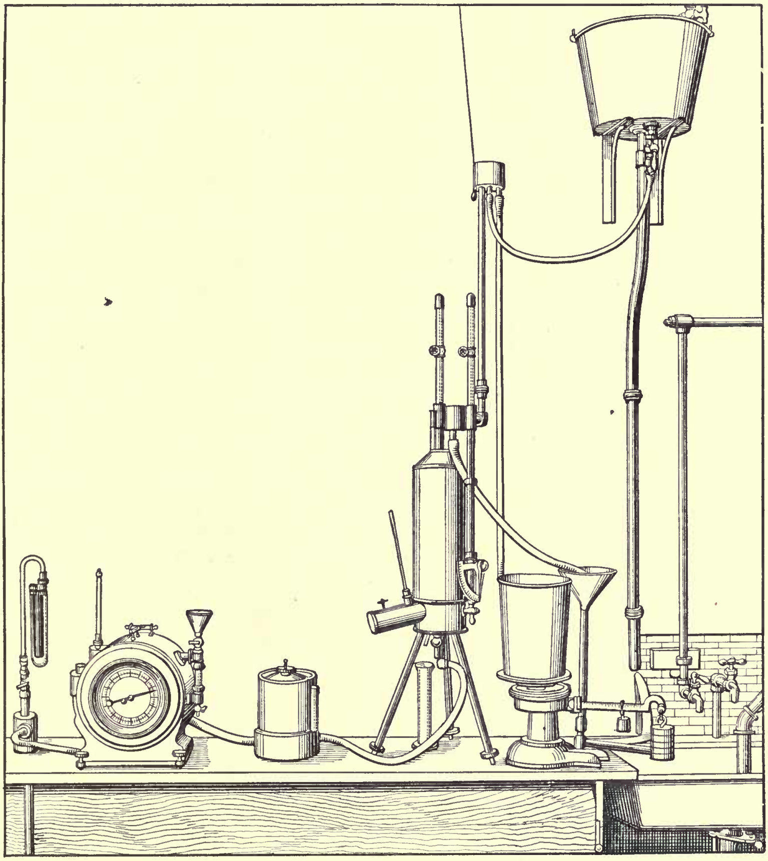

Fig. 31. Modified Junker Calorimeter.

"The lower or pendant portion of the box is kept cool by circulating water, the channel for which may be made in the solid metal, as shown on the right side, or by sweating on a tube as shown on the left. Connected to the water channel at the lowest point by a union are five or six turns of copper pipe, such as is used in a motor car

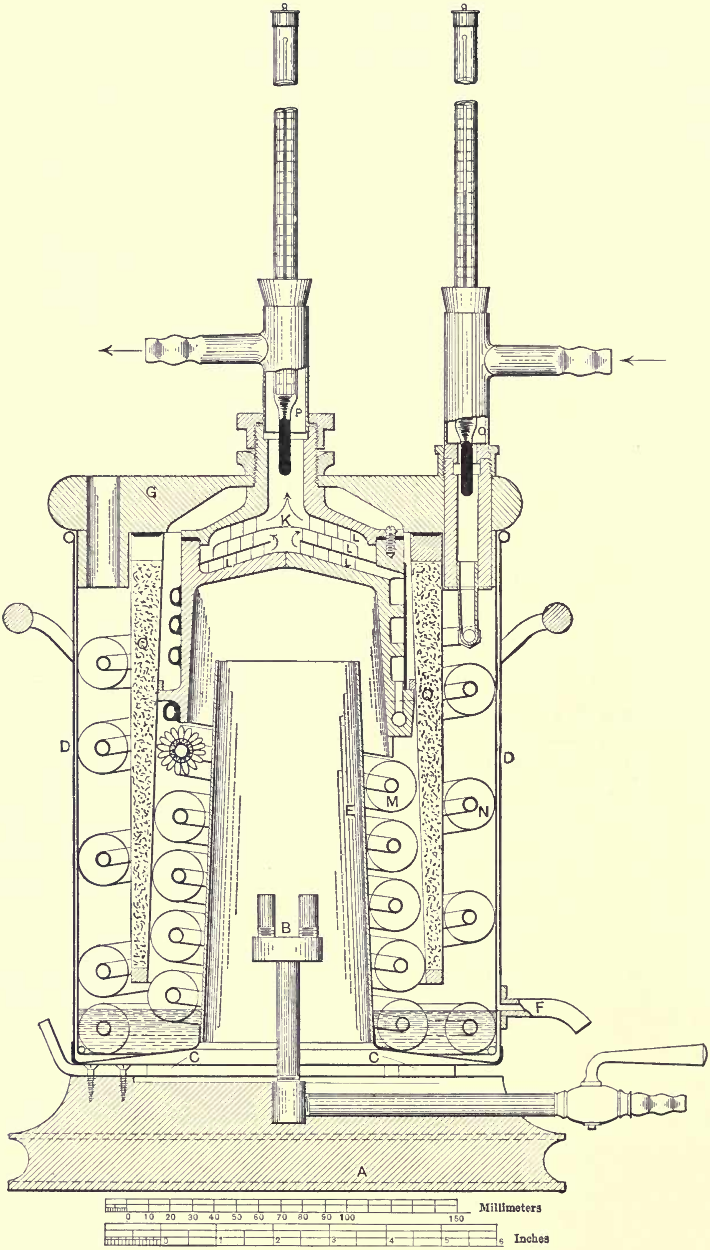

Fig. 32. Boys Calorimeter.

radiator of the kind known as Clarkson's. In this a helix of copper wire threaded with copper wire is wound around the tube, and the whole is sweated together by immersion in a bath of melted solder. A second coil of pipe of similar construction surrounding the first is fastened to it at the lower end by a union. This terminates at the upper end in a block, to which the inlet water box and thermometer holder are similarly secured above the equalizing chamber, *H*. The lowest turns of the two coils, *MN*, are immersed in the water which in the first instance is put into the vessel, *D*.

" Between the outer and inner coils, *MN*, is placed a brattice, *Q*, made of thin sheet brass, containing cork dust to act as a heat insulator. The upper annular space in the brattice is closed by a wooden ring, and that end is immersed in melted rosin and beeswax cement, to protect it from any moisture which might condense upon it. The brattice is carried by an internal flange, which rests upon the lower edge of the casting, *H*. A cylindrical wall of thin sheet brass, a very little smaller than the vessel, *D*, is secured to the lid so that when the instrument is lifted out of the vessel and placed upon the table, the coils are protected from injury. The narrow air space between this and the vessel, *D*, also serves to prevent interchange of heat between the calorimeter and the air of the room.

" The two thermometers for reading the water temperatures, and a third for reading the temperature of the outlet air, are all near together and at the same level. The lid may be turned round into any position relatively to the gas inlet and condensed water drip that may be convenient for observation, and the inlet and outlet water boxes may themselves be turned so that their branch tubes point in any direction.

" A regular supply of water is maintained by connecting one of the two outer pipes of the overflow funnel to a small tap over the sink. The overflow funnel is fastened to the wall about 1 meter above the sink, and the outer pipe is connected to a tube in which there is a diaphragm with a hole about 2.3 mm. in diameter. This tube is connected to the inlet pipe of the calorimeter. A piece of stiff rubber pipe long enough to carry the outflow water clear of the calorimeter is slipped on to the outflow branch, and the water is turned on so that a little escapes by the middle pipe of the overflow funnel and is led by a third piece of tube into the sink. The amount of water that passes through the calorimeter in four minutes should be sufficient to fill the graduated vessel to some point above the lowest division, but insufficient in five minutes to come above the highest division. If this is not found to be the case, a moderate lowering of the overflow funnel or reaming out of the hole in the diaphragm will make it so. The overflow funnel should be provided with a lid to keep out dust.

"The thermometers for reading the temperature of the inlet and outlet water should be divided on the Centigrade scale into tenths of a degree, and they should be provided with reading lenses and pointers that will slide upon them. The thermometers are held in place by corks fitting the inlet and outlet water boxes. The positions of these thermometers should be interchanged every month. The thermometers for reading the temperature of the air near the instrument and the effluent gas should be divided on the Centigrade scale into degrees.

"The flow of air to the burners is determined by the degree to which the passage is restricted at the inlet and at the outlet. The blocks, *C*, which determine the restriction at the inlet are made of metal three-sixteenths of an inch or about 5 mm. thick, while the holes round the lid which determine the restriction at the outlet are five in number and are five-eighths of an inch or 16 mm. in diameter. The thermometer used for finding the temperature of the effluent gas is held by a cork in the sixth hole in the lid so that the bulb is just above the upper coil of pipe.

"The calorimeter should stand on a table by the side of a sink so that the condensed water and hot water outlets overhang and deliver into the sink. A suitable change-over funnel may be constructed as follows: a piece of India-rubber tube reaching nearly to the base should be attached to the waste-water pipe so as to avoid splashing, and another piece may conveniently be slipped on to the condensed water outlet so as to lead the condensed water into a flask, but care should be taken that the small side hole is not covered by the tube. A glass vessel must be provided, of the size of the vessel, *D*, containing water in which is dissolved sufficient carbonate of soda to make it definitely alkaline.

"The calorimeter after use is lifted out of its vessel, *D*, and placed in the alkaline solution and there left until it is again required for use. The liquid should not, when the calorimeter is placed in it, come within 2 inches of the top of the vessel. The liquid must be replenished from time to time, and its alkalinity must be maintained."

The Gas Referees have made a special study of this instrument, and their reputation for careful, accurate and progressive work is well known; on this account, and also because of the fact that the Boys calorimeter is but little known or used in this country, it seems justifiable to insert here the Referees' own description of the method by which this apparatus is to be used.

"In order to test the gas for calorific power, the gas shall first pass through a meter and a balance governor of the same construction as those on the photometer table. It shall then be led to the gas inlet in the base of the calorimeter. The gas shall be turned on and lighted, and the tap of the calorimeter shall be so adjusted as to allow the meter hand to make one turn in from 60 to 75 seconds. The water shall be turned on so that when the regular flow through the calorimeter has been established a little may pass the overflow of the funnel and trickle over into the sink. Water must be poured in through one of the holes in the lid until it begins to run out at the condensation outlet. The calorimeter may then be placed upon its base.

"The measuring vessel carrying the change-over funnel shown in Figs. 16 and 18, pp. 42 and 43[1], should then be placed in position in the sink so that the outlet water is led into the sink. The hot water outlet tube of the calorimeter should be above but should not touch the change-over funnel. After an interval of not less than 30 minutes, the Gas Examiner, after bringing the reading glasses into position on the thermometers used for measuring the

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[1] See Notif. Met. G. Ref. 1908.

temperature of the inlet and outlet water, shall then make the following observations:

"When the meter hand is at 75 he shall read the inlet temperature; when it reaches 100 he shall move the funnel so as to direct the outflow into the measuring vessel and at the same time he shall start the stop-clock or a stop-watch. When the meter hand reaches 25 he shall make the first reading of the outlet temperature. He shall continue to read the outlet temperature at every one-quarter turn until 15 readings have been taken. The meter hand will then be at 75. He shall also at every turn of the meter except the last make a reading of the inlet temperature when the meter hand is between 75 and 100.

"When the meter hand reaches 100 after the last outlet temperature has been read, the Gas Examiner shall shift the funnel so as to direct the outlet water into the sink again and at the same time stop the clock or watch. The barometer and the thermometers showing the temperatures of the effluent gas, of the air near the calorimeter and of the gas in the meter, shall then be read. The time shown by the stop-clocks shall be recorded.

"The mean of the four readings of the inlet temperature is to be subtracted from the mean of the fifteen readings of the outlet temperature, and the difference is to be multiplied by 3 and by the number of liters of water collected, and the product is to be divided by the tabular number. The difference in degrees Centigrade of the temperature of the effluent gas and of the surrounding air shall be taken, and one-sixth of this difference shall be added to the result previously found if the effluent gas is the warmer of the two, or subtracted if the effluent gas is the colder of the two.[1] The result is the gross calorific power of the gas in Calories per cubic foot.

"In addition to the observations described, the amount of condensed water resulting from the combustion of the gas shall be measured. For this purpose the condensation water shall be led into a flask not less than 20 minutes after the calorimeter has been placed in position. The amount collected in not less than

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[1] This correction has been found by experiment.

30 minutes shall be measured, the time of collection having been accurately noted.

"The number of cubic centimeters collected shall be multiplied by the number of seconds in the time indicated by the stop-clock and by the number 1.86. The number of seconds in the time during which the condensed water was being collected shall be multiplied by the tabular number. The first product shall be divided by the second. The quotient is to be subtracted from the gross calorific power. The difference is the net calorific power in Calories per cubic foot. The gross and net calorific power in B.T.U. can be obtained by multiplying the corresponding number of Calories by 3.968."

While accurate results can doubtless be obtained with this instrument under certain circumstances, it is not a convenient form to operate, and cannot be recommended for use in this country. The Committee on Calorimetry of the American Gas Institute made a careful study of the Boys calorimeter and found several defects or undesirable points therein.

The water content is only about 0.7 of a pound, or less than one-half that of the Junker; this necessarily limits the rate at which the gas may be burned, and renders the instrument unsuitable for use with gases of high calorific value. The meter registers one-twelfth of a cubic foot per revolution, and the water gauge is of too great a diameter, making it difficult to secure accurate adjustment. The pressure regulator is complicated and liable to leak. The inlet and outlet thermometer openings are too small, and the connections so short that if the stopper be inserted firmly it is liable to throttle the flow of water.

There is no way of regulating the amount of air passing through the instrument, and if any adjustments become necessary on the burner or the rest of the apparatus, the operator is obliged to lift off the heavy coil and place it on some specially arranged support; it cannot be moved far without disturbing the water connections.

The burner provided gives a luminous flame, and this is decidedly undesirable, since with the rich gases so often found in the United States, it would smoke badly, and thus deposit carbon on the water coils. The use of the luminous flame was intended to aid the observer in seeing that it was always alight, but this end may be accomplished by other and better means.

In order to make more than one run, it is necessary to lift out the coil and shut off the water, since the device for shifting the water into the glass graduate is mounted on the latter. Last, but not least, the calorimeter must be taken apart in order to light or extinguish the burner. The price of the entire apparatus in England is about $61; delivered in the United States it would probably cost nearer $75 to $90.

CHAPTER II.

OTHER INSTRUMENTS AND METHODS.

THE Simmance-Abady calorimeter is, like the Boys, of English origin, and is seldom used in this country. Figs. 33 and 34 show the construction in detail. In Fig. 33, *A′* is the water inlet, whence the water passes through cock, *A*, and fills water level tube, *K* (for enabling the regularity of pressure to be seen at a glance), flows round bulb of thermometer, *D* (the thermometer being in Centigrade degrees, divided into tenths and arranged in a magnifying tube, to enable the height of the mercury column to be readily perceived), and along the course shown by arrows through the annular chambers, *EEEE*, down tubes, *FFFF*, and up through tubes, *G′G′*, past the baffle plate into upper receptacle, *H′*, round bulb of thermometer, *J*, which is similar to the thermometer, *D*, and thence by outlet, *G*. The heated water is discharged to waste, or, by turn of cock or tilt of bucket, into graduated measure, *M′*, which is subdivided into 2 c.c., and has a capacity of about 1000 c.c.

The products of combustion pass up center shaft, *N′*, and, partially condensing in chamber, *O′*, drop down annular passage, *MMMM*, and issue, being reduced to the temperature of the original fuel, which should be the same as the inlet water and approximate to the air of the room, as carbonic acid, non-condensible products and water, at lip *p*. A shutter is provided by which the flow of the products, and therefore their temperature at point of issue, can be regulated, and the result registered on a thermometer provided for the purpose.

The condensed water is collected in the graduated measure, *R*, for purpose of the deduction to be made upon gross results. *S* is the Bunsen burner for burning gaseous fuels, a special lamp and balance being provided for liquid fuels.

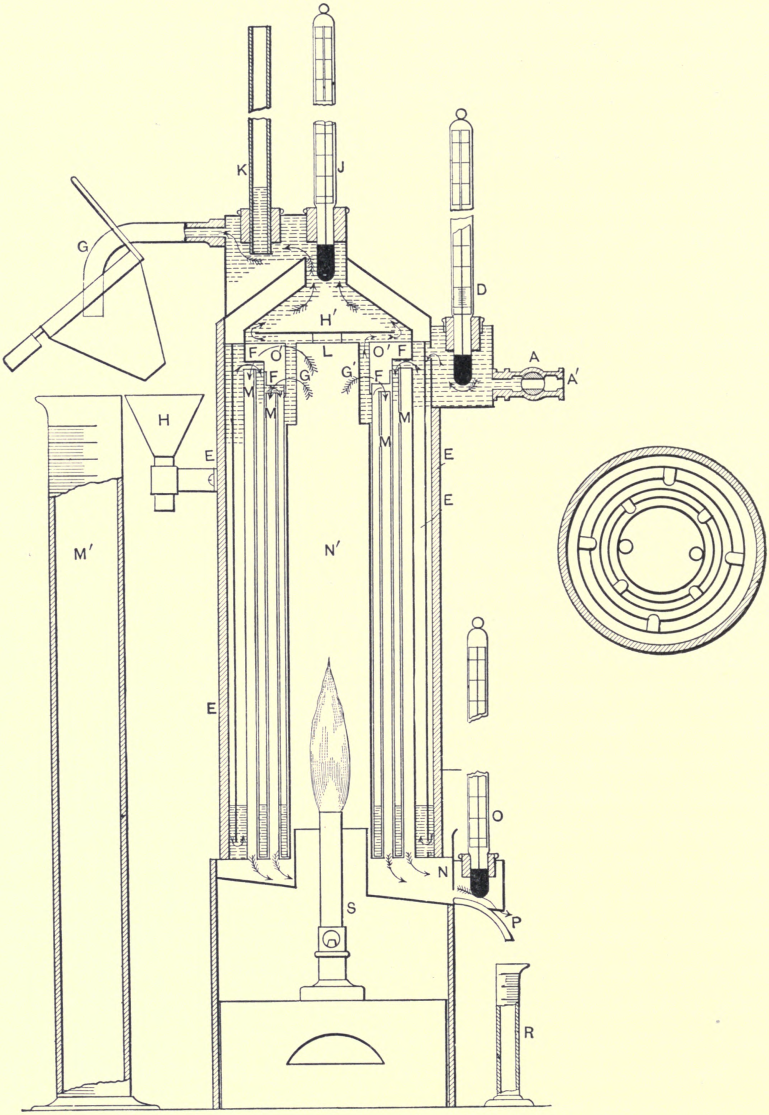

Fig. 33. Simmance-Abady Calorimeter.
Sectional View.

To fit up calorimeter, the stand is placed on a firm, level base, and the calorimeter is placed thereon, with the inlet cock convenient to the water supply. The two large thermometers are slipped carefully (after being wetted) through the rubber stoppers already placed in the sockets, *D* and *J*, the glass tube being put into the remaining socket. The two thermometers and water-level tube stand side by side, and the observation of their indications is thus facilitated.

The correct and rapid observation of the inlet and outlet thermometers and of the water level is, as will be seen hereafter, a most important point. The thermometers should be carefully tested, and any slight difference in their readings under like conditions noted. They indicate in tenths of a degree Centigrade, and are very sensitive; they require very careful handling, and once in their places should not be disturbed.

The inlet cock is connected to the water supply, which should be such as to provide a constant head. The outlet, *G*, is connected by a length of rubber tube to a convenient waste service. The burner is connected by rubber tube to a gas supply, which should be such as to provide a constant pressure. The gas is measured by an experimental meter, which should be in such a position as to be easily read by an operator working the water outlet of calorimeter. The products outlet thermometer is placed in the rubber stopper provided for that purpose. The proper appreciation of readings on this thermometer is important. The small glass measure is placed at the condensation outlet. The large glass measure is placed at the water outlet of calorimeter.

To Test Calorimeter. Turn on the water gently until it rises almost to the top of the glass tube, while it is flowing to waste at the outlet of calorimeter. Close the top of the glass tube, increase the water flow and let it run for one or two minutes. *This is only necessary when the calorimeter is first fitted up.* See that all joints are sound, and then unstop the glass tube, and reduce the water flow until it stands at about one-half way up the tube. Mark the meniscus by a rubber ring slipped round the glass tube.

To make a Test. Observe the water level and see that it is constant. If the water supply varies the water level in the tube will vary. *If an accurate test is required it should remain at the observed point.* Light gas burner outside calorimeter, put it under calorimeter and lift it until the stand can be slid beneath it. See that the burner rests in the space prepared, when it will be central with the central shaft, *N′*. A small mirror will enable the operator to see

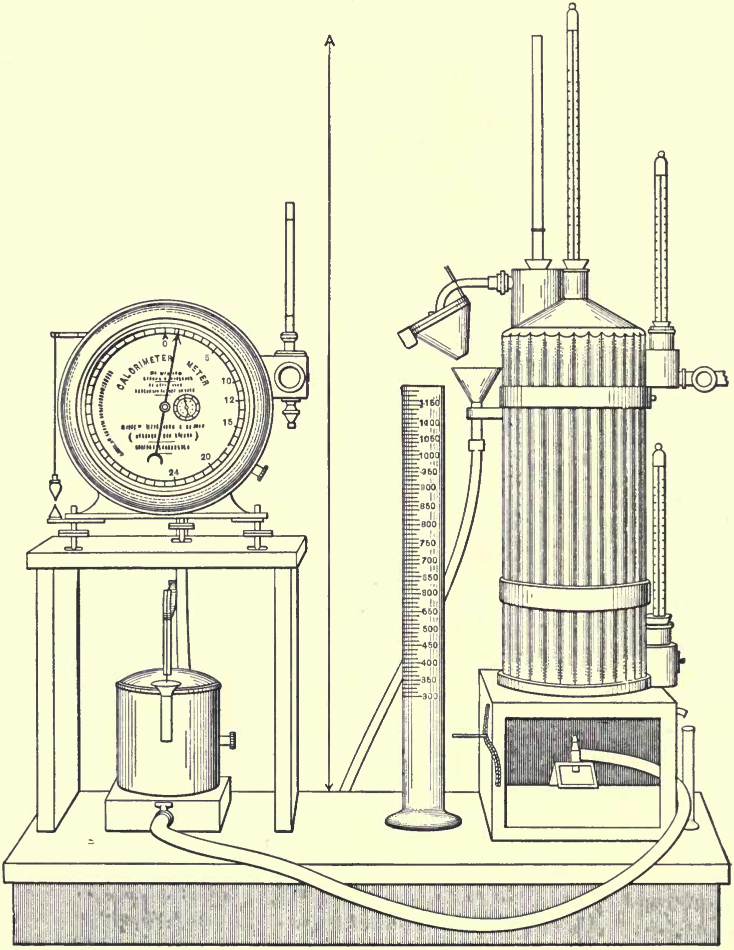

Fig. 34. Simmance-Abady Calorimeter.

how the flame is burning. Let the gas burn (having adjusted its rate and being assured of its regularity), allow the water to run until the outlet water thermometer, which will have risen as the water has absorbed the heat, has again become constant. Adjust the products outlet door until the temperature of the issuing products is the same as the inlet water. Observe the temperature of the gas and of the atmosphere. *The operator should endeavor to work under such conditions that the temperature of atmosphere, gas and inlet water approximate.* Also watch the reading of the barometer. Having effected the adjustment of the products outlet, watch both the water thermometers for a few seconds. See they are constant, *and note the difference,* adding or deducting any observed differences in thermometers when tested as described.

As the meter hand (an ordinary photometer meter is assumed) passes a division, say 0, turn the outlet water, which has been running to waste, into the tall cubic centimeter measure, and as the meter hand passes a second marked division (say 12), switch the water back to waste. Read on the scale of the glass measure the quantity of water run in the interval. Repeat the operation (which will take a few seconds only) twice, and take the mean of the three readings. The tall measure is emptied for each reading. The above description is adapted from the account of one of the inventors of the instrument, Dr. Jacques Abady.

Calculations. The readings of the inlet and outlet thermometers are to be averaged and the former result subtracted from the latter. The mean of the three readings of the meter gives the amount of gas consumed; while the quantity of water heated is judged from the average of the three readings of the glass cylinder. Assume the average temperature of the inlet water to be 15.4 degrees, of the outlet water 25.2 degrees, gas burned 0.0228 foot uncorrected, water heated 350 c.c. Temperature inlet gas 70° F.; barometer 29.67.

Correction for temperature	2.5 per cent −
Correction for barometer	1.1 per cent −
	3.6 per cent −

$.0228 \div 1.036 = .0220$ cubic foot gas corrected.

$$\frac{(25.2 - 15.4) \times .350}{.022} = 155.9 \text{ gross calories per cubic foot.}$$

To change this to British Thermal Units per cubic foot, multiply by 3.968. The heat due to the condensation is calculated in the same manner as with the Junker calorimeter, and the result is to be subtracted from the gross heat units, if the "net" heating value is desired. This calculation may be expressed by formula, thus: $H = \frac{W \times T}{G}$, where T = rise in temperature of the water, H = gross Calories per cubic foot of gas, W = the water heated, expressed in fractions of a liter, and G = the corrected amount of gas burned. The writer feels called upon to protest, however, against expressing results in this manner. The Calorie, as has been stated, is the amount of heat required to raise the temperature of 1 kilogram of water 1° C. All of these units are in the metric system, and to speak of Calories per cubic foot is simply to express part of the result in the English and part in the metric system. While the latter is undoubtedly the more scientific and desirable one for general use, it is not in commercial vogue in this country, and for this reason it would seem wise to report all results in British Thermal Units, which deal with pounds of water, degrees Fahrenheit, and cubic feet of gas, all of them standards in common use in the business life of the United States.

There is much to be said against the Simmance-Abady calorimeter and very little in its favor. The inlet and outlet water thermometers are on a level with each other and the gas flame is always visible, and these are very desirable features; unfortunately, they seem to be almost the only ones. The stand on which the instrument is mounted is large, heavy, and unwieldy, and tends to destroy the usefulness of the entire apparatus, if portability is to be considered.

The wooden jacket is unsatisfactory; it is provided with the idea of preventing radiation, but if water be spilled upon it, as frequently happens, the evaporation causes a distinct loss of heat which more than offsets the possible saving of radiant heat. Moreover, this jacket contains many joints or cracks, and is therefore difficult, if not impossible, to keep clean.

The water content is 12½ pounds, or over eight times that of the

Junker; this means that a change in temperature at the inlet will require a comparatively long time to become apparent at the outlet, and consequently readings covering only a short period are extremely liable to be erroneous. The dial of the meter is purposely so divided that the tests may be made with fractional revolutions of the drum; this tends to render the work inaccurate. The control of the inlet water by means of the water gauge has been found to be extremely unsatisfactory, and is decidedly inferior to the weir-overflow method.

The Committee of the American Gas Institute in its report on this instrument says:[1] "The circulation of water through the Simmance-Abady calorimeter does not seem to be such that the heat is absorbed from the waste products of the gas with any uniformity. The water courses up and down through the instrument several times while the gases go through once. This causes uneven heating, which is augmented by the construction of the last water pocket above the combustion chamber. This arrangement made the outlet water temperature very difficult to control, and led us to believe the average reading of the outlet thermometer did not record the average temperature of the outflowing water."

The conclusions of this committee are also worthy of note: "There is a considerable variation in the results obtained on the Simmance-Abady instrument. By referring to the original record sheets of tests made on the Simmance-Abady calorimeter, we find an explanation for these widely varying results. Take any test at random, say P–1; the temperature of the outlet water varies from 85.75 to 86.70 degrees. The mercury thread in the outlet thermometer was never steady at any one temperature for even a few seconds, and danced up and down over a considerable distance, making it impossible to obtain a fair average, although readings were made as rapidly as they could be recorded, one observing and another recording.

"Reference to the comments under test 'L' shows that with the construction of this Simmance-Abady instrument no reliability of result was obtained.

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[1] Proceedings American Gas Institute, October, 1908.

"Comparison of results in Series P, between the Junker and the Simmance-Abady instruments, on gas, shows the Simmance-Abady about 10 per cent above the Junker.

"Owing to the great fluctuations in the outlet temperature we are not at all certain that we obtained an actual average of the temperature of the water leaving the instrument. However, based on the two series of tests, one with the electric coil heater and the other on gas, both showing better than 100 per cent efficiency, we concluded that in its construction, as shown in this instrument, which is about five years old, the Simmance-Abady instrument could not be considered satisfactory."

It should be added that the electric tests mentioned consisted in supplying electrically a known quantity of heat energy for a known interval of time, and determining the quantity of heat absorbed in the usual way. There can be no question as to the accuracy of this method, and since it gave results with the Junker showing an average efficiency of that instrument of 99.5 per cent, it is evident that the Simmance-Abady is from 8 to 10 per cent in error, and is therefore not to be recommended. If, however, this instrument is desired, it may be procured for about $110.

NOTE. Later advice from Alexander Wright & Co. states that they are now prepared to furnish this instrument with a polished nickel jacket in place of the wooden one, and with a weir overflow similar to the Junker. This removes two of the most serious objections to the instrument, and it is quite possible, though not certain, that, with these changes, the calorimeter may give perfect satisfaction. The cost of the revised instrument complete with meter-governor is $169.50 delivered in New York.

The Sargent calorimeter is the only instrument of its kind which is made in this country and which has been used to any extent. It is seen in sectional view in Fig. 35, and complete with accessories in Fig. 36. The outer casing of this calorimeter is jacketed with wood to prevent radiation. The interior is a combustion chamber for the gas, surrounded by a compartment containing the jacket water. The combustion chamber is high enough to allow a suitable flame to be inserted without its impinging upon any part of the instrument.

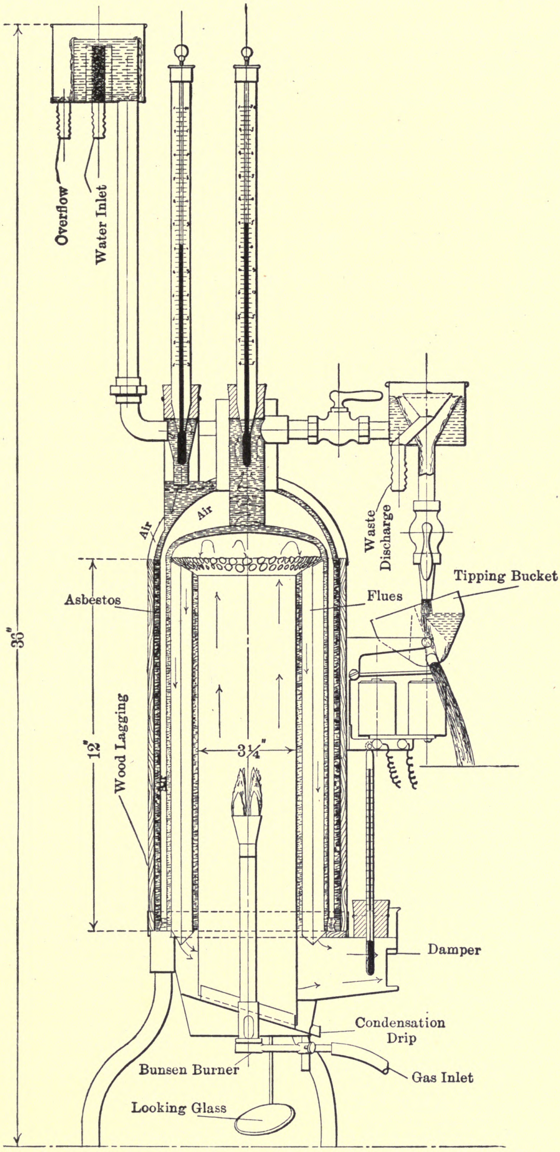

Fig. 35. Sargent Calorimeter.
Sectional View.

The products of combustion rise to the upper interior, then are diverted down through a series of small tubes to the bottom and pass on out through an opening, the size of which is controlled by a damper. The water enters in an opening at the top of the calorimeter. In the first Sargent instrument the water passed down through and just inside of the outer shell, then up and down several times, surrounding the small tubes, carrying off the products of combustion of the gas, and finally leaving at the top on a level with the inlet. In the second instrument the course of the water was down, adjacent to the outer shell, then up once, surrounding the combustion tubes, and passing in a direction opposite to the flow of the products of combustion.

The water head was originally controlled by a gauge on the outlet, but later, a fixed elevated weir was adopted for this purpose.

The outflowing water also leaves the calorimeter through a weir overflow, after passing through a controlling cock. The overflow passes to an automatic dumping bucket, which is divided into two parts, one part connecting to an overflow or waste, the other passing the water to a measuring vessel. This dumping bucket is held in position by a keeper. The weight of the water in the full side tends to oscillate the bucket so that the water will flow into the empty side and through another outlet to the empty receptacle. When the hand of the gas meter passes the zero point an electrical circuit is completed, which, passing through the solenoid, draws down the keeper, and allows the outlet water to automatically change from the full to the empty pail. With such a device the personal error is not only eliminated, but much of the work of the operator is done automatically, thereby allowing him more time for observing the temperatures and weighing the water delivered.

The gas meter is of the wet type, with a drum of one-tenth of a cubic foot capacity per revolution. The dial is divided in thousandths of a cubic foot.

The flow of gas from the meter to the burner is regulated by a small leather diaphragm governor, mounted on the top of the meter, at the gas outlet.

The thermometers indicating the temperatures of both inlet and outlet water are side by side, on the same level, at the top of the calorimeter, thus enabling both to be easily and quickly read. These thermometers read in the Fahrenheit scale, and are subdivided to read to one-tenth of one degree. There is a thermometer placed near the outlet damper to register the temperature of the outflow products of combustion.

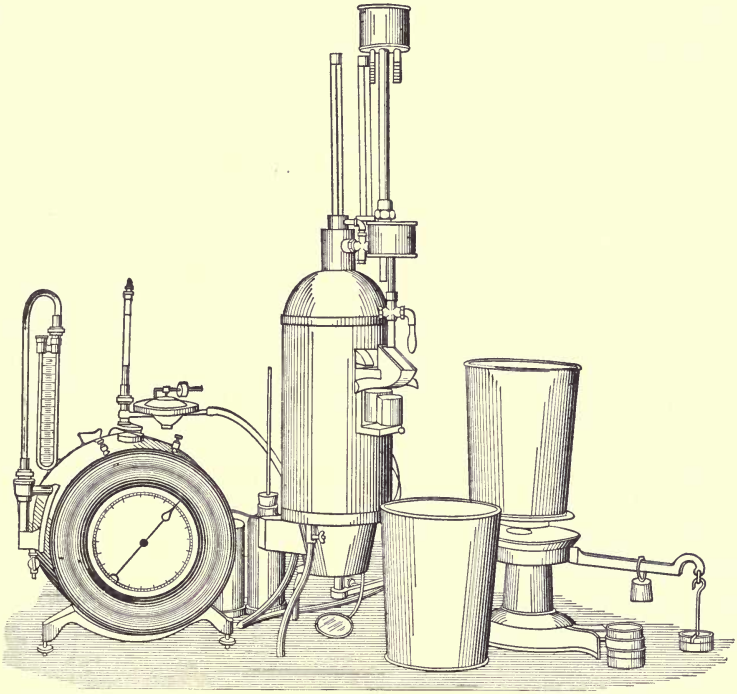

Fig. 36. Sargent Calorimeter.

The water after passing through the calorimeter is caught in a copper vessel and weighed on platform scales.

By weighing the discharged water and using Fahrenheit thermometers no transformation of units is necessary to get the result in British Thermal Units.

In setting up the calorimeter the meter is filled, leveled, and the water saturated by the passage of gas for two hours. The pressure gauge is connected to the top of the glass water gauge, and the governor to the outlet on the top of the meter. The battery is coupled with the terminals on the front and top of the meter and with the solenoid. The water supply is connected to the inlet, and a rubber tube passed from the inlet and outlet overflows to the sink; the apparatus is then ready for use.

The actual test is carried out as follows: Regulate the flow of water so that, when the overflow is shifted into the dumping bucket, the latter shall be able to handle the stream without danger of loss. Rate the gas at 5 feet per hour, adjust the air mixer so that the tip of the flame barely shows a luminous point, and place the burner in position in the calorimeter. Allow the gas to burn until the condensation is dripping freely and regularly, and the temperature of the outlet water is constant. Switch the outlet water into the dumping bucket, a weighed copper pail being placed under each spout. Throw the switch on top of the meter so that, as the meter hand passes the zero mark, the circuit is completed and the direction of the outlet water changed from one copper pail to the other. Make as many readings of the inlet and outlet water thermometers as convenient, and, when 0.1 foot of gas has been burned and the outlet water is again automatically shifted, weigh the pail containing the water which passed during the period of test. Record also the temperature of the gas in the meter, of the outlet gas, and of the room, and the barometric reading. The condensation test is carried out exactly as with the Junker calorimeter save that the water is weighed instead of being measured.

Calculations. Owing to the fact that the data are expressed entirely in English units, the calculations are very simple. They may be expressed by the usual formula:

H equals $\frac{W \times T}{G}$ when H equals gross British Thermal Units per cubic foot of gas; W equals weight of water in pounds; T equals difference in temperature between the inlet and outlet water, in degrees Fahrenheit; and G equals the volume of gas burned corrected for temperature and pressure.

Example. Gas burned (uncorrected) 0.1 cubic foot. Average temperature of inlet water 62.1 degrees; average temperature of outlet water 83.5 degrees; temperature of inlet gas 63 degrees; temperature of outlet gas 65 degrees; temperature of room 63 degrees; barometer 29.50 inches; weight of pail plus water 4.61 pounds; weight of pail 1.61 pounds; weight of condensation for one cubic foot of gas 0.06 pound. Correction for barometer 1.7 per cent –; for temperature 0.8 per cent –; total 2.5 per cent –.

$0.1 \div 1.025 = 0.0976.$
4.61 pounds – 1.61 pounds = 3.00 pounds of water passed.
$83.5 - 62.1 = 21.4$ degrees rise in temperature of the water.

Then

$$H = \frac{3.00 \times 21.4}{.0976} = 658 \text{ gross B.T.U. per cubic foot.}$$

For the heat of condensation, multiply the weight of condensed water, in fractions of a pound, by the factor 1081, and divide the product by the corrected volume of gas burned. Thus in the above example:

$(.06 \times 1081) \div 0.976 = 66$ B.T.U. from condensation.

The factor 1081 is derived in the following manner: the latent heat of steam is 537 calories, and this amount is given off in the transition from the gaseous to the liquid state. But the condensed water does not leave the calorimeter at 100° C., but more nearly at 40 degrees, and therefore gives up 60 more calories. Therefore every cubic centimeter of condensation collected means 0.597 calorie to be deducted from the gross, to get the net result. By multiplying by 3.968 this is changed to British Thermal Units per cubic foot per cubic centimeter of condensation; and since one pound equals 454 grams,

$0.597 \times 3.968 \times 454 = 1081$ = the factor to be used in multiplying the pounds of condensation to secure the British Thermal Units per cubic foot loss by such condensation.

The author made a careful investigation of the Sargent calorimeter in actual operation, discovering many good features, and some very poor ones. The wooden jacket is an objection, as was shown in the case of a Simmance-Abady. The water content is 12 pounds, an amount too large for general and rapid use, since slight changes in the heating value of the gas are liable to pass unnoticed. The legs are not adjustable, thus complicating the process of leveling the calorimeter. The governor did not work satisfactorily, and it is believed that a wet governor, of the type used with the Junker calorimeter, should be substituted.

The meter furnished with the instrument occasioned considerable trouble. There is only one hand on the dial, so that when it is desired to pass one foot of gas to obtain the condensation, the operator must either count the revolutions, or establish the rate accurately and remove the graduate from the condensate outlet after the lapse of a given time. The height of the water in the gauge glass is determined by a pin which projects downward from the top; this was found to be much more difficult to read accurately than the ring or scratch usually placed on the outside of the glass. Several times in adjusting the water line the latter stuck badly, due to the stoppage of the minute orifice in the top of the gauge. The meter is provided with a single circular level; two rectangular ones at right angles to each other would be better.

The metallic strip which completes the electrical circuit when the meter hand reaches the zero mark must be very carefully adjusted, or it will either entirely stop the hand, or will not make close contact enough to release the keeper. The system became short-circuited several times through the spilling of water from the bucket, and after five or six experiments had been lost in this way, the battery was disconnected and the keeper released by hand. This worked fairly well, but does away with some of the advantages claimed for the instrument, *i.e.* the elimination of the personal element and the automatic performance of much of the operation.

The burner has no cock for the adjustment of the flow of gas, a rather serious defect. With the instrument tested, the air mixer was so loose that it would not stay in position, and the greatest care had to be exercised to prevent its moving after having been once adjusted.

The lower part of the body of the calorimeter was so near the table that considerable difficulty was experienced in inserting the burner. This was the more noticeable since the writer never had any trouble with the Junker in this respect, although this is one of the points that was raised against the latter instrument by the Committee of the American Gas Institute.

The spout from which the condensed water drips is so low that a 25 c.c. graduate cannot be placed under it; the water must therefore either be weighed or turned from one vessel to another to be measured. As the total condensate from one cubic foot of gas is rarely over 30 c.c., or about one-fifteenth of a pound, and the balance furnished weighs only to 0.01 pound, there is liable to be an error of as much as 14 per cent in determining the weight of the condensate.

The damper for the outlet gases consists simply of a tin slide, which cannot be fixed in any one position (unless the outlet be wide open or totally closed) without the application of external aid.

The thermometers for the inlet and outlet water are entirely too large in diameter, and the divisions very fine. Reflections from all sides made it almost impossible to read them accurately, even to tenths of a degree. A reading lens proved of material assistance, and should always be used.

The dumping bucket caused considerable trouble, and several times shifted when it should not have done so.

To offset these disadvantages it must be admitted that when everything was running properly one man could handle the instrument with ease and accuracy. The thermometers are on the same level, a most desirable feature. The weighing of the water worked splendidly, and the personal equation, which enters when the outlet is shifted from one receptacle to another, was entirely eliminated. A long series of tests was made to show the accuracy of the instrument at differing rates of water and gas, and with varied regulation of the air supply to the burner. A check series was run with the Junker calorimeter, using the same gas supply. The results are given in a table in the appendix, and show (1) that the efficiency of the Sargent calorimeter is only about 98 per cent as compared with 99.5 per cent for the Junker; (2) that the efficiency was nearly the same for all rates of gas from 4 to 7 cubic feet per hour; (3) that a slight mistake in the regulation of the air mixer does not alter the results within the limits of error of the process; (5) although this does not appear from the above figures, it was shown that a slight change in the rate of flow of the water between two tests made no difference in the results, provided that sufficient water was used, and that, when the valve to the bucket was open, no water was escaping by the outlet overflow.

In conclusion, it is the writer's opinion that the Sargent calorimeter, with a few changes as suggested, is an excellent instrument; it is too heavy for portable work, weighing with all accessories about 80 pounds; its efficiency has only been tested with water gas; but if it is compared with a Junker for the kind of gas to be tested,. its per cent of efficiency determined and this figure used in all calculations, it would seem to be a very satisfactory piece of apparatus. Its cost, however, is considerable, and is composed of the following items, as taken from the descriptive pamphlet of the manufacturers: Calorimeter complete with automatic discharge buckets, thermometers, tubing, beaker and Bunsen burner, $150; gas pressure regulator with micrometer adjustment and ordinary U-tube pressure gauge, $20; special wet test meter with electrical attachment, batteries and wire, $70; two balanced copper receiving pails in which water is weighed, $3; special ten-pound scales weighing to .01 pound for accurate work, $10; two reading-glasses for thermometers, $2; total, $255, as compared with $225 for the Junker.

If the latter instrument be so altered that the thermometers are on a level, it is unhesitatingly recommended as by far the most accurate and satisfactory calorimeter for all purposes.

Later advice from the manufacturers of this instrument shows that they have appreciated the nature of the defects, and have remedied some of them. They will now furnish a calorimeter with a nickel jacket, a cock will be placed on the burner, leveling screws on the legs, and a mark on the outside of the water gauge for adjusting the meter. The inlet tube is to have a valve with a quadrant arm; the water content is to be diminished and a better thermometer is to be supplied.

With these and other improvements which will be made, the Sargent calorimeter will be found to furnish an extremely satisfactory instrument for permanent installations. Indeed, in some respects it is superior to the Junker, and should its efficiency under the new conditions prove equal to that of the latter instrument, it may replace the latter as a standard apparatus. It is only fair to state that the writer is informed by the manufacturers that the efficiency, as secured by the committee of the American Gas Institute, was found to be 99.4 per cent.

The latest instrument in the field is a portable one placed on the market late in 1908. It is called the Simmance-Abady Portable Calorimeter, and the following description is given by the manufacturers: "The instrument is very simple, strictly portable, of guaranteed accuracy and very cheap, and the following brief description will explain its working: The Simmance-Abady Portable Calorimeter consists of two parts, *A*, the combined gas aspirator and measure; *B*, the calorimeter vessel (Fig. 37). The aspirator is quite light and can be carried in one hand, and the charge of gas drawn into it even against a high vacuum. The outlet pipe is slipped on to the burner of the calorimeter, which has previously been filled with one liter of water and the temperature noted.

"The burner is lighted and a definite quantity of the collected gas is automatically measured and burned, the heat being imparted to the water. The difference in the thermometer readings before and after test is multiplied by the water value of the instrument, and the result is standard British Thermal Units per cubic foot."

The water value referred to is obtained by standardization with gas of known heating value. The makers believe that with careful manipulation the instrument is as accurate as the Junker; but this claim remains to be proved. The total weight of the apparatus is

25 pounds; its cost in this country is $80, and it can be packed in a box of inside dimensions of 18 × 10 × 24 inches. If the claims in its favor should be substantiated, a valuable portable calorimeter has been evolved; but until such verification has been made, the instrument should be employed with caution.

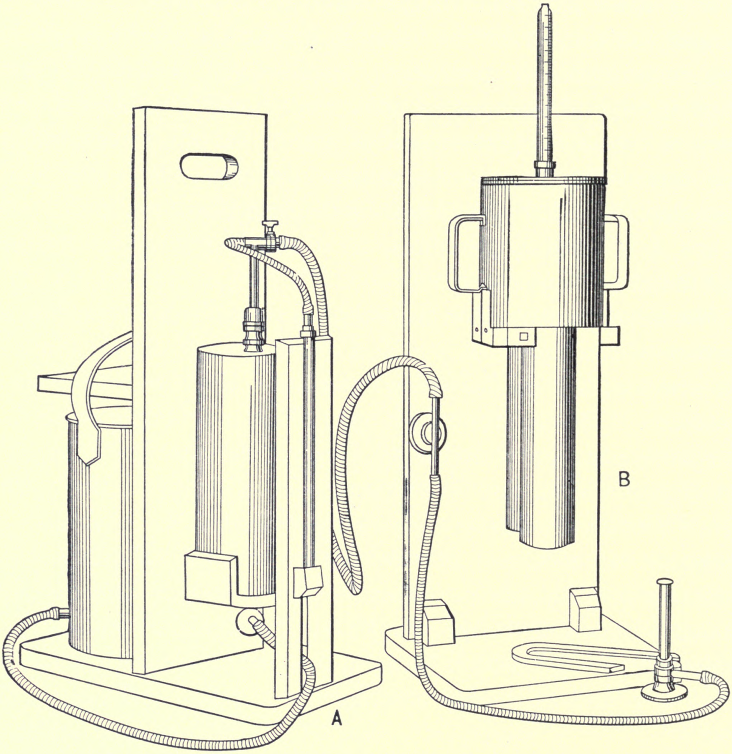

Fig. 37. Simmance-Abady Portable Calorimeter.

Very recently there has been a considerable number of calorimeters of new design described in various technical journals, and some of these are already upon the market. The Committee of the American Gas Institute did not investigate these instruments. The reasons given for such omission are excellent and are best given in the words of their report: "The only calorimeters considered by your Committee were of the Junker or water heater type, measuring the gas and determining the calorific power by transferring the heat developed to a known quantity of water, and determining the rise in temperature of this water.

"This, we think, is the only practical type of calorimeter on the market, and at this writing your Committee disapproved of the adoption for commercial practice of any instrument which determines the heating value by raising the temperature of metals, or that records the heating value by measuring the density of liquids, or by which the heating value is deduced from the quantity of air required for combustion.

"We also disapprove of the use of calorimeters which do not measure the total heating value of the gas. There have been designed calorimeters that allow the products of combustion to leave at temperatures such that the water vapors formed in the process of combustion will not be condensed in the instrument. This method of operating a calorimeter allows for many chances of error, and it does not provide for measuring the sensible heat that is lost in these products of combustion, and also increases the error occasioned by the presence of moisture in the atmosphere."

While such calorimeters have yet to prove their value, it is not impossible that the future may see one of them superseding the Junker and similar instruments, and a short description will therefore be given of several of them, each embodying a different principle.

In the *Journal fur Gasbeleuchtung*, 49, 1056, M. Casaubon gives a new method for the determination of heat units in gas. He states that the calorific value of a gas mixture is equal to the sum of the calorific values of the different constituents. Practically, it is possible to determine the heating value of a lighting gas by determination of the air volume necessary for the complete combustion. M. Casaubon uses, as a medium for the determination of the complete combustion, a radiant mantle of cerium oxide, to which the air is brought through a gas meter. The point where the reducing flame goes over to the oxidizing flame is marked very sharply by a change of the color from red to white. A minimum change in the addition of the air caused a sudden and distinct change in the color. The radiant mantle is obtained by soaking an ordinary mantle in a 30 per cent solution of cerium nitrate. The dial of the gas clock is divided directly in calories.

A determination of the heating value of the lighting gas needs three or four minutes, and the mistakes caused by reading are said not to exceed three or four calories. The calorimeter is also capable of employment with gases other than illuminating gas.

Mr. F. C. Jones, in the *American Gas Light Journal* for November 4, 1907, proposes the following: Each combustible gas has its own definite number of thermal units, depending upon and as unchangeable as its chemical formula; it also requires a certain definite volume of air for complete combustion. A study of the relation of the thermal value to the air required reveals the fact, or law, that equal volumes of all perfectly combustible mixtures of air and gas contain the same number of thermal units. Thus, one cubic foot of hydrogen contains 344 B.T.U. and requires $2\frac{1}{2}$ cubic feet of air for complete combustion; 1 cubic foot methane equals 1073 B.T.U. and requires 10 cubic feet of air. Then $3\frac{1}{2}$ cubic feet of the mixture of air and hydrogen equals 344 B.T.U. and 11 cubic feet of air and CH_4 (methane) equals 1073 B.T.U. $\frac{344}{3.5}$ or $\frac{1073}{11}$ equals nearly 100. Therefore one unit gas and the number units of air required for complete combustion, multiplied by 100, equals British Thermal Units per cubic foot of gas.

There are cases where this does not hold good, but this may be due to the factor's not being exactly correct. To use this principle in determining the calorific value of a gas, take 10 c.c. of the sample and explode it with an excess of air, say 70 c.c., and determine the amount of such excess, which may be assumed to be 10 c.c. Now 10 c.c. of gas required 60 c.c. of air for complete combustion; then 1 cubic foot of gas would use 6 cubic feet of air, making a total of 7 cubic feet, each of which contains the thermal constant 100. Therefore the heating value of the gas in B.T.U. per cubic foot would be 7 times 100, or 700. Mr. Jones states that practice has confirmed the correctness of such procedure, although if the

B.T.U. are less than 100, as with a lean producer gas, the law does not apply.

In the *Journal of Gas Lighting* for July 30, 1907, is described the Beasley calorimeter. This instrument is not intended to record gross heating values, but rather the amount of heat available for practical purposes. It consists of a U-tube filled with oil from a reservoir, one limb of the tube being heated by the gas to be tested, while the other is kept cool. The difference in height of the oil columns is considered to be a measure of the calorific value of the gas. By suitable floats, clockwork, and so forth, the record may be transcribed on a paper diagram, and thus a continuous record may be kept. A pressure regulator, stream controller and special atmospheric burner are used.

The Féry calorimeter depends on the difference in potential produced in a thermo-electric couple, one junction of which is heated by the gas to be tested. The apparatus is standardized by means of a standard amyl acetate lamp. The products of combustion rise through a glass chimney, the top of which is covered with a perforated nickel plate carrying one junction of a copper-constantin thermo-electric couple. The other junction is similarly placed at the top of the second chimney, down which the cold air for the combustion is drawn, a metallic tube forming the connection between the lower ends of the two chimneys. The first junction is heated by the products of combustion to a temperature of nearly 400 degrees, giving a difference of potential of about 16 millivolts between the two junctions. Experiment has shown that the voltage thus obtained is very exactly proportional to the calorific power and to the weight of fuel burned in a unit of time. The apparatus can be made self-registering by use of an integrating wattmeter whose velocity is proportional to the voltage of the thermo-electric couple. The instrument is seen in Fig. 38.[1]

Raupp's gas calorimeter is described by Lux as being superior to the Junker. It consists chiefly of a copper cylinder whose lower part is solid, the hollow upper part carrying a thermometer divided into tenths. Under the copper body is placed at a certain time the

[1] Journal Gas Lighting, June 18, 1907, p. 817.

gas flame, whose height has been previously determined, and the time necessary for the thermometer to rise 10 degrees is noted. The apparatus is standardized by means of gases of known heating value, so from the measured time the heating value can be calculated by consulting a table prepared for that purpose.

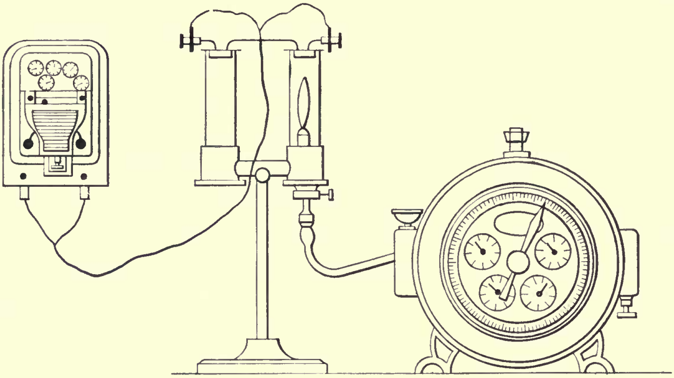

Fig. 38. Féry Calorimeter.

Schönberger's method is based on the fact that the speed of conflagration of a gas is in determinate proportion to its calorific value, and also depends on its pressure. The apparatus consists of a burner and a regulating valve, which controls the inflow of gas from the source of supply into a receiver, to which is attached a manometer tube. The height of the flame and the gas pressure are read off on graduated scales attached to the burner and tube, the pressure being regulated by the valve until the flame is on the point of extinction. This instrument has been recently patented in France, but has probably never been tested save by its inventor.

The essential parts of Stoecker and Rothenbach's calorimeter are an upright glass tube, 2.5 cm. in diameter, expanded in the middle into a bulb. The upper part of the tube is contracted to a diameter of 8 mm. and bent at right angles. The lower end of the tube is also narrowed somewhat in diameter, bent at right angles, graduated into divisions representing 0.1 c.c. and employed to form one of the feet of the instrument.

At a height of 5 cm. above the base, the coiled condensing tube is sealed into the above mentioned tube. The condenser is 2.5 meters long, and 8 to 10 mm. in diameter. A lateral neck is fused into the side of the bulb of the main tube about one-half way up, into which a brass sleeve is accurately ground. This carries the system of tubes through which the gas burned in the calorimeter, and the wires conveying a current of electricity for its ignition, are passed. These three tubes are fixed into the brass sleeve by means of a putty composed of litharge and pure anhydrous glycerine.

The whole piece of glass apparatus is placed in a vessel containing water, constructed in the manner designed by Mahler, the quantity of water being so calculated that it rises in temperature by one degree for every 4500 large calories absorbed. The calorimeter is intended as a convenient instrument for rapid estimation of the heating power of small volumes of gas; it requires, however, two men to operate it.[1]

Graefe's calorimeter is seen in Fig. 39,[2] and is composed of the following parts: a thermometer, *T*; a stirrer, *R*; a vessel, *M*, which holds 5 liters, for measuring the gas; a pipe, *A*, for filling *M* with water; a regulator, *N*, which automatically sets the level of the liquid; a pipe, *C*, leading to the sink; and a pipe, *E*, which can be attached either to the tube delivering gas or to the burner, *B*. The operation in brief is as follows: When the bottle is completely full of gas, *E* is connected to the burner, the gas is lighted, and *D* is so regulated that the flame is constantly two to three centimeters high. While gas flows out of *M*, water is admitted through *A* at such speed that some regularly overflows through *U*; this keeps the pressure constant. During the combustion of gas the stirrer, *R*, is worked in the usual manner, and finally the highest point to which the mercury rises in the thermometer above that which was indicated at the beginning of the test is read off.

While not at all in the class with any of the above, a short description must be given of the automatic Junker calorimeter. This instrument is similar to the ordinary form of Junker, the heat of

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[1] Journal Gas Lighting, April 14, 1908.

[2] Journal Gas Lighting, Oct. 8, 1907.

the flame being transmitted to a stream of water. The value is calculated from the quantities of water and gas, and the rise in temperature of the water. In the automatic calorimeter the flow of water and gas is constant, the difference in the temperature giving a direct indication of the calorific value. The instrument consists of the calorimeter proper, an automatic gas pressure regulator, an automatic water regulator, gas meter and a thermocouple connected to a millivolt meter. A recording device is also furnished whereby a continuous record of heating values may be kept. The complete apparatus can be purchased for about $800.

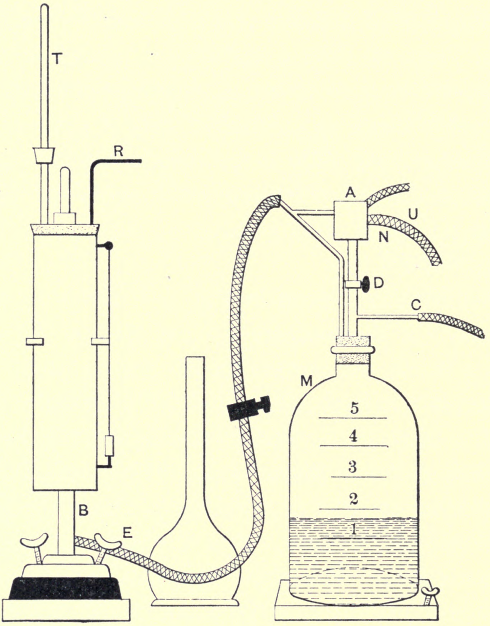

Fig. 39. Graefe Calorimeter.

It is the custom in many places to calculate the heating value from an analysis of the gas. The results obtained in this way may or may not be reliable, for the reason that it is almost impossible to exactly determine the per cent of the various hydrocarbons in the gas, and such determination is rarely made in a gasworks analysis. This introduces a serious error, because of the fact that the hydrocarbons are among the important heating elements in the gas, and the variation in their calorific value may be seen from the following table:[1]

Name.	Symbol.	Volume air required for each volume.	B.T.U. gross per cu. ft. at 60° and 30″.
Hydrogen	H	2.38	326.2
Carbon monoxide	CO	2.38	323.5
Methane	CH_4	9.52	1009.0
Ethane	C_2H_6	16.66	1764.4
Propane	C_3H_8	23.8	2521.0
Butane	C_4H_{10}	30.94	3274.0
Ethylene	C_2H_4	14.28	1588.0
Propylene	C_3H_6	21.42	2347.2
Butylene	C_4H_8	28.56	3099.2
Acetylene	C_2H_2	11.90	1476.7
Allylene	C_3H_4	19.04	2255.0
Benzene	C_6H_6	35.70	3807.4

To calculate the heating value from an analysis, first obtain the calorific values of the combustible constituents; these are worked out per cubic foot. Then multiply the per cent of each constituent by its corresponding calorific value, add the products and divide by 100, and the result will be the calorific value of the gas per cubic foot.

Example. $H = 54.1\%$; $CH_4 = 34.2\%$; $C_2H_4 = 3.0\%$; $C_6H_6 = 1.0\%$; $CO = 5.9\%$.

$$\begin{aligned} 54.1 \times 326 &= 17{,}637 \\ 34.2 \times 1009 &= 34{,}508 \\ 3.0 \times 1588 &= 4{,}764 \\ 1.0 \times 3807 &= 3{,}807 \\ 5.9 \times 323 &= 1{,}906 \\ \hline \text{Total} \quad & 62{,}622 \end{aligned}$$

$62{,}622 \div 100 = 626.2$ B.T.U. per cubic foot.

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[1] Abady's Gas Analysis Manual.

CHAPTER III.

CONSIDERATION OF RESULTS.

The results of a heat unit test will naturally vary according to the nature of the gas which is being examined; it may be of interest, however, to state the values found in various places and for different kinds of gas. In Magdeburg, Germany, the average gross British Thermal Units for the year 1907 was, for coal gas, 550; for water gas, 487; and for mixed gas, 534. The candlepower of these gases is not given, but must in every case have been low. In Zurich, the average net calorific value of the gas manufactured during 1907 was 552 British Thermal Units per cubic foot at 60 degrees and 30 inches pressure, calculated for gas in the dry state; its illuminating power when burned in a slit burner at a rate of 5.3 cubic feet per hour averaged 10 candlepower. Coal gas of 600 British Thermal Units and 17 candlepower is furnished in Sheffield, England, according to figures quoted in the *Journal of the American Chemical Society Abstracts*, January 20, 1907. In Liverpool the average of 263 tests made during 1907 was 668.91 British Thermal Units net, and the corresponding candlepower was 20.7. The Colombo Gas and Water Company of Colombo, South America, has a contract with the municipality for lighting the city with gas of 10 candlepower and 400 British Thermal Units.

In America the heating value is, as a rule, much higher than abroad. During the winter months of 1906 the Inspector for the District of Columbia found, as the average of 8 tests, that the British Thermal Units in Washington gas, which is a mixed gas of about 22 to 23 candlepower, was 632.3, with a minimum of 593.3 and a maximum of 651.1. The Massachusetts State Inspector's Report for January, 1902, shows that in seven cities, the calorific value of the gas varied from 708 to 594 British Thermal

Units, the average being 655. In New York State a long series of tests was made in 1908, and the results will be given in full in the discussion on the relation of candlepower and heat units.

The generally accepted theory is that a good coal gas of 16 candlepower should have from 600 to 625 gross British Thermal Units per cubic foot, and a carburetted water gas of 20 candlepower will have a slightly greater amount. Considering equal candlepowers, there is no question as to the superiority of the coal gas in heating value. In the *Journal of Gas Lighting*, January 14, 1908, appears an article on coke oven gas, in which the following figures are given:

	Coke oven gas.	Retort coal gas.	Carburetted water gas.
British Thermal Units per cubic foot..............	730	669	719
Candlepower.............	17.5	15.5	20.7

These figures may be true for some isolated case, but the heating values are far higher, considering the illuminating power, than the writer, in a rather wide experience with gases of all candlepowers, has ever found.

O'Connor gives the calorific value of coal gas as 600 to 625 British Thermal Units, and of carburetted water gas as 700, and these figures seem much nearer the truth, although even 700 is rather higher than the usual B.T.U. found in water gas at the present time.

With natural gas it is clearly impossible to state any heating value which shall be of wide application, owing to the differences in composition of gases from various fields. The Metric Metal Company in its catalogue gives the figures for natural gas as follows: average of Pennsylvania and West Virginia fields, 1145 B.T.U.; of Ohio and Indiana, 1095; of Kansas, 1100. The writer made an investigation of the gas from northwestern Pennsylvania and found heat units ranging from 1190 to 1352. Gill, in his " Gas and Fuel Analysis," states the calorific value of natural gas to be 980 B.T.U. per cubic foot; it is therefore probable that the correct figures are about 1000 to 1200. It should be stated that the heat of condensation with natural gas is much greater than with coal or water gas, the Jamestown samples mentioned having from 88 to 118 B.T.U. in this form.

Oil gas is very rich in calorific constituents, and the B.T.U. may reach as high a figure as 1400. Acetylene is also a valuable gas for heating purposes, and while there are very few results published regarding the commercial gas, the theoretical heat value of pure acetylene gas is 1477 B.T.U. per cubic foot (gross), and there is little reason to doubt that in present practice this figure will be closely approximated.

Standards. Standards for the heating power of gas have been established in many places, and it is hoped and expected that others will soon follow their lead. In Germany there is no generally accepted standard of calorific value, but the gas is carefully tested in this respect, and the figures from a number of cities show that on an average the gas contains 532 to 585 gross B.T.U. per cubic foot. In Colombo, as has been stated, the standard is 400 B.T.U.; in Omaha, Nebraska, 600; in Dallas, Texas, 650; in Milwaukee, Wisconsin, 600 (established by Dr. David Fisher, chemist for the state of Wisconsin); and the Wisconsin Railroad Commission has set the standard for the entire state as 600 for a monthly average, with a minimum of 550. These few instances will show the trend of opinion in scientific and government circles to-day.

The Relation of Calorific Value to Candlepower and Flame Temperature. A great deal has been written on this subject, and it is not proposed to enter into a detailed discussion of the question here, but merely to gather together some of the facts and figures which have resulted from investigations. The opinions of different experimenters vary widely, and the writer does not pretend to guarantee the accuracy of any of them; indeed, it is his personal belief that there is no definite relation between candlepower and calorific power, and this for the reason that the two depend upon entirely distinct factors connected with the constitution of the gas, and a change in composition which will greatly alter the heat units will have little or no effect on the candlepower. To understand this it is only necessary to consider the gases methane and hydrogen with heating values of 1009 and 326 B.T.U. respectively, and to remember that neither of these of itself possesses, practically speaking, any illuminating power.

E. St. Clair Deville, one of the most eminent investigators of the day, at the conclusion of a long and brilliant article in the *Journal of Gas Lighting*, for 1907, says: "The author is of the opinion that the illuminating power in the incandescent burner, or the illuminating duty of a gas, expressed in candles per cubic foot, can be defined only in this manner,viz.: The illuminating duty is the maximum value of the quotient of the absolute intensity divided by the consumption, or $\frac{I}{G}$, when a particular chosen mantle is used. When this value is divided by the calorific power, c, of the gas, the value obtained represents the duty in terms of heat expended. It is established that the duty obtained for the expenditure of a given number of units of heat per hour remains constant within 15 per cent, through the whole range of illuminating gases from neat water gas to rich cannel gas. The slight variations to which this duty is subject, appear connected with the corresponding variations in the flame temperature of the gases. The duty per cubic foot of gas consumed is very nearly proportional to the calorific power, being subject only to unimportant variations due to the effect of flame temperature. The specific or normal illuminating duty in the incandescent burner is proportional to the calorific power of the gas, and the story of the preponderating part played by the flame temperature must no longer be allowed to circulate."

As opposed to this, experiments reported in the *Journal of the American Chemical Society* for October, 1906, show that in the work of the writers the maximum variations of flame temperature from calorific power was as low as 2 per cent. Mr. Isaac Carr of Widnes, England, says: "It has often been said that calorific value bore no relation to illuminating power. This is quite true when comparing gases made from different coal fields and very different methods of production; but where the conditions were comparable, there was undoubtedly a relationship between illuminating power and calorific value. I have made hundreds of tests and found that the calorific value rose with the light-giving quality of the gas." Latta, in his "American Gas Engineering Practice," gives the following rather remarkable tables: [1]

Coal Gas.			Carburetted Water Gas.		
Candle-power.	B.T.U.		Candle-power.	B.T.U.	
	Gross.	Net.		Gross.	Net.
12	540	480	12	490	452
13	560	500	13	510	472
14	585	522	14	529	489
15	610	542	15	547	508
16	625	562	16	567	527
17	647	582	17	587	547
18	670	603	18	607	567
19	690	622	19	627	587
20	712	642	20	647	607

According to this table there is a constant increase of from 20 to 25 B.T.U. for each increase of one candlepower; but this is the only table which the writer has ever seen where such a perfect relation was shown. A series of similar purport, though less regular, is given in the *American Gas Lighting Journal*, February 4, 1907, and is here inserted:

Sample.	Candlepower with Argand No. 1.	Candlepower with Argand No. 2.	Net B.T.U. per cubic foot.
A	11.50	15.26	502.40
B	11.70	15.71	518.43
C	12.08	16.15	515.71
D	12.36	16.59	525.40
E	12.96	17.18	530.32
F	13.60	17.43	537.41
G	14.27	17.85	542.18
H	15.10	18.75	554.52
I	15.26	18.54	554.19

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[1] Journal of Gas Lighting, February 26, 1907.

Out of a long series of tests, the ensuing are selected from the reports of the Massachusetts State Gas Inspector:

Candlepower.	B.T.U.	Candle-power.	B.T.U.	Candlepower.	B.T.U.
21.1	677.2	19.3	662.2	27.0	714.3
23.7	705.3	22.6	645.9	26.2	661.4
23.2	684.5	21.0	679.2	26.2	684.9
24.2	670.7	20.0	642.4	23.3	659.4
21.6	654.6	19.8	676.2	25.0	661.6
23.1	676.7	20.8	704.8	24.5	674.4
21.3	681.9	21.4	688.2	19.1	664.1
20.8	687.4	27.1	691.2	21.4	688.2

Finally, the following table contains the results of tests made at various places throughout New York State in 1908, no two tests being of gas from the same plant:

WATER GAS.

Candle-power.	B.T.U. gross.	Condensation.	Candle-power.	B.T.U. gross.	Condensation.
21.3	637.1	45.0	19.9	620.3	33.8
14.9	553.9	23.0	21.3	692.7	38.5
20.8	589.6	25.0	23.4	624.4	42.5
19.8	652.8	36.3	19.4	566.0	47.0
19.9	652.7	41.9	21.5	610.0	29.0
20.0	622.3	38.5	23.6	623.5	38.0
20.2	620.9	41.7	21.0	569.5	35.0
27.1	802.5	47.3	20.9	624.0	39.0

COAL GAS.

Candle-power.	B.T.U. gross.	Condensation.	Candle-power.	B.T.U. gross.	Condensation.
12.3	550.7	50.6	16.0	657.5	68.0
16.9	622.6	45.8	14.4	647.0	63.0
15.6	717.9	67.4	17.9	690.5	67.0
16.4	713.5	63.3	13.0	592.0	54.0
19.4	703.4	66.4	16.1	577.0	54.0
14.9	661.5	59.9	16.4	642.0	49.0
17.8	663.3	64.6	16.0	659.0	59.0
12.0	552.0	52.0	16.1	627.0	62.0
13.6	559.0	58.0	16.5	638.0	69.0
18.3	670.5	57.0	18.4	674.0	65.0
16.2	583.5	52.0	14.7	616.0	54.0
16.1	590.5	59.0	16.1	623.5	58.4
14.1	626.0	62.0	13.0	632.0	58.0
16.5	671.0	58.0	16.4	659.0	58.0
15.7	647.0	55.0	13.3	605.0	57.0

CHAPTER IV.

PRESSURE AND SPECIFIC GRAVITY.

THE pressure at which gas is delivered is one of the most important factors in a satisfactory service; and in connection therewith, there are two points to be considered: first, the pressure should be as uniform as possible, and second, it should be neither too high nor too low. The first point is possibly the more important, since the evil effects of too high pressure can be guarded against by the consumer himself, and too low a pressure is rarely met. If the pressure is not uniform, however, all burners and stoves will be out of adjustment most of the time, and company and consumer will alike suffer. Too low a pressure means too small a supply of gas and consequent inefficient service as to illuminating and heating effects; if the pressure be too high, the average consumer will waste his gas by allowing burners and stoves to blow; he will thus receive less heat and light, while paying larger bills, and is pretty certain to complain of unfair treatment by the gas company.

Just what is the most desirable pressure to maintain is a disputed point. Research has seemed to show that the Welsbach burners operate more efficiently at a higher pressure, as may be partly gathered from the following table:[1]

PRESSURE 1.2″.

Burner.	Illuminating power, candles.	Consumption, cu. ft.	Efficiency.
Welsbach C	40.0	3.80	10.5
Veritas C	24.0	3.30	7.3
Compactum	12.0	3.325	3.6
Bray (with Welsbach)	32.5	2.90	11.2
Kern	47.0	3.35	14.0
Inverted	45.0	2.45	18.4

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[1] Journal of Gas Lighting, April 2, 1907.

PRESSURE 2″

Burner.	Illuminating power, candles.	Consumption, cu. ft.	Efficiency.
Welsbach C	78.5	4.95	15.85
Veritas C	60.0	4.25	14.10
Compactum	49.5	4.325	11.40
Bray and mantle	53.5	3.90	13.70
Kern	54.0	4.375	12.35
Inverted	58.0	3.20	18.10

PRESSURE 2.8″.

Burner.	Illuminating power, candles.	Consumption, cu. ft.	Efficiency.
Welsbach C	107.0	6.00	17.85
Veritas C	90.0	5.10	17.65
Compactum	76.0	5.20	14.60
Bray and mantle	55.0	4.10	13.40
Kern	57.0	4.60	12.40
Inverted	60.0	3.825	15.70

The very latest evidence, however, gathered from a large number of experiments by Professor McCormack of Chicago, proves, at least in the opinion of the experimenter, that 2.3 inches is the most satisfactory pressure for incandescent burners.[1]

For mantle lamps, gas arcs, etc., the Wisconsin Gas Association believes a high pressure, say 3 to 4 inches, improves the candlepower, but that for all-round use, the limits should be 2.5 to 4 inches, although in one place in Wisconsin a normal pressure of 32 inches is carried and gives satisfaction. The Railroad Commission of Wisconsin, in its recently issued rules, prescribes as follows: "Gas pressure, as measured at meter inlets, shall never be less than 1½ inches, nor more than 6 inches of water pressure, and the daily variation of pressure at the inlet of any one meter on the system shall never be greater than 100 per cent of the minimum pressure." The Second Class Cities' law in New York State requires a minimum of 1½ inches and a maximum of 3¾ inches, with an allowance of 1 inch for every 100 feet in altitude above the holder. This allowance is due to the

[1] American Gas Light Journal, November 23, 1908.

fact that gas, on account of its low specific gravity as compared with air, increases its pressure by a definite amount for each increase in altitude in the distributing system.

Mr. A. E. Forstall states the case thus: The drop in the pressure from the end of the service to the burner orifice is about 0.7 inch. With stoves, it is necessary for good results that the pressure at the burner orifice shall be at least 1 inch; therefore, a minimum of 1.7 inches must be constantly maintained in the main. This also holds good for incandescent burners. Any company which allows its pressure in the mains to drop below 1.5 inches is certain to have an enormous number of complaints. Mr. Forstall does not believe that there should be any maximum limit for pressure.

A minimum allowance of 1½ inches seems to meet with but little criticism, but the writer cannot admit that there should be no maximum limit set. An experience in one city where the gas company was more bitterly attacked than in any other place in the state, led to an investigation which seemed to prove conclusively that the whole source of the trouble lay in a pressure which was very often between 5 and 6 inches, and in several instances did not fall far short of 7 inches.

If the consumer could be educated to the use of Welsbach mantles, and to the proper regulation of stoves and burners, it is probable that no difficulty would be experienced with these high-pressures; but so long as flat-flame burners (and many of them of antiquated or utterly unsatisfactory type) are in use, and the consumer persists in opening wide the gascock, so long will there be disputes and hard feeling between the public and the gas company.

All that has been said thus far applies to coal and water gas companies, and the pressures are expressed in terms of the height in inches of a column of water which would be supported by the pressure in question. With acetylene, the insurance regulations require, first, that the working pressure at the generator must not vary by more than $\frac{10}{10}$ (1)-inch water column under all conditions of carbide charge and feed, and between the limits of no load and 50 per cent overload; and second, that apparatus not requiring pressure regulators must be so arranged that the gas pressure cannot exceed 6 inches water column.

Dr. Lewes says: "On consuming acetylene from a 000 U. J. burner at all ordinary pressures, a smoky flame is obtained, but on increasing the pressure to 4 inches a magnificent flame results, free from smoke and developing an illuminating power of 240 candles per 5 cubic feet of gas consumed." It seems doubtful, however, whether such a pressure is in any way common among acetylene plants in this country.[1]

With natural gas, much higher pressures are necessary, due partly to the distances which the gas has to be transported, partly to the decreased supply in the winter months, and partly to the fact that it has not seemed economical or desirable to cut too heavily the natural pressure at which the gas issues from the wells. Thus natural gas is frequently supplied under pressures ranging from 10 to 26 inches of water column, and for this reason the gauges are generally filled with mercury instead of water. Since mercury has a specific gravity of 13.56 at 15° C., a gas pressure of 26 inches water will only be equivalent to $\frac{26}{13.56}$, or 1.92 inches mercury. Pressure in the natural gas fields is also often expressed in ounces, and to aid in the comparison of these three forms of measurement, a table will be found in the appendix.

There are three general methods in vogue to-day for taking gas pressures: by the Bristol recording gauge, by the siphon or U gauge, or by an apparatus similar in principle to King's pressure gauge and sometimes called the arch pressure gauge. The Bristol gauge (Figs. 40 and 41), is an instrument designed for the continuous automatic recording of gas pressures. The record is made on a paper chart divided on its circumference into hours, radial arcs reaching from these points to the center. From the center towards the edge are concentric circles, each representing 0.2 inch pressure. The chart is revolved by clockwork in the

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[1] As nearly as the writer can learn, 3 inches seems to be the pressure generally recommended by managers of acetylene plants, as shown by their testimony at the meeting of the International Acetylene Association in August, 1908.

upper part of the case; below this is placed a series of diaphragms, *AA*, to the top of which is connected the arm, *C*, which carries the recording pen. The operation of this instrument, as described by the manufacturers, is as follows: "Pressure applied to the system of diaphragms, *A*, has a tendency to elongate the whole. This tendency is resisted by the flexible strip, *B*, and the result is a multiplied side motion sufficient to record directly by means of an inking pointer."

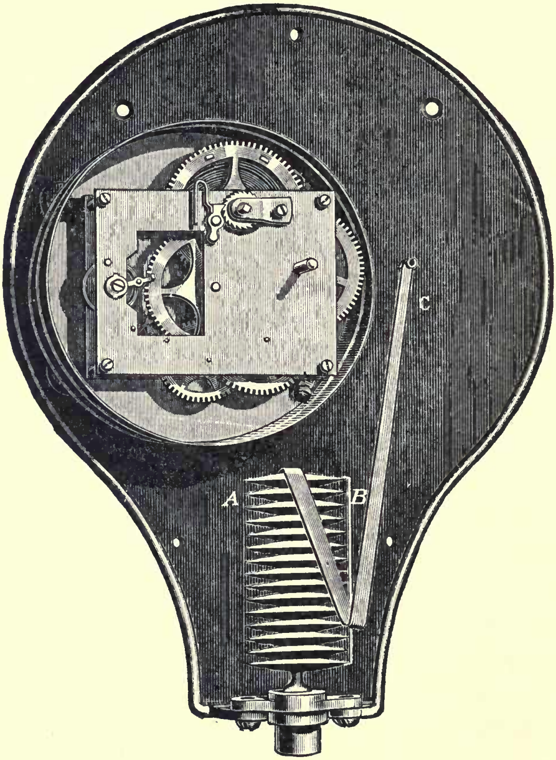

Fig. 40. Bristol Pressure Gauge, Interior View.

The gas supply is connected to the tube at the bottom of the case. To start the instrument, when in position, it is only necessary to wind the clock, place a chart upon the face and clamp it in position by the center thumb nut, fill the pen with ink and turn on the gas. Set it on zero pressure and at the proper hour of the day. The chart takes a record for 24 hours, when a fresh one may be substituted. The pen must be cleaned occasionally and filled with special ink furnished with the instrument.

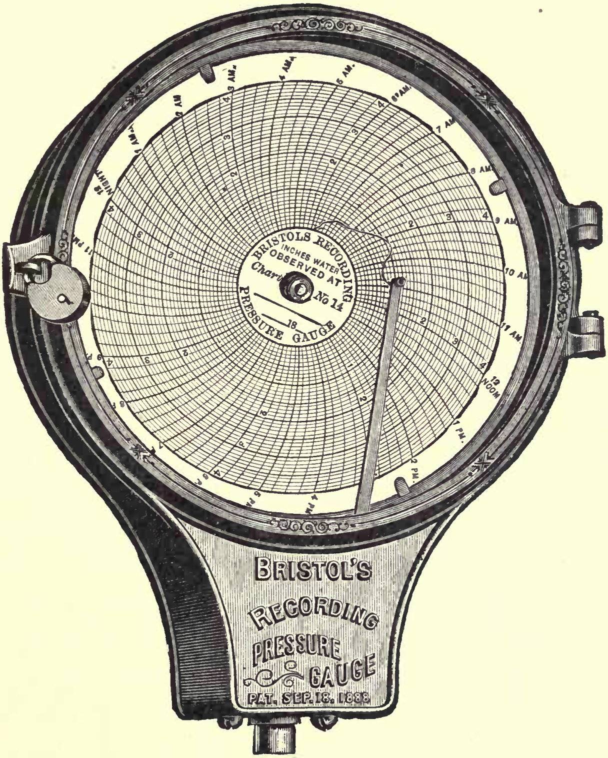

Fig. 41. Bristol Pressure Gauge.

It is well to standardize this gauge frequently by comparison with an accurate **U** gauge, as it is always possible that the diaphragms or arm may have become bent, or be working improperly. The arm and pen must be handled with great care, and when the latter is not actually recording, a blank chart should be placed under it to protect the point. The instrument is to be set up in a level position and preferably screwed against the wall where there is no vibration. The entire apparatus is eminently satisfactory, and the price is $50.

The siphon or **U** gauge is one of the simplest and most accurate contrivances employed in the testing of gas. It consists (Fig. 42), of a glass tube bent into the form of a narrow U, one arm of which is connected by a nickel tube with the gas supply. Between the two arms is a thin wooden scale graduated in inches, with the zero mark in the center and the numbers running both up and down the scale. The tube is filled with water up to the zero mark in both arms. When the gas is turned on the water in the right-hand limb is forced down, while that in the left-hand limb rises. The air displaced by the rising water escapes through a small hole in the nickel cap at the top of the left-hand arm. It is then only necessary to record the difference in height of the water in the two arms, and the result is the pressure of the gas in inches of water.

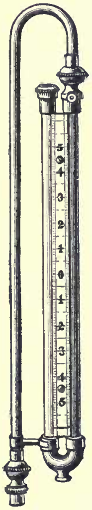

Fig. 42.
Siphon on
U Gauge.

The scale must be accurately graduated, but the diameter of the glass tube is unimportant, since pressure exerted on a liquid is transmitted undiminished in all directions and acts with equal force upon all surfaces of like area. The cost of a 6-inch gauge, which is the right size for nearly all city pressures with artificial gas, is $1.75; for works' use a 14-inch gauge is often needed, and this costs $5.50.

The arch pressure gauge, as seen in Fig. 43, depends for its action upon the rise and fall of a float, the motion being transferred to a pointer revolving along a semi-circular scale. The rectangular box at the base contains water, which, by the pressure of the gas, is forced up in the cylinder, causing the float to rise. These instruments were more popular in the past than at present; a 6-inch gauge costs $32.

Numerous other styles of gauges, such as the King's, Simmance-Abady, Alexander Wright & Co.'s Portable Register, Wright's

Register and Crosby's Register, are manufactured and sold in England, but are not frequently met in this country. Should any reader be interested in these, he should consult Alexander Wright & Co.'s splendid catalogue.

One final precaution must be mentioned before leaving this subject. It is a too common practice to take the pressure, with a U gauge, at the burner in a private house, and then, if the result proves low, to criticise the gas company. Now it may be the latter's fault; but there is also an excellent chance that the trouble may be due to stoppages in the pipes or meter, the former especially if the house is old and the pipes have never been cleaned. This may seem a trivial and unnecessary precaution; but the writer has seen many cases where it applied, and especially one where a long and costly suit against the gas company was barely averted by the

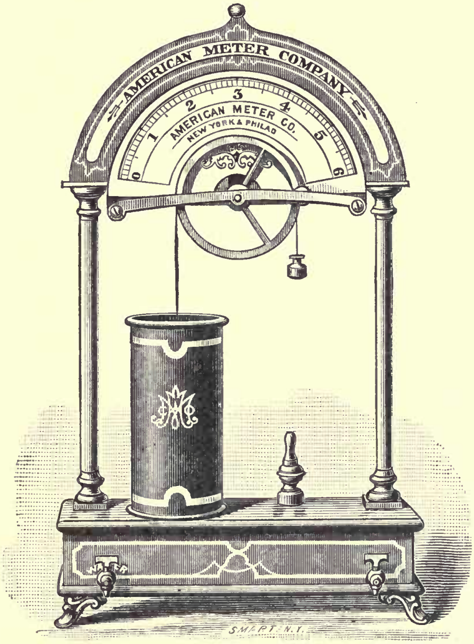

Fig. 43. Arch Pressure Gauge.

discovery that the complainant had been securing the pressure results of which he complained in an old house where the pipes were badly choked. Tests of the pressure in the surrounding neighborhood proved the error of his figures and saved trouble and expense to both company and consumer.

Specific Gravity. The specific gravity of a gas is the ratio which the weight of a given volume of it bears to the weight of an equal volume of air (or hydrogen) under similar conditions of temperature and pressure. In considering the specific gravity of illuminating gas, air is almost universally taken as a standard; but in scientific work, especially along chemical and physical lines, hydrogen is frequently used. The determination of this property of the gas is of value along three lines. In the first place, it is a necessary factor in the calculation of the flow of gas in pipes, as will be seen from the formula $Q = 1350\, d^2\sqrt{\frac{hd}{sl}}$, where d equals the diameter of the pipe in inches, h equals the pressure in inches of water, l equals the length of the pipe in yards, s equals specific gravity of the gas (air equaling 1); and Q, the quantity of gas in cubic feet per hour which will flow through the pipe under the given conditions. In the second place, it sometimes happens that the gas manager desires to know the weight of gas produced from a given weight of coal; here the specific gravity is clearly indispensable. Third, it furnishes some clue to the nature and amount of impurities in the gas. This arises from the fact that the gravity of each of the common impurities is far greater than that of the gas itself. Thus, coal gas has a specific gravity of about 0.45 and water gas of about 0.66; the figure for nitrogen is 0.97; for oxygen 1.11; for hydrogen sulphide 1.18; and for carbonic acid, 1.53; so that a considerable increase in the per cent of either or all of these is certain to have its effect on the specific gravity of the finished product.

Several pieces of apparatus have been devised for use in determining the specific gravity of gas, all of which depend upon an actual weighing of equal volumes of gas and air inclosed in detached glass globes. This requires an extremely sensitive balance, and the apparatus is delicate and costly; these processes are therefore utterly unfitted for gas works' use. There are only two methods in very general use in this country, so far as the writer knows, the one using the Lux balance and the other employing, in principle at least, the effusion test of Bunsen.

The Lux balance (Fig. 44) consists of a large glass bulb, *A*, attached to one end of the lever, *B*. This lever has its fulcrum in the support, *C*, and its other end is pointed and travels along the arc, *D*, which is so graduated that the direct readings of specific gravity may be made therefrom. The gas enters the bulb through *E* and is discharged through *F*.

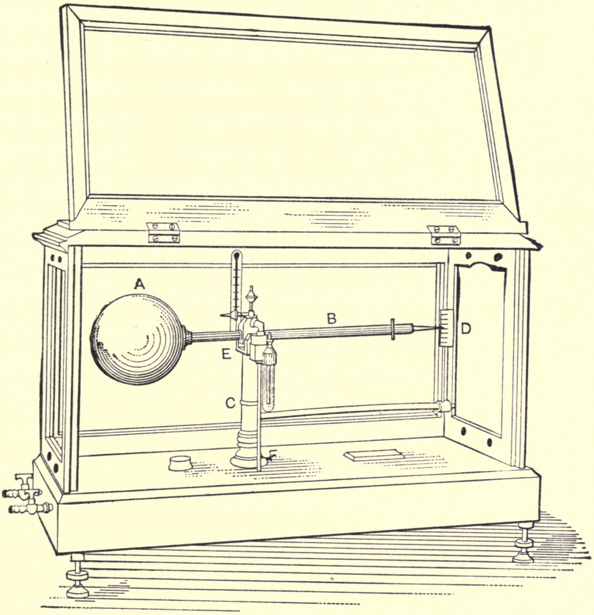

Fig. 44. Lux Balance.

To use this instrument after it is once adjusted and calibrated it is only necessary to completely fill the bulb with the gas to be tested to the exclusion of all air, and observe the reading indicated on the scale by the pointer. Corrections must be made for the temperature and pressure, and these Abady states as follows: "For every millimeter at which the barometer stands *above* or *below* 760 millimeters, 0.0007 is *added* or *deducted* from the specific weight indicated on scale. For every degree Centigrade at which the thermometer stands *above* or *below* 15 degrees, 0.002 must be *deducted* or *added.*"

This method takes no account of the moisture in the gas, and a true scientific determination of specific gravity ascertains the relation between *dry* gas and *dry* air. This, however, is a refinement which does not seem necessary for gas works' use, and the figures obtained with the Lux balance should be sufficiently accurate for all practical purposes.

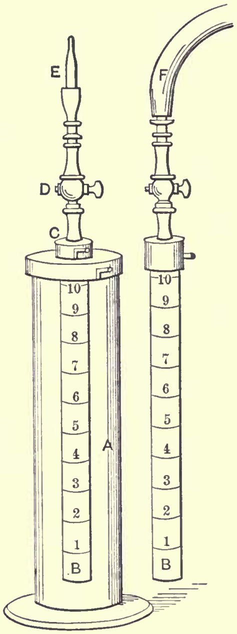

Fig. 45. Schilling's Specific Gravity Apparatus.

If it is desired to calibrate the instrument in the laboratory, fill the bulb with air at 15° C. and 760 mm. pressure, and mark the point on the scale indicated by the pointer as 1. Then fill the bulb with hydrogen at the same temperature and pressure; the position of the pointer in this case should be marked 0.07. The space between these two points is then subdivided, and the scale is ready for use. The cost of the Lux balance is $170.00.

The Bunsen effusion test is based on the fact that the specific gravities of two gases are inversely proportional to the squares of the speeds with which they escape through a minute opening in a thin plate. This ratio is not absolutely correct, but is near enough for all practical purposes. Mr. W. W. Goodwin made a series of experiments on this subject, with various gases, and found that this method gave results which differed from the theoretical figures by less than 0.016 in all cases but one. In the exception, one volume of carbon monoxide plus one volume of carbonic acid was used, and the specific gravity as determined experimentally was 1.203, while the theoretical result is 1.244.

The apparatus generally used is shown in Fig. 45. It consists of a glass jar, *A*, which when in use is filled with water; a glass tube, *B*, which is graduated, and employed for the measurement of the gas; a movable cap, *C*, and a tip, *E*, which contains the fine orifice through which the gas is to escape.

In using this instrument first remove the tube, *B*, and fill the cylinder, *A*, with water up to a point slightly above the level of the upper mark on *B* when the latter is in place. Close the cock above *B* and insert the tube in its place, where it is held in position by a catch. Now having a stop watch ready in the hand, open the cock, and as the water rising in the tube passes the line marked 1, start the watch. When the surface line of the water exactly reaches some other mark, say 10, the watch is to be stopped and the time recorded. Repeat the experiment, using gas instead of air, and being certain that all air has been expelled from the apparatus and that the water is saturated with the gas to be tested.

The specific gravity of the gas is then obtained from the formula $S = \frac{G^2}{A^2}$ where G = the time in seconds consumed by the gas in passing from line 1 to line 10; A = the corresponding time for the air.

Example. Gas took 81 seconds; air 127 seconds.

$$\text{Specific gravity} = \frac{81^2}{127^2} = 0.407.$$

This apparatus is furnished, in a neat carrying case, for $20.

Slightly different is the apparatus used by the inspectors of Massachusetts and New York for specific gravity determinations. It consists of two large perforated rubber stoppers, each having a brass tube projecting laterally near the large end, and connecting with the hole in the stopper. A glass piece in the form of a truncated cone fits tightly over one stopper; it is 9 inches long, 1½ inches diameter at the base and 1 inch at the top. A similarly shaped piece 9 inches long by 1½ inches diameter at the lower end fits over the second stopper; 2 inches above the latter the tube has a construction 1 inch in diameter, and at its upper part is narrowed to a neck five-sixteenths inch in diameter which is ground on the inside to receive the end of a tube 7½ inches long and one-fourth inch in diameter, in the upper end of which is fitted a platinum plate containing the emission orifice. One and three-fourths inches below this plate is a three-way glass stopcock, and 3 inches below the latter a scratch surrounds the tube and serves as the upper mark in the escape of the gas.

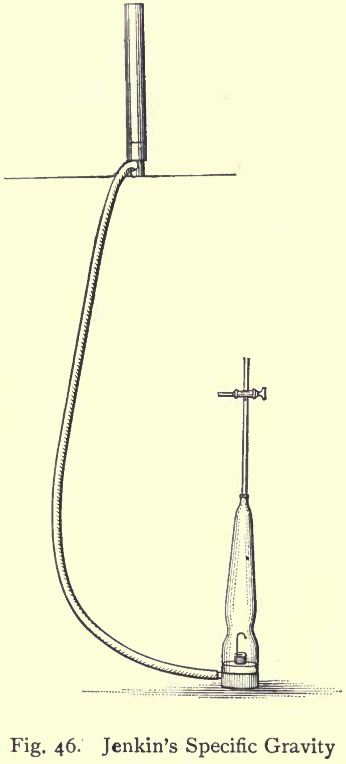

Fig. 46. Jenkin's Specific Gravity Apparatus.

Fitted into the hole in the stopper is a hollow cylinder of brass to which is soldered a curved piece of brass wire pointed at the end, which rises 1½ inches above the surface of the stopper. The two brass tubes projecting from the outside of the stoppers are joined by a piece of rubber tubing 15 to 18 inches long.

In using this instrument the larger tube is filled with water, of the temperature of the room, nearly to the top, the stopcock being turned so that egress of air from the smaller tube is prevented. The larger tube is placed on an elevated surface just high enough so that its bottom is above the level of the scratch on the narrow outlet tube, the cock is turned so that the air may escape through the orifice in the platinum plate, and at the second, when the point of the brass wire breaks the surface of the rising water, a stop watch is started. The latter is stopped when the water exactly reaches the scratch.

The large tube is lowered, and the stopcock turned so air may enter through its hollow point. When the water is again all in the large cylinder, the cock is turned to connect the small vessel with the outside air through the platinum tip, the large cylinder is replaced on the elevation and the operation repeated. Results should be obtained which check within one-fifth second.

Now connect a rubber tube to the gas supply and to the tip of the stopcock, lower the large cylinder and force the water into the latter by means of the gas pressure. Thoroughly saturate the water with the gas to be tested; this may be done by shaking gas and water together and by forcing the water up and down in the small vessel in contact with the gas. Repeat the operations with gas in the same manner as described for air. The calculation is made in exactly the way already described for the Bunsen or Schilling test.

The advantages of this apparatus are its portability, its cheapness, its rapidity and accuracy. When set up, the cylinders are inclined to be a trifle unstable; this may be overcome by fastening a lead plate to the base of each stopper. The writer has also substituted a copper cylinder for the larger glass vessel with satisfactory results. The entire outfit weighs less than 1½ pounds, and costs about $3.70. Four precautions in connection with its use should be emphasized: (1) The water must be of the room temperature; (2) the water must be thoroughly saturated with the gas; (3) the platinum tip, stopcock, and upper part of the tube must be kept dry and clean; (4) the large cylinder must always, in any one determination, be placed at the same height. Of these precautions Nos. 1, 2 and 3 apply equally well to the use of the Schilling instrument. If care is taken results may easily be obtained which check to within one-fifth second; a variation of the latter amount means on a coal gas of specific gravity 0.42, only about 0.001 in the final result.

Specific gravity is sometimes determined from the analysis of a gas, by calculations. The usual method of procedure is to multiply the per cent of each constituent by its specific gravity, add the products and divide by 100. This is not as accurate or satisfactory as an actual determination, but may be needed to furnish approximate results in certain cases.

The results of specific gravity determinations will necessarily vary with varying conditions, and the most that can be done to show what may be expected is to illustrate by certain figures which have been reached. For coal gas, results from various sources are from 0.380 to 0.574; the latter figure, however, is extraordinary, and was obtained with a coal gas of over 22 candlepower (the specific gravity of coke-oven gas is given as 0.508). 0.380 is a very low figure, and came from a gas of only 13.4 candlepower.

In general the specific gravity of coal gas seems to be between 0.400 and 0.460, although it may run beyond these in either direction.

Blue water gas has a specific gravity of about 0.431, while for carburetted water gas the figure is generally between 0.600 and 0.700. In an article in the *Journal of Gas Lighting*, for Jan. 14, 1908, the specific gravity of carburetted water gas is given as 0.528, but this figure seems to the writer to be far too low.

Mixed gas will of course vary in specific gravity according to the proportions and gravities of the water and coal gas used, so that any general statement attempting to cover this point would be valueless.

Oil gas of 50 candlepower may have a specific gravity of 0.850–0.880, although this figure also is necessarily tentative.

Pure acetylene has a specific gravity of 0.8982, and the commercial article will not vary much from this.

Natural gas varies greatly in gravity, according to its source and composition; in one of the Pennsylvania fields the writer obtained results between 0.707 and 0.717. The whole question of specific gravity, however, has its greatest field in connection with the routine determinations of one kind of gas, in which case a comparison of results will be of value; further consideration is, therefore, left to the analyst and manager who shall make and interpret the results on the spot.

The so-called Jet photometers are, in the true sense of the word, not photometers (or light measurers) at all. They depend for their action on the theory that a change in the specific gravity and composition of the gas will produce a proportionate change in the light of a long, thin and pointed flame, supplied by gas through a small orifice. If the gas to be tested were always of practically the same quality, the Jet photometer would doubtless reveal that fact; but it too often happens that a gas drops from 18 to 14 candlepower, and no indication of such change is recorded by the jet. This is doubtless partly due to improper care of the instrument, especially if the Jones jet be used. The interior of the chamber is allowed to become dirty and sticky, and the glycerine is either forgotten entirely or remembered at irregular intervals.

If such were the only causes of inaccuracy, however, no blame could attach to the instrument itself. Unfortunately, the trouble lies deeper, in the very principle of the apparatus, for, as has been already indicated in the chapter on Calorimetry, the gravity and heating value of the gas may remain almost constant, while its candlepower may wander over rather wide limits. This defect of the jet photometer has been repeatedly proven in practical work, by comparing its readings with those of a standard bar photometer, and the inaccuracy of the jet is so well attested to-day that it is rapidly falling into disuse, at least in progressive and well-informed circles.

PART IV.

TESTING OF METERS.

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CHAPTER I.

THE CUBIC FOOT AND METER PROVER.

As has been mentioned in connection with gas testing, the author has endeavored to deal only with the finished product. The same may be said with regard to meters. It is not within the scope of this work to treat of the construction, adjustment or other mechanical features connected with meter manufacture. All that will be attempted is to cover briefly but carefully the testing of the meter for accuracy of registration, and this only after the meter is topped and ready for service.

It is a curious and interesting fact that while gas has been in use in England for one hundred years, it is only since 1861 that meters have been subject to governmental regulations with regard to their accuracy of registration and the methods and apparatus to be employed in proving them. Thus the United States is not far behind in this respect, for it was about 1865 that Massachusetts appointed an inspector of gas and gas meters. This example has been widely copied in cities and states throughout the Union, and the gas companies themselves, perceiving the importance of the subject and the advantages accruing therefrom, have almost without exception followed suit, so that to-day it may be said that few indeed are the meters which are installed without having been tested by some one.

The advantages to be gained from such procedure are twofold. First, should the meter be fast, or, in other words, register against the consumer, disputes and hard feeling will arise between the latter and the gas company, and every manager will appreciate the importance of this. Second, if the meter be slow, or against the company, the latter is delivering goods for which it receives no pay, and the column of "unaccounted-for gas" will grow.

After the meter has been in service for some time it may either cease to register at all, on account of leakage, etc., or the diaphragms may dry and shrink, and the record of the dial be entirely incorrect. Meters are frequently set in either very hot or very cold places, and this is a bad practice, as temperatures below 40 degrees or over 100 degrees will injure the oiled leather of the diaphragms.

Moreover, occasionally a mistake in the factory may result in the wrong dial or cogs being placed in a meter. Thus, in Toronto, Canada, a 10-light dial was discovered on a 5-light meter, and the rebate which the company offered to settle the claim was $360. In New York State a shipment of meters was received by one of the companies, and, on test by a state inspector, it was discovered that all of them were in the neighborhood of 50 per cent fast. On searching for the cause, it was found that the wrong cogs had been used in the gearing.

For these reasons it is desirable that all meters should be tested at stated intervals, and it is becoming a more and more general custom to remove all meters at least once in every three or five years. This may seem to be an expensive operation, but it has been proven by experience to be economical in the long run.

The still more recent practice of oiling the meters seems to be an excellent one, as it not only prolongs the life, but also lengthens the period during which the meter retains its original accuracy; but even this custom will not obviate the desirability of testing the meters frequently.

It becomes then of importance to learn what apparatus is required for this work, how it should be used, and some of the finer points, which are in reality the essential ones, of meter testing.

The Standard. A meter is tested for accuracy of registration by passing through it a known volume of air or gas and observing the effect produced on the dial of the meter. This known volume of air is usually forced through the meter from a meter prover, but before the latter can be employed it must be standardized against some instrument of known value. Such an instrument is the standard cubic foot, which may be considered as the primary standard, or court of last appeal.

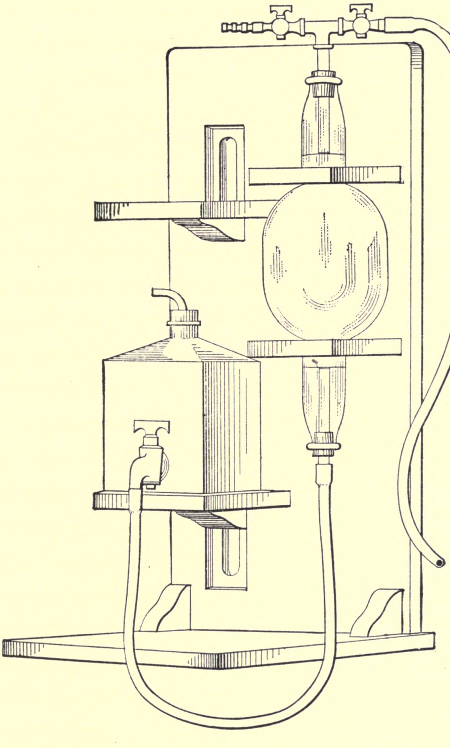

Fig. 47. Referees' Cubic Foot Bottle.

There are three forms of the standard cubic foot in use to-day: the one recommended by the Referees and used in London, the cubic-foot bottle formerly (and still to some extent) used in the United States, and the modern standard cubic foot which is of comparatively recent invention, and which seems destined to replace the older forms. Of these the English form, which is seen in Fig. 47, is intended more for use in the direct testing of meters, and so will not be described here. The methods employed with this instrument will be clear from the diagram and from what will follow regarding the other forms of standards; those interested in this subject, however, should consult the Notification of the Metropolitan Gas Referees for 1907 and 1908.

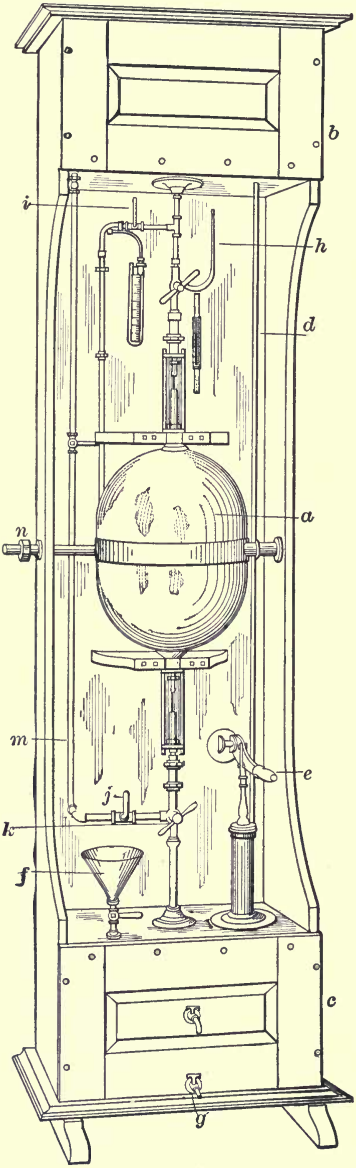

Fig. 48. American Standard Cubic Foot.

The modern standard cubic foot is to be seen in Fig. 48. It consists of an oval copper vessel, *a*, joined at the top and bottom with the water tanks, *b* and *c*, respectively. These tanks are of wood, metal lined, and are connected with each other directly by the pipe, *d*. At *e* is a pump which enables the water to be forced from the lower to the higher tank; *f* is a funnel through which water may be added; and *g*, a cock by which it may be drawn off. Immediately above and below the copper vessel are two small wooden shelves which are fastened to the wooden back of the instrument which runs from the upper to the lower tank and binds the whole together.

The pipe leading from the copper vessel, both above and below, is of glass for about six inches, and on these glass portions are marked the upper and lower limits of the cubic foot. Six inches above the upper glass tube is a three-way cock and a small tube, *h*, which permits of the escape of air. At *i* is a valve by which the cubic foot may be shut off from the apparatus under test, and *j* is a similar valve for controlling the flow of water from the upper tank to the copper vessel; *k* is a three-way cock connecting with the lower tank, the pipe, *m*, and the vessel above; *n* is a threaded connection by which the cubic foot and the apparatus to be tested may be joined. The standard and tanks are of oak, and all of the piping is nickel plated; the cost of the apparatus is $300.

Whenever possible it is desirable to have this cubic foot standardized and certified by the National Bureau of Standards at Washington; this may be done for a nominal sum, and the operator will thus be certain of the value of his primary standard. Should one desire to test the instrument personally, however, this may be done by filling the vessel up to the mark on the upper glass tube with water of 62° F., letting it run out until the mark on the lower gauge glass is reached, and weighing the water thus obtained. The apparatus is constructed to hold, between these two marks, exactly 62.279 pounds of water at 62° F. and 30 inches pressure. If it varies from this, there is an adjustment on the side of the vessel whereby any error may be rectified.

The instrument should be set up level and with the back resting against a solid wall. To prepare for use it is only necessary to fill the lower tank with water to the level of the upper cock, close *j* and pump the water into the upper tank. In filling the copper vessel, first adjust the upper three-way cock so that the only exit for air is through *h*. Turn *k* to connect the upper tank with the vessel, and finally open *j*. The water will run by gravity from the upper tank, the air expelled from the copper vessel escaping through *h*. When the water has risen a trifle above the mark on the upper gauge glass, close *j*, and by careful manipulation of *k* the level of the water may be brought exactly to the mark on the glass. Now turn the upper three-way cock so as to connect the copper vessel with the prover to be standardized, whose valve is closed, and everything is ready for the test.

Little need be said regarding the care of the cubic foot. It is an expensive and handsome piece of apparatus and should be treated accordingly. The nickel work will quickly grow dull on standing in the air, and this should be prevented by frequent polishing. The copper bell should likewise be kept clean and dry, and the pump and all valves should be frequently greased. If the cubic foot is to be but seldom used, it is well to draw off the water after finishing a test, in order that it may not act on the lining of the tanks, pipes, etc. The gauge glasses are so secured in place that they may be easily removed and cleaned, and this should be done whenever necessary.

The so-called water bottle is still employed in many places, and if properly handled will give excellent service. It consists in general of a cylindrical copper tank about 3 feet high and open at the top. From the sides two posts project upwards and at a height of some 6 feet are connected by a cross bar sustaining a wheel, over which passes a steel cord. One end of this is fastened to a weight which hangs outside the line of the cylindrical tank, while the other is connected to a hook in the top of a copper vessel which has somewhat the shape of a football with tapering ends. This vessel or bottle has an opening at the bottom about 1¼ inches in diameter, while at the top the only opening is through two valves which lead, the one by rubber tubing to the instrument to be tested, and the other to the open air. The tank is filled nearly to the top with water of the temperature of the room, and the apparatus is ready for use. The comparison of this instrument with the modern cubic foot will be reserved until after the actual operation of prover testing has been described.

The Meter Prover. There are many types of provers on the market, but as the general construction and operation of all are practically the same, but one kind will be described, although an attempt will be made to enumerate the points of difference noticeable in the other forms.

A prover consists (Fig. 49) of an outer tank, *a*, of galvanized iron, copper, or brass, resting upon three short legs. This tank will vary in dimensions according to the capacity of the prover; for a 5-foot size, it will be about 32 inches high and 24 inches in

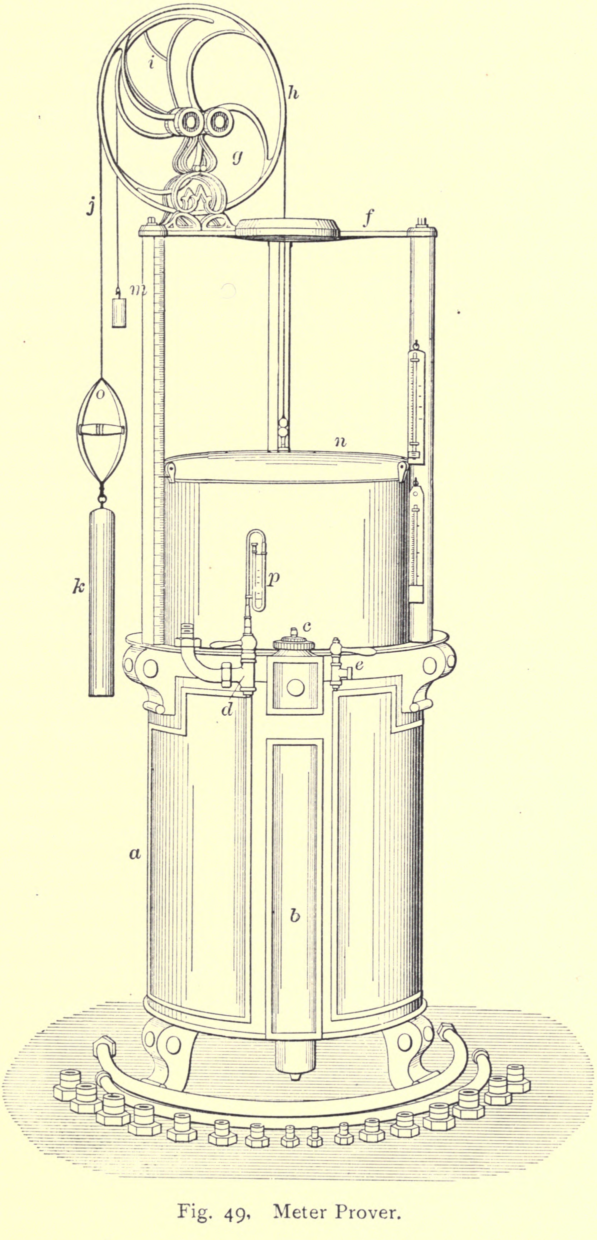

Fig. 49, Meter Prover.

diameter. On the front of this is a rectangular pipe, *b*, which, passing beneath the tank, connects the bell with the revolving valve, *c*, and with the two outlet valves, *d* and *e*. This pipe is known as the air chamber, and serves for the passage of air from the bell either to the room by the valve, *c*, or to the meter to be tested by the valves, *d* and *e*. In some provers this air chamber consists of a cast-iron pipe of about 1½ inches diameter, which has certain advantages as to solidity and indestructibility, but which does not possess the capacity of the rectangular chamber. On the side of the tank opposite to the air chamber is a faucet whereby the water may be removed.

Within the tank, the air chamber may lead above the surface of the water by either of two methods. First, by a slender pipe of about 2 inches diameter, which rises directly in the center of the tank, or, second, by a hole of the same size passing through the center of an interior shell or dome which is closed to both air and water, and which fills nearly the entire diameter of the tank. This second method would seem to be preferable for three reasons. (1) It requires less water to fill the tank; (2) because of this smaller volume of liquid, it is easier to adjust temperatures; (3) the air chamber is well protected, whereas, with the first method, the slender tube is liable to be bent or dented, in which case a leak may well result.

Three posts or columns, 34 inches long, are screwed into the upper rim of the tank at equal distances from each other; these serve to support the cast-iron tripod, *f*, which has in its center a large circular hole through which the chain passes to the top of the bell. The upright cast-iron bracket, *g*, bears two sets of anti-friction rolls, on which rests the axis of the large wheel, *h*, and of the cycloid, *i*. The tripod is held in place by acorns screwed on to the three columns. At the left of the air chamber a nickel scale is fastened to the column by long screws which pass through the latter and are secured in place by thumb nuts. The chain, *j*, is hooked to a loop projecting from the center and top of the bell; it then passes over a groove in the large wheel and is fastened at its other end to the weight, *k*. A cord passes from the end of the cycloid, through a groove in the circumference of the latter, to the nickel weight, *m*.

The bell, *n*, either of copper or galvanized iron, is a hollow cylinder of about the same height as the tank, but its top is slightly dome-shaped, and this portion is always above the level of the outer tank. Placed at equal intervals on the top and bottom are three wheels which run on brass rods attached to the columns and to the interior of the tank; this insures a steady vertical motion to the bell. To the wheel running on the left front column is attached a slender pointer held in place by a thumb nut and which projects well over the scale. *o* is a handle by which the bell is raised, and *p* is a **U** gauge screwed into the top of the valve, *d* or *e*, and which serves to show whether there is any leak in the system beyond this valve. It does not connect with the air chamber, save when the valve is open; when the latter is closed a small hole through it connects the gauge with the meter.

In another form of prover very commonly in use, the scale is screwed to the bell in line with the air chamber, and the pointer consists either of a needle or of a strip of metal about one inch wide which projects horizontally from the top edge of the tank.

Some of the older forms of prover have a circular scale, and the motion of the bell is transferred by suitable gearing to a hand revolving on the scale. In many cases the bell is not supported from the center, but a triangular chain reaches from hooks on the edge of the dome to the chain passing over the wheel. Certain well-equipped meter shops connect the valve, *e*, to a compressed-air supply; this saves a great deal of labor in raising the bell, but there seems to be danger that the temperature of the air entering the prover will not be the same as that of the water and meter. If this difficulty can be overcome, the device will prove most convenient and satisfactory.

In England the bell is raised by a crank at the side of the tank; the writer has never seen this in the United States, and he cannot recommend it, since it requires more time than, and just as much labor as, the method of direct pulling up of the bell by hand. The pressure gauge is not always screwed to the valve, but occasionally to the pipe beyond the latter. Several of these points are illustrated in Fig. 50.

Provers are usually manufactured in two, three, five, six, ten and twelve-foot sizes. For a small company, and especially for those supplying acetylene, the two or three-foot size will give excellent satisfaction. If, however, the company be large, or if it has meters larger than a ten-light to be tested, the five or ten-foot size is to be recommended. A two-foot galvanized iron

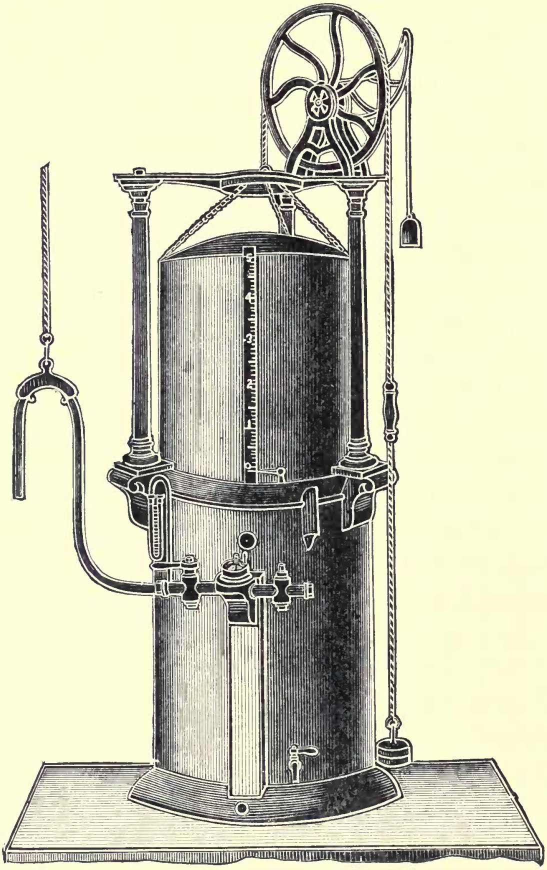

Fig. 50. Meter Prover.

prover may be purchased for $80, while the five-foot size of the same material costs $125, and the ten-foot $200.

If the bell be of copper, the five-foot prover will cost $190, and the two and ten-foot sizes will be proportionately expensive. It is coming to be recognized, however, that a copper prover is the more economical in the end, as it is practically unacted on by water, and the air only forms a thin film of oxide over the surface, which serves to protect the remainder from further attack. On the other hand, waters, and especially those carrying certain amounts of carbonic acid and oxygen in solution, attack vigorously the zinc which forms the coating of the galvanized iron, and it often happens that the bell is perforated with fine holes a few months after it is put in service. This action of the water is greatly facilitated if the galvanizing is thin at any point, since the moment both zinc and iron in contact with each other are exposed to the water, an electric current is generated which increases to a marked extent the attack of the water on the metals. For this reason the copper prover is to be commended to all companies for whom the initial outlay is not too serious a burden.

In setting up the prover, the following directions may be of aid. The tank is to be placed upon its legs and made to stand level. Screw the columns in position on the rim of the tank, and fasten the scale to the column at the left of the air chamber. Insert the bell in the tank, placing it so that the rollers are opposite to and engage with the guide rods on the columns; the roller bearing the pointer is to be adjacent to the scale. Place the iron tripod on top of the columns and fasten it in position by means of the acorns. The end of the tripod bearing the bracket is to be secured to the column bearing the scale.

The large wheel is next inserted between the arms of the bracket, its axis resting on the anti-friction rolls and the cycloid being behind the large wheel. Fasten the cord to the end of the cycloid, and attach the nickel weight to the acorn on the other end of the cord, allowing the latter to rest in the groove of the cycloid. Hook the chain on to the bell, pass it over the large wheel, and fasten the heavy iron weight to its other end. Screw the pressure gauge into the top of the outlet valve, and then, with the circular slide valve open, pour water into the space between the tank and the inner dome until the level of the liquid rises to within about two inches of the top rim of the tank. Haul up the bell by pulling on the chain handle until the pointer reaches the zero mark, then close the slide valve; the prover is now ready for use.

The prover should be set up in a well-lighted room where the temperature may be maintained between 60 degrees and 70 degrees throughout the year. It should not be placed near a radiator, hot-water pipes or register, and if it is near a window or door, care must be exercised to see that no drafts from the latter strike it, and that direct sunlight does not fall on or near the bell or tank. A supply of cold water should be handy, and some means provided whereby hot water may be readily secured. If the connection with the meter is to be made through the valve on the left, a bench should be placed on that side to hold the meter.

Connections and rates should be arranged in a drawer or on a board near by, and a supply of washers of various sizes should be provided. It will be found convenient to suspend the rubber hose, which connects the prover to the meter, from a hook in the ceiling, so that when it is disconnected from the meter it will remain hanging in the air ready for the next connection, and will not cramp.

Two thermometers must be provided which shall read the same under similar conditions. One of these should be used only for taking the temperature of the air; the other should be attached to a chain or string, whereby it may be lowered into the water in the tank. If the air thermometer were used for taking the temperature of the water, it could not again be employed for readings in the air for some time, since the evaporation of the moisture from the bulb cools the mercury, and the record of the instrument will be far too low until it is again entirely dry.

A simple device is in use in many places to enable the operator to devote the time while the meter is running to some other pursuit. This consists of a small bell fastened to one of the columns and a strip of metal to the contiguous part of the bell. When the latter has nearly reached the end of the test, the bell rings automatically and thus calls the tester, who may in the meantime have been busy in some other part of the room.

Care of the Prover. Certain precautions must be observed to keep a prover in good condition. The bell should never be left in the water for any length of time, especially if it be a galvanized-iron prover. The Canadian regulations for inspectors require that the bell shall be raised completely out of the water and held so by a brace placed between the spokes of the large wheel. This is not a bad idea, and may well be followed when the prover is not to be used for some days. A fresh coat of paint occasionally applied to the interior of the tank and to the exterior of the bell and dome or air pipe will also greatly retard the injurious action of the water on the metallic surfaces. The water in the tank should be changed occasionally as the stale water becomes foul with dirt, paint, iron oxide, etc. The scale should be kept polished, and likewise the nickel work on the valves.

Considerable attention must be given to the slide valve to see that it is kept clean and well greased. Small particles of dirt and grit settle on the exposed surfaces of this valve and are caught and held there by the grease used as lubricant. If these are not removed they will slowly grind into the smooth valve seat and cause a leak. A cup is usually furnished with all new provers, and this should be placed over the slide valve whenever the latter is not in use. The other valves must also be kept greased, or a leak will be the result. If the chain rusts badly it will not run smoothly over the wheel, and consequently the movement of the bell will be erratic.

The large weight and the one attached to the cycloid should never be changed after the prover has once been tested; this is very important, and the reason therefor will be made clear by a consideration of the functions of these weights. The chain weight is intended to counterbalance to a certain extent the weight of the bell, leaving, however, enough excess to the latter to maintain a pressure of 1.5 inches at the outlet of the prover. But as the bell is lowered into the water, the latter exercises a greater and greater buoyant effect, and therefore the chain weight, which might have been adequate for its purpose when the bell was at its highest point, would be incorrect when the water had, so to speak, removed a portion of the weight from the bell. The cycloid weight is intended to compensate for this, and is so constructed that at every point in the movement of the bell the pressure exerted by the latter is exactly the same. Now if either of these weights is altered, the pressure on the gas or air in the bell is likewise changed, with the result that the volume of air or gas is less or greater than it would be under standard conditions.

Standardizing the Prover. This operation must be performed in a room saturated with moisture and where the temperature may be kept constant for at least two hours. Drafts must be rigorously excluded, and, on account of the temperature qualification, no heating apparatus should be within the room itself. For the same reason no gas should be allowed to burn in the room during the test, and direct sunlight should be excluded. To saturate the room with moisture, the floors and walls should be kept wet, and blankets soaked in water hung from wires throughout the room, and especially in the neighborhood of the prover and the cubic foot.

The degree of saturation may be determined by means of a wet and dry bulb thermometer, or, if this be not available, it may be roughly estimated by dipping an ordinary thermometer in water and then hanging it in the air. If the room is saturated with moisture, the mercury in this thermometer will not fall to any extent, because the air already contains all the moisture which it can hold, and thus evaporation from the bulb of the thermometer, which would ordinarily ensue, with consequent lowering of the mercury column, is prevented. The reasons for these two precautions as to temperature and saturation will become plain as the description of the test proceeds.

Connect the prover and cubic foot by means of a piece of heavy rubber tubing, and test for a leak by turning on the prover valve and then, after a moment, turning it off and watching the pressure gauge above the valve. If there be a leak anywhere between this valve and the upper gauge glass of the cubic foot, the water in the U gauge will fall. If now the temperatures of water, room and cubic foot be all precisely the same, set the bell of the prover so that the pointer rests exactly on the zero mark of the scale, open the prover valve, turn the upper three-way cock of the cubic foot so that the latter is cut off from the small air-exit tube but is connected with the prover. See that the water in the gauge glass is at the standard mark on the latter, and then turn the outlet three-way cock so that the water runs into the lower tank.

When the water reaches the standard mark on the lower gauge glass, close the outlet cock on the cubic foot and scratch on the prover scale the position of the pointer. This will be the location of the one-foot mark. Pump the water into the upper tank of the cubic foot, turn the upper three-way cock so as to connect the cubic foot with the air outlet tube, open the water cock and allow the water to run into the copper tank until it reaches the upper standard mark.

With the pointer of the prover on the scratch at the one-foot mark, repeat the operation, and so on until the entire length of the scale has been marked in feet. Each foot may then be proportionately divided into tenths and such other divisions as may be desired.

The principle of the operation is this: As the water runs out of the copper tank it sucks over air from the bell of the prover, and since this copper vessel holds exactly one cubic foot between the two marks on the gauge glasses, if the water is run out for this distance precisely one cubic foot of air must have been drawn over from the bell. And now the importance of the precautions regarding temperature and moisture will be apparent; for if dry or unsaturated air were drawn into the bell of the prover, it would pick up moisture from the water in the tank, and thus would not measure the same when transferred to the cubic foot. In like manner, if the temperatures of prover and cubic foot were not the same, a cubic foot of air from the prover would occupy a different volume when transferred to the standard apparatus.

The method just described is only one of the two courses of procedure followed to-day. In the other, weights are attached to the chain or placed on top of the bell, until, with the slide valve open, the bell will remain in any position in which it is placed, thus indicating that there will be no pressure on its contents when filled with air. The remainder of the test is conducted as above described. This is doubtless the most scientific way to test a prover, since there is no compression of the air, and therefore no possibility of making the divisions on the scale too small (considering only the question of pressure). On the other hand, the first method tests the prover under exactly the same conditions which will prevail during a meter test, namely, with the bell exerting a pressure of 1.5 inches, and therefore, unless the results by this process vary materially from those secured by the second method, it would seem to be satisfactory for practical purposes. A short series of tests by the writer, using both forms of procedure, failed to reveal any appreciable difference between the two; indeed, the marks on the scale were exactly the same in each case, so that it would seem as if the difference between the two processes were more theoretical than real.

In addition to what has been already said, one further precaution should be noted. The bell should be raised to its full height and maintained there for a sufficient time, before commencing a test, to permit of its surface becoming thoroughly dry. The reason for this is that the evaporation of moisture from the outer surface would cause cooling of the air content and thus a diminution of the volume of the latter. If, however, the room be thoroughly saturated with moisture, this precaution loses much of its importance.

With the older form of water bottle the procedure is somewhat different. The bottle, after connection with the prover, is hauled out of the water and allowed to drain. Then it is lowered, and as soon as the lower end is sealed by the water in the tank, the valve leading to the prover is opened, and air is forced from the cubic foot into the bell of the prover. Of course in this case the graduation of the scale proceeds from the higher to the lower marks; if, however, the scale be on the bell itself, the zero mark will be at the bottom, and the calibration proceeds in the usual manner. With this form of standard, the bell of the prover must be exactly counterbalanced by weights on the chain, and it is not advisable to test with the 1.5 inch pressure method.

The styles of the cubic foot may now be compared. The modern form is very accurate, may be set up out of the way against a wall, and may be used with either the balanced bell or with 1.5 inches pressure. It is always ready for use, and the water content is less liable to fluctuations in temperature than is the case with the older form. On the other hand, it is difficult to clean the tanks, which may become fouled through the action of water on the metallic surfaces and through deposition of a mineral or organic sediment from the water itself. There are a great many joints to be watched and lubricated, and therefore many possibilities of a leak. The pumping of the water from the lower to the higher tank is a tedious process, and the entire test requires a much longer time than does the use of the water bottle. Finally, the apparatus is very heavy and in no sense portable.

The older water bottle operates more rapidly and nearly as accurately as the above; it is portable, simple and easily cleaned. There are but few joints to be watched, and the labor involved in a test is comparatively small. Its accuracy is somewhat diminished by the fact that the bottle during each foot run becomes submerged in the water, and on raising it there is an evaporation from the surface which tends to diminish the volume of air within.

The water is exposed to the air, and is thus liable to change its temperature frequently during the test. Moreover, in draining, the water runs in a comparatively small stream through the air, and thus becomes cooled. The end-point is not quite as sharp and as satisfactory as with the more modern instrument, and unless care is used, an error is liable to be introduced at this point.

Again, in testing with this form of standard, the bell starts from the bottom of the tank and works upward. When the portions which have been submerged come in contact with the air, the evaporation of water from the metallic surface cools the contents of the bell, and thus a change in volume may ensue.

On the whole, it is probable that the modern cubic foot is the more accurate and scientific instrument, but there is little doubt that, with careful manipulation and in experienced hands, the water bottle will furnish results which are more than sufficiently accurate for practical purposes.

CHAPTER II.

TESTING OF METERS.

Dry Meters. In the testing of meters the most important factor to be considered is that of temperature. This point has been dwelt upon at some length in connection with the standardization of provers, and as the same general principle applies to meter testing, the argument will not be repeated.

Meters must stand in the proving room for a sufficient length of time to permit them to acquire the room temperature. This period will vary with the seasons and the conditions of the meter shop, but in general it is safe to say that at least twelve hours should be allowed, although this may be materially lessened during the summer months. The meters should be placed upon a wooden shelf or platform raised from the floor, since the cold drafts in a room follow the lower levels, and the floor itself is generally much colder than the remainder of the room.

If ideal conditions could be secured, the temperature of this room would be maintained at all times at 62° F., since that is the temperature at which the standard cubic foot was calibrated. This is, of course, impossible, and is not essential for practical work. The thing which is absolutely indispensable, however, is that the temperature of the air in the room and in the prover, the water in the latter and the meter itself, shall be all within 2° F. of each other. It is, of course, desirable to have them even closer than this, but a difference of 2 degrees means only about one-half per cent error in the result, and from the nature of the meter it is generally conceded that it is practically impossible to regularly secure results which check within much less than this figure.

If the water in the prover be colder than the air, its temperature may be raised by the addition of hot water or by the injection of steam. Whichever of these methods is followed, the contents of the tank must be thoroughly mixed before again taking its temperature.

When all is in readiness for the test, the meter is placed upon the bench and its inlet connected to the prover by the use of the proper connecting union, which is wired into the end of the rubber hose. This union must be provided with a clean, sound washer which has not been ridged or cut. Do not screw on the union so tightly as to spoil the washer; the writer has seen so many connections made with a large Stilson wrench and the full power of two brawny arms that he has come to the conclusion that more leaks are caused, in the testing of a meter, by too much tightening than by too little tightening of the inlet union.

The next step is to test for a leak in the meter or connections. Open the prover valve, and as soon as it is seen that air is issuing freely from the meter outlet, place the palm of the hand tightly over the latter and turn off the prover valve. Watch the pressure gauge, and if the water falls more than 0.2 inch it is evidence of a leak between the valve and the outlet of the meter, and this must be stopped before proceeding. There is a very good reason for allowing air to pass through the meter before closing the outlet with the hand. It frequently happens that the meter sticks at first and may not pass gas at all. In such a case, if the hand were placed over the outlet at the start, the pressure gauge would indicate no leak, although such might exist.

If no leak be found, open the prover valve and allow a quantity of air to pass through the meter, the amount varying with the size of the latter. With a 3-light meter, from 1 to 2 feet is generally considered to be sufficient, and it is probable that one-half foot will answer all requirements. This air is passed to allow the meter to assume its normal rate of action before commencing the test, and to be certain that nothing but air of the room temperature fills the diaphragms when the test begins. For the larger sizes of meters it is obvious that a proportionately larger amount of air must be passed to accomplish this.

The testing circle of the meter is the small one in the center of the upper portion of the dial. For the 3 and 5-light sizes this is

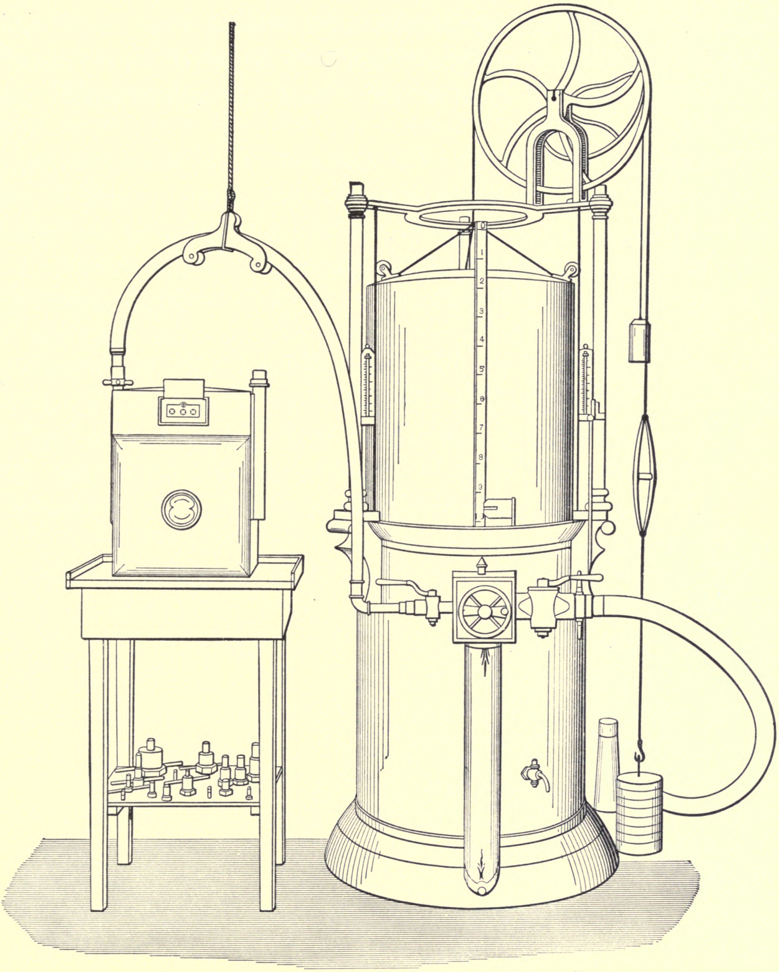

Fig. 51. Meter Prover and Meter Connected for Test.

usually a 2-foot circle, although with meters employed with acetylene it may be smaller than this; indeed, the writer has seen an 80-light meter with a 1-foot testing circle. This circle is divided into fractions of a foot by small marks or dots on its circumference. As the hand approaches one of these divisions on the side of the circle, the rate or speed union is to be placed on the meter outlet, and when the hand exactly covers the desired mark, the prover valve is closed.

Authorities differ greatly as to whether the test should be commenced with the hand at the top of the dial, at the bottom, on the down stroke or on the up stroke. If the mechanism of the meter were perfect, the starting point would probably have little or no influence on the result of the test; but various considerations of back-lash, lost motion, etc., have led to the belief that the error is less if the meter be started from a side point than if the top or bottom is selected. With regard to which side should be chosen, opinions of experts seem to be evenly divided, and therefore neither side is particularly recommended, it being the writer's belief that the results will not be seriously influenced, from a practical standpoint, by the selection of either the down or the up stroke.

The meter may be tested with open outlet and approximate results secured, but the generally accepted legal test is made with the rate on the outlet. Rates, or, as they are sometimes called, speed unions, are made in two styles. In one, a small threaded cap is perforated with a hole of the desired size, while the other consists of a small brass cylinder with a shoulder at the bottom, the top being closed save for the perforation. The size of this aperture varies for different sizes of meters, but all have this common property: with a pressure of 1½ inches on the inlet and the rate screwed on the outlet, the meter should pass gas at the rate of as many tenths of a cubic foot per minute as the meter has lights. In other words, a 3-light rate should pass 0.3 cubic foot per minute, or 18 feet per hour. With natural gas meters, which are classified by sizes and not by lights, the custom is to use the same rate as would be employed with an artificial gas meter of the same capacity.

The theory of the rate is that the meter should be tested under conditions which at least approximate those which will be met in service. It is therefore assumed that a 5-light meter, for example, will on an average be called upon to supply 30 feet per hour or less, although its capacity is over twice this amount. The assumption doubtless was fair in the earlier days of the gas industry, when cooking and heating appliances were practically unknown; but to-day, when the gas used for fuel purposes forms nearly 50 per cent of the total output, it is somewhat questionable whether the rate test is a reasonable criterion of the action of the meter when in service. As it is in many cases, however, a legal requirement, it will probably continue in use for some time to come.

It will be noticed that the rate is to be placed in position on the meter during the preliminary run and before the hand has reached the starting point of the test. The purpose of this is to see that the meter acquires its moderated speed before commencing the actual test. This may appear to be a small matter, and indeed, it is often ignored; but it should be borne in mind that accuracy in this, as well as in every branch of science and business, is secured only by strict attention to numerous small precautions, each of which in itself would seem hardly worthy of recognition.

The bell of the prover is now raised until the pointer is a trifle above the zero mark on the scale. Then by careful manipulation of the unemployed outlet valve, the bell is allowed to sink slowly until the pointer is exactly on zero. Now open the valve leading to the meter and allow sufficient air to pass through the latter to cause one complete revolution of the test hand. When this hand exactly reaches its starting point the prover valve is closed, and the reading on the scale noted. Results are expressed in per cent and fractions of a per cent; a fast percentage is designated as plus, and a slow one, as minus. Check tests of the same meter should be run from different points on the dial and should agree within 0.5 per cent.

To test meters having a testing circle of 10 feet or more on a 5-foot prover, the operation is commenced exactly as already described. When the prover reaches the 5-foot mark, it is shut off, drawn up to zero, and the operation repeated as many times as necessary. On the run immediately preceding the end, however, the prover is not stopped at exactly the 5-foot mark, but wherever it may be when the meter hand again reaches its starting point.

In testing meters which have just been removed from service, it will often be found that the meter will run faster and faster as test after test is made. The cause of this is simple: the passage of gas through the meter has left in the diaphragms certain light and volatile oils. When the air from the prover strikes these, the tendency is for them to evaporate, and in so doing, the diaphragm gradually dries out and shrinks. As the capacity of the diaphragm decreases, the register increases, because the latter makes a certain movement for each pulsation of the diaphragm, which in turn is caused by the passage of a definite amount of gas. If now a smaller amount of gas produces the same pulsation and consequently the same movement on the dial, it is clear that the meter is registering more gas than it passes, and consequently is fast. In the case of meters which behave in this manner and for the above-mentioned cause, it would seem that the first test made represented most nearly the registration of the meter while in service, and therefore is the one to be accepted and reported if the meter belongs to the "complaint" class.

Another difficulty not infrequently met in the case of meters recently removed from service, is to have the valves drag after air has been passed through them. This is caused by the fact that the valves may hold a certain amount of condensate from the gas, which will not affect the action of the meter as long as gas is passing through it. As soon, however, as air comes in contact with this condensate, a chemical change sets in, and the deposit hardens, and so hinders the working of the valves.

In many cases the test of a meter is made with gas instead of air, and this will serve to obviate both of the above-mentioned difficulties. Indeed, where it is convenient, it is well to keep one prover filled with gas and to test all complaint meters thereon. The general practice of testing all meters with gas is not to be recommended. The gas issuing from the meter must either be led outside of the building or be burned at the outlet. In the first case it is liable to become a nuisance, and in the second it serves to rapidly change the temperature of the room. Air costs nothing, and may readily be obtained of the room temperature; gas is, relatively speaking, expensive, and coming from the holder or mains, it is liable to be of very different temperature from the water in the prover and from the meter. Gas gives no more satisfactory results (except in the cases above mentioned) than does air, and has the final disadvantage of being dangerous. This may seem absurd, but the writer has seen the entire top of a heavy iron meter blown out by carelessness in testing with gas, and only by the best of fortune did the tester escape serious bodily injury.

There are two methods in common use to-day for calculating the percentage error of the meter, and as there has been considerable controversy over these, they will be discussed somewhat in detail. The first, which will be called method A for brevity, consists in dividing the difference between the readings of the meter and prover, multiplied by 100, by the prover reading; the second, or method B, divides the same figure by the reading of the meter. To illustrate, assume that the meter read 2.0 feet and the prover 1.96 feet. By method A the percentage error of the meter would be

$$\frac{(2.00 - 1.96) \times 100}{1.96}, \text{ or } 2.04 \text{ per cent fast.}$$

By method B the calculation would be

$$\frac{(2.00 - 1.96) \times 100}{2.00} = 2.00 \text{ per cent fast.}$$

In practice these calculations are seldom employed, the percentage by method A being found from a table which will be given in the appendix, and by method B being read direct from the prover scale, as will be explained later.

Reduced to simple terms, the difference between the two methods is this: "A" determines what percentage of the gas passing, registers; "B" determines what percentage of the gas registered, actually passes the meter. "A" takes the volume of gas passing as the central point or basis of the calculation; "B" accepts the register of the meter as the basis. Now it would seem indisputable that both of these methods are correct, if we assume the bases of calculation as given above. This may seem strange at first in view of the illustration recently quoted, wherein the meter was found to be 2.04 per cent fast by one method and 2 per cent by the other. If, however, the base of the calculation is remembered, these results are in no wise contradictory or discordant. By method A it is seen that the meter registered 102.4 per cent of the gas which it actually passed, which was 1.96 feet, and 102.4 per cent of 1.96 is 2 feet, the amount which the meter registered in the test. By method B, it is stated that the meter passed only 98 per cent of what the register showed, and 98 per cent of 2 feet gives us 1.96 feet, the quantity of gas passed as shown by the prover reading.

For method A, it is urged that the reading of the prover, which is authoritative, is accepted as the standard, but so it is with method B, that is, the reading of the prover is accepted as absolutely correct, but the register of the meter is the central thought and is taken as the total, or 100 per cent. This seems just for two reasons: First, the register itself is rarely in error, the fault almost always lying with the valves or diaphragms; second, the register is the only visible means which the consumer possesses of ascertaining the action of his meter. As a rule, the vital point of interest to both consumer and company is not the amount of gas which passes the meter, but the quantity which is to be paid for, and this is necessarily the amount shown by the dial.

Moreover, one statement of percentage by method B answers all questions, and this is not true of method A. For instance, a certain consumer was informed that his meter was 10 per cent fast (this percentage being reached by method B), and he wrote to the Public Service Commission of the Second District, New York, to know what rebate he might expect. The answer was simplicity itself, 10 cents on each dollar which he had paid. Compare this with a similar case where the percentage was determined by method A. Another meter was tested in New York and reported to the consumer as 42 per cent fast. The attorneys for complainant took this report to the company and were informed that a rebate of 42 per cent could not be granted, but that the correct percentage on which to figure said rebate was the ratio of 42 to 142, or 29.6 per cent, this latter figure being exactly the one which would have been reached in the first place by method B.

In this connection the following paragraph quoted from the report of the General Inspector of the company (the latter, by the way, one of the largest in the world) is very pertinent: "As indicated, the test of the meter showed that it was recording with an accuracy of 142 per cent. This does not mean, permit me to suggest, that the meter was 42 per cent fast, but rather approximately 30 per cent. The meter record should be 100 per cent; the actual record was 142 per cent; . . . the percentage of the overcharge, it will be apparent, is the ratio of 42 to 142, which you will notice is much less than 42 per cent. The exact result is reached by dividing 42 by 142, which is almost exactly 29.6 per cent." In replying to the attorneys for the complainant, and referring to the above paragraph, the commission to which this matter was referred, says: "The contention of the . . . company is therefore correct."

Certain mathematical considerations likewise seem to point to method B as the most advisable one to adopt. According to method A, it is mathematically impossible for a meter to be infinitely slow, namely, to pass gas forever without registering at all. This will be clear if we remember that the formula for calculating percentage by this method is "difference of prover and meter divided by prover." In order to make this quotient infinity, it is necessary that the divisor should be zero. But a meter cannot be found slow unless the prover has passed more gas than the meter; consequently the reading of the prover cannot be zero, and the quotient cannot be infinity. Now with method B, the reading of the meter is the divisor, and this may be, and frequently is, zero, thus giving a quotient of infinity. It is a matter of common knowledge and occurrence that, through leaky diaphragms or other causes, a meter may pass gas without registering, and such a meter is clearly infinitely slow; this fact, then, is brought out by method B, and not by method A.

Again, by method A, it is mathematically possible to have a meter infinitely fast, that is, to register gas forever without passing anything. This conclusion is reached in the following manner: If the meter registers 2 feet and the prover 1 foot, the meter is 100 per cent fast. If the prover reads but 0.5 foot, the percentage is 300 fast; if it reads 0.1 foot, the percentage is 1900 fast; if it reads 0.01 foot, the percentage is 19,000 fast, and so on. Pushing this to its *mathematical* conclusion, we reach a point where the prover reads zero and the meter is infinitely fast. An infinitely fast meter would be a violation of one of the first principles of physics, since we would then have motion without the expenditure of energy. With method B, no meter can ever be found to be infinitely fast, because the divisor of the fraction above mentioned is the reading of the meter, and this, it is self-evident, can never be zero with a fast meter.

One more point of evidence in favor of method B is worthy of note. The vast majority of meter provers have their scales divided, in the vicinity of the 2, 4, 5 and 10-foot marks, so as to enable one to read off the percentage error of the meter direct, if method B is used. Such graduation is purposely so made by the manufacturers with exactly that end in view. This saves a great deal of time and labor, and it would seem evident that this action on the part of the manufacturers indicates their belief that method B is at least as satisfactory as method A. The divisions at the 2-foot mark are 0.02 foot; at the 4-foot mark they are 0.04 foot, at the 5-foot mark, 0.05, and at the 10-foot mark 0.1 foot, thus in each case being one one-hundredth, or 1 per cent, of the total length of the scale from zero to that point.

Let it be distinctly understood that the writer is not endeavoring to prove that method A is incorrect; on the contrary, it is his firm belief that both methods are correct, but that "B" involves less labor, is more easily comprehensible, serves better to explain certain facts connected with meters (that they may be infinitely slow, for instance), is less liable to give rise to difficulties with consumers, and is in general better suited to meter work. It is realized that "A" is upheld by many eminent authorities and is undoubtedly scientifically correct; method B has, however, equally eminent advocates, and the mathematical deductions above given have been confirmed by several of the best authorities in the United States.

While, as has been said, the temperatures of the room, the meter and the prover should all be within 2 degrees of each other, it occasionally happens that the inspector desires to make a correction for variations in temperature. For this, Abady gives the following rule: "Multiply the number of cubic feet and parts delivered from the holder by the number of degrees of difference in temperature and by 0.0025, and, (*a*) if the gas from the meter be higher in temperature, add the product to the quantity indicated by the gas holder; (*b*) if the gas be of lower temperature at the outlet of the meter, subtract the product from the gas holder reading."

Wet Meters. In testing a wet meter, such as is used with a photometer, a somewhat different procedure is followed. The meter is first very accurately leveled and then filled with water of the room temperature up to a certain chosen mark on the gauge glass. In this test the temperatures of the room and prover should be exactly the same; the wet meter is intended for very accurate work, and no allowance of 2 degrees, or even 0.5 degree, can be made. The prover is connected to the meter inlet and air passed through the meter at the rate of 6 feet per hour for some time. To secure this rate the writer uses a 6-foot lava tip inserted in a perforated cork, the latter being placed in the outlet of the meter. Shut off the prover when the meter hand reaches zero, set the prover on zero, and run 2 feet of air through the meter. If the latter is found to be slow, add water and repeat the test. The amount of water to be added can only be roughly stated; a difference of one-sixteenth inch in the height of the water in the gauge glass is supposed, with a 6-foot photometer meter, to make a difference of about 1 per cent in the registration of the meter, but this clearly will not be the same with different meters, varying sizes of the gauge glass, etc. The tests are continued until the readings of the meter and prover exactly agree. Then the meter is disconnected, the rate removed, and the valve above the water glass opened.

Now, with the meter perfectly level, make a scratch on the glass at the lowest point touched by the meniscus of the water in the gauge. If no alterations are made to the meter, this mark will remain accurate for a long time, as there are no diaphragms or valves to the wet meter to change or become clogged. It should never be forgotten, however, that the water level must be adjusted every time that the meter is used, and always *with the inlet and outlet open to the air*, or, in other words, with absolutely no pressure on the meter.

For the sake of increased accuracy, the small wet meter used with the calorimeter, the o-light dry meter and the special photometer meter employed by the writer are always tested against a standardized wet meter, and with gas from the city mains. The standard meter is permanently set up on a bench, and its outlet is connected with an iron pipe, on which are several connections for rubber tubing. The meter to be tested is connected to one of these, and after the whole system is full of gas, the latter is shut off and the readings of both meters recorded. A definite amount of gas is then passed, at a rate approximating that at which the meter under test will generally be used, and again the readings of both dials are noted. It is then a simple matter of arithmetic to figure the percentage error of the meter.

In proving meters with the tops off, or open-top meters, as they are called, the dial is not used, as more accurate results can be secured by the use of the tangent as an indicator. Set this at a chosen point, and, starting the prover at zero, run 2 feet of air through the meter and count the number of revolutions of the tangent. If, when the prover shows 2 feet, the position of the tangent is the same as at the beginning of the test, and if the number of revolutions is correct for the size of meter under examination, no further adjustment is necessary. If, however, the meter is fast, loosen the nut on the tangent and turn it outward; this causes the flag arms to make a longer circuit, and consequently the meter passes more gas for the same number of revolutions. The number of such revolutions which a meter will make in passing 2 feet, depends on the size of the meter and, somewhat, on the type. Thus, a 3-light meter of American manufacture will make 18 revolutions, and a 5-light, 12 revolutions, while there is a 3-light meter which makes but 16. In the appendix will be found a table giving the capacities of some of the commoner types and sizes of meters.

In general, laws regarding the accuracy of gas meters require that they shall not be more than 2 per cent in error, although in Great Britain 3 per cent is allowed if the error be in favor of the consumer, while in St. Louis, Mo., the meters are required to be within 1 per cent of theoretical accuracy. Considering these fairly uniform regulations, it seems just to compare the results of meter tests from various localities. In view of the general idea of the consumer, that most meters are fast, and in order to supply figures with which such statements may be met, the following statistics of recent date may be of value.

During the year 1907, 80,703 meters were subjected to regular inspection in London. Of this number 78,739, or 97.6 per cent, were correct, while of the incorrect meters, only 401, or 0.5 per cent of the total number, were registering against the consumer. Out of 86,025 meters tested in Edinburgh in the year ending May 15, 1908, 770, or nine-tenths of 1 per cent, were incorrect, and the remaining 99.1 per cent were correct within legal limits. In Canada, during the year 1906–1907, 29,154 meters were tested, and only 58, or 0.2 per cent, were incorrect to the prejudice of the consumer, while 99.5 per cent were correct. The Massachusetts State Inspector reports 58,676 meters tested during 1908; of these about 99.8 per cent were correct, and 0.2 per cent were incorrect. In New York State, outside of New York City, the Public Service Commission tested, during 1908, 103,236 meters. Of these, 99,065, or 96.0 per cent, were correct; 2045, or 2.0 per cent, were fast; and 1675, or 1.6 per cent, were slow. The average error of the fast meters was 4.0 per cent, and of the slow meters, 5.6 per cent. Evidence such as this could be multiplied indefinitely to prove that the vast majority of gas meters in use to-day were correct when they were put in service, and while with "complaints" the number of fast meters is naturally much greater than with regular meters, the average percentage error of such meters, if taken over a considerable period of time, will rarely exceed 5.5 per cent, and the burden of evidence seems to prove conclusively that the gas company loses vastly more by its slow meters than it gains by those which are fast.

APPENDIX.

TABLE I. — ATOMIC WEIGHTS.

Name.	Symbol.	O = 16.	H = 1.	Name.	Symbol.	O = 16.	H = 1.
Aluminium......	Al	27.1	26.9	Mercury.......	Hg	200.0	198.5
Antimony......	Sb	120.2	119.3	Molybdenum ..	Mo	96.0	95.3
Arsenic.........	As	75.0	74.4	Nickel........	Ni	58.7	58.3
Barium.........	Ba	137.4	136.4	Nitrogen.......	N	14.04	13.93
Bismuth........	Bi	208.5	206.9	Oxygen........	O	16.00	15.88
Boron..........	B	11.0	10.9	Palladium.....	Pd	106.5	105.7
Bromine........	Br	79.96	79.36	Phosphorus....	P	31.0	30.77
Cadmium.......	Cd	112.4	111.6	Platinum......	Pt	194.8	193.3
Calcium........	Ca	40.1	39.8	Potassium.....	K	39.15	38.86
Carbon.........	C	12.00	11.91	Radium.......	Ra	225.0	223.3
Chlorine.......	Cl	35.45	35.18	Selenium......	Se	79.2	78.6
Chromium......	Cr	52.1	51.7	Silicon........	Si	28.4	28.2
Cobalt.........	Co	59.0	58.56	Silver.........	Ag	107.93	107.12
Copper.........	Cu	63.6	63.1	Sodium........	Na	23.05	22.88
Fluorine........	F	19.0	18.9	Strontium......	Sr	87.6	86.94
Gold...........	Au	197.2	195.7	Sulphur.......	S	32.06	31.83
Helium.........	He	4.0	4.0	Tin...........	Sn	119.0	118.1
Hydrogen......	H	1.008	1.000	Titanium......	Ti	48.1	47.7
Iodine.........	I	126.97	126.01	Tungsten......	W	184.0	182.6
Iron...........	Fe	55.9	55.5	Uranium......	U	238.5	236.7
Lead...........	Pb	206.9	205.35	Vanadium.....	V	51.2	50.8
Lithium........	Li	7.03	6.98	Yttrium.......	Yt	89.0	88.3
Magnesium.....	Mg	24.36	24.18	Zinc..........	Zn	65.4	64.9
Manganese.....	Mn	55.0	54.6	Zirconium.....	Zr	90.6	89.9

TABLE II. — COMPARISON OF ENGLISH AND METRIC SYSTEMS.

1 milligram = 0.001 gram = 0.01543 grain.
1 gram = 15.432349 grains = 0.0022 pound.
1 kilogram = 1000 grams = 2.2046 pounds Avoirdupois.

1 grain = 0.064799 gram.
1 ounce Avoirdupois = 28.3496 grams.
1 pound Avoirdupois = 453.59 grams.

1 liter = 61.028 cubic inches.
1 liter = 0.220215 Imperial gallon.

1 millimeter = 0.03937 inch.
1 meter = 39.37079 inches.

1 cubic inch = 0.016386 liter.
1000 cubic feet = 28,315 liters.

1 inch = 25.39954 millimeters.
1 foot = 0.3048 meter.

1 square inch = 645.137 square millimeters.
1 square foot = 0.0929 square meter.
1 square yard = 0.8361 square meter.

1 cubic inch = 16,386 cubic millimeters.
1 cubic foot = 0.028315 cubic meter.

TABLE III. — COMPARISON OF FAHRENHEIT AND CENTIGRADE SCALES.

Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.
212	100.0	162	72.2	112	44.4	62	16.6
211	99.4	161	71.6	111	43.8	61	16.1
210	98.8	160	71.1	110	43.3	60	15.5
209	98.3	159	70.5	109	42.7	59	15.0
208	97.7	158	70.0	108	42.2	58	14.4
207	97.2	157	69.4	107	41.6	57	13.8
206	96.6	156	68.8	106	41.1	56	13.3
205	96.1	155	68.3	105	40.5	55	12.7
204	95.5	154	67.7	104	40.0	54	12.2
203	95.0	153	67.2	103	39.4	53	11.6
202	94.4	152	66.6	102	38.8	52	11.1
201	93.8	151	66.1	101	38.3	51	10.5
200	93.3	150	65.5	100	37.7	50	10.0
199	92.7	149	65.0	99	37.2	49	9.4
198	92.2	148	64.4	98	36.6	48	8.8
197	91.6	147	63.8	97	36.1	47	8.3
196	91.1	146	63.3	96	35.5	46	7.7
195	90.5	145	62.7	95	35.0	45	7.2
194	90.0	144	62.2	94	34.4	44	6.6
193	89.4	143	61.6	93	33.8	43	6.1
192	88.8	142	61.1	92	33.3	42	5.5
191	88.3	141	60.5	91	32.7	41	5.0
190	87.7	140	60.0	90	32.2	40	4.4
189	87.2	139	59.4	89	31.6	39	3.8
188	86.6	138	58.8	88	31.1	38	3.3
187	86.1	137	58.3	87	30.5	37	2.7
186	85.5	136	57.7	86	30.0	36	2.2
185	85.0	135	57.2	85	29.4	35	1.6
184	84.4	134	56.6	84	28.8	34	1.1
183	83.8	133	56.1	83	28.3	33	0.5
182	83.3	132	55.5	82	27.7	32	0.0
181	82.7	131	55.0	81	27.2	....	....
180	82.2	130	54.4	80	26.6	....	....
179	81.6	129	53.8	79	26.1	....	....
178	81.1	128	53.3	78	25.5	....	....
177	80.5	127	52.7	77	25.0	....	....
176	80.0	126	52.2	76	24.4	....	....
175	79.4	125	51.6	75	23.8	....	....
174	78.8	124	51.1	74	23.3	....	....
173	78.3	123	50.5	73	22.7	....	....
172	77.7	122	50.0	72	22.2	....	....
171	77.2	121	49.4	71	21.6	....	....
170	76.6	120	48.8	70	21.1	....	....
169	76.1	119	48.3	69	20.5	....	....
168	75.5	118	47.7	68	20.0	....	....
167	75.0	117	47.2	67	19.4	....	....
166	74.4	116	46.6	66	18.8	....	....
165	73.8	115	46.1	65	18.3	....	....
164	73.3	114	45.5	64	17.7	....	....
163	72.7	113	45.0	63	17.2	....	....

TABLE IV. — SHOWING SPECIFIC GRAVITY, WEIGHT AND SOLUBILITY OF VARIOUS GASES.[1]

Name.	Sp. Gr. Air= 1.	Weight of 1 cu. ft. in lbs. avoir.	Weight of 1 cu. ft. in grains.	No. of cu. ft. equal to 1 lb.	Solubility. 100 vols. of water absorbed.
Hydrogen	0.0691	0.00529997	37.09	188.68	1.93 vols.
Light carburetted hydrogen	0.559	0.0428753	300.12	23.32	3.91 vols.
Ammonia	0.590	0.045253	316.77	22.09	72,720 vols.
Carbon monoxide	0.967	0.0741689	519.18	13.48	2.43 vols.
Olefiant gas	0.968	0.0742456	519.71	13.46	16.15 vols.
Nitrogen	0.9713	0.07449871	521.49	13.42	1.48 vols.
Air	1.000	0.0767	536.90	13.03	1.70 vols.
Nitric oxide	1.039	0.0796913	557.83	12.54	Not soluble.
Oxygen	1.1056	0.08479952	593.59	11.79	2.99 vols.
Sulphuretted hydrogen	1.1747	0.09009949	630.69	11.09	323.26 vols.
Nitrous oxide	1.527	0.1171209	819.84	8.53	77.78 vols.
Carbonic acid	1.529	0.1172743	820.92	8.52	100.20 vols.
Sulphurous acid	2.247	0.1723449	1206.41	5.80	4276.60 vols.
Chlorine	2.470	0.189449	1326.14	5.27	236.80 vols.
Carbon bisulphide	2.640	0.202488	1417.41	4.93	Not soluble.

[1] Latta's Hand Book of American Gas Engineering Practice.

TABLE V.—SHOWING CORRECTIONS FOR TEMPERATURE AND PRESSURE.

BAROMETER.

TEMPERATURE	28.6	28.7	28.8	28.9	29.0	29.1	29.2	29.3	29.4	29.5	29.6	29.7	29.8	29.9	30.0	30.1	30.2	30.3	30.4	30.5
107	.816	.820	.823	.826	.829	.832	.835	.838	.841	.844	.847	.851	.854	.857	.860	.864	.867	.870	.874	.877
106	.820	.823	.826	.829	.832	.835	.838	.841	.844	.847	.851	.854	.857	.860	.863	.867	.870	.874	.878	.881
105	.823	.827	.830	.833	.836	.839	.842	.845	.848	.851	.855	.858	.861	.864	.867	.871	.874	.878	.881	.884
104	.827	.830	.833	.836	.839	.842	.845	.848	.851	.854	.858	.861	.864	.867	.871	.874	.878	.881	.884	.887
103	.830	.834	.837	.840	.843	.847	.849	.852	.855	.858	.862	.865	.868	.871	.874	.878	.881	.885	.888	.891
102	.834	.837	.840	.843	.847	.850	.853	.856	.859	.862	.865	.868	.871	.874	.878	.881	.885	.888	.891	.894
101	.837	.840	.843	.846	.850	.853	.856	.859	.862	.865	.868	.872	.875	.878	.882	.885	.888	.891	.895	.898
100	.840	.843	.846	.849	.853	.856	.859	.862	.865	.868	.872	.875	.878	.881	.885	.888	.891	.895	.898	.901
99	.844	.847	.850	.853	.857	.860	.863	.866	.869	.872	.876	.879	.882	.885	.889	.892	.895	.898	.902	.905
98	.847	.850	.853	.856	.860	.863	.866	.869	.872	.875	.879	.882	.885	.888	.892	.895	.898	.902	.905	.908
97	.850	.853	.856	.859	.863	.866	.870	.873	.876	.879	.882	.885	.888	.891	.894	.898	.901	.905	.908	.911
96	.854	.857	.860	.863	.867	.870	.873	.876	.879	.882	.886	.889	.892	.895	.898	.901	.904	.908	.911	.914
95	.857	.860	.863	.866	.870	.873	.876	.879	.882	.885	.889	.892	.895	.898	.901	.904	.908	.911	.914	.918
94	.860	.863	.866	.869	.873	.876	.879	.882	.885	.888	.892	.895	.898	.901	.904	.907	.911	.914	.918	.921
93	.863	.866	.869	.872	.876	.879	.883	.886	.889	.891	.895	.898	.901	.904	.907	.910	.914	.918	.921	.924
92	.866	.869	.872	.875	.879	.882	.885	.889	.892	.894	.898	.902	.904	.907	.910	.914	.917	.921	.924	.928
91	.869	.872	.875	.879	.882	.885	.889	.892	.895	.898	.902	.905	.908	.911	.914	.917	.921	.924	.928	.931
90	.872	.875	.878	.881	.885	.888	.892	.895	.898	.901	.905	.908	.911	.914	.917	.920	.924	.927	.931	.934
89	.875	.878	.882	.885	.889	.892	.895	.898	.901	.904	.907	.910	.914	.917	.920	.923	.927	.931	.934	.937
88	.878	.881	.885	.888	.892	.895	.898	.901	.904	.907	.910	.913	.917	.920	.923	.926	.930	.934	.937	.940
87	.881	.884	.888	.891	.895	.898	.901	.904	.907	.910	.913	.916	.920	.923	.926	.929	.933	.937	.940	.943
86	.884	.887	.890	.894	.898	.901	.904	.907	.910	.913	.916	.919	.923	.926	.929	.932	.936	.940	.943	.946
85	.887	.890	.893	.896	.900	.903	.906	.909	.913	.916	.919	.922	.926	.929	.932	.936	.939	.943	.946	.949
84	.889	.893	.896	.899	.903	.906	.909	.912	.915	.919	.922	.925	.928	.932	.935	.939	.942	.946	.949	.952
83	.892	.895	.899	.902	.906	.909	.912	.915	.918	.921	.924	.928	.931	.935	.938	.942	.945	.949	.952	.955
82	.895	.898	.901	.905	.908	.911	.914	.918	.921	.924	.927	.931	.934	.937	.941	.945	.948	.951	.954	.958
81	.898	.901	.905	.908	.911	.914	.917	.921	.924	.927	.930	.934	.937	.940	.944	.948	.951	.954	.957	.960
80	.901	.904	.907	.910	.914	.917	.920	.923	.927	.930	.933	.937	.940	.943	.946	.950	.954	.957	.960	.963
79	.904	.907	.910	.914	.917	.920	.923	.926	.930	.933	.936	.939	.943	.946	.949	.953	.956	.960	.963	.967
78	.906	.909	.913	.916	.919	.923	.926	.929	.932	.936	.939	.942	.946	.949	.952	.956	.959	.962	.966	.969
77	.909	.912	.915	.919	.922	.925	.928	.931	.935	.938	.942	.945	.948	.951	.955	.958	.962	.965	.968	.972

TEMPERATURE																				
76	.911	.915	.918	.921	.925	.928	.931	.935	.938	.941	.944	.948	.951	.954	.958	.961	.964	.968	.971	.975
75	.914	.917	.921	.924	.928	.931	.934	.937	.940	.943	.947	.950	.954	.957	.960	.963	.967	.971	.974	.978
74	.917	.920	.924	.927	.930	.933	.937	.940	.943	.947	.950	.953	.957	.960	.963	.966	.970	.973	.977	.980
73	.920	.923	.926	.930	.933	.936	.940	.943	.946	.949	.953	.956	.960	.963	.966	.969	.972	.976	.980	.983
72	.922	.925	.929	.932	.935	.939	.942	.945	.949	.952	.955	.959	.962	.965	.968	.972	.975	.979	.982	.986
71	.925	.928	.931	.935	.938	.941	.945	.948	.951	.954	.958	.961	.965	.968	.971	.975	.978	.981	.985	.989
70	.927	.931	.934	.937	.941	.944	.947	.950	.954	.957	.960	.964	.967	.970	.974	.977	.980	.984	.988	.991
69	.930	.933	.937	.940	.944	.947	.950	.953	.957	.960	.963	.967	.970	.973	.977	.980	.983	.987	.990	.994
68	.932	.936	.939	.942	.946	.949	.952	.956	.959	.962	.966	.969	.972	.976	.979	.983	.986	.989	.993	.997
67	.935	.938	.942	.945	.949	.952	.955	.959	.962	.965	.968	.972	.975	.979	.982	.985	.989	.992	.996	1.000
66	.938	.941	.944	.948	.951	.954	.958	.961	.964	.968	.971	.974	.978	.981	.985	.988	.992	.995	.998	1.002
65	.941	.944	.947	.950	.954	.957	.960	.963	.967	.970	.973	.977	.980	.984	.987	.991	.994	.997	1.001	1.005
64	.943	.946	.949	.953	.956	.959	.963	.966	.969	.973	.976	.980	.983	.986	.990	.994	.997	1 000	1.004	1.008
63	.945	.949	.952	.955	.959	.962	.965	.969	.972	.975	.979	.982	.985	.989	.993	.996	1.000	1.003	1.006	1.010
62	.947	.951	.954	.958	.961	.964	.968	.971	.975	.978	.981	.985	.988	.991	.995	.999	1.002	1.005	1.009	1.013
61	.950	.954	.957	.961	.964	.967	.971	.974	.977	.981	.984	.987	.991	.994	.998	1.001	10.05	1.008	1.011	1.015
60	.952	.956	.959	.963	.966	.969	.973	.976	.980	.983	.986	.990	.993	.997	1.000	1.004	1.007	1.010	1.014	1.017
59	.955	.959	.962	.966	.969	.972	.976	.979	.983	.986	.989	.992	.995	.999	1.003	1.006	1.010	1.013	1.016	1.020
58	.957	.961	.964	.968	.971	.975	.978	.981	.985	.988	.992	.995	.998	1.002	1.005	1.009	1.012	1.016	1.019	1.023
57	.960	.963	.967	.970	.974	.977	.980	.984	.988	.991	.994	.997	1.000	1.004	1.007	1.011	1.014	1.018	1.021	1.025
56	.962	.966	.969	.973	.976	.979	.982	.986	.990	.993	.996	1.000	1.003	1.007	1.010	1.014	1.017	1.021	1.024	1.028
55	.965	.968	.972	.975	.979	.982	.985	.989	.993	.996	.999	1.002	1.006	1.009	1.013	1.016	1.020	1.023	1.027	1.030
54	.967	.970	.974	.977	.981	.984	.988	.991	.995	.998	1.001	1.005	1.008	1.012	1.015	1.019	1.022	1.026	1.029	1.033
53	.969	.973	.976	.980	.983	.986	.990	.993	.997	1.000	1.004	1.007	1.011	1.014	1.018	1.021	1.025	1.028	1.031	1.035
52	.971	.975	.978	.982	.985	.989	.992	.996	.999	1.003	1.006	1.010	1.013	1.017	1.020	1.024	1.027	1.031	1.034	1.038
51	.974	.977	.981	.984	.988	.991	.995	.998	1.002	1.005	1.009	1.012	1.016	1.019	1.023	1.026	1.030	1.033	1.037	1.040
50	.976	.980	.983	.987	.990	.994	.997	1.001	1.004	1.008	1.011	1.015	1.018	1.022	1.025	1.029	1.032	1.036	1.039	1.043
49	.979	.982	.986	.989	.993	.996	1.000	1.003	1.007	1.010	1.014	1.017	1.021	1.024	1.028	1.031	1.035	1.038	1.042	1.045
48	.981	.985	.988	.992	.995	.999	1.002	1.006	1.009	1.013	1.016	1.020	1.023	1.027	1.030	1.034	1.037	1.041	1.044	1.048
47	.984	.987	.991	.994	.998	1.001	1.005	1.008	1.012	1.015	1.019	1.022	1.026	1.029	1.033	1.036	1.040	1.043	1.047	1.050
46	.986	.990	.993	.997	1.000	1.004	1.007	1.011	1.014	1.018	1.021	1.025	1.028	1.032	1.035	1.039	1.042	1.046	1.049	1.053
45	.989	.992	.996	.999	1.003	1.006	1.010	1.013	1.017	1.020	1.024	1.027	1.031	1.034	1.038	1.041	1.045	1.048	1.052	1.056
44	.991	.994	.998	1.001	1.005	1.008	1.012	1.015	1.019	1.022	1.026	1.029	1.033	1.036	1.040	1.043	1.047	1.050	1.054	1.058
43	.993	.997	1.001	1.004	1.008	1.011	1.015	1.018	1.022	1.025	1.029	1.032	1.036	1.039	1.043	1.046	1.050	1.053	1.057	1.060
42	.995	2.999	1.003	1.006	1.010	1.013	1.017	1.020	1.024	1.027	1.031	1.034	1.038	1.041	1.045	1.048	1.052	1.055	1.059	1.063
41	.998	1.001	1.005	1.009	1.012	1.016	1.019	1.023	1.026	1.030	1.034	1.037	1.041	1.044	1.048	1.051	1.055	1.058	1.062	1.065
40	1.000	1.004	1.007	1.011	1.014	1.018	1.021	1.025	1.028	1.032	1.036	1.039	1.043	1.046	1.050	1.053	1.057	1.060	1.064	1.068
39	1.002	1.006	1.010	1.013	1.017	1.020	1.024	1.028	1.031	1.035	1.038	1.042	1.045	1.049	1.052	1.056	1.059	1.063	1.066	1.070

TABLE VI. — SHOWING THE EFFECT OF TEMPERATURE ON CANDLEPOWER.

TESTS MADE ON WATER GAS, USING AN OPEN BURNER.

Temperature in degrees Fahr.	Observed candlepower.	Corrected candlepower.	Increase or decrease.	Per cent increase or decrease.
30	8.46	19.27	2.92	13.2
35	8.82	20.09	2.10	9.5
41	9.02	20.56	1.63	7.3
50	9.46	21.55	0.64	2.9
56	9.70	22.10	0.09	0.4
60–66	9.74	22.19	....	....
72	9.91	22.57	0.38[1]	1.7
81	10.10	23.01	0.82[1]	3.7
89	10.26	23.36	1.17[1]	5.3
100	10.84	24.69	2.50[1]	11.3

[1] Increase.

TESTS MADE ON COAL GAS, USING LONDON ARGAND BURNER.

35	8.84	16.26	0.17	1.0
41	8.85	16.28	0.15	0.9
47	8.87	16.32	0.09	0.5
56	8.92	16.41	0.02	0.1
61–65	8.93	16.43	....	....
70	8.94	16.45	0.02[1]	0.1
81	8.97	16.50	0.07[1]	0.4
87	9.12	16.78	0.35[1]	2.1
95	9.52	17.51	1.08[1]	6.6
100	9.76	17.95	1.52[1]	9.3

[1] Increase.

Room was kept at 60° F. throughout the tests, but the air supply of the burner was heated.

TABLE VII. — SHOWING THE EFFECT ON THE CANDLEPOWER OF AIR IN THE GAS.[1]

Per cent air in mixture.	Per cent loss of candlepower.	Per cent loss of candlepower per 1 per cent of air.
2.82	5.72	2.03
4.94	10.08	2.04
5.40	11.24	2.08
8.51	18.04	2.12
8.95	19.06	2.13
9.62	21.16	2.20
10.40	23.24	2.24
11.20	26.66	2.38
12.35	29.02	2.35
12.81	30.48	2.38
15.25	37.66	2.47
16.98	42.28	2.49
17.65	44.30	2.51
19.84	51.19	2.58
21.56	56.69	2.63
22.22	58.88	2.65
24.16	64.51	2.67
27.69	72.82	2.63
31.30	80.44	2.57
32.95	83.36	2.53
34.53	87.02	2.52
37.50	90.37	2.41
40.79	93.82	2.30

Experiments were carried out on a 25 to 27 candlepower water gas with a No. 7 Slit Union Bray burner with a regulated consumption of 5 cubic feet per hour.

[1] Royle, Chemistry of Gas Manufacture.

TABLE VIII. — SHOWING THE CORRECTIONS APPLIED TO STANDARDS FOR ATMOSPHERIC CONDITIONS.[1]

For moisture: —

Pentane lamp, candlepower $= 10 + 0.066\,(10 - E)$ where $E =$ liters of water vapor per cubic meter of dry air.

Hefner lamp, candlepower $= 0.914 + 0.006\,(8.8 - E)$.

For barometric pressure: —

Pentane lamp, candlepower $= 10 - 0.008\,(760 - b)$ where $b =$ the barometric reading in mm. of mercury.

Hefner lamp, candlepower $= 0.914 - 0.0001\,(760 - b)$.

Carcel lamp. This varied 3 per cent from the mean during one day, and so no corrections were worked out for it.

For carbonic acid: —

Pentane lamp, candlepower $= C'P' - 0.297\,(C - 0.23)$ where $C'P' =$ the candlepower corrected for aqueous vapor and $C =$ liters carbonic acid per cubic meter.

Hefner lamp, candlepower $= 0.926 - 0.0066\,C$ where C equals liters carbonic acid per cubic meter of dry and pure air.

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[1] Journal of Gas Lighting, July 7, 1908.

Formula for the correction of candlepower for aqueous vapor.[1] The tentative formula suggested is:

Candlepower $= 1 + 0.0087\,(9.3 - e)$ where $e =$ liters of water vapor per cubic meter of dry air, and 9.3 is the normal number of liters of vapor per cubic meter of dry air.

This formula to be employed when candles are used as standards.

TABLE IX. — SHOWING THE EFFECT OF NITROGEN ON CANDLEPOWER.[2]

Per cent nitrogen.	Rate of burning	Observed candlepower.	Candlepower for 5 ft. per hr. of mixture.	Loss of candlepower.	Per cent loss candlepower for each 1 per cent nitrogen.	Candlepower for 5 ft. per hr. of gas.	Loss candlepower.	Per cent loss candlepower for each 1 per cent nitrogen.
0	4.8	20.8	21.8	......	....	21.8	......	....
2.2	4.8	20.0	20.6	1.2	2.4	21.1	0.7	1.4
4.0	4.9	19.1	19.6	2.2	2.5	20.4	1.4	1.5
6.2	4.9	17.9	18.5	3.3	2.5	19.7	2.1	1.6
7.6	5.4	18.8	17.4	4.4	2.6	18.8	3.0	1.8
1.5	5.3	20.7	19.5	2.3	7.1	19.7	2.1	6.5
0	5.1	21.4	21.0	......	....	21.0	......	....
2.1	5.0	20.9	20.9	0.2	0.4	21.2	......	....
3.5	5.2	21.2	20.5	0.5	0.7	21.2	......	....
5.3	4.7	18.6	19.9	1.1	1.0	21.0	......	....
8.6	5.4	20.4	18.8	2.2	1.3	20.6	......	....
11.3	5.6	20.1	18.0	3.0	1.3	20.3	......	....
15.9	6.0	19.7	16.5	4.5	1.3	19.6	......	....

First set with Suggs' Table Top burner.
Second set with Suggs' London Argand D.

[1] Proceedings American Gas Institute, October, 1907.

[2] Massachusetts State Gas Inspector's Report, January, 1893.

TABLE X. — SHOWING THE EFFECTS OF CARBONIC ACID ON CANDLEPOWER.[1]

Per cent carbonic acid.	Rate of burning.	Observed candlepower.	Candlepower for 5′ per hr. of mixture.	Loss of candlepower.	Per cent loss candlepower for each 1 per cent carbonic acid.	Candlepower for 5′ per hr. of gas.	Loss of candlepower.	Per cent loss candlepower for each 1 per cent carbonic acid.
(1) 0	2.54	20.5	40.4	......	....	40.4	......	....
1.6	2.59	20.2	39.0	1.4	2.1	39.6	0.8	1.2
3.0	2.68	20.2	37.7	2.7	2.2	38.8	1.5	1.3
5.0	2.79	20.1	35.9	4.4	2.2	37.8	2.5	1.2
5.7	2.75	19.3	35.1	5.2	2.3	37.3	3.1	1.3
6.9	2.85	19.4	34.1	6.3	2.2	36.6	3.7	1.3
0	2.76	20.6	37.3	......	....	37.3	......	....
8.1	3.36	20.8	31.0	6.3	2.1	33.7	3.6	1.2
8.6	3.40	20.7	30.4	6.9	2.1	33.3	4.0	1.3
9.9	3.31	19.7	29.7	7.6	2.1	33.0	4.3	1.2
12.1	3.71	20.9	28.2	9.1	2.0	32.1	5.2	1.2
15.5	3.73	19.5	26.2	11.1	1.9	31.0	6.3	1.1
18.1	4.09	20.1	24.7	12.6	1.9	30.1	7.2	1.1
(2) 0	4.74	20.0	21.2	......	....	21.2	......	....
2.0	5.20	20.0	19.3	1.9	4.4	19.7	1.5	3.5
3.3	5.59	20.2	18.1	3.1	4.4	18.7	2.5	3.6
4.4	6.00	20.8	17.3	3.9	4.2	18.1	3.1	3.3
5.2	6.11	20.2	16.5	4.6	4.2	17.4	3.7	3.4
6.2	6.35	19.7	15.5	5.7	4.3	16.5	4.6	3.5
(3) 0	3.43	19.8	29.0	......	....	29.0	......	....
2.0	3.72	20.4	27.4	1.5	2.7	28.0	1.0	1.7
2.7	3.79	20.5	27.0	1.9	2.5	27.8	1.2	1.5
3.2	3.77	20.1	26.6	2.4	2.6	27.5	1.5	1.6
3.5	3.90	20.5	26.3	2.7	2.7	27.2	1.7	1.7
3.8	3.99	20.6	25.8	3.2	2.9	26.8	2.2	2.0
5.5	4.31	21.0	24.4	4.6	2.9	25.8	3.2	2.0
6.2	4.72	22.4	23.7	5.2	2.9	25.3	3.7	2.0
7.1	4.87	22.7	23.3	5.7	2.8	25.1	3.9	1.9
8.1	5.26	23.1	22.0	6.6	2.8	23.9	4.7	2.0
9.2	5.28	22.3	21.1	7.5	2.8	23.2	5.4	2.0
11.1	5.10	20.4	20.0	8.6	2.7	22.6	6.0	1.9
(4) 0	......	16.7	....	......	....	16.7	......	....
1.1	5.0	15.5	15.5	1.2	6.4	15.7	1.0	5.5
2.2	5.1	15.3	14.6	2.1	5.7	14.9	1.8	4.8
3.2	5.8	15.5	13.3	3.4	6.4	13.7	3.0	5.6
4.3	5.7	14.7	12.8	3.9	5.4	13.4	3.3	4.7
5.5	6.6	14.9	11.3	5.4	5.8	12.0	4.7	5.1
(5) 0	5.4	14.7	13.6	......	....	13.6	......	....
0.8	5.7	14.7	12.7	0.9	8.4	12.8	0.8	7.4
1.3	6.2	14.8	11.9	1.8	10.0	12.0	1.6	9.1
1.6	6.2	14.5	11.6	2.0	8.8	11.8	1.8	7.9
2.1	6.8	14.3	11.2	2.4	8.5	11.5	2.1	7.7
2.7	7.1	15.1	10.7	2.9	8.0	11.0	2.6	7.2
3.3	8.0	15.3	9.5	4.1	9.3	9.8	3.8	8.5
3.6	8.4	14.6	8.7	4.9	10.0	9.0	4.6	9.3
(6) 0	5.2	16.7	16.0	......	....	16.0	......	....
3.8	5.9	16.8	14.2	1.8	3.0	14.8	1.3	2.1

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[1] Massachusetts State Gas Inspector's Reports, January, 1889 and 1890.

NOTE. — Gas was burned from Bray slit burners marked from 2 to 7 feet per hour. The mixture was burned so as to give a well-proportioned flame of about 20 candle-power, the aim being to burn each mixture under the ordinarily occurring conditions best suited to it. Carbonic acid was measured in a small meter reading to one ten-thousandth of a foot and was mixed with the rich gas before reaching the ordinary photometer meter. The Methven slit was used as a standard. The gas was a naphtha gas containing some nitrogen. In the last three columns the rate of burning is supposed to be that of the illuminating gas alone. Series (2) employed a coal gas enriched with naphtha. Series (6) was the same gas as in series (5), but an Argand burner was used.

TABLE XI. — TESTS OF THE 5-CANDLE ELLIOTT LAMP AGAINST THE HEFNER LAMP AND AGAINST CANDLES.

Date.	Hefner.	Candles.
January 25, 1909.....	5.6	5.04
January 26, 1909.....	5.58	5.04
January 26, 1909.....	5.58	5.05
January 27, 1909.....	5.6	5.01
January 27, 1909.....	5.6	5.07
January 28, 1909.....	5.5	5.07
January 28, 1909.....	5.5	5.08
January 29, 1909.....	5.6	5.05
January 29, 1909.....	5.5	5.01
January 30, 1909.....	5.65	5.14
January 30, 1909.....	5.65	5.19
Average.............	5.58	5.07

TABLE XII. — VALUE OF A 5-CANDLEPOWER ELLIOTT LAMP.

Date.	A	B	C	D	E
October.					
6th	5.06	4.99	....	5.03	5.02
7th	5.15	5.04	5.04	5.08	5.07
8th	5.11	5.09	5.10	5.10	5.06
9th	5.13	5.03	5.12	5.09	5.08
10th	5.07	5.07	5.10	5.08	5.04
11th	4.98	5.09	....	5.04	5.05
12th	5.10	5.07	5.08	5.08	5.05
13th	....	....	....	....	....
14th	5.07	5.06	5.07	5.07	5.06
15th	5.15	5.07	5.06	5.09	5.08
16th	5.05	5.09	5.10	5.08	5.10
17th	5.12	5.03	5.10	5.08	5.12
18th	5.13	5.06	5.15	5.08	5.05
19th	5.02	5.06	5.02	5.03	5.07
20th	5.08	5.10	5.10	5.09	5.10
21st	5.08	5.00	5.02	5.03	5.08
22d	5.07	5.11	....	5.09	5.06
23d	5.11	5.10	5.05	5.09	5.07
24th	5.04	5.08	5.03	5.05	5.00
25th	5.08	....	....	5.08	....
26th	5.06	5.08	5.02	5.05	5.03
27th	5.06	5.02	5.08	5.05	5.09
28th	5.12	5.06	5.07	5.08	5.05
29th	5.07	5.11	5.07	5.08	5.03
30th	5.02	5.06	5.04	5.04	5.03
31st	4.95	5.01	5.04	5.00	5.02
November.					
1st	5.03	5.06	....	5.05	5.01
2d	5.06	5.02	5.01..	5.03	5.02
3d	5.08	5.06	....	5.05	5.02
4th	5.08	5.03	5.08	5.06	5.06
Average	5.07	5.06	5.06	5.06	5.05

Explanation. A = Value of lamp found by comparing same with the Holder gas, the candlepower of this gas having been previously determined against candles.

B = Value of lamp found by comparing same direct with candles.

C = Value of lamp found as in A but against a different gas.

D = Average A, B, and C. This value is determined by 9 A.M., and is used as the value of the lamp until 4 P.M.

E = Value of lamp at 4 P.M. found by comparing same against candles, and is used as the value of the lamp through the night.

TABLE XIII.—SHOWING THE COMPARISON OF THE CANDLEPOWERS OBTAINED WITH THE OLD D AND NEW F ARGAND BURNERS.

Coal gas.

Candlepower with—		Difference in candlepower in favor of—		Candlepower with—		Difference in candlepower in favor of—	
O.D.	N.F.	O.D.	N.F.	O.D.	N.F.	O.D.	N.F.
15.3	14.0	....	1.3	17.1	18.8	......	1.7
12.0	12.8	....	0.8	13.7	14.3	......	0.6
11.5	11.0	0.5	....	12.9	13.0	......	0.1
9.1	10.3	....	1.2	12.6	13.1	......	0.5
13.9	13.3	0.6	....	15.5	16.3	......	0.8
17.0	19.5	....	2.5	12.0	12.5	......	0.5
10.7	10.8	....	0.1	12.7	12.7	......	....
17.8	17.1	0.7	....	16.1	15.4	0.7	....
16.8	16.4	0.4	....	14.5	15.8	......	1.3
15.0	12.9	2.1	....	12.8	12.4	0.4	....
15.3	14.6	0.7	....	14.0	14.1	......	0.1
17.7	16.0	1.7	....	17.7	17.5	0.2	....
15.5	14.8	0.7	....	17.9	18.5	......	0.6
14.9	13.6	1.3	....	17.5	17.5	......	....
16.4	14.1	2.3	....	17.8	17.1	0.7	....
15.7	15.1	0.6	....	18.5	18.0	0.5	....
16.5	15.9	0.6	....	17.9	17.9	......	....
16.1	15.3	0.8	....	17.3	18.3	......	1.0
16.3	15.5	0.8	....	19.3	19.4	......	0.1
17.3	18.3	....	1.0	18.1	17.7	0.4	....
17.0	17.9	....	0.9	16.4	17.1	......	0.7
14.3	15.7	....	1.4	18.9	17.4	1.5	....

TABLE XIV. — SHOWING THE COMPARISON OF CANDLEPOWERS OBTAINED WITH THE NEW F ARGAND BURNER AND THE NO. 7 SLIT UNION BRAY BURNER.

Water gas.

Candlepower with —		Difference in candlepower in favor of —		Candlepower with —		Difference in candlepower in favor of—	
N.F.	Bray.	N.F.	Bray.	N.F.	Bray.	N.F.	Bray.
20.7	18.7	2.0	....	19.8	20.8	......	1.0
25.5	27.2	....	1.7	20.0	22.2	......	2.2
20.2	17.9	2.3	....	19.6	14.5	5.1	....
18.8	16.4	2.4	....	20.0	17.8	2.2	....
19.4	20.9	....	1.5	21.3	17.1	4.2	....
19.6	14.8	4.8	....	19.8	18.3	1.5	....
17.8	13.5	4.3	....	21.8	23.1	......	1.3
19.9	21.9	....	2.0	19.7	21.0	......	1.3
18.9	14.8	4.1	....	21.1	22.6	......	1.5
21.8	22.1	....	0.3	22.3	23.3	......	1.0
20.6	21.2	....	0.6	20.5	21.7	......	1.2
20.1	20.7	....	0.6	20.2	21.9	......	1.7
20.0	16.8	3.2	....	20.0	21.5	......	1.5
20.3	16.2	4.1	....	19.3	20.1	......	0.8
21.4	18.2	3.2	....	20.6	22.5	......	1.9
20.8	18.0	2.8	....	20.1	18.7	1.4	....
21.3	16.5	4.8	....	20.2	19.0	1.2	....
18.7	19.3	....	0.6	21.4	18.2	3.2	....
18.9	19.7	....	0.8	20.0	14.2	5.8	....
20.4	13.7	6.7	....	20.2	20.4	......	0.2
20.1	20.8	....	0.7	20.2	12.9	7.3	....
20.7	21.3	....	0.6	18.2	13.1	5.1	....
21.0	21.7	....	0.7	19.3	21.0	......	1.7
21.7	25.9	....	4.2	16.0	19.4	......	3.4
19.2	20.2	....	1.0	20.1	21.0.	......	0.9

TABLE XV. — SHOWING THE CANDLEPOWER OF BURNERS AT VARYING PRESSURES.

Burner.	Candlepower per cubic foot at pressures of —		
	1″	3″	5″
No. 7 Slit Union Bray	3.95	3.76	3.97
No. 7 Union Jet Bray	3.75	3.63	3.73
Gas Governor burners with aluminum tips	3.40	3.38	3.61
3-foot steel tip	2.11	2.02	2.32
3-foot American E. H. lava tip	2.56	2.60	2.68

NOTE. Tests were made on a water gas of about 19.8 candlepower.

TABLE XVI. — SHOWING THE PERCENTAGE OF LOSS OF LIGHT BY MIXING AIR WITH COAL GAS.[1]

Air.	Loss of light.	Air.	Loss of light.	Air.	Loss of light.	Air.	Loss of light.
Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1	6	8	58	5	33	20	93
2	11	9	64	6	44	30	98
3	18	10	67	7	53	40	100
4	26	15	80				

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[1] Newbigging's Hand Book for Gas Engineers and Manufacturers.

TABLE XVII. — SHOWING THE EFFECT OF PRESSURE ON LUMINOSITY.

Pressure of air in inches of mercury.	Observed illuminating power.	Pressure of air in inches of mercury.	Observed illuminating power.
30.2	100 0	18.2	37.4
28.2	91.4	16.2	29.4
26.2	80.6	14.2	19.8
24.2	73.0	12.2	12.5
22.2	61.4	10.2	3.6
20.2	47.8		

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[1] Experiments by Dr. Frankland.

TABLE XVIII. — COMPARING (APPROXIMATELY) THE SPECIFIC GRAVITY OF GAS (AIR BEING 1.000) WITH THE ILLUMINATING POWER IN STANDARD SPERM CANDLES.[1]

Number of candles.	Specific gravity.	Number of candles.	Specific gravity.	Number of candles.	Specific gravity.
10 equal to about	0.380	20 equal to about	0.508	29 equal to about	0.662
11......do......	0.392	21......do......	0.522	30......do......	0.678
12......do......	0.405	22......do......	0.537	31......do......	0.694
13......do......	0.416	23......do......	0.550	32......do......	0.708
14......do......	0.430	24......do......	0.565	33......do......	0.722
15......do......	0.443	25......do......	0.585	34......do......	0.738
16......do......	0.455	26......do......	0.605	35......do......	0.755
17......do......	0.468	27......do......	0.625	36......do......	0.775
18......do......	0.482	28......do......	0.645	37......do......	0.790
19......do......	0.495				

[1] Newbigging's Hand Book for Gas Engineers and Manufacturers.

TABLE XIX. — COMPARISON OF THE JUNKER AND SARGENT CALORIMETERS.

	Sargent.		Junker.		
Number of tests.	Rate in feet per hour.	Average gross B.T.U.	Rate in feet per hour.	Average gross B.T.U.	Percentage efficiency of Sargent.
4	4	650.0	5	664.0	97.4
4	5	661.5	5	676.3	97.3
4	6	665.5	5	681.5	97.2
5	7	654.0	5	665.4	97.8
4	5	658.0	5	676.8	96.7[1]
4	5	652.0	5	669.0	97.0[2]

[1] Test made with a slight excess of air admitted to the Sargent burner.
[2] Test made with a slight deficiency of air in the Sargent burner.

TABLE XX. — SHOWING COMPARISON OF PRESSURES STATED IN OUNCES AND INCHES OF WATER AND IN INCHES OF MERCURY.

Ounces of water.	Inches of water.	Inches of mercury.	Ounces of water.	Inches of water.	Inches of mercury.
0.146	0.25	0.018	7.0	12.12	0.892
0.292	0.51	0.037	8.0	13.85	1.019
0.438	0.76	0.055	9.0	15.59	1.148
0.584	1.01	0.074	10.0	17.32	1.275
1.0	1.73	0.127	11.0	19.05	1.402
2.0	3.46	0.255	12.0	20.78	1.529
3.0	5.20	0.382	13.0	22.52	1.658
4.0	6.93	0.510	14.0	24.25	1.785
5.0	8.66	0.637	15.0	25.98	1.913
6.0	10.39	0.765	16.0	27.71	2.036

TABLE XXI.—SHOWING ANALYSES OF VARIOUS GASES.

Coal Gas—(in some cases enriched with oil gas).

No.	C.P.	Illuminants. %	CH_4 Per cent.	H Per cent.	CO Per cent.	N Per cent.	O Per cent.	CO_2 Per cent.
1	19.8	6.19	37.79	45.93	6.74	2.06	0.39	0.90
2	17.9	5.44	35.74	47.70	6.75	3.13	....	1.24
3	16.8	5.58	35.18	47.09	5.18	5.78	0.09	1.64
4	17.4	5.81	35.45	50.20	6.63	0.76	0.07	1.08
5	17.8	4.76	36.84	48.88	7.70	0.54	....	1.28
6	18.6	5.21	37.67	49.76	6.03	1.15	0.08	0.10
7	18.1	5.45	35.25	51.50	7.80	....	....	....
8	17.7	5.05	37.05	49.62	6.25	1.95	0.04	0.04
9	17.8	5.40	37.18	48.62	6.30	2.37	....	0.13
10	......	4.20	35.33	52.81	5.84	1.82	....	....
11	17.4	5.35	37.59	49.01	5.99	2.02	....	0.04
12	18.0	6.00	35.33	51.41	6.61	0.52	0.06	0.07
13	18.3	7.99	37.54	44.87	6.49	2.05	0.07	0.99
14	17.3	5.25	36.40	47.26	6.55	3.46	0.12	0.96
15	17.7	4.96	37.56	43.39	6.52	6.60	0.97	....
16	17.4	4.55	35.22	50.05	6.35	3.27	0.56	....
17	17.2	5.82	35.68	48.73	6.74	1.85	....	1.18
18	17.2	5.62	37.30	48.57	6.41	2.10	....	....
19	18.4	5.38	36.36	48.83	6.68	1.52	0	1.23
20	12.9	4.90	36.00	47.24	5.65	4.66	0.13	1.42
21	12.6	6.69	34.32	49.49	6.09	2.61	....	0.80
22	13.5	3.69	34.95	52.29	7.85	0.99	....	0.23
23	15.4	5.73	34.53	43.53	6.87	7.84	0.56	0.94
24	13.9	3.06	37.22	49.57	4.46	3.60	....	2.09
25	13.4	3.83	33.03	39.61	6.61	13.95	0.99	1.98

Water Gas.

No.	C.P.	Illuminants. %	CH_4 Per cent.	H Per cent.	CO Per cent.	N Per cent.	O Per cent.	CO_2 Per cent.
1	......	15.0	25.9	27.9	25.3	3.0	....	2.9
2	21.4	15.11	19.32	31.82	25.88	4.24	....	3.63
3	24.4	13.43	22.70	29.86	25.25	4.61	0.30	3.85
4	23.7	11.51	23.81	28.06	27.82	3.24	....	5.56
5	27.1	14.83	20.59	32.19	27.25	2.31	....	2.83
6	22.4	13.82	18.46	31.86	29.85	3.12	0.26	2.63
7	23.2	15.68	21.83	28.37	26.72	4.65	0.27	2.48
8	19.4	14.70	24.10	30.00	17.50	7.40	....	6.30
9	19.5	13.70	28.31	24.42	23.80	8.12	....	1.65
10	21.2	16.54	21.43	31.90	26.03	2.55	....	1.55
11	22.9	20.26	18.01	29.21	27.42	3.19	....	1.91
12	21.6	14.09	27.16	28.32	24.08	1.27	....	5.08
13	20.2	13.24	15.47	36.84	31.50	2.22	0.24	0.49
14	22.2	12.61	17.44	33.26	32.29	2.06	....	2.34
15	17.9	13.45	14.75	31.97	27.96	7.00	....	4.87
16	18.6	11.34	20.00	32.23	27.90	2.57	0.21	5.75
17	18.7	9.70	22.15	35.33	25.44	5.02	....	2.36
18	18.9	12.48	20.38	33.57	26.85	3.59	....	3.13
19	21.7	12.06	17.69	35.65	28.49	2.50	....	3.61
20	21.8	14.37	15.92	36.02	27.22	3.18	....	3.29
21	24.7	15.40	22.84	29.88	26.22	2.89	....	2.77
22	0	0.12	1.30	52.14	36.31	3.78	0.03	6.33[1]
23	14.3	7.97	29.66	42.71	14.87	3.92	0.34	0.53
24	15.6	11.07	17.55	47.77	16.24	4.82	0.34	1.21
25	......	17.10	27.22	24.40	24.33	2.63	0.53	3.79

[1] Blue Gas.

TABLE XXI. — *Continued.*

Mixed Coal and Water Gas.

No.	Illuminants.	CH_4	H_2	CO	N	O	CO_2	C.P.
1	8.53	31.07	44.79	14.50	0.88	0	0.23	19.8
2	8.80	34.78	46.35	9.15	0.92	0	0	18.8
3	6.33	33.98	43.85	9.33	4.77	0.69	1.05	17.5
4	5.61	34.24	48.43	7.11	3.24	0.13	1.24	17.4
5	6.58	30.79	48.52	12.67	0.92	0	0.52	20.6
6	5.63	34.15	50.26	8.77	0.84	0.09	0.26	18.0
7	4.44	35.41	51.20	6.77	1.11	0	1.07	17.2
8	6.08	28.21	52.41	8.26	3.74	0	1.30	17.5
9	7.25	25.14	42.44	21.90	1.57	0	1.70	17.9
10	11.93	29.87	36.78	18.62	1.81	0	0.99	20.7
11	5.78	35.69	49.15	7.29	1.08	0.03	0.98	18.5
12	7.87	30.59	43.13	12.37	4.04	0.34	1.66	17.2
13	7.00	30.99	46.24	10.97	3.15	0.32	1.33	18.0
14	9.48	31.73	36.90	14.76	3.12	0.12	3.89	20.8
15	7.93	29.49	42.20	13.51	4.29	0.13	2.45	16.7
16	9.60	34.87	35.42	14.26	3.65	0.15	2.05	20.7
17	7.88	32.43	44.90	11.09	2.99	0.56	0.15	17.3
18	6.57	36.55	48.10	7.93	0.76	0.03	0.06	18.2
19	5.55	40.65	38.20	8.73	6.10	0.13	0.64	18.8
20	6.92	41.64	39.44	8.74	2.85	....	0.41	18.8
21	6.98	31.97	50.22	8.64	0.60	....	1.59	16.9
22	9.01	29.26	41.94	13.58	2.67	0.53	3.00	19.3
23	5.44	35.32	49.59	7.51	0.60	0.03	1.51	17.3
24	5.98	35.75	47.27	10.90	....	0.10	....	18.1
25	5.59	36.84	49.90	6.91	0.66	....	0.10	17.3[1]
26	5.65	36.74	49.93	6.97	0.61	....	0.10	17.3[1]

[1] Same sample analyzed by two different persons to show the accuracy of Hinman's apparatus.

Natural Gases.

No	O_2	CO_2	C_2H_4	CO	CH_4	C_2H_6	H_2	N
1	0.05	0.00	0.40	0.00	70.00	16.75	0.27	12.38
2	0.00	0.73	0.86	0.00	77.40	14.18	0.00	6.66
3	0.00	0.24	0.65	0.00	88.10	7.37	0.25	3.60
4	trace	0.05	....	0.40	80.85	14.00[1]	0.10	4.60
5	0.15	0.20	....	0.50	93.60	0.30[1]	1.50	3.60
6	0.00	0.30	....	1.00	93.65	0.25[1]	0.00	4.80
7	0.34	0.26	0.30	0.50	92.61	....	2.18	3.61
8	0.20	0.10	0.10	0	81.10	11.95	0	6.39
9	0.00	0.00	0.61	0	83.40	10.31	0.33	5.19
10	0.10	0.00	0.81	0	94.00	1.97	0	2.98
11	0.40	0.70	0.00	0.30	91.50	0.00	0	6.97
12	0.22	0.33	0.30	0	90.30	4.26	0	4.45
13	0.20	0	....	0	14.85	0.41	trace	82.70
14	0.10	0.00	0.00	0	97.18	0	0.25	2.36
15	0.00	0.92	0.61	0	95.70	0	0	2.69
16	0.15	0.81	0.10	0	92.40	0	0	6.46
17	0.20	0.83	0.50	0.10	92.90	0	0	5.43
18	0.10	0.60	1.20	0.20	87.20	7.03	0	3.65
19	0.40	0.70	0.00	0	98.00	0	0	0.88
20	0.10	0	0	0	14.33	1.06	trace	82.87
21	0.10	0.20	0	0	51.80	0	0	46.40
22	0.30	0.15	0.55	0	78.60	7.71	0	12.13
23	0	0.54	....	0	74.10	0	trace	24.85
24	trace	0.20	0.16	0	94.30	0.36	0	4.61
25	trace	0.20	....	0	98.06	0	trace	1.57

[1] Entered in original as "other hydrocarbons."

With regard to natural gas, it is of course understood that the gas from different fields will vary very greatly in chemical composition.

TABLE XXI. — *Continued.*

Other Gases.

No	Illuminants.	CH_4	H_2	CO	N	O	CO_2	C.P.	Kind of gas.
1	39.08	55.57	4.61	0	0.41	0.07	0.26	52.8	Oil gas.
2	11.15	28.68	11.68	9.07	27.83	3.66	7.93	......	Wood gas.
3	14.91	10.67	4.25	0.89	54.76	12.52	2.00	9.0	Oil, water and air gas.
4	25.14	27.02	0.70	......	37.07	9.59	0.48	28.4	Oil and air gas.
5	14.39	30.54	36.58	9.15	3.96	0.23	5.15	28.3	Baby process water gas.
6	19.06	38.10	0.33 C_2H_6	11.80	16.29	0	14.42	23.5	Mixed wood and oil gas.
7	19.17	37.43	2.25	14.26	10.65	0	16.24	21.5	Mixed wood and oil gas.
8	11.57	32.81	20.35	13.96	8.89	0.42	12.00	15.6	Mixed wood, water and coal gas.
9	9.81	12.21	......	3.01	66.42	2.30	6.25[1]	(less than) 8	Stoneham, Mass., gas.
10	5.28	37.10	48.62	5.46	2.69	......	0.85	17.3	Coal gas enriched with cannel.
11	17.78	25.81	25.02	6.18	23.30	......	1.87	24.0	Kendal process. Oil, air and steam injected in heated generator.
12	37.60	53.35	8.21	0.68	0.08	......	0.08	52.4	Naphtha gas.
13	5.8	40.8	37.6	5.6	6.1	0.4	3.7	17.5	Coke oven.
14	99.36 C_2H_2	0.04	0.06	0.01	0.11	0.08	(a)	about 200	Crude C_2H_2.

---

[1] Includes H_2S.

(a) Also H_2S 0.17; PH_3 0.04; NH_3 0.10; SiH_4 0.03.

SAMPLE PAGE FOR GAS INSPECTION NOTE BOOK.

Company..
Munic'p'ty............................Place of test.....................
Distance......................miles from..................................
Date..................................Kind of Gas.......................

NH_3 at..................
S.M. end..................
" start..................

(1)

Gas, end..................
" start..................

Candles..................

(2)
Gas, end..................
" start..................

Candles..................

(3)
Gas, end..................
" start..................

Candles..................

S_2 Mr. Corr..................

Average

Burner

Readings

(1) (2) (3)

C P.

S_2

NH_3

H_2S

Press.

Time

Bar.

Temp.

ft. for S_2

CORRECTIONS

(1)
Meter.............. %
Bar................
Temp..............
Gas................
Candles............

Corr. C.P.................

(2)
Meter.............. %
Bar................
Temp..............
Gas................
Candles............

Corr. C.P.................

(3)
Meter.............. %
Bar................
Temp..............
Gas................
Candles............

Corr. C.P.................

Remarks:

SAMPLE PAGE FOR CALORIMETRIC RECORDS.

CALORIMETER TESTS.

Place . . . .

Locality . . . .

Date . . . .

Time . . . .

Water passed . . . .

Temp. inlet water.	Temp. outlet water.
. . . .	. . . .
. . . .	. . . .
. . . .	. . . .
. . . .	. . . .
. . . .	. . . .
. . . .	. . . .
. . . .	. . . .
. . . .	. . . .
. . . .	. . . .
. . . .	. . . .
. . . .	. . . .
. . . .	. . . .
. . . .	. . . .
. . . .	. . . .
. . . .	. . . .
. . . .	. . . .
Average.	. . . .

Kind of gas . . . . C.P. . . . .

Meter at end . . . .

" " start . . . .

Gas burned . . . .

Length of test . . . .

Temp. of room . . . .

" inlet gas . . . .

" outlet gas . . . .

Barometer . . . .

Meter error . . . .

C. P. TEST.

No. 1.	Readings. No. 1.	Readings. No. 2.
Gas at end		
" " start		
" burned		
Candles		
Temp.		
Barom.		
No. 2.		
Gas at end		
" " start		
" burned		
Candles		
Meter error		

Condensation . . . . CC for . . . . ft. gas

. . . . × . . . . = ... B.T.U. Gross

. . . . × . . . . = ... B.T.U. Condensation

. . . . Net

TABLE XXII. — SHOWING THE AVERAGE CAPACITIES OF DRY GAS METERS OF ALL MAKES IN CUBIC FEET PER HOUR WITH 0.5 INCH ABSORPTION.[1]

Size.	Capacity.
3-light	66 cu. ft.
5-light	95 cu. ft.
10-light	141 cu. ft.
20-light	218 cu. ft.
30-light	287 cu. ft.
45-light	315 cu. ft.
60-light	475 cu. ft.
100-light	750 cu. ft.
150-light	1175 cu. ft.
200-light	1600 cu. ft.
300-light	2050 cu. ft.
500-light	3300 cu. ft.

---

[1] Catalogue of the Pittsburg Meter Company.

TABLE XXIII. — PRESSURES IN INCHES OF WATER AND IN POUNDS AND OUNCES.

Inches.	Lbs.	Oz.	Inches.	Lbs.	Oz.	Inches.	Lbs.	Oz.
1	0	0.59	15	0	8.82	29	1	1.06
2	0	1.18	16	0	9.41	30	1	1.65
3	0	1.76	17	0	10.00	31	1	2.24
4	0	2.35	18	0	10.59	32	1	2.82
5	0	2.94	19	0	11.18	33	1	3.41
6	0	3.53	20	0	11.76	34	1	4.00
7	0	4.12	21	0	12.35	35	1	4.59
8	0	4.71	22	0	12.94	36	1	5.18
9	0	5.29	23	0	13.53	37	1	5.76
10	0	5.88	24	0	14.12	38	1	6.35
11	0	6.47	25	0	14.71	39	1	6.94
12	0	7.06	26	0	15.29	40	1	7.53
13	0	7.65	27	0	15.88	......	....	....
14	0	8.24	28	1	0.47	......	....	....

TABLE XXIV. — SHOWING THE PERCENTAGE OF ERROR IN METERS WHOSE REGISTRATION DIFFERS FROM THE AMOUNT SHOWN ON THE PROVER SCALE.

Meter registering 2 feet.				Meter registering 5 feet.						Meter registering 10 feet.	
Feet passed according to prover.	Per cent of error.	Feet passed according to prover.	Per cent of error.	Feet passed according to prover.	Per cent of error.	Feet passed according to prover.	Per cent of error.	Feet passed according to prover	Per cent of error.	Feet passed according to prover.	Per cent of error.
1.70	+17.65	2.16	− 7.41	4.50	+11.11	4.96	+0.81	5.42	− 7.75	9.00	+11.11
.71	+16.95	.17	− 7.83	.51	+10.86	.97	+0.60	.43	− 7.92	.05	+10.50
.72	+16.28	.18	− 8.26	.52	+10.62	.98	+0.40	.44	− 8.09	9.10	+ 9.89
.73	+15.60	.19	− 8.68	.53	+10.38	.99	+0.20	.45	− 8.26	.15	+ 9.29
.74	+14.94	2.20	− 9.09	.54	+10.13	5.00	0.00	.46	− 8.42	9.20	+ 8.70
.75	+14.29	.21	− 9.50	.55	+ 9.89	.01	−0.20	.47	− 8.59	.25	+ 8.11
.76	+13.63	.22	− 9.91	.56	+ 9.65	.02	−0.40	.48	− 8.76	9.30	+ 7.53
.77	+12.99	.23	−10.31	.57	+ 9.41	.03	−0.60	.49	− 8.93	.35	+ 6.95
.78	+12.36	.24	−10.71	.58	+ 9.17	.04	−0.79	5.50	− 9.09	9.40	+ 6.38
.79	+11.73	.25	−11.11	.59	+ 8.93	.05	−0.99	.51	− 9.26	.45	+ 5.82
1.80	+11.11	.26	−11.50	4.60	+ 8.70	.06	−1.19	.52	− 9.42	9.50	+ 5.26
.81	+10.50	.27	−11.89	.61	+ 8.46	.07	−1.38	.53	− 9.59	.55	+ 4.71
.82	+ 9.89	.28	−12.28	.62	+ 8.23	.08	−1.57	.54	− 9.75	9.60	+ 4.17
.83	+ 9.29	.29	−12.66	.63	+ 7.99	.09	−1.77	.55	− 9.91	.65	+ 3.63
.84	+ 8.70	2.30	−13.04	.64	+ 7.76	5.10	−1.96	.56	−10.07	9.70	+ 3.09
.85	+ 8.11	.31	−13.46	.65	+ 7.53	.11	−2.15	.57	−10.23	.75	+ 2.56
.86	+ 7.53	.32	−13.75	.66	+ 7.30	.12	−2.34	.58	−10.39	9.80	+ 2.04
.87	+ 6.95	.33	−14.16	.67	+ 7.07	.13	−2.53	.59	−10.55	.85	+ 1.52
.88	+ 6.38	.34	−14.53	.68	+ 6.84	.14	−2.72	5.60	−10.71	9.90	+ 1.01
.89	+ 5.82	.35	−14.89	.69	+ 6.61	.15	−2.91	.61	−10.87	.95	+ 0.50
1.90	+ 5.26	.36	−15.25	4.70	+ 6.38	.16	−3.10	.62	−11.03	10.00	0.00
.91	+ 4.71	.37	−15.61	.71	+ 6.16	.17	−3.29	.63	−11.19	.05	− 0.50

TABLE XXIV. — *Continued.*

.92	+ 4.17	.38	−15.97	.72	+ 5.93	.18	−3.47	.64	−11.35	10.10	− 0.99
.93	+ 3.63	.39	−16.31	.73	+ 5.71	.19	−3.66	.65	−11.50	.15	− 1.48
.94	+ 3.09	2.40	−16.66	.74	+ 5.49	5.20	−3.85	.66	−11.66	10.20	− 1.96
.95	+ 2.56	....	....	.75	+ 5.26	.21	−4.03	....	....	.25	− 2.44
.96	+ 2.04	....	....	.76	+ 5.04	.22	−4.21	....	....	10.30	− 2.91
.97	+ 1.52	....	....	.77	+ 4.82	.23	−4.40	....	....	.35	− 3.38
.98	+ 1.01	....	....	.78	+ 4.60	.24	−4.58	....	....	10.40	− 3.85
.99	+ 0.50	....	....	.79	+ 4.38	.25	−4.76	....	....	.45	− 4.31
2.00	0.00	....	....	4.80	+ 4.17	.26	−4.94	....	....	10.50	− 4.76
.01	− 0.50	....	....	.81	+ 3.95	.27	−5.12	....	....	.55	− 5.21
.02	− 0.99	....	....	.82	+ 3.73	.28	−5.30	....	....	10.60	− 5.66
.03	− 1.48	....	....	.83	+ 3.52	.29	−5.48	....	....	.65	− 6.10
.04	− 1.96	....	....	.84	+ 3.31	5.30	−5.66	....	....	10.70	− 6.54
.05	− 2.44	....	....	.85	+ 3.09	.31	−5.84	....	....	.75	− 6.98
.06	− 2.91	....	....	.86	+ 2.88	.32	−6.02	....	....	10.80	− 7.41
.07	− 3.38	....	....	.87	+ 2.67	.33	−6.19	....	....	.85	− 7.83
.08	− 3.85	....	....	.88	+ 2.46	.34	−6.37	....	....	10.90	− 8.26
.09	− 4.31	....	....	.89	+ 2.25	.35	−6.54	....	....	.95	− 8.68
2.10	− 4.76	....	....	4.90	+ 2.04	.36	−6.72	....	....	11.00	− 9.09
.11	− 5.21	....	....	.91	+ 1.83	.37	−6.89	....	....	.05	− 9.51
.12	− 5.66	....	....	.92	+ 1.63	.38	−7.06	....	....	11.10	− 9.91
.13	− 6.10	....	....	.93	+ 1.42	.39	−7.24	....	....	.15	−10.31
.14	− 6.54	....	....	.94	+ 1.21	5.40	−7.41	....	....	11.20	−10.71
.15	− 6.98	....	....	.95	+ 1.01	.41	−7.58	....	....	.25	−11.11

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