DEPARTMENT OF COMMERCE

CIRCULAR
OF THE
BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 48

STANDARD METHODS OF GAS TESTING

[2d Edition]
Issued June 10, 1916

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1916

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STANDARD METHODS OF GAS TESTING

PREFACE

The need for an American publication which could be accepted as a standard guide to the methods of testing gas distributed for illuminating and heating purposes was first indicated by the inquiries which were frequently addressed to the Bureau of Standards. This circular was prepared with the hope of meeting this need, and the results of the publication of the first edition have fully justified the continuation of the work. For this second edition a thorough revision of the circular has been made in order to correct minor errors, to incorporate suggestions of value which have come to the Bureau, and to take account of results of recent investigations carried out at the Bureau of Standards and elsewhere.

Although the circular is somewhat similar to the English publication, entitled "Notification of the Gas Referees" (London), it is radically different in one important respect. The latter publication, which is published primarily for London, where the referees have authority to prescribe the methods of testing, gives only one method for each test, and its directions are intended to be followed exactly. In the present circular, no attempt is made to fix upon a single method to be used in every case, for it is not believed that uniformity of method is always necessary in order that the results of a test be considered standard. However, satisfactory results may be expected only if such methods are used as have been critically examined by experienced workers and found to be trustworthy. It is the function of this circular to collect and summarize the experience of gas chemists and inspectors in order to assist them in obtaining satisfactory results.

The methods included in this circular are intended primarily for use in official testing and in works laboratories which are checked by city or State inspectors. In each case as much freedom in choice of method is allowed as seems permissible; but the simplest procedure or apparatus with which satisfactory results can be had is given preference. The discussion is so arranged that an inexperienced man may utilize the information, but exactness of description has not been sacrificed in the effort to simplify the directions.

This circular contains suggestions as to location and equipment of gas-testing laboratories, a description of some of the accepted forms of apparatus, directions for the making of the various tests, and recommendations as to the interpretation of experimental results. It does not discuss the testing necessary for good works control, although a few works laboratory methods are included, which have direct bearing on the quality of the finished gas.

The full discussion of the influence of various conditions upon the results of tests and the theoretical considerations such as would properly accompany a publication of the results of a research are not given here. Such full discussion may be found in the various sources of information which have been consulted; in the appendix a bibliography is given of some of the important publications of this character.

This publication is intended to present only standard or accepted methods which have been found satisfactory in the laboratories of the Bureau or by experienced gas testers elsewhere. In the preparation of this edition the Bureau has not found opportunity to check in its own laboratories all of the methods that have been discussed; and in these cases the attempt has been made to describe the methods which represent the best current practice.

It is hoped that as more evidence accumulates any errors that may have been overlooked in this edition may be eliminated from future editions of the circular. With this object in view it is hoped that those interested in the subject will call the attention of the Bureau to any such error and will communicate any results they may have relating to the subjects discussed.

S. W. Stratton, *Director.*

INTRODUCTION

For the purposes of official inspection it is usually necessary to determine heating value (or candlepower), purity, and pressure of the gas supplied, and the accuracy of the gas meters in use; but, as an additional measure of the quality of service, a chemical analysis and a density determination are often useful. The following sections discuss the general equipment for a laboratory and the apparatus and methods suitable for these various determinations. The chemical analysis is not usually a portion of the official testing, and is much too large a subject to be treated in a circular of this size; consequently only the simple methods used for determining undesirable impurities are given.

The appointment of inspectors has already been considered in the circular on "Standard Regulations for Manufactured Gas and Gas Service" (Circular No. 32 of this Bureau). Aside from the selection of a competent inspector, the choice and equipment of the testing station is the most important step toward the proper enforcement of an ordinance. In the choice of apparatus and methods, the relative accuracy, convenience, and cost will usually be the deciding factors. The following rules may be considered axiomatic:

First. Such accuracy is necessary as will assure the public that any deficiency which might cause loss or damage will not pass undetected and as will protect the company from undeserved penalty.

Second. Convenience of apparatus or method should be second only to accuracy. The simplest procedure giving satisfactory results is preferable.

Third. Initial or operating expense should not be unduly cut down at the sacrifice of accuracy or convenience. The simplest method giving correct results is most economical in the end.

Accuracy is obtained only by proper construction, calibration, and operation of the apparatus employed, correct calculations from the data obtained experimentally, and proper interpretation of results. In the following sections the points to be considered in the selection of the various instruments will be indicated. The calibration of meters, standard lamps, thermometers, etc., can not always be done by an inspector; therefore those instruments which require special test will be indicated. The correctness of the operation of the standard instruments and the proper interpretation of experimental data depend largely upon the ability and the experience of the operator. The importance of appointing a careful and, if possible, experienced inspector is therefore evident.

In general, when the result of a test shows such deficiency in gas quality as is prohibited by regulation, it is advisable at once to confirm or correct the first observation by a repetition of the full test. Proper ordinance provisions take account of the probable accuracy of the tests upon which determinations of violations will be based; but good practice requires the repetition, when practicable, of any such test in order to eliminate, as far as may be, all chance for accidental injustice being done.

When considering the results of tests of gas from an official standpoint the idea of penalties should be strongly subordinated to the idea of good service. A penalty is merely a tool to be used as a last resort in the enforcement of good service; and the following proposed rules are drawn with this fact in mind.

After completing a test which shows a considerable deficiency in heat value, candlepower, purity, or pressure, the inspector should communicate the results to the company. The company is then in position to search for the cause of any difficulty and to remedy the condition promptly. The inspector can also reasonably expect to have the result of the company's tests on the quality of the gas given to him from time to time. The comparison of the tests made at two different points on the system will be valuable and the cooperation of the company and city testers can be made valuable to both. In some cases cooperative tests made both in the city's and company's laboratories may help to increase the accuracy of the methods employed in the two laboratories.

Forms suitable for recording and reporting experimental results are suggested in the discussions. On the record of each test should clearly appear a note of any irregularity observed during the test. It is by no means safe to indicate only that a result is questioned without stating the reason for doubt. The record must be self-explanatory and not depend upon the inspector's memory for any details of irregular operation of apparatus or method employed.

Simply because a result seems improbable it is not proper to reject it. However, if several repetitions of a test give results which agree among themselves, but not with the first, and which are at the same time more probable than the first result, then it is proper to omit the first irregular result from an average; but it is best to preserve the record of the test thus omitted for later comparison, if some question arises as to the correctness of the average result accepted. Indeed, every test made, even though incomplete or rejected for a good reason, should be shown by the inspector's records, the records of those tests not accepted being clearly marked to show the cause of their rejection.

For official testing it is essential that the original record, containing all of the observed data, should be kept. Numerous forms of abbreviated record cards have been used, which either do not contain all of the essential data or which require the transfer of the computed data to the record. In either case the result entered on such record can not be as conveniently checked back to the original observations. In case that the official test record is used in a case where compliance with rules or ordinance requirements is in question it is very important that the record show on its face every observation which is necessary for the complete test. Inspection or adjustments which involve merely the scrutiny of one part of the apparatus or another to see that it is in proper order should in some way be indicated upon the card, so that when the test record is complete there can be no question subsequently whether or not all of the adjustments of this sort were properly made. For example, the heating-value record card should indicate that a test was made for leakage, that the meter was properly adjusted, that the damper was in proper position, that the gas was burning at its proper "normal rate," and that the temperature of the products was not excessive, in order that subsequently it will be shown clearly on the records themselves that the necessary precautions were observed.

The object and the significance of the various records are clear in most cases; the precision with which they should be recorded has been made clear in the operating directions.

A. LOCATION AND GENERAL EQUIPMENT OF LABORATORY

1. LOCATION OF THE LABORATORY

In establishing a gas testing station it is necessary, first of all, to select a location which will insure that the gas tested fairly represents the gas furnished to the customers of the district in which the station is located. As to location, a testing station should fulfill the following conditions unless they are inconsistent with franchise or ordinance requirements:

1. It should usually be about 1 mile from the nearest manufacturing station of the company; in small cities it should be at least as far from the works as the average distance from the works to the customers.
2. It should be centrally located—i. e., so that it draws gas from one of the principal trunk mains at or near the center of gas consumption.
3. If there are two or more gas testing stations, they should be at least a mile apart, each at or near the center of an important district of gas consumption.
4. The station used as headquarters should be conveniently located for the access of the general public.

The reason for locating a testing station some distance from the works of the gas company is to make provision for the change in gas quality during travel through the mains. This can best be done by fixing the station location. During its first mile of travel the gas usually will change as much as it does before reaching the majority of the customers; thus a sample taken at this distance from the works fairly represents the gas used by all of them. If a test is made at the point of use most distant from the works, the gas will be found to be of poorer quality than that delivered to the majority of customers; therefore, the distance should be limited, especially where tests are made for candlepower, which is the quality most affected by travel. In large cities, tests more than 2 miles from a works would be fair if a belt system of distribution were in use, or if the testing station were not far from an auxiliary holder. In any case, it is preferable that testing stations should not be very close to a point at which district governors or district holders feed into the distribution system; however, an allowance of a full mile from such points is not necessary. Tests of gas quality made at the manufacturing works are of limited value for inspection purposes since an improperly condensed gas might indicate conformity to regulations there, but after travel for a half mile or more in the mains be below standard. On a gas which has been properly condensed there would be a fairly uniform difference in heating value or candlepower between works and some other fixed point on the system. The loss over this distance would vary with the ground temperatures, but a fair check could be had on the results at the outlying station by tests made at the works taking account of this loss in distribution. The tests at the works for operating control would thus be sufficient for this purpose except under unusual conditions, when they would be supplemented by the results from the outlying station. All official tests should, however, be made at some distance from the works.

The condition imposed that the gas tested be from one of the principal mains is intended to render the test representative of gas for a whole district.

As a headquarters or office of the inspector, the city hall is the most natural place to select; and, in fact, when only one station is needed it may often be located there to advantage. However, if such location does not meet the conditions necessary for the obtaining of a representative gas sample, another place should be selected, even if this would require some extra expense for maintenance. A test on gas not representative of that furnished to the city or the district concerned is useless, and may even be misleading and unfair either to the company or to the public.

In the selection of a location, a map of the distribution system offers the best guide, but a general familiarity with local conditions is also necessary.

2. SELECTION OF SUITABLE LABORATORY ROOMS

A small store, an apartment, one floor of a residence building, and even the second floor of a barn or garage have been used conveniently as laboratories in various cities. After selecting the neighborhood in which to locate a station, it will usually not be difficult to find suitable rooms; but the quarters chosen should meet the following specifications:

1. The main from which gas is drawn must be one of the principal or trunk mains of the neighborhood.

2. The service pipe into the building should be made short, with as few turns as possible, and should not pass through any place which is subject to great temperature change—e. g., furnace room or cold-air shaft.

3. The rooms used should be on the first or second floor of the building, preferably with only a north exposure.

4. The rooms should be subject to as little temperature change as possible, but must be well ventilated. Rooms with fairly high ceilings are to be preferred.

The importance of each of these precautions will be apparent from the discussion of the influence of conditions upon the results of the tests described in the later sections of this circular. No amount of care can make a poorly selected laboratory convenient for good testing work.

The amount of room needed for a station will vary with the tests to be made. Two or three rooms are usually needed, each having at least 200 square feet of floor space; but if provision for much meter testing must be made, an additional room is generally desirable. When several stations are in use, only the central one will require more than a single room; for the main station four separate rooms are usually desirable for office, for photometer and calorimeter room, for chemical laboratory, and for meter-testing shop. In any case it is inadvisable to combine in one room two or more of the four just named unless the room can be partitioned off to make the parts practically separate rooms.

3. EQUIPMENT OF OFFICE AND LABORATORIES

(*a*) **Inspector's Office.**—It is not necessary to discuss here the furniture and furnishings of the office, but some of the special equipment may be indicated.

In order to illustrate, especially to complainants, the character of the tests made on gas and the operation of a gas meter, certain demonstration apparatus is desirable. A demonstration meter, with top and sides of glass, is especially instructive. For the benefit of a customer complaining of high bills, the use of various types of burners to illustrate the quantity of gas consumed by each is convenient; and a demonstration of the character of flame or light produced by the same gas used in the same appliance at different pressures is valuable in explanation of the effect of pressure, a matter perhaps the most difficult to explain to the average customer.

By means of a simple combination of these pieces of apparatus the operation of the meter, the comparative consumption of the burners, and the effect of pressure on each of the latter may be explained very simply. The use of this apparatus will often indicate to a complainant the cause of the excessive consumption of gas, since very frequently these complaints are due to misunderstanding rather than to error in meter registration. A gas company should encourage such demonstration work.

(*b*) **Gas-Testing and Chemical Laboratories.**—The apparatus for gas testing will be discussed in connection with the methods described in the latter parts of this circular. Only a few suggestions as to general facilities which should be provided are included here. Two rooms will usually be needed—one for photometric and calorimetric work and one for chemical operations. Neither room need be large, 200 square feet of floor space being ample; but good light and ventilation are needed. The use of separate rooms is not absolutely necessary; but since the fumes from chemical work will injure the instruments used for the heating value and candlepower testing, separate rooms are a great advantage, unless only the simplest chemical testing is done. Since a dark room is desirable for the photometric work, the rooms should be arranged so that it is not necessary to interrupt other work while the room is darkened for the candlepower observations.

In addition to the arrangements usually made for the equipment of a chemical laboratory, there are a few special provisions which should be made for a laboratory to be used for gas testing. The gas connections should be planned with particular care. As already indicated the laboratory should be so located that the service pipe from the street main may be short; and this pipe, of course, should be of such size as to give ample gas supply without appreciable pressure loss, since the pressure will be measured by a gage in the laboratory. The company should be allowed to install as large a service pipe as they wish. It is desirable to cover with asbestos, or other heat-insulating material, the gas service pipe from the point where it enters the basement to the inlet of the meter, which should be located in the laboratory. The service from the main to the laboratory should be made free from valves, traps, or other side connections, so that for its entire length the gas is subject to no modifying influence. The service should tap into the side or top of the main, not into the bottom, and should fall slightly toward the main so that no condensation can accumulate and change the quality of the gas after it leaves the main. Failure to observe the above precautions has sometimes led to serious difficulty, and hence it is well to make sure that no disturbing influence on the service pipe shall vitiate the results of the tests.

Good ventilation and uniform temperature of the laboratory are important. In the photometric room a continuous supply of fresh air must be maintained, but without draft. Occasional opening of windows to "air the room" is not satisfactory, as the temperature changes and drafts which result may affect other tests even when they do not disturb the subsequent photometric or calorimetric determinations. The reasonable uniformity of temperature needed in a gas laboratory can usually best be attained in a room with only a north exposure, as the influence of direct sunlight is then eliminated. North light is generally preferable for a laboratory.

One convenience not often provided for a gas laboratory is a gas "blow-off." This consists of a pipe run from the meter outlet up above the roof of the building, so arranged that the gas in the service and the meter can be quickly replaced by other gas fresh from the main. This allows the inspector to obtain, in a few minutes, gas which fairly represents that being distributed. For ordinary work it is customary to light several burners and burn the old gas from the connections; but this requires as much as an hour in some cases and, unless the ventilation is exceptionally good, the air of the room is likely to be seriously affected. The amount of gas necessarily wasted each day by the blow-off would be less than that required to purge the connections by the slower method. The blow-off valve should be so arranged that it can not be left open accidentally—e. g., a spring valve which closes automatically may be used.

The amount of space needed for each part of the equipment and the details of calorimeter and photometer room and of the other pieces of general equipment are given in connection with the description of apparatus in the following sections.

(*c*) **Meter-Testing Laboratory.**—When all of the meters installed by the gas company are tested by a city inspector, it is most economical to arrange that this be done at the company's meter repair shop. The facilities to be provided for this work will, of course, vary with the number of meters to be handled; but in any case it is usually necessary to arrange only for the prover and its accessories. No special precautions as to room used need be made more than to select a place where the temperature changes are small and where drafts can be prevented. If they can be avoided, changes greater than 5° to 10° F should not occur during a period of 24 hours, since it is essential that the prover and the meters to be tested be at the same temperature; if a rapid change in room temperature occurred, the meters would change temperature more rapidly than the prover, and a discrepancy would result.

For testing complaint meters it is often better to provide a small laboratory at the office of the inspector, in order to avoid the suspicion that the company could influence or control the results of such tests if they were made at its meter shop. Such laboratory would be subject to the same conditions as the larger one just discussed.

4. OUTLINE OF EQUIPMENT FOR GAS INSPECTION

The following outline is intended to aid in making an estimate of the cost of equipping and operating an office and laboratory for the use of the inspector; it is drawn for the most elaborate case which would probably arise. Simpler laboratory equipment can easily be selected from this comprehensive list, and the less expensive forms should be selected when these are such as would probably give satisfaction, as indicated in the later sections. For the sake of completeness even the office furnishings have been indicated.

Office furniture.—Desk, chairs, table, bookcase, letter files, and typewriter.

Files for records of gas pressure, gas quality, meter tests, and complaints.

Reference books, laboratory record books, etc.

Demonstration apparatus, including meter, pressure governor, burners, and setting.

Laboratory equipment.—Hood with steam bath, calorimeter cabinet, chemical laboratory bench, wall cases for apparatus, and photometer room.

Apparatus.—Photometer, calorimeter, and pressure gages, each with accessories.

Apparatus for determination of hydrogen sulphide, total sulphur, and ammonia.

Gas analysis outfit, density determination apparatus, barometer, psychrometer, and dew-point apparatus.

Supply of miscellaneous glassware and apparatus, and stock of chemicals.

Meter-shop equipment.—Meter prover, cubic-foot bottle, and accessories.

Workbench and tools.

Shelving for meter storage.

Outside equipment.—Motor cycle or automobile, portable pressure gages, tools and fittings for setting gages, and portable apparatus for gas testing.

The current expenses of a gas-inspection department would vary widely. Only a bare outline of this phase of the subject can be suggested as an aid to inspectors.

Current expenses.—Salaries, rent, heat, and janitor service.

Electricity, gas, telephone, office supplies, postage, etc.

Repairs, laboratory supplies of glassware and chemicals.

B. MEASUREMENT OF GAS

Gas is almost universally measured by volume, not by weight. Unlike a solid or liquid, any amount of gas always completely fills the space in which it is confined. It is therefore impossible to change the volume of gas contained in a measure without changing the capacity of the measure; and such measure must, of course, be closed on all sides. The gas-measuring devices in common use are almost all so designed that the pressure and temperature of the gas are kept nearly constant, while the volume occupied varies automatically when gas is introduced or withdrawn. This is accomplished as a direct measurement either by the use of a containing vessel with collapsible walls operating like an old-fashioned bellows, as in the ordinary dry meter, or by partially or completely filling the container with a liquid above which the gas is confined, as in the gas burette, wet meter, cubic-foot bottle, and meter prover.

There is also a group of instruments by which the volume or mass of gas can be measured indirectly by measurement of one or more of the natural or acquired properties of the gas as it flows through the apparatus. To this group belong the pitot meter, the venturi meter, the orifice meter, the Thomas meter, the anemometer, etc. These instruments are used almost exclusively for measurement of gas in large quantities; they are not discussed in the present edition of this circular.

The direct type of gas-measuring apparatus may be conveniently classified into three groups: (1) Apparatus used for calibration, of which the cubic-foot bottle and meter prover are the most familiar examples; (2) the integrating flow meters used for measuring the quantity of gas as it is supplied at any point, which are called wet meters or dry meters, according to whether they do or do not make use of a confining liquid; and (3) experimental apparatus used in the laboratory for the accurate measurement of small amounts of gas, the gas burette and aspirator bottle belonging to the latter type. The third of these groups need not be considered in this circular; the apparatus of the first and second groups is described on pages 158 and 23, respectively. Before describing any form of apparatus, however, the principal effects of temperature, moisture content, and pressure on gas volume will be considered.

1. EFFECT OF CONDITIONS ON GAS VOLUME

The volume occupied by a given quantity of gas varies with the temperature and pressure. In order to make two volumes of gas comparable it is therefore necessary either to measure them under the same conditions of temperature and pressure, or to make corrections to determine what volumes would have been occupied if they were under the same conditions. Ordinarily, standard conditions of temperature and pressure are chosen for this comparison; for scientific work, where the metric system is employed, the standard conditions generally chosen are 0° C and 760 mm of mercury pressure. In technical work, and especially in the gas industry, 60° F and 30 inches of mercury pressure are usually chosen.

When the temperature remains constant the volume of a dry gas [1] varies inversely as its pressure.[2] In other words, the product of the pressure and volume remains constant. This is expressed by the equation:

$$p_1v_1 = p_2v_2 \tag{1}$$

where p_1 and v_1 represent one pressure and the corresponding volume, and p_2 and v_2 represent any other pressure and the corresponding volume occupied by the fixed quantity of gas. Obviously, if p_1, p_2, and v_1 are known, the volume v_2 may be ascertained from the equation: [2]

$$v_2 = \frac{v_1p_1}{p_2} \tag{2}$$

When the pressure remains constant the volume of the dry gas varies directly as the temperature above a certain point called the absolute zero. This point is about −273° C (or −459.4° F). In other words, the volume of a gas increases one two hundred and seventy-third of its volume at 0° C for every degree rise in temperature on the centigrade scale, or one five hundred and twentieth of its volume at 60° F for every degree rise in temperature on the Fahrenheit scale. When the volume v_1 is known at any

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[1] The term "dry gas" as used here means a gas that contains no water vapor or other constituent that will be condensed to the liquid condition by the temperature or pressure changes of the magnitude under consideration.

[2] It must always be remembered that the pressure on a gas is equal to the pressure above atmospheric usually observed, *plus* the barometric pressure at the time of observation. Gas pressures above atmospheric are usually expressed by the height of the water column supported by the gas pressure. This must be divided by 13.6 to reduce it to the height of the equivalent mercury column in terms of which the atmospheric pressure is usually expressed.

temperature t_1, the volume v_2, which it would occupy at the temperature t_2, may be found from the equation:

$$v_2 = \frac{v_1\ (t_2+273)}{(t_1+273)} \tag{3}$$

or,

$$v_2 = \frac{v_1\ (t_2+459.4)}{(t_1+459.4)} \tag{4}$$

depending upon whether the centigrade or Fahrenheit scale is used. The variations from these laws are far too small to be of any consequence in the regular work of a gas inspector.

These four equations may be combined to give two equations for calculating the volume of dry gas when both temperature and pressure change; of the following (5) is used when temperatures are expressed in centigrade degrees and (6) when in Fahrenheit degrees.

$$v_2 = \frac{v_1\ p_1\ (t_2+273)}{p_2\ (t_1+273)} \tag{5}$$

or,

$$v_2 = \frac{v_1\ p_1\ (t_2+459.4)}{p_2\ (t_1+459.4)} \tag{6}$$

The above equations apply only to dry gas.

When the gas is confined over water there is always some water vapor present, which increases the pressure or the volume of the confined gas. If enough time has been allowed for the gas to become saturated, the increase in pressure or volume due to the water vapor depends only upon the temperature. Since commercial illuminating gas always contains water vapor and is usually measured over water in testing work, it is customary and most convenient to measure the saturated gas. The effect of the water vapor on the pressure or the volume of the gas is indicated by the following equations; in these the vapor pressure of water, w_1 and w_2, corresponding to temperatures t_1 and t_2, respectively, are subtracted from the total pressures p_1 and p_2.

$$v_2 = \frac{v_1\ (p_1-w_1)\ (t_2+273)}{(p_2-w_2)\ (t_1+273)} \tag{7}$$

or

$$v_2 = \frac{v_1\ (p_1-w_1)\ (t_2+459.4)}{(p_2-w_2)\ (t_1+459.4)} \tag{8}$$

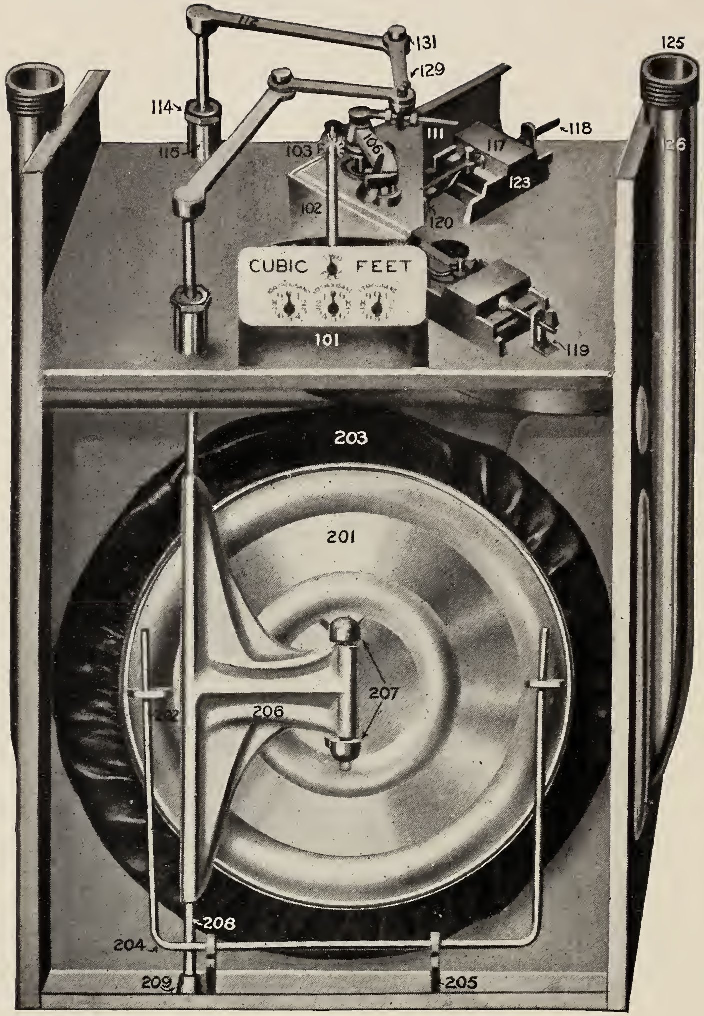

Fig. 1.—*Interior of service meter*

By these equations the volume v_2 of any amount of gas saturated with moisture under any conditions, such as p_2 and t_2, can be calculated if the volume of this gas v_1 is known for pressure p_1 and temperature t_1. If it is desired to find the volume occupied by this amount of gas when dry, it is only necessary to consider w_2 as equal to zero and proceed with the same equations. Similarly if the gas is dry when at p_1 and t_1, w_1 is considered as equal to zero.

In ordinary gas testing, correction is made to determine the volume of the gas when saturated at 60° F and 30 inches pressure; the table on pages 190–191 is calculated for this latter purpose by the formula indicated at the foot of the table.

2. THE DRY GAS METER

The dry gas meter is the instrument almost exclusively used in the United States for the measurement of the gas sold to a customer; it is also very largely used in England and in some of the continental countries.

There are a number of different types of dry gas meters in use, which, while differing considerably in external appearance and design of parts, operate on the same general principles. These general principles would be understood from a description of any one of the types and therefore only one of the most commonly used will be described.

The external appearance of the meter is well known. The interior is shown in Fig. 1, with the front and top of the meter and the top of the valve chamber removed. Essentially the meter consists of four chambers, which are filled and emptied of gas by the action of the meter mechanism. The number of times this filling and emptying of the measuring chambers is performed is recorded on the dial in cubic feet. Two of the measuring chambers are shown in the figure; one is the space between the disk (201) with attached leather diaphragm (203) and the middle partition (the plate just behind the diaphragm) of the meter; the other is the space between this same disk and diaphram and the outside walls of the meter. The other two measuring chambers are like the two described, and are situated symmetrically to them on the opposite side of the middle partition. The filling and emptying of the measuring chambers is effected by the backward and forward movement of the disks. These disks operate in conjunction with the valves and recording mechanism above the measuring chambers. Each set of two measuring chambers thus constitutes a kind of double-acting bellows, the number of times these are filled and emptied being a measure of the volume of gas passed through them. The power for operating this very simple and effective instrument is furnished by the pressure of the gas itself which acts upon the disks, pushing them back and forth just as the power to operate the steam engine is furnished by the steam which presses upon the sides of the piston. The index (101) upon which the volume of gas passed is recorded is connected to the other mechanism by means of the shaft (102) and gear wheel (103).

It is evident that the travel of the disks, and therefore the displacement of gas during each revolution of the tangent (111), depends upon the distance of the "tangent post" (129) (to which the short flag arms are attached) from the center of rotation of the tangent. The tangent post is held between two nuts screwed onto the tangent, and by turning these nuts the amount of gas passed by the meter per revolution of the tangent is adjustable within wide limits.

3. LABORATORY GAS METERS

(*a*) **Description.**—Laboratory gas meters, which are intended for precise measurement of gas volumes, are commonly of the wet-meter type, and are usually made with capacities of one-tenth or one-twelfth cubic foot or of 3 liters for one revolution of the measuring drum; one-twentieth cubic foot meters are also made for inspection work.

A detailed description of the construction and mode of operation of laboratory gas meters, together with an account of an investigation of the sources of error to which such meters are liable, and the accuracy attainable in their use, may be found in Technologic Paper No. 36 of this Bureau.

The mode of operation of such meters will be described with reference to the diagrammatic sketch of Fig. 2. The meter consists of an outer cylindrical casing which is filled with water to the level indicated. Within this casing is the measuring drum rotating on a horizontal axis. This axis projects through the front of the meter casing, passing through a stuffing box. The bearing at the other end of the axis, not shown in the figure, is entirely under water.

Outside of the stuffing box the end of the axis of the drum is connected to the indicating mechanism of the meter. It is preferable to have the principal hand (the long hand) of the meter mounted directly upon the axis of the drum and in such a way that the hand can not slip relative to the drum or axis. The smaller hands of the meter, which indicate multiples of the quantities indicated by the principal hand, are connected to the axis of the drum by means of a system of gear wheels.

The measuring drum has five compartments, four of which are made by dividing the cylindrical portion by means of suitable partition walls. These four compartments are so shaped that the openings of each compartment, one on the front and one on the back of the drum, are nearly radial and make an angle of about 160° with each other. The fifth compartment covers the whole of the back face of the measuring drum, and opens into each of the four other compartments.

The mode of operation of such a meter may be understood by following one of the four compartments of the drum through a complete revolution, starting with the compartment at its lowest position, when it is full of water and both the openings are under water.

The gas, passing through the inlet tube enters the back compartment and by its pressure on the inclined faces of the partition walls of the other compartments, causes the drum to revolve. The opening at the rear of the compartment which is under water emerges, allowing the gas to enter the compartment, while the contained water is discharged through the other openings along the axis and at the front. As the drum continues to revolve, the compartment gradually becomes filled with gas. However, before the opening at the front emerges from the water the one at the back dips into and is closed by the water, sealing off momentarily a certain volume of gas. As the drum now continues to revolve, the opening at the front emerges from the water and the gas escapes into the outer casing, being displaced by the water entering through the large opening along the axis and the radial opening at the back, the process continuing until the compartment is again entirely submerged. The gas is discharged from the meter casing through the outlet connection.

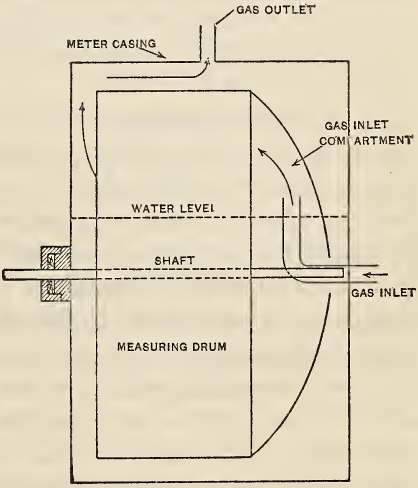

Fig. 2.—*Section of experimental gas meter*

During each revolution, each compartment delivers the amount of gas it contained at the instant it was sealed off, an amount which will evidently depend on the position of the water level.

(*b*) **Choice of Meter.**—There is little that can be said that will aid the purchaser in the choice of a meter, as the working parts are concealed and wearing qualities are not easily determined by inspection. All the wet meters furnished with the gas calorimeters listed in this circular, with one exception, were practically identical in essential details of design, and differed principally in the materials of construction and in the grade of workmanship, factors on which the satisfactory operation of the meters is largely dependent. Important features are as follows:

(1) The leveling device usually consists of three leveling screws on tripod base with two levels at right angles, or a circular level, or a plumb bob on the meter.

(2) Provision should be made for adjustment of water level in the meter to a fixed mark, either with a gage glass, a sight box (which is an extension of the meter casing having front and back faces of glass), or an automatic overflow. The gage glass and the sight box are equally satisfactory, but the automatic overflow, as exemplified in the Elster meter furnished with the Junkers calorimeters, was found to be unsatisfactory. The inside diameter of the gage glass should be not less than three-eighths inch and the connecting tubes between the gage glass and the meter should be so large as to avoid the possibility of the passage being obstructed. The mark to which the water level is set must be of such form that accurate settings can be made; a simple pointer on the outside of the gage glass is not satisfactory.

(3) The use of materials that will not give trouble due to corrosion is important.

(4) Well-made bearings, stuffing boxes, etc., and accessibility of stuffing box for repacking are essential.

(5) Proper shaping of the measuring compartments of the drum to give a fair degree of proportionality of the graduated scale and to avoid undue fluctuations of the water level during the rotation of the drum, is, of course, very necessary.

(6) Provision should be made for emptying and cleaning the meter and for running in and withdrawing water in adjusting the water surface, as well as provision for draining the "dry well" at the meter inlet.

(7) An enamel dial is preferable, without glass face plate. While the latter does not increase the error due to parallax, it reflects light and sometimes increases the difficulty of reading.

(8) In one-tenth and one-twelfth cubic foot meters the subdivision of the dial is usually into 100 parts, each tenth graduation being numbered and being somewhat longer than the intermediate graduations; it would be a convenience to also lengthen every fifth graduation. An auxiliary dial giving the rate of gas delivered from readings of the meter dial one minute apart is also provided on some meters, as well as suitable small dials on the face of the meter to register the number of revolutions of the meter index.

(9) The large hand should extend to the middle of the graduations, with its end close to the dial.

(10) A thermometer should be provided, with its bulb immersed in the water in the meter.

(11) A well-made meter in proper adjustment, with the stuffing box packing not too tight, should operate on a small and constant back pressure, so that the calibration will be practically independent of the rate up to rates of about 10 cubic feet per hour.

(*c*) **Adjustment of Meter.**—Before proceeding with the calibration, the meter must be carefully adjusted as follows:

(1) Level the meter with the aid of the levels or the plumb bob mounted on the meter. Care should be taken to insure that the levels are not loose nor in such condition that they can be easily displaced relative to the meter.

(2) Adjust the index of the meter relative to the drum in the following manner: It will be observed that there is considerable fluctuation of the water level in the gage glass four times during each revolution of the index, these fluctuations occurring each time that a compartment is sealed off. The index should be so set relative to the drum that the index will pass through the zero position midway between two such fluctuations of water level, e. g., if the dial is divided into 100 divisions the index should be at 12.5, 37.5, 62.5, and 87.5 approximately at the times these fluctuations in water level occur. Unfortunately meters are usually made with slip hands, so that this adjustment must be frequently verified by the user.

(3) Adjust the surface of the water in the meter. The water in the meter should be saturated with the medium used in testing, by passing 2 or 3 cubic feet of the gas or the air through the meter before this adjustment is made; and enough water should be

used to bring its level somewhat above the fixed mark to which it is to be adjusted. Pass enough gas through the meter to bring the long hand to the zero position and then disconnect the tubing leading to the inlet, thus leaving both inlet and outlet open to the air. To avoid displacing the meter, it is better to disconnect not at the meter, but at the distant end of the inlet tube. Drain off the water until the lower boundary of the meniscus in the gage glass or in the sight box coincides with the fixed mark. The meter should then be again connected to the gas supply, run one or more revolutions, again disconnected, and the adjustment verified.

An error of one-sixteenth inch in the setting of the water surface, a similar displacement of the fixed mark, or an equivalent error in the leveling of the meter will cause an error of about 1 per cent in the indications. It is evident therefore that the leveling of the meter and the adjustment of the water surface should be done with great care.

(*d*) **Calibration of Meter.**—For the calibration of the laboratory wet gas meter one may use a fractional cubic-foot bottle, a cabinet-type or an immersion-type cubic-foot bottle, a meter prover, or a calibrated meter; or the meter may be tested by direct weighing of the water displaced from a suitable container by the gas, or displacing the gas which passes through the meter during one or more revolutions of the drum. For any one of these methods either air or gas may be used as the testing medium if care is taken to saturate the water with the air or gas before the test and to prevent the water from giving up any of the dissolved gas during the test. The water in the test apparatus may be quickly saturated by bubbling gas through it and the water in the meter is saturated by the passage of 1 or 2 cubic feet of gas. Except when it is desired to calibrate a meter containing the same water that has previously been used in it, it is generally more convenient to test with air than with gas.

In the calibration of the meter an accuracy of 0.2 or 0.3 per cent or better should be secured if possible. If the highest accuracy obtainable in the use of a wet meter is to be obtained, it must be calibrated in place after adjustment at the time when it is to be used. However, this procedure is not generally necessary, since the probable accuracy of readjustment of the meter is usually sufficient when care is taken, and the procedure is often inconvenient, (See "Interpretation of results," p. 33.)

If considerable resistance is offered to the motion of the meter drum, as evidenced by a considerable drop of gas pressure between inlet and outlet, then the capacity of the drum per revolution will be appreciably different at different rates of gas passage. For this reason a meter which shows a difference of pressure between inlet and outlet of more than 0.1 or 0.2 of an inch of water pressure should be tested when running at the speed at which it is to be used. A meter showing a difference of pressure of 0.1 inch or less may generally be tested at any speed less than the one at which it is to be used without introducing serious error in the result.

Tests of laboratory meters can be successfully made with either the cabinet-type or the immersion-type cubic-foot bottle at any speed at which such meters would ordinarily be used. The precautions and operating method will be evident from the following section, describing the use of a fractional cubic-foot bottle and from the directions given for the calibration of meter provers. (See p. 162.) When using either type of bottle, the air should remain in the bottle until there is no doubt that it is fully saturated with water vapor and at the temperature of the bottle. In using the immersion-type bottle care must be taken to prevent changes of temperature due to evaporation of the water from the surface of the bottle as described under the section on "Calibration of meter provers."

Using a meter prover which has been calibrated, the test of a laboratory meter may be performed at the speed at which the meter is to be used; but it is necessary to exercise great care in securing nearly constant temperature of the air inside and around the prover bell. In this respect the covered-bell prover has marked advantages. If the test is carried out with the air in the prover at the ordinary pressure of 1½ inches of water, the speed of the meter should be regulated by stopping down the outlet of the meter so that the rate will be the same as that while the meter is being used. In such tests a sufficient quantity of air should be discharged through the meter to permit reasonable accuracy in the reading of the prover; with the ordinary 5-cubic-foot prover at least 2 cubic feet of gas should be used in order to secure an accuracy of 0.1 per cent.

The method of comparison of a laboratory meter with another calibrated meter is described in detail in Technologic Paper No. 36 of this Bureau. If a meter which requires a small differential pressure for its calibration has been calibrated by the use of a fractional cubic-foot bottle, this can then be used for testing other meters at various speeds even though the other meters require considerable pressure for their operation at these higher rates.

The method of testing, in which the water which displaces or is displaced by the gas is weighed, is described in detail in Technologic Paper No. 36.

(*e*) **Calibration with Fractional Cubic-foot Bottle.**—The ordinary fractional cubic-foot bottle can not be conveniently used to test meters at a speed as great as 5 or 6 cubic feet per hour; it is, however, very convenient for testing those meters which may be tested at a lower speed. Since many of the modern American-made meters are included in this class, the fractional cubic-foot bottle method is much used.

The fractional cubic-foot bottle is a metal container terminating at the top and at the bottom in glass tubes. The bottle is made so that the volume included between two gauge marks on the glass tubes is equal to one-tenth (or one-twelfth) cubic foot. The upper outlet of the bottle is closed by a three-way stopcock, by means of which the bottle may be connected either to a supply of gas or to the meter to be tested. The lower outlet of the bottle is connected by flexible tubing to a movable reservoir. Enough water is put into the system so that when the movable reservoir is set on the lower of two adjustable shelves, the water level in the bottle will be at the lower gage mark, while when the movable reservoir is set on the upper shelf, the water level in the bottle will be at the upper gage mark. To facilitate maintenance of the proper temperature, the bottle may be surrounded by a small tank filled with water at the temperature of the water in the meter.

For the calibration of a one-tenth cubic-foot meter a one-tenth cubic-foot bottle, and for the calibration of a one-twelfth cubic-foot meter the one-twelfth cubic-foot bottle would, of course, be chosen.

Manipulation.—After the water in both meter and bottle are saturated with gas or air and the temperature of both instruments and the contained water is adjusted to be equal to room temperature, the meter is leveled and the water surface in it adjusted. The amount of water in the bottle and the height of the supports for the leveling tank are also adjusted to bring the water to the proper graduations at each position of the tank. The test is then carried out as follows:

(1) Connect one branch of the three-way stopcock of the bottle to the gas supply and the other branch to the meter inlet. Connect a burner provided with a pilot light to the outlet of the meter.

(2) Starting with the bottle filled with water, displace the water with gas.

(3) Test for gas leaks. Force the gas in the bottle through the meter, but before all of the gas has been discharged from the bottle shut off the gas beyond the meter. Put a block about 2 inches high on the upper adjustable shelf and set the movable reservoir on this, and allow a sufficient quantity of gas to escape through the meter so that the water in the bottle is visible in the upper glass tube. The pressure on the gas will then be equivalent to at least 2 inches of water. Then observe whether, during a period of five minutes, there is any appreciable displacement of the water level in the bottle.

(4) Again fill the bottle with gas and force enough gas through the meter to bring the index to the zero position.

(5) Fill the bottle with gas. Since the gas is supplied under pressure, it is necessary after the bottle is filled to disconnect it from the gas supply and allow the surplus gas to escape into the air (not through the meter). The water level in the bottle should now be at the gage mark.

(6) Note and record the temperature of the room, of the meter, and of the water in the movable reservoir, and the reading of the meter.

(7) Raise the movable vessel to the upper adjustable shelf, displacing the gas contained in the bottle through the meter. When the water level in the bottle has come to rest at the upper gage mark, read and record the reading of the meter.

(8) Refill the bottle and displace the gas through the meter, performing the operation five or six times, recording temperatures and meter readings each time.

Computations.—(1) The volume of the bottle may be so accurately adjusted that there should be no necessity for applying a correction for the error in the volume of the bottle. The change in the volume of the bottle, due to the thermal expansion of the metal, may be neglected.

(2) The gas in the bottle is measured at atmospheric pressure, but while this gas is forced through the meter the pressure is increased slightly, and in the meter the gas is measured at this

increased pressure, with the result that the volume indicated by the meter is smaller than it would have been if measured at the same pressure in the meter as in the bottle. Usually the increase of pressure will be only a few tenths of an inch of water, so that the error introduced will be negligible. It is well, however, to connect a U gage to the line leading from the bottle to the meter so as to measure the pressure existing while the meter is running. If the pressure was found to be equivalent on the average to 1 inch of water the volume indicated by the meter would have to be increased by 0.2 per cent. It is preferable, however, to make the manipulations so that the correction will be small enough to be negligible.

(3) If the water in the bottle and that in the meter are at different temperatures, then the gas will successively acquire these temperatures and tend to expand or contract in passing from the bottle to the meter, depending upon whether the water of the meter is at a higher or lower temperature than that in the bottle. Correction for such difference in temperature must therefore be applied to the results obtained in order to obtain a correct comparison of the meter and the bottle. These corrections may be made by the use of the formulas already given (p. 21); or the volume under each condition of measurement may be reduced to standard conditions, using the correction factors given in Appendix 4. However, if the difference in temperature between the meter and the bottle is very small, it is possible to correct for this by increasing the volume indicated by the meter by 0.3 per cent for each 1° F that the meter temperature is below the bottle temperature. This last procedure should be adopted for only small differences of temperature.

(4) The calculations should be made separately for each bottle full of gas displaced through the meter and the results averaged. While the same result would be obtained by taking only the initial and final readings, no check would be provided on the accuracy of the test if this were done; and possibly a false impression would be created as to the accuracy attained.

Example. Suppose the following observations were made:

Temperature of room	70° F
Temperature of bottle	70.5° F
Temperature of meter	69.5° F
Gas pressure while meter is running (inch of water)	1.4
Initial meter reading	15.1993
Final meter reading	15.2996

The simple method of correction would then be as follows:

Volume indicated by meter	.1003
Correction for pressure	+3
Correction for temperature	+3
Volume indicated by meter per 0.1 cubic foot of gas	.1009

Therefore, the meter delivers 0.0991 cubic foot per revolution.

In this example significant differences in temperature and pressure were assumed in order to illustrate the method of making the corrections. In an actual test it is desirable, and generally possible, to make these differences so small that no correction is necessary.

Alternate Method.—If a supply of gas at constant pressure—e. g., from a gas holder—is available there are some advantages in using the method of displacing the gas through the meter into the bottle. The procedure outlined may be readily modified so as to be suitable for use in this method of calibration. The principal modification would be in making the test for gas leaks. This test should be made with the bottle filled with gas and the indication of leakage would be given by the motion of the meter index.

(*f*) **Interpretation of Result.**—The result obtained by the calibration of the meter with the particular adjustments which it had at the time of the test is the one to be used for the meter on the day that the calibration is carried out, provided, of course, that the water level, etc., of the meter are not readjusted. However, when the meter is used after it has been releveled and the water level readjusted, then the average of all recent calibrations should be used, since it is more probable that this average corresponds to the adjustment made. A number of calibrations for the meter when set up and adjusted as directed on page 27 should be made at different times; and unless a progressive change in the meter is indicated, the average of all the results should be used as best representing the calibration

C. MEASUREMENT OF HEATING VALUES

The results of an experimental investigation of a number of gas calorimeters that have found an extensive application in the testing of the heating values of gases are given in Technologic Paper No. 36 of the Bureau of Standards. In the present circular, when the results of tests of calorimeters are referred to, it will be understood that reference is made to that paper, which for brevity will be designated as T. P. No. 36. The calorimeters included in that investigation are listed in the following table. For illustrations of these calorimeters and for brief descriptions of their more important details of construction and of their mode of operation, the reader is referred to that paper.

Types of Calorimeters, the Tests of Which are Described in T. P. No. 36

Calorimeter	Maker [8]
Junkers, old type	Junkers & Co., Dessau, Germany.
Junkers, new type	Do.
Hinman-Junkers	American Meter Co., Eleventh Ave. and Forty-seventh St., New York, N. Y.
Sargent	Sargent Steam Meter Co., 136 West Lake St., Chicago, Ill.
Simmance-Abady, English type	Alex. Wright & Co. (Ltd.), Westminster, London, England.
Simmance-Abady, American type	Precision Instrument Co., 102 Randolph St., Detroit, Mich.
Boys	John J. Griffin & Sons (Ltd.), Kingsway, London, W. C., England. Alex. Wright & Co. (Ltd.).
Doherty	Improved Equipment Co., 60 Wall St., New York, N. Y.
Parr	Standard Calorimeter Co., East Moline, Ill.

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[8] The English type of Simmance-Abady calorimeter may be obtained from the Precision Instrument Co. Some of the foreign-made calorimeters are listed in the catalogues of Eimer & Amend, 205–211 Third Ave. New York; Bausch & Lomb Optical Co., Rochester, N. Y.; James G. Biddle, 1211 Arch St., Philadelphia Pa.; E. H. Sargent & Co., 143 Lake St., Chicago, Ill.; Scientific Materials Co., 717 Forbes St., Pittsburgh Pa.; Arthur H. Thomas Co., 230 South Seventh St., Philadelphia, Pa.

1. HEAT UNITS AND HEATS OF COMBUSTION

Heat Units.—A quantity of heat is usually measured by the change in temperature which it can produce in a known mass of water. The heat unit is therefore defined as the quantity of heat required to raise the temperature of unit mass of water one degree. As the specific heat of water is not a constant, but varies slightly with the temperature, it is further necessary in precise scientific work to specify the temperature of the water. Although the heat unit has not been defined by any international congress, it has become the general custom to express quantities of heat in terms of water at 15° C (59° F). More recently many experimenters have preferred to express their results in terms of the 20° calorie and most of the calorimetric work done at the Bureau of Standards is now referred to this unit. The change in the unit amounts to only about 0.1 per cent, and hence would necessitate no changes in the operating directions for industrial calorimeters. The 15° calorie is retained in this circular, since 15° C corresponds practically to 60° F, the standard temperature used in commercial gas measurement.

The units in which the heating values (or heats of combustion) of fuels, foods, explosives, etc., are expressed are: (a) The small *calorie;* (b) the large *Calorie;* and (c) the *British thermal unit,* designated briefly Btu.

The calorie is the quantity of heat required to raise the temperature of 1 gram of water 1° at 15° C.

The Calorie is the quantity of heat required to raise the temperature of 1 kilogram of water 1° at 15° C.

On the same basis the British thermal unit is the quantity of heat required to raise the temperature of 1 pound of water 1° F at 59° F.

For the order of accuracy required or readily attainable in nearly all engineering or industrial tests the variation of the specific heat of water in the range of temperatures within which calorimetric experiments are conducted is so small that it may be neglected. For example, the amount of heat required to raise the temperature of a given mass of water 1 degree at 35° C (95° F) is about 1 part in 500 (0.2 per cent smaller than that required at 15° C (59° F).

For converting quantities of heat expressed in terms of any one of the heat units defined above to quantities of heat expressed in terms of either of the other two heat units, the following are the conversion factors:

1 Calorie = 1000 calories.
1 British thermal unit = 252.0 calories.

The effect of impurities in tap water on its specific heat are considered in Technologic Paper No. 36. It is sufficient here to state that impurities likely to be present in any city water supply will cause no variations in the specific heat of sufficient magnitude to require consideration in industrial gas calorimetry.

Heats of Combustion.—In addition to the number of heat units produced, the mass or volume of the substance that is burned must be expressed in the evaluation of the heating value. Thus we speak of the Btu per pound of fuel or per cubic foot of gas, of calories per gram of fuel, per liter of gas, etc.

If the substance burned be a gas, the mass contained in a given volume will evidently depend on the temperature and pressure of the contained gas. Hence, in order that the term "heat of combustion of a gas" may have a definite meaning and that the results of different observers may be comparable, the volume of the gas must be referred to some standard temperature and pressure. In most engineering tests and for the purposes of the industrial testing and measurement of gases the standard temperature and pressure almost invariably used in the United States are 60° F and 30 inches of mercury, and the gas, for purposes of testing, is saturated with water vapor. The reduction of volumes of gas, measured at various temperatures and pressures, to the corresponding volumes at standard temperature and under standard pressure is considered on pages 190–191.

In stating the heat of combustion of a substance, in addition to the number of heat units produced by the combustion of a unit mass or volume of the substance, it is further necessary to state the conditions under which the combustion is carried out—e. g., whether the combustion takes place at constant volume or at constant pressure, whether the resulting products are cooled down to the original temperature of the substance, and whether all water vapor formed in the processes of combustion is condensed or whether the products are allowed to escape at a higher temperature and thus carry off sensible and latent heat.

The following definitions of heats of combustion are sufficiently precise for purposes of industrial and engineering tests.

The *total heating value* of a gas, expressed in the English system of units, is the number of British thermal units produced by the combustion, at constant pressure, of the amount of the gas which would occupy a volume of 1 cubic foot at a temperature of 60° F, if saturated with water vapor and under a pressure equivalent to that of 30 inches of mercury at 32° F and under standard gravity, with air of the same temperature and pressure as the gas, when the products of combustion are cooled to the initial temperature of gas and air, and when the water formed by combustion is condensed to the liquid stage.

The *net heating value* of a gas, expressed in the English system of units, is the number of British thermal units produced by the combustion, at constant pressure, of the amount of the gas which would occupy a volume of 1 cubic foot at a temperature of 60° F, if saturated with water vapor and under a pressure equivalent to that of 30 inches of mercury at 32° F and under standard gravity, with air of the same temperature and pressure as the gas, when the products of combustion are cooled to the initial temperature of gas and air and the water formed in combustion remains in the state of vapor.

The net heating value, according to the above definitions, differs from (is less than) the total heating value by an amount of heat equal to the heat of vaporization, at the initial temperature of the gas and air, of the water formed in the combustion of the gas. For most calorimetric calculations, the heat of vaporization of water may be taken as 580 calories per gram, corresponding to 2.3 Btu per cubic centimeter.

In addition to the terms total heating value and net heating value, the term *observed heating value* will be used as a matter of convenience in discussing experimental data. The observed heating value for a flow calorimeter will be understood to be the value obtained by multiplying the mass of water which flowed through the calorimeter during the test by the corrected rise in temperature of the water, and dividing by the volume (referred to the standard conditions of 60° F and 30 inches) of gas burned.

It has been the general practice to regard the observed heating value as identical with the gross (total) heating value. This practice is not permissible if an accuracy better than 2 or 3 per cent is required, since, even with a perfect flow calorimeter, these two heating values would necessarily differ by 2 per cent or more under certain atmospheric conditions (e. g., 10 per cent humidity and 90° F), while for some of the calorimeters tested the difference might amount to about 4 per cent.

In view of the fact that the term "gross heating value" was intended to mean total heating value, but has generally been applied to the observed heating value as well, it seems desirable to discontinue the use of the term "gross heating value."

2. TYPES OF CALORIMETERS

Many types of calorimeters have been suggested and used to measure heats of combustion of gases.

(*a*) In the Berthelot bomb type, the combustion takes place at constant volume within a bomb, in the presence of sufficient oxygen to insure complete combustion. This type of calorimeter gives the total heat of combustion at constant volume.

(*b*) In the Regnault and the Julius Thomsen types the gas is burned in a combustion chamber within the calorimeter and the products of combustion are caused to give up their heat by being passed through a worm immersed in the water of the calorimeter.

(*c*) In the comparison type, such as the Parr gas calorimeter, the rise of temperature produced in a calorimeter by the combustion of a given volume of the gas is compared with the rise of temperature produced in a similar calorimeter by the combustion of a given volume of another gas, the heat of combustion of which is known. In a restricted sense the Strache calorimeter is an instrument of this type.

(*d*) The water-flow type is utilized most frequently for the calorimetry of gases and is exemplified in the calorimeters listed on page 34, with the exception of the Parr calorimeter. The principles of the flow calorimeter are discussed in the following section.

(*e*) A large number of gas calorimeters have been devised, the operation of which depends on the indications of some thermometric device, heated by gas burned at a constant rate as controlled by a pressure regulator or other regulating mechanism. The thermometric device may be thermoelectric or may depend on the expansion of a solid, of a liquid, or of a gas. The Fery calorimeter, the Farenheim, the Smith, and the Sarco recording calorimeters, and the Simmance-Abady calorgraph are calorimeters of this type. In another class of calorimeters a definite quantity of gas is burned in the apparatus and the heating value of the gas deduced from the change of temperature of a mass of material subjected to the action of the flame. The Graefe and the Raupp calorimeters are of this type. The indications of these calorimeters are arbitrary and their scales must be calibrated by comparison with a standard calorimeter. Since the products of combustion escape from such calorimeters at relatively high temperatures, these instruments are usually calibrated for indicating or recording net heating values.

In all of the types described, except (*a*), the combustion takes place under the condition of constant pressure. Calorimeters of types (*b*), (*c*), and (*d*) are used to measure the total heat of combustion at constant pressure, and when suitably constructed some of them may be used to measure the net heat of combustion at constant pressure. Calorimeters of type (*d*) have been used in connection with recording devices to obtain continuous records of total heating values.

The reader will find descriptions of numerous calorimeters in the publications of Immenkötter[4] and of Coste.[5]

3. PRINCIPLES OF FLOW CALORIMETRY

In flow calorimeters the heat to be measured is imparted to a stream of water; the mass of water flowing through the calorimeter during the time that a known mass or volume of the combustible is burned within the calorimeter and the resulting change in temperature of the water furnish the data necessary for calculating the heat imparted to the water.

There are always some heat losses the magnitude of which must be determined, in order that suitable corrections may be applied to the observed heating value, if such losses are large enough to be of significance for the accuracy that is sought.

The gas, the heating value of which is to be determined, is measured with a suitable wet meter, and is burned at a constant rate in a suitable burner within a nearly closed chamber, called the combustion chamber. The air necessary to support the combustion enters the combustion chamber through the open bottom of the calorimeter, the circulation through the calorimeter being induced by the heated products of combustion. Under some conditions (e. g., open damper and small rate of gas consumption) the air drawn through the calorimeter is very considerably in excess of that required for combustion, while at high rates of combustion the air supply may be insufficient to insure complete combustion. The heated products[6] pass up through the combustion chamber, which is surrounded by the flowing water, then downward through tubes or spaces also water-cooled, and finally are discharged into the atmosphere through an outlet in which

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[4] Über Heizwertbestimmungen mit besonderer Berücksichtigung gasförmiger und flüssiger Brennstoffe, published by R. Oldenbourg, Munich and Berlin.

[5] The Calorific Power of Gas, published by Chas. Griffin & Co. (Ltd.), London.

[6] As a matter of convenience, the gases discharged from the calorimeter, which include all of the products of combustion except the water condensed in the calorimeter, as well as the nitrogen and excess oxygen from the entering air, will be referred to as the products of combustion or simply the products.

a damper is usually placed, by which the amount of air drawn through the calorimeter may be controlled. The heated gaseous products are thus made to impart to the water flowing through the calorimeter nearly all the heat resulting from combustion.

The temperature of the water entering and leaving the calorimeter is measured by the inlet and outlet water thermometers, respectively. A mixing device should be provided to thoroughly mix the heated water before it reaches the bulb of the outlet-water thermometer in order that this thermometer shall indicate the true mean temperature of the effluent water. The water flows through the calorimeter under the pressure determined by the difference in level of the inlet and outlet overflow weirs. The rate of flow of water, and hence its rise of temperature, may be varied by a suitable valve.

The determination of the heating value of a gas by means of a flow calorimeter is carried out as follows: Gas is burned at the proper rate (as measured by the gas meter) and with proper air supply (controlled by a damper) in a suitable burner placed within the combustion chamber of the calorimeter, the rate of flow of water through the calorimeter being so adjusted (by the valve) that the rise of temperature of the water is the desired amount (usually 15° to 20° F.); the temperature of the water is so regulated that it enters the calorimeter at approximately room temperature. After the gas has been burning long enough for a condition of thermal equilibrium to be set up in the calorimeter, the data necessary for a heating value determination are obtained by observing: Pressure, temperature, and humidity of air; temperature of products of combustion; temperature of gas meter and the gas pressure at meter inlet; series of temperatures of inlet and outlet water; weight or volume of water which flowed through the calorimeter during the combustion of the chosen volume of gas.

Two or three readings of the outlet-water thermometer are taken before the index of the gas meter passes through its zero position; at this instant the change-over device, into which the water discharges from the calorimeter, is shifted to divert the water from drain to measuring vessel; readings of the outlet-water thermometer are then made at frequent and regular intervals until the index of the meter has made nearly two complete revolutions; if the temperature of the inlet water is not maintained constant, the inlet-water thermometer also should be read frequently during the test; the instant the index of the meter passes through zero, on completion of its second revolution, the change-over device is shifted, diverting the water from measuring vessel back to drain. One or two more readings of the outlet-water thermometer and one more reading of the inlet-water thermometer are taken and then the weight or the volume of the water collected is determined. The readings of the outlet-water thermometer before and after shifting the change-over device are taken simply to show that steady conditions have been maintained before and after the test. The barometric pressure is read to enable the volume of gas burned during the test to be reduced to standard conditions, and the humidity of the air of the room is determined by a suitable psychrometer to enable the correction to be determined to reduce the observed heating value to the total heating value as hereinafter explained.

The observations above referred to, all of which may be taken in a few minutes, give all the data necessary for a single determination of the total heating value of the gas. For calculating the net heating value of the gas, the amount of water vapor condensed out of the products of combustion of a known volume (1 cubic foot is sufficient) of the gas is collected and measured in a suitable graduate placed under the drip tube at the base of the calorimeter. The collection of this condensate for purposes of measurement should obviously not be started until the gas has been burning in the calorimeter long enough to insure that the inner walls and tubes of the calorimeter have become uniformly wetted and the drainage therefrom has become uniform.

The observed heating value, in Btu per cubic foot of the gas, is found by multiplying the number of pounds of water collected in the measuring vessel by the number of degrees Fahrenheit rise in temperature, and dividing the product so found by the number of cubic feet (referred to standard conditions) of gas burned during the test. To find the total heating value, the observed heating value is corrected for heat losses, for the effect of atmospheric humidity, and for the variation of the specific heat of water. The sum of these corrections usually amounts to less than 2 per cent of the total heating value. To find the net heating value, the latent heat of vaporization of the water condensed in the calorimeter per cubic foot of gas (referred to standard conditions) must be subtracted from the observed heating value, after correcting the latter for heat losses and for the variation of the specific heat of water.

The Doherty calorimeter, while utilizing the essential principles of flow calorimetry just described, differs from the ordinary types of flow calorimeters in that the volume of water heated is made equal to the volume of gas burned, so that separate measurements of the gas and of the water are unnecessary.

4. CHOICE OF CALORIMETER

In considering the equipment of a calorimetric laboratory, the first question that arises is the choice of type of calorimeter—i. e., whether one of the usual flow type, or a flow calorimeter of the Doherty type, or a comparison calorimeter of the Parr type will prove most satisfactory when all the conditions are considered. The careful reading of that part of T. P. No. 36 and of those parts of the reports for 1908, 1909, and 1912, of the committee on calorimetry of the American Gas Institute, in which tests of various gas calorimeters are described, is recommended in connection with the choice of a calorimeter. It has been shown that total heating values may be determined with sufficient accuracy with most of the calorimeters listed in this circular, if suitable corrections are applied, although the corrections for calorimeters of some types would have to be determined by comparison with a calorimeter of another type. If both total and net heating values are to be determined with the calorimeter, the Parr calorimeter would be excluded from consideration, and the Doherty calorimeter would be at a disadvantage. However, if total heating values only are to be determined, the choice, even if cost is disregarded, ultimately resolves itself into a comparison of the relative advantages and disadvantages of a number of instruments, in which comparison different features would be weighted differently by different persons.

(*a*) **Flow Calorimeters.**—The choice among the usual types of flow calorimeters is a question of weighing relative advantages and disadvantages. Most of the flow calorimeters listed in this circular can be used to measure the total and net heating values of most gases with an accuracy of 1 per cent, if due precautions are taken and if necessary corrections are applied. However, as will be seen from the tests of these calorimeters, some require the application of a correction of 1 to 2 per cent for heat losses, while others require modifications to insure satisfactory operation—e. g., change in the burner support so that the burner can be raised, provision for a mixing device for the outlet water, etc. Many calorimeters are apparently sent out by the makers without having been operated under service conditions, and in such calorimeters minor adjustments are often necessary.

The differences in mechanical construction of the calorimeters arise mainly from the differences in design adopted to secure transfer of heat from the products of combustion to the water—e. g., whether the condenser tube, the water shell, or the radiator coil is adopted. All are, however, probably equally efficient if properly applied.

Although gas meters are usually furnished with calorimeters, it is well to choose the two instruments independently. The important features of meter construction have been considered on page 24.

Among the more or less important features in which the ordinary types of flow calorimeters differ are the following:

(1) Magnitude of heat losses.
(2) Construction and workmanship.
(3) Accessibility of parts.
(4) Suitability for the determination of net heating values.
(5) Time required to attain thermal equilibrium; water content.
(6) Steadiness of outlet-water temperature.
(7) Thoroughness of mixing of outlet water.
(8) Position of burner and use of radiation shields.
(9) Conveniences in use.
(10) Gas-burning capacity of calorimeter.

(1) *Magnitude of Heat Losses.*—Some of the calorimeters tested were found to give heating values as much as 2 per cent lower than others, due to such a mode of construction that the heat developed within the calorimeter was not effectively communicated to the circulating water. All of the instruments showing this defect happened to be of the radiator coil type. Heating values determined with these calorimeters are subject to a constant error, the magnitude of which must be determined by comparison with another calorimeter free from the defects mentioned, in order that a correction, determined by means of such a comparison, may be applied to results obtained with the calorimeter in question. It is evident that a calorimeter requiring an empirically determined correction is not as suitable for official testing as is a calorimeter requiring no such correction.

In all calorimeters operated with the inlet water at room temperature there are some losses of heat from the surfaces arising from the fact that the water heated in its passage through the calorimeter loses heat to the surroundings before reaching the bulb of the outlet-water thermometer. This loss is usually referred to as the radiation loss. There will be an additional loss (or a gain) of heat if the inlet water is not at room temperature. The so-called radiation loss is of small importance for any of the flow calorimeters tested, rarely necessitating a correction as large as 0.2 per cent of the heating value. In standardizing a calorimeter the amount of these heat losses, when the inlet water is at room temperature, is determined, and in subsequent use of the instrument the necessary corrections may be applied. In general, it is not worth while to complicate the water circulation system of a calorimeter by features of design intended to minimize this small loss of heat. For the purpose of minimizing this heat loss, the distance traversed by the heated water before reaching the bulb of the outlet-water thermometer has, in most of the calorimeters, been reduced to a minimum. Since the heat loss is very small, it would be desirable rather to increase the length of the tube in which the outlet-water thermometer is inserted, so as to permit the use of an effective mixing device and also of a thermometer with a bulb of reasonable size. The portion of the tube for the outlet-water thermometer in which the water circulates might, with advantage, be made about 4 inches long instead of 3 inches or less, thus leaving a length of nearly 2 inches for a mixing device and as much more for the thermometer bulb.

The additional loss (or gain) of heat due to the inlet water not being at room temperature is also negligibly small for temperature differences of a few degrees Fahrenheit and is smaller than other errors introduced into the calorimetric measurements due to such temperature difference.

Measurements of the loss of heat from the surfaces of old and of new calorimeters of identical construction have shown that the importance of a high polish has been generally overestimated.

(2) *Construction and Workmanship.*—There are decided differences in the quality of workmanship shown in calorimeters from different makers. As very few of the types of calorimeters are completely standardized as to details of construction, different calorimeters, even of the same make, may differ in these details; e. g., the size of the openings in the damper may be different, thus varying the normal rate of gas consumption at which the calorimeter should be operated. Sometimes apparently trivial defects

of construction, which may be easily corrected, may cause trouble in the operation of the calorimeter. Examples of such defects that have been found are: Leakage in cocks and unions in the water systems; mounting of the combustion-products thermometer so as to interfere with the operation of the damper; mounting of the outlet tube for combustion products in such a way that it caught some of the condensate; inner wall of combustion chamber tightly fitted to base of calorimeter by a brass ring so that some of the condensate dripped off this inner wall at the bottom instead of being led to join the condensate drained from the condenser tubes. This last defect, while easily corrected by turning down the brass ring in a lathe, was sufficient to render worthless the results of determinations of net heating values. Such defects would be largely avoided if the calorimeters were operated under service conditions before being sent out by the makers.

(3) *Accessibility of Parts.*—Accessibility of parts is a desirable feature for the reason that it enables the user to make repairs of leaks, etc., that may develop, thus avoiding the necessity of returning the instrument to the maker for simple repairs. It also enables the instrument to be cleaned from time to time. This feature is particularly emphasized by some users of the instruments. Most of the tests made by the Bureau have been on new instruments, so that the deterioration due to use was not brought out. A few calorimeters were tested, however, that had been in long service, and these instruments showed no errors due to deposits on the interior surfaces. It would seem that no trouble would be expected so long as the water circulation was not interfered with or the products were not discharged at excessive temperatures. If the water supply was of such character that a deposit was left in the calorimeter, frequent cleaning might be necessary.

The Hinman-Junkers calorimeter represents the type most accessible in all its parts and the Doherty calorimeter the least accessible.

(4) *Suitability for Determination of Net Heating Values.*—Regularity of the drainage of the condensate, which determines the accuracy with which net heating values can be determined from the combustion of a moderate volume of gas (about 1 cubic foot), is best secured in those calorimeters which are so designed that there is no accumulation of water within the calorimeter. For example, in the Boys calorimeter the drainage takes place from a water surface of large area, and the delivery of the con-

densate is apt to be irregular. The regularity of drainage also depends on details of design and workmanship, such as shaping and condition of surfaces, channels, ends of condenser tubes, etc. All of the condensate should be delivered through a drain tube provided for the purpose. Some calorimeters have been found to deliver part of the condensate either into the outlet tube for the products of combustion or through the opening at the bottom of the combustion chamber; defects of this kind, which are due to defective construction, are in most cases easily corrected.

(5) *Time Required to Attain Thermal Equilibrium; Water Content.*—Some of the calorimeters—e. g., the Boys and the American type of Simmance-Abady—require a long time to attain a condition of thermal equilibrium. This is not necessarily a source of error provided that sufficient time is allowed, after lighting the gas, for the attainment of thermal equilibrium and that conditions can be maintained sufficiently constant. Under unfavorable conditions of testing the use of a calorimeter requiring a long time to attain thermal equilibrium will be inconvenient and may give rise to appreciable errors. There is no special advantage in reducing the water content of a calorimeter to a minimum, but a calorimeter of very large water content requires a somewhat longer time to come to a condition of thermal equilibrium and requires a water supply at more nearly constant temperature.

(6) *Steadiness of Outlet-Water Temperature.*—The fluctuations in the readings of the outlet-water thermometer will depend upon (1) steadiness of heat supply, which in turn depends not on the calorimeter but on the gas-pressure governor, on the protection of the flame against drafts by shielding, by suitable placing of the burner, and by suitable location of the calorimeter; on (2) regularity of water flow; and on (3) thorough mixing of the outlet water. Regularity of water flow depends primarily on the design of the calorimeter. To secure steadiness of water flow, a constant head of water must be provided either in the calorimeter itself or by means of accessory apparatus, and the water-circulation system must be so designed as to avoid the accumulation of air in the water spaces. Of the flow calorimeters listed on page 34, the Boys and the Doherty calorimeters showed greater steadiness of outlet-water temperature than did any of the others, which were about on a par in this respect. In one or two calorimeters the somewhat larger fluctuations observed were due to entrapped air around the bulb of the inlet-water thermometer, which was in a descending stream of water, or to entrapped air under surfaces

that were too nearly horizontal. While these fluctuations are not necessarily sources of error when the thermometers are read frequently, they undoubtedly increase the difficulty of taking observations. It is undesirable to secure steadiness of outlet-water temperature by a design which increases largely the time required for the calorimeter to attain thermal equilibrium.

(7) *Thoroughness of Mixing of Outlet Water.*—In some of the calorimeters tested the outlet water was not mixed sufficiently to insure that the outlet-water thermometer would indicate the mean temperature of the effluent stream. It was necessary to supply a suitable mixing device.

(8) *Position of Burner and Use of Radiation Shields on Burner.*—The burner should be so mounted that the base of the flame is not less than 1½ inches above the lowest level at which the water circulates in the calorimeter. In some of the calorimeters tested the burner was placed so low that the observed heating values could be increased 1 per cent by raising the burner 3 inches.

Radiation shields on the burner are furnished with some calorimeters. The rise in observed heating values due to the use of shields, which is considered in T. P. No. 36, was found to be from 0.2 to 0.7 per cent. If shields are not furnished, they may readily be made from sheet metal. If the burner is set sufficiently high in the combustion chamber, the use of shields becomes of less importance.

(9) *Convenience in Use.*—It is convenient to have the inlet and outlet water thermometers at the same level. This convenience is, however, sometimes attained by a mode of construction that results in the formation of an air pocket around the bulb of the inlet-water thermometer, with a resulting irregularity in the flow of water. If provision is made for a water supply at practically constant temperature, so that the temperature of the inlet water need be read only two or three times for each heating-value test, the location of the thermometers at different levels is not an inconvenience of any moment.

Various devices (change-over funnels, stopcocks, electrically operated dumping buckets, etc.) are used to divert the effluent stream of water from drain to measuring vessel and back to drain. All of these devices are capable of manipulation with the required degree of accuracy, and are preferable to shifting by means of a rubber tube. The Simmance-Abady calorimeters were provided with pivoted outlet funnels that were adapted to a special method of testing that is not recommended. These funnels are inconvenient for the usual method of testing in that they must be held in position during the progress of the test. Automatic change-over devices must be unusually well made to insure satisfactory service.

A stopcock, preferably one with an index moving over a graduated arc, to regulate the flow of water through the calorimeter is desirable.

To simplify the test for leakage of gas, there should be a stopcock on the burner.

One point to which very little attention has been given is the adaptation of water and gas connections to sizes of tubing that are readily obtainable. For one calorimeter tested it was necessary to use two sizes of tubing, with a reducer, in order to connect the meter and pressure regulator.

Mounting the thermometers in metal holders held in place by screw caps is undoubtedly more convenient than the usual mounting in a rubber stopper, but the mounting is so rigid that increased breakage of thermometers is certain to result unless a suitable metal tube, cut away at the front and back, is used to protect the thermometer.

The calorimeter should be so mounted that the burner with its radiation shields can be conveniently inserted and removed without danger of extinguishing the flame.

(10) *Gas-Burning Capacity of Calorimeter.*—The different calorimeters have different capacities at which the gas can be burned in them. The proper rate of gas consumption should be determined for each individual calorimeter and for the gas to be tested, in the manner described on page 59. The capacity of most of the calorimeters is so high that it must be reduced by the use of a damper, in order to secure a convenient rate for operation. In general the gas-burning capacity will not be a determining factor in the choice of the calorimeter.

(*b*) **Doherty Calorimeter.**—As between the Doherty calorimeter and a flow calorimeter of the ordinary type, the former dispenses with the gas meter and its attendant disadvantages, with the pressure regulators, and with the apparatus for weighing or measuring water. If an average sample of gas taken during a definite period is to be tested, a gas holder will be required, unless a single test of such sample is deemed sufficient. Apparently the main disadvantages of the Doherty calorimeter are the complexity of the connections and the inaccessibility of the parts for cleaning or repairs. There is, however, no danger of damage to the calorimeter due to failure of the water supply. How much of a disadvantage the complexity of the connections would be could only be established by long service tests, so that the limited tests made at the Bureau gave no information on this point. It seems that the instrument might become clogged if the water was not free from foreign matter or if it contained in solution materials that would deposit in the pipes.

The various heat losses can be determined for most of the flow calorimeters so that heating values can be determined with them without the necessity of determining the errors by comparison with another instrument. However, the various heat losses in the Doherty calorimeter—e. g., the proportion of the heat generated in the combustion chamber which is not imparted to the flowing water, the heat imparted to the insulation between the calorimeter and the gas tank, etc.—could not be readily determined with the instrument itself, and it was necessary to calibrate it by comparison with another calorimeter.

The temperature rise to be measured in the Doherty calorimeter is proportional to the heating value of the gas to be tested, and for ordinary illuminating gas (600 Btu) is only about half that generally used in flow calorimeters, but the temperature of the outlet water is somewhat less subject to fluctuations than it is in most other flow calorimeters, so that the rise can probably be determined with about the same relative accuracy in either type of calorimeter. In testing gases of low heating value with the Doherty calorimeter the temperature rise to be measured would be small.

For operation of the Doherty calorimeter under the most favorable conditions the inlet water should be 9° or 10° F below room temperature in testing ordinary illuminating gas (600 Btu), so that provision would have to be made for cooling the small overhead tank of water; when tap water is not at low enough temperature, ice water will be required. The calorimeter might, however, be operated like the other flow calorimeters, with the inlet water at room temperature, and a correction applied. When thus operated the calorimeter gives heating values that are somewhat low, e. g., about 1 per cent for Doherty calorimeter No. 16 (see T. P. No. 36). The computations for the Doherty calorimeter are practically the same as for an ordinary flow calorimeter.

(*c*) **Parr Calorimeter.**—As between the Parr calorimeter and a calorimeter of the flow type, the former dispenses with much accessory apparatus, such as overhead water tank, gas meter, pressure regulators, barometer, and psychrometer. Some of this accessory apparatus may, however, be required in a gas testing laboratory for other than calorimetric measurements. The Parr calorimeter gives total heating values directly and the computations are of the simplest form, no barometer readings, reductions to standard conditions, corrections for effect of atmospheric humidity or for heat losses being necessary. There is no danger of damage to the calorimeters due to failure of the water supply. On the other hand, the Parr calorimeter requires the use of a hydrogen generator, and provision must be made for cooling the water in the calorimeters to a temperature about 5° F below room temperature, and for a water motor or wiring for the electric motor to operate the stirrers. More time is required to make a number of tests and, on account of the small rise of temperature of the calorimeters (about 5° F for a 600 Btu gas), the precision attained in a single test is not great, so that a number of tests will usually be required. The skill required for the operation of the Parr calorimeter is not greatly different from that required in the operation of a flow calorimeter. The former requires considerable care and some skill in filling the cylinders with pure hydrogen and with the sample of gas to be tested and in determining the rise of temperature in such a way that the effect of heat interchange with the surroundings shall be eliminated; and the latter demands corresponding skill and care in the calibration and adjustment of the meter, in shifting the change-over device for collecting the water, and in the computation of the results from the observed data.

With the angle-stem thermometers furnished with the Parr calorimeter, the space that is available for the bulbs of the thermometers is quite restricted and the user should assure himself that the indications of the thermometers are not affected by conduction of heat along the stems to the bulbs of the thermometers. It might be preferable to use thermometers inserted into the tops of the calorimeters, thus permitting the use of thermometers of the ordinary type. The thermometers could then be readily interchanged and the constant thermometric errors thus eliminated by making two tests.

The design of the hydrogen generator supplied with the Parr calorimeter has been criticised by Lawrence,[7] who also regards the use of two generators as desirable.

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[7] Proc. Am. Gas Institute, 7, p. 149; 1912.

5. CALORIMETRIC LABORATORY AND EQUIPMENT

(*a*) **Laboratory.**—If a number of rooms are available, one should be chosen the temperature of which is not subject to rapid changes during the times at which observations will be made; a room which is not subjected to direct sunlight at about the time observations are to be made is therefore desirable. A room used exclusively for the calorimetric or calorimetric and photometric laboratory is to be preferred.

Connections to a water supply and to the supply of gas to be tested must of course be available in the laboratory, and it is a great convenience also to have a hot-water supply. A sink with water and drain connections should be installed in the laboratory. The gas-supply pipe leading from the main to the laboratory should be suitably located and properly drained; precautions to be observed in obtaining gas for testing purposes are given on page 13 of this circular.

(*b*) **Equipment.**—If a flow calorimeter of the ordinary type is to be installed, the following equipment for the calorimetric laboratory will be required, in addition to the necessary piping (for hot and cold water, gas, and drain), valves, cocks, hose nipples, tubing for connections, etc.

(1) Calorimeter and accessories.
(2) Thermometers, reading glasses.
(3) Apparatus for weighing or measuring water.
(4) Small graduate for measuring condensate.
(5) Gas meter.
(6) Pressure regulators.
(7) U gage for measuring gas pressure.
(8) Barometer.
(9) Psychrometer.
(10) Gas holder (not always necessary).
(11) Overhead water tank ⎫
(12) Table ⎭ or (13) calorimeter cabinet.

Apparatus for calibrating the meter by one of the methods described on page 28 is a very desirable although not an absolutely necessary part of the equipment.

If a Doherty flow calorimeter is to be installed, the apparatus for weighing or measuring the water, the gas meter, the pressure regulators, and the U gage will not be required.

If a Parr calorimeter is to be installed, the necessary equipment, in addition to the calorimeter, consists of calorimetric thermometers, hydrogen generator, supply of hydrone, table or cabinet for calorimeter, gas holder, piping for gas and for water, some means of cooling the water in the calorimeters, and piping for a water motor or wiring for an electric motor. For testing the accuracy of the adjustments, such as equality of the calorimeters and of the gas cylinders, a balance and weights, having a capacity of 12 pounds or more, and sufficiently accurate for weighing loads of from 3 to 12 pounds to an accuracy of 0.1 per cent will be necessary.

(1) *Calorimeter.*—The choice of calorimetric apparatus is discussed in the preceding section of this circular.

(2) *Thermometers.*—The inlet and outlet water thermometers should be graduated to 0.1° or 0.2° F. Thermometers for the Parr calorimeter should be graduated to 0.05° or 0.1° F.

At least four calorimetric thermometers should be provided for each calorimeter to avoid delays otherwise resulting from breakage of thermometers. Detailed specifications for high-grade calorimetric as well as for other laboratory thermometers will be published in a special Bureau circular now in preparation.

For convenience in reading the calorimetric thermometers and to avoid errors due to parallax, suitable reading glasses conveniently movable along the stems of the thermometers should be provided.

Thermometers graduated to 1° F are suitable for measuring the temperature of the gas and the products of combustion.

(3) *Apparatus for Weighing or Measuring Water.*—It is easily possible to weigh the water with an accuracy beyond that required for calorimetric work, or, with suitable precautions, to measure the water volumetrically with sufficient accuracy.

The scale should be of such construction that weighings can be conveniently and quickly made. The combined errors of the scale (such as those due to inequality of arms, to varying positions of the weights on the scale pan, limiting sensibility due to friction, etc.) and of the weights should be so small that the masses of water to be weighed in calorimetric tests (about 7 pounds) can be determined with an accuracy of 1 part in 1000. The buckets in which the water is collected during a test should all be of the same weight, and the scale should preferably be so made that the weighing bucket is exactly counterpoised when in position on the scale. The weights, rider, and graduation of the arm of the scale should be such that the weighings are made directly in pounds and decimals of a pound.

Graduates of cylindrical form are often used to measure the volume of water collected in calorimetric tests. While it is possible to use such graduates with an accuracy of 0.2 per cent, this requires so much time and care in reading that the main advantages in measuring the water over weighing it are lost. It is preferable to use a graduate in which the lower portion is enlarged and only the upper cylindrical part graduated, e. g., from the 6 to the 8 pound graduations, thus providing a more open scale. If gases of quite different heating values are to be tested, several such graduates of different volumes might be desirable, or it may be that weighing the water would prove more convenient under such circumstances.

Standard specifications for glass volumetric apparatus may be found in Bureau Circular No. 9. Glassware is usually graduated in cubic centimeters at some standard temperature. Graduates subdivided in pounds and decimal fractions of a pound and suitable for use with calorimeters would, so far as is known to the Bureau, have to be made to order.

(4) *Graduate for Measuring Condensate.*—A 25-cc glass graduate of the usual form is suitable for this purpose. Graduates conforming to the Bureau specifications (Circular No. 9) are to be preferred.

(5) *Gas Meter.*—The points to be considered in the choice of a laboratory gas meter are considered on page 26.

(6) *Pressure Regulators.*—Two types of wet pressure regulators are furnished with flow calorimeters, the simple float type, consisting of a small gas holder, the pressure of the gas on the inside of the holder actuating the gas valve connected therewith, and the counterbalanced float type, in which the gas holder, suspended from one arm of a balance, is counterbalanced and may be compensated so as to maintain a constant pressure for all positions. In the latter type the gas pressure desired on the outlet side of the regulator is attained by varying the counterbalancing weights, and in the former type this is done by weighting the gas holder with suitable weights. In both types the pressure which is controlled by the regulator is the outlet pressure, which is the pressure of the gas within the holder. The simple float type, when properly constructed, is quite satisfactory.

(7) *U Gage.*—A U gage on which the pressure in inches of water at the meter inlet may be read should be provided. Some of the float pressure regulators have a U gage mounted so as to indicate the outlet pressure, and if one of these regulators is connected between the gas supply and the meter, the separate U gage will be unnecessary. Some meters are furnished with U gages which indicate the pressure at the meter outlet. While the pressure

under which the gas is metered is the pressure at the meter inlet, no appreciable error would ordinarily be introduced in a calorimetric measurement due to the use of a gage indicating the pressure at the meter outlet.

(8) *Barometer.*—Satisfactory mercurial barometers will be found listed in the catalogues of a number of thermometer and instrument makers. A barometer that can be read to 0.02 inch, or even 0.05 inch, will suffice for most industrial testing. The bore of the barometer tube, in the region where the position of the meniscus is read, should be not less than three-eighths of an inch. The barometer should be provided with an attached thermometer.

A barometer should be carefully tested before it is put into use, since the scale may be in error, the setting of the fixed point defining the position of the lower mercury surface may not correspond exactly to the zero reading of the scale, etc. An error of 0.05 inch in the barometer reading will cause an error of 1 part in 600 in the estimated volume of gas burned in a test—i. e., 1 Btu in a 600 Btu gas. If the user can not arrange to have his barometer tested, he should at least make a series of comparisons with the barometer readings of a near-by station of the Weather Bureau, reading his own barometer at the same time of day and making any allowance that may be required for difference in level of his station and that of the Weather Bureau, and correcting his barometer readings to inches of mercury at 32° F.

It is always advisable, except possibly in traveling inspection work, to use a mercury barometer instead of an aneroid barometer, although the latter may be used if suitable precautions are observed. The user of an aneroid barometer is apt to be deceived by the fact that the scale of the instrument is readable to 0.01 inch or even closer. Its indications, however, will depend not alone on the pressure at the time it is read, but also on the pressure and the rate of variation of the pressure for some time previous, on how well it is compensated for temperature changes, whether it has been jarred sufficiently to derange its working parts, etc. With the average aneroid of high grade which has been carefully tested at a standardizing laboratory, and which has been again checked when received at its destination by a comparison with a standard barometer to insure that it has not been damaged in transportation, an accuracy of 0.05 inch may be attained in measuring the barometric pressure at a given station—i. e., under conditions where the aneroid is not subject to large and sudden variations in pressure as it is in altitude measurements.

If an aneroid barometer is used, its readings should be frequently compared with the barometric pressure recorded at a nearby station of the Weather Bureau, due allowance being made for difference in altitude of the two stations. Further information relating to aneroid barometers may be found in Bureau of Standards Circular No. 46.

(9) *Psychrometer.*—Information relating to the various types of psychrometers and to their method of use may be found on page 183.

(10) *Gas Holder.*—If it is desired to test an average sample of gas collected over any period of time, a small gas holder must be installed, preferably in the calorimeter room. Such holders will be found listed in the catalogues of some makers of calorimeters and of gas appliances.

A holder of small capacity (about 2 cubic feet) which is easily constructed may be used if a simple arrangement is provided by which the calorimeter may be brought to equilibrium conditions with gas drawn from the supply line, and then about 2 or 3 turns of the meter before the test is to be started the gas from the holder is turned on by a three-way stopcock. The 2 cubic feet of gas will then suffice for four heating value tests. The gas in the holder, being in contact with water, may suffer a slight deterioration in its heating value if allowed to stand thus for a long time; the party making the tests should determine whether the effect of such deterioration is noticeable for the gas under the test, and make due allowance in interpreting results if the effect is of appreciable magnitude. (In this connection see T. P. No. 36.)

(11) *Overhead Tank.*—The temperature of tap water is usually too variable and too different from room temperature to permit of its use as a source of water supply for flow calorimeters. A shallow overhead tank of at least 25 gallons capacity should therefore be provided as a source of water supply at room temperature. A copper or a copper-lined tank in preferable to an iron tank, in that it is more durable and is less likely to cause trouble by rust getting into the calorimeter. The tank should be shallow, both to promote uniformity of temperature throughout the water and to minimize variations in the rate of water flow. The tank should be covered to keep out foreign matter and a screen should be provided over the outlet which may well be an inch or so above the bottom of the tank, so as to keep the opening above any sediment that may deposit on the bottom of the tank. The tank should be provided with a suitable overflow connected to a drain and preferably with a water gauge showing the depth of water.

Unless the water supply is very clear it should be filtered into the tank. It will be found convenient to have a supply of both hot and cold water for filling the tank, and in this case there should also be provided, either some means for stirring the water in the tank or of running the hot and cold water in at the same time through a single inlet pipe in which a thermometer is mounted so that the tank can be filled with water at room temperature. In a laboratory where numerous heating value tests have to be made, a thermostat, such as is described in T. P. No. 36, for controlling the temperature of the water supply, is a convenience.

With a Doherty calorimeter a smaller tank of water will suffice, 6 or 8 gallons being sufficient for a single test. If this calorimeter is operated so that the temperature of the outlet water will be equal to the room temperature, which has been found to be the most satisfactory method of operation, means should be at hand to cool the water in the tank below room temperature by an amount depending on the heating value of the gas to be tested, about 9° to 10° F for ordinary illuminating gas (600 Btu).

It is not necessary to install a water supply tank for the operation of the calorimeter. The calorimeter may be filled with tap water through special connections provided for that purpose. A small supply of cold water may be necessary for adjusting the initial temperatures of the calorimeters.

(12) *Table.*—The calorimeter and its accessory apparatus may be mounted on a table of suitable size (e. g., 30 by 60 inches), and of the usual height. While, perhaps, not strictly necessary, since the calorimeter should never be left in operation when the observer is absent from the testing room for any considerable length of time, it is an additional safeguard against fire to have the top of the table of stone or other fire-resisting material. The table should be provided with suitable plumbing connections to the overhead water supply to drain and to the supply of gas to be tested.

(13) *Calorimeter Cabinet.*—If the calorimeter is of the flow type, it, together with the accessory apparatus, may be mounted in a special cabinet such as that described in the report of the committee on calorimetry, Proceedings of the American Gas Institute, vol. 4, pages 205–206, 1909. The advantages of this form of mounting are that the apparatus is protected while not in use from dust and from fumes, if such be present, and that the cabinet may be locked. The cabinet contains an overhead tank which serves as a source of water supply to the calorimeter.

Special calorimeter cabinets are also listed by some of the makers of calorimeters.

(*c*) **Portable Equipment.**—None of the calorimeters listed in this circular, with the exception of the Parr, are too cumbersome to be used as portable calorimeters in traveling inspection work. For traveling inspection work suitable carrying cases, such as may be obtained from the manufacturers of some of the calorimeters, should be used. It is better to have the gas meter, and if possible the calorimeter also, carried by hand, since the damage when carried by express may be serious, and it is impossible to transport a calorimeter as baggage with reasonable safety. A portable outfit, to be useful, would have to include practically the complete laboratory equipment mentioned above, with the exception of the gas holder, overhead tank, and table.

It is not absolutely essential that an inspector carry around with him a complete calorimetric equipment if one is to be found where the test is desired. A set of standardized thermometers, a standardized 1-pound weight, or a standardized graduate, and a one-tenth cubic foot bottle, will afford the facilities necessary for checking the accuracy of the results found with any of the calorimeters listed in this circular. The barometer may be checked by comparison with the barometer at the nearest station of the Weather Bureau. An inspector familiar with the operation of flow calorimeters will readily detect any defect of the calorimeter.

6. STANDARDIZATION OF APPARATUS

(*a*) **Calorimeter and Accessory Apparatus.**—From the tests described in T. P. No. 36, it is seen that heating-value determinations with some types of calorimeters are subject to a constant error amounting to nearly 2 per cent. There can be no doubt, therefore, that it is desirable to have a calorimeter tested before it is put into use, although the behavior of the calorimeter in use will often give some indication as to its reliability. Important checks on the efficiency of a flow calorimeter may be obtained by observing whether the burner is set high enough, whether the combustion products are discharged at a temperature not too much in excess of inlet-water temperature, whether the normal rate of gas consumption is about what it should be for the type of calorimeter in question, and whether the outlet-water thermometer gives the true mean temperature of the effluent stream of water. This latter feature may be tested by moving the bulb of the thermometer so that it will occupy different positions in the cross section of the effluent stream of water. The tests necessary for the standardization of the Parr calorimeter are described in a subsequent section.

The calorimetric thermometers should be tested in a recognized standardizing laboratory, and the corrections so determined should be applied in computing the results of tests.

The graduate for measuring the condensed water should be tested; it should not be in error by as much as 0.2 cc, so that the application of corrections to the volumes measured with it will be unnecessary.

The gas meter must be tested, and it is desirable, as stated elsewhere, that the user should occasionally recalibrate it, using one of the methods described on page 28. It may be possible to set the fixed mark to which the water level is adjusted so that the volume of gas delivered by the meter, as determined by a series of calibrations, will be equal to the nominal volume, within 0.2 or 0.3 per cent, in which case the application of the correction for error of the meter may be omitted. However, the accuracy of the meter in use is limited by the accuracy with which the water level can be readjusted to the fixed mark.

The barometer should be tested as stated on page 54.

The thermometers of the psychrometer and of the barometer, and those used with the gas meter and for measuring the temperature of the products of combustion should also be tested, but it is possible to obtain thermometers which are sufficiently correct so that their errors may be neglected. If the thermometer in the gas meter is correct within 0°.3 F, and if the other thermometers mentioned are correct within 0°.5 F, no corrections need be applied to their readings.

The apparatus for weighing or measuring the water should also be tested. The weighing apparatus should be accurate to 0.1 per cent, so that the application of corrections will be unnecessary, but the application of the corrections may be necessary if volumetric apparatus is used.

(*b*) **Differential Correction for Time Changes of Calorimetric Thermometers.**—When thermometers for use with flow calorimeters are standardized, the corrections determined and certified are those applicable at the time of test. However, small changes in the volumes of the bulbs are likely to occur, making all corrections of a thermometer differ by a constant quantity from what they were at the time of the test. The manner of determining a differential correction, and thus eliminating from the calorimetric measurements the errors due to relative changes in the volumes of the bulbs of the thermometers, is shown in the following example:

Thermometer A has a certificate correction of −0°.04 at 70° F. and thermometer B has a certificate correction of −0°.06 at 70° F.

The two thermometers were held with bulbs adjacent in a well-stirred pail of water, a little below room temperature (70°), and the following readings were taken. The thermometers were read alternately, at equal time intervals, beginning and ending with the same thermometer, in order that the means of the two sets of readings might correspond to the same instant of time:

	A	B
	69.43	69.48
	.45	.49
	.46	.50
	.47	.....
Means	69.45	69.49
Certificate correction	−.04	−.06
Corrected readings	69.41	69.43

It will be seen that the corrected reading of B is 0°.02 higher than that of A. A differential correction of −0°.02 must therefore be applied, in addition to the certificate corrections, to all readings of thermometer B. The differential correction should be calculated for and applied to the readings of the outlet-water thermometer, thus:

	A	B
Mean of thermometer readings	69.45	69.49
Certificate correction	−.04	−.06
Differential correction		−.02
Corrected temperatures	69.41	69.41

The differential correction should be determined about once a month. It should be determined at, or very near, some temperature at which the thermometers have been tested, in order to avoid introducing into the differential correction any errors resulting from interpolation between two certificate corrections.

(*c*) **Determination of Normal Rate of Gas Consumption.**—The normal rate of gas consumption for the kind of gas to be tested and for the calorimeter in question, operated with the damper set as it is to be subsequently used in testing the gas, should be determined before the calorimeter is put into service and should be redetermined from time to time thereafter (at intervals of a few months is sufficient). The normal rate has been defined as 70 per cent of the rate at which combustion begins to be incomplete. (See T. P. No. 36.)

A convenient procedure for determining the rate at which combustion is no longer complete is as follows: With the calorimeter in operation the rate of gas consumption is increased step by step—e. g., by successively increasing the number of weights on the pressure regulator. As long as combustion is complete, the effect of increasing the gas rate is to cause an increment in the reading of the outlet-water thermometer. However, when the gas rate attains such a value that combustion is no longer complete, there will be a decrement in the reading of the outlet-water thermometer accompanying an increase in the gas rate. The gas rate at which combustion begins to be incomplete (for a given damper setting, etc.) can thus be determined to within a few per cent. An almost equally good test is furnished by the odor of the combustion products, as the odor due to incomplete combustion is readily perceived for most gases.

SETTING UP APPARATUS

If the calorimeter is of the usual flow type, it should be set up about midway of the length and forward of the center line of the table, in such a position as to leave room at the left for the pressure regulator and the meter, and on the right for the weighing bucket and scale, or for the graduate, if the latter is used instead of the scale. The Simmance-Abady English type calorimeter differs from the others in that the graduate is placed immediately to the left of the calorimeter.

(*a*) **Water Connections.**—Temporary connections from the overhead tank to the inlet of the calorimeter and the necessary connections to drain may be made by means of rubber tubing. In a permanent laboratory installation it is preferable to use piping, making the connections between the ends of the pipes and the calorimeter with short lengths of rubber tubing. Ordinarily ⅜-inch pipe with suitable nipples for rubber tube connections will be found satisfactory for the various water connections. If the calorimeter has an inlet overflow wier, it is some convenience to have a short length of glass tubing in the line leading from this wier to drain. This affords a ready means of determining whether sufficient water is being delivered to insure that no air will be carried down into the calorimeter with the water and thus cause variations in the water flow. All valves and cocks in the supply pipes to the overhead tank and from the overhead tank to the inlet of the calorimeter should be so located as to be conveniently accessible to the observer, so that the necessary manipulations can be made without endangering the thermometers or other parts of the apparatus.

(*b*) **Gas Connections.**—The pressure regulator may be connected either between the gas supply and the meter or between the meter and the burner. The former location has the following advantages: (*a*) The pressure at meter inlet is constant; (*b*) leak tests are more easily made; (*c*) the effect of leaks in the regulator or its connections are eliminated; (*d*) the effect of variation in volume of the regulator, due to motion of the drum, is eliminated; (*e*) the U gage on the regulator may be used to measure the gas pressure at the meter inlet. The principal reason for putting the regulator between the meter and the burner is to eliminate the effect of fluctuations in gas pressure due to the operation of the meter. With a well-constructed meter in good working condition the fluctuations which it introduces are scarcely noticeable in their effect on the readings of the outlet-water thermometer.

If a wet-pressure regulator is connected between the meter and the burner, a similar regulator should also be connected between the gas supply and the meter, unless the gas supply is drawn from a gas holder in the laboratory. It is desirable for a number of reasons that the pressure of the gas in the meter should not exceed 2 or 3 inches of water. It has been found that a wet-pressure regulator of proper construction may be used to reduce the pressure from 10 or 12 inches of water to the pressure required at the burner. Under any circumstances the gas should not be shut off beyond the regulator, if the pressure is sufficient to break the water seal.

The gas meter should be set up so as to be viewed normally by the observer when manipulating the change-over device; i. e., the meter dial will not, in general, be parallel to the front edge of the table. A well-illuminated white background should be provided back of the gage glass or the sight box. It is not well, however, to attempt to secure this background by the use of a milk-glass background in the sight box itself, since under such circumstances the adjustment of water level is difficult.

Connections should be made to a U gage to indicate the pressure, in inches of water, at the meter inlet. As shown in T. P. No. 36, the pressure at the meter inlet may be so adjusted that the total pressure of the gas in the meter is equal to the observed barometer reading; this is done by making the excess of gas pressure above atmospheric pressure equivalent (i. e., equal and of opposite sign) to the temperature correction to the barometer reading. Even if this method of compensating the barometer corrections is not used, the observations and computations will be somewhat simpler if the pressure of the gas at the meter inlet is kept constant.

The necessary connections between the gas supply, the service or other pressure regulator, the meter, and the wet-pressure regulator may be made with ordinary ¼-inch pipe, or suitable metal tubing, the ends of the pipe or tubing being connected to the apparatus by short lengths of rubber tubing or by suitable unions. However, connections that are too rigid and difficult to disconnect may prove a source of inconvenience. The connection to the burner must be flexible to permit the withdrawal of the burner from the calorimeter. Thick-walled rubber tubing may be used throughout provided care is taken to saturate the tubing with the gas before making tests. The use of metal hose has been recommended for the connections, and it is undoubtedly desirable from the point of view of reducing the fire hazard, but such tubing is very often found to leak slowly and should therefore be carefully tested for leaks before use. Small leaks in the connections ahead of the meter, of course, do not affect the results of heating-value determinations.

A part of the above remarks concerning setting up of apparatus apply, with obvious modifications, to the Doherty calorimeter and, to a limited extent, to the Parr calorimeter. Further directions relating to the installation of these calorimeters may be found in subsequent sections.

8. DIRECTIONS FOR OPERATING FLOW CALORIMETERS

(*a*) **Manipulation and Observations.**—It is assumed that provision has been made for obtaining a representative gas supply, observing the precautions noted on page 13. If an average sample of the gas is to be tested this must be collected in a small holder, the supply being drawn from a line from which gas is being used, to insure that fresh gas is collected, at a rate which will give a sample of not less than 2, and preferably as much as 5, cubic feet for the test; but if gas for the test is drawn direct from the supply line, it is only necessary that the connections be flushed free from old gas as directed below, so that the test will be made on gas representative of that in the mains. Having the gas supply thus properly provided and the calorimeter set up as directed in the previous section, each test is made in the following manner:

(1) *Free gas connections from old gas* by use of "blow-off" if this is provided (see p. 17), or by starting several burners to rapidly burn out the old gas which is in the supply pipe. When burning the gas for this purpose, it is well to use an appliance connected to the same supply line, but located in an adjoining room, in order to avoid large temperature changes in the room where the test is to be made. It is well to *burn one burner continuously throughout the period of test,* connecting this burner to an outlet near the point from which the gas supply for the calorimeter is drawn.

(2) *Observe temperature of laboratory* in the vicinity of the calorimeter, using a thermometer which is shielded from radiation or drafts from hot or cold objects near by, such as cold walls, windows, radiators, or even the heated body of the calorimeter itself. The reading of the dry bulb thermometer of the psychrometer, used as in the determination of the atmospheric humidity, can be taken as the room temperature. The observation taken at this time is not entered on the record, but is used merely to enable the observer to adjust the temperature of the gas meter and of the water supply.

(3) *Adjust the gas meter for: Temperature; level; position of index relative to drum; water level; and saturation of water with gas.* The meter temperature, as indicated by a thermometer, the bulb of which is in the water in the meter, should not differ from room temperature by more than 3° F; it may be adjusted by pouring in warm or cold water and then running gas through the meter for a few minutes to thoroughly stir the water. The screw plug at the bottom of the "dry well" at the back of the meter should be removed occasionally to drain off any water accumulated there. The meter is leveled as judged by levels of plumb bob attached; and this leveling must be carefully done in the same manner as the leveling at the time of calibration of the meter. Frequently, preferably before each test, it should be determined that the index is in the proper position relative to the drum of the meter, and adjustment should be made, if necessary, as directed on page 27. The level of the water in the meter must be adjusted as accurately as possible *before each test,* unless several tests are made on the same day, the adjustment being made in the same manner as is done before calibration of the meter (p. 28). When verifying adjustment of water level the index should be in the zero position and the inlet and outlet of the meter *must*

be open to the air. When a meter is filled with fresh water, the absorption of gas by the water usually causes no significant effect on the heating value after 2 or 3 cubic feet of gas have been passed through the meter. Full directions for adjustment and calibration of meters are given on pages 27–33. If a meter has been shipped or carried from one laboratory to another, it should be recalibrated before use in determinations of heating values. It will probably be found inconvenient to recalibrate the meter each time it is used, although a somewhat higher accuracy may be attained by following this procedure.

(4) *Test for gas leaks.* If the wet-pressure regulator is connected between the gas supply and the meter, this test may be made as follows: Remove the burner from the calorimeter and, after passing from 0.1 to 0.2 cubic foot of gas through the meter to insure that any explosive mixture of gas and air has been removed from the meter, light the gas. The movable drum of the pressure regulator should be displaced up and down several times to remove air and old gas contained in the regulator. After the meter has made three or four revolutions, shut off the gas at the base of the burner and immediately afterwards shut off the gas supply to the regulator to prevent the gas pressure from breaking the water seal of the regulator. The regulator will contain a sufficient volume of gas for the leak test. If during an interval of 10 minutes the meter index does not show a movement exceeding one one-hundredth of a revolution (0.001 cubic foot leakage) the leakage may be considered negligible. While waiting for this test the adjustments required in paragraphs (5) and (6) may be made. The test for leaks should be made each day. It is evident that only leaks in the meter or between the meter and the burner (base of flame) affect the determination of heating values, and only such leaks are detected by the above test.

If the wet-pressure regulator is connected between the meter and the burner, a constant gas pressure, which is not high enough to break the water seal of the regulator, must be provided at the meter inlet in order that the test for leaks may be made. Such a constant pressure may be obtained in the manner described above from another wet-pressure regulator connected between the gas supply and the meter or from a gas holder in the laboratory. It is necessary to depress the float of the regulator connected between the meter and the burner to allow the pressures on both sides of the valve of this regulator to equalize before taking the initial meter reading for the leak test, as otherwise there probably will be a slow creeping of the meter index due to leakage through the valve of the regulator.

(5) *Adjust temperature of water in supply tank.* The water supplied to the calorimeter should be within 2° F of the laboratory temperature, and if the water in the tank is not within this limit it should be adjusted by adding hot or cold water, as may be required, and stirred to insure uniformity of temperature throughout the tank. When the tank is filled after one day's test is completed, the water will come to room temperature for the next day's test if the room temperature is quite uniform in the interval; but in any case where hot and cold water are available, the adjustment to the proper temperature can be made easily. If the water temperature is 5° F different from the laboratory temperature, it will make a difference of about 3 Btu in the observed heating value. In this connection see also page 69.

(6) *Start flow of water through calorimeter and expel air from water circulation system.* With the inlet-water valve of the calorimeter set at approximately the position for regular operation (see p. 66), turn on enough water so that some will be discharged to the drain from the overflow weir at the inlet of the calorimeter. To promote the escape of air from the water-circulation system, open and close the inlet-water valve on the calorimeter a number of times, and if necessary in order to remove air from about the thermometer bulbs lift the stoppers holding them in place, so that all of the air and a small amount of water will be forced out. If the calorimeter has an inlet weir, the water supply must be sufficient to provide for a continuous overflow from this weir during the above manipulation in order to avoid drawing more air into the calorimeter. Air entrapped in the water-circulation system is apt to cause fluctuation in the rate of water flow, with resulting fluctuations in the outlet-water temperature. Occasionally before the burner is inserted—operation (7)—the water should be run through the calorimeter for a considerable time to determine whether there are any leaks in the water-circulation system.

(7) *Light gas, adjust rate of gas consumption, adjust air mixer on burner, and insert burner into calorimeter.* When it is determined that no leakage is occurring, as described in paragraph (4) above, the burner is lighted and the flow of gas is adjusted to the *normal rate* (within ±5 per cent is sufficient) previously determined for the kind of gas and the calorimeter used and for the particular

damper setting, etc., with which the calorimeter is operated. (See p. 59.) The air supply to the burner is adjusted so that the luminous tip of the flame just disappears, and the burner is inserted in the calorimeter, being placed at the proper height on its support.

(8) *Adjust water flow and set damper.* The rate of water flow is adjusted so that the rise in temperature of the water will be 15°–20° F, and the damper is set in the position determined in fixing the normal rate for this calorimeter. (See p. 59.) A lowering of 2 per cent, or even more, in the observed heating value may result from leaving the damper open when the rate of gas burning is that determined for a closed perforated damper. The magnitude of this lowering would depend not only on the construction of the calorimeter, but also on the character of the gas and the humidity of the air of the laboratory.

(9) *Allow time for establishment of a condition of thermal equilibrium.* The time required for the attainment of thermal equilibrium is about 5 minutes for calorimeters of the Junkers, Hinman-Junkers, or Sargent type, somewhat longer for the English type of Simmance-Abady calorimeter, and from 20 to 30 minutes for the Boys and the American type of Simmance-Abady calorimeter. If net heating values are to be determined, it will be necessary to wait until the condensed water from the products of combustion has begun to drain regularly from the calorimeter. During this interval most of the observations and records called for in the next paragraph may be made.

(10) *Prepare record sheet and make the preliminary observations.* The record form, which is illustrated on page 72, is prepared for use in the test by entering the following items:

Date, time, place of test, and kind of gas;

Identification marking (number or name) of calorimeter, meter, and thermometers;

Statement whether the gas line has been purged and whether proper tests have been made for leaks and for meter adjustment; and

Position of water valve[8] and of damper (by number of scale division, or by "open" or "closed" in case of damper).

The "preliminary observations," as they may be called, should be made during the few minutes just preceding the period when

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[8] This is recorded largely as a matter of convenience for the operator. Examination of the records extending over a considerable period might show whether the water passages were becoming clogged.

the condensed water is collected; these observations include the following made in the order listed:

(*a*) Temperature of the barometer (to the nearest 1° F).

(*b*) Barometric height (to nearest 0.01 inch).

(*c*) Gas pressure at meter inlet (to nearest 0.1 inch of water column).

(*d*) Reading of meter thermometer (to the nearest 0°.1 or 0°.2 F).

(*e*) Readings of the wet and dry bulb thermometers of the psychrometer, as directed on page 185.

(*f*) Reading of products thermometer (to the nearest 1° F).

(*g*) Time in seconds of one revolution of the index of the meter.

(11) *Begin collection of condensate.* As the index of the meter passes through the zero position, place the 25-cc graduate under the drain tube of the calorimeter and record the meter reading (i. e., total revolutions).

(12) *Take the first series of observations*, which is carried out in the following manner:

(*a*) Record one or two readings each of inlet and outlet water thermometers before the meter index has completed the first revolution after the collection of condensate is begun.

(*b*) As the meter index passes through the zero position, shift the change-over device to divert the effluent stream of water from drain to measuring vessel. The operations of shifting the change-over device, both on and off, should be made in the same manner and with the greatest care, so that the time interval between the two operations shall be as nearly as possible equal to that defined by the passages of the meter index past the zero position of the dial.

(*c*) Read the inlet and outlet water thermometers alternately at approximately equal intervals of time during the two revolutions of the meter index. If the thermometer readings are spaced so that the interval between them corresponds to the time required for the index of the meter to pass over about 10 divisions of a dial having 100 divisions, a sufficient number of readings will be obtained. If the inlet-water temperature is fairly constant, this procedure will give more readings of the inlet-water thermometer than are really required, in which case one reading of the inlet-water thermometer at the beginning, a second reading at the completion of the first revolution of the meter index, and a third reading on the completion of the second revolution of the meter index may be taken instead of alternate readings as above indicated. If the variations in inlet-water temperature are sufficiently large so that the average of the three readings does not give a sufficiently accurate average of the inlet-water temperature, it may be found that the average of the alternate readings may not give results of the desired accuracy, in which case the method of reading used by Immenkötter (see p. 70) must be adopted.

(*d*) At the instant the index of the meter passes through the zero position, on the second turn after the water was turned into the measuring vessel, shift the change-over device diverting water from measuring vessel back to drain.

(*e*) Record one or two readings of the outlet-water thermometer.

(*f*) Weigh the water collected and record the weight (to the nearest 0.01 pound); or observe and record its volume (to the nearest 0.01 pound or nearest 5 cc). If a cylindrical graduate is used, great care in reading will be required to keep the error within the above limits. If a special graduate with enlarged bottom and open scale is used, the required accuracy may be readily attained.

(13) *Take the second (and later) series of observations.* As soon as convenient after the first series is complete repeat the full set of observations of operation (12). At least two series of observations should be made for a test.

(14) *Stop collection of condensate* by removing the small graduate from under the drip tube of the calorimeter just at the instant the index of the meter passes the zero position after not less than 7 (or preferably 10) revolutions since beginning the collection of the condensate. Record meter reading (total revolutions) and the amount of water collected (to nearest 0.1 or 0.2 cc). If the net heating value is to be determined with the same accuracy as the total heating value, another collection of condensate similar to the first should be made, in order that the result may not depend upon a single observation.

(15) *Repeat the preliminary observations of operation* (10). This is done on the general principle that no single observation should be accepted without some check, and secondly, because it enables the observer to decide whether the determination should be repeated on account either of a mistake in the first readings or on account of a change in conditions sufficient to affect the results.

(16) *Turn off gas and then turn off water.* The apparatus may be stopped at once after completing a test; or if the water supply in the tank is ample, the calorimeter may be left running until the calculation of the test data has been completed so that a repetition of the test may be made at once in case there is some reason

for desiring to verify the whole test. In any event, it is well before shutting down the apparatus to glance over the test record sheet and be sure that no portion of the record is incomplete.

CAUTION.—In operating a flow calorimeter great care must always be taken, and especially when starting or stopping a test, to insure that the gas is not burning in the calorimeter when the water is shut off.

Notes on reading the thermometers.—It is preferable to make an estimate of the average reading of the outlet-water thermometer during each interval, and to record this average as the reading rather than to record the readings observed at certain instants. The inlet and outlet water thermometers should be provided with suitable reading glasses and the observer should estimate the thermometer readings to one-tenth of the smallest graduation interval, i. e., if the thermometer is graduated to 0°.1 the readings should be made to 0°.01. With a little practice this can be so easily done that it is to be preferred to reading the nearest one-half graduation interval. To avoid error due to parallax, the line of sight must be perpendicular to the thermometer stem, a condition which will be secured with a properly constructed reading glass, if the mercury meniscus of the thermometer is in the center of the field of view.

To minimize the fluctuations in the reading of the outlet-water thermometer, due to drafts and to air currents, the calorimeter should be shielded from drafts and the observer should move about as little as possible while taking the thermometer readings.

An error of 0°.1 in the determination of the average temperature of either the inlet or the outlet water or a combined error of 0°.1 in the two temperatures will cause an error of one part in 150 i. e., 4 Btu with a 600 Btu gas, if the temperature rise is 15°.

Operation of Flow Calorimeters if Inlet-Water Temperature is Variable.—It is always preferable to keep the variation of temperature of the inlet water during a single complete series of observations within 0°.05 F, which can easily be done if care is taken to have the water in the overhead tank at a uniform temperature throughout when the test is started.

Under the usual methods of operation, where inlet and outlet water temperatures are read alternately, the errors introduced into heating-value tests by variations in the inlet-water temperature will depend not alone on the magnitude of such variations but also on the water content of and the rate of water flow through the calorimeter that is used in the test.

The effect, on the observed heating value, of variations in the inlet-water temperature may be very materially reduced, even if not wholly eliminated, by the procedure recommended by Immenkötter, viz: Each of the readings of the inlet-water thermometer should be made earlier than indicated in the directions already given by an interval of time equal to that required for the water to flow through the calorimeter, this interval being equal to the water content of the calorimeter divided by the rate of flow of water.

The method recommended by Immenkötter is a desirable one under any conditions of operation. If the temperature of the inlet water is variable and also differs considerably from the room temperature, it will be necessary, besides reading the thermometers as above indicated, to make additional corrections as described in the following section.

Operation of Flow Calorimeters if Inlet-Water Temperature Differs Considerably from Room Temperature.—In a permanent laboratory installation, such as that outlined in this circular, there should be no difficulty in adjusting the temperature of the inlet water so that it shall be nearly equal to room temperature, thus making very small the error introduced into the results of heating-value tests due to the lack of equality of the two temperatures. Under some conditions, as in traveling inspection work, it may be necessary to make tests under less favorable conditions, in which case fairly good results could still be obtained by applying suitable corrections in calculating the total and the net heating values, to allow for the effect of a considerable difference between inlet-water temperature and room temperature. Even when an overhead tank is used to supply the water to the calorimeter there will often be a difference of a few degrees between the temperature of the water and the temperature of the room. A considerable increase in accuracy may be obtained by making a correction for the heat interchange due to this difference, and it is much easier to apply the correction than to secure exact agreement between inlet-water and room temperatures.

(*b*) **Records and Computations.**—The observed data and the important steps in the computations of a heating value test, made up of two or three series of temperature observations, as described above, may be entered in a record form similar to that shown on page 72. This form may conveniently be on an 8 by 10 inch sheet, or, if it is desired to file the records in a way corresponding to the other test records, on a 5 by 8 inch card, utilizing both sides of the card.

For official testing it is essential that the original record, containing all of the observed data, should be kept. Numerous forms of abbreviated record cards have been used which either do not contain all of the essential data, or which require the transfer of the computed data to the record. In either case the result entered on such record can not be as conveniently checked back to the original observations.

The computations will be very much facilitated if all of the calibration data of calorimeter, meter, thermometers, barometer, etc., are entered on a card for convenient reference. If this is done, the application of the corrections is so simple that there is no justification for omitting them. The original certificates of test should be preserved for reference in a safe place and should not be used in making routine computations. It is also desirable to have conveniently accessible the necessary tables and charts. A complete set of tables for this work would be made up of the following, some of which are given in this circular.

Corrections for reduction of barometric heights to standard temperature (Appendix 11).

Reduction of pressures in inches of water to equivalent pressures in inches of mercury.

Correction factors for gas volume (Appendix 2).

Relative humidities for various dry and wet bulb readings of ventilated psychrometer (Appendix 6).

Rate in cubic feet per hour corresponding to various times (in seconds) of revolution of the meter index.

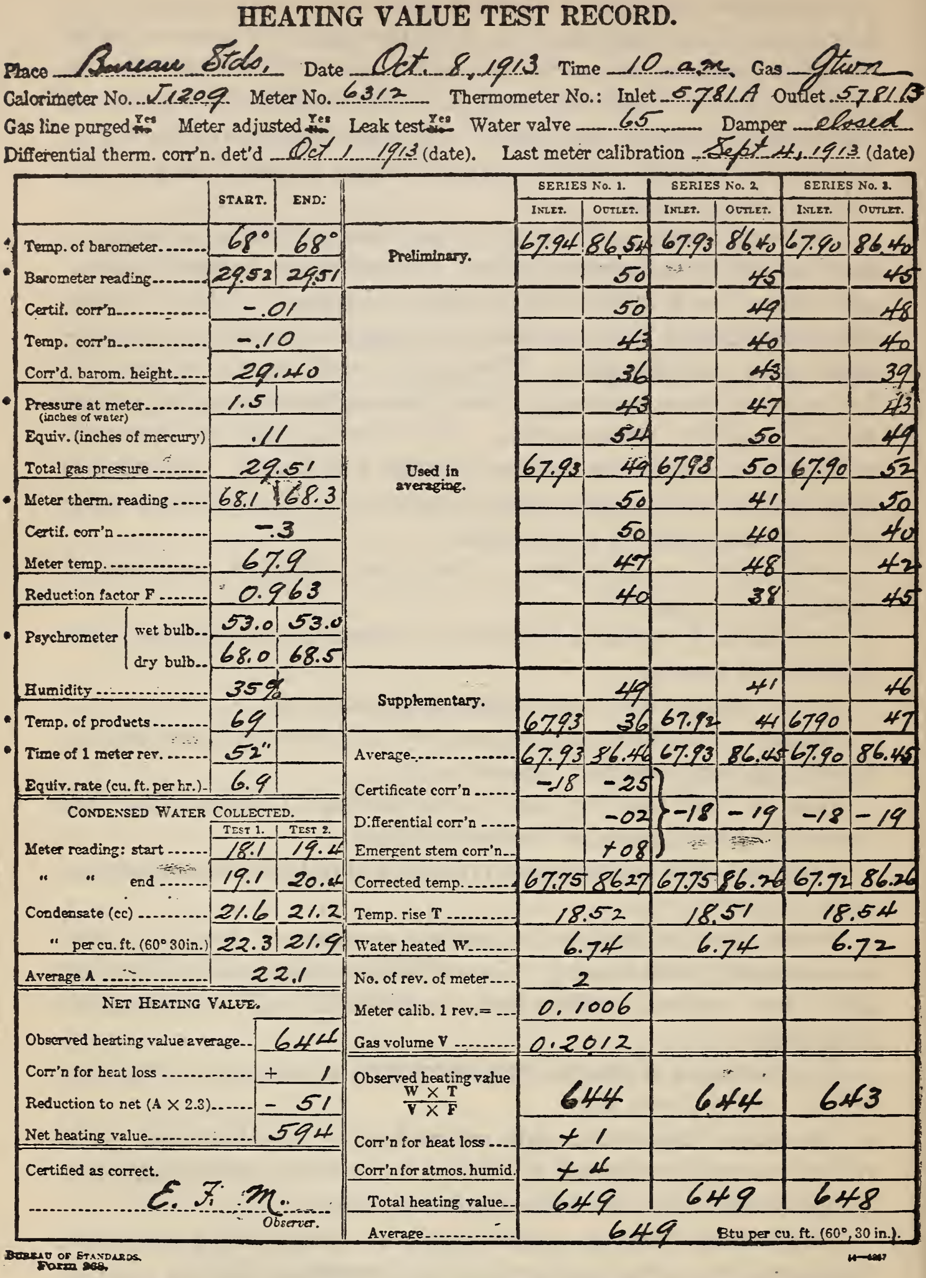
Emergent stem corrections to readings of outlet-water thermometers (Appendix 12).

Corrections (in Btu) to be applied to observed heating values in calculating total heating values of illuminating gases (about 600 Btu) for various atmospheric humidities and temperatures (Appendix 5).

If the water is measured volumetrically, Appendix 13 should be added to the above list.

The card of calibration data referred to in the calculation would contain a number of small tables and memoranda, thus assembling in convenient form the following information:

Calorimeter number, meter number, thermometer numbers, position of water valve under ordinary condition, damper position which corresponds to that used in determining normal rate, the date of the determination of the differential thermometer correction and the correction itself, date of last meter calibration, table



HEATING VALUE TEST RECORD.

Place Bureau Stds. Date Oct. 8, 1913 Time 10 a.m. Gas Gtown
Calorimeter No. J1209 Meter No. 6312 Thermometer No.: Inlet 5781A Outlet 5781B
Gas line purged Yes/No Meter adjusted Yes/No Leak test Yes/No Water valve 65 Damper closed
Differential therm. corr'n. det'd Oct 1 1913 (date). Last meter calibration Sept 4, 1913 (date)

	START.	END.
• Temp. of barometer	68°	68°
• Barometer reading	29.52	29.51
Certif. corr'n	-.01	
Temp. corr'n	-.10	
Corr'd. barom. height	29.40	
• Pressure at meter (inches of water)	1.5	
Equiv. (inches of mercury)	.11	
Total gas pressure	29.51	
• Meter therm. reading	68.1	68.3
Certif. corr'n	-.3	
Meter temp.	67.9	
Reduction factor F	0.963	
• Psychrometer wet bulb	53.0	53.0
Psychrometer dry bulb	68.0	68.5
Humidity	35%	
• Temp. of products	69	
• Time of 1 meter rev.	52"	
Equiv. rate (cu. ft. per hr.)	6.9	

CONDENSED WATER COLLECTED.

	TEST 1.	TEST 2.
Meter reading: start	18.1	19.4
" " end	19.1	20.4
Condensate (cc)	21.6	21.2
" per cu. ft. (60° 30in.)	22.3	21.9
Average A	22.1	

NET HEATING VALUE.

Observed heating value average	644
Corr'n for heat loss	+ 1
Reduction to net (A × 2.3)	- 51
Net heating value	594

Certified as correct.

E. F. M.
Observer.

	SERIES No. 1.		SERIES No. 2.		SERIES No. 3.	
	INLET.	OUTLET.	INLET.	OUTLET.	INLET.	OUTLET.
Preliminary.	67.94	86.54	67.93	86.40	67.90	86.40
		50		45		45
Used in averaging.		50		49		48
		43		40		40
		36		43		39
		43		47		43
		54		50		49
	67.93	49	67.98	50	67.90	52
		50		41		50
		50		40		40
		47		48		42
		40		38		45
Supplementary.		49		41		46
	67.93	36	67.92	41	6790	47
Average	67.93	86.46	67.93	86.45	67.90	86.45
Certificate corr'n	-18	-25				
Differential corr'n		-02	-18	-19	-18	-19
Emergent stem corr'n		+08				
Corrected temp.	67.75	86.27	67.75	86.26	67.72	86.26
Temp. rise T	18.52		18.51		18.54	
Water heated W	6.74		6.74		6.72	
No. of rev. of meter	2					
Meter calib. 1 rev. =	0.1006					
Gas volume V	0.2012					
Observed heating value $\frac{W \times T}{V \times F}$	644		644		643	
Corr'n for heat loss	+ 1					
Corr'n for atmos. humid.	+ 4					
Total heating value	649		649		648	
Average	649	Btu per cu. ft. (60°, 30 in.).				

BUREAU OF STANDARDS.
Form 268.

[illegible]

Fig. 3.—*Heating-value test record*

of certificate corrections for barometer, certificate corrections for inlet and outlet water thermometers, the correction for heat loss from calorimeter, and such other data as the inspector found was needed from day to day in routine computation.

The calculation may be performed as follows, although the order of the operations may, of course, be varied. When the computer becomes familiar with the reasons for the various steps in the calculations it may be preferable to follow a different sequence, e. g., it would probably be more convenient to enter on the records at one time all the data to be taken from the card of calibration data, such as constant correction to barometer reading, correction to meter thermometer, certificate correction to inlet and outlet water thermometers, the differential correction to outlet-water thermometer, the meter calibration constant, and correction for heat loss from calorimeter. The sequence given below was adopted because it admits of a more logical presentation in explaining the reasons for the various operations.

(1) Enter from the card of calibration data the *certificate correction* and, from Appendix 13, the *temperature correction* to the barometer. The corrections thus entered are added to (or subtracted from) the *barometer readings* to find the *corrected barometric height*, the *average* obtained from the two barometer readings being entered on the record.

The certificate correction is that determined in a test of the barometer, and in a well-constructed instrument this correction should not exceed 0.02 inch, in which case the correction may be omitted. The temperature correction must be applied to the observed reading of a mercury barometer on account of the thermal expansion of the mercury and of the brass scale. (See p. 198.)

(2) Enter the *equivalent, in inches of mercury*, of the pressure at meter inlet, and add this to the *corrected barometric height* to find the *total gas pressure.*

The figures in the above calculations should be carried out to 0.01 inch of mercury.

The table for reducing the pressure, in inches of water, at the meter inlet, as read from the U gage, to the equivalent in inches of mercury, is calculated by dividing the pressure expressed in inches of water by 13.6 (the density of mercury). This correction for gas pressure in the meter and the temperature correction for the barometer may both be omitted if they are made equal and of opposite sign, as suggested on page 61.

(3) Enter from the card of calibration data the *certificate correction* to meter thermometer; and calculate the corrected *meter temperature*, only the average calculated from the two readings of the meter thermometer being entered on the record.

(4) From Appendix 4 enter the *reduction factor, F.* (to the third decimal place), corresponding to the *total gas pressure* and the *meter temperature.*

The gas is measured at a temperature entered in the record as the meter temperature and at a pressure entered in the record as the total pressure of the gas, the volume being equal to the number of revolutions of the meter index (viz, 2) multiplied by the calibration constant of the meter (entered on the record as 1 revolution of meter= . . .). Multiplication of this measured volume by the factor F. gives the volume which the same quantity of gas would have occupied at a temperature of 60° F. and under a total pressure of 30 inches of mercury.

(5) From Appendix 9 enter on the record the relative atmospheric *humidity* (to the nearest 5 per cent) corresponding to the recorded *dry bulb* and *wet bulb* thermometer readings of the ventilated *psychrometer.*

The thermometers of the psychrometer should not be in error by as much as 1° F., and if such is the case no certificate corrections need be applied to the observed readings. The reading of the dry bulb thermometer should be taken as the room temperature whenever that temperature is used in the subsequent calculations.

(6) The temperature of the products of combustion is ordinarily not used in the calculation, but is of value in showing whether or not the calorimeter was operating as it should. In the better types of flow calorimeters the excess of temperature of the products above the temperature of the inlet water is less than 2° F. if the burner is properly placed in the calorimeter. Even when the excess of temperature is 4° to 5° F. the resulting error, due to neglecting this heat loss, as is done in these calculations, is only a few tenths of 1 per cent of the total heating value.

(7) Enter the *rate* in *cubic feet per hour* corresponding to the *time* in seconds *of one revolution* of the meter index.

The rate of gas consumption in cubic feet per hour may be calculated as follows:

$$\text{Rate (for a } \tfrac{1}{10} \text{ cubic foot meter)} = \frac{360}{\text{time of 1 rev. in secs.}}$$

$$\text{Rate (for a } \tfrac{1}{12} \text{ cubic foot meter)} = \frac{300}{\text{time of 1 rev. in secs.}}$$

The rate is entered on the record to show that the calorimeter was operated at about its normal rate (within ±5 per cent). The calibration correction of the meter need not be taken into account in the calculation of the rate, unless, of course, that correction is unusually large.

(8) Average separately, for each series, the *readings of the inlet and of the outlet water thermometers,* omitting the *preliminary* and *supplementary* readings, and enter these *averages* on the record.

(9) Enter from the card of calibration data the *certificate corrections* corresponding to the average readings of the inlet and outlet water thermometers.

(10) Enter from the card of calibration data the *differential cerrection* to the reading of the outlet-water thermometer.

This correction, determined as described on page 58, is applied in order to correct for any relative change that may have occurred in the thermometers since the determination of their certificate corrections.

(11) Enter on the record from Appendix 7 the *emergent stem correction* to the average readings of the outlet-water thermometer.

Correction for emergent stem of thermometer.—If the mercury thread of a thermometer is not at the same temperature as the bulb, the emergent stem correction may be too large to be neglected. The correction for emergent stem may be computed from the formula:

Stem correction $= K \times n\ (T^\circ - t^\circ)$.

K = factor for relative expansion of mercury in glass; 0.00015 to 0.00016 for centigrade thermometers, 0.000083 to 0.000089 for Fahrenheit thermometers, at ordinary temperatures, depending upon the glass of which the stem is made. For ordinary calorimetric thermometers graduated on the Fahrenheit scale, the value $K = 0.000085$ may be used.

n = number of degrees emergent from the bath.

T = temperature of the water.

t = mean temperature of the emergent stem.

If a flow calorimeter is operated with the inlet water at room temperature, the stem correction for the inlet-water thermometer will obviously be zero, while the outlet-water thermometer will read too low. Under the conditions stated, the stem correction to be applied to the readings of the outlet-water thermometer will depend upon the temperature of the room, the temperature rise, and the point on the scale to which the thermometer is immersed.

The stem corrections to be applied to the readings of the outlet-water thermometer are given in Appendix 7, page 193. In computing the table some allowance was made for the fact that the mean temperature of the stem of the outlet-water thermometer is slightly above that of the room.

It is evident that, if the inlet water is not at room temperature, the readings of both the inlet and outlet water thermometers will be subject to stem corrections. If the two thermometers are both immersed to the same graduation, and if the inlet water does not differ by more than 5° F from the room temperature, the application of the tabular corrections, Appendix 7, to the readings of the outlet-water thermometer will lead to the same results for the temperature rise as applying the two stem corrections independently. If, on the other hand, the two thermometers have each the same number of degrees emergent, the application of the tabular corrections to the readings of the outlet-water thermometer will lead to the same result as applying the two stem corrections independently, regardless of the difference between inlet-water temperature and room temperature. The statements in this paragraph may be readily verified by actually making the computations.

In the example cited on the record sheet, page 72, the stem corrections may be computed by the formula given above, or they may be taken from the table. The temperature of the inlet water ($T = 67.93$) being practically equal to room temperature, ($t = 68$) $T^\circ - t^\circ$ is very small and hence the stem correction to the inlet-water thermometer is negligible. The outlet-water thermometer used in the test was immersed to the 30° mark so that, n, the number of degrees emergent, was $86^\circ - 30^\circ = 56^\circ$. The bulb temperature was $86^\circ - 68^\circ = 18^\circ$ above that of the room, and since the mean temperature of the emergent stem was a little above that of the room, on account of heat received from the calorimeter, $T^\circ - t^\circ$ was equal to 17°, and hence the emergent stem correction to the outlet-water thermometer $= 0.000085 \times 56 \times 17 = +0^\circ.08$ F. The correction interpolated from Appendix 7 is also $+0^\circ.08$ F.

(12) Enter on the record the *corrected temperature* of the inlet and of the outlet water for each series by applying the several corrections to the averages of the readings of the inlet and outlet water thermometers.

(13) Subtract the corrected temperature of the inlet water from the corrected temperature of the outlet water for each series, and enter this *temperature rise*, T, on the record.

(14) The weight of *water collected*, W, is corrected if calibration has shown any error in the weights used.

Such correction, however, should not be necessary. In general, the correction for buoyancy and the correction for the variation of the specific heat of water may be neglected, since both corrections are small and are, for the conditions under which flow calorimeters are used, of opposite sign. If the water is measured volumetrically, the observed volume corrected for error of the graduate must be multiplied by a factor taken from Appendix 8.

(15) Opposite *number of revolutions of meter* enter on the record the number of revolutions made by the meter index during the time the effluent water for each series was being collected.

(16) Enter from the card of calibration data the meter calibration constant, viz, the number of *cubic feet corresponding to one revolution* of the meter.

(17) Enter on the record the *gas volume*, V, which is the product of the number of revolutions of the meter and the meter calibration constant.

(18) Calculate and enter on the record for each series the observed heating value found from the following equation:

$$\text{Observed heating value} = \frac{\text{Water heated } (W) \times \text{Temp rise } (T)}{\text{Gas volume } (V) \times \text{Reduction factor } (F)}$$

Heating-Value Computer.—The arithmetical work involved in the computations may be greatly diminished by the use of the heating value computer, which is illustrated in the Proceedings of the American Gas Institute, volume 3, page 373, 1908. The computer is a circular slide rule with which the observed heating value may be read directly when the temperature and the total pressure of the gas, the volume of gas indicated by the meter, the weight of water heated, and the rise of temperature of the water are known. The computer can be read with an accuracy of 1 or 2 Btu, and if a few check computations are made occasionally no significant error should be introduced due to the use of the computer. The computer is published by the United Gas Improvement Co., Broad and Arch Streets, Philadelphia, Pa.

Agreement of Duplicates.—In general 2 or 3 series of observations should give observed heating values which do not differ from one another by more than 6 Btu for a 600 Btu gas. Greater variation is sometimes allowable if it is impossible to get good conditions for work, as, for example, if a water supply of uniform temperature is not available. But, in general, results which do not agree well within 6 Btu indicate either that the operator has neglected some important precaution or that the apparatus is not in good condition.

(19) Enter from the card of calibration data the *correction for heat loss.*

The heat lost from the surface of a calorimeter, due to the average excess of the surface temperature above that of its surroundings, is often called the radiation loss. The radiation loss, when the inlet water is at room temperature and the temperature rise is 15° to 20° F, is of the order of 0.1 or 0.2 per cent (i. e., about 1 Btu for a 600 Btu gas) of the total heating value of the gas for the Junkers (original and new types), Hinman-Junkers, Sargent, and Simmance-Abady (English type) calorimeters, and may therefore be neglected or applied as desired. For the Boys and the Simmance-Abady (American type) calorimeters a correction for heat loss should be applied. (See T. P. No. 36.)

(20) Enter from Appendix 5 the *correction for effect of atmospheric humidity*, using the correction corresponding to the room temperature (reading of dry bulb thermometer of psychrometer) and to the percentage *humidity* as entered on the record.

If natural gas (about 1000 Btu) is being tested instead of illuminating gas (about 600 Btu) the correction for effect of atmospheric humidity should be taken from Appendix 6 instead of from Appendix 5.

The correction for the effect of atmospheric humidity is fully considered in T. P. No. 36. The necessity for a correction for the effect of atmospheric humidity is evident from the following considerations: On a dry day the air entering the calorimeter will carry in very little water vapor, while the products of combustion, being practically saturated at the temperature at which they escape from the calorimeter, will carry off a considerable amount of the water vapor formed in combustion, and the latent heat of condensation of this water vapor will not be measured in the calorimeter. On a day of high humidity the amount of latent heat thus lost will evidently be less, and under conditions of very high humidity more water vapor will be carried in by the air and gas than is carried out by the products, and heat will thus be imparted to the calorimeter.

The tabular values apply for the condition that room temperature, inlet-water temperature, gas temperature, and products temperature are all equal. In using the table, the correction corresponding to room temperature is taken, since if the inlet-water temperature differs appreciably from room temperature, an additional correction must be applied, as explained on page 199.

(21) Calculate the *total heating values* by applying to the *observed heating values* the *correction for heat loss*, including the correction for the effect of difference between inlet-water temperature and room temperature, and the *correction for effect of atmospheric humidity.* The *average* of the *total heating values* found from all the series is then entered on the record.

The heating value thus found is, to within the limits of experimental error of the test, the total heating value of the gas, as defined on page 36.

Calculation in case inlet-water temperature differs from room temperature.—The correction to be applied in calculating the total heating value on account of the difference of temperature between room and inlet water will be different from that to be applied in calculating the net heating value, due to the fact that part of the change in the observed heating value is due to a difference in the amount of water vapor condensed in the calorimeter, a difference which is eliminated in the determination of the net heating value.

In Appendix 15 are given the data from which to determine the amounts by which the total and the net heating values, calculated from the observed heating value as if the inlet water had been at room temperature, must be corrected on account of difference between inlet-water and room temperatures. For example, if the room temperature were 80° F and the inlet-water temperature were 76° F, the total heating value, calculated in the usual way, is too high by 0.8 Btu per 1° difference; i. e., the value is too high by $4 \times 0.8 = 3$ Btu. Similarly the net heating value is too high by $4 \times 0.4 = 2$ Btu.

The corrections calculated from Appendix 15 may be applied without sensible error to heating values of illuminating gas of about 600 Btu as determined with any of the flow calorimeters listed in this circular, except the Doherty calorimeter. The corrections for heat loss and for effect of atmospheric humidity must be made exactly as they would have been made if the inlet water had been at room temperature, and then the additional corrections, calculated from the table, must be applied to the results obtained for the total and net heating values. The corrections in the table are strictly applicable only for small differences between inlet-water temperature and room temperature. These data may also be used in correcting observations obtained when the inlet water is considerably below room temperature; but results obtained in this way will not be quite as reliable as those obtained when the temperature difference between room and inlet water is small. When this difference is large, the correction factor corresponding to the mean of the two temperatures should be used rather than the factor corresponding to room temperature.

The use of Appendix 15 will be illustrated by the example below. Suppose the following data had been obtained with a flow calorimeter:

Room temperature=70° F.
Humidity=40 per cent.
Inlet-water temperature=55° F.
Weight of water collected, W=8.00 pounds.
Corrected rise of temperature, T=15.°00 F.
Volume of gas, V=0.2000 cubic foot.
Factor, F=1.000.
Condensed water per cubic foot=21.0 cc.

Then:

$$\text{Observed heating value} = \frac{(W)\ 8.00 \times (T)\ 15.00}{(V)\ 0.2000 \times (F)\ 1.000} = 600 \text{ Btu.}$$

		Total.	Net.
Observed heating value	=	600	600
Correction for heat loss	=	+ 1	+ 1
Correction for atmospheric humidity (70° F, 40 per cent)	=	+ 3	
Reduction to net=21.0×2.3	=		− 48
Additional corrections for difference between inlet water and room temperatures:			
Correction for calculating total=15×0.6	=	− 9	
Correction for calculating net=15×0.4	=		− 6
Heating values	=	595	547

(22) If it is desired to find the *net heating value*, proceed as follows:

(a) Subtract the *meter reading at the start* from the *meter reading at end of collection of condensate*. This difference gives approximately the number of cubic feet of gas (measured at *meter temperature* and under a pressure equal to that entered above as the *total gas pressure*) burned during the collection of the recorded *condensate* (*cc*). Multiply this difference, as found above, by the *factor*, *F*, to find the volume of the gas under standard conditions (i. e., 60° F, 30 inches pressure), and divide the *condensate* (*cc*) collected by this product and enter the resulting quotient on the record as the *condensate per cubic foot* of gas measured at 60° F and 30 inches pressure. Enter on the record the average, *A*, of the two values found as above from the two tests for condensed water collected.

The volume indicated by the meter (as given by the difference between the final and initial meter readings corresponding to the collection of condensate) is sufficiently accurate for the purpose of determining the net heating value unless the error of the meter is large (over 1 per cent); thus, if the meter reading is in error by 2 per cent, the resulting error in the net heating value will be about 1 Btu for an ordinary illuminating gas of about 600 Btu.

The two values obtained for condensate per cubic foot (60°, 30 inches) should not differ from one another by as much as 5 per cent. If the difference attains 5 per cent, it indicates that the drainage of the condensed water was not sufficiently regular to justify calculation of net heating values from the data obtained.

(b) Enter on the record the *average* of the *observed heating values*.

(c) Enter on the record the *correction for heat loss*, as already used in calculating the total heating value.

(d) Multiply the *condensate per cubic foot* of the gas (measured at 60° F and 30 inches), entered opposite *A* in the record, by 2.3 and enter the product thus found as the *reduction to net*.

The amount of heat required for the vaporization, at the usual room temperatures, of 1 cc of water is about 2.3 Btu. The reduction to net as calculated above, therefore, represents the amount of heat imparted to the calorimeter by the condensation of the water collected.

(e) To the *observed heating value* add the *correction for heat loss*, including the correction taken from Appendix 15 for the effect of difference between inlet-water temperature and room temperature, and subtract the number derived as explained above, representing the *reduction to net*, and enter the result as the *net heating value*.

The heating value thus found is, to within the limits of experimental error of the test, the net heating value of the gas, as defined on page 37.

It is shown in T. P. No. 36 that determinations of net heating values are not affected, provided combustion is complete, either by variations in the amount of air passing through the calorimeter or by variations in atmospheric humidity.

The observer making the test should sign the record as evidence that, to the best of his knowledge, the observations have been carried out as directed and that the computations have been correctly made. The signing of the record should not be regarded as a perfunctory operation and should not be done until the observer has satisfied himself by careful and critical inspection and review and by check computations that the results set forth are reliable.

9. DIRECTIONS FOR OPERATING THE DOHERTY CALORIMETER

The Doherty calorimeter is a modification of the usual type of flow calorimeter and the operating directions already given will, with obvious omissions, modifications, or additions, be applicable. In the operating directions below, the essential operations required in a heating-value test are specified without going into the details concerning the manipulation of the various valves and cocks to accomplish such operations as starting flow of water, filling gas tanks, etc. Complete directions concerning the manipulation of the calorimeter are furnished by the makers.

(*a*) **Manipulation and Observations.**—It is assumed that provision has been made for obtaining a representative gas supply, observing the precautions noted on page 13. If an average sample of the gas is to be tested, this may be collected in the gas tank of the calorimeter or in a small gas holder, the supply being drawn from a line from which gas is being used, to insure that fresh gas is collected. If gas for the test is to be drawn direct from the supply line, it is only necessary that the connections be flushed free from old gas as directed below, so that the test will be made on gas representative of that in the mains. At the inlet of the gas tank a T connection should be provided and one branch of the T should be connected to the supply of gas to be tested and the other branch to a burner, so that gas can be burned continually before and during the filling of the gas tank of the calorimeter.

Having the gas supply thus properly provided and the calorimeter set up, each test is made in the following manner:

(1) *Free gas connections from old gas* as directed on page 17. Gas should be burned continuously in the burner connected to the T at the calorimeter inlet until the gas tank has been filled with gas for the test.

(2) *Observe temperature of laboratory* as directed on page 63.

(3) *Fill the gas tank of the calorimeter with water* at room temperature, if not already so filled, unless the tank is already filled with gas collected for test; then displace a little of the water with the gas to be tested and refill with water.

(4) *Fill the gas tank of the calorimeter with the gas to be tested* by displacing the water from the tank. Shut off connection to drain and to gas supply when the tank is nearly filled with gas.

(5) *Test for gas leaks.* Disconnect the burner of the calorimeter from its tubing, close end of tubing with a suitable plug, open the valve leading to the burner, and note if there is any change in reading of the water manometer attached to the gas tank during a

period of about 10 minutes. While waiting for this test the observations, etc., described in paragraphs 6 to 7 may be made. If the change in pressure due to leakage does not exceed 0.5 inch, when the initial pressure is 2 inches of water or more, the leakage may be regarded as negligible. The observer should bear in mind that this leak test is not a decisive one, as the indications of the manometer are affected by variations in temperature and in barometric pressure. Thus a change of 0.9° F in the temperature of the gas or of 0.07 inch in the barometric pressure would cause a change of 1 inch in the indications of the manometer.

(6) *Adjust temperature of water in overhead tank.* For the most favorable conditions of operation the temperature of the outlet water should be equal to room temperature; and therefore, in testing illuminating gas (about 600 Btu), the temperature of the water in the tank should be 9° or 10° F below room temperature. If the inlet-water temperature is adjusted to room temperature, a correction must be applied; in one calorimeter tested (Doherty No. 16) this correction amounted to about 1 per cent.

(7) *Read and record: (a) The temperature of the barometer and the barometric height; (b) the readings of the wet and dry bulb thermometers of the psychrometer.*

(8) *Reconnect the burner, start flow of water through the calorimeter, light the gas at the burner, adjust air mixer on burner, and place the burner in position under the calorimeter.* The valves controlling the rates of flow of water and of gas should be set so that the rate of gas consumption shall be the *normal rate* for the calorimeter and the gas in question. The proper setting of the valves to give the normal rate and a suitable gas pressure in the tank may be determined by a preliminary test. It is also assumed that the adjustable damper has been so set as to cause the products of combustion to be discharged at as nearly room temperature as possible.

The normal rate of gas consumption, with the damper setting specified above, may be determined by a method similar in all essential respects to that described on page 59, the rates of gas consumption being determined from the time required to burn a volume of gas defined by two positions of the water level in the graduated gage glass on the front of the gas tank. One calorimeter tested (Doherty No. 16) had a normal rate for illuminating gas of about 2.5 cubic feet per hour.

(9) *As the water level in the gage glass on the front of the gas tank approaches the lowest graduation, make and record the following*

observations: (a) Reading of thermometer in the gas tank to 0.1° or 0.2° F; (b) reading of U gage on gas tank to 0.1 inch; (c) reading of combustion-products thermometer to nearest 1° F.

(10) *Note time water level in gage glass passes lowest graduation.* This observation, together with (13), is made to determine the rate of gas consumption.

If the net heating value is to be determined, the graduate for collecting condensate is placed in position at this time.

(11) *Make a series of readings of the inlet and outlet water thermometers,* reading the former at least three times and the latter at least ten times, while the water level in the gage glass is ascending from the lowest to the topmost graduation. For notes on reading thermometers, see page 69.

(12) *Make observations and record as follows: (a) Before the water level in the gas tank has reached the bulb of the thermometer mounted in the tank, make another reading of this thermometer; (b) read U gage on gas tank; (c) read combustion-products thermometer.*

(13) *Note time water level in gage glass passes topmost graduation.* Remove graduate from under drain tube at this time.

(14) *Repeat the observations indicated in paragraph* (7).

Note on Number of Tests.—It is good practice to make at least two tests, as nearly independent as possible. To enable two tests to be conveniently made without the necessity of refilling the overhead water tank and adjusting its temperature between tests, a tank of suitable size (12 to 15 gallons) should be provided.

Notes on Net Heating Values.—If net heating values are to be determined, the capacity of the gas tank (nominally one-third cubic foot) between the extreme graduations on the gage glass should be determined. Enough gas must be burned in the calorimeter to insure that the interior surfaces have become uniformly wetted before the collection of the condensate is attempted, i. e., the data necessary for determining the net heating value can not be obtained until one or two tanks of gas have been burned in the calorimeter. After the interior surfaces have become uniformly wetted, the tank should again be filled with gas and the heating-value test started as soon as possible. From the condensate collected during the combustion of one-third cubic foot of the gas, at the temperature and pressure existing in the gas tank, the amount of condensate corresponding to 1 cubic foot at 60° F and 30 inches pressure may be calculated.

Net heating values obtained with the Doherty calorimeter are less reliable than those obtained with other flow calorimeters for the following reasons: (1) The volume of condensate collected is small; (2) the amount of condensate collected will be unduly increased if the water at low temperature is used, as it should be for most satisfactory determination of total heating value; and (3) the amount of condensate collected would be diminished on account of the fact that the drainage from the calorimeter might not have become uniform in the short time before the collection of condensate was begun.

(*b*) **Records and Computations.**—The record form shown in Fig. 3 may be readily modified by the user of a Doherty calorimeter into a form suitable for his records.

The means of the readings of the inlet and outlet water thermometers are to be corrected as explained on page 69. The difference of these corrected readings gives the rise in temperature of the water flowing through the calorimeter. This rise of temperature multiplied by the capacity for heat of a cubic foot of water at the outlet-water temperature gives approximately the heating value in Btu of a cubic foot of the gas measured at the temperature and pressure actually existing in the gas tank during the test. (See Appendix 8 for data as to the capacity for heat, in Btu, of 1 cubic foot of water at various temperatures.)

The heating value, calculated as above described, must then be reduced to the value corresponding to standard conditions (e. g., 60° F, 30 inches) of gas measurement. For this purpose the total pressure of the gas in the tank must be calculated by adding to the corrected barometric pressure (see p. 198) the pressure of the gas in the tank as measured with the U gage, first reducing the pressure in inches of water to inches of mercury. The average temperature of the gas in the gas tank is taken as the mean of the two readings of the thermometer in the tank, the thermometer corrections being applied if necessary.

From Appendix 4 the reduction factor corresponding to the total pressure and the average temperature of the gas is found. The heating value, found as above indicated, must be divided by this reduction factor to obtain the so-called "observed heating value" of the gas. To find the total heating value, the observed heating value must be corrected for heat losses and for the effect of atmospheric humidity. Under the conditions of operation specified, viz, outlet water at room temperature, the heat losses may be neglected. The correction for atmospheric humidity corresponding to the room temperature (not inlet-water temperature) and per cent humidity observed during the test is to be taken from Appendix 5.

The quantity of water condensed in the calorimeter per cubic foot (60° F, 30 inches) of gas burned is calculated by multiplying the amount of water collected by three and dividing the result by the factor (from Appendix 4) which was used in calculating the observed heating value of the gas.

The net heating value is found by correcting the observed heating value for heat losses and then subtracting from this corrected value the heat of condensation of the quantity of water condensed in the calorimeter per cubic foot (60° F, 30 inches) of gas burned. For the purpose of calculating the heat of vaporization of the water condensed in the calorimeter, the heat of condensation of water is taken as 2.3 Btu per cubic centimeter.

The following example will serve to illustrate the essential steps in the determination of heating values with the Doherty calorimeter:

Temperature of laboratory	=80° F	
Humidity	=30 per cent	
Temperature of gas in tank	=80°.5 F	
Excess of pressure in gas tank	= 1.5 inches of water = 0.11 inches of mercury	
Observed barometric height	=29.50 inches	
Certificate correction	= .00	
Temperature correction (temp. =80° F)	= .14	
Corrected barometric height	=29.36 inches	
Excess of pressure in gas tank	=+.11	
Total pressure of gas	=29.47	inches
Mean of readings of inlet-water thermometer	=71.18	
Mean of readings of outlet-water thermometer	=.....	80.24
Correction from certificate	=−.04	−.07
Differential correction	=.....	+.03
Stem correction (thermometers immersed to 50° graduation)	=−.02	.00
Corrected temperature	=71.12	80.20
Rise of temperature of water	=	9.08
Approximate heating value of gas measured at 80°.5 F and 29.47 ins.=62.1×9.08	= 563	Btu
Factor from Table—to reduce to standard conditions	=0.928	
Observed heating value÷563+0.928	= 607	Btu
Correction for heat losses	= 0	
Correction for atmospheric humidity (80° F, 30°)	= +6	
Total heating value	= 613	Btu
Condensate collected	= 6.3	cc
Condensate per cubic foot of gas at 60°, 30 ins.=6.3×3÷0.928	= 20.4	cc
Observed heating value	= 607	Btu
Correction for heat losses	= 0	
Reduction to net=20.4×2.3	= 47	
Net heating value	= 560	Btu

10. DIRECTIONS FOR INSTALLING AND OPERATING THE PARR GAS CALORIMETER

The Parr gas calorimeter is of the comparison type; that is, the heating value of the gas under test is compared with that of hydrogen. The comparison of heating values is made by comparing the rise in temperature of two as nearly as possible equal calorimeters, in one of which the gas to be tested is burned and in the other of which an equal volume, or a multiple or submultiple of this volume, of hydrogen is burned, the gases being displaced under equal pressures from cylinders kept at equal temperatures. The relative volumes of hydrogen and of the gas tested are chosen so as to cause nearly equal rises of temperature in the two calorimeters. Therefore, in the testing of ordinary illuminating gas, two volumes of hydrogen are burned within one calorimeter and one volume of the illuminating gas within the other calorimeter.

Since the quantity measured with the Parr calorimeter is the ratio of the heating value of the gas tested to that of hydrogen, a ratio that is independent of the temperature and pressure prevailing during the test, the heating value of the gas, referred to standard conditions of gas measurement, is found by multiplying the ratio found with the calorimeter by the number expressing the heating value of hydrogen under standard conditions. The heating value of hydrogen may be taken as 321 Btu per cubic foot, saturated with water vapor and measured at 60° F and at a pressure of 30 inches of mercury.

The directions on pages 13–18 concerning choice of laboratory room and provision for a suitable supply of gas for testing purposes should be consulted in connection with the installation of a Parr calorimeter.

(*a*) **Installation and Standardization of Apparatus.**—(1) *Water Supply.*—If water at least 5° F below room temperature is available, the piping for filling the calorimeters may be connected to this supply, a separate valve being provided for each of the two pipes. If no such cold-water supply is available, the initial temperatures of the calorimeters may be adjusted by the use of ice water. The tank containing the gas cylinders and the "gravity tank" should be filled with water.

(2) *Gas Connections.*—If illuminating gas is to be tested, the two gas cylinders on the left side will be used in parallel for hydrogen and the third cylinder for the illuminating gas. A T connection should be made in the line as near to the inlet of this cylinder

as possible, one branch of the T being connected to the supply of gas to be tested and the other to a burner, so that enough gas can be burned, before and during the filling of the cylinder, to insure a sample of fresh gas.

Gas connections to the pilot lights will also be required, and the connections should be so arranged that the flow of gas to each of the lights can be controlled.

The hydrogen generator should be charged with "hydrone" and should be put into operation according to the instructions furnished by the makers.

(3) *Thermometers.*—It is preferable to use thermometers so mounted that they can be conveniently interchanged. The constant errors of the thermometers may be eliminated from the result by taking the mean of two tests in which the thermometers were interchanged.

(4) *Preliminary Tests.*—Before the Parr calorimeter is put into regular use for the measurement of the heating values of gases it should be carefully standardized as follows:

The accuracy of adjustment of the three gas cylinders to equality should be tested. This may be done by determining the weight of water necessary to fill the cylinders from a lower graduation to an upper graduation of the gage glass, both graduations bearing the same number. If the volume of the two cylinders connected in parallel differs appreciably from twice that of the third cylinder, the correct ratio must be determined and subsequently used in computation of all tests of illuminating gas.

The volume corresponding to one division of the upper portion of each of the gage glasses should be determined, since, in testing, it is not always possible to stop the meniscus in the gage glass at the predetermined point. If the volume corresponding to one division is known, the necessary correction can be readily applied. In one Parr calorimeter tested (No. 2) one division of the gage glass corresponded to about 0.25 per cent of the total volume of gas burned in a test.

The accuracy of adjustment of the two calorimeters to equality should be tested by weighing the two calorimeters while empty. The weights should not differ by more than 20 grams. The completed calorimeters will probably be found to be equal to within a very few grams, but this does not necessarily indicate that they have the same capacity for heat. Since a quantity of insulating material is incorporated into the calorimeters, it is necessary that the weights and also the dimensions of the corresponding parts be equal, if equality of heat capacity is to be insured.

The accuracy of adjustment of the water content of the two calorimeters to equality should be tested, and if necessary, a readjustment should be made by changing the position of the overflow siphons. In making the test, the calorimeters should be in position on the stand, and the stand should be leveled with the aid of the level mounted on it. The calorimeters should then be filled with water until the overflow siphons operate, after which the weight of water in each calorimeter should be determined, e. g., by draining the water from the calorimeter through the cock provided for that purpose, and weighing this water. The water contents of the two calorimeters should not differ by more than 3 grams.

In addition to the above tests it is highly desirable to test the equality of the heat capacities of the two calorimeters by burning equal volumes of the same gas under each calorimeter and noting whether the rise in temperature is the same for the two calorimeters. In making this test, the procedure indicated in the operating directions below should be followed. A series of such tests will be necessary to determine whether or not there is a significant difference in the heat capacities of the two calorimeters.

(*b*) **Directions for Operating the Parr Gas Calorimeter.**—(1) *Make provision for obtaining a representative sample of the gas to be tested.* (See p. 16.)

(2) *Open the connections to the gravity tank and fill the gas cylinders with water*, allowing a little water to run from the gas inlet cocks from which the rubber tube connections to gas and to hydrogen have been removed. During this operation the burner valves must be kept closed, but the valves at the top of the gage glasses should be opened.

(3) *Fill with hydrogen the two gas cylinders connected in parallel*, using necessary precautions to prevent contamination of the hydrogen with air. For this purpose the gravity tank must be removed from its shelf and set on a stand of such height that the top of the tank is about on a level with the top of the calorimeter table. Since it is not certain that all the air in the cylinders and connections was displaced by water, it is desirable, after the cylinders are about half full of hydrogen, to again fill them with water, allowing the hydrogen to escape through the valve at the top of the gage glass, and then to fill them with the hydrogen to be used in the test.

(4) *Fill the gas cylinder with the gas to be tested.*—If the precautions described on page 16 have already been observed, the burner connected to the T connection should be started and gas burned in it for 5 or 10 minutes before taking the sample. The gas should then be drawn into the cylinder, but the gas supply to the burner should not be cut off. The precautions to be observed to prevent contamination in filling the hydrogen cylinders should also be observed in filling the gas cylinder with the gas to be tested. After the cylinder is filled, the gas should be shut off from the burner.

(5) *See that the calorimeter stand is leveled.*

(6) *Adjust the water levels in the gage glasses to the same level and record the readings.*—The adjustment is made by allowing enough hydrogen and gas to escape from the respective cylinders, using the valves at the top of the gage glasses, so that the water in the two gage glasses will be at the same level. The water levels may be easily adjusted to the same level within one-fourth inch, and as such a difference would introduce an error into the results of the test of about 0.06 per cent, due to the difference in pressure in the two cylinders, the difference in the water levels should not be allowed to exceed one-fourth inch.

To avoid explosions, unburned gas should never be allowed to escape into the calorimeters.

(7) *Observe and record the temperature of the room.*

(8) *Adjust the temperatures and the water contents of the two calorimeters.*—Adjust the temperatures of the two calorimeters so that at the close of the experiment the temperature of each will be as nearly as possible equal to that of the room. The calorimeters may be cooled with the tap water or with ice water. If the filling tubes mounted above each calorimeter are used to run the water into the calorimeter, the observer must take care that the water is completely shut off from these tubes after the adjustments have been made, or that they are swung out of position so that any leakage from them will not be delivered into the calorimeters. Care must also be taken that no water is introduced into the calorimeters after the siphons have drained off the surplus water, unless enough water is filled in to again cause the siphons to operate, as otherwise the quantity of water in the calorimeters will not be correct. In adjusting the temperatures of the calorimeters, it is necessary to operate the stirrers, but in the final adjustment of the water level by means of the siphons the stirring must be interrupted.

A convenient method of adjusting the temperatures of the calorimeters, if these temperatures are too low, is to warm the calorimeters with the pilot lights.

(9) *Adjust the flames of the pilot lights.*—The flames of the pilot lights should be made as small as possible without danger of extinction in operation; e. g., if illuminating gas is used, the flames should be made so small as to be nonluminous, and the two should be made as nearly equal as possible.

(10) *Note and record the positions of the water levels in the gage glasses*, and compare with the previously recorded positions to determine whether there is any leakage of gas or of hydrogen. If both levels have changed by an equal amount, the changes are not necessarily due to leaks, but may be due to temperature changes, or to changes in the barometric pressure. However, if the water level in one gage glass has changed more than that in the other, this change is probably due to a leak. If the change in water level in one gage glass differs from that in the other by as much as one-eighth inch (one-half division for Parr calorimeter No. 2) during 10 minutes, the leak should be located and eliminated.

(11) *Start the motor which operates the stirrers.*

(12) *Observe and record a series of readings of the two thermometers in the calorimeters, and ignite the gas under the two calorimeters.*—The thermometer readings and the operations of lighting the gas under the two calorimeters may be performed in the following order. Suppose that the left-hand calorimeter is to be started first. Read the thermometers alternately at half-minute intervals, beginning with the one in the left-hand calorimeter, and make the same number of readings (three or four) of each thermometer, the last reading being therefore made on the thermometer in the right-hand calorimeter. One-half minute after the last thermometer reading, ignite the gas under the left-hand calorimeter, and one-half minute later, ignite the gas under the right-hand calorimeter.

The sequence of operations indicated above is such that the effect of heat interchange between the calorimeter and the room is the same for each calorimeter. The necessary condition for the elimination of the effects of such heat interchange is that the time intervals between reading the thermometers and igniting the gas shall be the same for each calorimeter. Other sequences of operations may, of course, be devised to accomplish the same result.

The thermometers must be read to 0°01 F. To avoid errors due to parallax, the line of sight must be perpendicular to the thermometer stem, a condition which will be secured with a properly constructed reading glass mounted on the thermometer stem, if the mercury meniscus of the thermometer is in the center of the field of view.

To light the gas the pilot light should be swung into position under the calorimeter, the valve leading to the burner opened, and the pilot light immediately swung out again. If the gas fails to ignite immediately, the test must be started again. As soon as the gas has ignited the size of the flame should be adjusted (see below). Even if the pilot lights are turned as low as possible, significant errors may be introduced by leaving the light under one calorimeter 5 seconds longer than under the other. (See T. P. No. 36.) In the testing of illuminating gas, the temperature rise to be measured in the Parr gas calorimeter No. 2 was of the order of 5° F, hence an error of 0°01 F in the deterimnation of the temperature rise of either calorimeter would cause an error of about 0.2 per cent (1.2 Btu) in the heating value.

(13) *Adjust the size of the flames.*—The flames should be so adjusted that the gases in the cylinders will be burned in from 7 to 9 minutes, keeping the water level in the gage glass of the side first started a little above the water level in the other gage glass. As the pressure on the gases changes considerably during the test, the sizes of the flames should be readjusted from time to time.

(14) *Close the burner valves* when the water levels in the gage glasses reach the upper graduated portions of these glasses, the rates of combustion having been so regulated that the water in the gage glass on the side first started reaches the graduated portion about one-half minute before the water level in the other gage glass reaches the corresponding graduated portion. The valves should be so manipulated that the final positions of the water levels in the two gage glasses are nearlv the same. Record the final positions of the water levels.

(15) *Observe and record a series of readings of the two thermometers.*—As the calorimeters are now at or very near to room temperature, so that the rate of temperature change is slow, the exact timing of the readings is not important, provided only that the readings are not made until uniformity of temperature has been established throughout the calorimeters. However, for the sake of uniformity of practice, a series of thermometer readings

at half-minute intervals should be taken and recorded, following the sequence used in the previous series of thermometer readings.

As this latter series of thermometer readings will be made with a practically stationary or perhaps even a falling temperature, it is necessary to tap the thermometers just before each reading in order to avoid errors due to sticking of the mercury meniscus. The vibration due to the operation of the motor and the stirrers may or may not be sufficient to prevent the sticking of the meniscus.

At least one more test should be made, taking another sample of gas and following the directions given above. For the second test it is desirable, as already noted, to interchange the calorimetric thermometers. This interchange is not convenient and is hardly to be recommended if the angle-stem thermometers mounted in the calorimeters are used. The results of sucessive tests on gas of identical composition should not differ by as much as 2 per cent.

To attain an accuracy of 1 per cent in the result, at least two tests will usually be necessary, while to attain an accuracy better than 1 per cent, four or more consecutive tests should be made.

(c) **Computations.**—The means of the four groups of readings of the calorimetric thermometers should be corrected for calibration errors of the thermometers, and from the corrected means the rise of temperature of each calorimeter is found. No stem corrections are required.

Assuming that the two calorimeters are thermally equivalent, the total heating value of the gas tested may be found from the formula:

$$\text{Total heating value} = \frac{R^\circ}{L^\circ} r\ (1+e)\ \times 321$$

where:

R° = rise in temperature of the right calorimeter under which the gas to be tested was burned.

L° = rise in temperature of the left calorimeter under which the hydrogen was burned.

r = volume of the two hydrogen cylinders divided by volume of the gas cylinder. If the adjustment is correct, $r=2$. If r differs from 2, the value of r found from the experiments described on page 86 must be used.

e = a small correction factor to allow for the effect of the error in r due to stopping with the water levels in the gage glasses at different heights. In the Parr calorimeter No. 2, e amounted to

0.0025 for one division of the gage glass, i. e., the volume corresponding to one division of the gage glasses was 0.0025 of the volume of the cylinders.

The number 321 is the total heating value of hydrogen in Btu. Example:

Suppose the following data had been obtained:

Ratio of gas volumes, $r=1.982$.
Initial readings on gage glasses: Left, 4.0; right, 4.0.
Final readings on gage glasses: Left, 3.0; right, 5.0.
Corrected rise in temperature of left calorimeter, 4.98°.
Corrected rise in temperature of right calorimeter, 4.73°.

Then:

$$\text{Total heating value}=\frac{4.73}{4.98}(1.982)(1-0.005)\times 321=601 \text{ Btu.}$$

11. INTERPRETATION OF RESULTS

As has already been stated, any of the calorimeters listed in this circular may be used to measure total heating values to an accuracy of about 1 per cent, if necessary precautions are taken, and if suitable corrections are applied in making the computations. It is evident, therefore, that if there appears to be a deficiency in heating value the likelihood of experimental error making the heating value appear deficient, when it really was up to standard, is not great; and a deficiency in monthly average greater than 2 per cent or 3 per cent can probably be taken to represent real deficiency and rarely need be considered as due to experimental error.

In case the result of a single calorimetric test shows the quality to be close to the limit allowed, it is desirable that a second test be made to confirm the first. Such test can best be made shortly after the completion of the first. And if the average of the two or more tests thus taken shows deficiency it is desirable, if possible, to repeat the series of tests at a later time on the same day to determine whether or not the condition found continues and to eliminate as far as possible any experimental error. Such check tests are valuable and should be made from time to time, even if no deficiency is found.

As has been recommended by the Bureau in Circular No. 32, any penalty should usually be based on a monthly average heating value, unless the deficiency of the heating value below the average allowed is excessive. If the inspector notes that during the first portion of any month the heating value is running close to or below the average required, this fact should be brought to the attention of the company, in order that they may take suitable precautions to avoid deficiency of the monthly average. As a matter of fact, when operating on the heating value basis it will rarely be necessary to consider the desirability of assessing penalty, since in practically every case, if the heating value requirement be reasonable, the company can meet the requirement on a monthly average basis without difficulty. Except for serious accident in the works or very cold weather the value for a single day should rarely be much below the general average and so penalties on single day values will probably be even more rare than those on monthly average heating values.

D. CANDLEPOWER DETERMINATION

Candlepower is not a definite property of the gas, as heating value is, but represents a performance which depends on the conditions of combustion as well as on the quality of the gas. By "candlepower of a gas" is usually meant the horizontal intensity which a flame would have when burning 5 cubic feet of the gas per hour in a given type of burner, under standard conditions of pressure and temperature and in an atmosphere of normal purity, humidity, and pressure.

The photometer outfit serves to determine more or less accurately this somewhat indefinite property of the gas. Three types of photometers are commonly used in gas testing: The open bar, the closed bar, and the portable form. The table or V-bar photometers are rarely used in this country and are not described in the following sections; the "jet photometer" is really not a photometer and is used only as a guide in works control.

The open-bar instrument is most commonly employed, and is preferable to all other forms for gas testing. It has the advantage over the closed bar of giving better ventilation to flames, less temperature change about the flame, and no chance for reflection of light into the sight box from the gallery. Although the closed-bar instrument is slightly cheaper and the flames are less disturbed by drafts in the room, these advantages are less important than those which favor an open bar. By proper setting of screens on an open-bar instrument, the latter can be used with accuracy in a room only partially darkened and without blackened walls, with as great ease and satisfaction as can the inclosed-bar form. (See p. 112 for discussion of screens.)

The portable photometer may be used advantageously in many cases, but it is somewhat less reliable than the stationary open-bar type. In cities where a permanent equipment is necessary, the portable form is not used for official testing and, in general, it should not be used when a fixed apparatus can be secured. Some portable instruments suitable for State inspectors' use and for testing in various parts of a city will be described.

For official testing a jet photometer is not suitable, since it is not really a photometer but must itself be calibrated by a photometer.

If properly used, it may be a valuable guide to the gas maker in a small coal-gas or oil-gas works; but for water gas it is of no value, since the density and length of flame of this kind of gas do not change at all proportionately with the candlepower. This instrument is described briefly on page 112.

1. BAR PHOTOMETERS AND ACCESSORIES

An open-bar photometer outfit consists of a standard burner for the gas and a standard light set a fixed distance apart, with a graduated bar between them, a comparison disk mounted in the sight box which moves on the bar, a gas meter, which is often equipped with a clock attachment, a gas-pressure governor connected between the gas meter and the gas burner (another governor to regulate the pressure at the meter inlet is also used on some forms of apparatus), one or more gages to indicate the pressure of the gas at various points in the instrument, and a set of screens to protect the flames from drafts and to exclude extraneous light from the sight box.

The essential parts of a closed-bar photometer are the same as those of the open-bar instrument, the distinction between them being that the bar and flames of the former type are inclosed by two cabinets with a connecting gallery. The cabinets and gallery inclose the portions of this instrument which require the most attention, and consequently interfere somewhat with the operation of the apparatus. The flames are less exposed to draft, but this is scarcely an advantage, since it at the same time renders proper ventilation very difficult. The installation of a closed-bar photometer is not recommended, but laboratories already equipped with this form can get satisfactory results if care is exercised in the use of such equipment.

(*a*) **Form and Setting of Bar.**—The bar of the photometer should be mounted on its two supporting pillars in such manner that it may be readily adjusted, both at the correct height to bring the disk on the same level as the flames, and in the position from left to right so that its graduations indicate correctly the distances from the two lights. The bar is made of metal or of well-seasoned wood, either being satisfactory; but it is generally better to have the track on which the sight box moves made of metal so that the carriage may move more smoothly and with the minimum chance of displacement to front or rear from correct position between the flames. It is customary to mark both inches and candlepower graduations on the bar. The latter are not essential, but are very convenient, since they greatly simplify calculations, even when the graduations are based on a standard having a value different from the one used. The graduations are usually made for a 1-candle standard, and in this case the reading is simply multiplied by the value of the standard used.

The photometers used in this country are 60, 80, or 100 inches between the lights to be compared; there is no great advantage in one of these over the others. The 60-inch instrument is most frequently used, as it is slightly cheaper and can be set up in a smaller space than the others. With the shorter bar a given movement of the disk is equivalent to a larger change in the candlepower reading than with the longer instruments; but the setting and reading on a 60-inch bar can probably be made with as great precision as the ordinary worker is able to attain on a longer one, the largest irregularity of observation being usually due to change in judgment as to when a correct setting has been made.

(*b*) **Disk and Sight Box.**—The Leeson contrast disk has been strongly recommended. It can be easily cleaned or renewed and it is nearly as accurate as the more complicated optical combinations which are sometimes employed. At the present time it is more largely used than any other form. The Lummer-Brodhun, the Bunsen or grease-spot, and the disappearing-star disks are all used to some extent. In precise work the Lummer-Brodhun form is almost always employed, but for ordinary testing any of the forms mentioned will give satisfactory results.

The disk and mirror holders should be so mounted in the sight box that they can be reversed during a test. This reversal is not always necessary; but it is readily accomplished and it should be made in each test to avoid chance of error due to difference in the two sides of the disk or in the two mirrors. Even when once made alike on the two sides, it is easy for one side to become slightly more dusty and an error to be introduced unless a reversal is made during each set of observations.

It is often found that an observer will favor the light on one side or the other. Each observer should determine whether or not his observations are subject to such error by reversing the sight box on the bar and making comparisons from the back of the photometer. If a large number of readings taken this way show definitely higher or lower results than similar tests from the front of the bar, all future work should be arranged so that half of each series will be taken in the reversed position of the sight box. This causes a little extra work, but it is necessary in order that such constant error be eliminated.

One other method of eliminating this tendency to favor the right or left hand light is to make the observations by substitution. In this method the gas flame and the standard light are each compared with a third source of light whose value must be constant, but need not be known. The standard is first compared with the third or comparison lamp, and then the gas flame is substituted for the standard and compared with the third lamp. By these two comparisons the ratio of gas to standard is fixed. As the standard and the gas flame are located on the same side of the observer, any tendency to favor one side or the other has no influence on the final result as calculated for the ratio of gas flame to standard.

The sight box should slide over the bar easily and without jar. The mirrors should be of good quality and must be readily accessible for cleaning.

(*c*) **Gas Meter.**—For measuring the gas supplied to the test burner a wet meter should generally be used. It is not material whether this gives one-tenth or one-twelfth of a cubic foot per revolution, but the former can be read and recorded more conveniently. The only advantage of the latter is that the rate of burning is more easily observed, since for 5 cubic feet per hour the meter hand must revolve once per minute.

The meter should be attached to the gas supply by joints sufficiently flexible to allow leveling without straining of the meter. Lead connections have been recommended by the gas institute committee.[9] No rubber connections should be used for a photometer, since it is possible that illuminants from the gas may be absorbed by the rubber or may be again given off into the gas passing through it. With rubber connections there is also greater danger of leakage than with metal connections.

When gas from several supplies is to be tested at one photometer, a separate meter must be used for each kind of gas. Unless this is done much time is consumed in resaturation of the water in the meter each time a change is made from one gas supply to the other.

Sometimes the meter is provided with an elaborate and expensive stop-clock attachment, but the American Gas Institute committee's recommendations express a preference for a meter

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[9] Proc. Amer. Gas Institute, 2, p. 459; 1907.

"unencumbered by a superimposed clock." Either a stop watch or a small separate stop clock is cheaper and equally satisfactory.

The detailed recommendations already given on page 26 apply to the selection of a photometer meter as well.

(*d*) **Pressure Governor and Gages.**—In order to make the measurement of the volume of the gas more accurate and to steady the gas flame during a test at least one pressure governor is essential. This may be placed either at the inlet or at the outlet of the meter, preferably the outlet; but it is best to have a governor at both inlet and outlet. Dry governors are usually employed, as a wet governor increases the time necessary for purging the gas line before test can commence. A wet governor is slightly more sensitive, but when two good dry governors are used the control of pressure is excellent.

To test the gas pressure at various points, gages should be provided; a movable siphon or U gage or a fixed multiple-arch gage may be used. The former may be attached at various points on the photometer as required; the latter is always connected to several points of the gas line, measurement at any of these points being made by opening the cock on the proper connection pipe. Either arrangement of gages is suitable, but the simple movable gage will probably be preferred in most cases because of its much smaller cost.

(*e*) **Gas Burner.**—In an ordinance regulating the candlepower of gas, the burner to be used in testing is often definitely specified, and this is the best plan.

Of the open-flame burners employed for gas photometry, the Bray No. 7 L. P. slit-union burner has probably been most used in this country. Those who have used it state that it is excellently made, and that various burners of this kind give uniform results. It can probably be used by any inspector with satisfaction. It has the advantage of giving as high values for rich water gas as most Argands do, and with coal gas it is not much less efficient. The efficiency changes only slightly with small variations in rate of gas consumption, so that the variations which may occur will not affect the luminous efficiency appreciably. The No. 7 union jet Bray is recommended by some, but its tip is more apt to be obstructed by dust, and it is therefore less used. Among the other forms of open-flame burners occasionally used in this country are several forms of iron or aluminum tipped and "table-top" burners. The Von Schwarz "8-foot E. H."

(excavated-head) burner is also used by some, and certain tests indicate that for gas of the ordinary grade it gives higher values than most other open-flame burners.

For lower grades of gas (up to 18 candlepower) the argand burners are more efficient, at least when judged on the basis of the horizontal candlepower, than are the various open-flame burners. The old and new forms of the "D" and "F" and the Carpenter or "Metropolitan No. 2" Argand are most used. The objection to the use of any argand burner is clearly indicated in the circular on gas-testing regulations, but where the law requires use of "the burner best suited to the gas," a burner of this form is often used. Under these latter conditions it has been the practice in New York State and some other places to try several burners and determine which gives the highest results. Whenever this is necessary it will be best to have an agreement between the company and the city that the burner thus selected will be used for the official tests. As a guide to such selection the following rules will generally apply. For all except very rich gas the Metropolitan No. 2 Argand gives the highest values. For gas in the neighborhood of 20 candlepower the ordinary argand and open-flame burners are about equally efficient. For gas of higher candlepower than 20 the open-flame burner is usually the more efficient, while below 20 candles most of the argand burners give higher values than any of the open-flame burners. The above assumes a measurement of horizontal candlepower and the use of this value as a measure of the efficiency of the burner. To provide for the various cases which may arise, the methods for use of the various forms of burner are given, although the Bureau prefers the open-flame test burner.

By tests on a considerable number of burners from a single maker it has been shown that various tips of the same kind agree well in efficiency, variations above and below average being usually less than 2 per cent. One of the main factors affecting the efficiency is the width of the burner slit, the wider slit giving higher efficiency when the burners are otherwise alike. When the tips having a slit either measurably wider or measurably narrower than the average are eliminated, the others of a lot have been found to agree among themselves very well, no one tip being more than 1 per cent above or below the average of all.

The Bureau is prepared to examine and test open-flame burners for inspectors and others who may desire to secure burners certified as having a standard efficiency. This, it is hoped, will permit the use of a calibrated test burner in official work and will eliminate one of the points of uncertainty in gas photometry.

With all burners the rate of gas flow should be 5 cubic feet per hour, measuring the gas under the existing laboratory conditions. Correction for effect of temperature and pressure upon the mass of the gas burned should subsequently be made as indicated in the methods of calculation from test data, which are given in a subsequent section.

The burner support on the more elaborate photometers is equipped with a micrometer cock for regulation of the rate of gas consumption. Some prefer to control the rate by adjustment of the pressure governor. There seems to be no reason for choice between these methods, except the preference of the operator. For most workers the micrometer cock is more convenient; but it is by no means essential, especially since it is not necessary to burn the gas at exactly 5 cubic feet per hour, a variation of several per cent from this rate having no appreciable effect on the efficiency of the open-flame burner. However, under some conditions, and especially at lower barometric pressures, the argand burners vary in efficiency rather rapidly; hence with them the gas rate should be carefully adjusted to 5 cubic feet per hour. Of course, a correction is made to a 5-foot rate in the calculation.

The burner should be set on a swing bracket so that the standard lamp may be used at this end of the bar, if it is desired to test the gas by the substitution method, or if two standard flames are to be compared. The method of the alignment of the burner will be given in the directions for making a test. When not in use, a small, loose-fitting cap may be placed over the burner to keep the tip from being clogged with dust.

(*f*) **Standard of Light.**—Five types of flame standards are in use in this country by gas companies and official inspectors, viz: Candles, pentane lamps, Hefner lamps, Elliott lamps, and Edgerton standards. Standardized electric lamps are used in very few gas-photometry laboratories; the Carcel lamp is practically unused in this country.

These five standards differ in accuracy, portability, color of flame, and convenience; but the use of any one of them is proper, if its limitations are clearly recognized. The candlepower of each standard is fixed in terms of the international candle.

(1) *Candles.*—Candles are still used in this country more than any other standard for gas photometry. A statement of the candlepower of a lamp does not, of course, imply that candles

must be used as the standard for the test. The name "British Standard Sperm Candles" or any equivalent term has lost its significance, since there is no longer any sperm candle which is recognized in England as standard. The purchaser of candles must depend upon the reliability of the maker for his assurance that the candles bought are correctly made.

Candles are simple, cheap, and portable. They are, therefore, well suited for use where accuracy is not required. It is not uncommon to find discrepancies of 5 per cent in the light from different candles of the same lot, or even in the light of single candles at different times on the same day. If a sufficient number of observations of the candlepower are taken, candles may be used with fair success; but one should not consider such results as representing the value of the gas tested closer than 5 per cent (plus or minus) when a single pair of candles has been used for a series of not more than 10 or 20 observations. When several series of observations are averaged, a greater accuracy would result. (See interpretation of candlepower results, p. 123.)

Sperm candles, 6 or 12 to the pound, are used. When the former size is employed each candle is usually cut into halves and burned from the center toward the ends of the original candle. Some advantage has been claimed for this use of long candles, but the data presented do not seem to support the claim. "Twelves" are more convenient and probably fully as uniform as the longer candles. They are usually burned in pairs in some form of candle balance. The candles are set in the balance, lighted, allowed to burn until steady, and then, if necessary, moved slightly to the proper position relative to the bar just before the observations are made.

When burning properly the flame is steady, regular in form, and smokeless. The wick should be smooth and free from projecting fibers. It should curve so that the end is nearly horizontal, and the tips should show a distinct glow. The cup at the base of the wick should be the full width of the candle, with its rim as nearly uniform in height as possible. The cup should contain only a small amount of melted sperm. If an irregular cup allows drops of sperm to run out, large variations in the light will occur.

Three methods for setting the candles are given, as follows:

1. The curvature of each wick makes an angle of 45° with the disk and 90° with the other wick, one curving toward the disk, the other away from it.[10]

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[10] Proc. American Gas Institute, 1907, p. 492.

2. The plane of curvature of one wick should be at right angles to that of the other, and one glowing end should face the disk.[11]

3. The two wicks point in opposite directions, both parallel to the disk.

Careful measurements of the light given off horizontally in different directions from the candle flame do not show an appreciable difference in the amount on any side as compared with any other side. This result might be expected, as the flame is so transparent that each particle of hot carbon can give out light equally well in all directions. The relative position of wicks is therefore of no consequence as far as the light value of the candle is concerned. However, if the heat from one candle appears to melt down the cup of the other irregularly, the third method is preferable. Otherwise there is no choice between the three plans suggested.

The candles should each burn at the rate of 120 grains per hour. Thus, in a 10-minute test 40 grains of sperm are consumed. If the 40 grains are burned in less than 9½ minutes or more than 10½ minutes, the test is usually discarded. However, in hot, humid weather as high as 11 minutes may be allowed if it is certain that the slowness of burning is not due to lack of proper ventilation. The intensity of the flames is assumed to be proportional to the rate of burning of the sperm. Thus, if 9¾ minutes are required for the consumption of 40 grains, the candlepower of the pair is taken as 2.05 candles. The usual rule for correction is: Add 1 per cent to the observed candlepower of the gas for each 6 seconds less than 10 minutes required for burning 40 grains of sperm, or substract 1 per cent for each 6 seconds more than 10 minutes.

(2) *Pentane Lamp.*[12]—The Harcourt pentane lamp, which is the official standard in England, has met with considerable favor in this country and is now used more than any other standard except candles. The chief objections to the lamp are its somewhat cumbersome form and the character of the fuel employed, but it possesses several advantages over all other flame standards. The light is very constant and is only slightly affected by the ordinary variation in the quality of the fuel or a small difference in flame height, and when fitted with a good burner giving a smooth-topped flame this lamp will give excellent checks on consecutive measure-

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[11] Public Service Commission of Second District of New York. "Rules and Regulations Governing Inspection of Gas."

[12] For a full discussion of pentane lamps, see Scientific Papers 216 and 222 of this Bureau.

ments. When standardized and used with proper precautions the pentane lamp is the most accurate and most precise flame standard known.

Fig. 4 is a sectional view of the English form of 10-candle pentane lamp, showing the details of air and fuel circulation.

In general, American-made lamps are heavier than those of English manufacture, castings being substituted for sheet metal in several parts. The partitions of the saturator are arranged somewhat differently, and the tube connecting saturator to burner is of metal instead of rubber. The inner chimney is supported near the bottom instead of at the top, and the burner is detachable. In older American lamps the piece connecting chimney and standard is metal, and the triangular plate below the saturator is fastened to the standard by rings; but in the English and recently made American lamps the connecting piece is of insulating material and the plate is brazed to the standard. The latter construction tends to cool the standard and promote the air circulation, thus making the flame broader and of higher candlepower.

The fuel for the lamp is defined by the London referees as follows:

> The pentane to be used in the 10-candle lamp should be prepared and tested in the following manner:
>
> Preparation: Light American petroleum, such as is known as gasoline [12a] and used for making air-gas, is to be further rectified by three distillations at 55°, 50°, and 45° C, in succession. The distillate at 45° is to be shaken up from time to time during two periods of not less than three hours each with one-tenth 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°. 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 at 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°. 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 cc of nitric acid, specific gravity 1.32 (made by diluting pure nitric acid with half its bulk of water); add 1 cc of a dilute solution of potassium permanganate, containing 0.1 gram of permanganate in 200 cc. Pour into the bottle 50 cc of the sample of the pentane, and shake strongly during five 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 of 1 per cent of amylene or benzene, the color will have disappeared.

[12a] Material now on the market as "gasoline" would probably not be suitable as a source of pentane, since the character of this material is much different than that referred to in these specifications.

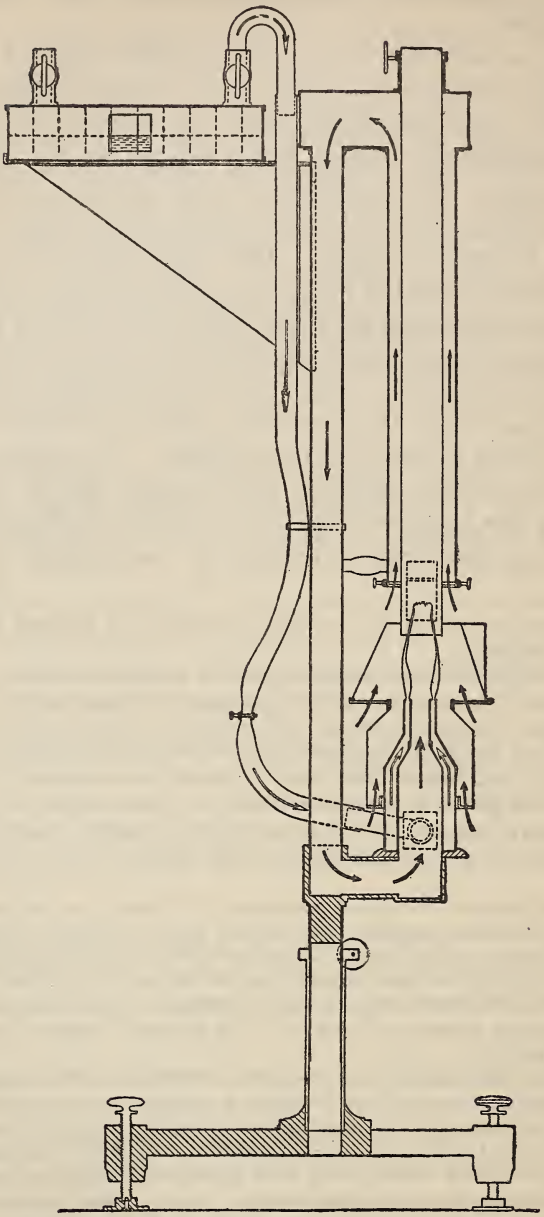

Fig. 4.—*Sectional view of pentane lamp (English form)*

Pentane is usually shipped in this country in one-sixth gallon tins. It must be kept sealed until used, as it boils at summer temperature (85–90° F). It should be stored in a cool place to avoid bursting of the containers.

Directions for use: The saturator should be from one-third to two-thirds filled with pentane at starting, and the height of the liquid as seen against the window of the saturator should never be less than one-eighth inch. The lighter portion of the pentane evaporates first and the residue in the saturator becomes heavier and contains a larger proportion of impurities as the evaporation goes on. The rate at which impurities collect in the residue naturally depends very largely on the quality of the pentane used. The English testing station practice is to discard the residue at least once each month, when three tests are made each day; but a better practice and one that is especially necessary when the quality of the pentane is at all doubtful is to empty the saturator after it has been refilled only three or four times. Even when the fresh pentane is pure enough to pass the specified tests the candlepower increases perceptibly as the density of the fuel becomes greater. This increase in the case of good pentane has been found to be about 1 per cent for a change of 0.01 in density of the fuel above 0.630.

In standardizing lamps fresh pentane is always used, and at the Bureau of Standards the residues are discarded when the density reaches 0.635. The value certified for a lamp may therefore be considered as correct for a density of 0.630. If residues of high density, or pentane which is originally too heavy, are to be used, the accuracy of the results will be increased by correcting for this. For example, if the fuel used runs up to 0.650, the candlepower of the lamp should be taken as 2 per cent above that certified. If the pentane was originally impure, the candlepower may run even higher than this, but it is impracticable to give corrections for such uncertain conditions.

Since the pentane is very volatile and the heavy vapor flows downward, it is extremely hazardous to fill a lamp while it is burning. It should be an inviolable rule of the laboratory that no pentane in an open vessel shall be brought near any flame.

Before lighting the lamp the height of the chimney above the burner should always be tested. The window in the chimney must be turned so that no light from it can fall on the photometer disk, but it should not be turned directly toward the lamp standard or the pentane feed tube. The chimney should stand centrally over the burner, but the screws by which this adjustment is made in the English lamp are not to be turned up tight. Since the wooden gage ordinarily used for setting the chimney may shrink, it is necessary to examine it from time to time to make sure that it remains 47 mm long. A metal gage is, for this reason, much preferable to the wood.

In placing the lamp, distance should be measured from the center of the burner. The American lamps are provided with a plumb line beneath the burner which is intended to facilitate setting the lamp over a line marked on the photometer table. Initially the correctness of both plumb bob and line should be checked by a direct measurement of the distance from the center of the burner to the photometer disk. The lamps are adjustable in height and according to the directions of the gas referees are to be so set that the bottom of the chimney is on a level with the middle of the photometer disk. The American Gas Institute Committee has, however, recommended that the middle of the flame be set on a level with the center of the photometer disk, and in tests at the Bureau this recommendation has been followed. The lamp should be leveled by means of the screws in the feet; a level, or in some cases a plumb bob, is attached to the standard of the American lamp for this purpose. With the English lamp a small plumb bob which will hang inside the burner, with the plumb line passing through the center of a cap on the chimney, will be found convenient.

After the lamp is lighted, the conical shade about the flame must be turned so that the whole flame is visible from the photometer disk. A short time is required to set up the air circulation in the lamp, and in the meantime the flame is blue. If pentane is allowed to flow out of the burner before it is lighted, some of it may collect in the base of the burner and may cause a harmless explosion, extinguishing the lamp, when the circulation starts.

For the first few minutes after the lamp is lighted the intensity rises rapidly. It reaches a maximum in 8 to 10 minutes and then decreases gradually to a steady value after a few minutes more. The flame should be kept at approximately the correct height, and no measurements should be taken with an American lamp of the older type till it has been burning a half hour. With the newer American lamps (which have brazed radiation plates and insulating connection between the chimney and standard) 20 minutes is sufficient; with an English lamp this time may be reduced to 15 minutes. The error which is introduced by taking measurements too soon may be as great as 3 per cent.

Height of flame: When the lamp is burning both cocks on the saturator should be partially, but not necessarily completely, open. The practice of the gas referees is to regulate the height of flame by the opening of the air inlet to the saturator, but this is decidedly unsatisfactory, especially in warm weather. The regulation may always be accomplished by the cock at the pentane outlet, but it is most easily done in the case of English lamps by putting a screw pinch-cock on the lower part of the rubber tube. This is regularly done at the Bureau. Some American lamps have a regulating cock in the feed tube, usually provided with a micrometer adjustment, which is satisfactory.

In order to make the intensity as nearly as possible independent of small variations in flame height it is desirable in standardizing a lamp to set the flame at the height which gives the maximum candlepower. The English lamps are so designed that the maximum is obtained when the flame extends halfway up the lower opening of the mica window in the chimney, or about 27 mm above the bottom of the chimney. In the American lamps the window has a crossbar to the top of which the flame is supposed to be set, but this bar has been so placed that its top is only about 22 mm above the bottom of the chimney. Consequently the Bureau has adopted the practice of making a line on the window at the height which gives the maximum intensity and then setting the flame at that height for standardization. When this is done the certificate given for the lamp states the height of flame to be used. Naturally whatever flame height has been used in calibrating the lamp must be used in making measurements. The amount of variation which is introduced by change of flame height depends considerably on the form of the flame. If it is smooth and flat-topped the decrease in intensity caused by a departure of one-quarter inch in height is rather less than 1 per cent. The flame below the chimney as seen from the photometer, should appear full and symmetrical.

To obtain the most consistent results a second observer may be needed to regulate the flame and to give warning if it is poor, but usually the variation in the flame is so slight that the second observer is not necessary.

Drafts: In using the pentane lamp, besides providing good ventilation in general, one must be especially careful not to have drafts blowing over the lamp. With open flames drafts must be avoided simply because they disturb the flames; in the case of the pentane lamp the flame is fairly well shielded, but the drafts may affect the temperatures of the various parts enough to cause variation in the air circulation and hence in candlepower.

When the lamp is not in use, both cocks of the saturator should be kept closed, and a cap should be placed over the burner to prevent injury to it or the collection of dust in the passages. All parts should be kept well blackened.

(3) *Hefner Lamp.*—The Hefner lamp has the advantage of simplicity, reproducibility, and portability, in all of which respects it excels other flame standards. Its fuel is a definite compound and is readily obtained and preserved in a sufficiently pure state; but the flame color offers some disadvantage as it is much redder than the ordinary gaslight, being about the color of the candle flame. Other difficulties are its small flame intensity, its unsteadiness, and the uncertainty in setting the flame height.

This lamp is seldom used in this country, but it is an excellent substitute for candles. A Hefner lamp and its fuel are as readily portable as candles and a candle balance and the flame colors are about the same. Both the precision and the accuracy obtainable are greater with the Hefner than with candles, but the accuracy obtained is largely dependent upon the skill and care of the operator. With proper manipulation the Hefner lamp is almost, if not quite, as accurate as the pentane lamp; but to attain the same accuracy greater care is required with the Hefner.

There are two forms of Hefner lamp used, the first with a simple sight for adjusting the flame height, the second with a Krüss sight. The latter form permits somewhat more accurate adjustment, and it is much easier to use.

The fuel for the lamp is amyl-acetate. It should conform to the following specifications:

1. The specific gravity must be between 0.872 and 0.876 at 15° C.

2. When distilled (in glass) at least nine-tenths of the amyl-acetate should pass over between 137° and 143° C.

3. The amyl-acetate must not strongly redden blue litmus paper.

4. It should mix without turbidity with an equal volume of benzine or carbon bisulphide.

5. One cubic centimeter shaken with 10 cubic centimeters of 90 per cent (by volume) alcohol and 10 cubic centimeters of water should give a clear solution.

6. A drop should evaporate from white filter paper without leaving a grease spot.

For exact work the fuel should satisfy all of these conditions; but for ordinary use a sample of amyl-acetate obtained from any reliable dealer, with the understanding that it is for photometric use, should be satisfactory. In any case the fuel should meet tests 1 and 3, which are easily applied.

The lamp is operated as follows:

Before lighting the lamp one should see that the air holes beside the wick tube are open. The top of the wick must be cut off smooth and flat, and when saturated with amyl-acetate must move up and down readily without displacing the wick tube. The height of the latter and the position of the sighting device must be tested from time to time by means of the control gage.

The lamp should burn at approximately the proper height at least 10 minutes before measurements are begun. It is desirable to have the temperature of the room between 15° and 20° C. Variation of temperature has no known appreciable effect on the intensity, but high temperature very seriously affects the steadiness of the flame.

In setting the flame with the Hefner sight, according to the inventor's directions, the bright center of the flame should appear, when one looks through the flame toward the sight, to play against the bottom of the flat plate. The faintly luminous tip of the flame will then almost coincide with the thickness of the plate; by close inspection one will be able to see a glimmer of light up to about 0.5 mm above the sighting plate. The edges of the sight toward the flame are always to be kept bright.

It will, however, be found much less trying to the eye to reverse the position indicated and to look through the sight toward the flame. At best there is a large element of personal judgment in applying the directions above. The Krüss optical gage is much easier to use and is likely to give more consistent results. Although there are some objections to the Krüss form when the lamp is considered as a primary standard, this sight is far preferable to the Hefner form for ordinary use.

In the Krüss sight the extreme outer edge of the flame is not visible on the ground glass; consequently the height is to be so regulated that the extreme visible tip of the image just touches the line on the glass. The observer should look perpendicularly at the glass.

The proper setting of the flame height is extremely important, because a variation of 1 millimeter causes an error of 2 per cent in the intensity.

(4) *Elliott Lamp.*—The Elliott kerosene lamp has been used to a considerable extent in this country. It is steady, independent of ordinary drafts, and requires but little attention after it is once adjusted. The color of the flame is good; the fuel is cheap and can be stored without excessive risk. The lamp must be standardized before use; and if a new chimney is used or the screen opening is changed, it must be restandardized. It is particularly suited for use as a comparison standard, being checked frequently against the pentane lamp.

The wicks used may be of any good brand. They should be kept thoroughly dry and should be changed frequently. The oil should be clear, water white, and of low density, since heavy oils generally clog the wick more quickly and also form more of a crust over the top of the wick. The oil ordinarily specified is Pratt's Astral or some other oil of density 49° to 50° Baumé (0.782 to 0.778, at 60° F, referred to water at 60°), but such light oil is seldom found on the market. Oil of density below 0.79 (47.2° Baumé) will usually be satisfactory, and some much heavier oils of western origin are very good. The difference in initial candlepower given by different oils is not great, but in general heavy oils give a redder flame and fall off in intensity more quickly, probably because of the more rapid incrustation of the wick.

Before use the wick must be trimmed to give an even flat-topped flame. The flame is set at a constant height, the top three-eighths of an inch above the opening in the screen. The chimney must be carefully cleaned at least daily, as even a smoky coating not noticeable on ordinary inspection will cause marked lowering of the candlepower. The chimney must always be set with the same side toward the photometer disk as when the lamp was calibrated.

(5) *Edgerton Standard.*—The Edgerton standard is a convenient comparison lamp, but it must be frequently calibrated against a standard of known value. It consists of a Sugg D argand burner with a glass chimney 1¾ inches by 7 inches, surrounded by a brass sleeve. In the sleeve a slot is cut thirteen thirty-seconds inch high and wide enough to show the whole diameter of the flame. The lower edge of the slot is seven-eighths inch above the top of the burner, and when the flame is set to a height of 3 inches the most luminous portion of it is intended to come at the level of the slot. It was originally claimed that the intensity of this part was practically independent of the quality of the gas.

Although this is not true, the variation of intensity with quality of gas is decidedly reduced by keeping the flame at a constant height, and there is a considerable advantage in using only the most luminous portion, because then slight variations in the height of the flame have no marked effect on the intensity. The standard gives between 4 and 7 candles, according to the gas used, and must of course be calibrated against some standard of known value.

This standard may be used for control of works operation, but it makes changes in the quality of the gas produced appear smaller than they really are. If a uniform quality of gas can be supplied to it from a small holder, it is more reliable. It is not suitable for use in official testing.

The flame is usually set at a height of 3 inches; but if the flame is set to give the maximum light obtainable from the kind of gas to be used, greater constancy will result. The burner is set with its center nine-tenths of an inch back of the zero line of the photometer, both for calibration and use.

(6) *Electric Standards.*—In accuracy of value, certainty of performance, and convenience of operation none of the flame standards can compare with standardized electric lamps. By using metal-filament lamps, standards of convenient intensity for gas tests can be operated on portable storage batteries or even with dry cells. While it is necessary to make the electrical measurements with considerable accuracy, the measuring instruments used are so simple in operation that no great degree of skill is required to obtain the necessary accuracy. Various methods of measurement are in use, but in most of them all the operator has to do is to close a switch to turn on the current, and then to slide a contact along a wire resistance until the pointer on the instrument comes to a designated line.

Objection has always been made to the use of electric standards in gas testing, because they do not change with atmospheric conditions as the gas flame and the flame standards do. If the changes are alike in standards and in gas flames, no correction to the measurements need be made for the effects produced on the flames by fluctuations in atmospheric humidity and pressure, whereas in using electric standards such corrections are often of considerable magnitude. These corrections, however, are not difficult to make. The conditions which cause a decrease in candlepower of the gas flame in case of insufficient ventilation of the photometer room are not so easy to measure and correct for, and thoroughly good ventilation is, therefore, extremely important if electric standards are used.

The electric standards deserve a wider use in gas photometry than they have at present, but experience with them has been so limited that it is not possible to say just what form of equipment will prove to be most suitable for that work. Some apparatus already in use has been described,[13] and it is probable that more will come into use as the advantages of the electric standards become more widely known. The Bureau will be glad to learn of any other equipment developed for such use and to cooperate with inspectors or others who desire to obtain electric standards and the accessory apparatus.

(g) **Screens.**—Most gas photometers are provided with a number of screens, but in many cases insufficient arrangement is made to eliminate stray light. If properly arranged, no stray light can enter the sight box and fall directly upon the disk. In order to determine whether this condition has been fulfilled it is only necessary to determine that the disk is not visible from any point when the screens are all in place.

Even with such an arrangement of screens it is well to have the photometer room fairly dark, since the observer's eyes are thus made more sensitive. It is convenient, but not necessary, to have the walls and ceiling painted a dark color; in any case a dull-finish wall and ceiling is preferable to one with a shiny surface

2. JET PHOTOMETERS

The jet photometer has been severely condemned, and it must be recognized that for official testing it is useless; nevertheless if properly operated it may be a useful guide in coal-gas manufacture. The instrument is based on the assumption that the candlepower of a gas bears a definite relation to the height of a flame produced by this gas when burned from a small jet burner. This is approximately true for coal gas and perhaps for oil gas, but is not a correct assumption for water gas.

Two types of jet photometer are in use. In one the flame is set to a fixed height, usually 7 inches, and the pressure necessary to give this height of flame is measured; in the other the gas is supplied at a constant pressure, and the height of flame is measured.

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[13] H. L. Farrar, Gas Age, 32, pp. 407–409 (April 15), 1913; and Sharp and Schaaf, Proc. Amer. Gas Inst.; 1913.

The pressure scale on the first and the chimney of the second of these instruments is marked to read directly in candlepower. The value of these graduations may be checked by comparison with a bar photometer; but in any case the values indicated by the jet photometer must be considered only as comparative results. Thus a rise in the candlepower indication would show that a better quality of gas was being tested, but the numerical values indicated would be of little significance.

3. PORTABLE PHOTOMETERS

In the inspection of gas as carried on by most States no regular candlepower tests will be needed, and in cities where a candlepower regulation is in force a stationary bar photometer will usually be available for tests. The use of a portable photometer will therefore be necessary only in exceptional cases; but since this necessity does sometimes arise, two forms of apparatus of this kind will be briefly described.

So far as the Bureau knows, there is now on sale in this country only one form of portable photometer which has been designed for the particular purpose of testing gas. It is practically a small, closed bar photometer made collapsible, so that it can be carried in a trunk. Photometers similar to this are in use in New York and Massachusetts for traveling gas-inspection work. This outfit is usually provided with a candle balance, but a Hefner lamp can be substituted for this, if desired. The dry meter could also be replaced by a wet meter, but usually the latter will not be needed.

The general directions for the operation of bar photometers given in the previous section can be readily adapted to this form of portable photometer. When carefully used this apparatus will undoubtedly give results which are sufficiently accurate for official testing, though the necessities of its form and the lack of many of the conveniences which can be had on the bar photometers make the use of this instrument less satisfactory than the bar instrument. The results are not quite as certain as those from the latter form, because of the use of a less satisfactory standard than the pentane lamp, which is not portable, and because of the use of a dry meter which may vary somewhat from time to time without opportunity of checking it except at the beginning and the end of each trip of inspection. The apparatus also has the weak points common to all closed bar photometers, that errors may be introduced by insufficient ventilation or by reflections from the walls of the cabinet. In general, in order to obtain good results the operator of such portable apparatus must compensate for the defects of the apparatus by using it with the greatest possible care.

A number of convenient and fairly accurate portable photometers designed primarily for the measurement of illumination have been developed, and although not commonly used in gas testing, there is no apparent reason why they should not be so used. Some of them have a flame as a comparison source, which would obviate the use of corrections for atmospheric conditions; but the greater convenience and certainty afforded by an electric standard lamp in the photometer make its use advisable in spite of the necessity of carrying a storage battery, a voltmeter or ammeter, and a hygrometer to determine the moisture in the atmosphere. All this accessory apparatus can be purchased in very compact form, and the determination of the atmospheric corrections requires little time. (See p. 183.)

In making candlepower measurements with the common type of portable photometer the instrument is set at a fixed distance from the test burner and a photometric balance is obtained by moving a small electric lamp in the photometer to such a position that its light in the photometric field appears of the same intensity as the light from the test burner. The candlepower of the gas flame is then read directly from the scale of the instrument. The photometer is calibrated as a whole by setting it at the proper distance from a lamp of known candlepower, setting the comparison lamp at the point where the scale reads that candlepower, and adjusting the current through the comparison lamp so as to get a photometric balance. The current thus found is then maintained during tests until a recalibration is made. Such recalibration should be made rather frequently, but if care is taken to keep the glasses clean and not to send excessive currents through the photometer lamp, the instrument may be used for several weeks without appreciable departure from correct readings, using the current originally determined.

The photometer itself can be operated without difficulty in a light room, but it is necessary to provide sufficient screening around the gas flame and the photometer tube to make sure that no light except that from the flame enters the tube. A darkened room is, therefore, an advantage.

4. PHOTOMETER ROOM

(*a*) **Construction of Special Room.**—If a well-ventilated room of suitable size is available it may be used for a photometer room; but often it is best to partition off one portion of the laboratory for this purpose. This is often done by building a small room within the larger laboratory. This method secures the advantages of a uniform temperature and good ventilation without excessive drafts; outside light is easily excluded, and the instrument is well protected from laboratory fumes.

The room should have a capacity of 1600 or more cubic feet. For a 60-inch bar photometer a convenient shape is 9 by 15 feet with a 12-foot ceiling; but if a 100-inch bar is used a room 8 by 17 feet is better. When provision must be made to test gas from more than one supply, it is necessary to have one meter for each kind of gas, and an increase of 18 inches in the length of the photometer, and therefore of the room, may be desirable for each extra meter.

A composition board or plaster board is excellent material for construction of the photometer room. The former has the advantage of being light and cheap, but the latter is fireproof and therefore preferable. Either can be nailed directly to a wooden framework.

A simple but very satisfactory room of this sort may be constructed in any position desired at reasonable expense. Plaster board is nailed on the inside of a framework of 2 by 4 inch lumber down to within 4 inches of the floor. A second side layer is put outside the frame for a height of 3 feet from the floor. Air is thus supplied to the room on all sides by passing down between the two walls and through the 4-inch opening at the bottom of the inner wall. Such air inlet should have an area of 10 square feet or more. The ceiling is double over most of the top; but two openings at least 3 feet apart, each 6 inches wide and the length of the room, are left in the inner ceiling and a wider opening between these in the outer. In most cases this last opening must be covered with a ventilating duct leading to the outer air. This air outlet should have a fan to aid the draft unless it leads up to such height as will furnish a sufficient air current. It is often most convenient to arrange a fan for draft and have the ventilation outlet carried to the nearest window. On pages 483–484 of the 1907 Proceedings of the American Gas Institute a more elaborate arrangement of this sort of photometer room is shown.

It is not necessary to paint the walls of a photometer room black, although it is an advantage to have them dark. The use of a few screens properly located prevents any light from the walls entering the photometer. These screens still can be used to advantage, even though the walls are black.

(*b*) **Adaptation of an Ordinary Room.**—If a suitable room for the photometer is obtainable without the construction above recommended, a few special precautions as to its equipment must be observed. The discussion already given of temperature, color of walls, ventilation, etc., would, of course, apply to such a room. The ventilators must be so located that they create no draft directly about the instruments. All walls which are exterior walls of the building may with advantage be lined with some heat insulator to render the temperatures more uniform, since walls which are considerably warmer or colder than the air of the room will cause objectionable drafts. It is desirable to provide the windows with close-fitting opaque shades; shutters are also useful in excluding light. If double windows can be provided, they will be of great assistance in preventing excessive drafts, especially in cold or windy weather.

(*c*) **Effect of Atmospheric Conditions.**—*Draft.*—It is often erroneously supposed that if a flame is so shielded as to prevent flicker the bad effect of a draft is eliminated. The irregularity of temperature due to air currents is often appreciable, and the influence of strong upward air currents about a flame other than those produced by the flame itself may be serious even if no flickering is appreciable. An example of this is the change of candlepower of a pentane lamp when a horizontal current of air cools the outer chimney or when an unusual upward air current surrounds the lamp. Such drafts may cause the flame to become more slender, and hence to have a smaller luminous area exposed to the photometer.

Ventilation.—An inadequate supply of fresh air will permit an undue increase in the water and carbon dioxide content of the air in the photometer room and a decrease in the proportion of oxygen. The presence in large amount of water vapor or carbon dioxide materially reduces the luminosity of a flame, as does a deficiency in oxygen. If the gas flame and the standard of light were always affected in equal degree, no error would result. The difference in effect on the two flames is negligible within certain limits, but it is better to ventilate the photometer room carefully, so as to secure conditions as near normal as possible; when using an electric standard, this is especially necessary.

Atmospheric Pressure.—Fortunately the influence on candlepower measurements of ordinary variation in atmospheric pressure is small, and this change is usually disregarded in the comparison of two flames. Thus a comparison of a gas flame with a flame standard is always made without correcting for any change in the intensity of the light due to change in barometric pressure. The light produced by flames is less at lower barometric pressures, and consequently the actual candlepower of a gas of a given composition is lower at high altitudes; and this is true even when correction is made to a rating based on the consumption of a constant mass of gas per hour, instead of a constant volume. Since the measurements are usually made by comparison with a flame standard which is affected in the same direction, this decrease is largely compensated, and the rated candlepower is only slightly affected by the difference in barometric pressure unless the change in barometric pressure is considerable. In extreme cases it will be necessary to make allowance for the fact that different flames are not affected to exactly the same extent by change of barometric pressure. The following example gives an illustration of this difference. It has been found at the Bureau[14] that at a pressure of 25 inches of mercury the Hefner lamp burned at constant flame height gives 96 per cent of its normal value and the pentane lamp 90.5 per cent, while the Bray No. 7 Slit Union burner supplied with mixed gas of about 20 candles at the rate of 5 cubic feet per hour at 25 inches barometric pressure gives about 70 per cent of its normal candlepower, or 14.0 candles. If calculations are made in the usual way, the pentane lamp being rated at 10 candles, although its actual candlepower is only 9.0, the gas flame which actually gives 14.0 candles will be called 15.5, and when this is corrected for the effect of pressure on volume it becomes 18.6 candles. Hence, gas of quality such that it gives 20 candles at sea level (burning 5 cubic feet per hour) actually gives only 14.0 candles at 25 inches barometric pressure (burning 5 cubic feet per hour at that pressure), but by the current method of testing it is rated at 18.6 candles when using this particular type of burner. With other burners, the results would be different. The results obtained with several different types are discussed in the paper referred to.

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[14] Trans. Illum. Eng. Soc. 10, pp. 843–867, 1915; Bureau of Standards, Scientific Paper, to be published.

Temperature.—Correction of gas-volume measurements for temperature changes can be readily made; but this is the least serious effect produced by variation in the laboratory temperature. If the photometer meter be used at 60° F. on one day and then at 80° F. on the next, the gas passing through it on the second day will pick up large amounts of the gas constituents condensed at the time of previous use unless care is taken to resaturate the water with the gas at the new temperature. The observed candlepower would, therefore, be too high. The reversal of these conditions has the opposite effect. Moreover, it is claimed that the same gas measured at a uniform temperature has a higher candlepower when burned in a warmer room. There is no means of preventing errors from these sources except by regulating the temperature of the room to a fairly constant condition.

It is, of course, essential that the gas be exposed to no lower temperature after leaving the main than that to which it was subject during its travels in the main.

Humidity.—The humidity in the laboratory is widely variable and is not generally subject to control; but it is generally assumed that the gas and the standard flame are affected in an equal degree, and therefore no correction is necessary. Recent investigations indicate that this assumption is justified. The differences between the effects on various flames are small.

5. TAKING OF CANDLEPOWER

(*a*) **Calibration of Apparatus.**—When a photometer is first set up it is desirable to check the measurements between the fixed marks on the photometer table by which the correct relative position of the bar and the flame is maintained. The mark for the center of the bar should lie just half way between the lines drawn between the pair of marks at each end of the table, and these two lines should be parallel. When once checked these marks can be used indefinitely without further checking.

The disk and the pointer on the sight box should be in a single plane at right angles to the bar. Occasional examination should be made to see that this condition exists, as the pointer may become bent by accident and thus indicate incorrect values, even when the setting of the disk is correct.

The calibration of the standard lamp, if Hefner or pentane lamp is used, should be done by the Bureau of Standards or some other standardizing laboratory. Different lamps have been found to be considerably different in light value without varying appreciably from the specifications indicated above, so that preliminary calibration is desirable. The Elliott lamp may be calibrated by comparison with a pentane lamp or with candles, the former being much better. When a new chimney is used or the opening in the screen is changed, a recalibration is necessary. The Edgerton standard requires very frequent checking. Candles are not subject to calibration, but if made by reputable makers by standard methods will usually be satisfactory within the limits indicated in the earlier section.

The meter used to measure the gas must be calibrated. The several methods used for this calibration are described on page 28. The precautions to be observed and the methods to be employed in the adjustment and use of wet meters have been considered on page 27.

(*b*) **Procedure for Each Testing.**—The following outline is based on the assumption that the pentane lamp is to be used as the standard light. If a Hefner lamp, an Elliott lamp, an electric standard, or candles are to be employed, paragraph 1 of the procedure should be omitted and paragraph 5 changed to suit the standard employed. Directions for substitution in paragraph 5 will be found under the description of the several standards.

1. If the saturator is less than one-third full, fill it so that the fuel level is two-thirds of the way up the window. This must be done when no flames are burning in the photometer room.

2. See that gas meter is level and then with inlet and outlet open to the air adjust the water level to the correct height. An error of one-sixteenth of an inch in water level will cause a discrepancy of about 1 per cent in the gas measurements, and, therefore, it is evident that the adjustment must be very carefully made. No water should be left in the funnel after the adjustment is completed.

3. Open the gas connections and allow the meter to revolve about a quarter turn, then stop the gas flow by placing the finger over the slit of the burner or by slipping a small rubber tube closed with a pinch cock or glass plug over the tip. The meter will then remain at rest unless a leak exists between it and the burner outlet. Even a small leak (e. g., one as large as 0.001 cubic foot in 10 minutes) must, of course, be located and stopped. In making this test care should be taken that no dust or dirt gets into the burner tip.

4. Light the gas burner and allow the connections to be filled with fresh gas and the meter to be saturated with this gas for a period of an hour before the test is made. The ventilating fan

should run during this period unless the room is well ventilated by allowing the door of the photometer room to stand open.

5. Examine the pentane lamp to see that it is vertical and that the inner chimney is centered at the correct height above the burner. (See p. 106.) Light the lamp after the gas has burned for 40 minutes. During the first few minutes of burning, it is desirable to adjust the flame height frequently; but when the lamp has become fairly steady, it is only necessary to readjust it occasionally until the test is begun. During the test it is usually unnecessary to change the adjustment unless insufficient time for equalization has been allowed before beginning the observations.

6. See that the bar, the gas flame, and the standard lamp are correctly located, judging by the plumb bobs; that the gas flame has its broad side parallel to and at the same height as the disk; that the standard flame is at the height of the disk and the small conical shield opens directly toward the disk; that all screens are properly placed, so that no light may reach the disk by reflection, but no part of either flame is shut off; and that the disk and mirrors are clean.

7. Close the photometer room door and darken the room about five minutes before beginning the test. During this last few minutes all movement about the room should be such as to avoid as far as possible creating drafts, and the observer should avoid looking directly at either of the flames. A smoked or colored glass may be used to protect the eyes during the final setting of the flames as required by paragraph 9, so that the eyes will be more sensitive when observations are begun.

8. Adjust the rate of gas consumption so that it is within 1 or 2 per cent of 5 cubic feet per hour. By using a U gage to indicate the gas pressure at the burner and determining the pressure difference which gives the correct gas rate, the proper rate can be secured quickly by adjusting to this pressure. If a one-twelfth cubic foot meter is used, one revolution should require between 58 and 62 seconds; but for a one-tenth cubic foot meter between 70 and 75 seconds is required.

9. Make a final adjustment of the standard flame, start the stop watch as the gas meter hand passes zero, and the apparatus is ready for observations.

10. Make observations as follows: The sight box is moved back and forth through a diminishing range past the point of equal illumination until stopped at the point where the disk appears to be equally illuminated by the two flames. Settings should be

made quickly, as greater accuracy will result by taking a larger number of readings made in rapid succession than by a smaller number, each made after deliberate setting, even though the former series may be more discordant. Difference in color should not be mistaken for difference in intensity.[15] Each setting should be made without reference to previous settings. The observer should attempt to neglect any impression as to the appearance of the disk or the location of the sight box on earlier observations, each single comparison having thus an independent value. After each group of five readings the disk should be reversed and a total of 20 to 30 settings made in a period of 10 minutes. Setting once each minute, as often recommended, is not as satisfactory nor as accurate as the plan of more rapid observation with a larger number of values from which to take the average. Each reading [16] should be recorded as soon as made and none may be discarded, even if widely discordant. *All or none of the settings should be accepted and averaged.*

11. The readings should be completed within 10 or 11 minutes, so that the stop watch may be stopped when exactly 1 cubic foot of gas has passed. It is not necessary to take the rate of gas flow during the test as above indicated; it may be determined by timing the meter registration over a shorter period just before and just after the period in which observations are made. This latter plan is preferable when candles are used as the standard and the stop watch is required to check their rate of burning.

12. Determine the temperature of the meter and the barometer height and record in the corresponding blanks on the test record.

13. Calculate the corrected candlepower from the experimental data. (The standard and gas may well be left burning for the few minutes required to make this calculation, so that if a second test is needed they will be ready for such use.)

(*c*) **Recording of Data and Calculations.**—A card 5 by 8 inches is well suited for the candlepower record, as it is of convenient size,

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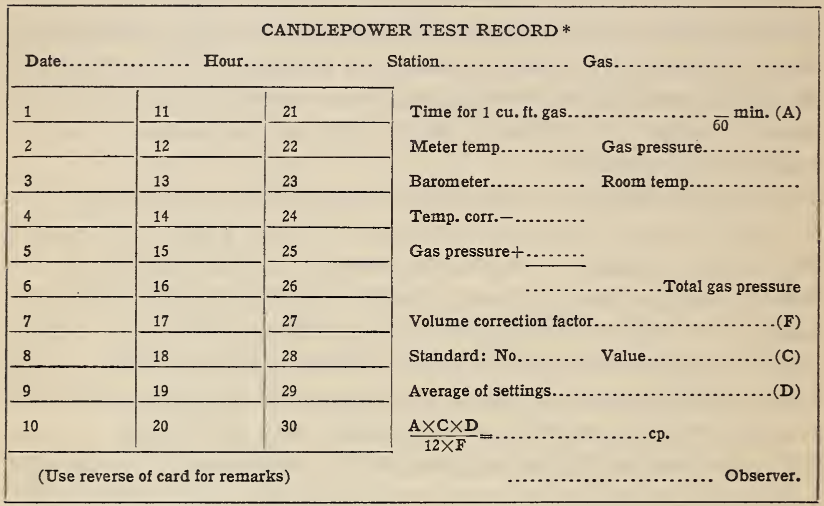
[15] Usually in gas photometry there is an appreciable difference in color between the lights to be compared, This causes some difference between the photometric settings of different observers which is not eliminated by the method described above. In order to make sure that a given observer has normal color vision and that his settings are not materially different from those of the average man, comparative settings should be made with other observers. When a proper method of setting is used the difference between observers due to difference in color perception is usually small. More serious errors arise from an incorrect method of judging the photometric balance. It should be remembered that in all cases the proper setting is that which makes the two sides of the disk equally bright. In the case of the star disk, for instance, the star will seldom disappear, but will usually appear either light on a dark background or dark on a light background. The proper setting is obtained when the relative brightness of star and background is the same on both sides of the disk.

[16] To read each setting of the photometer a special light is needed. A small hand flash lamp or a 2-volt glow lamp with a dry cell is convenient; but a hand mirror may be used by holding it so as to reflect the light from either flame onto the pointer.

and when filled out it can be filed in a standard filing cabinet. A form for the candlepower test is suggested in Fig. 5. In entering the figures in the record indicate: Meter and room temperatures to the nearest five-tenths of a degree Fahrenheit; barometer to the nearest hundredth inch; time to the nearest second; each setting to nearest hundredth candle when made at a point near the graduations 1.0 or 2.0, but to the nearest tenth if the readings are near 10 or greater.

The entry of date, hour, station, and kind of gas can be made just before the beginning of observations; each observation should be recorded as soon as made; and meter temperature, room temperature, barometer, and gas pressure read and entered on the record at once at the close of the period when the time for burning 1 foot of gas has been observed. This time is usually the time required to burn the cubic foot of gas which is consumed during the period when observations on the photometer are being made. Having these entries complete on the record, it is only necessary to make the indicated calculations from the test data.



CANDLEPOWER TEST RECORD*

Date.................. Hour.................. Station.................. Gas.................. ......

1	11	21
2	12	22
3	13	23
4	14	24
5	15	25
6	16	26
7	17	27
8	18	28
9	19	29
10	20	30

Time for 1 cu. ft. gas.................. $\frac{—}{60}$ min. (A)

Meter temp............ Gas pressure..............

Barometer............. Room temp...............

Temp. corr.—..........

Gas pressure+........

..................Total gas pressure

Volume correction factor..........................(F)

Standard: No......... Value..................(C)

Average of settings...................................(D)

$\frac{A \times C \times D}{12 \times F}$=....................cp.

(Use reverse of card for remarks) .... Observer.

*If an electric standard lamp is used, blanks should be provided for recording the "Room humidity" and "Correction factor for standard."

FIG. 5.—*Candlepower test record form*

From the table given on page 198 the temperature correction of the barometer reading can be determined; and the correction for the pressure above atmospheric of the gas when metered is also made. Having thus calculated the total gas pressure and knowing the meter temperature, the gas factor, F, can be determined by table such as given on pages 190–191. This factor is the number by which the observed volume must be multiplied to reduce it to the conditions usually taken as standard for the gas measurement. The method of correcting gas volumes is described in full on page 74.

Now having the factor to the third decimal place, the time to the nearest hundredth of a minute, the average of settings to the nearest five-thousandths of a candle if pentane standard, or nearest five-hundredths if Hefner standard, and the value of the standard expressed to nearest five-hundredths or nearest five-thousandths, according as pentane or Hefner standard, the candlepower of the gas is calculated by the formula given on the record chart.

The result should be calculated to the nearest tenth of a candle. The hundredths of a candle are not significant and there is no advantage in expressing the value further than the nearest tenth; in fact, it is often misleading to do so. (See below for the significance and interpretation of the testing results.)

If candles are used for the test, the line "Standard: No. —, Value — (C)" should be changed to read: "Time for 40 gr. sperm . . . . . . min. . . . . . . sec. = ... min. (C)"; and the calculation becomes:

$$\frac{5 \times A \times D}{3 \times F \times C} = \text{......candlepower.}$$

The back of the record card should be used for remarks, and any irregularity which might affect the result of the test should be recorded.

6. INTERPRETATION OF RESULTS

The interpretation of candlepower results may have either of two objects: First, the determination of regularity of works operation or fixing of cause for irregularity; or, second, the determination of compliance or noncompliance with a technical regulation as to the quality of the gas. It is only the latter which is considered here, since it is clearly outside the function of this circular to discuss the manufacturing or works control processes.

The candlepower calculation is often made to the second or even third decimal place. It should be recognized that the candlepower calculation, when a flame standard or a gas flame is involved, should usually be carried no further than to the nearest tenth of a candle. As a matter of fact, the tenths of a candle are significant only when very careful work is done, or when several independent determinations are averaged. This does not apply to the calibration of a standard whose value is one or two units such as the Hefner lamp, for in this case the value to the nearest hundredth of a candle may be significant.

If the candlepower determined by the first test fulfills the specification no further test need be made; but if the first value obtained indicates that the gas is below standard quality, a second test should usually be made at once. The second test in such case should usually duplicate the result of the first within a half candle; and unless some irregularity of testing method is interfering a duplication within two or three tenths of a candle may be expected on such tests made without change of operating conditions. The purpose of the second test, which will require only 15 or 20 minutes additional, is to insure that no large error of observation has been made in the first test.

If both tests thus made indicate a deficiency of candlepower, all parts of the testing apparatus should be examined carefully to see that the position and adjustment of each is correct. If such inspection of the equipment shows no irregular condition, a new setting of flame height, of rate of gas burning, etc., should be made, and a third test performed. If the third test agrees with the first two the average of all, expressed to the nearest tenth of a candle, may be taken as the measure of the quality of the gas being supplied to the photometer.

If the above three tests are discordant the cause of the irregularity must be located and removed, and a new test then made to give the value of the gas for the day in question. If two of the tests agree and are above the standard, it is usually necessary to consider the gas of a quality to satisfy the requirement even though the third value may be enough below to make the average below that required.

If penalty is to be assessed upon the candlepower of the gas for a single day, it is desirable to make a second group of tests (from two to five series of observations) after some time has elapsed from the first series which showed a deficiency in quality. Two series made as much as four or six hours apart and each showing a material deficiency in candlepower may be taken as showing that the gas for the day was below standard. However, the uncertainties of the candlepower test and the necessary irregularities in works operation make it desirable to allow a tolerance on a single day of one or two candles below the average required. (See Circular 32, pp. 22 and 44.) As has been recommended by this Bureau, a monthly average candlepower is a much better requirement on which to base penalties. In any case if the average of the results of the tests for one day indicates a deficiency of only a few tenths or even one-half candle, it is questionable whether penalty should be assessed, if for no other reason than because the errors of measurement are liable to be of this magnitude. However, if such deficiency is regularly found, it should not be considered due to experimental error unless this can be proven.

When the values for a month are averaged, at least 20 daily values are needed to represent fairly the gas quality for the month. The average of this number of daily values can be taken as representing the real average value for the gas supplied to the test station for the whole period, and a deficiency of more than one-tenth of a candle indicated by the average can usually be considered as a real deficiency in the quality of the gas.

When candles are used as a standard greater irregularities of results may be found, and, in general, an individual test thus made is less reliable than one in which a pentane or Hefner lamp is employed. Similarly, results obtained with a portable photometer are somewhat less reliable than those obtained on an open-bar stationary instrument. Nevertheless, in most cases the exercise of reasonable care will give results sufficiently accurate to be used for official purposes. The proposals for regulation of candlepower of gas given in the circular on gas-testing regulations take into account the possible discrepancies in testing method. The values required are low enough to allow for both manufacturing and testing irregularities.

It is necessary, even though no deficiencies be found, to make a thorough periodic examination of all apparatus and method in order that no regular error may persist. Such inspection is more valuable if made by some one other than the regular observer.

E. DETERMINATION OF IMPURITIES

Official inspection will usually require methods only for the detection of hydrogen sulphide and the determination of total sulphur and ammonia. In addition to these impurities it is at times desirable to determine carbon disulphide, naphthalene, and tar; but these latter determinations will not be described in the following sections, as they are employed only for works control.

1. HYDROGEN SULPHIDE

For the examination of illuminating gas it is ordinarily not necessary to determine the amount of hydrogen sulphide present, the proof of the presence or absence of the impurity being sufficient. When it is stated that a sample of illuminating gas contains "no hydrogen sulphide" it is usually meant that there is less of this substance present than can be detected by the method of examination employed. It is thus quite essential that the methods of test be carefully defined in order that the significance of the result shall be apparent.

The presence of any large amount of hydrogen sulphide in a gas mixture would, of course, be revealed by its characteristic odor; but it is not often possible to detect by this odor such small amounts as may be present in illuminating gas which has been almost wholly purified by the ordinary works procedure, although a number of careful inspectors claim the ability to do so. Certainly with gas which has been enriched by oil, the odor of a sample entirely free from hydrogen sulphide might be misleading because of the similar odor of the more complex sulphur compounds likely to be present.

For the detection of hydrogen sulphide, a piece of white paper moistened with a solution of lead acetate is most frequently used. The following method, which is sufficiently sensitive for the detection of undesirable amounts of hydrogen sulphide, but not so delicate as to be impracticable, has been selected as being most satisfactory for ordinary inspection purposes. Whenever the law governing the testing makes any specifications as to the procedure to be followed, such specifications should, of course, be observed in preference to the following:

Method of Test Recommended.—A strip of white filter paper is dipped in a solution containing 5 per cent by weight of lead acetate, the excess solution being removed from the test paper with a blotter. This paper while moist is exposed for one minute (see the following paragraph) to a current of the gas flowing at the rate of approximately 5 cubic feet per hour in an apparatus of the form described below, or other similar apparatus. The gas may be considered free from hydrogen sulphide if the paper thus exposed is not distinctly darker than another paper, moistened with the same solution, but not exposed to the gas.

The length of time during which the test paper is exposed to the gas determines very largely the severity of the test. One minute may not be the proper period for the test under all circumstances, but, in general, this length of time gives a test of satisfactory commercial significance if the apparatus recommended below is used. If the Referees apparatus is used, the test should be extended to three minutes to make it comparable with the one-minute test in the simple apparatus recommended. In some cases, where particular difficulty in purification is met, it may be desirable to reduce the period of test to one-half minute when using the tester recommended. However, this will rarely be necessary, since purification sufficient to permit the gas regularly to be passed by the test in one-half minute will usually also be sufficient to meet the test of one minute. Of course, in any case where the rules or law specifies a definite test period, such regulation should be observed. These questions are fully discussed in Technologic Paper No. 41 of this Bureau.


Fig. 6.—*Simple hydrogen sulphide tester*

The form of apparatus recommended for this test is shown in Fig. 6. It is simple, inexpensive, and may easily be made from material ordinarily available in any laboratory. It is made from a cylindrical gas chimney 8 inches long and 1¾ inches in diameter. The pillar of a gas burner from which the lava tip has been removed is inserted through the lower stopper; and a small watch glass, 1 to 1¼ inches in diameter, is supported above the pillar to prevent the gas from impinging directly on the test paper. The watch glass may be supported on three glass pegs, ½ to 1 inch high, being held in place with small bits of wax. The gas is burned from an ordinary open-flame burner on the upper stopper; this burner should be so selected that it will pass 5 cubic feet of gas per hour at the ordinary pressure of the gas supply. The test paper is hung on a glass hook so that it is held midway between the watch glass and the bottom of the upper stopper. This apparatus may be attached permanently to a wall bracket; or a Bunsen burner may be inserted through the lower stopper in place of the pillar, so that the apparatus can conveniently be attached at any outlet with a rubber hose.

The apparatus specified for this test by the London gas referees and another form known as Young's sulphur and ammonia test apparatus are often used in this country; but the price of these more elaborate forms is $20 to $25 and there is no compensating advantage attending their use. The Referees apparatus gives somewhat variable results and both forms are inconvenient to use.

There are several departures from the procedure recommended which would materially affect the sensitiveness of the test. The test is more sensitive when made with moist lead-acetate paper than with dry paper; but with dry paper the results obtained are somewhat irregular, depending upon the humidity of the gas. Changing the strength of the lead-acetate solution has little influence on the result of the test unless the concentration is reduced considerably below that recommended. It has been customary to use a 6.5 per cent lead-acetate solution, but this gives no different results than a 5 per cent solution; and the latter has, therefore, been adopted for sake of simplicity. The 6.5 per cent solution was originally adopted to correspond with the English practice which prescribes a solution containing 100 grains of crystallized lead acetate dissolved in 100 cc of water. Large variations in the rate of gas flow, of course, affect the sensitiveness of the test; however, any rate between 4.5 and 5.5 cubic feet per hour is satisfactory. The form and size of the apparatus used affect the depth of coloration produced, the test being more sensitive when the gas impinges on the paper or when a larger proportion of the gas comes in contact with the paper. Continuing the test for a longer period of course makes it more sensitive. None of these modifications of the procedure is recommended.

The effect of these and other variables upon the sensitiveness of the test and the relative sensitiveness of the test when made in different forms of apparatus are fully discussed in Technologic Paper No. 41 of this Bureau.

2. TOTAL SULPHUR

The methods for determining total sulphur in gas are of various kinds; but only those methods are suitable or are commonly used for official gas testing in which the gas is burned with an excess of air in a Bunsen type of burner, the sulphur oxides in the products of combustion are condensed and oxidized to sulphate, and the sulphate is determined by one of the ordinary volumetric or gravimetric procedures.

Of the apparatus for methods of this group only the Referees, the Hinman-Jenkins, and the new model of the Drehschmidt type recently devised in the laboratories of this Bureau are recommended. Each has its peculiar advantages, and it is not possible to combine all of these in any one composite apparatus, nor is one of the three superior to the other two for all purposes.

For use in traveling inspection work the Hinman-Jenkins apparatus is most convenient, since when taken down it can be packed in a very small case and is then easily portable. It is also somewhat more satisfactory than the Referees in that the condensation of sulphur by the ammonium hydroxide used in it seems to be more certain and perfect than by ammonium carbonate. However, this advantage is lost unless fresh ammonia is added frequently (every 20 to 30 minutes), a condition which makes this apparatus less convenient than the Referees, since it can not be left to run unattended for such long periods as the latter.

The Referees apparatus is most often used in gas testing in this country, and on this ground alone has some advantage for official use, since a result obtained with a form of apparatus in very general use is more generally accepted than a result from apparatus not so well known. This general use of the Referees apparatus has been justified by its simplicity, convenience, and accuracy; and, although the accuracy obtainable with this as well as with other forms has often been overestimated, yet the results are quite satisfactory for all commercial or official work if reasonable care is observed in the selection and operation of the instrument.

The Bureau of Standards form is the only one that can be used with accuracy in a room where the air is contaminated with sulphur from other burners or from any other sources, since it is the only one which permits the purification of the air entering the apparatus. It is also more reliable in the collection of sulphur oxides formed, and is consequently to be preferred in every case where the highest degree of accuracy is desired. It is possible to burn the gas at a much more rapid rate and to complete a test in a shorter time than with the other forms. On the other hand, since it is unnecessary to renew the supply of alkali, it may be left running for many hours without attention. The disadvantage of the apparatus is that it requires a considerable amount of accessory apparatus, viz, a battery and induction coil, three gas wash bottles, a soda lime tower, and a jet pump or some other means of producing suction.

(*a*) **Forms of Apparatus.**—*Referees Apparatus.*—The apparatus recommended by the London Gas Referees, and the one most commonly used in this country, is illustrated in Fig. 7. It may be described as follows:

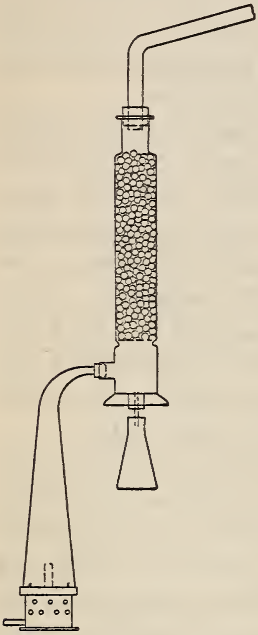


Fig. 7.—*Referees sulphur apparatus*

The gas is burned in a small Bunsen burner, which is mounted on a short cylindrical stand perforated with holes for the admission of air, and having on its upper surface, which is also perforated, a circular channel to receive the wide end of a glass trumpet tube. On top of the stand, between the stem of the burner and the trumpet tube, are to be placed as many pieces of crystallized ammonium carbonate as will conveniently lie in place.

The products both of the combustion of the gas and of the gradual volatilization on the ammonium salt go upward through the trumpet tube into a glass cylinder with a tubulure near the bottom. From the contracted part to the top the cylinder is packed with glass marbles, about 15 millimeters in diameter, to break up the current and promote condensation. From the top of this condenser proceeds a chimney tube, serving to effect some further condensation as well as to regulate the draft. In the bottom of the condenser is fixed a small glass tube, through which the liquid formed during the test drops into a flask placed beneath. The lower end of this tube is contracted, so that when in use it may be closed by a drop of water. If the tubulure and trumpet tube are about the same size, Fig. 8a shows the simplest method of connection; if the trumpet tube is considerably smaller than the tubulure, as is the case with the apparatus sold by some makers, connection can be made as in Fig. 8b. The use of a rubber connector, as illustrated in the "Notification" of the London referees, or substitution of rubber for cork in either form of Fig. 8, is not desirable.

It is best to allow the small glass outlet tube at the base of the condenser to project slightly above the rubber stopper which holds it, in order that the stopper may be protected from the hot gases by a layer of liquid.

A perforated lead plate, to be used at the bottom of the condenser as a support for the glass marbles, is furnished with the apparatus by some dealers. This should be replaced by a porcelain or glass plate or by a support made of glass rod bent to S shape. The lead plate would always be likely to cause errors in the determination of the sulphate, and would certainly do so during the first few runs while a film of lead suphate was forming over the metal surface. When setting up the apparatus it is best to fill the condenser cylinder with water, so that the marbles may be dropped in without danger of breaking it.

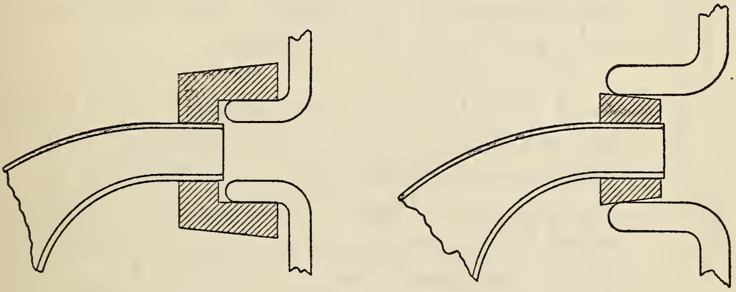


FIG. 8a FIG. 8b.

Connection of trumpet tube and condenser in Referees apparatus

Hinman-Jenkins Apparatus.—The apparatus, known from the names of its inventors as the Hinman-Jenkins form, is illustrated in Fig. 9. It is described by Jenkins in the following words:

> The upper vessel is a "bead glass" 300 mm long and 60 mm in diameter; this is filled with large cut-glass beads, held up by a suitable fluted glass, giving a large condensing surface without obstructing the draft. To this bead glass is attached, by a rubber connector, the adapter, 410 mm long and 50 mm lower internal diameter. To the upper adapter is attached, by means of the "connecting piece," the lower adapter, 400 mm long and 40 mm lower diameter. The connecting piece projects 12 mm above the top of a rubber stopper, fitting the upper adapter, and is surmounted by a watch-glass deflector carried on platinum wires. An overflow tube carries the condensation to the Erlenmeyer flask hung on the stopper, as shown; this tube is so adjusted that some liquid remains on the stopper to keep it cool and to absorb some of the ascending gases. The Bunsen burner is fitted with a lava tip having a 5-mm hole; surrounding the burner is a glass tube 20 mm in diameter, forming the inner wall of an annular chamber, of which the outer wall is a glass ring 50 mm in diameter. Into this chamber, which serves to contain 10 per cent ammonium hydroxide, the lower adapter dips 10 mm.

The lower adapter is joined to the connecting piece by a short, cork-like lined metal tube.

The Bureau recommends that the original form be followed exactly, since this has been found by work at the Bureau, as well as by several State insepctors, to be very satisfactory. However, it would be preferable to have the beads used in the condenser solid and not perforated, since the washing of the latter form is necessarily less efficient; and the bead jar should be filled to within 1 inch of the top with these beads (it is often only half filled). The burner should give a blue flame with sharply defined inner cone, and when burned at ordinary pressure (1.5 to 2.5 inches of water) should pass about 0.5 cubic foot of gas per hour. The proper adjustment of the burner is important, since otherwise error may result from leakage of the gas from the air holes at the base of the burner.

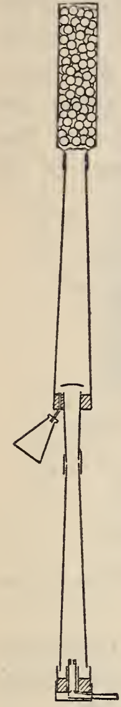


FIG. 9.—*Hinman-Jenkins sulphur apparatus*

Elliott Apparatus.—The new form devised by Dr. A. H. Elliott has not been fully described by him in any publication, only a brief reference to it being found in Baskerville's Municipal Chemistry (p. 319). In Technologic Paper No. 20 is shown the form preferred by the originator, as given to the Bureau in a private communication. A porcelain Bunsen burner, with a perforated porcelain plate near the top, supports pieces of ammonium carbonate. A trumpet tube resting on the plate conveys the products of combustion mixed with ammonia to the top of the first condenser (a 24-inch calcium chloride tower). The tubulure at the bottom of this cylinder is connected with that of the second cylinder of the same kind. Glass tubes drawn down to small tips are fitted into rubber stoppers in the bottom of each tower, allowing the condensate to drip into flasks placed beneath. The principle and general form of the apparatus is similar to that of the Referees. The procedures for setting up and operating the Elliott apparatus will be evident from the directions given for the Referees form; they are also given in Technologic Paper No. 20.

When the gas is burned at 1 to 1.2 cubic feet per hour in the Elliott apparatus it is possible to get a full test within one and one-half or two hours of the beginning of the test; but it requires a larger bulk of wash water than the forms recommended, and it is also rather large and clumsy. The increase in size over the Referees form is a distinct advantage if a rapid rate of burning of the gas is desired, but it is not at all certain that in the end any time is gained by this increase in rate, since the evaporation of the solutions to the proper bulk is a slow process.

Bureau of Standards Apparatus.—The sulphur apparatus which is shown in Fig. 10 is the same in principle as the well-known Drehschmidt apparatus and its many modifications; the gas is burned in a burner of the Bunsen type and the oxides of sulphur are collected by passing the products of combustion through an alkaline absorbing solution. The novel features of the apparatus illustrated are the burner and the combustion chamber.

The entire apparatus consists of pressure regulator, U water gage, meter, sulphur apparatus, wash bottles, and jet pump, connected in the order named; and soda-lime tower for the purification of the air, and battery and spark coil, connected to the burner.

The burner is a porcelain tube of 3–4 mm internal diameter. The gas is ignited by an electric spark between platinum terminals, which are soldered to nickel leads, in order that only a short length of platinum wire will be needed. One of the leads is placed within the burner tube, its lower end being brought out through a small side tube which is sealed to the glass tube just below the rubber stopper; the wire can be held in place and the opening closed by sealing wax. The terminal outside is wired to the porcelain burner tube. The platinum wire becomes heated by the flame and thus reduces the likelihood that the flame will be extinguished by fluctuations in gas pressure. This igniter therefore eliminates the principal difficulty both of lighting and of regulating the burner which is experienced with apparatus of this type.

The stopper which closes the lower end of the combustion chamber also serves as a connector, the porcelain burner tube and the glass T piece being firmly fastened into it by means of Khotinsky or sealing wax. The small tip through which the gas enters just above the primary air inlet is also held in with Khotinsky cement. The tip can be easily removed for cleaning, or tips of various sizes adapted to the gas to be burned can be inserted. The air necessary for complete combustion after being purified by passage through the large soda-lime tower is supplied to the flame in two portions. The primary air is drawn in by the gas as it passes through the small tip; the secondary air enters through the two inlets at the side of the combustion chamber.

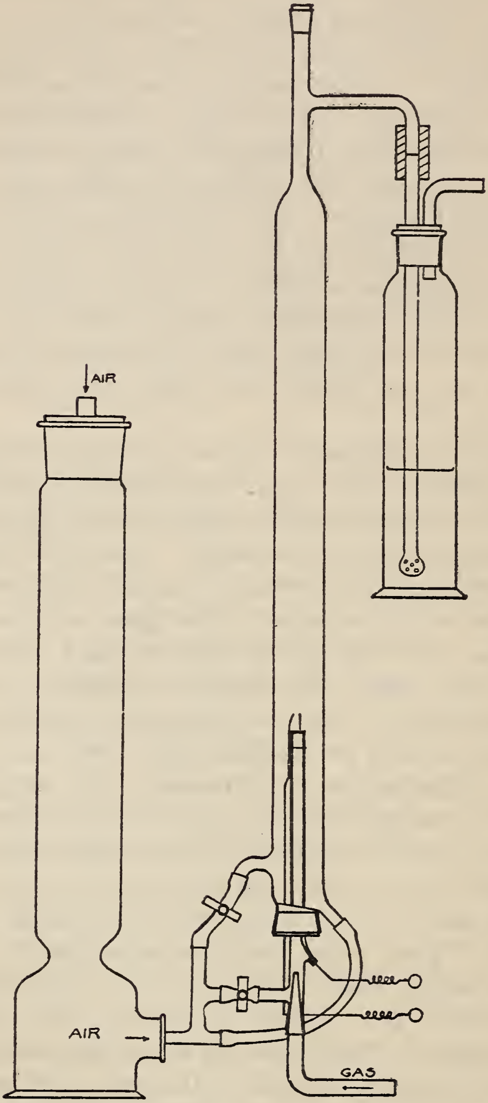


FIG. 10.—*Bureau of Standards form of sulphur apparatus*

The combustion chamber, made of Jena glass tubing, is about 360 mm long and about 25 mm in internal diameter. The narrow tube at the top may be used for introducing water when it is desired to rinse out the apparatus; when in operation this tube is closed with a small cork. Satisfactory drainage is provided by the sloping layer of paraffin or sealing wax covering the stopper at the bottom. When the burner is lighted the secondary inlet air keeps the base of the apparatus cool, but the rest of the combustion chamber up to the side tube is heated so that no condensation takes place on the walls. For that reason it is usually unnecessary to rinse out the combustion chamber.

By means of a cork connector the first of a series of wash bottles is attached to the apparatus. Rubber tubing must not be used at this point on account of the danger of introducing sulphur from it; but the wash bottles may be connected to each other and to the suction pump by rubber tubing, which may also be used to connect the air inlets to the soda lime-tower.

Only one wash bottle is shown in the illustration, but three are usually required for satisfactory operation. In order that the suction may pull the gas steadily through the wash bottles it is necessary that the end of the inlet tube of the first bottle be perforated with a number of small holes. With a single, large opening the operation of the burner is not steady. The wash bottles may be of any of the ordinary forms; for example, those illustrated in Fig. 12. Each bottle should contain enough absorbant that the products of combustion will bubble through a depth of 1 to 1½ inches of liquid.

The air is drawn in and the products of combustion are drawn through the apparatus by the suction of a small water-jet pump, or its equivalent. The spark for igniting the gas is produced by a single dry cell and an induction coil of the size rated as giving a quarter-inch spark.

(*b*) **Directions for Setting up Apparatus.**—If the Referees or the Hinman-Jenkins form of apparatus is used, it is necessary for accurate work that it be set up in a room where no other gas is being burned in order that the air entering the apparatus may be free from sulphur. This will ordinarily cause no inconvenience. The apparatus can be readily set up in the office room of the inspector instead of in the chemical laboratory, since a simple gas connection is the only piping needed and the operation of the instrument need cause no objectionable dirt or odor.

The Bureau of Standards form of apparatus may be set up in a room where other gas is being burned, but it must be placed where connection may be made for water supply and drain to permit operation of the suction pump.

The entire apparatus consists of pressure governor, U water gage, meter, and sulphur apparatus, these being connected in the order given. If the gas used for the sulphur test is also used for the ammonia test, the ammonia absorber is connected between the source of gas supply and the pressure governor. For connecting the various parts of the apparatus rubber tubing is not satisfactory for two reasons. First, the rubber can absorb sulphur from or give it up to the gas according to the quantity in the gas and the temperature; and, second, the rubber tubing soon becomes hard and is much more apt to leak than is a metal or a glass tube. It is usually most convenient to make permanent the connections from governor to gage, gage to meter, and meter to burner; these can be of glass tubing with good quality, heavy rubber connections tied on, except the connection of meter to the Referees or the Hinman-Jenkins burner. For the latter it is best to braze or screw a metal tube to the burner inlet (about 6 to 8 inches is a convenient length) so that if the flame strikes back during a test the connection is not broken at the base of the burner and gas allowed to escape or take fire at this point. Especially for long runs, when no one is in the room for a long time during the test, such a connection is much safer than one of rubber.

The meter and governor used may be of either the wet or the dry type. The usual precautions as to leveling and proper adjustment should, of course, be observed. The pressure on the governor should be so adjusted once for all that when the gas is turned on full at the supply cock the burner will pass gas at the desired rate.

For the sulphur and ammonia test a meter which automatically cuts off the flow of gas after passing a certain predetermined volume is often used; but where a short run is to be made, as is recommended, this meter usually has but little advantage. If necessary to leave the apparatus in operation, however, it will be a very convenient form of meter.

The connection between meter and burner, as well as the meter itself, should be frequently tested to show the absence of leaks. Any leaks, even very small ones, may cause appreciable errors in the test, since the rate of gas consumption is small.

(*c*) **Methods of Operation Recommended.**—*Referees and Hinman-Jenkins Apparatus.*—After all connections of the apparatus have been made a test for leaks should be made, the old gas should be removed from the supply line, and the meter should be adjusted. Directions on pages 27–33 will make evident the proper procedure for these operations. The gas should be burned from the apparatus for several hours to saturate the meter and governor water and to purge the connections, a burner which will pass 5 cubic feet or more per hour being substituted for the regular test burner. Before each test the line may be purged in this way by burning the gas for about a half hour.

When the line is thus purged, the regular burner is put in place and lighted; and ammonia or ammonium carbonate placed on the burner. For the Referees apparatus as much ammonium carbonate is used as will find place about the burner pillar, and for the Hinman-Jenkins about 10 cc of strong ammonia solution is used. The ammonium carbonate should be in large lumps which have been freed from efflorescent portions. The gas is burned at one-half cubic foot per hour in the Referees or the Hinman-Jenkins apparatus.

It is usually desirable to rinse out condenser and chimney tubes just before starting the test, in order to prevent dust which might have collected there between tests from contaminating the condensate. This also prevents loss of sulphur from the dry condenser during the first few minutes. When all parts, including the flask to collect the condensate, are in place, the trumpet tube is set over the burner and quickly connected with the condenser, the meter reading being noted at the instant the trumpet tube is put in place. This reading and the time, meter temperature, barometer, and manometer readings are recorded in the test record.

The test can be continued for any desired period, the ammonia or ammonium carbonate being renewed, as indicated below. If the sulphur in the condensed liquid is to be determined by means of a turbidimeter (see a later section of this circular), it is necessary to burn gas in the apparatus only two hours. If the sulphate is to be determined gravimetrically, it is generally desirable to burn at least 2½ or 3 cubic feet of gas for a test. However, there is no need for burning 10 feet, as usually is done, since the gravimetric method is sufficiently accurate on the sulphur from 2.5 feet of ordinary coal gas or water gas to give no error as great as the irregularities of condensation in the apparatus. These are not appreciably lessened by longer runs. The advantage of burning the gas over a long period in order to get a so-called "better average sample of the gas" is much overestimated. With the ordinary uniformity of works operation and a single coal supply, changes in the sulphur content of the gas from day to day are very small. For this reason a short test will usually give as fair a sample of the full day as one taken over a long period.

When it is desired to burn more than 3 cubic feet of gas for a test, it is necessary to replenish the supply of ammonium carbonate in the Referees apparatus. To do this the gas is shut off and the trumpet tube allowed to cool so that it may be handled comfortably. A fresh supply of carbonate is then added, the burner relighted, and the trumpet tube replaced quickly. If more than a very few thousandths of a cubic foot of gas are burned with the trumpet tube off, the amount so burned should be deducted from the total used for the test. A fresh supply of carbonate must be added in this manner after every 3 feet of gas burned in this apparatus. With the Hinman-Jenkins apparatus 2 or 3 cc of fresh ammonia solution is added every 20 minutes, but with this apparatus the flame need not be extinguished, since the ammonia can be run in from a small pipette without disconnecting the trumpet tube.

When sufficient gas has been burned, the supply is cut off and the apparatus allowed to cool. The time, meter reading, meter temperature, and barometer are recorded again at the close of the test. The trumpet tube is then washed once and the condenser four times. Each portion of wash water is 50 cc and is added all at once to thoroughly flush the condenser. Before adding the last two portions with the Hinman-Jenkins apparatus the burner is replaced by a beaker and the drip tube closed by a rubber tube and pinchcock. The water then rinses the inside of the chimney tube. In this way the wash water is kept at reasonable bulk.

The sulphate in the condensed liquid and wash water is determined by one of the methods given in the next section. From sulphate found and corrected volume of gas burned the sulphur content of the gas (in grains of sulphur per 100 cubic feet of gas) is calculated.

Bureau of Standards Form.—Before beginning a determination the apparatus should be adjusted to burn gas at the required rate, not more than 2.5 cubic feet per hour, and to use the proper amount of primary and secondary air. The amount of gas burned should be adjusted by removing the small glass inlet tip from the burner and reducing or enlarging the opening as required. The opening may be reduced by heating carefully in a flame; it may be enlarged by filing back the tip until the required internal diameter is reached. To adjust the air supply the wash bottles are filled with water to the depth of 1 to 1½ inches above the lower end of inlet tubes. The jet pump is then turned on to draw air through the apparatus at a rapid rate, the battery circuit is closed to produce a continuous spark, and the gas is turned on last. This order should be followed every time the burner is lighted. If the gas is turned on before both the air flow and the spark are started, an explosion may result. As soon as the gas has ignited the battery circuit may be opened.

The amount of air entering the burner tube must be regulated rather carefully, so that the flame is entirely nonluminous with a clearly defined inner cone. The amount of secondary air flowing through the apparatus must, of course, be sufficient to give complete combustion. This is assured when the outer cone of the flame is steady and sharply defined. If the outline of the flame appears "ragged" or indistinct, some of the sulphur is certain to escape oxidation. There is little danger of having too much secondary air, but the amount is limited by the capacity of the wash bottles. To insure complete absorption and prevent mechanical loss of the sulphate solution, it is desirable to keep this rate of air flow reasonably low, but it is better to use too much air than too little. The primary air is regulated by the pinch cock on the inlet tube, but the adjustment of secondary air should be made by regulating the jet pump rather than by closing the air inlet.

When these adjustments have been completed a test for leaks should be made, the gas-supply line purged, and the meter adjusted as directed for the Referees form. While the line is being purged the soda lime tower is filled and sufficient 5 per cent solution of potassium carbonate (K_2CO_3), with a few drops of hydrogen peroxide or of bromine water, is introduced into each wash bottle to bring the liquid 1 to 1½ inches above the bottom of the inlet tube.

The burner is now connected to the meter and the meter reading recorded. The suction, spark, and gas are then turned on in order, and pressure and temperature readings are made and recorded. The burner should usually be adjusted to consume about 1 cubic foot of gas per hour. When enough gas has been burned the gas is turned off first; then the valve controlling the jet pump is closed carefully to prevent tap water being sucked back into the wash bottles. The meter, barometer, thermometer, and manometer readings are again recorded. The contents of the wash bottles are transferred to a beaker and the bottles rinsed twice with a little water. It is ordinarily unnecessary to wash out the burner chamber since it is dry at all times and the sulphur is mostly present in the form of sulphur dioxide, which passes on quantitatively. The hot walls prevent the condensation of any sulphur trioxide which may be present. The sulphate in solution is determined by one of the methods given in the next section.

(*d*) **Determination of Sulphate in the Solutions Obtained.**—In all the forms of apparatus described the sulphur is obtained in solution in the form of sulphates, and it is this sulphate which must be determined. The oxidation from sulphites to sulphates is accomplished in the Referees or the Hinman-Jenkins apparatus by the action of the oxygen in the hot products of combustion on the alkaline solution of sulphite formed in the condenser. It is unnecessary to add any oxidizing agent, such as bromine, as is recommended for the solution used with the Bureau of Standards form.

The methods of determining the sulphate which are available for use for this work are of three kinds—gravimetric, volumetric, and turbidimetric. In the following sections four methods are given which have been tried out with solutions of the character obtained from the Referees type of apparatus. Comparisons have shown that they are sufficiently accurate for this kind of work.

For accurate work the gravimetric methods are to be preferred, but for rapid work the turbidimetric and volumetric methods will serve very well, and, unless the test indicates that the sulphur is very near the permissible limit, they are probably sufficiently accurate for official use. The volumetric method is adapted especially for use in State inspection, where a large number of test solutions are collected in the field work and subsequently examined at the headquarters laboratory. In most cases, however, the turbidimeter, which is easily portable, may be carried with the inspector and a test made at the time the sulphate is collected, thus avoiding the necessity of transporting the solutions obtained to headquarters.

METHOD 1. Gravimetric, with Evaporation to Dryness.—Dilute or evaporate the portion of liquid taken for analysis to about 300 cc, add 50 cc of concentrated hydrochloric acid, heat to boiling, then run in 10 cc of 10 per cent barium chloride solution through a tube or from a burette, delivering it at the rate of about 8 to 10 cc per minute, stirring constantly during the addition. After evaporation to dryness on a water bath or steam bath, take up with 75 to 100 cc of hot water, filter through a good, close-grained paper, and wash with hot water until the bulk of the filtrate and washings amounts to 200 cc. In a weighed platinum crucible char the paper with a low Bunsen flame and finally ignite until the precipitate appears white. Cool the crucible in a desiccator and weigh.

The precipitate now contains a small amount of silica, which may cause an error of 0.1 to 0.4 grain per 100 cubic feet in the apparent amount of sulphur in the gas. Bearing this source of error in mind, it is only necessary to correct for it when the amount of sulphur exceeds the legal limit by a small amount. The correction is easily made by moistening the precipitate with a drop of hydrofluoric and then one of sulphuric acid, drying, igniting, and weighing again. The silica is all removed by this operation.

METHOD 2. Gravimetric, Precipitation in Nearly Neutral Solution.—In the more common procedures for the gravimetric sulphate determination, the precipitation of the barium sulphate is made in nearly neutral solution. This method may be used as follows:

To the solution which is diluted or concentrated to about 300 cc add 2 or 3 drops of paranitrophenol or methyl-orange solution [17] and neutralize with hydrochloric acid, adding this solution dropwise, and finally add 2 cc of the 1 : 1 acid in excess. Heat to boiling, add 10 cc of 10 per cent barium-chloride solution, boil five minutes, allow to stand on a steam bath for a half hour or longer, filter, wash, ignite, and weigh the barium sulphate as in Method 1. The precipitation when always made in the presence of a fixed amount of acid is affected always in equal degree by the solubility of the barium sulphate in the acid. Under the conditions given, the loss from this source is negligible for the present work.

METHOD 3. Volumetric.—A number of volumetric methods have been recommended for the determination of sulphates, several of which are suitable for use with the liquids obtained from the Referees and Hinman-Jenkins apparatus. Only one of these, a modification of that recommended by Hollinger,[18] will be described.

The following solutions are required for this method:

(*a*) A solution of sodium thiosulphate containing 15.1 g of $Na_2S_2O_3.5H_2O$ per liter.

(*b*) A solution of barium hydroxide containing 50 g of $BaCl_2.2H_2O$ per liter.

(*c*) A solution of potassium bichromate containing 30.5 g of $K_2Cr_2O_7$ per liter.

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[17] Any other indicator sensitive to ammonia, but not affected by carbon dioxide, may be used.

[18] Zs. anal. Chem., 49, p. 84; 1910.

(*d*) A solution of ammonium hydroxide made by diluting one volume of the concentrated solution (sp gr 0.90) with two volumes of water.

(*e*) A 2 per cent solution of ferric chloride.

(*f*) A solution of hydrochloric acid made by diluting concentrated acid with an equal volume of water.

(*g*) A dilute starch solution.

(*h*) A saturated solution of potassium iodide.

The first three solutions should be made up by carefully weighing the salts and measuring the water, and the thiosulphate should be allowed to stand two or three weeks before use. The strength of the others need be only approximate. The starch solution may be prepared by dissolving a little soluble starch in cold water or by stirring 1 g of ordinary starch into a thin paste with cold water, adding this to 200 cc of boiling water, allowing to settle, and decanting or filtering off the clear liquid, which is the solution used. When tests are made only once a week, as will usually be the case where this method is used in gas-inspection work, it is best to make up a fresh starch solution for each series of tests, though the solution can be kept almost indefinitely if carefully prepared and sterilized. Methods of preserving a starch solution will be found in most books on quantitative analysis.

Before proceeding to determine the sulphur in an unknown solution it is first necessary to make a blank test upon the solutions used and to standardize the sodium-thiosulphate solution by titrating a solution containing a known amount of sulphate. The blank test is made as follows: To 300 cc of water add 10 cc of the 1:1 hydrochloric acid and exactly 15 cc (from pipettes, one of which should be kept for each solution) of the barium-chloride and of the potassium-bichromate solutions; heat to boiling, add two or three drops of ferric-chloride solution, then slowly add ammonium hydroxide until a precipitate forms which does not redissolve on stirring. Add 5 cc of the ammonia solution in excess, boil five minutes, filter and wash thoroughly with hot water. Allow the filtrate to cool, acidify with strong hydrochloric acid, add 2 cc of the potassium-iodide solution (or 2 g of solid potassium iodide), and titrate with the sodium-thiosulphate solution. When the brown color of the iodine has nearly disappeared, add 1 or 2 cc of starch solution and continue the addition of the sodium thiosulphate carefully until the blue color disappears. The amount of thiosulphate solution used in this blank is to be subtracted from the amount used in each subsequent determination.

To make a determination of the sulphate in a solution, dilute or concentrate the sample taken to 300 cc, add 10 cc of 1:1 hydrochloric acid, heat to boiling, add 15 cc of barium-chloride solution from the pipette used in the blank test, boil 5 minutes, add 15 cc of potassium-bichromate solution and a few drops of ferric-chloride solution, precipitate with ammonium hydroxide, and complete the determination exactly as in the blank test. From the amount of thiosulphate solution used subtract the amount required in the blank. The remainder represents the sulphate in the sample taken.

The thiosulphate solution is standardized by treating a solution containing a known amount of sulphur in the manner just described and calculating the weight of sulphur represented by each cubic centimeter of the standard solution. (It will be equivalent to approximately 0.01 grain of sulphur per cc when the standard solution is made according to the directions given above.)

The reactions upon which the method is based are:

$$BaCl_2 + H_2SO_4 = BaSO_4 + 2HCl.$$
$$BaCl_2 + K_2CrO_4 = BaCrO_4 + 2KCl.$$
$$2K_2CrO_4 + 16HCl + 6KI = 6I + 10KCl + 2CrCl_3 + 8H_2O.$$
$$2I + 2Na_2S_2O_3 = Na_2S_4O_6 + 2NaI.$$

The above method was selected in preference to other methods previously used, which have been open to the following objections:

1. In those using a hydrochloric acid solution of barium chromate the reducing action of the acid on the chromate has introduced serious errors.

2. In those which use exactly equivalent amounts of barium chloride and potassium bichromate, it is somewhat difficult to make the solutions of exactly the right strength and a blank test must be made.

3. The use of a suspension of barium chromate or of the solid is less convenient than that of solutions, and since it is sometimes difficult to obtain the barium salt free from alkali chromate a blank test should also be made when the solid is used.

4. In all methods the solubility of the barium chromate should be taken into account.

All these sources of error or difficulty are taken care of by a single blank test, when the chromate solution is slightly stronger than the barium-chloride solution, as in the method described.

The solubility of barium chromate is somewhat affected by the concentration of ammonium chloride and of ammonium hydroxide in the solution; but by having the same bulk of solution, adding the same amount of hydrochloric acid, and precipitating in the same manner in the blank as in the determination, the the effect of this source of error is also eliminated. The use of a small amount of ferric chloride, as recommended by Holliger (loc. cit.), aids greatly in collecting the precipitate of barium chromate and barium sulphate for the filtration.

METHOD 4. Turbidimetric.—The following method is recommended for use if it is desired to employ a turbidimetric procedure:

The condensate and washings from the sulphur apparatus are neutralized with hydrochloric acid,[19] then 2 cc of 1 : 1 hydrochloric acid is added in excess. The solution is measured (to the nearest cubic centimeter) and a 90 cc portion placed in a small beaker for the test. It may be measured in an ordinary graduated cylinder if it is certain that the ratio of the small cylinder to the larger measuring vessel first used is correct. While the solution is at a temperature between 25° and 30° C, 10 cc of a 10 per cent solution of $BaCl_2.2H_2O$ is added and the whole stirred vigorously until the precipitation appears to be complete. (This usually requires less than one minute's stirring.)

The suspension is now poured into the clean and dry turbidimeter tube, a small portion at a time, until the filament of the lighted lamp disappears from view. After the first trial the solution is poured back into the beaker, stirred vigorously, and the observation of the point at which the filament disappears is repeated until this is fixed within 1 mm. During the time the solution is being added the portion remaining in the beaker should be kept well stirred, so that the small portions added from it will be representative of the whole bulk. The first time the solution is poured into the observation tube the latter must be dry and clean. In cleaning it care should be taken to remove, without scratching the tube, the film of sulphate which adheres so persistently to the bottom.

Further tests on a second 90 cc of the original neutralized solution of sulphate should be made if considerable accuracy is needed. The amount of sulphur indicated by the curve on page 197, corresponding to the depth of liquids in the turbidimeter measurement, is multiplied by the number of cubic centimeters of neu-

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[19] An indicator is required which is sensitive to ammonia but not to carbon dioxide. Paranitrophenol is the most satisfactory because it is colorless in acid solution.

tralized condensate and divided by 90 (the volume of sample taken) to give the total amount of sulphur obtained by burning the gas. For convenience in this calculation, the condensate after neutralization can be made up to 270 or 360 cc, and the observed values for the 90 cc portion are then multiplied by 3 or 4.

The turbidimeter used is shown in Fig. 11. It consists of a cylindrical glass tube graduated from the bottom in centimeters, surrounded and held in place above the light by a brass tube. The light should be in most cases a 16-candlepower carbon filament lamp, so placed that a straight portion of the filament extends diametrically across just below the bottom of the tube.

The incandescent filament gives a sharper end point than any other source of light so far devised. It is not affected by drafts, does not smoke or crack the tube, and can be conveniently placed under a table or in another out-of-the-way place. A series of comparisons, using the incandescent filament, the standard candle, and the 0.5 mm slot recommended by Leighton, has shown that the three light sources give excellent agreement.

The curve on page 197 may be used by any observer, if care is exercised in following exactly the method given in the preceding paragraph; the acidity and temperature limits must be particularly observed; the character of light used is less important. In any case it is well for an inexperienced observer to take known amounts of a standard sulphuric-acid solution and run through the test until assured that his observations are consistent and correct.

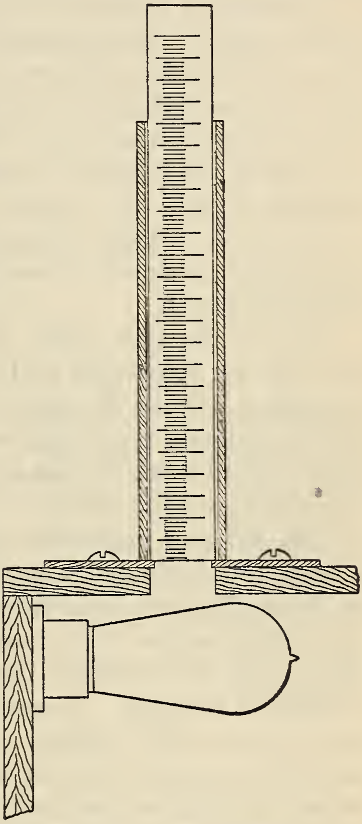


Fig. 11.—*Turbidimeter*

When more than one portion is precipitated and used for a determination, the accuracy would be materially increased, so that in tests on three portions of a solution the average of the three ought not to be much more than 1 per cent in error. It should be remembered that three tests can be made in this way much more quickly than a single test by any other method.

3. AMMONIA

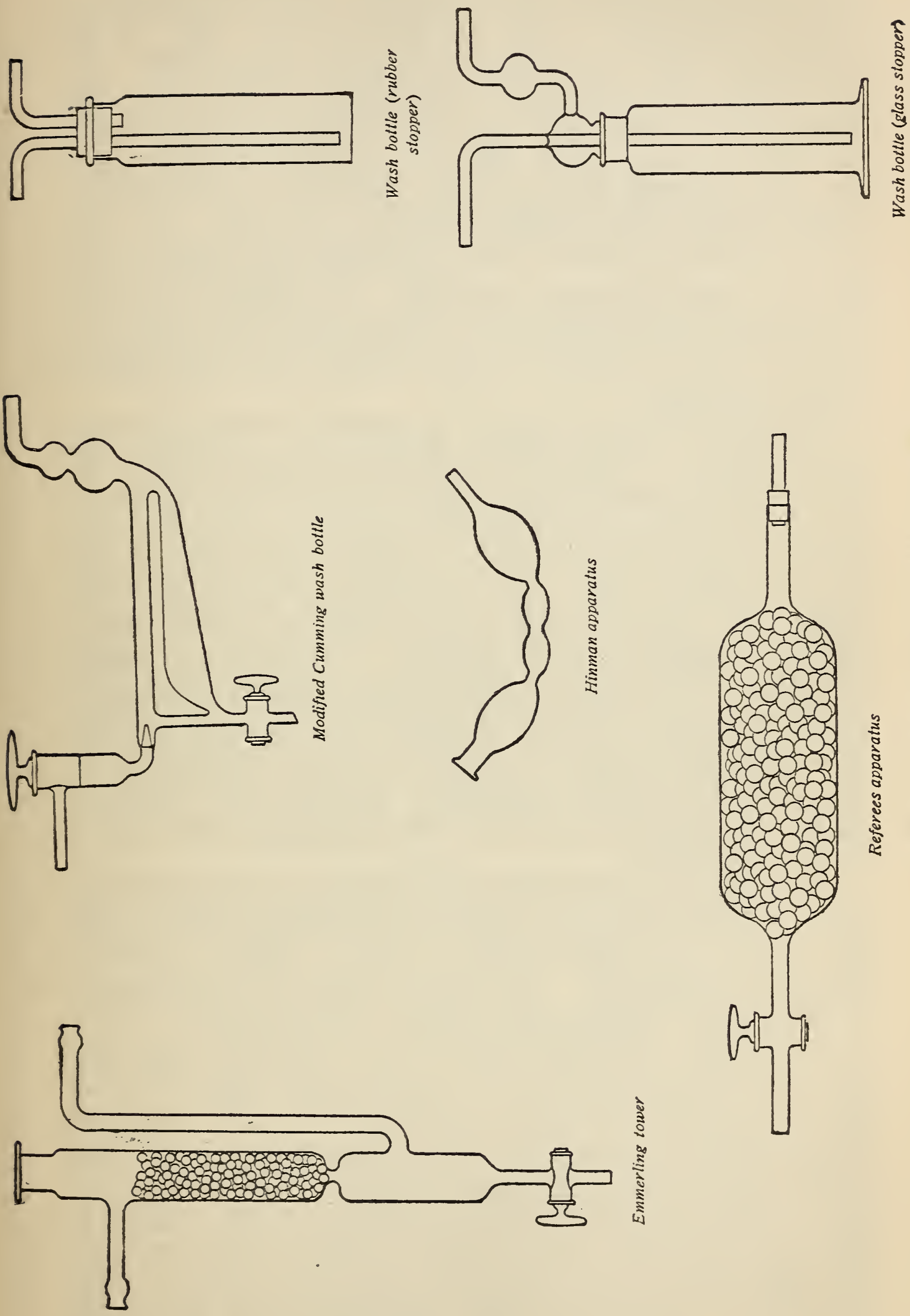
The determination of ammonia is usually accomplished by one of the two variations of the following general procedure:

A measured volume of gas (generally the sample to be burned in the sulphur determination) is passed through a fixed volume of an acid solution of known strength; then, either the amount of the acid neutralized by the ammonia is determined by titration of the excess of the acid or the occurrence or absence of a change of color of the indicator is noted after passage of a predetermined amount of gas. By the first method the amount of ammonia in the gas is actually determined; but by the second method the amount of ammonia is merely shown to be above or below the limiting amount.

Five of the best forms of absorption apparatus which may be used are illustrated in Fig. 12. These are (*a*) the Referees apparatus, (*b*) the Emmerling tower, (*c*) the Hinman apparatus, (*d*) the ordinary type of gas wash bottle, all glass, (*e*) the ordinary type of wash bottle, rubber stoppered, and (*f*) a modification of the Cumming gas wash bottle.

The Referees apparatus has been extensively used, but it is clumsy to handle and a large bulk of wash water must be used to insure complete removal of the acid from the beads. This is especially the case if the beads are perforated, and is undesirable because of the inaccurate titration which may result in the larger volume of solution. To secure complete absorption, it is necessary to have the cylinder completely filled with beads and to keep them moist with the acid during the run. If this is not done, the acid on the beads in the upper part of the chamber may be neutralized, permitting the escape of ammonia while the bulk of the liquid in the bottom remains acid. Owing to the solubility of ammonia in water this is not likely to cause serious errors, but should be guarded against during long runs by occasionally rotating the tube.

It sometimes happens that the large surface of glass exposed by the beads is so rapidly attacked with consequent liberation of alkali as to neutralize an appreciable part of the very dilute acid used. For this reason the solubility of the beads should be determined. This may be done in the following manner: Take 100 or



Wash bottle (glass stopper)

Referees apparatus

Hinman apparatus

Wash bottle (rubber stopper)

Modified Cumming wash bottle

Emmerling tower

Fig. 12.—*Ammonia absorption apparatus* (¼ size)

150 cc of the beads and wash thoroughly with distilled water and then dry completely. Place the beads in a dry flask and add 100 cc of the acid to be used in the regular determination. Prepare a blank by placing 100 cc of the same acid in a similar flask. Stopper both flasks tightly and let stand for some convenient period, say 12 or 24 hours. Then after thoroughly mixing, pipette out 25 cc portions from each and titrate with standard alkali. After a further interval titrate another 25 cc portion. The probable loss of acid, caused by the beads during a determination lasting 1 or 2 hours, can then be calculated. The permissible loss from this source must be determined by the operator giving consideration to the amount of ammonia being determined and the degree of accuracy required.

The operator should also test his method of washing to insure completeness of washing with a minimum of wash water. This may be done by placing in the apparatus the amount of acid used in a determination and washing with successive portions of water until a portion is secured which is neutral to the indicator used. If the amount of wash water thus shown to be necessary is excessive, the volume of each portion should be reduced and the number increased as may be necessary. The amount of solution to be titrated can be kept at a minimum by draining the apparatus completely without washing, titrating to the end point, and using this neutralized solution to wash out the acid remaining in the apparatus; the acid thus removed by washing is then neutralized with the standard alkali and the operation repeated until the end point is permanent.

The advantages of the Referees apparatus are the small amount of gas pressure required to operate it and the rapid rate at which the gas may be passed without causing a serious decrease in efficiency of absorption. This makes it especially suitable for use in series with a sulphur-test apparatus burning gas at a rate in excess of half a cubic foot per hour—e. g., the Elliott apparatus. For traveling inspection work, the large size and weight of the referees apparatus is a disadvantage as compared with some of the smaller forms described later. Some makers are supplying the referees apparatus with metal unions and cocks cemented to the glass ends. These metal pieces and the cement are quickly attacked by the acid and render the apparatus unreliable. The apparatus should be made completely of glass, preferably of the form figured; connections can then be made conveniently with thick-walled rubber tubing.

The Emmerling tower gives excellent absorption of the ammonia when the gas is passed at any rate up to 1 cubic foot per hour; and it has the advantage that it can be rinsed out thoroughly with but a moderate amount of wash water, while clamped in position and without disconnecting it from the gas supply or the meter. The solubility of the beads used and the method of washing should be tested as noted in preceding paragraphs. It requires a greater gas pressure to operate it than do the other forms, a disadvantage especially when it is desired to operate it in series with a sulphur apparatus.

To insure satisfactory operation, the Hinman apparatus requires careful regulation of the quantity of acid introduced, the rate at which the gas passes, and the angle at which it is set. It should be so filled and set that the gas is required to bubble past each of the constrictions. Care should be taken to see that acid is not lost by bubbles breaking too close to the outlet. It operates with very little drop of pressure between the inlet and the outlet, which is often an advantage. The Hinman is a good form to use when it is desired to determine whether the ammonia is below a certain amount by noting whether the passage of a predetermined amount of gas produces a color change in the indicator, which is proof of the saturation of a known amount of acid. The color change denoting neutralization of the acid can be correctly observed while the gas is passing only if the apparatus is shaken just before the observation is made, to insure mixing of the acid throughout the apparatus. Absorption of the ammonia is good in this form of apparatus, but in any case the apparatus should not be operated to pass more than 0.6 cubic foot of gas per hour. The apparatus is readily portable and is especially suited for use in official tests where it is only necessary to determine whether or not the ammonia exceeds the limit allowed by the rules or laws in force.

The ordinary gas wash bottle gives slightly less complete absorption of the ammonia, but it is not seriously inaccurate, and it is often most convenient since it is commonly available in any chemical or gas-testing laboratory. If the gas is to be passed through the ammonia apparatus faster than 0.6 cubic foot per hour—e. g., if the test is made in connection with a determination of sulphur, using the Bureau of Standards type apparatus—it is well to use two gas wash bottles in series for the ammonia absorption. A wash bottle with rubber stopper has the advantage of all other forms in the matter of simplicity and cost; it can be prepared by anyone from materials readily obtainable in any locality.

The modification of the Cumming gas wash bottle shown in the figure is a very convenient and efficient form of apparatus. It can be connected permanently in series with the sulphur apparatus, as it can be filled, emptied, and rinsed out without changing the connections. It gives practically complete absorption when run at the rate of 0.6 cubic foot of gas per hour and requires very little pressure to operate. The injector action of the small nozzle, through which the gas enters, gives rapid and continuous circulation. It may be run with equal facility either to determine the quantity of ammonia or to determine whether or not this impurity exceeds the maximum allowed.

(*a*) **Method of Operation Recommended.**—Place in the absorption apparatus of the form selected an accurately measured portion of a standard solution of sulphuric acid, prepared as directed below, and add two drops of the indicator solution. About 25 cc should be used in each form of apparatus except the Hinman, which is constructed to hold only about 15 cc conveniently. The acid should be measured from a pipette or a burette, and may then be diluted with distilled water until the volume is obtained which gives the best operation with the particular apparatus in use. Connect the apparatus with the gas supply, and with a meter on the outlet of the bottle pass the gas to be tested, at the rate of 0.5 to 0.6 cubic foot per hour, for from two to five hours, according to convenience and accuracy required. Somewhat greater accuracy is secured by the longer test, and, if desired, the gas may be passed more rapidly with the Referees or the Emmerling apparatus. The method of measurement of the gas has already been described in a previous section. (See p. 20.) When the requisite amount of gas has passed the supply is shut off and the color of the solution noted to determine whether the acid has been neutralized, as shown by the indicator, or the acid remaining unneutralized is determined, as follows: The contents of the apparatus is rinsed into a beaker with distilled water, using the smallest amount possible to secure complete removal of the acid, and the solution is titrated with a standard solution of sodium hydroxide.

The method of calculating the ammonia content of the gas from the test data will be apparent from the formula given on the test record card (p. 151).

(*b*) **Selection of Indicator.**—The selection of an indicator is more important in securing good results than the choice of form of apparatus. The indicator should be sensitive to ammonia and not be seriously affected by ammonium salts, give a sharp end point in dilute solutions, and be but little, if at all, affected by carbon dioxide. Sodium alizarinsulphonate, cochineal, and paranitrophenol are suitable for this purpose.

The solution of *sodium alizarinsulphonate* for use is made by dissolving 1 g of the material in 100 cc of water and filtering off the undissolved portion. In titrating the end point is reached when the color changes from greenish yellow to light brown. The color further changes to red, but the first change is the proper one for this work. The change is sharp, and the end point indicated is less affected by carbon dioxide than with either cochineal or paranitrophenol.

Cochineal gives a fairly sharp change from brownish rose to lilac and may be used with good results. A solution may be prepared by grinding in a mortar 3 g of cochineal with 250 cc of 25 per cent alcohol in the cold and filtering off the undissolved residue.

Paranitrophenol gives a sharp color change from colorless to yellow, which can be easily recognized. It is affected more by carbon dioxide than the above two indicators, but gives very good results with ordinary illuminating gas. A solution of 2 g in 100 cc of 95 per cent alcohol is used. This solution will be colorless if prepared from pure material.

SULPHUR AND AMMONIA TEST RECORD

Station.............................. Gas.............................. Date..............................

Time started...................... Time finished................ Elapsed time....................

	Meter	Meter temp.	Barometer		Manometer		Total pressure
Start	....	....	....	+	....	=	....
Finish	....	....	....	+	....	=	....

Gas used..............(A) Av........... Av...........

Volume correction factor......................(F)

Weight—$BaSO_4$+crucible..............(grams)

—Crucible...............................

—$BaSO_4$..............................(B)

Sulphur found $=\frac{212\times B}{A\times F}=$.....grains per 100 cu. ft.

(Use reverse of card for remarks)

Hydrogen sulphide..........................

Cc standard acid used..........................(a)

Cc standard alkali used..........................

Acid equivalent of alkali......................(b)

(a)−(b)..........................(C)

Equivalent of 1cc of acid..................(D)

Ammonia found $=\frac{100\,C\times D}{A\times F}=$grains per 100 cu. ft.

.... Observer

FIG. 13.—*Sulphur and ammonia test record form*

Phenolphthalein and *Litmus* must not be used for this purpose because they are affected by carbon dioxide. Results with phenolphthalein are inaccurate in the presence of ammonium salts.

Methyl orange and *Congo red* give very indefinite end points, and their use is not recommended.

Rosolic acid is too sensitive to carbon dioxide to give satisfactory results.

Methyl red has about the same degree of sensibility toward carbon dioxide as paranitrophenol, but when the color change takes place slowly, as when passing gas through the solution, the pink fades into the pale yellow so gradually as to make the end point indefinite.

Hematoxylin gives color changes which are variable and transitory, and its solution is also unstable, being oxidized by the atmospheric oxygen.

(*c*) **Preparation of Solutions.**—The sulphuric acid may be conveniently made of such strength that 1 cc neutralizes approximately 0.005 grain of ammonia, and its exact strength is determined by standardization. If the inspector has a large number of determinations to make, it would be desirable to make the solution somewhat stronger, and after determining its strength dilute it so that 1 cc is exactly equivalent to some convenient unit of ammonia—e. g., 1 cc = 0.01 or 0.005 grain ammonia. Sulphuric acid is suggested rather than hydrochloric, as it may be standardized by a process with which any gas tester will be familiar, i. e., by the barium-sulphate precipitation, which is used in the determination of the total sulphur. To make and standardize this solution the following procedure is recommended: To 2 liters of distilled water add between 1.25 and 1.50 cc of pure concentrated sulphuric acid and mix thoroughly by shaking. This solution must be carefully preserved in a glass-stoppered bottle to avoid contamination and evaporation. For the standardization of the acid a 50 cc portion is accurately measured into a 400 cc beaker, diluted to 250 cc, and treated with 10 per cent barium-chloride solution in the manner already given (p. 140). The weight of barium sulphate (in grams) obtained by this process is multiplied by 2.25 and then divided by the number of cubic centimeters of solution taken as a sample. The result is then expressed in grains of ammonia equivalent to 1 cubic centimeter of the acid.

The sodium-hydroxide solution for titrating the excess of the acid is prepared by dissolving approximately 1.8 g of sodium hydroxide in 2 liters of water and mixing thoroughly. To obtain the ratio of the acid to the alkali, measure out the same amount of acid as is ordinarily titrated in a determination and add distilled water until the volume of solution is about equal to that obtained in washing out the apparatus after a determination; add 2 drops of indicator solution and complete the titration with the alkali. For convenience, the strength of the alkali may be made equivalent to the acid by dilution or further addition of alkali.

4. INTERPRETATION OF RESULTS

In Circular No. 32 of this Bureau the model ordinance and rules proposed indicate the proper method of interpretation of the tests for impurities. The test for presence of hydrogen sulphide in the gas should be made daily. Determination of total sulphur and ammonia need not be made more often than once a week unless the result of a first test shows that either impurity is apparently present in excess of the amount allowed by law or rule. In this latter case a second test should be made to confirm the results of the first. Unless the impurity is then a full grain (or more) in excess of the limit allowed penalty should not be demanded, since the uncertainty of experiment may be as great as 1 grain on the average of two tests. When very close to or barely above the limit, the company should be warned of the fact that the gas is dangerously near the limit in this particular.

F. PRESSURE RECORDS

For the measurement of gas pressures the siphon or U gage and the recording gage are the two forms most used in this country. The pot, arch, differential or King's gages are seldom, if ever, employed for inspection purposes.

1. SIPHON OR U GAGE

The siphon or U gage consists of a U-shaped glass tube, one arm of which is attached to the gas supply pipe. The scale, placed between the two arms of the gage, permits a direct reading of the gas pressure in inches of water. This scale must be correctly graduated, but otherwise no special precautions as to form need be observed, as any gage of this type on the market will undoubtedly be satisfactory.

The simplicity and accuracy of gages of this general form make them very satisfactory for gas-pressure tests in laboratory work; but when a continuous pressure record is desired they are, of course, not suitable. They may be used to advantage in checking the readings of the recording gages, such as are described in the next section, which are necessary for routine service inspections.

2. RECORDING PRESSURE GAGE

Two types of recording pressure gages are employed for taking gas-pressure records. These may be characterized as the diaphragm type and the tank and float type. The first of these is used in this country at the present time almost to the exclusion of the other type. They are made for various pressure ranges, from 0 to 10 inches being convenient for most gas-inspection laboratories.

The portable gage of the diaphragm type differs from the stationary form only in construction of the case, the works being inclosed in a wooden box suitably arranged to be carried by hand. These instruments cost about the same as the corresponding forms for wall use.

There are several good instruments of this type on the market, which, though operating upon the same principle, differ somewhat in detail of construction. Several points which it is well to consider in the selection of an instrument are the ease and accuracy with which charts may be attached and adjusted, the construction of the pen mechanism, the character of the record traced, the sensibility of the instrument to small changes in pressure, the accuracy of registration for gradual or sudden changes over the whole range of pressure for which the instrument is intended, and the liability of the recorder to get out of working order. Every gage should be frequently calibrated by comparison of its readings with those of a siphon gage connected to the same supply pipe, and if not properly set it should be adjusted, preferably being returned to the maker where more than a simple adjustment is needed. The pen should press only heavily enough on the chart to trace a clear record. The charts are arranged to give 24-hour or 7-day records, the former being preferable unless daily replacing of the chart will be inconvenient. For the laboratory which is visited three or four times a week the daily chart may often be used to advantage by allowing two days' records to be traced on the single sheet. It is seldom that it will be difficult to distinguish the two records thus superimposed. Care should be taken to secure the proper charts. Instruments made by the same company and covering the same range of pressure may require different charts because the pen arms are of different lengths.

To protect the case and works from fumes of the laboratory, it is sometimes desirable to inclose the wall gages in a protecting wooden case with glass front. When the gage is in an office and not subjected to fumes, no such precaution is necessary.

The tank type of recording gage is not much used in this country. A number of inspectors have gages of this type, however, and are using them with satisfaction. The main advantage of this form of record is that when a chart is completed it can be spread out so as to show at a glance the maximum and minimum pressures which have been recorded. The circular chart must be examined more carefully to determine these readings, but is not seriously inconvenient even in this respect.

3. SETTING OF A PRESSURE RECORDER

For the location of a pressure recorder in the testing stations it is only necessary to be sure that a suitable gas connection can be made, but it is often best to place the gage in the office room, where it will not be exposed to the fumes of the laboratory. The supply pipe for the gage should, if possible, be connected to the service pipe between the main and the meter. This prevents any irregularity in the meter action from affecting the pressure record, and thus the readings better represent the conditions prevailing throughout the district. It is, of course, essential that the pressures measured be practically those existing in the main.

The only special precautions in connection with portable gages in traveling inspection or for complaint tests are to be taken in the selection of location for the test and in frequent checking of the gage with a U gage. The location of a permanent pressure-testing station must be carefully considered, so that the records taken will, if possible, represent conditions of a considerable area. To accomplish this, it is necessary to make a study of the distribution system, first by examining the maps of the mains and often also by a number of tests in different parts of the neighborhood where the permanent station is to be located. To accomplish the latter purpose, a number of gages can be operated over the same period at different points in the neighborhood; and by comparison of the records thus obtained the proper location is selected.

For a permanent station it is usually best to locate the pressure gage at the point that trouble will probably first be met; if a regular record is taken at such point the future difficulties will be known and may be met before they become serious. A special service pipe, from which no gas is used, can be installed for such station, or if the regular service is of ample size to prevent large pressure losses, it may be employed. In the latter case the gage should be connected ahead of the meter.

In case of complaints of poor gas or insufficient supply of gas, pressure records taken at the appliance and at the service head will often show the cause of the difficulty. In such cases low pressure in a single customer's house piping is often found to be the cause of unsatisfactory service; and cleaning the dirty service pipe, replacing a meter which operates with large pressure losses, or enlarging the service pipe will relieve the difficulty in many instances. In still other cases the house piping may be of insufficient capacity.

4. INTERPRETATION OF PRESSURE CHARTS

The rules governing the pressure of gas will usually be so specific that the proper interpretation of the pressure records is apparent from them. In the Bureau's circular on "Standards for Gas Service" these regulations are discussed at length, and the discussion there makes clear the principal causes of irregular pressures. (See pp. 52–57 of the third edition of Circular No. 32.) The records taken by a good gage can be considered reliable to one or two tenths of an inch of water pressure, if checked occasionally by a U gage. A wall gage should be checked by the U gage once a week and a portable gage each time it is set or removed.

In the examination of charts the maximum and minimum pressures recorded for each day should be noted, and the cause of any sudden changes of pressure either up or down should be investigated. If a pulsating pressure is indicated, the cause of this should be located; it will usually be found to be a gas engine which has insufficient pressure-control attachments. It is also important to notice whether in any locality the pressures are tending gradually to be lower from one year to the next. When a gradual diminution in minimum is resulting from the increased consumption, steps should be taken to prevent this going too far; and it must be borne in mind that good pressure during seasons of light load does not insure good service at periods of maximum output. If the maximum days of one season show pressures falling nearly to the lower limit allowed, it is probable that deficiency more or less serious will be found at the next peak-load season, unless in the meantime some steps are taken to reinforce the mains feeding the distributing system of this district. It is by comparing records taken at one place during different years or different seasons that unsatisfactory service can be predicted and then prevented from becoming serious. Every effort should be made by city and company officials to cooperate in this work.

G. METER TESTING

As far as the Bureau has been able to learn, the testing of consumer's meters on a commercial scale has been carried out satisfactorily only by the use of a meter prover. The use of a calibrated meter for this testing is not customary and in very few cases does the lack of a meter prover render it necessary since even a small company can afford to own a prover. Indeed, it seems certain that any company owning as many as 200 or 300 meters will be warranted in the purchase of a 2-foot or larger prover. In several States even the smallest companies are required to purchase meter provers; but an exception to such rule might be made if a small company would arrange to have its meters tested by a larger company in a near-by city. However the shipment of meters after test is not good practice and should be avoided when possible. The testing of meters in place on customers' premises has never been successful for regular work.

1. METER PROVER AND ACCESSORIES

The provers ordinarily used for meter testing are of two types—the standard and the automatic. The latter type is made for use in meter-adjusting work where a single revolution of the tangent is used for the test; and it is, therefore, usually used only for testing meters which have the top of the case removed, and is not so well adapted for inspection work. It is said to have considerable advantage in speed for meter repair shop use. The standard type of prover has many variations in the form of its parts and accessories, but only the more important of these will be discussed in this circular.

The prover tank is preferably made annular so that a minimum amount of water will be needed to fill it. This permits the prover to assume the room temperature more rapidly, allows more rapid filling and emptying, and makes the whole outfit less heavy. On the other hand, the annular tank makes it more difficult to clean or repaint a prover and is, therefore, not as well liked by some users. The bell is usually made of copper or of galvanized iron; the copper bell, though initially more expensive, is considered by some to be more economical because of its greater resistance to corrosion. It is claimed that a copper or brass bell has the advantage that if kept well polished and slightly oiled, practically no water will adhere to its surface; the temperature change due to evaporation from the surface of the bell is thus reduced.

A decided improvement over the ordinary type of prover, in which the wet outside surface of the bell is exposed directly to the air of the room, is being manufactured by a number of firms. This improvement consists in having the bell operate entirely within a metal cover which is closed to the air of the room, except for a small opening in the top through which the chain supporting the bell travels and through which the air of the room passes in or out of the cover as the bell is lowered or raised. Experiments made at this Bureau have shown that this device is very effective in reducing the rapid temperature changes due to drafts and to evaporation from the wet outside surface of the bell.

The prover should preferably be raised from the floor by legs with screw feet. This facilitates leveling of the apparatus; and it reduces the lag of the temperature of the prover behind that of the room by allowing free circulation of air under the prover. This construction also lengthens the life of the prover by preventing the corrosion which results from the accumulation of moisture on the underside of the prover tank.

The scale may be screwed to the bell and the pointer located on the tank; or the scale may be placed on one of the pillars which carry the bell support, the pointer being located at the top of the bell. Some provers are provided with a vernier device for reading the scale. If the vernier and scale are accurately divided, the readings can be more easily and accurately made by this means. The U gage should be connected to the outlet of the prover beyond the outlet cock; it may be set near the top of the tank or more conveniently placed on a pillar at the level of the eyes.

The air thermometer should be mounted about half way up one of the prover pillars and at such a distance from the operator that his presence does not influence its readings. The water thermometer should preferably be so constructed and so mounted that, with its bulb in the water of the prover tank, it may be easily read without being touched by the operator. The smallest divisions on the thermometer should represent a temperature difference of not more than 1° F, and should be of such length that the scale may be read to 0.2° F. Both thermometers should be tested to establish their accuracy. If it is not convenient to have them tested in the usual method, a comparison may be made by holding them with bulbs adjacent in a well-stirred pail of water at approximately room temperature. If the temperature readings of the two instruments are then the same, it is probable, though not certain, that the thermometers are both approximately correct. Even if the thermometers agree but do not indicate the actual temperatures to which they are subjected, they are still useful, for they indicate when the temperatures of the prover and surrounding air are the same.

A dial form of scale is sometimes used instead of the usual scale and pointer; its hand is mounted by a friction joint on a drum, which is rotated by a fine wire attached to the top of the bell. This device, if properly made, is probably as accurate as the regular scale, and it is claimed that it has certain advantages in speed of operation for routine testing work. It can be calibrated by bottling the prover, as is done with the regular scale.

Provers are commonly made in 2, 5, 10, and 20 cubic foot sizes. The smaller gas companies might require only a 2 cubic foot prover; but since some meters larger than the "10-light" size may have to be tested, a 5 cubic foot prover is preferable. Except in large cities, it is seldom necessary to have a larger than a 5 cubic foot prover, since the few meters of large capacity which are to be tested can be checked against a number of smaller meters set in parallel, each of the small meters being checked separately against the prover.

2. INSTALLATION AND CARE OF PROVER

In a previous section (p. 13) the various conditions as to a proper location for a meter-testing laboratory have been indicated. The maker should provide careful directions for assembling the prover.

It is very important that the prover be so located that it may be maintained at a temperature that is nearly uniform and the same as that of the surrounding air. In order to secure this condition, the prover should be protected from the disturbing effects of stoves, radiators, steam pipes, direct sunlight, etc. It should also be protected from drafts, not only those of hot or cold air incident to heating and ventilation, but also those at the temperature of the air in the room, such as might be produced by an ordinary electric fan. It is also well to place the prover at some distance away from outside walls and windows, for it must be remembered that a large cold surface near the prover may be as disturbing as a warm one. A difference of 3° C (5.4° F) between the prover and the meters under test will cause an error of more than 1 per cent.

Uniformity of temperature is necessary at night as well as by day to insure that the meters and prover will be at the same temperature in the morning when testing is begun. The proving-room temperature should not be suddenly changed in the morning before starting work on the meters which have stood there overnight. Any difference in the temperature of the air and water in the prover should be overcome by changing the water in the prover. Thermostatic control of room temperature has been found advantageous and should be adopted where practicable.

It is necessary to arrange at one side of the prover a bench or table on which meters may be placed during the test, preferably with the test dial at about eye level. If one man uses two provers—a very economical arrangement where a considerable number of meters are tested—the bench may be placed between these, and the two meters under test at any one time are thus within easy reach of the operator.

The hose for connecting meter and prover should be conveniently supported in such a way that when disconnected from a meter it can not become so cramped as to be cracked after only a short period of usefulness. The form of support supplied with some makes of provers consists of a curved bracket so suspended that when the hose is supported by it cramping is very unlikely to occur. When a considerable number of meters must be tested, a device for rapidly connecting the meter with prover and vent is desirable.

In order to decrease the corrosive action of the water upon the prover bell, it is desirable that at all times when the prover is not in use the bell should be raised almost, if not wholly, out of the water in the tank, and the scale should always be wiped dry before the prover is left for the night. The water in the tank should be renewed frequently, and at all times the tank and bell should be kept clean both inside and out. A fresh coat of paint on the interior of the tank and exterior of the bell, if this is iron, is often helpful in prolonging the life of the prover; the interior of the bell should not be painted.

The valves of the prover should be kept free from dust and be well greased at all times. Any grit in the valves will soon so scratch the wearing surface as to cause leaks. When not in use the circular slide valve should be covered to keep out the dust.

Since, when the prover is in use, it must be at the temperature of the room, means should be provided for conveniently changing the temperature of the water in the prover tank. This is commonly done by adding hot or cold water to the tank, and in some cases steam jets are arranged for heating the water. In any case where the water is thus heated or cooled, great care should be exercised to insure thorough mixing of the water before its temperature is compared with the room temperature. In every case the meters undergoing test must also be at room temperature.

The chains supporting the counterweights should be flexible and should run smoothly over the wheel and the spiral, so that under no circumstances will binding cause the bell to stick or to be deflected from a vertical position. The weights should be adjusted so that the gas in the bell is at a constant pressure, usually 1½ inches of water pressure, irrespective of the position of the bell. The variation in the pressure of the gas in the bell should not be greater than one-tenth inch of water for the entire range. If the spiral weight is not properly adjusted to give this uniformity of pressure at all heights of the bell, it may be corrected in the following manner: The counterweights are so adjusted that with the outlet valve open the bell will neither rise nor fall of itself; the spiral weight can then be increased or decreased in size, the main counterweight being simultaneously decreased or increased, until the bell will remain stationary at any height with the outlet valve open. The main counterweight can then be decreased again until the pressure in the bell is equal to 1½ inches of water pressure as shown by the gage.

3. CALIBRATION OF PROVER

Although all provers sold are carefully tested by the manufacturer before shipment, they must be examined again after being set up for use to insure that they have not been damaged in shipment.

The prover bell should first be examined carefully to see that it is not dented. It is then filled with air, the counterweight adjusted to throw a very small pressure, the air allowed to escape, and the fall of the bell noted to see that it is easy and regular. The prover connections should be tested for leaks by leaving the bell partially filled with a very small quantity of air under a pressure of 2 or 3 inches and observing whether there has been any escape of air after a period of one or more hours, making the proper correction for any change of temperature, pressure, and vapor pressure which may have taken place.

For official use in meter testing it is necessary that the prover be tested by the inspector, in order that he may be able to certify his results and, if necessary, use them when under oath in court. Except for small cities where very few meters are tested, the purchase and use of a cubic-foot bottle is recommended.

(*a*) **Cubic-foot Bottle.**—Three types of cubic-foot (or fractional cubic foot) bottles are in use in this country at this time: The cabinet type of bottle is arranged so that a cubic foot of air is displaced by or displaces an equal volume of water in a stationary bottle; the immersion bottle operates on the same principle as the meter prover, the fixed volume of air being displaced by lowering the bottle into the water tank; and the third type is a displacement bottle operated by raising or lowering the leveling tank attached by a flexible tube.

The immersion bottle has an advantage over the cabinet bottle, both in simplicity and in ease of operation; but it can not be used quite as conveniently for "bottling out" of the prover (see p. 167), since when the bottle rises from the water the outside is wet and the resulting temperature changes may be appreciable, causing either inconveniently slow operation or errors which are serious. The immersion bottle is more readily portable than is the cabinet type; but the third type with a wet meter is more portable than either. It is probable that this combination will be most frequently used by traveling inspectors who are required to do much meter-prover testing. Previous to the present time, the cabinet bottle has probably been most used, but the immersion bottle is now almost exclusively employed.

Since the standardized bottle is the basis of all of the gas measurements made in inspection or sale of gas, great care should be taken to insure its accuracy. If requested by the purchaser, all companies making this sort of equipment will supply a bottle which has been tested and certified by the Bureau of Standards. This standardization is very desirable for all bottles which are to be used in checking official instruments.

(*b*) **Calibration Methods and Precautions.**—For the standardizing of a prover it is essential to have the temperature of the room constant throughout the period of test, and with some methods of operation it is a great advantage if the air of the room is saturated with moisture. To prevent temperature changes occurring, drafts must be excluded. In some laboratories the air is kept nearly saturated by sprinkling the floor and hanging wet sheets in the room. The latter procedure is not, however, always necessary, for when care is taken to saturate the air used for the test before it is measured and to prevent temperature changes due to the evaporation of water on the outside of the bell the humidity in the room is without influence.

The comparison of the cubic-foot bottle with the prover can be made either by measuring air into the prover 1 cubic foot at a time until the prover is filled or by filling the prover and measuring the air out 1 cubic foot at a time. The latter method has several advantages, especially if a cabinet-type bottle is employed. It is often recommended that for each test of a prover comparisons be made both by the method of bottling in and bottling out of the prover. Unless lack of time prevents this plan being followed, it is probably best to make both forms of comparison the first time a prover is tested; but after a first test it is not usually necessary to recalibrate by more than one of the two methods. There is no inherent reason why the two methods should not agree, and if a discrepancy is found it must be due to experimental errors.

Successive calibrations should agree with each other within 0.3 per cent.

Recalibration of a prover once a year is usually sufficient, unless it has been removed, damaged, or repaired; an extra checking more often than this requires so little time that it may be desirable. When a State inspector supervises company testing, it may seem impossible to recalibrate all provers once a year; but with a portable one-tenth cubic-foot bottle it is not hard to check a wet meter and then run this against the prover at least that often.

METHOD 1. Bottling Out of the Prover with Cabinet Bottle.—The bottle and prover should be filled with water and should stand near together over night before beginning the test, so that the temperature of the two will be the same. During this time the prover bell should be raised as far as possible without unsealing it, so that the air in the bell will be fully saturated with water vapor and the outside of the bell will be dry before the beginning of the test. The bottle while empty is connected with the prover and the connections tested for tightness by opening the valves between bottle and prover until the pressure in the former is equal to that in the prover. If the temperature of the gas in the bottle does not change, then after closing the prover valve the pressure indicated by the gage on the prover connection will stay constant unless a leak exists in the bottle or the connection to it.

When the tightness of the connections is assured, the bottle should be filled with water to the upper mark and enough air allowed to escape from the prover to bring the bell exactly to the zero mark. The air from the prover is then allowed to pass into the bottle until the water level just reaches the lower graduation of the latter. The lower valve of the bottle is then closed and the prover reading noted. After closing the connection to the prover and opening the outlet to the outer air the bottle is again filled with water. The prover reading is again taken and a second foot of air measured out of the prover. This cycle of operations is repeated until each of the cubic-foot intervals has been checked. It is to be noted that when the water reaches the lower mark on the bottle after drawing each foot of air from the prover, by leaving the prover valve open until after the lower water valve of the bottle is closed, the air in the bottle will be brought to the same pressure that it had originally in the prover.

With this method of calibration no change of counterweights or corrections for pressure is required. By leaving the air used for calibration inclosed in the prover bell over water for some hours before beginning the test this air is fully saturated with moisture, and there is no need for saturating the air of the room. When several comparisons of bottle and prover are desired, a second prover full of air can be saturated by allowing a couple of hours to elapse between the completion of one comparison and the beginning of the next. In this way there will be no difficulty in completing three or even four comparisons in a single day, and the person making the tests will have more than half of his time free for other duties.

METHOD 2. Bottling into the Prover from a Cabinet Bottle.—The measurement of 1 cubic foot of air at a time from the cabinet bottle into the prover is more subject to error than the method of bottling out as described in Method 1, since unless the air is saturated 1 foot at a time before measurement by the bottle it will continue to take up water vapor and, therefore, to expand after measurement. Another source of error in bottling into the prover is that, since the bell rises from the tank wet, the cooling effect of the evaporation from its surface may be appreciable unless considerable time is allowed after the air enters the prover before the prover reading is taken. This latter difficulty may be avoided by having the air of the room saturated with water vapor, and it may be reduced by coating the outside of the prover with oil or paraffin so that the outer surface of the bell will be nearly dry and therefore less subject to the cooling effect. Such a coating will also aid in protecting the bell from corrosion.

The method of operation in bottling out of the prover is very similar to that used when bottling into the prover, except that in the last-mentioned method the test starts with the bell empty and 1 cubic foot of air at a time is introduced from the bottle. The same precautions apply as in the previous method.

Before making a test of a prover by "bottling in," the bell of the prover may be counterweighted so that it is just balanced and therefore will stay at any point without compressing or expanding the air within it. This is easily done by changing the counterweight until with outlet open the bell neither rises nor falls. After being thus adjusted the prover and bottle are connected, and, with the extra counterweight temporarily removed, the connections are tested for leaks as described above in Method 1. The extra counterweight is then replaced, the prover submerged to the highest graduation, and the bottle filled with air approximately to its lowest graduation.

If it is desired to test the prover at the pressure at which it is used, this may be done by bringing each cubic foot of air in the bottle to this pressure before it is measured and introduced into the prover.

If the air of the room is saturated with moisture, it is possible to fill the bottle with air and then transfer the air to the prover without delay; but ordinarily, the atmosphere being only partly saturated with moisture, the air will take up more water vapor and expand for some time after being taken into the bottle. To determine when saturation is complete, the bottle is left open to the prover connection, on which a U pressure gage is usually located; when no increase of pressure greater than 0.3 inch in 10 minutes can be detected on the water gage, the air may be considered to be saturated. The air should be drawn into the bottle through water, whereby it will be brought nearly to saturation and less time will be required before it is ready to be passed into the prover.

After the air in the bottle is saturated with moisture the water is brought exactly to the lowest graduation of the bottle with the waste-air valve open. The waste valve is closed, the bottle opened to the prover, the air passed into the prover, and the reading of the prover taken. The process of saturating the air 1 cubic foot at a time and transferring it to the prover is repeated until the prover is filled.

METHOD 3. Bottling out of Prover with Immersion Bottle.—Bottling out of the prover with the immersion bottle may be done, using air either at atmospheric pressure or at the pressure at which the prover is used to test meters. When bottling out with the air in the prover and bottle at atmospheric pressure, the bell is counterweighted as described in the preceding method; but it is preferable in most cases to test the prover under the ordinary working conditions, and it is then necessary to adjust the counterweight as for regular meter testing. (See p. 162.) When using a bottle in this way there is a slight difficulty in making a comparison, due to the fact that when the bottle is filled with air the lower orifice of the bottle is still 1½ inches under water (assuming that the air in the prover is at 1½ inches of water pressure). Thus, it is necessary to raise the bottle very slowly when it is nearly filled with air, and stop the motion when the water surface outside the bottle is 1½ inches above the lower end of the bottle, as shown by a small attached scale.

In the case of bottling out with the immersion bottle the prover bell may be raised several hours before the test so that it will be dry and the air inside saturated when the test is commenced. Then, even though the air of the room be unsaturated, the only error due to evaporation will take place by the cooling of the wet surface of the cubic-foot bottle. This error is not serious if the outside surface of the bottle is kept so well polished or so oiled that very little water will cling to it.

The method of operation for a test will be apparent from the precautions just outlined.

METHOD 4. Bottling into Prover with an Immersion Bottle.—This method has the disadvantage that the air of the room must be completely or very nearly saturated with water vapor, or that care must be taken to have each cubic foot of air saturated with water vapor before being measured out of the bottle into the prover. The amount of water which clings to the outside of the bell or bottle should be kept as small as possible. Here again an oil or paraffine coating might be used with advantage on both bottle and the outside of the prover bell. The errors that may occur when saturated air is not used may amount to 3 per cent or even more. The importance of these precautions is therefore evident.

This method is the reverse of the preceding, with the exception that it is practically necessary to use atmospheric pressure in the bottle and prover during the test. In order to accomplish this it is necessary to increase the large counterweight, not the spiral weight, as has been described. The method of operation is then very simple and is evident from the form of the apparatus.

METHOD 5. *Calibration with Fractional-foot Bottle and Wet Meter.*—For traveling work in the testing of provers, the easily portable tenth cubic-foot bottle and a wet meter, such as used in experimental work, are very convenient. The wet meter is set up near the prover to be tested, and after the meter, the prover, and the bottle have come to the same temperature the meter is calibrated as described in another section (see p. 28); the prover is then connected to the inlet of the meter and the outlet of the meter connected with a burner or cap which will allow the air to pass at a rate of 5 to 10 cubic feet per hour. The air in the prover is allowed to escape through the meter and the prover reading noted at the times when each cubic foot has passed as shown by the meter. When this method is used the wet meter must be calibrated after being set up for use; and the readings of the meter must be taken as of value only when full revolutions of the drum are made, since fractional revolutions are often considerably in error due to irregularities in the drum. Used with proper care and observance of the general precautions already given under other methods, this procedure should give excellent results; and as the testing equipment is readily portable in a hand-carrying case, it may be applied in traveling work to especial advantage. It has the added merit that the equipment required will be available as part of the calorimetric or photometric equipment, and no extra apparatus especially for prover testing will be needed.

(*c*) **Substitution of Oil for Water in Testing Apparatus.**—In what has gone before it has been assumed that water exclusively was used as a sealing and displacing liquid in the meter prover tank and with the cubic-foot bottles; and the precautions that it is necessary to take in order to get accurate results when water is so used have been given. In view of the errors introduced into measurements of volumes of gases in contact with water it would seem that it would be a great advantage to use a mobile oil of low vapor pressure as a substitute for water. This could be used with both the cabinet and immersion type cubic-foot bottles, and in the prover tank when gas is not used in testing. The advantages of this would be:

1. The errors due to change in volume by the introduction of a vapor into the air to be measured would be avoided.

2. Errors due to a change of volume caused by the cooling effect of evaporation on the outside surfaces of the bottle and the proving bell would be eliminated.

3. The low specific heat of the oil would permit the prover to follow changes of room temperature more closely.

4. The testing apparatus itself would not be injured by the sealing liquid, but rather preserved in good condition.

Thus the cubic-foot bottle and meter prover could probably be compared with as great accuracy and with much less trouble than when water is used. Also, the errors in actual meter testing could be reduced since no undesirable change of volume of the air, assuming the temperature of the room constant, would occur.

The use of oil has, on the other hand, some possible disadvantages, none of which appear serious, however. The oil increases the risk of fire slightly and it may adhere to the bell and form a film, changing the proof of the bell; where gas is used for testing, certain constituents may be absorbed, changing the volume of the gas during the test. It is probable, however, that proper selection of an oil will reduce these disadvantages to a point where they can be ignored.

An investigation of the desirability of the use of oil, including a study of the various oils which may be used, has been taken up at this Bureau.

4. ROUTINE METER TESTING

The questions as to the frequency of removal of meters for testing and the relative merits of official testing and testing by the company have been discussed in Circular 32 of this Bureau. The following plan of testing assumes that the work is to cover the routine tests on all the meters in use in a city; and it makes little difference whether the actual testing be done by deputy inspectors or only under the supervision of the inspector.

(*a*) **Handling of Meters.**—Only the employees of the gas company should be allowed to set or remove a meter. When for any cause a meter is removed from its place, it should almost invariably be taken to the shop of the company and tested before being reset; but if a meter is merely moved from one place to another after only a few months of use since its last testing it is the practice of some small companies not to take it to the meter shop for examination or retest. However, if a meter is disconnected after a year or more of service a retest is always desirable.

As soon as the meter is disconnected the inlet and outlet should be corked or capped to prevent the drying out of the diaphragms. It must be carefully handled and hauled with as little roughness as is consistent with prompt work. Particularly with meters of large size, care must be exercised to prevent straining the seams of the case or leaks will result. When delivered to the meter laboratory, the meters must stand for five or six hours in the proving room before being tested, so that they will assume the room temperature. It is customary to allow the meters to stand over night in the proving room before test. The precautions as to the character of this room have already been indicated (see p. 18). After testing, each meter is again capped and put into stock or set aside to be repaired, painted, or reset, according to its condition. It is usually best to test each meter before the case is opened, even though it is intended to repair the meter later. Such test gives the best idea of the meter as it was in service and affords a basis for adjustment of charges which may have been incorrect, but previously not known to be so. The methods of testing, of record keeping, and of sealing those meters to be reset are described in the next sections.

If all meters are to be tested by a deputy inspector, he should be located at the company's meter shop. The incoming meters, both new and old, and all repaired and adjusted meters, should be delivered first to him; and then after testing and, if ready to be set, sealing, they can be passed on to the stock room or repair shop, as their character may require. Such official testing on each meter, if properly done, is not a duplication of work; however, unless the deputies doing this work perform it to the satisfaction of the company it is often found that the company desires to duplicate the work by having one of its employees also make a check test. Any such duplication is expensive, and by careful supervision should be rendered unnecessary. Every effort should be made by both company and inspector to have this routine work done by the deputy in such way as to avoid any necessity of checking it regularly. The records of this testing, whether done by company employees or by deputy official, should be open to both company and city inspector. There is no point at which reasonable cooperation is more essential than in this part of the meter inspection.

(*b*) **Methods of Testing.**—For official testing the checking of the accuracy of the meter registration at its so-called "normal rate" is usually considered sufficient. Additional testing at twice and at one-third this normal rate is required in a few places; and several other cities specify tests to show that the meter will register small amounts of gas, that it does not leak, and that it operates without causing appreciable variation in the light of a flame supplied with gas through it. On the whole, it seems probable that more than a test at normal rate will be unnecessary for official work; but the tests, such as for leakage and for registration at a lower or a higher rate of gas flow than normal, can well be made by the company as a part of the repair-shop routine. It is assumed in the following discussion that only a normal rate test is desired; but if other tests are required they can easily be performed in connection with this.

A very convenient set-up for routine meter testing consists of two provers with a bench between them arranged for a single operator, suitable connections to prover and to vent being provided. Such arrangement will easily allow a speed of 60 to 80 meters per day by one man, if only a single test on each is required and if this man is not expected to perform other duties than those of the testing proper. One assistant to receive and deliver meters and to seal those requiring sealing would be necessary, if as many as 75 meters per day were regularly handled; but such assistant could do this work for two or more testers.

Either gas or air can be used in meter proving. Some companies are very strongly in favor of gas, claiming that the use of air dries out the diaphragms of the meters so rapidly that accurate results can not be obtained with it; and although the majority of companies and inspectors still use air as the testing medium, the use of gas for this work is apparently increasing. It is customary to test under a pressure of 1.5 inches of water, and as all outlet caps or "rates" are made for use at this pressure there is considerable advantage in adhering to the usual practice.

For routine work the following scheme is suitable. The precautions indicated for each operation must be observed.

Meters must stand near the prover before testing for at least five or six hours, and preferably over night.

The temperature of the room and the water in the prover should not differ by more than 1° F. The thermometers used to check these temperatures should be occasionally compared to determine that they read the same when both are in the air and dry. Readings of room and water temperature should be taken frequently during testing, not less often than once an hour.

The prover should show a pressure of 1.5 inches of water, which pressure should be constant for all heights of the prover bell.

For convenience of test, meters of the same size should be arranged together. The testing procedure for a meter is then as follows:

Select hose coupling of proper size and connect the meter with the prover. With connection of prover to meter closed, fill the prover with air. Connect the outlet to the vent, and, preferably with outlet cap in place, allow about one-half to one or more cubic feet of air to pass through the meter to be sure that it operates properly; more air may well be used for meters larger than 10-light size. The tightness of the connections and soundness of the meter are then tested as follows: Close the meter outlet with the hand and throw the correct prover cock wide open so that the full pressure of the prover is on the meter and its connections. Shut prover cock and watch pressure gage. If the pressure falls, there is a leak which must be found and stopped before test. If the leak is in the meter itself, the meter is rejected as unsound without test for accuracy.

Place the proper outlet cap on the meter to allow air to pass at 6 feet per hour per rated light capacity, and again connect the outlet to the vent pipe.

By passing air or gas through the meter bring the test dial hand exactly to one of the division lines of the dial. It is always well to bring the test hand to the same mark on all meters so that there is no chance for confusion as to which mark was selected for any one test. The mark selected should be such that the test hand stands in a nearly horizontal position. Adjust the prover by raising it above the zero mark and allowing air to escape until it is exactly at zero. Open the connection to the meter and allow air to pass till exactly one revolution of the test hand has occurred. Usually this requires 2, 5, or 10 cubic feet of air, varying with the size of the meter.

Record the reading of the meter prover to the nearest one-hundredth cubic foot, and from this calculate the error of the meter. The two methods of calculating the error are as follows:

$$\frac{\text{meter reading} - \text{prover reading}}{\text{prover reading}} \times 100 = \text{per cent error.}$$

$$\frac{\text{meter reading} - \text{prover reading}}{\text{meter reading}} \times 100 = \text{per cent correction.}$$

The first formula gives the error in per cent of gas actually passed or of prover reading; the second gives the error in per cent of the meter reading and therefore it shows the per cent of readings to be added or subtracted to get correct readings. While either method may be used, the latter formula is probably the best one to use, first, since it bases the percentage upon the meter reading which is the factor upon which bills are based; and, second, since the meter prover scale is so graduated that the per cent, if based upon this formula, may be read directly from the scale. When the first-mentioned method of calculating the per cent of error is in use, a table should be prepared from which the errors may be read without calculation.

If the meter is not over 1 per cent fast or slow, it may be passed on this one test. If it is in error by more than 1 per cent, a second comparison should be made and the average of the two results taken as the error of the meter. If the two tests thus made do not agree within 0.5 per cent, a third test should be made and the average of the three taken.

If the average of the two tests shows the meter to be not over the permissible percentage fast or slow, it is customary to consider it "correct" within the meaning of the law; however, most companies do not wish to set a meter which is more than 1 per cent in error either fast or slow. Meters can readily be adjusted to be not over 0.5 per cent, or in some old-style meters 1 per cent, in error; and whenever new, repaired, or adjusted meters are submitted to a check test they should, in general, be correct within such limits or be made so before being put into service, even though the law may allow a greater tolerance.

When it is desired to test a meter at other than the "normal" rate, such special tests may be made just as described for the regular test by substituting the proper size cap for the outlet.

For testing a meter to show that it will register small quantities of gas it is customary to connect it to a burner consuming about one-half a cubic foot of gas or less per hour. After running it with such burner for 15 to 20 minutes a meter which does not register at such rate is easily detected by the failure of the test hand to move. Such testing, and that for case leaks, is properly part of the meter repair work rather than of the meter testing.

If, after a meter has been in service for some time, a number of consecutive tests be made upon it, using air as the test medium, it may be found that those tests, after the first few, indicate that the meter has become faster. The difference between consecutive tests may be as much as 1 per cent. The cause of this is probably as follows: The gas in passing through the meter saturates the diaphragms with light and volatile oils often spoken of as "condensates," and since the gas is ordinarily more or less saturated with these, it has no tendency to reabsorb these oils. But if air is brought into contact with the diaphragms, the evaporation of the oils immediately commences, with the result that the diaphragms gradually become hard and stiff and the measuring chambers formed by them will not have the same capacity as before; but will usually be decreased in volume since the air can not by its small excess of pressure over atmospheric pressure smooth out the diaphragm as it did when it was soft and pliable. Thus the first and second tests of a dry meter with air, if carefully performed, probably give more nearly correct results than subsequent tests. This fact should be borne in mind, especially when "complaint" meters are being tested.

Experiments have been made [20] in using as a proving medium for testing meters gas saturated with water vapor and also with the condensates that normally are introduced into the meter and diaphragm. By doing this the following advantages are apparent:

1. In passing through the meter no evaporation of the condensate occurs, so that the volume of the proving medium remains constant and the diaphragms are not dried out. Thus, successive tests of the same meter agree much better than when using air as the proving medium.

2. The error due to the increase in volume of gas by water vaporization after the proving medium is introduced into the bell is avoided. The error due to the evaporation from the outside of the bell will remain—unless the means previously outlined to prevent this are adopted—and must be considered.

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[20] Proc. Amer. Gas Institute, 7, p. 657; 1912.

(*c*) **Sealing of Meters.**—Four methods of sealing a meter are available: Wax impression sealing, soldering on metal seal, pasting a paper seal, and wiring with a soft-lead impression seal. The wire with impression seal is used only on cast-iron meters, such as those used for natural gas or on high-pressure artificial gas systems. The wax, metal, or paper seals are placed over the soldered seams on the case of the ordinary tin meters. Many inspectors use only metal seals, soldering one or two of the seams in such manner that the case can not be opened to repair or readjust the meter without breaking the seal. Others prefer to use one metal and one wax seal on each meter, but it is not customary to use the wax seals alone. The use of a paper label permits the date and result of the last test to be marked on the meter in a convenient manner.

For official use, the most satisfactory method of sealing is, perhaps, to use a metal seal on which is stamped the official badge of the city or State official by whom the sealing is done and the serial number of the test; and to use also a wax impression seal placed on the opposite corner of the meter top to show month and year when the test is made and initial of the deputy actually making the test. Approximately such a plan is being followed in New York at the present time.

If a company makes the regular tests of its meters, a simple paper label giving the date of the test would probably be sufficient. Indeed, in any case, an unduly complex or time-consuming method should be avoided.

(*d*) **Record of Meter Tests.**—The simplest method of keeping meter-test records is by a card-index file. When the meter comes to the inspector for check test it should be provided with a tag, on which a full record of the test can be made; and when the meter has been sealed or returned to the shop for repairs, adjustment, or painting, the tag can be filed as the only test record, except in the case of complaint meters, for which a duplicate record may be needed, one copy to be kept by the company and one by the inspector.

(*e*) **Supervision of Company's Testing.**—If a company is officially required to make regular meter tests under the supervision of the inspector, the work which has been described in the preceding sections would be that with which the inspector would be concerned. If such supervision were judiciously carried out, it might be more satisfactory to a company to be able to directly control the testing work; and there is every reason to believe that the inspector could fully protect the public by merely overseeing the company's tests. He should be privileged to test the company's provers and from time to time to check any meters he may wish. By making extra check tests upon a few meters without previous notice to the company of his intention to do so, he would be able to meet the possible criticism that the company's testing was not really subject to his supervision.

5. TESTING OF METERS ON REQUEST

When a consumer desires to have an official test of his meter, it is usually required that he make a deposit sufficient to cover the expense of the test, which deposit is to be returned to him if the meter be more than the allowable per cent fast. Upon receipt of such deposit the inspector should request the company to remove the meter in question and deliver it to him at the testing laboratory. It is often required that the company remove such meters only in the presence of the inspector or his deputy, and that the meter be officially sealed until tested. Such plan, of course, prevents the company from making alteration or readjustment of the meter before the official test is made; but it is doubtful whether such elaborate precaution is necessary in order to insure that the company will not alter the meter before delivery to the inspector.

More care must be exercised in handling a complaint meter, and it is usually desirable to make three comparisons with a prover to insure greater accuracy in its testing. The company and the complaining consumer should be notified as to the result of a complaint-meter test.

H. SPECIFIC GRAVITY DETERMINATION

The specific gravity (density relative to air) of illuminating gas is usually expressed as the ratio of the weight of a given volume of the gas to the weight of an equal volume of air, both being measured under the same conditions.

The measurement of gas by means of flow meters, requiring a knowledge of the density of the gas passing through the meter, has called attention to the need for accurate commercial methods of determining this property. At the present time this Bureau has in progress an investigation of the subject and expects in the near future to make definite recommendations as to apparatus and methods of operation. Although complete recommendations can not be given here, the preliminary results are such as to make desirable the mention of some important precautions for this work which have already been investigated.

The only absolute method for determining the density of a gas is that of direct weighing of a sample in a closed globe. All other methods give the specific gravity referred to some gas adopted as standard, usually air. The method of direct weighing is not adapted to commercial practice, so that comparison methods are in almost universal use. Weighing is of great value, however, in checking other methods. The comparison methods fall into two classes—indirect weighing methods and effusion methods.

The Lux balance is an instrument representative of the first class. So many descriptions of this balance and directions for its use are to be found in the textbooks on gas analysis and testing that it need not be described here. Other methods of this class also give promise of being useful and are now being investigated.

The effusion method is based upon the fact that the times required for the escape of equal volumes of two gases (under the same pressure) through the same small orifice are approximately proportional to the square root of the densities of the gases. Therefore, if the density of air is taken as unity, the specific gravity of the gas can be calculated as follows: $d=\frac{(t_g)^2}{(t_a)^2}$, where $(t_g)^2$ equals the square of the time required for the escape of the gas and $(t_a)^2$ is the square of the time required for the escape of the same volume of air.

The effusion process, as it occurs in the various forms of apparatus now in use, is not so simple as indicated by the square root relation given above. Quite a number of factors other than the density of the gases affect the relative rates of effusion. Of these may be mentioned thickness of orifice plate and size and shape of orifice, the pressure under which the gas effuses, the ratio of the specific heats, the viscosity of the gas, etc. The quantitative effect of several of these factors has not been determined as yet.

The character of the orifice used is a factor of prime importance. The plate in which it is made (usually platinum) should be as thin as practicable; platinum-iridium as thin as 0.02 mm can be used for this purpose. The orifice should be smooth and round without any projecting burr. The orifice should be as large as possible, giving consideration to the time of outflow necessary for the required accuracy of timing.

When water is used as the confining liquid in the effusion apparatus, considerable care must be exercised to eliminate, so far as possible, the error due to condensation of moisture in the orifice. Condensation is indicated by a decreasing rate of effusion as shown by an increase in successive times. This may be a serious source of error and should be guarded against by passing dry air or gas through the orifice before use as often as may be necessary. The orifice should never be dried by heating over a flame. The trouble due to condensation of moisture in the orifice is eliminated in those forms of apparatus which use mercury as a confining liquid.

It is important that the apparatus should always be operated with the same pressures at start and finish of the timing. The excess of pressure above atmospheric at the end of the time interval taken should not be less than 2 inches water pressure; preferably it should be somewhat greater. The initial pressure should not be too high, generally not over 20 inches of water pressure should be allowed.

In filling the apparatus with gas, it is essential that the method employed be such as to introduce a sample uncontaminated by air. It is probably better to fill the apparatus with gas which is practically at the temperature of the apparatus and which has been saturated with water vapor previous to its introduction into the apparatus, unless the gas is being measured dry or partially saturated in an apparatus using mercury. When the orifice tube is filled with air at the beginning of a run, the timing should not be begun until sufficient gas has passed through to sweep out all of this air.

For a specific gravity determination, several consecutive runs should be made on both gas and air. With a time interval less than two minutes, it is probably necessary to secure three or four intervals which agree within one-half of 1 per cent before the average can be considered as satisfactory. Any series of results in which the effusion time is constantly changing in one direction should be discarded.

In order to determine the degree of accuracy secured with any instrument under certain operating conditions, it is necessary to compare the results so obtained with the density of the same gas determined by an accurate weighing method. Apparatus calibrated in this manner may be used with some degree of satisfaction provided the physical properties of the gases tested do not differ greatly from those of the gas with which the calibration was made.

I. DEW POINTS OF THE GAS

Both the "water vapor dew point"[21] and the "oil dew point" are of interest in gas testing, as showing the lowest temperature to which the gas has been cooled and as confirming a test of candlepower or heating value which is low, due to such cooling. In any large gas-testing laboratory the water dew point should be taken occasionally and special test of this made whenever unusually low results for candlepower or heating value are found.

The apparatus commonly used for determination of the dew point of the gas consists essentially of two concentrically placed tubes, the gas entering the bottom of the outer tube and being drawn over and into the inner through a tube set into the latter, so that the gas must bubble through a short column of a volatile liquid which is contained in the inner tube. The passage of the gas evaporates the liquid, usually ether or petroleum ether, and cools the inner tube. The gas entering comes in contact with the outer surface of the tube thus cooled and when the dew point is reached dew deposits on this surface. If the apparatus is properly constructed, the temperature of this surface is practically the same as the liquid within; and, the latter temperature, as read by the inclosed thermometer when dew is just deposited, is the dew point. As it is somewhat difficult to determine just when the dew first appears, it is better to note both the temperature when it can first be seen and the temperature when it just disappears on warming in a stream of the gas, the average of the two being the dew point.

The rapid evaporation of the cooling liquid, produced by allowing the gas to bubble up through it, causes the temperature to fall rapidly; and it will generally fall below the proper point before enough dew is deposited to be noted. To avoid the necessity of always changing the temperature very slowly, preliminary observations are made to locate the dew point approximately, first lowering the temperature till the dew point appears and then allowing it to rise till the dew disappears. The apparent dew point will then be between these two temperatures; but it may be

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[21] Whenever the phrase "dew point" is used alone, the water vapor dew point is meant; the oil dew point should never be referred to without including the word "oil."

much nearer one of them than the other, depending on the rates at which the temperature rose and fell and on the amount of dew that was deposited. In succeeding readings the temperature should be lowered more slowly as the dew point is approached, and, if possible, less dew should be allowed to deposit, in order that it may disappear more quickly.

With low dew points there is very little vapor available for the formation of dew; and when there is any doubt as to whether the dew is being deposited therefore it is advantageous to keep a stream of gas flowing around the depositing surface while the surface is held at a constant temperature. If, because of the form of apparatus, the gas can not be made to flow around this surface without also flowing through the cooling liquid, then the flow can be cut down enough to stop the fall in temperature. When the dew is evaporating a stream of gas should continue to flow over the surface to make the evaporation take place at the proper temperature.

By more careful regulation of the rise and fall of the temperature the difference between the temperatures of appearance and disappearance of the dew is reduced till it is not much more than the allowable uncertainty in the dew point. The mean of these two temperatures is generally taken as the true dew point; and this is sufficiently accurate for all ordinary work in gas testing. But if these temperatures are close to gether, if the dew point is very low, and the temperature of disappearance has been sharply defined, then the temperature of disappearance of the dew will be nearer the true dew point. This process eliminates to some extent the effect of running past the proper temperatures before the appearance or disappearance of the dew is noted. But in very careful work, and especially where the dew is deposited on a thick vessel or on poorly conducting material, the temperature of the surface, and therefore the dew point, may be above the apparent temperature of disappearance—that is, above the temperature of the thermometer when the dew disappears. This effect is negligible for the ordinary determinations of the dew point of a gas; but it may amount to one or two degrees for low dew points, even on metal vessels, unless the metal is very thin or a specially good conductor of heat.

Since in practice the water vapor dew point is considerably higher than the oil dew point, it can be determined without precautions as to the oil. But to obtain the oil dew point the gas must be carefully dried. If the oil dew point is low and the gas is not sufficiently dried, a second water vapor dew point may be found for the drier gas instead of the oil dew point. The drying material must, therefore, be carefully watched, there must be a sufficient quantity of it, and the gas must not pass too rapidly through it. In case of doubt as to the correctness of the oil dew point found, it may be tested by drawing moist air through the drying tube and the dew point apparatus at the same rate at which the gas flowed and noting the dew point found. This will, of course, be the water-vapor dew point, and unless the rate of flow of the gas was excessively great it should not be far from the dew point of the partly dried gas. Unless the oil dew point found was above this by a safe amount, it should be tried again, using greater care in drying the gas.

J. DETERMINATION OF ATMOSPHERIC HUMIDITY

The humidity of the air may be determined by a psychrometer or by a dew-point instrument; or where a very large number of observations are to be made it may be advisable to have a hair hygrometer as an auxiliary instrument since it indicates the relative humidity directly. However, special precautions must be observed in the care and use of a hair hygrometer and such an instrument always requires frequent calibration by comparison with a psychrometer or dew-point apparatus.

In general, a psychrometer is preferable for all work, but where a dew-point instrument is available it can be used to determine humidity by drawing air through it and noting the dew point of the air in the same manner that the gas dew point is observed (see p. 180). From the dew point noted, the humidity can be determined from the data of Table 3, page 189. This method gives values accurate enough for ordinary testing.

The Assman aspiration psychrometer and the sling psychrometer are among the best forms of psychrometer; but any wet and dry bulb instrument if properly ventilated is practically equivalent to the sling instrument. The stationary wet and dry bulb form of hygrometer with proper tables may also be used as an unventilated instrument, if care is taken that the air about the bulb is still during the test. Most wet and dry bulb hygrometers that do not have forced ventilation seem to be furnished with charts or tables that are calculated for instruments that do have such special ventilation, and they are therefore often in error by 10 or 20 per cent in the relative humidity, unless the special ventilation is provided for as recommended here. For work of moderate accuracy these instruments can be used in still air if the relative humidity is read from Table 10, page 195, instead of from the one provided for the ventilated instrument.

In operation of any form of unventilated psychrometer care must be taken not to allow the cool air from the wet bulb to come near the dry bulb. The covering of the wet bulb must be kept clean, since grease or other foreign material of various sorts may prevent the proper wetting of the cloth or may retard the evaporation; and distilled water should be used in order to prevent the pores of the cloth becoming filled with deposits of various salts always present in ordinary water.

Care must be taken that the breath of the observer does not enter the ventilating current, and that the hands or other parts of the body are not kept near the bulbs of the thermometers. Direct radiation from flames or other hot objects must be screened off as completely as possible.

With the ventilated instruments the air should move past the wet bulb at a rate of at least 3 meters (about 10 feet) per second, but very high rates are not advisable. With the Assman instrument the fan (driven by clockwork) gives the proper rate, and in case of the sling instrument the proper rate of whirling is easily maintained. When using an unventilated psychrometer the air surrounding the wet bulb should be quiet, any draft from an outside source being serious.

To make a test with any of the forms, the wet bulb is moistened and the ventilating device (if any) is started. After about one-half minute, readings of the wet-bulb thermometer are taken at intervals of from 10 to 20 seconds, according to circumstances, and continued till successive readings show that the temperature of the wet bulb has stopped falling. The temperatures of both wet and dry bulb thermometers at this time are then recorded. It is best to read the dry-bulb thermometer several times also, both as a check on the final reading and to be sure that it is not changing. For medium or high humidities one or two minutes may be sufficient to secure satisfactory readings, but for low humidities a longer time will be required and special care may then be necessary to avoid errors caused by the drying out of the covering of the wet bulb. This bulb must still be wet when the final readings are taken.

The simplest form of the sling psychrometer consists of a wet and a dry bulb thermometer attached to a small frame at the upper end of which is a handle by which the whole instrument can be whirled. This form demands considerable skill in handling, both to avoid danger of breakage and to obtain readings immediately upon stopping the instrument, since the temperature of the wet bulb begins to rise as soon as the motion of the instrument is stopped. The psychrometer should be whirled with a steady uniform motion, keeping the hand nearly stationary, between two and three revolutions per second giving a satisfactory rate of ventilation.

The stopping of the instrument is the most difficult part of the operation. This can and should be done in a single revolution. By suddenly allowing the hand to follow the instrument up and out into a larger circular or spiral path the instrument can be brought to rest as it descends, and the wet-bulb reading noted within a second or two. The whirling should then be continued immediately in order to secure the successive readings, as noted above. The operation of whirling and stopping is very simple when the knack of doing it properly has once been obtained. When the instrument is mechanically whirled, as in some more elaborate forms, the handling of the instrument is, of course, very much simpler.

In reading the psychrometer for calorimetric work the readings should be made to the nearest 0.5° C (or nearest 1° F), but for photometric work more accurate observation of the two temperatures is desirable.

The hair hygrometer may be a valuable auxiliary instrument, as it is about as sensitive as a psychrometer, but it can not be depended upon to be correct when purchased. The old method of testing it at 100 per cent humidity by placing a wet cloth around the hair is entirely unsatisfactory, for the reason that the instrument is unreliable for some time after such treatment, and it may have the readings entirely changed. It must be kept and tested in the range of ordinary humidities, the testing being most easily done by comparing its readings with those obtained from a psychromter or a sensitive dew point instrument.

The hair hygrometer may undergo slow changes extending over long periods of time, and must, therefore, be recalibrated or checked from time to time. The frequency and extent of the checking required will depend on the particular instrument and on the conditions under which it is kept. In some cases the checking of a single point once in several weeks may be all that is needed, particularly if the checking is sometimes done at the lower and sometimes at the higher humidities. By this system of checking and the avoidance of exposure to humidities close to saturation accurate results may be obtained.

Calculation of Relative Humidity.—The charts given on pages 194 and 195 give the relative humidity corresponding to the wet and dry bulb thermometer readings, both for ventilated and unventilated instruments, reading either in centigrade or Fahrenheit degrees.

These charts are based on the following formulas

$$e = E' - Ab(t - t')$$

and

$$\text{Relative humidity} = \frac{e}{E} 100$$

in which t is the temperature of the air (dry bulb)
t' is the temperature of the wet bulb
E is the pressure of saturated water vapor at the temperature t
E' is the pressure of saturated water vapor at the temperature t'
e is the actual pressure of the water vapor in the air (partial pressure)
b is the height of the barometer
A is the "psychrometer constant" (0.000 662 for centigrade temperatures and a ventilated instrument).

For a barometer height of 755 millimeters (29.72 inches) the product AB becomes ½ (for a ventilated instrument reading in centigrade degrees) and the above formulas may be united into one:

$$\text{Relative humidity} = \frac{E' - \frac{1}{2}(t - t')}{E} 100$$

The relative humidity may thus be easily calculated with the aid of only a table of pressures of saturated water vapor at various temperatures.

Absolute Humidity Determination.—In photometric work the absolute humidity is expressed in liters of water vapor per cubic meter of dry air, both reduced to standard conditions. This can be calculated directly from the vapor pressures obtained from the psychrometer formula, by the equation·

$$h = \frac{e}{b - e} \times 1000$$

A chart to aid in calculation of the photometric correction for humidity direct from the psychrometer readings is given on page 196.

Correction for Barometric Pressure.—For calorimetric work it is not necessary to correct for the barometer reading when determining the atmospheric humidity, and for photometric work the effect of the barometer is shown on the chart of Appendix 11.

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APPENDIXES

APPENDIX 1

Approximate English-Metric Equivalents[22]

1 centimeter=0.3937 inch.
1 meter=1.094 yards.
1 cubic centimeter=0.0610 cubic inch.
1 cubic meter=35.31 cubic feet.
1 cubic centimeter=0.0338 liquid ounce.
1 liter=1.057 liquid quarts.
1 gram=15.43 grains.
1 gram=0.0353 ounce avoirdupois.
1 kilogram=2.2046 pounds avoirdupois.
1° centigrade=$\frac{9}{5}$ degrees Fahrenheit.
1 calorie=3.968 British thermal units.
1 calorie per cubic meter=0.1124 Btu per cubic foot.
1-mm Hg pressure=0.535 inch water pressure.

1 inch=2.540 centimeters.
1 yard=0.9144 meter.
1 cubic inch=16.39 cubic centimeters.
1 cubic foot=0.0283 cubic meter.
1 liquid ounce=29.57 cubic centimeters.
1 liquid quart=0.9463 liter.
1 grain=0.0648 gram.
1 ounce avoirdupois=28.35 grams.
1 pound avoirdupois=0.4536 kilogram.
1° Fahrenheit=$\frac{5}{9}$ degree centigrade.
1 British thermal unit=0.2520 calorie.
1 Btu per cubic foot=8.89 calories per cubic meter.
1-inch water pressure=1.87-mm Hg pressure.

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[22] A more complete list of equivalents of metric and customary units will be found in Circular No. 47 of this Bureau, and may be had upon application.

APPENDIX 2

Vapor Pressure of Water[23]

Temperature	Pressure	Temperature	Pressure	Temperature	Pressure
° C	mm Hg	° C	mm Hg	° C	mm Hg
0	4.58	20	17.5	40	55.3
5	6.54	22	19.8	50	92.5
10	9.21	24	22.4	60	149
12	10.5	26	25.2	70	234
14	12.0	28	28.4	80	355
16	13.6	30	31.8	90	526
18	15.5	35	42.2	100	760

[23] Data principally those of K. Scheel and W. Heuse, Annalen der Physik, 4th series, vol. 31, p. 715 (1910).

APPENDIX 3

Relative Humidity[24]

[This table gives the humidity of the air, for temperature (t) and dew-point (d), expressed in percentages of the saturation value for temperature (t)]

Depression of the dew-point (t—d)	Temperature of the air, t° F				Depression of the dew-point (t—d)	Temperature of the air, t° F			
	40°	60°	80°	100°		40°	60°	80°	100°
° F					° F				
0	100	100	100	100	12	61	65	67	69
1	96	97	97	97	15	53	58	60	63
2	93	93	94	94	18	46	51	54	57
3	89	90	91	91	20	42	48	51	53
4	86	87	88	89	25	33	39	42	45
5	82	84	85	86	30	26	32	35	38
6	79	81	82	83	36	19	24	28	31
7	76	78	79	81	42	14	18	22	25
8	73	75	77	78	48	10	13	18	20
9	70	72	74	76	54	7	10	13	16
10	67	70	72	73	60	5	7	10	13

[24] Smithsonian Meteorological Tables, 3d ed. (1907).

APPENDIX 4

Correction Factors for Gas Volume

[Multiply observed volume of saturated gas by factor to correct to volume of saturated gas at 30 inches of mercury pressure (32° F) and 60° F[25]]

Temperature	Total gas pressure—Inches of mercury												
	28.0	28.1	28.2	28.3	28.4	28.5	28.6	28.7	28.8	28.9	29.0	29.1	29.2
°F													
99	0.825	0.828	0.831	0.834	0.837	0.840	0.844	0.847	0.850	0.953	0.856	0.859	0.863
98	.828	.831	.834	.838	.841	.844	.847	.850	.853	.856	.860	.863	.866
97	.831	.834	.838	.841	.844	.847	.850	.853	.856	.860	.863	.866	.869
96	.834	.838	.841	.844	.847	.850	.853	.856	.860	.863	.866	.869	.872
95	.837	.841	.844	.847	.850	.853	.856	.860	.863	.866	.869	.872	.876
94	.841	.844	.847	.850	.853	.856	.860	.863	.866	.869	.872	.876	.879
93	.844	.847	.850	.853	.856	.860	.863	.866	.869	.872	.876	.879	.882
92	.847	.850	.853	.856	.860	.863	.866	.869	.872	.875	.879	.882	.885
91	.850	.853	.856	.859	.862	.866	.869	.872	.875	.878	.882	.885	.888
90	.853	.856	.859	.862	.866	.869	.872	.875	.878	.882	.885	.888	.891
89	.856	.859	.862	.865	.868	.872	.875	.878	.881	.885	.888	.891	.894
88	.859	.862	.865	.868	.872	.875	.878	.881	.884	.888	.891	.894	.897
87	.861	.865	.868	.871	.874	.878	.881	.884	.887	.890	.894	.897	.900
86	.864	.868	.871	.874	.877	.880	.884	.887	.890	.893	.897	.900	.903
85	.867	.870	.874	.877	.880	.883	.887	.890	.893	.896	.900	.903	.906
84	.870	.873	.876	.880	.883	.886	.890	.893	.896	.899	.902	.906	.909
83	.873	.876	.879	.883	.886	.889	.892	.896	.899	.902	.905	.909	.912
82	.876	.879	.882	.885	.889	.892	.895	.898	.902	.905	.908	.911	.915
81	.878	.882	.885	.888	.891	.895	.898	.901	.904	.908	.911	.914	.918
80	.881	.884	.888	.891	.894	.897	.901	.904	.907	.910	.914	.917	.920
79	.884	.887	.890	.894	.897	.900	.904	.907	.910	.913	.916	.920	.923
78	.887	.890	.893	.896	.900	.903	.906	.910	.913	.916	.919	.923	.926
77	.889	.892	.896	.899	.902	.906	.909	.912	.916	.919	.922	.925	.929
76	.892	.895	.898	.902	.905	.908	.912	.915	.918	.921	.925	.928	.931
75	.894	.898	.901	.904	.908	.911	.914	.918	.921	.924	.928	.931	.934
74	.897	.900	904	.907	.910	.914	.917	.920	.924	.927	.930	.933	.937
73	.900	.903	.906	.910	.913	.916	.920	.923	.926	.930	.933	.936	.939
72	.902	.906	.909	.912	.916	.919	.922	.926	.929	.932	.936	.939	.942
71	.905	.908	.912	.915	.918	.922	.925	.928	.931	.935	.938	.941	.945
70	.907	.911	.914	.917	.921	.924	.927	.931	.934	.937	.941	.944	.947
69	.910	.913	.917	.920	.923	.927	.930	.933	.937	.940	.943	.947	.950
68	.912	.916	.919	.922	.926	.929	.932	.936	.939	.942	.946	.949	.952
67	.915	.918	.922	.925	.928	.932	.935	.938	.942	.945	.948	.952	.955
66	.917	.921	.924	.928	.931	.934	.938	.941	.944	.948	.951	.954	.958
65	.920	.923	.927	.930	.933	.937	.940	.944	.947	.950	.954	.957	.960
64	.922	.926	.929	.932	.936	.939	.943	.946	.949	.953	.956	.959	.963
63	.925	.928	.932	.935	.938	.942	.945	.948	.952	.955	.959	.962	.965
62	.927	.931	.934	.937	.941	.944	.948	.951	.954	.958	.961	.964	.968
61	.930	.933	.936	.940	.943	.947	.950	.953	.957	.960	.964	.967	.970
60	.932	.936	.939	.942	.946	.949	.953	.956	.959	.963	.966	.969	.973

[25] Formula used: Correction factor $=\frac{(P-E)\,(60+459.4)}{(t+459.4)\,(30-0.5170)}$

P = total gas pressure
E = vapor pressure of water at t°
t = temperature of gas (°F)

APPENDIX 4—Continued

Correction Factors for Gas Volume—Continued

[Multiply observed volume of saturated gas by factor to correct to volume of saturated gas at 30 inches of mercury pressure (32° F) and 60° F[25]]

Temperature	Total gas pressure—Inches of mercury—Continued												
	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
°F													
99	0.866	0.869	0.872	0.875	0.878	0.882	0.885	0.888	0.891	0.894	0.897	0.900	0.904
98	.869	.872	.875	.879	.882	.885	.888	.891	.894	.898	.901	.904	.907
97	.872	.876	.879	.882	.885	.888	.891	.894	.898	.901	.904	.907	.910
96	.876	.879	.882	.885	.888	.891	.895	.898	.901	.904	.907	.910	.914
95	.879	.882	.885	.888	.892	.895	.898	.901	.904	.907	.911	.914	.917
94	.882	.885	.888	.892	.895	.898	.901	.904	.907	.911	.914	.917	.920
93	.885	.888	.892	.895	.898	.901	.904	.908	.911	.914	.917	.920	.923
92	.888	.891	.895	.898	.901	.904	.907	.911	.914	.917	.920	.923	.927
91	.891	.894	.898	.901	.904	.907	.910	.914	.917	.920	.923	.926	.930
90	.894	.898	.901	.904	.907	.910	.914	.917	.920	.923	.926	.930	.933
89	.897	.901	.904	.907	.910	.914	.917	.920	.923	.926	.930	.933	.936
88	.900	.904	.907	.910	.913	.916	.920	.923	.926	.929	.933	.936	.939
87	.903	.907	.910	.913	.916	.920	.923	.926	.929	.932	.936	.939	.942
86	.906	.910	.913	.916	.919	.922	.926	.929	.932	.935	.939	.942	.945
85	.909	.912	.916	.919	.922	.925	.929	.932	.935	.938	.942	.945	.948
84	.912	.915	.919	.922	.925	.928	.932	.935	.938	.941	.945	.948	.951
83	.915	.918	.922	.925	.928	.931	.934	.938	.941	.944	.948	.951	.954
82	.918	.921	.924	.928	.931	.934	.937	.941	.944	.947	.950	.954	.957
81	.921	.924	.927	.930	.934	.937	.940	.944	.947	.950	.953	.957	.960
80	.924	.927	.930	.933	.937	.940	.943	.946	.950	.953	.956	.960	.963
79	.926	.930	.933	.936	.940	.943	.946	.949	.952	.956	.959	.962	.966
78	.929	.932	.936	.939	.942	.946	.949	.952	.955	.959	.962	.965	.968
77	.932	.935	.938	.942	.945	.948	.952	.955	.958	.961	.965	.968	.971
76	.935	.938	.941	.944	.948	.951	.954	.958	.961	.964	.968	.971	.974
75	.937	.941	.944	.947	.950	.954	.957	.960	.964	.967	.970	.974	.977
74	.940	.943	.947	.950	.953	.957	.960	.963	.966	.970	.973	.976	.980
73	.943	.946	.949	.953	.956	.959	.963	.966	.969	.972	.976	.979	.982
72	.945	.949	.952	.955	.959	.962	.965	.969	.972	.975	.978	.982	.985
71	.948	.951	.955	.958	.961	.965	.968	.971	.975	.978	.981	.985	.988
70	.951	.954	.957	.961	.964	.967	.971	.974	.977	.981	.984	.987	.991
69	.953	.957	.960	.963	.967	.970	.973	.977	.980	.983	.987	.990	.993
68	.956	.959	.962	.966	.969	.973	.976	.979	.983	.986	.989	.993	.996
67	.958	.962	.965	.968	.972	.975	.979	.982	.985	.989	.992	.995	.999
66	.961	.964	.968	.971	.974	.978	.981	.984	.988	.991	.995	.998	1.001
65	.964	.967	.970	.974	.977	.980	.984	.987	.990	.994	.997	1.001	1.004
64	.966	.970	.973	.976	.980	.983	.986	.990	.993	.996	1.000	1.003	1.007
63	.969	.972	.975	.979	.982	.986	.989	.992	.996	.999	1.002	1.006	1.009
62	.971	.975	.978	.981	.985	.988	.992	.995	.998	1.002	1.005	1.008	1.012
61	.974	.977	.980	.984	.987	.991	.994	.997	1.001	1.004	1.008	1.011	1.014
60	.976	.980	.983	.986	.990	.993	.997	1.000	1.003	1.007	1.010	1.014	1.017

[25] Formula used: Correction factor $= \frac{(P-E)\,(60+459.4)}{(t+459.4)\,(30-0.5170)}$

P= total gas pressure
E= vapor pressure of water at $t°$
t= temperature of gas (°F)

APPENDIX 5

Corrections, in Btu, to be Applied to Observed Heating Values in Calculating Total Heating Values of Illuminating Gas (About 600 Btu)

[The tabular corrections are applicable when inlet water, air, gas, and products are all at approximately the same temperature and when the calorimeter is operated at normal rate of gas consumption. (See p. 59.)]

Temperature of room, etc.	Relative humidity of air									
	10 per cent	20 per cent	30 per cent	40 per cent	50 per cent	60 per cent	70 per cent	80 per cent	90 per cent	100 per cent
°F										
40	+ 2	+ 2	+ 1	+1	+1	+1	0	0	0	−1
45	+ 2	+ 2	+ 2	+1	+1	+1	0	0	0	−1
50	+ 3	+ 3	+ 2	+2	+1	+1	0	0	0	−1
55	+ 3	+ 3	+ 3	+2	+1	+1	+1	0	0	−1
60	+ 4	+4	+ 3	+2	+2	+1	+1	0	0	−1
65	+ 5	+ 4	+ 4	+3	+2	+2	+1	0	−1	−1
70	+ 6	+ 5	+ 4	+3	+3	+2	+1	0	−1	−2
75	+ 7	+ 6	+ 5	+4	+3	+2	+1	+0	−1	−2
80	+ 8	+ 7	+ 6	+5	+4	+3	+1	0	−1	−2
85	+10	+ 9	+ 7	+6	+4	+3	+2	0	−1	−3
90	+12	+10	+ 9	+7	+5	+4	+2	0	−2	−3
95	+14	+12	+10	+8	+6	+4	+2	0	−2	−4

APPENDIX 6

Corrections, in Btu, to be Applied to Observed Heating Values in Calculating Total Heating Value of Natural Gas (About 1000 Btu)

[The tabular corrections are applicable when inlet water, air, gas, and products are all at approximately the same temperature and when the calorimeter is operated at normal rate of gas consumption. (See T. P. 36, for discussion of these corrections)]

Temperature of room, etc.	Relative humidity of air									
	10 per cent	20 per cent	30 per cent	40 per cent	50 per cent	60 per cent	70 per cent	80 per cent	90 per cent	100 per cent
°F										
40	+ 4	+ 3	+ 3	+ 2	+ 2	+1	+1	0	0	−1
45	+ 4	+ 4	+ 3	+ 3	+ 2	+1	+1	0	0	−1
50	+ 5	+ 5	+ 4	+ 3	+ 3	+2	+1	0	0	−1
55	+ 6	+ 6	+ 5	+ 4	+ 3	+2	+1	0	−1	−1
60	+ 8	+ 7	+ 6	+ 4	+ 3	+2	+1	0	−1	−2
65	+ 9	+ 8	+ 7	+ 5	+ 4	+3	+2	0	−1	−2
70	+11	+ 9	+ 8	+ 6	+ 5	+3	+2	+1	−1	−2
75	+13	+11	+10	+ 8	+ 6	+4	+3	+1	−1	−3
80	+15	+13	+11	+ 9	+ 7	+5	+3	+1	−1	−3
85	+18	+16	+13	+11	+ 9	+6	+4	+1	−2	−4
90	+21	+19	+16	+13	+10	+7	+4	+1	−2	−5
95	+25	+22	+19	+15	+12	+8	+5	+1	−2	−6

APPENDIX 7

Emergent Stem Corrections to Readings of Outlet-Water Thermometers for Different Immersions of Thermometers in Calorimeter

[Table applicable when temperature of inlet water is approximately equal to room temperature.]

	Temperature rise of water	Temperature of room					
		50°	60°	70°	80°	90°	100°
	°F						
Thermometer immersed to 30° F..	10	+0.02	+0.03	+0.04	+0.05	+0.05	+0.06
	15	+ .04	+ .05	+ .06	+ .07	+ .09	+ .10
	20	+ .06	+ .07	+ .09	+ .11	+ .13	+ .15
Thermometer immersed to 40° F..	10	+ .01	+ .02	+ .03	+ .03	+ .04	+ .05
	15	+ .03	+ .04	+ .05	+ .06	+ .08	+ .09
	20	+ .04	+ .05	+ .07	+ .09	+ .11	+ .12
Thermometer immersed to 50° F..	10	+ .01	+ .01	+ .02	+ .03	+ .04	+ .05
	15	+ .02	+ .03	+ .04	+ .05	+ .07	+ .08
	20	+ .02	+ .04	+ .06	+ .07	+ .09	+ .11
Thermometer immersed to 60° F..	10	+ .00	+ .01	+ .02	+ .02	+ .03	+ .04
	15	+ .00	+ .01	+ .03	+ .04	+ .05	+ .06
	20	+ .00	+ .02	+ .04	+ .05	+ .07	+ .09

This table is not applicable if the emergent portion of the stem includes an enlargement in the capillary. Instead of using the above table, it will probably be somewhat more convenient to make out a stem-correction table for the particular outlet-water thermometer that is to be used with the calorimeter, the data for this separate stem-correction table being interpolated from the above table.

Suppose, for example, the outlet-water thermometer to be used was one that was immersed to the 30° F mark on the scale, and a stem-correction table were wanted for an 18° F rise in temperature, then from the above table we obtain the following stem-correction table:

Stem Correction for Outlet-Water Thermometer No. —

[Table applicable when inlet water is approximately at room temperature, when thermometer is immersed to the 30° F mark, and when the temperature rise is approximately 18° F]

Inlet-water temperature	Stem correction	Inlet-water temperature	Stem correction
°F	°	°F	°
50	0.05	80	0.09
60	.06	90	.11
70	.08	100	.13

In the same way a table could be made out for any outlet-water thermometer by interpolation in the general table. The table so prepared would apply for the particular point to which the thermometer was immersed and for the particular rise in temperature with which the observer had chosen to work.

APPENDIX 8

(*a*) Factors for Converting Observed Water Volume to Weight

[The observed volume, corrected for error of the graduate, and multiplied by the factor corresponding to the outlet-water temperature, is equal to the equivalent mass of water at 60° F]

Outlet-water temperature	Factor	Outlet-water temperature	Factor
°F		°F	
60	1.000	90	0.993
70	.998	100	.991
80	.995	110	.989

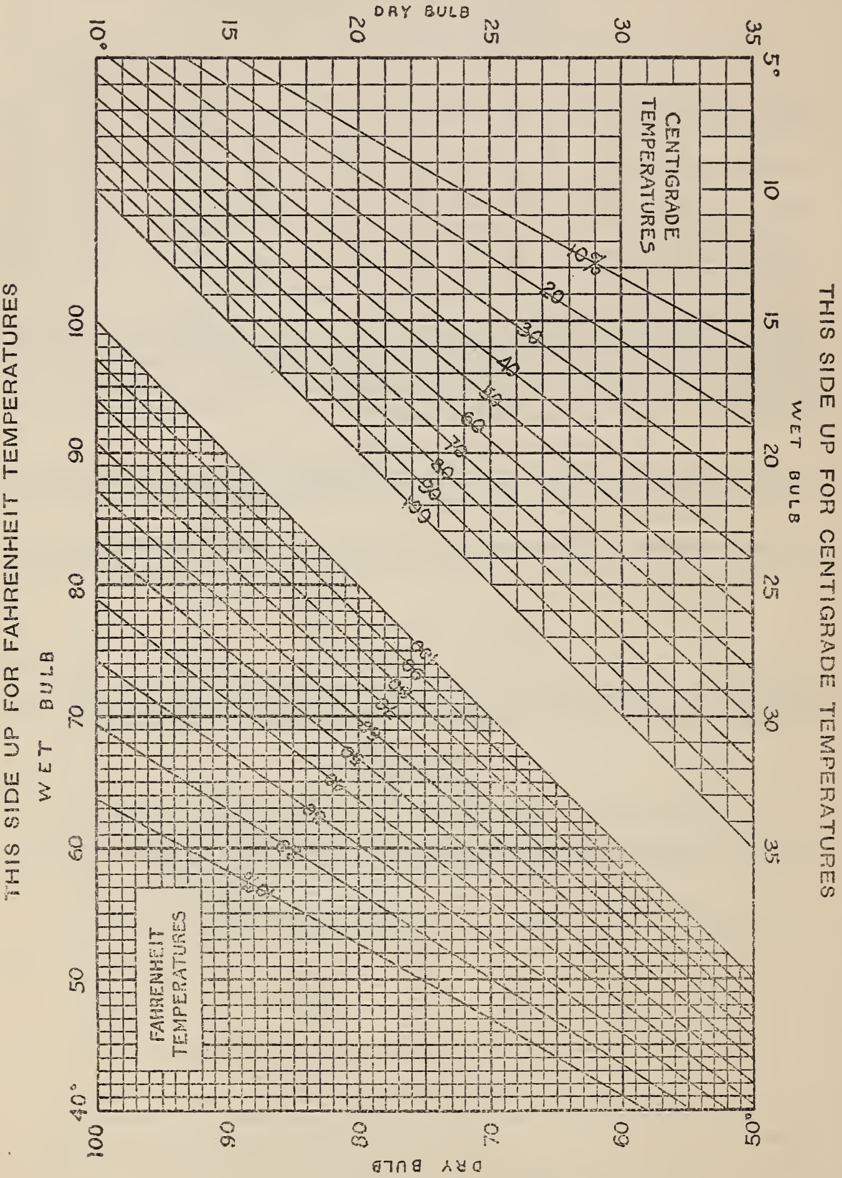
(*b*) Heat Capacity of Water

Temperature (° F)	50°	60°	70°	80°	90°	100°
Heat capacity of 1 cubic foot of water (Btu)	62.6	62.4	62.2	62.1	62.0	61.9

APPENDIX 9

Relative Humidity from Wet and Dry Bulb Thermometer Readings for Pyschrometer with Rapid Ventilation

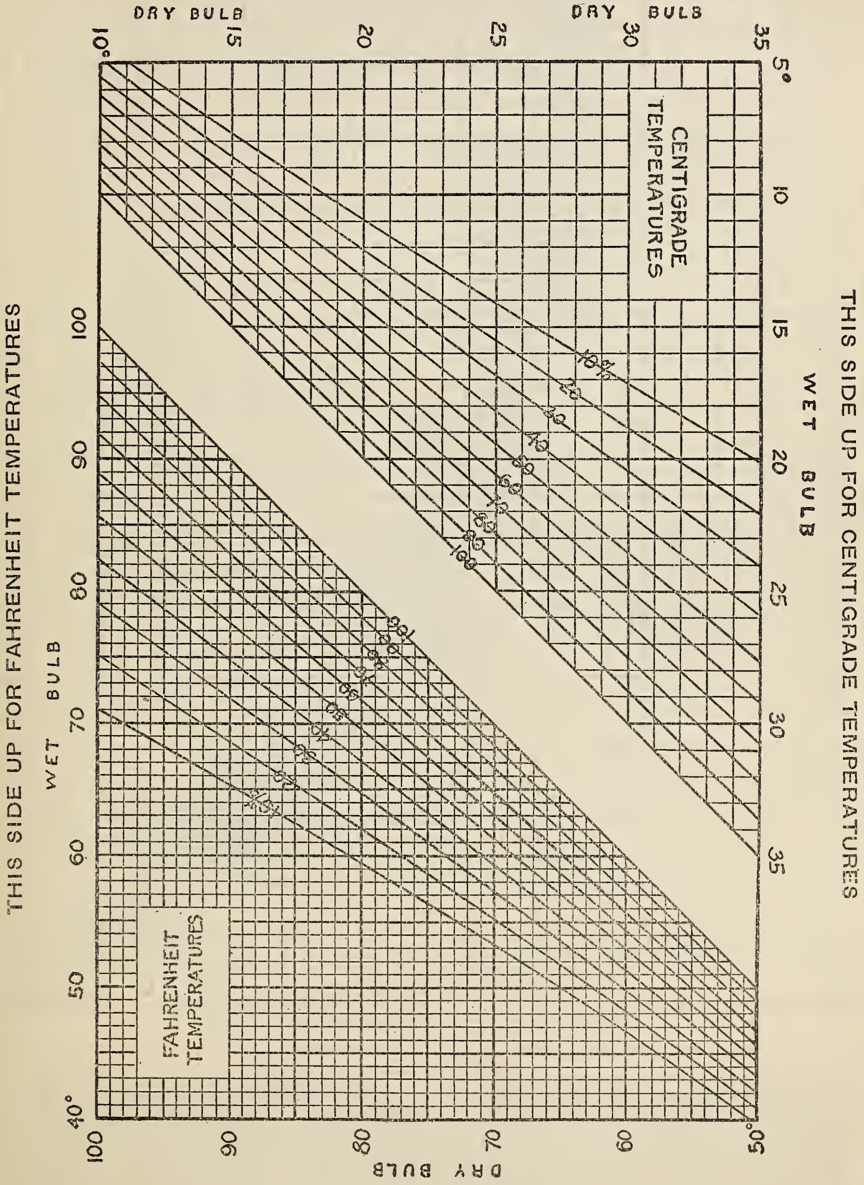
[Calculated for a barometer height of 755 mm. At altitudes of 6000 feet or over the reduction in barometric pressure will cause an error of 5 per cent or over at very low humidities.]



APPENDIX 10

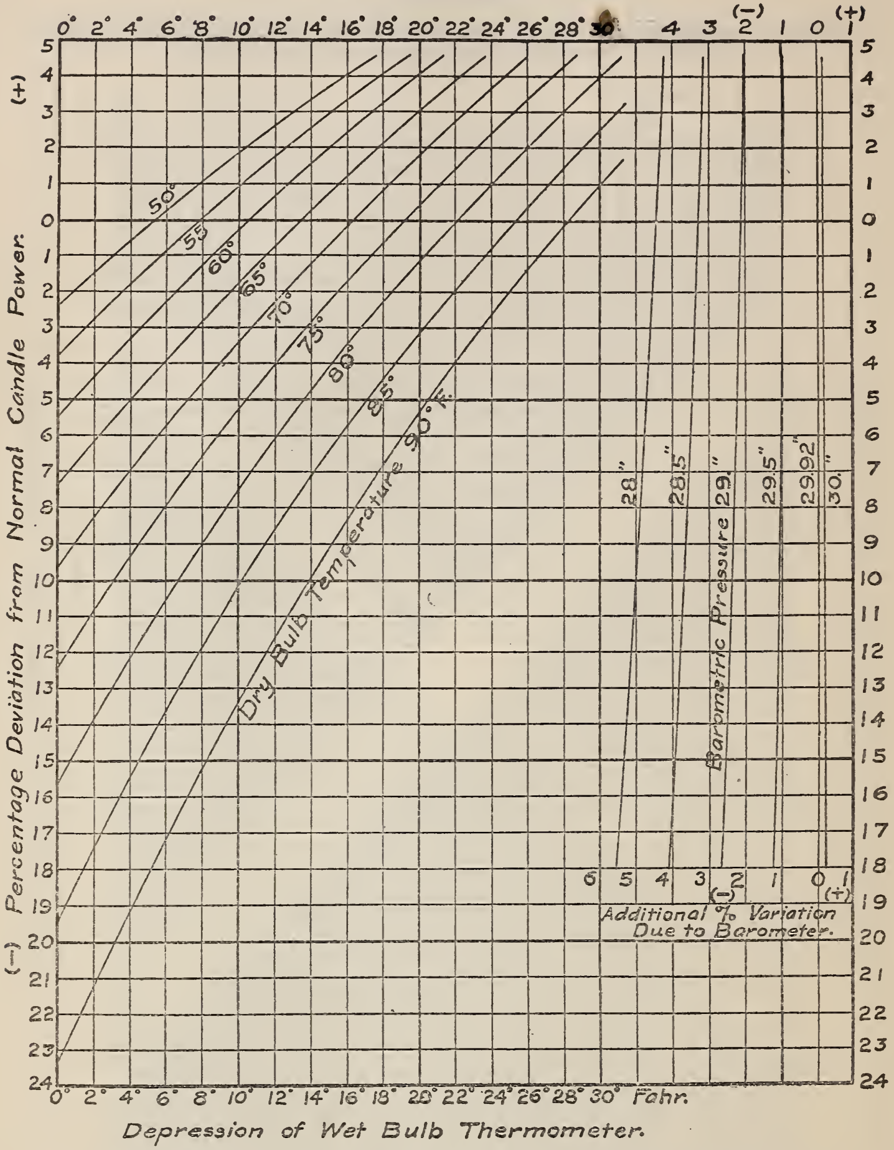
Relative Humidity from Wet and Dry Bulb Thermometer Readings in Still Air

[Calculated for a barometer height of 755 mm. At altitudes of 6000 feet or over the reduction in barometric pressure will cause an error of 5 per cent or over at very low humidities]



APPENDIX 11

Variation of Candlepower of Pentane Lamps with Humidity and Barometric Pressure

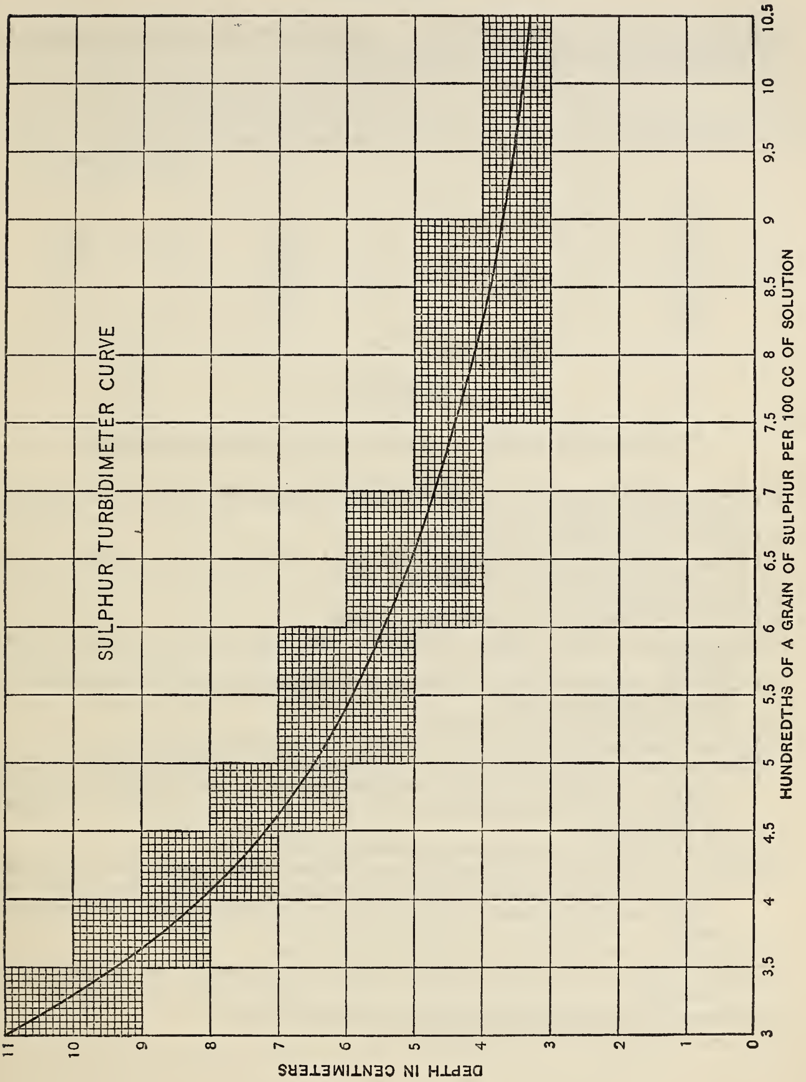


The curves at the left of the chart give the percentages of deviation from normal candlepower which correspond to the given temperatures and wet-bulb depressions when the barometric pressure is normal, which for the Pentane lamp is 760 mm. When the pressure is different from this, the additional deviation can be found from the curves at the right as follows: First, read off the deviation as if the barometer were normal, and note this; then from this point pass horizontally across the sheet to that curve at the right which represents the actual pressure. Vertically above or below the point at which this curve is reached will be found the amount to be added to the deviation as read from the first curves. This added amount is made up chiefly of the direct effect of pressure on the candlepower, but it includes also a proper allowance for the fact that the amount of water vapor which corresponds to a given pair of bulb readings depends somewhat on the barometer pressure.

The chart is plotted for the Pentane lamp, but it may be used for other flames without introducing serious errors. It would certainly be justifiable to measure gas flames, for instance, with electric standards and to correct the observed candlepowers to obtain normal values according to the chart. The barometric pressure corrections indicated are somewhat larger than proper, as judged by the most recent work; but the maximum deviation on this account would not exceed 1 per cent.

APPENDIX 12

Sulphur Turbidimeter Curve



APPENDIX 13

Corrections for Reduction of Barometric Heights to Standard Temperature (32° F)

[In the table are given, for barometric heights of 20, 25, and 30 inches, the amounts, in inches, to be subtracted from the observed readings of a barometer with brass scale, to reduce the heights, observed at various temperatures, to inches of mercury at 32° F]

Temperature	Observed barometric height, inches		
	20	25	30
F°			
40	0.02	0.03	0.03
50	.04	.05	.06
60	.06	.07	.09
70	.08	.09	.11
80	.09	.12	.14
90	.11	.14	.17
100	.13	.16	.19

APPENDIX 14

Summarized Operating Directions for Flow Calorimeters

(1) Free gas connections from old gas and burn one burner from this time continuously throughout the period of test.
(2) Observe temperature of laboratory.
(3) Adjust the gas meter for temperature, level, position of index relative to drum, water level, saturation of water with gas.
(4) Test for gas leaks.
(5) Adjust temperature of water in supply tank.
(6) Start flow of water through calorimeter and expel air from water circulation system.
(7) Light gas, adjust rate of gas consumption, adjust air mixer on burner, and insert burner into calorimeter.
(8) Adjust water flow and set damper.
(9) Allow time for establishment of a condition of thermal equilibrium.
(10) Prepare record sheet and make the preliminary observations of temperature and height of barometer, pressure and temperature of gas in meter, wet and dry bulb thermometer readings, temperature of products, and time of revolution of meter index.
(11) Begin collection of condensate and record meter reading.
(12) Take the first series of observations as follows: Make preliminary notation of water temperatures, shift water, observe series of water temperatures, shift water, make supplemental notation of water temperatures, and weigh the water.
(13) Take the second (and later) series of observations.
(14) Stop collection of condensate and record meter reading and amount of condensate.
(15) Repeat the preliminary observations of operation (10).
(16) Turn off gas and then turn off water.

APPENDIX 15

Corrections for Difference Between Inlet-Water Temperature and Room Temperature

[In this table are given the data from which to determine the amounts by which the total and the net heating values, calculated from the observed heating value as if the inlet water had been at room temperature, must be corrected on account of any difference in temperature between inlet water and room. The correction calculated from this table may be applied without sensible error to heating values of illuminating gas of about 600 Btu as determined with any of the flow calorimeters listed in this circular except the Doherty calorimeter. The correction is added if the inlet water is warmer than the room; subtracted if the inlet water is colder. See page 77 for an example of method of application of this data to the calculation. Incalculating the observed heating value, the stem corrections to both the inlet and outlet water thermometers must be taken into account when the inlet-water temperature differs from room temperature.]

Room temperature	Corrections in Btu per 1° F	
	For calculating total heating value	For calculating net heating value
°F		
50	0.5	0.4
60	.6	.4
70	.7	.4
80	.8	.4
90	.9	.5
100	1.0	.5

INDEX

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