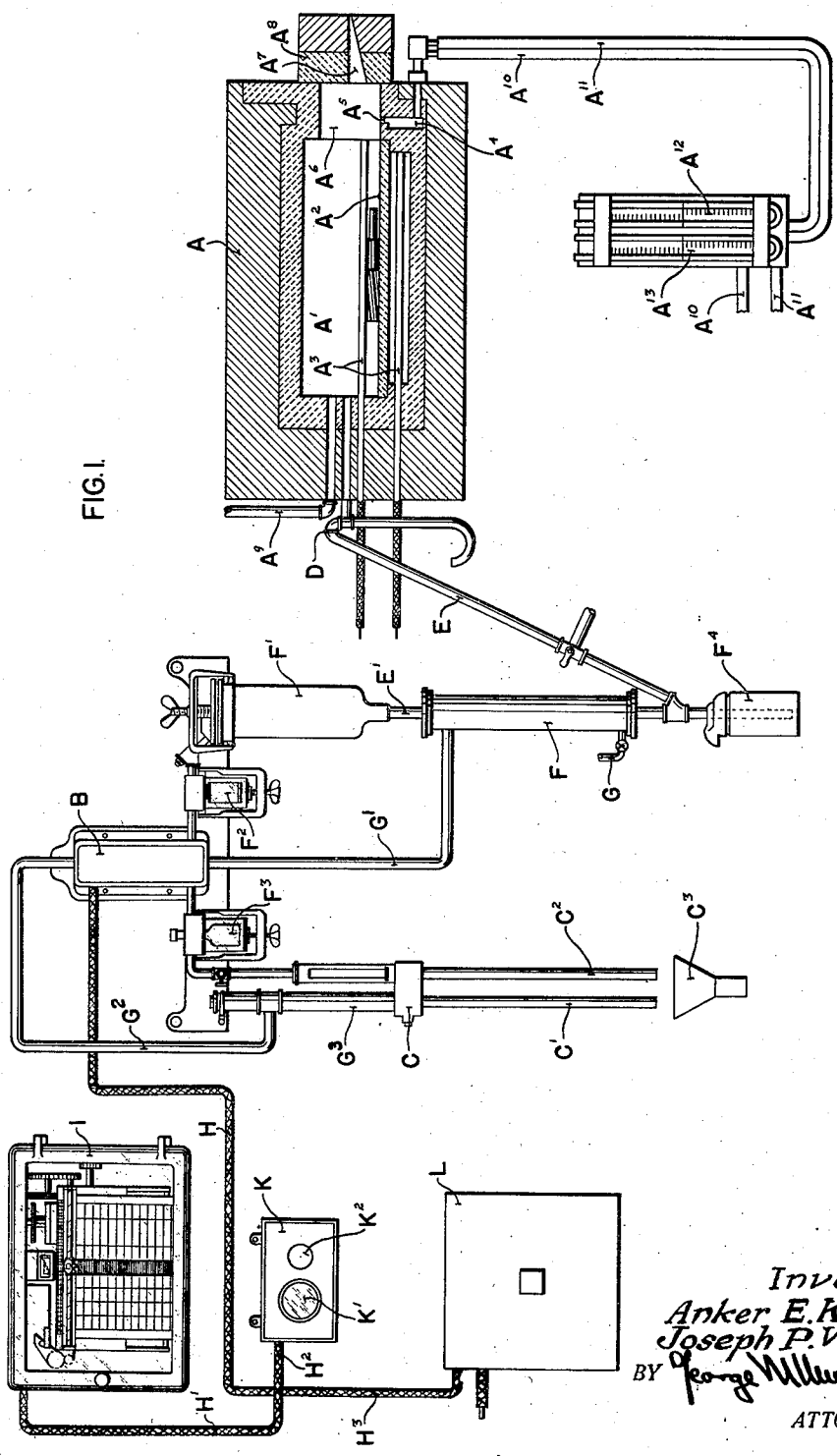
May 13, 1941. A. E. KROGH ET AL 2,241,555

GAS ANALYSIS APPARATUS

Filed May 22, 1937 3 Sheets-Sheet 1

FIG. I.



Inventors.
Anker E. Krogh,
Joseph P. Voltrath.
BY George M. Illmschamp
ATTORNEY

May 13, 1941. A. E. KROGH ET AL 2,241,555

GAS ANALYSIS APPARATUS

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FIG. 2.

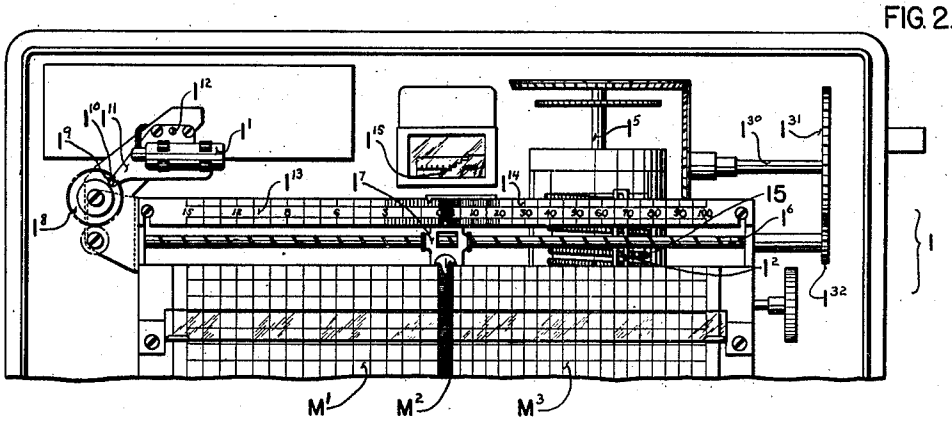
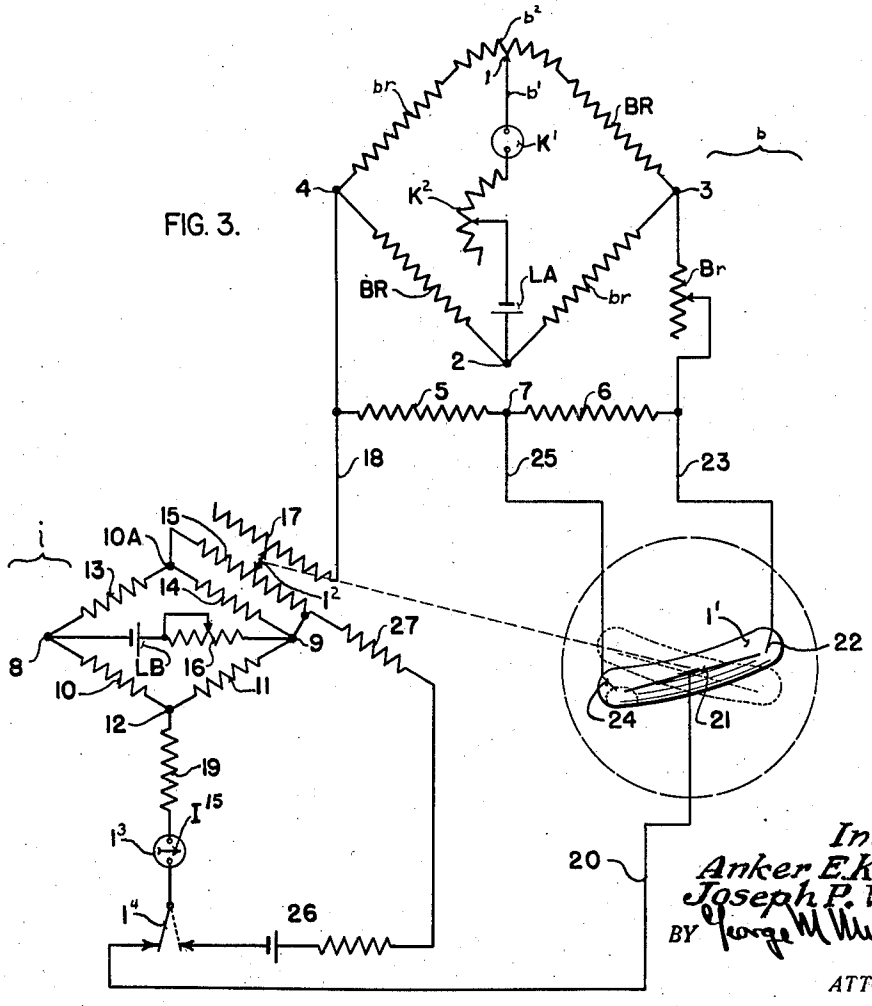


FIG. 3.



Inventors.
Anker E. Krogh,
Joseph P. Vottrath.
BY George M. Winschaup
ATTORNEY

May 13, 1941. A. E. KROGH ET AL 2,241,555

GAS ANALYSIS APPARATUS

Filed May 22, 1937 3 Sheets-Sheet 3

FIG. 4.

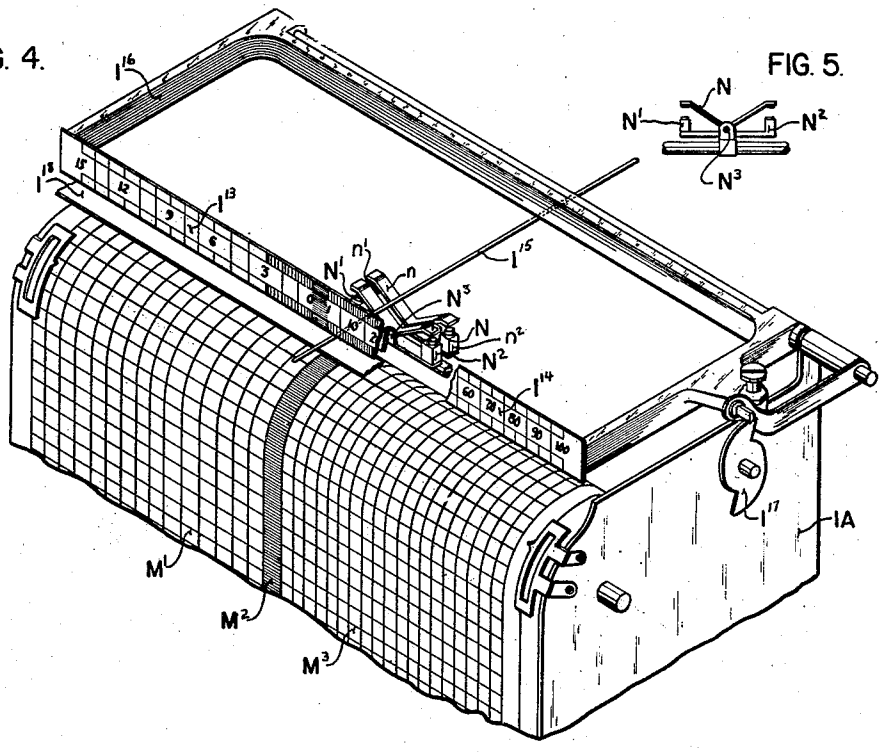


FIG. 5.

FIG. 6.

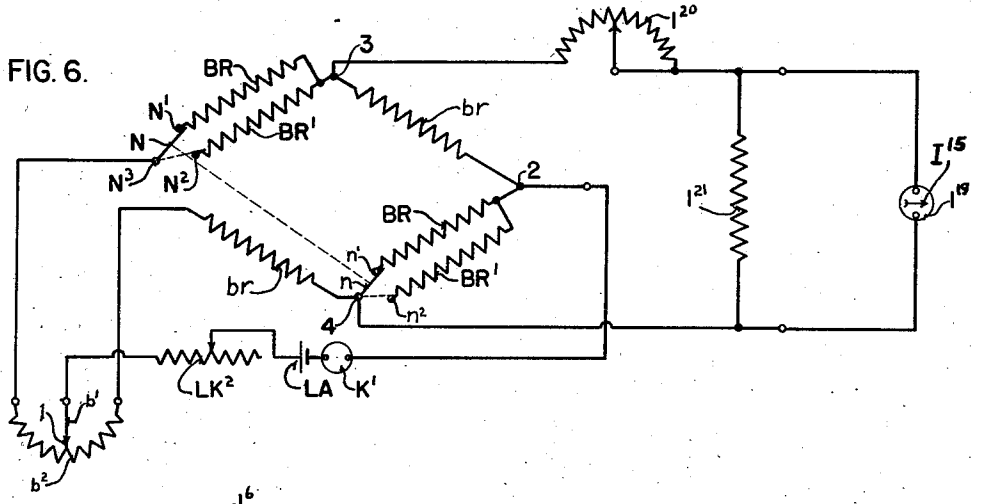
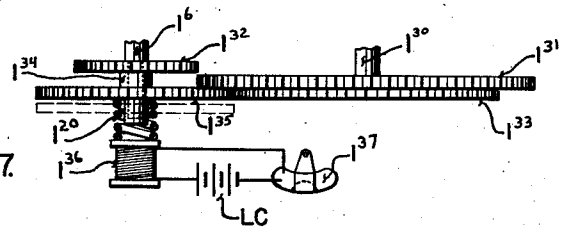


FIG. 7.



Inventors,
Anker E. Krogh,
Joseph P. Vollrath.
BY George M. Unverzagt
ATTORNEY

Patented May 13, 1941 2,241,555

UNITED STATES PATENT OFFICE

2,241,555

GAS ANALYSIS APPARATUS

Anker E. Krogh and Joseph P. Vollrath, Philadelphia, Pa., assignors to The Brown Instrument Company, Philadelphia, Pa., a corporation of Pennsylvania

Application May 22, 1937, Serial No. 144,288

13 Claims. (Cl. 73—51)

One general object of the present invention is to provide an improved means for gas analysis.

Another object of the invention is to provide a measuring instrument with simple and effective means for making measurements to one or another of two different scales, accordingly as the value of the quantity measured is above or below a certain intermediate value in the range of variation to which the instrument is adapted to respond.

A more specific object of the invention is to provide for the analysis of the atmosphere in the furnace chamber of a heat treating or analogous industrial furnace, by continuous measurement of the thermal conductivity of the gaseous mixture constituting said atmosphere in such manner as to furnish measurements which, in different portions of the range of measurement, are to different scales, specially adapted to facilitate the manual or automatic maintenance of a desired furnace chamber atmosphere.

It is now generally recognized that for the heat treatment of tools and for various other more or less analogous heat treating operations, it is practically important to surround the tool or other steel or metal object treated, by a fluid medium having certain special characteristics, the nature of which depends upon the composition of the article treated, and the character, and particularly the temperature of the treatment. For the ordinary heat treatment of steel tools, it is generally recognized that objectionable scaling will result from the envelopment of the tool undergoing treatment by an atmosphere which is definitely oxidizing, and that the tool may be injured by subjecting it to a carburizing action, or to a decarburizing action which does not necessarily result in scaling.

For some heat treatments of metals, it is possible to prevent oxidizing, carburizing, or decarburizing troubles by immersing the article treated in a suitable molten metal bath. In general, also, it is theoretically possible to conduct the treating operation with the article treated enveloped by a gas inert to said article at the temperature range of the treatment. Nitrogen, for example, is suitably inert for use in ordinary heat treatments of steel tools. It is not practically feasible, however, to use a special inert gas such as nitrogen for the bulk of the heat treatment and other operations, in which the composition of the furnace chamber atmosphere should be of a special character.

This has led to the development and extensive use of special furnaces each including provisions for maintaining a so-called controlled furnace atmosphere, by forming in, or introducing into, the furnace chamber, the gaseous products formed by the more or less complete combustion of some available combustible gas, such as Pyrofax, or ordinary city gas, or some other available fuel gas not too variable in its composition. The problem of operating such a furnace so as to secure the best practical results obtainable with it, has been difficult in the past because of the practical inability of the furnace operator to obtain the knowledge of the composition of the furnace atmosphere, needed to enable the operator to repeatedly establish and maintain the particular furnace atmosphere giving satisfactory results for the operator's particular purpose, and to avoid the furnace atmosphere conditions which give unsatisfactory results.

Some of the difficulties which operators of the controlled atmosphere furnaces have experienced, result from the fact that the composition of the furnace atmosphere may vary as a result of dissociation of gases, and particularly the liberation of H_2 from methane and ethane, as the furnace temperature is raised, even though the composition of the combustible gas supplied to form the furnace atmosphere and the gas and combustion air ratio be kept constant. Moreover, for many heat treatments, a furnace atmosphere which is mildly reducing is desirable, and such an atmosphere formed in the manner above described may, and ordinarily will, include both CO and H_2 and may also include CO_2, all of which gases in slightly different proportions, may also be found in furnace atmospheres sufficiently oxidizing to produce scaling.

There are various chemical methods of gas analysis theoretically available for use in determining the composition of the above mentioned control furnace atmospheres, but the known chemical methods, available for laboratory work, are not practically suitable for the use of the operators of controlled atmosphere furnaces. We have discovered, however, that it is practically possible for the furnace operators to obtain immediately useful and valuable knowledge concerning the composition of the above mentioned controlled furnace atmospheres, by measuring the thermal conductivity of the gaseous mixture constituting said atmosphere with the apparatus which we have devised for the purpose. That apparatus is characterized in particular by provisions for changing the measurement scale, as the thermal conductivity varies

from one side or the other of a certain intermediate value, so as to furnish suitably sensitive and accurate measurements both when the thermal conductivity of the furnace atmosphere is relatively low and when it is relatively high.

In the preferred practical embodiments of our invention, we take into account, and give effect to, the significance of appreciable amounts of CO_2 and H_2 in the furnace atmosphere. The thermal conductivity of CO_2 is less than six-tenths that of air. The thermal conductivity of H_2 is nearly seven times that of air. Oxygen, nitrogen and carbon monoxide have thermal conductivities differing only a few percent from that of air. In general, when a furnace atmosphere of the kind above mentioned has a thermal conductivity less than that of air, there has been substantially complete combustion of the combustible elements supplied to form the atmosphere, and the difference between the thermal conductivities of the furnace atmosphere and air is proportional to and forms a measure of the CO_2 content of the atmosphere. On the other hand, when the thermal conductivity of such a furnace atmosphere is significantly above that of air, the difference will be due to the presence of H_2 in the atmosphere, and will constitute a measure of the hydrogen content of the atmosphere.

In the preferred practical embodiment of our invention, we divide the deflection range of the measuring instrument into substantially equal high and low deflection sections, separated by a narrow intermediate section, and provide means for changing the scale of the measurements so that the low deflection section may be effectively utilized in determining the CO_2 content of the atmosphere, through the normal range of variation in that content from zero up to about 14%, and so that the high deflection section may be effectively utilized in measuring the hydrogen content of the atmosphere, which may vary from zero up to 100%, though in the normal intended use of most such furnaces, the hydrogen content will be substantially less than 100%.

Those skilled in the art will understand that in the use of any particular combustible gas to maintain a controlled furnace atmosphere in any particular furnace for any one particular heat treating operation, the furnace atmosphere composition should be maintained approximately constant, and may be so maintained by the use of the measuring apparatus which we have devised.

The various features of novelty which characterize our invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For a better understanding of the invention, however, its advantages, and specific objects attained with its use, reference should be had to the accompanying drawings and descriptive matter in which we have illustrated and described a preferred embodiment of the invention.

Of the drawings:

Fig. 1 is a diagrammatic view illustrating the use of the present invention in connection with a treating furnace of well known commercial type;

Fig. 2 is a partial front elevation of a recording potentiometer instrument included in the apparatus shown in Fig. 1;

Fig. 3 is a diagram illustrating a preferred measuring circuit arrangement for use in and as a part of the apparatus diagrammatically shown in Fig. 1;

Fig. 4 is a perspective view of a portion of a recording millivolt meter which may be used in lieu of the potentiometer instrument shown in Figs. 1 and 2, to record furnace atmosphere variations;

Fig. 5 is an elevation of a switch mechanism included in the instrument shown in Fig. 4;

Fig. 6 is a diagram of a portion of a measuring circuit arrangement including different test gas cell resistors for use in different portions of the measuring range; and

Fig. 7 is a view illustrating a portion of an instrument including changeable gear means for maintaining different measuring scales in different portions of the measuring range.

In Fig. 1, we have illustrated diagrammatically a preferred embodiment of the present invention used in analyzing the atmosphere in a furnace A, and in continuously indicating and recording the analysis results. The furnace A shown in the drawings is of a well known commercial type in extensive use for the heat treatment of tools and analogous metallic articles which while being treated, must be enveloped in an atmosphere of definite composition and closely controlled, to obtain the best heat treatment results. As shown, the metal tools or other parts treated are supported in the furnace chamber A', on a refractory support A^2, which extends across the chamber, and about which the furnace chamber atmosphere may circulate. Within the chamber are resistance bars or other suitable electric heating elements A^3.

A suitable atmosphere forming, fuel gas is burned in a precombustion chamber A^4, formed in the refractory housing of the chamber A', and from which products of combustion pass through a port A^5 into the throat A^6 of the chamber A'. The port A^5 is in the form of a narrow slot in the bottom wall of the throat. The combustion occurring in the chamber A^4 may be regulated to provide gaseous products of combustion having the composition desirably maintained in the chamber A'. Those products are discharged through the port A^5 in a sheet-like jet, forming a curtain extending across the throat A^6. Such a curtain is effective to prevent atmospheric air from passing into the furnace chamber through the peephole A^7, shown as formed in the door A^8 normally closing the outer end of the throat, and is also effective to prevent the influx of air when the door is opened. In the furnace conventionally illustrated, means are provided for increasing the volume of products formed in the chamber A^4 and discharged across the throat A^6, during each period in which the door A^8 is displaced from its normally closed position.

In addition to its curtain forming effect, the combustion gases discharged through the port A^6, displace objectionable atmospheric constituents which may be within the chamber A' at the beginning of a heat treating operation. Excess products of combustion escape from the chamber A through its vent outlet A^9. As shown, gas, and air for its combustion, are supplied to the chamber A^4 through pipes A^{10} and A^{11}, respectively, and A^{12} and A^{13} represent gages associated with the pipes A^{10} and A^{11}, respectively to provide measures of the rates of flow through the pipes, and guidance for the adjustment of valves controlling said rates of flow, so as to insure the desired composition for the products of composition.

The present invention is not limited to use in

connection with a furnace similar in type or kind to the furnace A, and the latter forms no part of the present invention, but the use to which such a furnace A is ordinarily put is one in which the present invention may be used with great advantage, so as to permit a highly efficient use of the special provisions made to control atmospheric conditions in the furnace chamber A'.

In the form shown in Fig. 1, the gas analyzing apparatus associated with the furnace A comprises an aspirator C constantly moving a stream of gas from the furnace chamber A' through the test cell or cells of a thermal conductivity comparison cell structure B, along a flow path comprising a sampling tube D, conduit sections E and E', and gas conditioning elements F, F', and F^2.

In many cases the exhaust gases from the equipment illustrated in Fig. 1 are obnoxious, inflammable or otherwise undesirable and under such circumstances we may dispense with the aspirator and provide a continuous pipe line from the outlet of the cell B back to the furnace A. A circulating pump may then be inserted in the said pipe line for drawing gases through connections D, E, F^4, F, E', F', F^2, B, F^3 and the pump back into the furnace. This method is desirable also from the standpoint of the maintenance of the desirable gas pressure and flow.

The comparison cell structure B can be of any usual or suitable type, and in particular it may, and will be herein assumed to be, of the type disclosed in the Harrison Patents 1,818,619 granted August 11, 1931, and No. 1,829,649 granted October 27, 1931, in which two test gas and two standard gas cells of cylindrical form, are arranged side by side in a one-piece metallic cell block, an electric current carrying resistor being arranged in each cell. In using such a cell structure in the arrangement of Fig. 1, the test gas withdrawn from the chamber A', is passed in separate parallel streams continuously through the two test gas cells, and the standard gas in the other two cells, may be air sealed in those cells. The two test cell resistors BR and the two standard cell resistors *br* are connected in a suitable measuring circuit, a preferred form of which is shown in Fig. 3, so that the changes in relative resistance of the resistors in the test and standard gas cells, due to differences in their temperatures produced by differences in the thermal conductivities of the test and standard gases, create potential changes in the circuit which can be measured.

In order that the composition of the gas in a heat treating furnace chamber such as the chamber A', may be determined with suitable accuracy, it is necessary to avoid contamination or modification in the composition of the gas as a result of the contact of the gas, while at a high temperature, with the walls of the flowpath. To this end, the sampling tube D may well be made of the refractory ceramic material known as sillimanite, and the adjacent section of the flowpath, for the length of 20 feet or so required to cool the gas down approximately to an atmospheric temperature, may well be in the form of a lead tube.

Accuracy of measurement requires that the test gas should pass through conditioning means by which the gas is brought to a certain standard condition, in respect to temperature, moisture content, and freedom from impurities, before entering the test cells, and that the general temperature of the test cell structure should be kept approximately constant. To these ends, the gas conditioning means illustrated in Fig. 1 comprise a gas cooler or condenser F, a gas dryer F', and a gas cleaning filter F^2. Backflow of air into the test cells through the aspirator C is prevented by a glycerin seal F^3. Liquid separating from the gas in the condenser F is received in a receptacle F^4 providing a liquid seal between the atmosphere and the gas space in the condenser. The condenser and cell structure B are cooled by water supplied by a pipe G to a cooling space in the condenser F, from which the water passes through pipe connections G', a cooling space in the cell structure B, and pipe portions G^2 and G^3, to the aspirator C, in which the water serves as the motive fluid for creating a suitable and suitably constant suction at the outlet of the seal F^3. The water, and the gas drawn by it into the aspirator C, escape from the latter through downwardly directed discharge pipes C' and C^2, the drip from which is received by a sump connection C^3.

The cable sections H, H', H^2 and H^3 shown in Fig. 1, include the conductors employed to operatively interconnect the cell resistors in the comparison cell structure B, the recording potentiometer instrument I, a control panel K, including a milliameter K' and a rheostat K^2 for maintaining the proper energizing current flow through the cell resistors, and a source of current L. The latter may be a battery, or in some cases it may advantageously be an A. C. adapter, energized from an alternating current supply source and including rectifying means and potentiometer or other means for impressing suitable direct current voltages on the cell resistors and the potentiometric instrument.

In the desirable cell resistor and measuring circuit arrangement shown diagrammatically in Fig. 3, the two test cell resistors BR of the cell structure B, are included in opposing arms of a Wheatstone bridge *b*, each of the other two arms of which include a corresponding one of the two standard gas cell resistors *br*. As shown, one of the two energizing junctions, **1**, of the bridge *b*, is the point of engagement of a calibrating switch arm *b'* with a slide wire resistance b^2. The latter connects one resistance BR in one, and one resistance *br* in the other of the two branches of the bridge circuit connecting the bridge energization junction **1**, to the second bridge energization junction **2**. The bridge energizing source of current, shown in Fig. 3 as a battery LA, the control panel ammeter K' and rheostat K^2, and the switch arm *b'* are connected in series with one another between the bridge energizing junctions **1** and **2**.

In operation, the rheostat K^2 is adjusted from time to time as required to maintain the bridge energizing current flow indicated by the ammeter K' at a predetermined normal value. The switch arm *b'* is adjusted along the slide wire resistance b^2 for calibration purposes, when and as may be desirable to insure the proper distribution of flow through the two bridge branches connecting the junctions **1** and **2**, when the various cell resistors are subjected to standard temperature conditions. On a change in composition producing a change in the thermal conductivity of the test gas, the resultant change in the resistance of the test cell resistors BR, produces changes in opposite directions in the potentials of the bridge junctions **3** and **4**. Those potential changes produce variations in the current flow in a circuit branch which connects

the bridge junctions 3 and 4, and includes two resistances 5 and 6, connected in series with one another. Normally the various resistors BR and *br* may be separately adjusted for purposes of circuit calibration, but such calibrating adjustments may be effected, if desired, by manipulation of a resistor B*r* inserted in the conductor 23.

By way of illustration it is noted that the potential of battery LA may desirably be 6 volts and that correspondingly suitable resistance values for the various bridge resistors may be as follows:

	Ohms
BR	2.5
br	2.5
b^2	.068
K^2	8
B*r*	30
5	15.7
6	5.72

The instrument I includes provisions for measuring either the potential drop in the resistance 5, or the total potential drop in the two resistances 5 and 6, accordingly as the thermal conductivity of the test gas is above or below a certain standard which is predetermined, and which, for the ordinary use of the apparatus shown, is the thermal conductivity of the standard gas. Whether the instrument I is in condition to measure the potential drop through the resistance 5, or the total potential drop through the resistances 5 and 6, depends upon whether an instrument switch I', shown as a mercury switch, is in its full line or in its dotted line position shown in Fig. 3. As hereinafter described, the switch is adjusted between its two positions by movement in either direction of the recording pen carriage I^7 of the instrument I through an intermediate portion of its range of movement.

The measuring circuit provisions of the instrument I in the form shown in Fig. 3 comprise a bridge *i*. The energizing junctions 8 and 9 of the bridge are connected by three circuit branches, one of which includes series connected resistances 10 and 11, their connection point 12 forming a third junction of the bridge *i*. A second circuit branch connecting junctions 8 and 9, includes a resistance 13 connecting the bridge junction 8 to the fourth bridge junction 10A. The latter is connected to the bridge junction 9 by resistances 14 and 15 in parallel with one another, the resistance 15 being the slide wire resistance of the instrument I. The third circuit branch connecting the junctions 8 and 9, is the bridge energizing branch including a source of current LB and a variable resistance 16.

The instrument contact I^2 which is moved along the slide wire resistance 15, in instrument rebalancing operations, is a bridging contact, connecting the resistance 15 to a slide wire resistance 17 alongside the resistance 15, and having one end connected by a conductor 18 to the junction 4 of the cell resistance bridge *b*, and to the corresponding end of the resistance 5. The instrument bridge junction 12 is connected through a resistance 19, the galvanometer I^3 of the instrument I, a normally closed switch I^4 and a conductor 20 to the middle terminal 21 of the switch I'. When the switch I' is in its position shown in dotted lines in Fig. 3, the terminal 21 is connected by the mercury within the switch container, to the right end contact 22 of the switch. The contact 22 is connected by a conductor 23 to the junction 3 of the cell resistor bridge, and to the corresponding end of the resistance 6. When the switch I' is in its full line position shown in Fig. 3, the mercury in the switch container connects the middle switch contact 21 to the left end contact 24. The latter is connected by a conductor 25 to the point 7 at which the resistances 5 and 6 are connected to one another.

The switch I^4 is the instrument calibrating switch. When the switch I^4 is adjusted into its dotted line position shown in Fig. 3, the instrument galvanometer pointer I^3 is disconnected from the switch I', and is connected in series with a standard cell 26 and a calibrating resistance 27 between the bridge junctions 9 and 12.

Whether the potential difference between the junctions 3 and 4 of the cell resistor bridge *b* will increase, or will decrease, as the thermal conductivity of the test gas increases, depends upon the relative resistances of the bridge arms including the different cell resistors, and is a matter of instrument design. If, for example, the resistance of each bridge arm including a cell resistor BR is greater than the resistance of the bridge arm in series therewith for all temperatures of the resistors BR within the measuring range, the temperatures and resistances of those resistors, and the potential difference between the bridge junctions 3 and 4, will progressively decrease as the thermal conductivity of the test gas increases throughout the measuring range. As hereinafter appears, in a major contemplated field of use of the invention, the possible increases in thermal conductivity of the test gas above that of the standard gas, are of much greater extent than the possible decreases below the standard gas thermal conductivity. For such use, the apparatus collectively shown in Figs. 1, 2, and 3, may advantageously be arranged to tilt the switch I' from its full line position into its dotted line position, or in the reverse direction as the thermal conductivity of the test gas respectively decreases below or rises above a certain predetermined intermediate value.

The instrument I shown in Figs. 1 and 2 is a self-balancing potentiometer of the commercial type known as the "Brown potentiometer," and a form of which is shown in the Harrison Patent No. 1,946,280, granted Feb. 6, 1934. That instrument comprises periodically actuated relay mechanism controlled by the deflection of the pointer I^{15} of galvanometer I^3 on a change in the quantity measured, to angularly adjust a shaft I^5 and thereby move the contact I^2 along the slide wire resistance 15 in the direction to rebalance the instrument and for a distance which is dependent upon the extent of galvanometer deflection starting the rebalancing operation. The angular adjustment of the shaft I^5 is attended by a corresponding angular adjustment of a helically grooved shaft I^6. The rotation of the latter adjusts a pen or marker carriage I^7 longitudinally of the shaft I^6 with which the carriage is in threaded engagement.

The rotation of the shaft I^6 thus moves the recorder carriage transversely of a record sheet or strip which includes low and high conductivity sections M' and M^3 at opposite sides of a narrow central section M^2. As the recorder carriage moves the recording element in one direction or the other across the strip M^2, the switch I' is tilted from its full line position into its dotted line position, or in the opposite direction, accordingly as the carriage movement is to the right or to the left as seen in Fig. 2.

The mechanism through which the switch I' is automatically actuated and the form and character of the switch employed to do what is done by the switch I' in the circuit arrangement shown in Fig. 3, may differ widely, and are not of the essence of the present invention. The switch I' is a single pole, double throw switch, and should be arranged to connect both end contacts **22** and **24**, to its contact **21** in each tilting operation so that at least one of the two circuits through the switch is always closed. In practice the single switch I' may well be replaced by similarly actuated single pole switches, one controlling the circuit including the conductor **25**, and the other the circuit including the conductor **23** of Fig. 3 in the manner in which those circuits are controlled by the switch I'. The two single throw switches, when used are arranged for such overlapping action that neither will open until the other is closed.

The switch I' of the instrument shown in Figs. 1 and 2, is actuated by the rotation of the shaft I^6, through mechanism devised by Coleman B. Moore, and disclosed fully and in detail in the application for patent Serial No. 144,320, filed of even date herewith. As shown herein, that mechanism comprises a disc like actuating element I^8 rotated by and in accordance with the rotation of the shaft I^6 and formed with a notch I^9 adapted to receive a projection I^{10} carried by a switch support I^{11}. The latter is mounted to oscillate about a supporting pivot I^{12} in fixed relation with the instrument framework. In effect, the disc I^8 with its notch I^9 and the switch support I^{11} with its projection I^{10} form a Geneva-gear mechanism for tilting the switch I' in one direction or the other as the marking element moves in one direction or the other across the record strip M^2.

In the mechanism disclosed in said Moore application the actuating element I^8 comprises two side by side notched disc elements rotated at different angular speeds by the shaft I^6, and having their individual notches brought into register to collectively form the notch I^9 of the element I^8, only when the pen carriage marking element is alongside the chart section M^2. Such a two disc arrangement permits an angular velocity of the element I^8 great enough to shift the switch I' between its full and dotted line positions, on a comparatively small movement of the pen carriage I^7, so that the record chart strip M^2 may be suitably narrow.

In the use of the apparatus shown in Figs. 1, 2, and 3, the pen carriage will be displaced to the right or to the left as seen in Fig. 1, by increases and decreases respectively, in the thermal conductivity of the test gas, but ordinarily, the position of the pen carried along its path of travel can be expected to directly furnish information of more direct and immediate importance than the mere thermal conductivity of the gas. Under the operating conditions most usual in furnaces of the type illustrated in Fig. 1, the measurements recorded on the record strip M' will be thermal conductivity measurements obtained when the combustion of the gas supplied to the chamber A^4 has been complete. The thermal conductivity of the test gas will then vary substantially in inverse proportion to its CO_2 content, and the scale portion I^{13} in register with the record strip M' may well be graduated and provided with scale marks to indicate the CO_2 percentage in the test gas.

Under the conditions described, the measurements on the chart strip M^3 will be measurements of the thermal conductivity of the test gas, obtained when that gas is reducing, and its thermal conductivity is high because of its H_2 content. In consequence the scale portion I^{14} in register with the chart strip M^3, may well be graduated and provided with scale marks to indicate the H_2 percentage of the gas. Whether the furnace chamber gas owes its reducing properties wholly or mainly to its H_2 content, or in substantial extent to its CO content, does not materially affect the value of the measurements given in terms of an assumed H_2 content. If that assumed content is higher or lower than the operator has found satisfactory for the work in hand, the operator will know that conditions will be improved by respectively increasing or decreasing the ratio of air to gas supplied to the chamber A^4.

Under the operating conditions assumed, in an intermediate portion of the range of thermal conductivity variation, where the H_2 content of the gas may vary only from a little less, to a little more than 1%, the thermal conductivity measurements do not give a reliable indication of the gas composition, and it is thus an advantage rather than a disadvantage to have the strip M^2 wide enough to cover the said intermediate range portion.

The above mentioned values for the various circuit resistances may advantageously be changed in accordance with the normal maximum H_2 content to be encountered in the furnace under measurement. For example, the values specified for the resistors **5** and **6** above renders the device suitable for H_2 values of the order of 8% maximum. Maximum H_2 values of 20% or 50% may be measured by substitution resistors **5** and **6** as follows:

	20% H_2	50% H_2
	Ohms	*Ohms*
5	18.1	19.4
6	3.29	2.08

It may be noted that the sum of the resistors **5** and **6** for various maximum H_2 values is approximately constant which is desirable for the maintenance of an approximately constant bridge circuit resistance thereby maintaining a substantially constant instrument measuring sensitivity.

In Figs. 4 and 5, we have illustrated an embodiment of the invention in which the measuring instrument IA is not a potentiometer instrument, but is a simple deflecting type of galvanometer, which might have its terminals connected to the junctions **3** and **4** of such a resistor cell bridge arrangement as is shown in Fig. 3, so that the galvanometer pointer I^{15} would deflect in direct response to the potential difference between said junctions. The instrument IA comprises a pivoted depressor I^{16} having its pointer engaging portion normally above the path of deflection of the galvanometer pointer I^{15}, but periodically lowered by the action of a constantly rotating cam I^{17} to depress the pointer I^{15} into a position in which it is supported by the record chart and its support. When the pointer is depressed it presses a carbon ribbon or other transfer medium I^{18} against the chart and thereby makes a record of the pointer position on the record chart strip. The latter is shown as comprising sections M', M^2, and M^3, like those shown in Fig. 2.

As the pointer I^{15} deflects across its mid posi-

tion, and is depressed by the action of the depressor I^{16}, it tilts a switch member N about its pivot axis N^3, in one direction or the other. When tilted counterclockwise, the switch member N engages a switch contact N', and when tilted clockwise, the switch member N engages a switch contact N^2. The switch member N remains in each position into which it is tilted, until tilted into the other of its two positions as a result of a corresponding change in the deflective position of the pointer I^{15}. As will be apparent, one terminal of the galvanometer including the pointer I^{15} may be connected to the bridge junction 4 of Fig. 3, with the other galvanometer terminal connected to the switch member N, and with the switch contacts N' and N^2 respectively connected to the bridge junction 3 and resistance connection point 7 of Fig. 3. In such case, the instrument IA will measure the thermal conductivity of the gas passing through the test cells to one scale when the gas is oxidizing, and to a different scale when the gas is reducing, in the general manner in which the different scale measurements are effected with the apparatus of Figs. 1, 2, and 3.

To adapt it for another use, the instrument IA is provided with a second switch *n*, like and coaxial with the switch N. With its two switches N and *n*, the galvanometer of the instrument IA may be used as the galvanometer I^{19} in the circuit arrangement shown in Fig. 6. In that arrangement the switches N and *n* are employed to change the measurement scale, by cutting one or the other of two pairs of test cell resistors into, and the other of the two pairs out of the measuring circuit, as the switches are actuated. To this end in the arrangement shown in Fig. 6, each test gas cell includes a resistor BR, and a second resistor BR' having a resistance value definitely different from that of the resistor BR. The gas analysis bridge of Fig. 6 is like the bridge *b* of Fig. 3, in respect to the relative arrangement of the resistors BR and *br*. In the bridge of Fig. 6, however, the switch N is arranged to connect the bridge junctions 1 and 3 either through the corresponding resistor BR or the adjacent resistor BR', and the switch *n'*, similarly connects the bridge junctions 2 and 4 either through the corresponding resistor BR or adjacent resistor BR'. The switch member *n* is directly connected to the bridge junction 4.

One terminal of the galvanometer I^{19} is connected to the bridge junction 4, and the other galvanometer terminal is connected to the bridge junction 3 through an adjustable instrument resistance I^{20}. As shown, the galvanometer is shunted by a resistance I^{21}. The operation of the form of the invention illustrated collectively by Figs. 4, 5, and 6, will be plainly apparent from what has already been said. As the galvanometer pointer I^{15} deflects through its midposition with the result that the switches N and *n* are tilted in one direction or the other, the extent of the deflection of the galvanometer pointer produced by a given extent of change in the thermal conductivity of the test gas will be altered.

The measuring scale change which is effected by one measuring circuit change in Fig. 3, and by a different measuring circuit change in Fig. 6, may be effected in still different ways. In particular, it may be effected by mechanical adjustments of the measuring apparatus. Thus, for example, in an instrument of the general character shown in Fig. 2, the scale change may be effected by adjustment of the mechanism shown in Fig. 7, through which the angular speeds of the shafts I^5 and I^6 are related. As shown in Fig. 2, the shafts I^5 and I^6, are geared together for simultaneous and proportional rotative movements, by means including a shaft I^{30} connected to the shaft I^5 by bevel gears, and connected to the shaft I^6 by spur gears I^{31} and I^{32}, respectively carried by the shafts I^{30} and I^6.

In Fig. 7, the shaft I^{30} carries a second spur gear I^{33} alongside the gear I^{31} and of appreciably smaller pitch diameter. In Fig. 7, the gear I^{32} is connected by a hub portion I^{34} to a larger gear I^{35} and the two gears are splined for axial movement on the shaft I^6. Their movement in one direction brings the gear I^{32} into mesh with the gear I^{31}, while their movement in the opposite direction brings gear I^{35} into mesh with the gear I^{33}.

As will be apparent with the modification illustrated in Fig. 7, a given change in the thermal conductivity of the test gas will result in a greater or lesser angular adjustment of the shaft I^6, accordingly as the gears I^{31} and I^{32} or the gears I^{33} and I^{35} are in mesh. As shown, a spring I^{20} tends to hold the gears I^{33} and I^{35} in mesh, but the action of the spring is neutralized, and the gears I^{31} and I^{32} may be brought into mesh by the energization of an electro-magnet I^{36}. The latter is energized by current supplied by battery LC, when the energizing circuit is closed by a switch I^{37}, which may form part of a measuring instrument like that shown in Fig. 2, or that shown in Fig. 4, and be operated generally as is the switch I' of the first mentioned instrument or the switch N or *n* of the second mentioned instrument.

While in accordance with the provisions of the statutes, we have illustrated and described the best forms of embodiment of our invention now known to us, it will be apparent to those skilled in the art that changes may be made in the form of the apparatus and procedure disclosed, without departing from the spirit of our invention as set forth in the appended claims, and that in some cases certain features of our invention may be used to advantage without a corresponding use of other features.

Having now described our invention, what we claim as new and desire to secure by Letters Patent, is:

1. Apparatus for determining the composition of a controlled furnace atmosphere containing gases formed by the more or less complete combustion of air and a fuel gas, comprising in combination with means including test and standard cells for creating a potential difference varying as the thermal conductivity of said atmosphere is varied, a deflectable element, associated measuring means responsive to said potential difference for causing said element to deflect in accordance with changes in said thermal conductivity and including adjustment means automatically actuated as said potential difference attains a certain intermediate value, to adjust said apparatus for deflection of said element through approximately one half of its deflective range in response to the change in the thermal conductivity of said atmosphere produced by a variation in its hydrogen content and for deflection of said element through substantially all of the remainder of its deflection range in response to the change in the thermal conductivity

of said atmosphere produced by a variation in its CO_2 content.

2. Measuring means for determining the composition of a controlled furnace atmosphere containing gases formed by the more or less complete combustion of air and a fuel gas comprising in combination a measuring circuit including test and standard cell resistors for creating a potential difference varying as the thermal conductivity of said atmosphere is varied, and deflecting means responsive to and deflecting in accordance with said potential difference, and adjustment means automatically actuated as said potential difference passes through a certain intermediate value to adjust said measuring means for deflection of said element through approximately one half of its deflective range in response to the change in its thermal conductivity produced by a variation in the hydrogen content of said atmosphere from zero to approximately 100%, or for deflection through substantially all of the remainder of its deflection range in response to the change in thermal conductivity produced by a variation in the CO_2 content from zero to 14%.

3. Measuring means for determining the comparison of a controlled furnace atmosphere formed by the gaseous resultant of the more or less complete combustion of air and a fuel gas, comprising in combination a measuring circuit including test and standard cell resistors for creating a potential difference varying in accordance with changes in the thermal conductivity of said atmosphere, an element adapted to deflect in accordance with changes in said potential difference, and adjustment means including a switch mechanism operated by the deflection of said element through an intermediate portion of its range of deflection for adjusting said measuring means into one or the other of two operating conditions, accordingly as said element moves in one direction or the other through said intermediate position, said measuring means being operable when in one of its conditions, to effect deflection of said element through a substantial portion of its total range of deflection on a thermal conductivity change corresponding to an increase in the CO_2 content of said atmosphere from zero to approximately 14% and being operable in the second of said conditions to effect deflections of said element through second portion of its range of deflection of no greater extent than the first mentioned portion, as the hydrogen content of the atmosphere increases from zero to a percentage substantially greater than 14%.

4. In a measuring instrument, the combination with a measuring circuit comprising points having their relative potentials varied by a change in the value of a quantity measured, mechanism responsive to variations in the relative potentials of said points and actuated thereby to respond to variations in the quantity measured, of an exhibiting member moved by said mechanism progressively in one direction along a path of deflection on a progressive variation of said quantity in one direction through a measurable range of variation, and means actuated by said mechanism to adjust said measuring circuit as required to vary the ratio of the movement of said member to the change in said quantity on the attainment by the latter of a certain intermediate value, whereby measurements of said quantity are made to one scale, or to a second scale, accordingly as the value of said quantity is below, or above, said intermediate value.

5. In a measuring instrument, the combination with a measuring circuit comprising points having their relative potentials varied by a change in the value of a quantity measured, mechanism responsive to variations in the relative potentials of said points and actuated thereby to respond to variations in a quantity measured, of a member moved progressively by said mechanism in one direction along a path of deflection on a progressive variation of said quantity in one direction through a measurable range of variation, and means actuated by the movement of said member through a position corresponding to an intermediate value of the latter, to adjust said measuring circuit as required to vary the ratio of the movement of said member to the change in said quantity, whereby the measurements of said quantity are made to one scale, or to a second scale, accordingly as the value of said quantity is below, or above, said intermediate value.

6. In a measuring instrument, the combination with means for measuring a varying quantity, of a member adapted to be moved by said means in proportion to the changes in said quantity as the latter varies through a measurable range of variation, an exhibiting element, an operative connection between said member and said exhibiting element through which movements of said member gives movements to said exhibiting element, and means actuated by said first mentioned means to adjust said operative connection to maintain different proportions between movements of said member and said exhibiting element accordingly as said quantity is in a lower or in an upper portion of said range.

7. In thermal conductivity measuring apparatus, the combination with a circuit network comprising comparison and test gas cell resistors and means for creating a current flow through said resistors, of a self-balancing potentiometer for measuring the difference in potential between points in said network the relative potentials of which vary in response to changes in test cell resistor resistance, comprising slide wire resistance means including a part adjustable to rebalance the potentiometer, a shaft rotatable in correspondence with the adjustments of said part, an element deflected by the rotation of said shaft to an extent and in a direction depending on the magnitude and direction of rotation of the shaft, and adjusting means including an electric switch mechanism actuated by the rotation of said shaft to increase or decrease the magnitude of the rebalancing adjustment of said part required to compensate for a given change in the thermal conductivity of the test cell atmosphere accordingly as the latter conductivity is less than or exceeds a predetermined amount.

8. In thermal conductivity measuring apparatus the combination with a circuit network comprising comparison and test gas cell resistors and means for creating a current flow through said resistors, of means for measuring the difference in potential between points in said network, the relative potentials of which vary in response to changes in test cell resistor resistance, comprising a galvanometer connected to said network and deflecting in correspondence with the changes in test cell resistor resistance, mechanical relay means periodically actuated to engage and depress said pointer and a switch mechanism adapted to be actuated in one or the other of

two ways, by depression of the pointer when the latter moves in one direction or the other through an intermediate portion of its range of deflection and means through which the actuation of said switch mechanism in one direction or the other increases or decreases the extent of galvanometer deflection produced by a given change in the thermal conductivity of the atmosphere in the test cell.

9. Apparatus for determining the thermal conductivity of a controlled furnace atmosphere containing gases formed by the combustion of a fuel gas including carbon and hydrogen constituents, comprising an electric circuit network including a resistor varying in resistance with the thermal conductivity of the atmosphere, means for creating an electric current flow in said network, a deflecting element, means operatively connecting said element to said network to deflect in response to changes in the resistance of said resistor, and adjusting means actuated by the deflection of said element through an intermediate portion of its range of deflection for adjusting said apparatus to effect a magnitude of deflection of said element in response to a given extent of change in the thermal conductivity of said atmosphere, which is greater in the portion of said range at one side than in the portion of said range at the other side of said intermediate portion.

10. Apparatus for determining the thermal conductivity of a controlled furnace atmosphere containing gases formed by the combustion of a fuel gas including carbon and hydrogen constituents, comprising comparison cells and resistors therein, a deflecting element operatively connected to said resistors and thereby caused to deflect as the thermal conductivity of the atmosphere varies through a certain range, and means actuated by the deflection of said element occurring on a change in said atmosphere between a reducing and an oxidizing condition for adjusting said apparatus to effect a deflection of said element on a given change in the thermal conductivity of the atmosphere which is substantially greater when the atmosphere is in an oxidizing condition than when it is in a reducing condition.

11. Apparatus for determining the thermal conductivity of a controlled furnace atmosphere containing gases formed by the combustion of a fuel gas including carbon and hydrogen constituents, comprising an electric circuit network including a resistor varying in resistance with the thermal conductivity of the atmosphere, means for creating an electric current flow in said network, a deflecting element, means operatively connecting said element to said network to deflect in response to changes in the resistance of said resistor, and adjusting means actuated by the deflection of said element to adjust said apparatus for a magnitude of deflection of said element in response to a given extent of change in the thermal conductivity of said atmosphere which is greater in the portion of the range of deflection of said element in which the thermal conductivity of said atmosphere is primarily dependent on its CO_2 content, than in the range portion in which the thermal conductivity of the atmosphere is primarily dependent on its H_2 content.

12. In thermal conductivity measuring apparatus, the combination with a circuit network comprising comparison and test gas cell resistors and means for creating a current flow through said resistors, of a self-balancing potentiometer for measuring the difference in potential between points in said network, the relative potentials of which vary in response to changes in test cell resistor resistance, comprising slide wire resistance means including a part adjustable to rebalance said potentiometer, a deflecting element, a mechanical connection between said part and element adjustable to vary the extent of element deflection produced by a given adjustment of said part, said mechanical connection including a shaft rotatable to effect the deflection of said element, and means actuated by said shaft to an extent and in a direction depending on its rotation to adjust said mechanical connection as the thermal conductivity of the test cell atmosphere varies through a certain intermediate value, to increase or decrease the extent of element deflection produced by a given change in the thermal conductivity of the test cell atmosphere, when said conductivity is less than or exceeds a predetermined amount.

13. Apparatus for determining the composition of a controlled furnace atmosphere containing gases formed by the more or less complete combustion of air and a fuel gas, comprising in combination with means including test and standard cells for creating a potential difference varying as the thermal conductivity of said atmosphere is varied, a deflectable element, associated measuring means responsive to said potential difference for causing said element to deflect in accordance with changes in said thermal conductivity and including adjustment means automatically actuated as said potential difference attains a certain intermediate value, to adjust said apparatus for deflection of said element through a substantial portion of its deflective range in response to the change in the thermal conductivity of said atmosphere produced by a variation in its hydrogen content and for deflection of said element through substantially all of the remainder of its deflection range in response to the change in the thermal conductivity of said atmosphere produced by a variation in its CO_2 content.

ANKER E. KROGH.
JOSEPH P. VOLLRATH.