THESIS TRACEINGS

OF

ARTHUR STERT

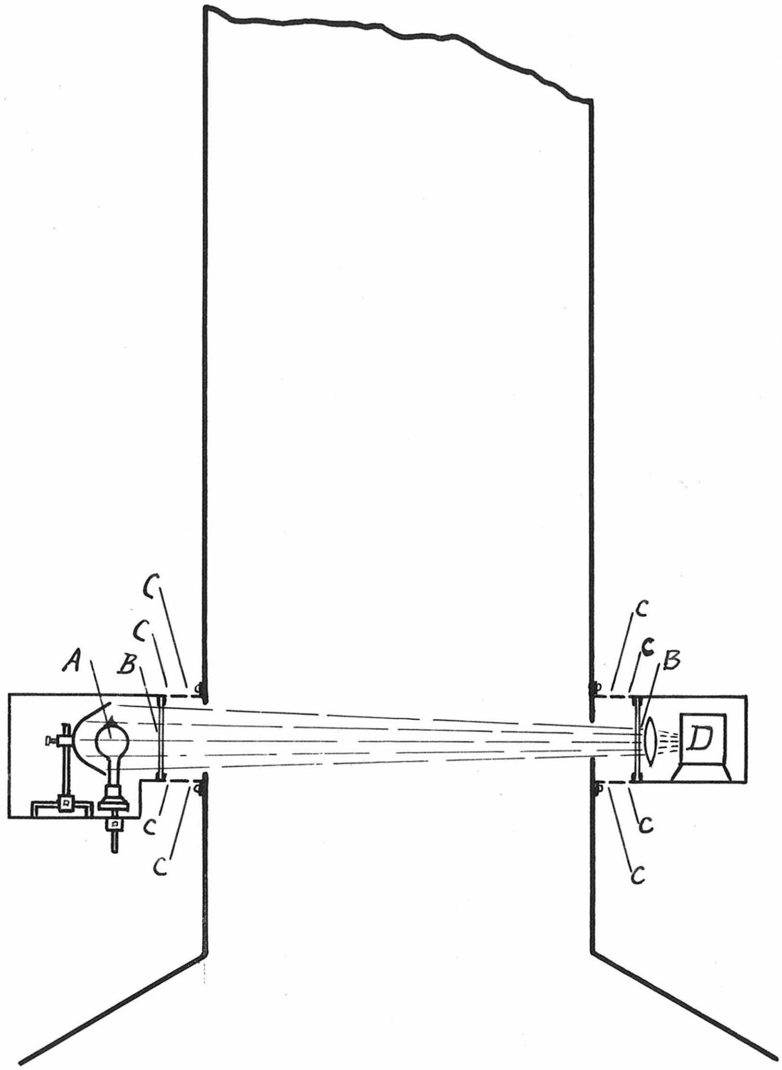
CLASS OF NINETEEN HUNDRED AND SEVENTEEN

DEPARTMENT OF MECHANICAL ENGINEERING

THROOP COLLEGE OF TECHNOLOGY

PASADENA , CALIFORNIA

1917



Smoke Indicator

Method of attaching to Stack.

A Source of Light

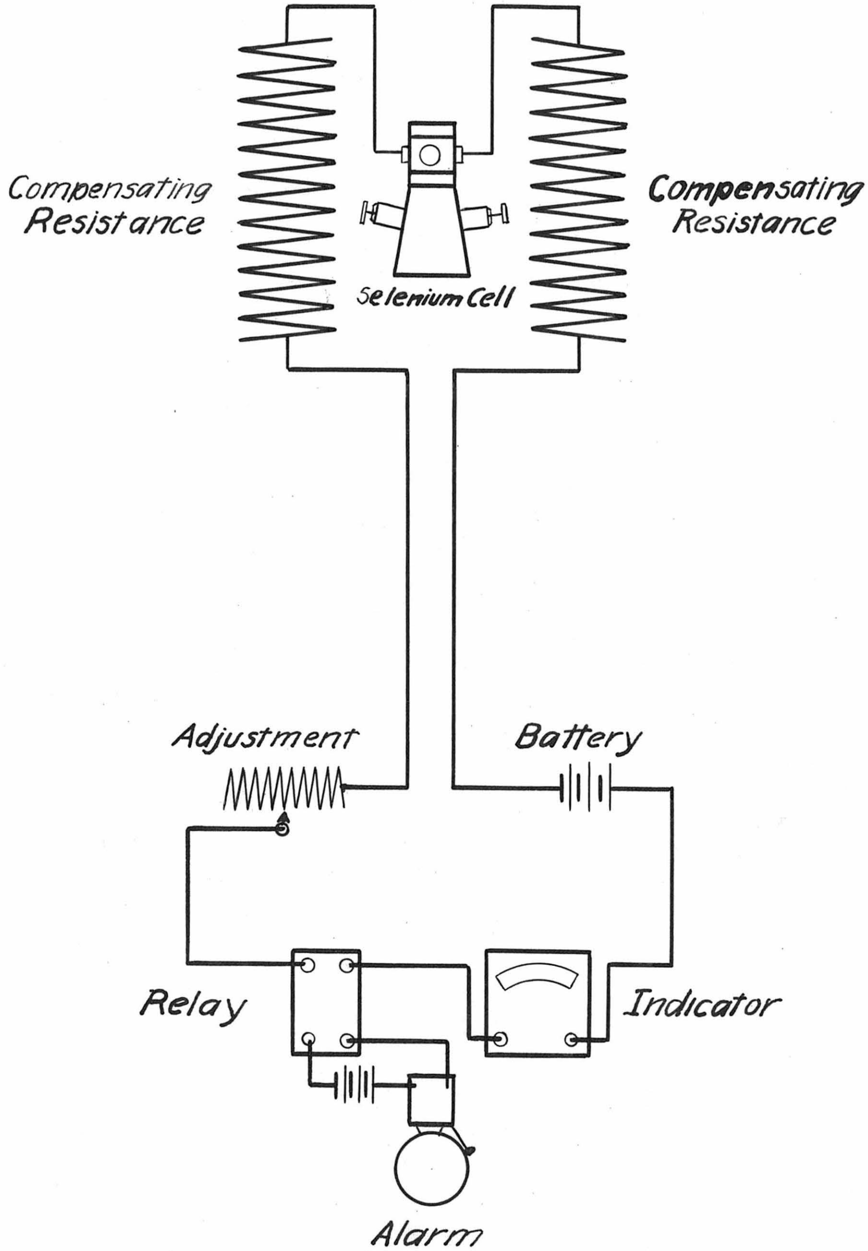
B-B Protecting Glass Windows

C-C Vents to give inward air draught.

D Apparatus for detecting light Variation.

Diagram No. 1.

Arthur Stert

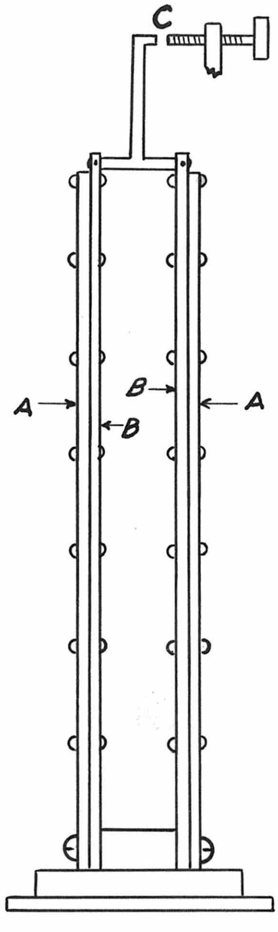


Selenium Cell Indicator

Diagram of Electrical Connections

Diagram No. 2.

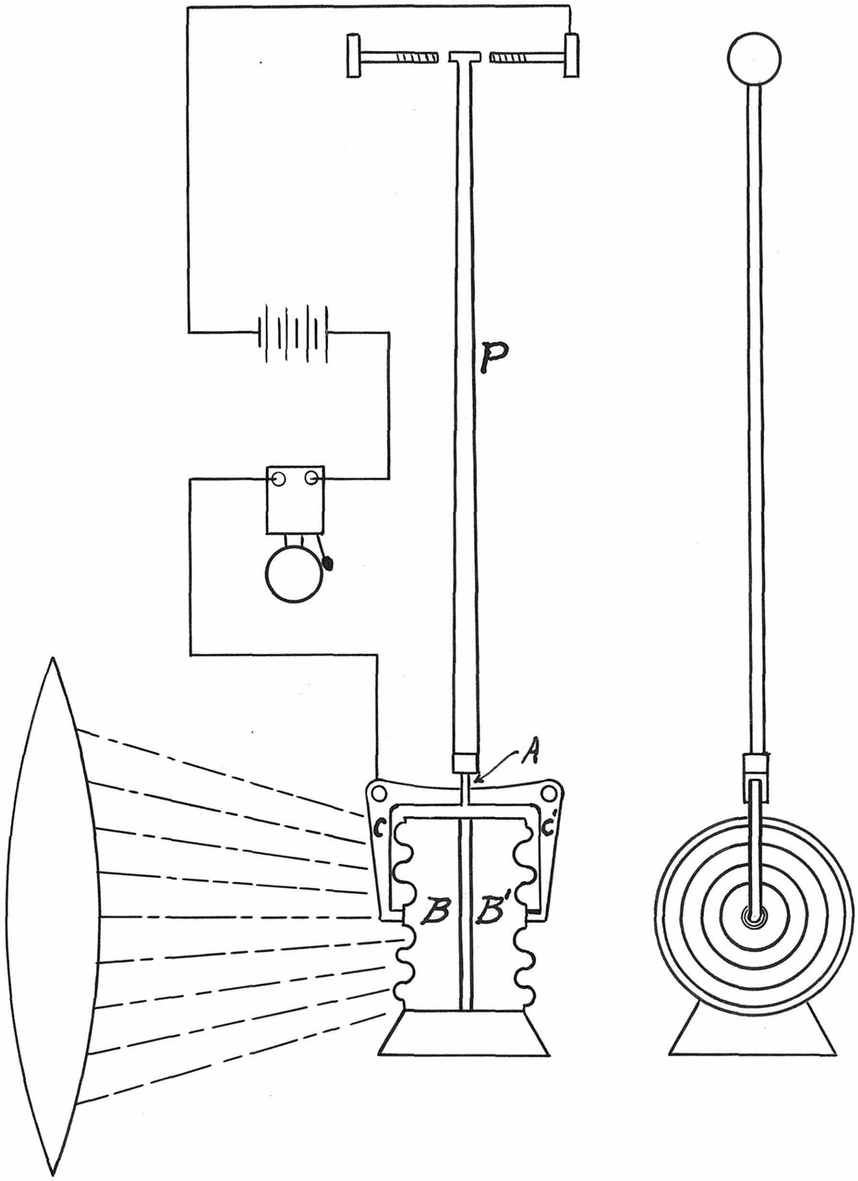
Arthur Stert.



Steel and Ebonite Thermostat Smoke Alarm.

Diagram No. 3

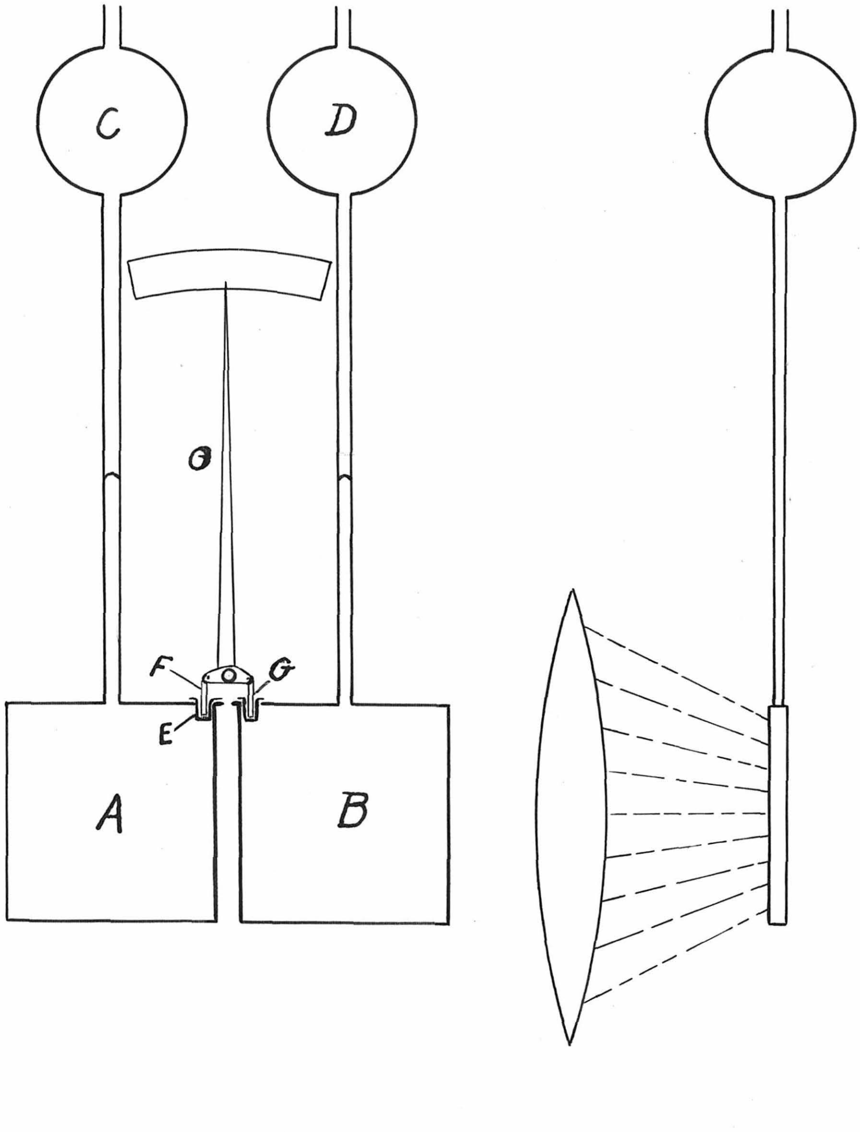
Arthur Stert.



Air Expansion Smoke Alarm.

Diagram No. 4

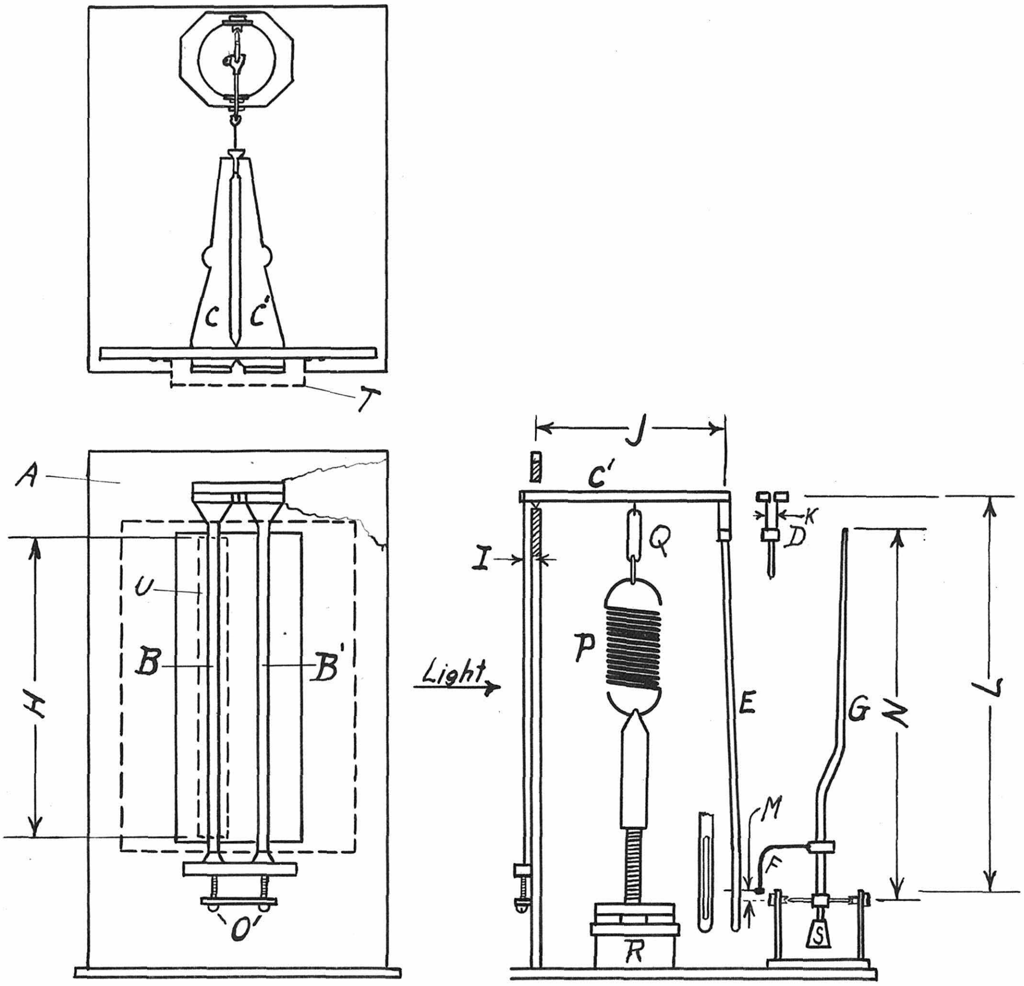
Arthur Stert.



Mercury Expansion Smoke Indicator

Diagram No 5.

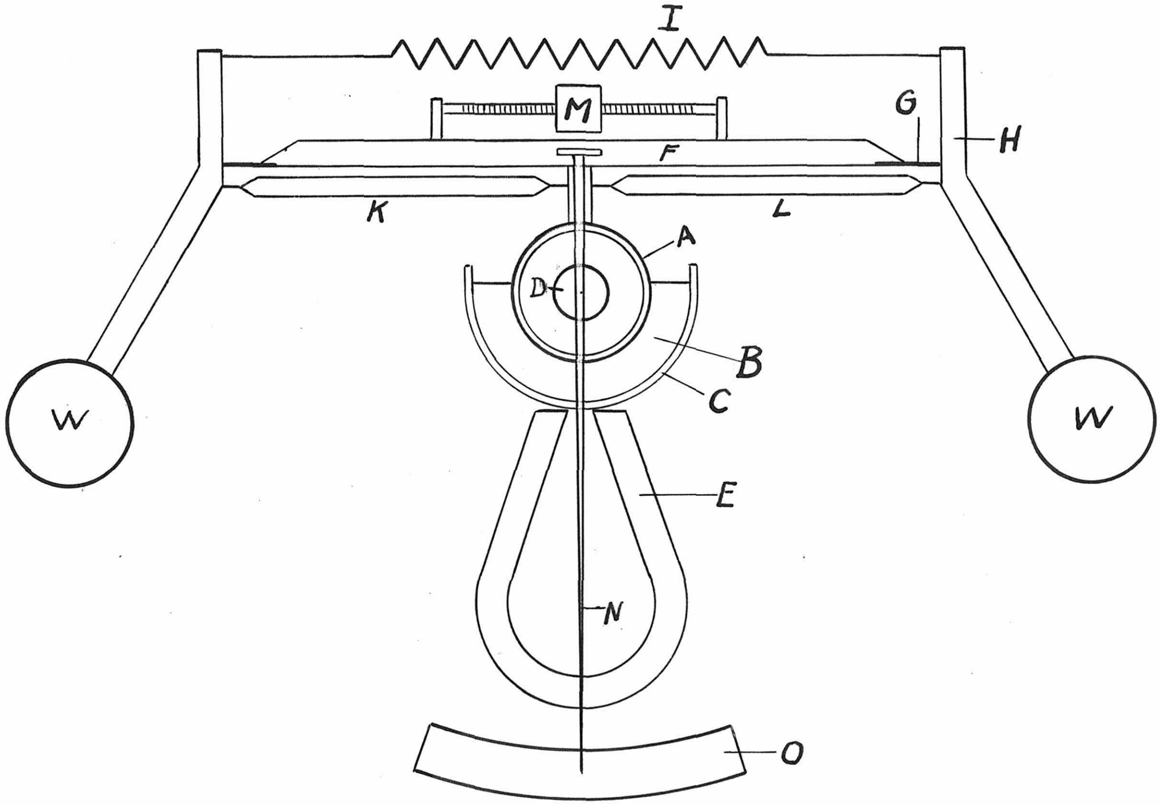
Arthur Stert.



Aluminum Expansion Smoke Indicator

Diagram No. 6.

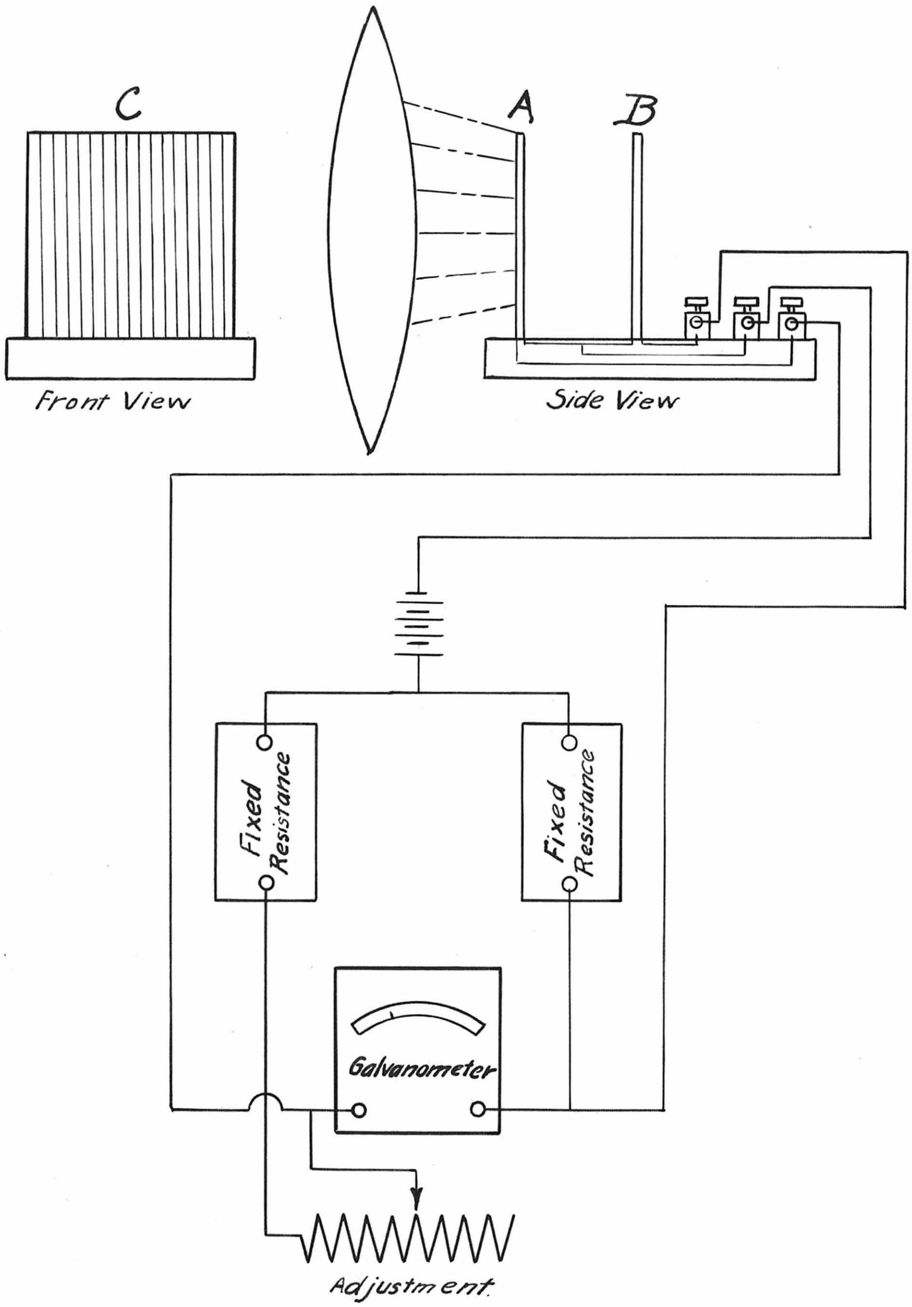
Arthur Stert.



Mercury Pivot Balance Smoke Indicator

Diagram No 7.

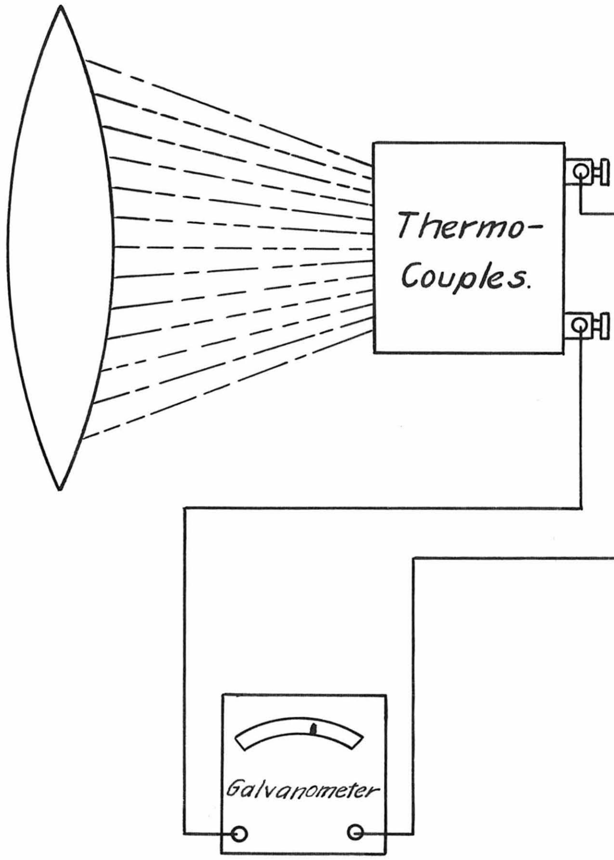
Arthur Stert.



Resistance Smoke Indicator
Electrical Connections

Diagram No. 8

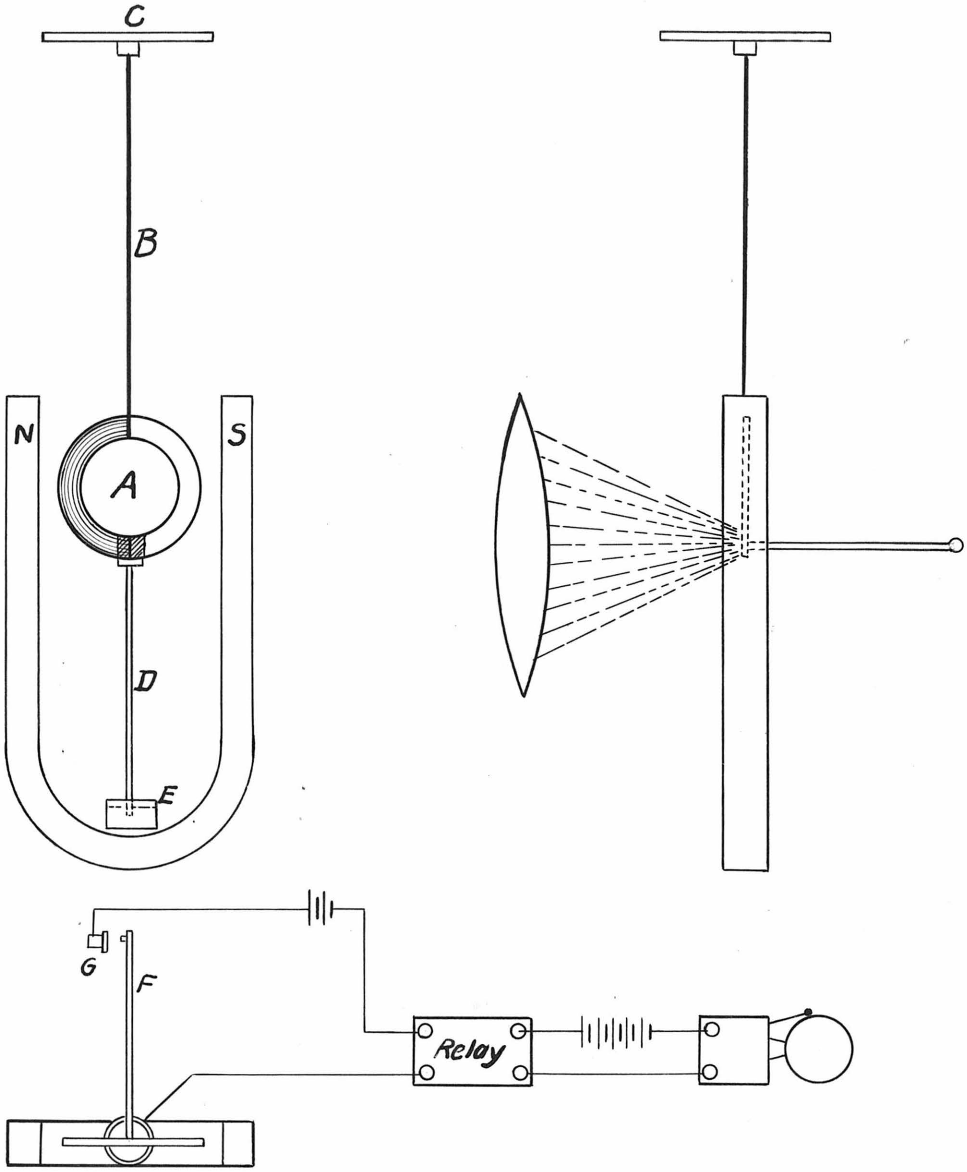
Arthur Stert.



Thermo-Couple Smoke Indicator
Electrical Connections.

Diagram No. 9.

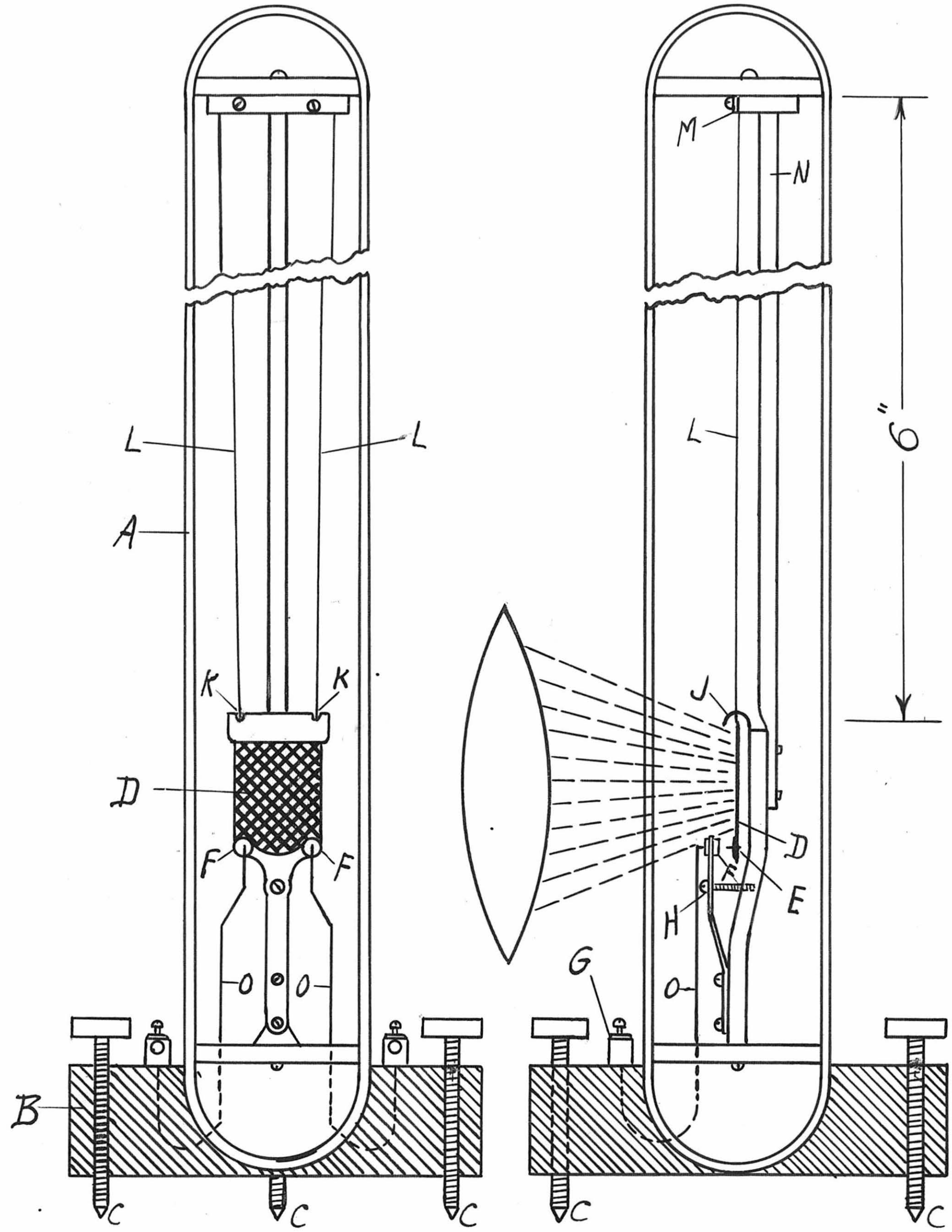
Arthur Stert.



Thermo Couple Galvanometer Smoke Alarm.

Diagram No. 10

Arthur Stert.

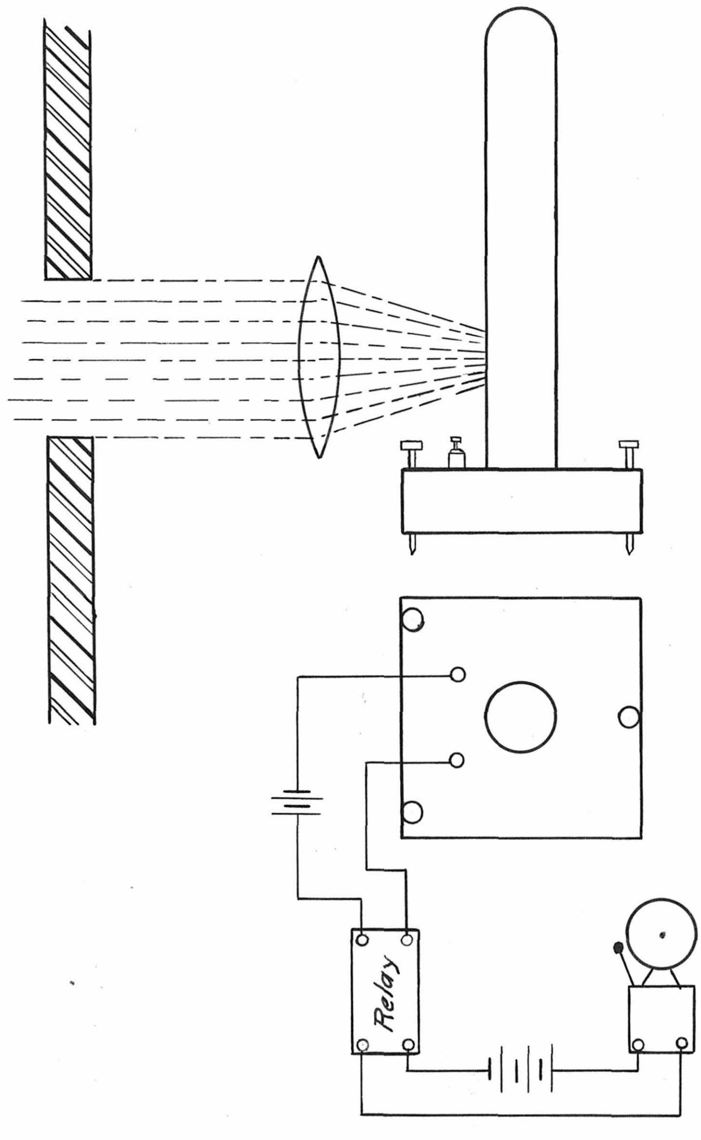


Radiometer Smoke Alarm.

Scale Full Size

Diagram No.11.

Arthur Stert.

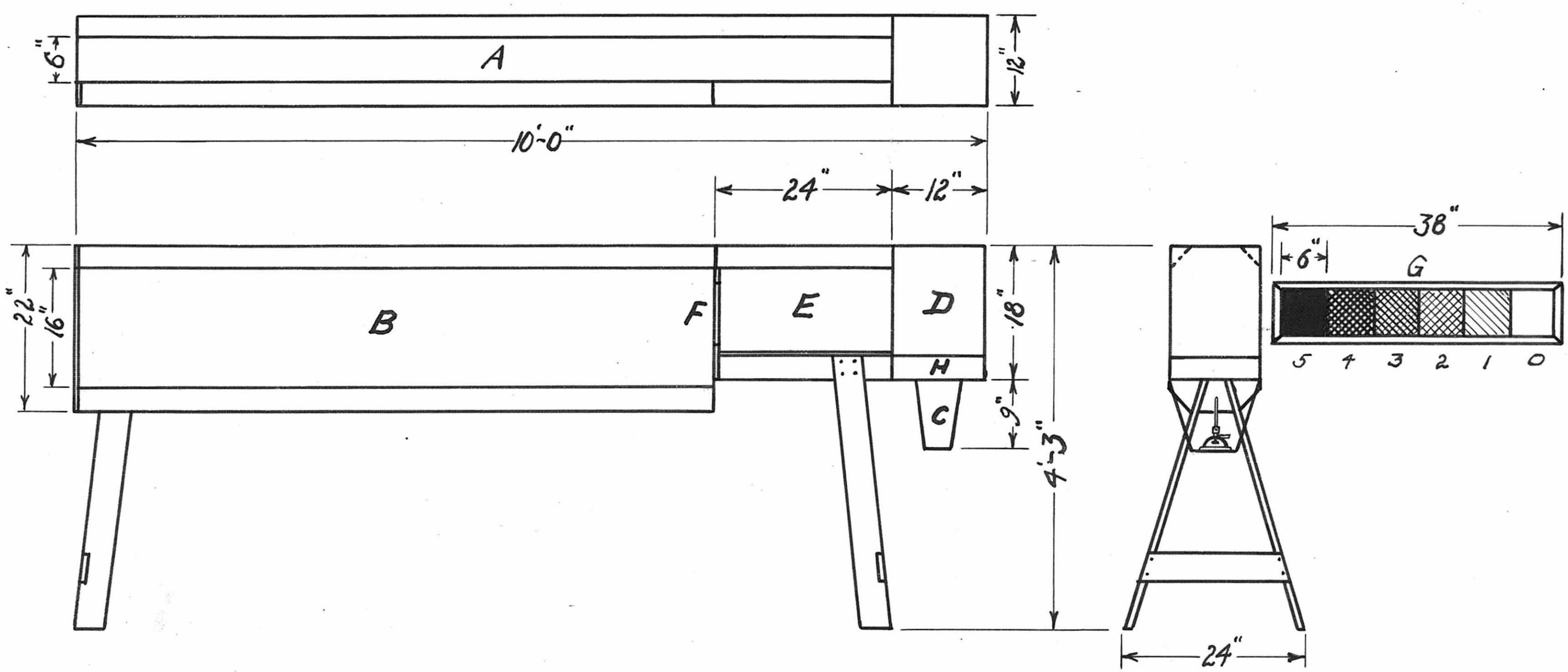


Radiometer Smoke Alarm

Electrical Connections

Diagram No 12.

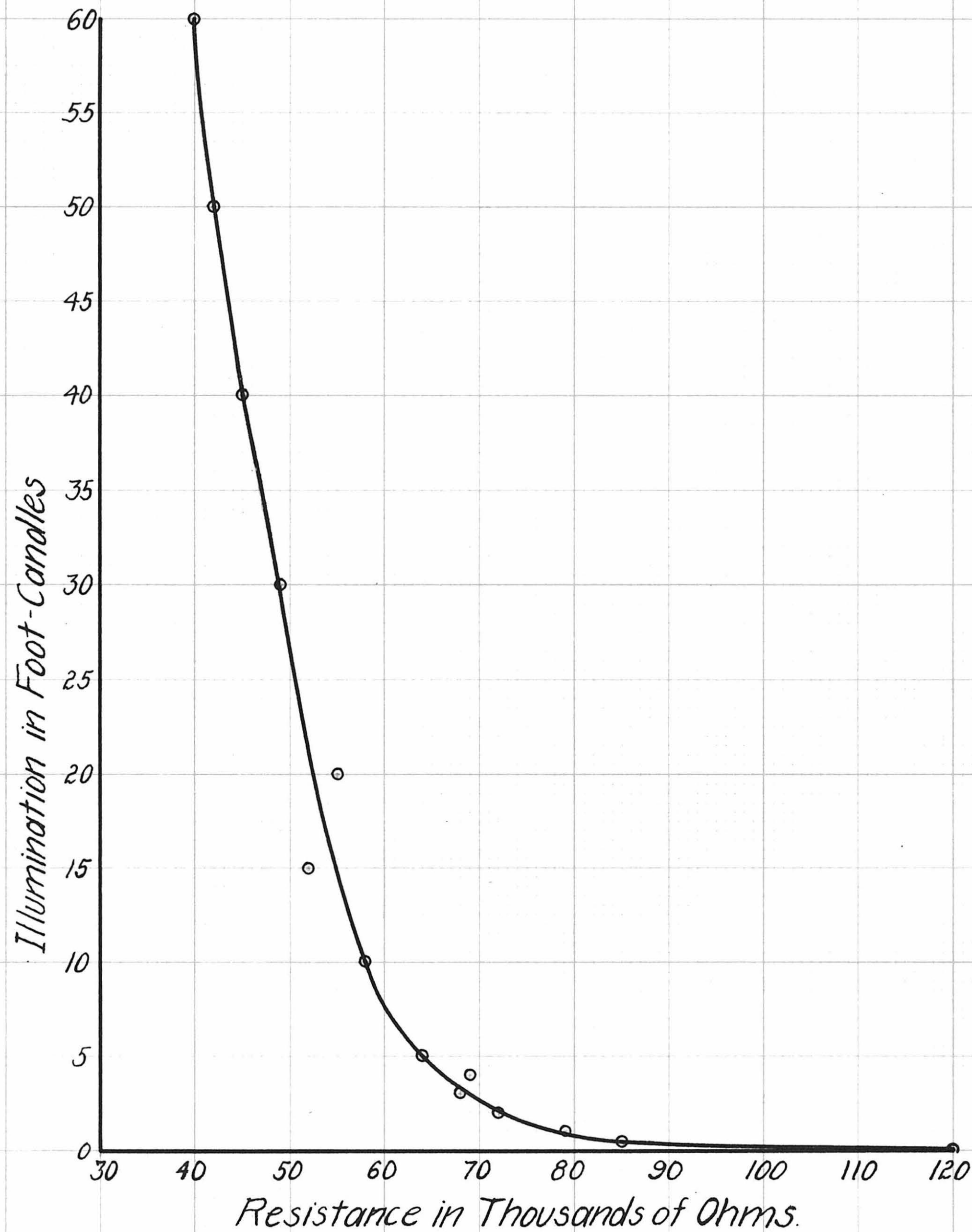
Arthur Stert.



Apparatus for Testing
Smoke Indicator.

Diagram No. 13

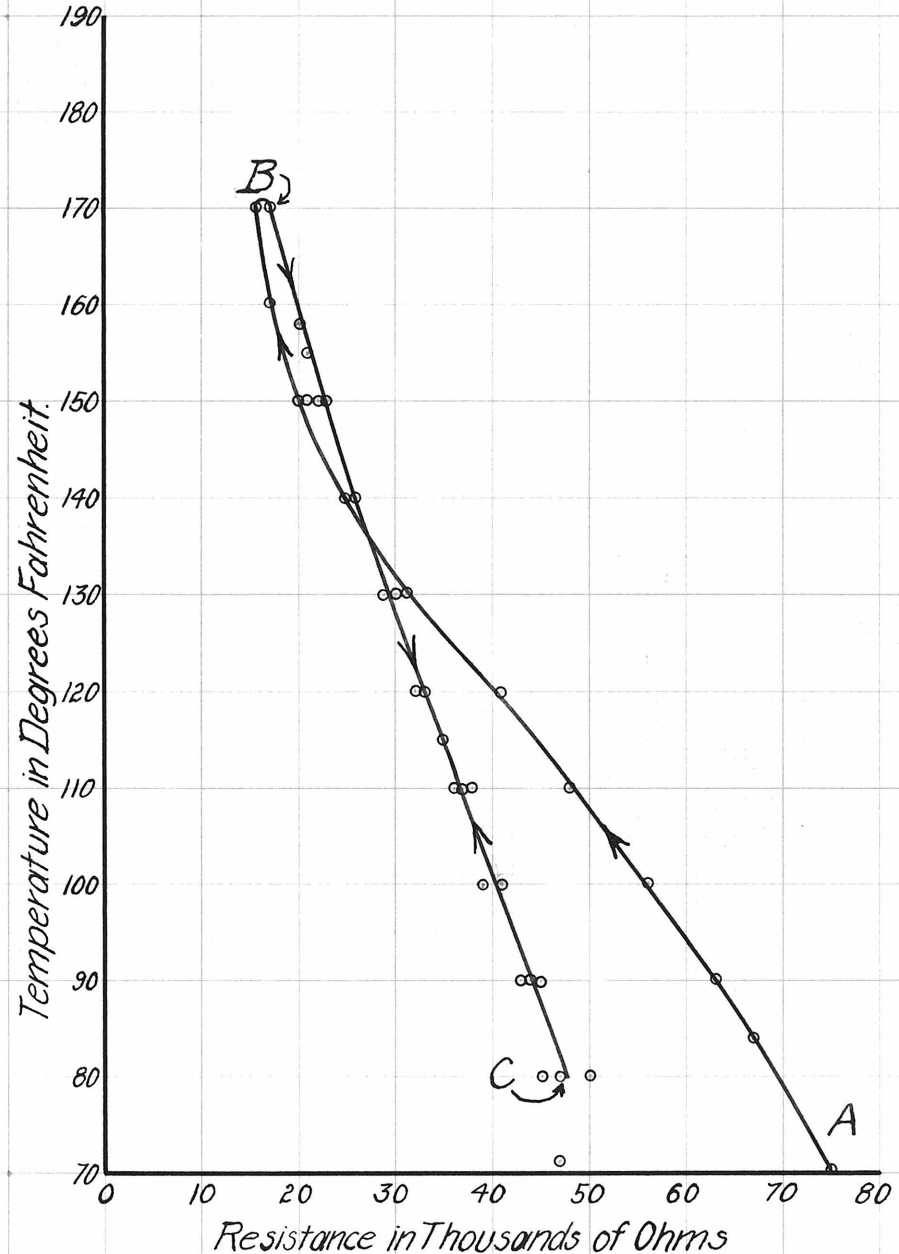
Arthur Stert.



Illumination Effects at Constant Temperature of 70°F.

Curve Sheet No. 1.

Arthur Stert.

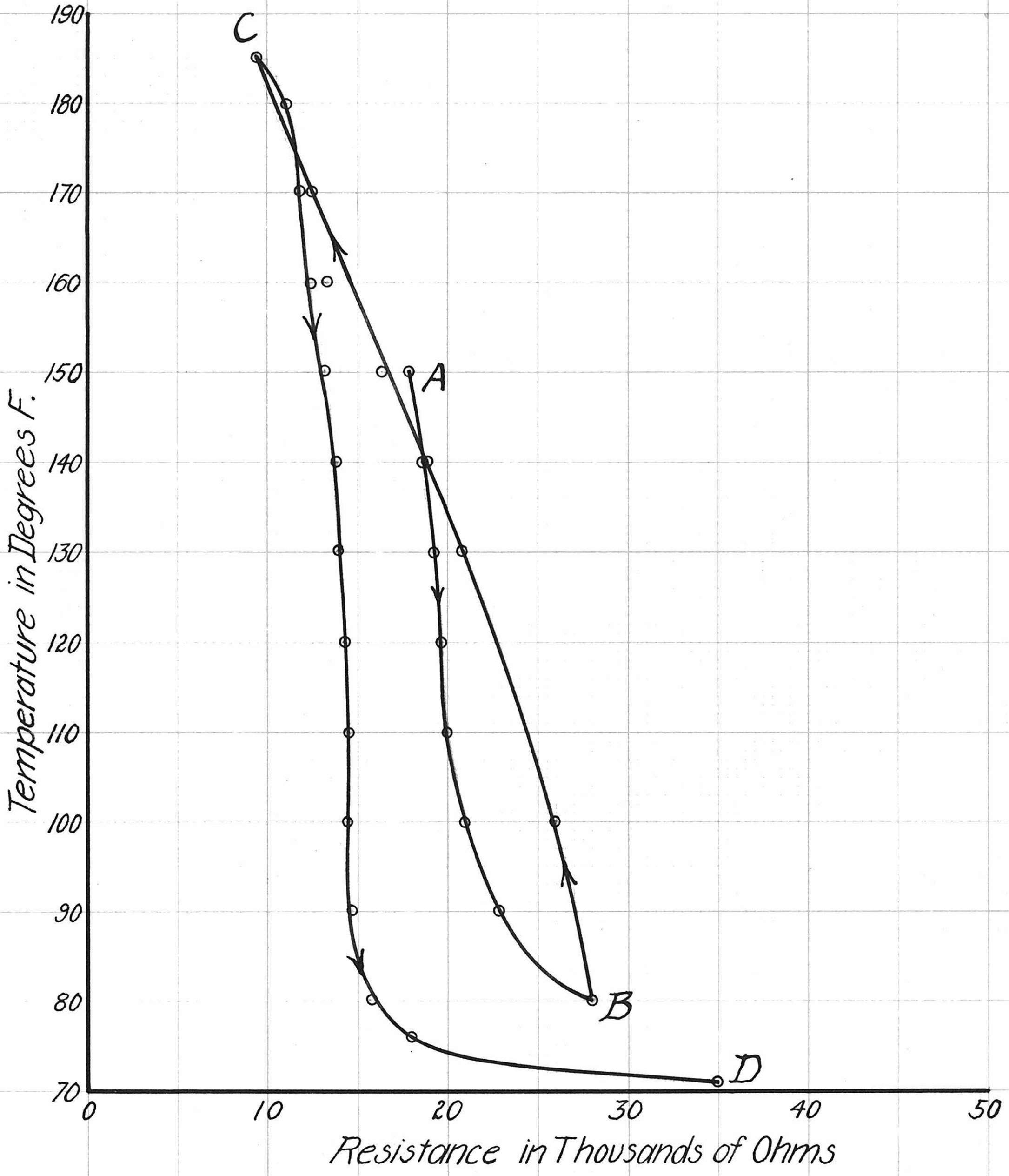


Temperature Effects
at Zero Illumination.

E.I. Co. Selenium Cell.

Curve Sheet No. 2.

Arthur Stert.



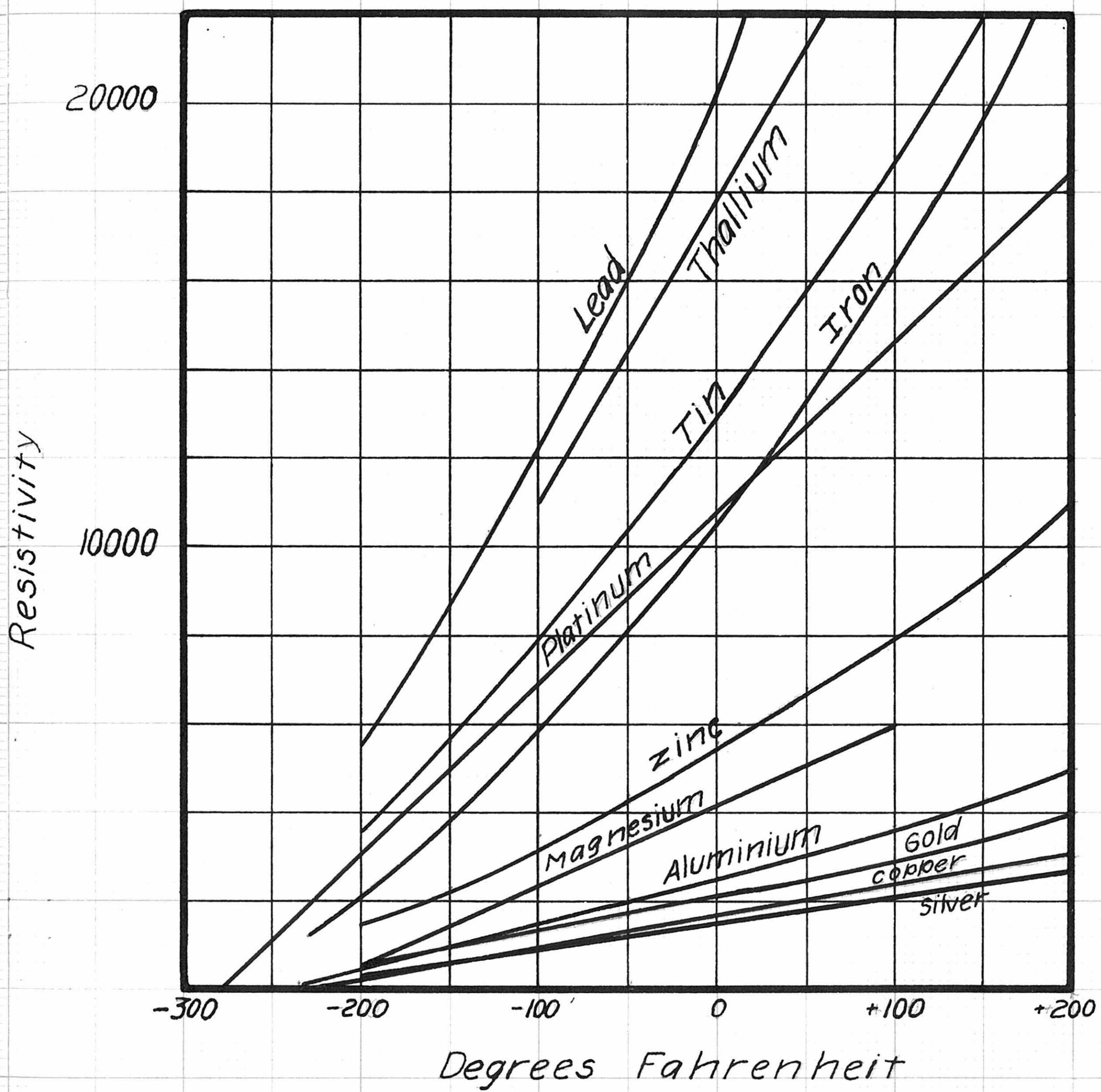
Temperature Effects at
60 Foot-Candles Illumination.

E.I. Co. Selenium Cell.

Curve Sheet No. 3.

Arthur Stert.

Change of Resistance with Temperature.
(Taken from Carhart's Physics.)



Curve Sheet No. 4.

Arthur Stert.

THESIS

The Design, Construction and Comparison
of several Types of Automatic Power
Plant Smoke Indicators.

by

Arthur Stert.

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Department of Mechanical Engineering.

THROOP COLLEGE OF TECHNOLOGY
Pasadena, California.

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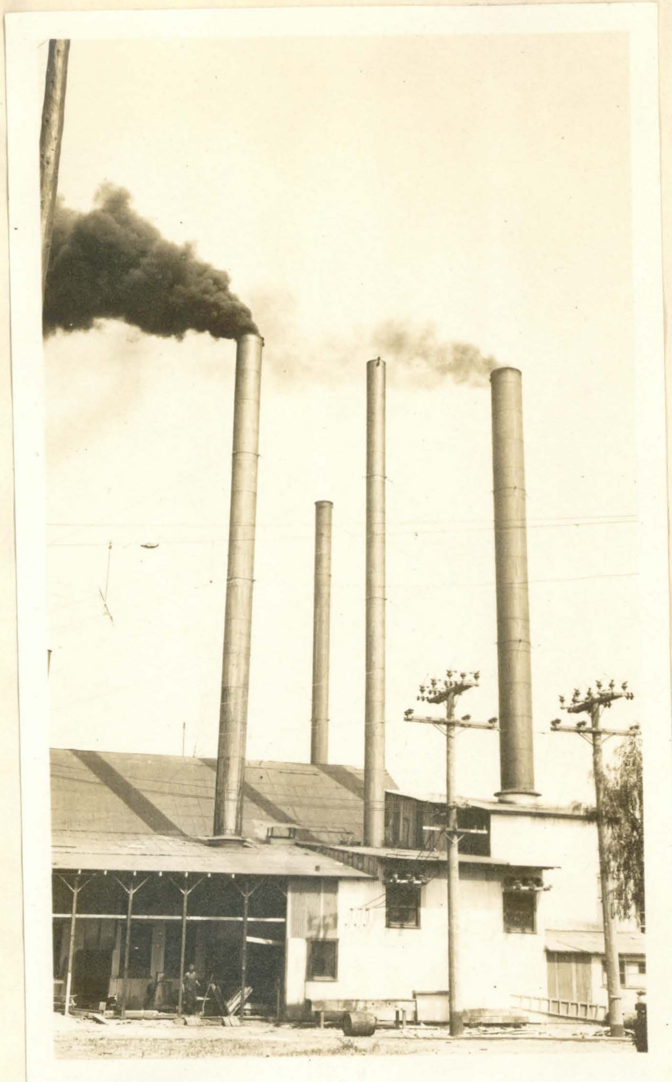

Pasadena City Light Plant

Throop College Power Plant

THE NECESSITY FOR SMOKE ALARMS IS ANNOYINGLY NOTICEABLE

INTRODUCTION.

The progress of civilization which has increased, more and more, the demands for power, has been heretofore a selfish commercial development. Now public comfort is beginning to be considered of sufficient consequence to necessitate the discontinuance of obnoxious power production. The increasing black clouds of suffocating smoke streaming over cities from every factory stack must be a thing of the past. No longer will the people stand for having their buildings blackened and disintegrated, their vegatables blighted and their lungs poluted.

The following is a summary of literature on the subject of smoke abatement as compiled by the Chicago Smoke Commission.

CONCLUSIONS TO BE DRAWN FROM A STUDY OF THE LITERATURE RELATING TO SMOKE ABATEMENT IN LARGE CITIES.

"Smoke abatement in large cities has been a matter of public interest for many years and the literature on the subject is extensive. It presents evidences of wide differences in the practice of cities in their efforts to secure relief from smoke, and many points of disagreement in the opinions of experts as to the effects produced by smoke. This condition emphasizes the fact that the art of smoke abatement has not as yet been fully developed, and that much in the nature of scientific research and investigation remains to be accomplished before definite standards of practice can be established.

The more important facts and conclusions which seem to be generally accepted, or which were justified by the weight of the evidence presented, have been set forth in the concluding paragraphs of each section of this review. These may be summarized as follows:

1. Definite evidences of interest in smoke abatement date back six centuries or more to the time of Edward I (1272-1307) in England. The first authentic information relating to the use of coal is contained in complaints against it as a nuisance.

2. The British Parliament, in 1819, appointed a Select Committee to study and report upon the matter of smoke abatement. Since that date, there have been innumerable discussions and reports of investigations and the mass of literature has grown with great rapidity.

3. Two conceptions of the meaning of the word "smoke" exist. The usual and popular conception regards smoke as the visable exhalation of a burning substance. The other conception takes account of all the products of combustion, both visable and invisable, solid and gaseous.

4. Smoke becomes an object of concern to the city smoke inspector immediately upon being discharged from the stack. It is assumed to be objectionable in direct proportion to its visible density. The controlling factors in smoke inspection are:

a. The requirements laid down by the ordinance, under which action proceeds, as to the character of non-permissable smoke, as, for instance, "dense smoke" or "black smoke."

b. A standard by which smoke discharges may be evaluated in terms to meet the requirements of the ordinance.

c. The means by which smoke observations may be made and recorded.

5. A survey of the atmosphere of several of the world's great cities shows an improvement in atmospheric conditions during recent years. It shows also that Chicago suffers less from the effects of smoke than certain other large cities of this and other countries.

6. The comparison of the air of cities with that of the country has revealed characteristics which may and apparently must be attributed to the smoke of the cities; but it has also been shown that they may in part be attributed to other sources, as, for example, leakage from gas mains, the pollution due to sewers, the dust of the streets and decaying organisms. Air analysts have admittedly not been able to separate the products of com-

bustion as dispersed in the air from other agents of air pollution.

7. The industrial activity of all important cities has brought about an increase in coal consumption which is greater than the increase in population. Smoke formation and the consequent pollution of the atmosphere by smoke have in recent years tended to increase, and have done so exdept so far as the adoption of various means in smoke prevention have proved effective. The fact is repeatedly pointed out that, in securing results of scientific value for use in abating smoke, no one individual and no one city can accomplish the work that mush be done. The observations must be numerous and must extend over decades.

8. The fact appears firmly established that there is a well defined relation between smoke and fog and that the presence of smoke induces fog. It is agreed that sunshine is a function of the amount of smoke present in the atmosphere.

9. Certain investigations have shown that the amount of carbon dioxid in the atmosphere of cities is, as a rule, only about one per cent greater than in country air. The sulphur compounds in the city air usually form a more important constituent than is the case in country air. Sulphur compounds in the atmosphere are generally due to the combustion of coal.

10. Among the sources of pollution of city air by smoke, the world over, domestic chimneys are conspicuous. The mention of them by observers and students is much more frequent than the mention of any other source.

11. The most successful means which have been employed to abate smoke have included not only legal prohibition but also the development of co-operative and educative measures.

12. The mechanical and physical means in smoke abatement which are suggested in the literature on the subject, not all of which can be accepted as practicable, include:

a. The removal of fuel consuming industries to points remote from the city.

b. The construction of smoke sewers or community chimneys of such size and height as to permit of directing the discharges of many flues into one stack and thereby delivering the combined stream far above the city.

c. The establishment of central heating and power plants.

d. The employment of devices for washing smoke discharges before their emission into the atmosphere.

e. The condensation and deposition of smoke.

particles by means of electric devices.

f. The abolition of many small coal fires through an extension of the use of gas and electricity.

g. Improvement in the methods of firing.

13. Fires of bituminous coal may be maintained without becoming sources of visable smoke, providing certain principles are recognized in the design of furnaces and in the manner in which they are fired,

14. It is possible to secure smokeless combustion of fuel in fires under stationary boilers by hand-firing, though such a result implies careful supervision.

15. Most mechanical stokers and methods of stoking which serve to distil and consume the volatile products contained in the fuel are generally approved as a means in smoke abatement where bituminous or other coals high in volatile matter are used.

16. With reference to the effects of smoke, the following conclusions seem justified by the literature on the subject:

a. There is a general agreement among sanitary authorities that polluted air is harmful to health, but at the present time there exists no accurate method of measuring this harm nor of determining the relative responsibility of the different elements which enter into the mixture of gases and solids commonly referred to as atmospheric air.

b. The direct effects of smoke or of any of its attributes, including soot, dust and gases, in amounts which may ordinarily pervade the atmosphere of a smoky city are not shown to be detrimental to persons in normal health, but the general physical tone is lowered as a result of long continued breathing of polluted air.

c. The direct effect of smoke upon those who are ill has been most extensively studied in connection with tuberculosis and pneumonia. It appears that smoke does not in any way stimulate the onset of the tubercular process nor militate against the rapidity of recovery when once this disease has been contracted, but that it has a direct antiseptic effect and tends to localize the disorder. In cases of pneumonia, the effect becomes seriously detrimental.

d. The tarry matter and sulphur compounds present in coal smoke have been shown by experiments to affect certain classes of vegetation when applied in sufficient quantities.

e. Smoke is popularly regarded as a source of loss and damage in its effects upon building materials, objects of virtu, clothing and other property. While these effects of smoke seem obvious, it has not been possible to estimate their extent with any degree of accuracy."

Practically all of the larger cities now have ordinances which prohibit smoking of stacks. Chicago ordinances are good examples of those existant elsewhere.

CHICAGO ORDINANCE OF 1881.

"Section 1650. The emission of dense smoke from the smoke-stack of any boat or locomotive or from any chimney, anywhere within the City, shall be deemed and is hereby declared to be a public nuisance; provided that the chimneys of buildings used exclusively for private residences shall not be deemed within the provisions of this ordinance.

Section 1651. The owner or owners of any boat or locomotive engine and the person or persons employed as engineer or otherwise in the working of the engine or engines in said boat or in operating such locomotive, and the proprietor, lessee or occupant of any building, who shall permit or allow dense smoke to issue or be emitted from the smoke-stack of any such boat or locomotive, or the chimney of any building within the corporate limits, shall be deemed and held guilty of creating a nuisance, and shall for every such offence be fined in a sum not less than Five Dollars nor more than Fifty Dollars. Sections 1650, 1651 and 1652 shall take effect and be in force from and after May 1, 1881.

Section 1652. It shall be the duty of the Commissioner of Health and the Superintendent of Police to cause Sections 1650 and 1651 of this Article to be enforced, and to make complaint and cause to be prosecuted all persons violating the same."

The latest smoke ordinance in Chicago were enacted in 1907. The following is the section relating particularly to smoking.

" Section 17. The emission of dense smoke within the city from the smoke-stack of any locomotive, steam boat, steam tug, steam roller, steam derrick, steam pile-driver, tar-kettle, or other similar machine or contrivance, or from the smoke-stack or chimney of any building or premises, excepting a period of six minutes in any one hour during which the fire-box is being cleaned out or a new fire being built therein, is hereby declared to be a nuisance and may be summarily abated by the smoke inspector, or by any one whom he may duly authorize for such purpose. Such abatement may be in addition to the fine hereinafter provided. Any person or persons, or corporation, owning, operating, or in charge or control of any locomotive, steam boat, steam tug, steam roller, steam derrick, steam pile driver, tar kettle, or other similar machine or contrivance, or of any building or premises, who shall cause or permit the emission of dense smoke, within the city, from the smoke-stack or chimney of any such locomotive, steam boat, steam tug, steam roller, steam derrick, steam pile driver, tar kettle, or other similar machine or contrivance, of from the smoke-stack or chimney of any building or premises so owned, controlled, or in charge of him, her or them, except for a period of six minutes in any one hour during which the fire-box is being cleaned out or a new fire built therein, shall be deemed guilty of a violation of this ordinance, and upon conviction thereof shall be fined not less than ten dollars nor more than one hundred dollars for each offense; and each day of such emission of dense smoke shall constitute a separate offense."

The prevention of smoke has been the subject of much thought and experiment. As a result, boiler setting designs have been so far perfected that practically smokeless combustion is now possible with even the softest bituminous coals. This is true, however, only so long as all conditions remain in a fixed relation to each other. For instance, with hand firing, if a hole burns thru the firebed or if the door is opened to put in more coal, then the balance of air supply against air consumption is disrupted and a puff of smoke goes up the stack. Even with automatic stokers, a sudden load drops the steam pressure which speeds up the stokers and the dampers must be regulated right for the increased demand for air.

Steam jets have been successfully used to thoroly mix the unburned air and coal gases so as to give complete and smokeless combustion, but it is expensive to run them continuously and the fireman never knows if they are needed until he happens to take a look at the fire, perhaps five minutes after it started to smoke.

In the case of oil fired furnaces smoking may be prevented by proper regulation of air and of atomizing steam at the burner. Again the fireman does not know if he is smoking unless he looks at the fires. If a load comes on suddenly the regulators send an extra amount of oil to the burners, and the furnace smokes. It is a simple matter for the fireman to readjust air and steam for the new rate of combustion but until he does so, the community is annoyed by a dense cloud of black smoke shutting out the daylight and getting the washing on the lines all sooty.

THE PROBLEM.

What is needed in connection with the present existing efficient methods of smoke prevention is some simple, reliable, automatic and rapidly acting instrument which will audibly warn the fireman when any particular furnace is smoking. It would also be of advantage to have this instrument made so that it would indicate, by a pointer for instance, just what density of smoke was being emitted.

Any mechanical instrument which is to operate when smoke is being produced must do so by taking advantage of one or more of three conditions: first, that which was, itself, the cause of the smoke; second, some property inherent in the smoke; and third, some rapidly following result of the smoke having been formed.

The causes of smoke are, as before stated, largely poor boiler design, wrong amount of air, or poor distribution of air among the fuel gases. The former of these causes is a fixed quantity. The two latter, while varying with the amount of smoke, their variation is far too indefinite to be used as a basic principle in the operation of a smoke indicator or alarm.

The results following smoking are: sooting of tubes, flue and stack, a disagreeable cloud in the sky, soot particles floating to the ground, a sickening odor in the air, formation of acids in the atmosphere by the fumes and finally, a complaint from the smoke inspector followed by a fine in court. All of these effects are more or less slow in action and even if instruments could be devised which would make use of any of the results they would be intolerably slow in performing their function.

We must now turn for a solution to some property inherent in the smoke. What is smoke? What peculiarities has it? Which of its qualities can we make an inert machine take advantage of automatically to announce its presence. Let us note down all the properties of smoke that we can think of.

1. Smoke has mass.
2. Smoke is black. (Appears so because it absorbs what light falls upon it.)
3. Smoke has an odor.
4. Smoke carries particles of soft carbon in suspension.
5. Smoke may be a poorer insulator of electricity than clear flue gases.
6. Smoke is opaque.

What ~~properties~~ possibilities lie in the above inherent properties?

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1. Smoke has mass. If the flue gases were caused to impinge on a flat plate a greater force would be exerted with smoke in the flue due to the extra mass of the soot particles. This is plainly an unsatisfactory method to use as it would be difficult and require intricate complications to compensate for temperature and hence density variation, and for variable normal and stray air-currents.

Since the smoke has mass the specific gravity of the flue gas is increased by its presence, but this is too difficult of satisfactory measurement and of compensation for accompanying alien conditions.

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2. Smoke is Black. The reason the smoke looks black is because it absorbs all the light that falls on it. It is a physical truth that light absorbed becomes heat. Hence smoke will be hotter in the light than in the dark. This might possibly be used as a means of detecting smoke tho it would hardly be feasible practically. For instance: suppose two similar funnels were placed side by side, open ends down, near the middle of the stack. Then smoke passing up the chimney would enter and issue equally from the spouts of each funnel. Then if a horizontal pipe extended from the edge of one funnel to the outside of the stack so that a beam of light could be projected thru the stack so as to fall on the smoke entering one of the funnels, the smoke issueing from that funnel would be slightly hotter than the smoke issueing from the other funnel. When smoke was not present, the light would not be absorbed and the clear flue gases would pass thru each funnel at the same temperature. The difference of reading of two thermometers placed one in each funnel spout would indicate the amount of smoke. Of course, to be at all usable, the readings would have to be visible from without the stack and preferably some sort of differential thermometer should be used to read temperature differences directly. Two small air chambers, each connected to one side of a delicate different-

ial pressure guage might work nicely. The disadvantages of this method are, the delicate instruments necessary to indicate the very small temperature differences that would be obtainable, and the fact that an appreciable amount of time would have to elapse after smoking started before the thermometric apparatus would receive sufficient heat to operate.

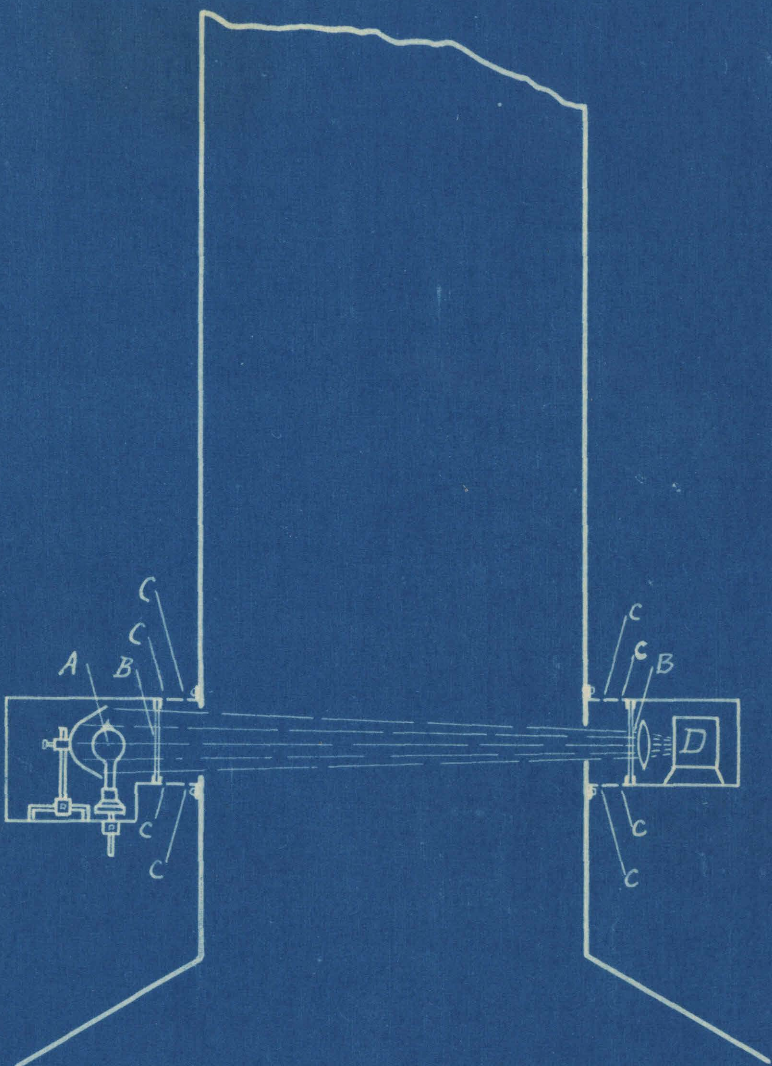
3. Smoke has odor. The odor which characterizes smoke is not due to the suspended particles of soot, but to gases of combustion which are present whether or not the flue gases are visible. Hence this is not really a characteristic of the objectional smoke.

4. Smoke carries particles of soft carbon in suspension. The only apparently usable portion of this condition has already been taken advantage of in the Hammler-Eddy Smoke Recorder in which a continuous sample of flue gas is drawn from the chimney, passed thru a drier and then blown in a small jet against a moving chart of white paper. The smudge on the paper is proportional to the amount of smoke passing up the stack at any particular time. The disadvantage of this instrument is that it merely records what has happened in the past and cannot serve as an audible alarm to warn the fireman that a furnace has started to smoke.

5. Smoke may be a poorer insulator of electricity than clear flue gas. In reality, after looking up

references to the matter, it was found that smoke is a better insulator than clear flue gas and that this property has already been taken advantage of in a Smoke recorder and Monitor invented by W. W. Strong and described by him in Power, Vol. 40, page 912. This apparatus has a spark gap placed in the stack and a condenser and the high potential secondaries of a transformer are each connected across the gap. When no smoke is present the current ~~spits~~ sparks right across the gap, leaving the condenser discharged. When there is smoke, the discharge stops and the condenser is charged. An electrical apparatus indicates whether or not the condenser is charged, thus indicating the presence of smoke. This type of instrument has also been built so as to record the smoke curve for each day on a chart.

The fact that smoke is a good insulator might be used by passing the flue gas between large condenser plates. The dielectric would be of different strength depending whether or not smoke was present. This would vary the capacity of the condensor and this variation of capacity could be recorded in some manner. For instance: have two Tesla coils nearly in tune, with the capacity in the circuitof one coil. The varying capacity would make the coils more or less in tune, causing more or less current to flow. This could operate a meter to indicate smoke.



Smoke Indicator

Method of attaching to Stack.

A Source of Light

B-B Protecting Glass Windows

C-C Vents to give inward air draught.

D Apparatus for detecting light Variation.

Diagram No. 1.

Arthur Stert

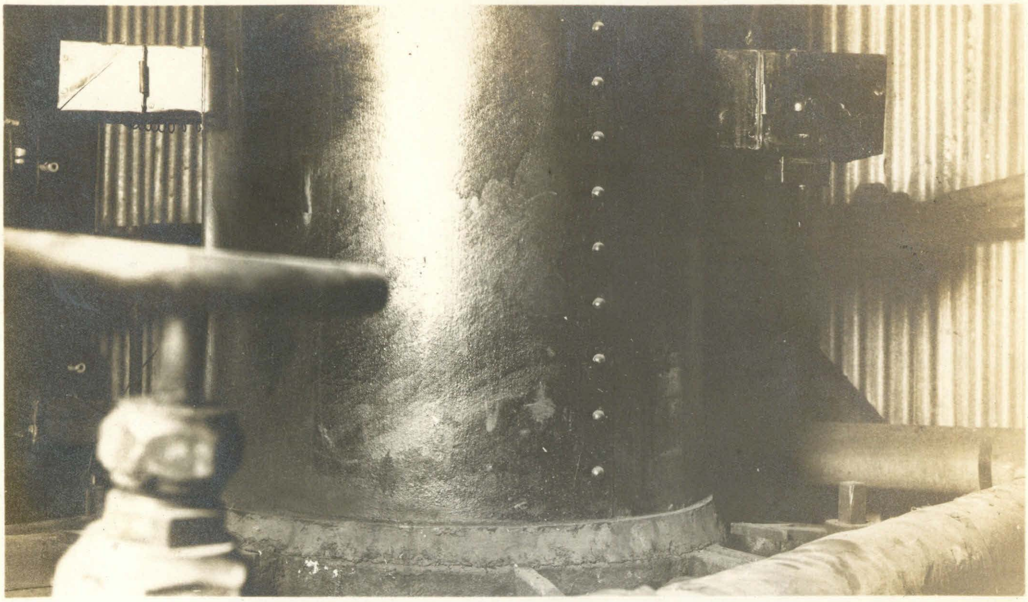


Photo No. 3 Apparatus on a Stack

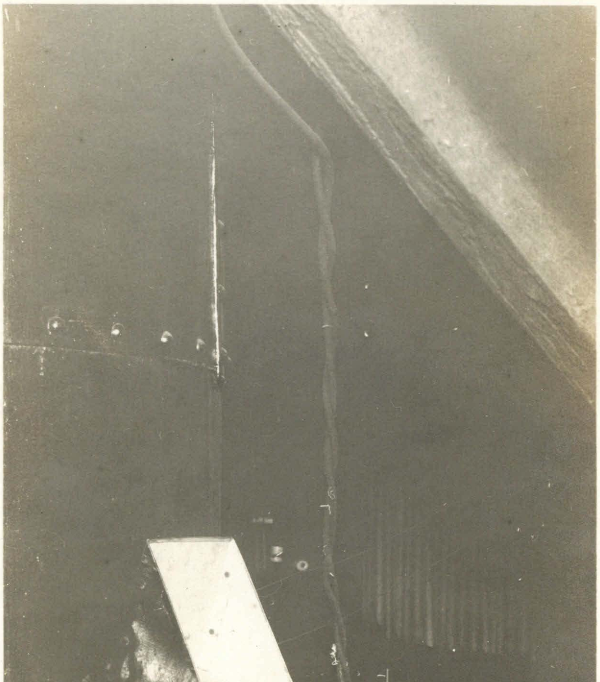


Photo No. 4. Interior of Light Box

LIGHT-DETECTING INSTRUMENTS.

Light may be detected and its variations measured in several different ways.

(a) By comparison with a standard of illumination.

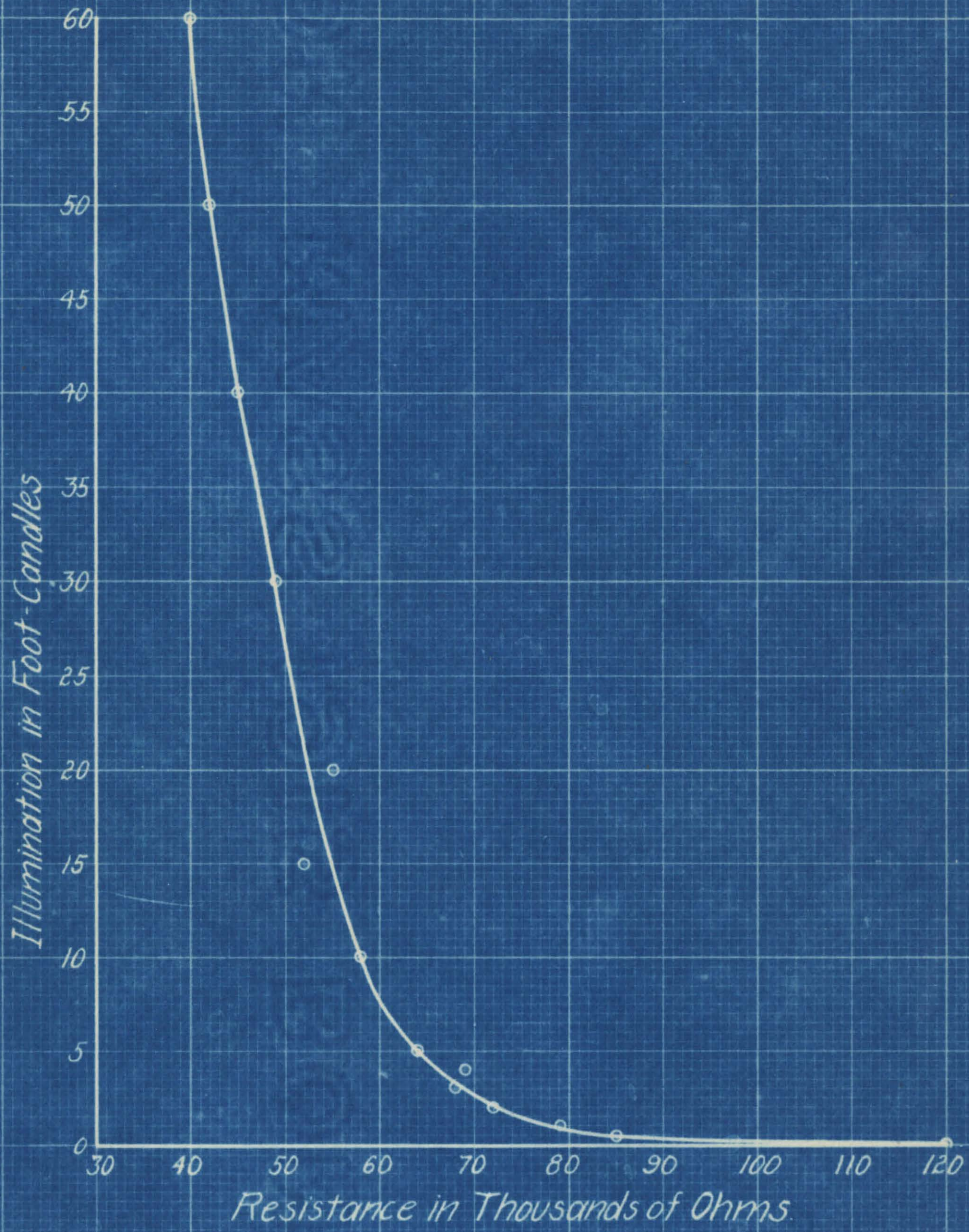
(b) By its physical effects on selenium.

(c) By its action on certain chemicals.

(d) By changing its form into heat by absorbtion and measuring the resulting rise of temperature.

(a) It is entirely necessary for a smoke detector to be automatic in order to be of practical value. Any ordinary photometer, such as the Bunsen, would be very difficult to make automatic in its operation. Hence direct measurement by comparison of the light intensity after passing the stack is not a suitable means of accomplishing the desired result.

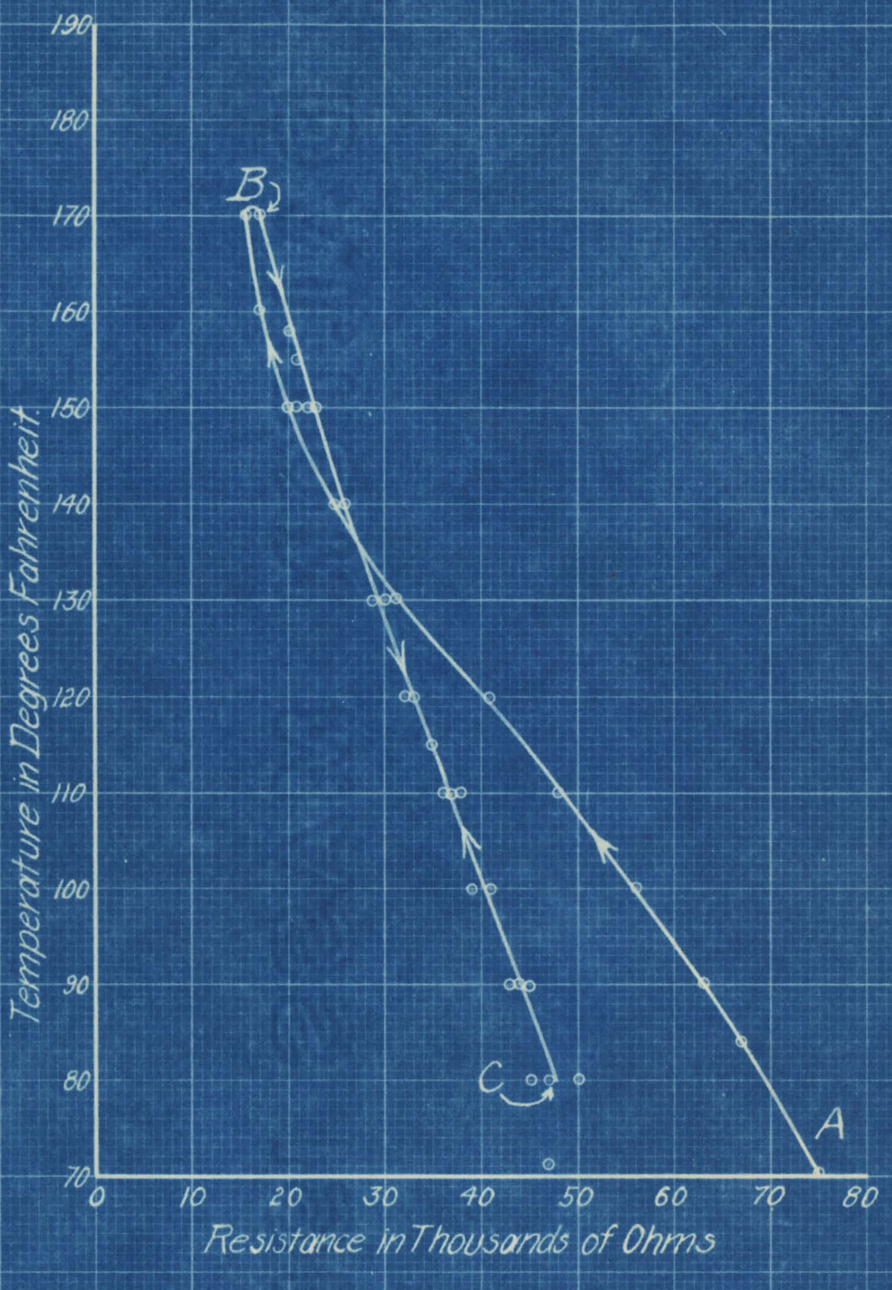
(b) The effect of light on selenium, which is now very generally known, is naturally one of the first methods to suggest itself for the detection of smoke by the light-beam method. The writer experimented with this method during the summer of 1915 at the Pasadena Municipal Light Plant, though unsuccessfully at that time, due to lack of sufficiently delicate instruments. Since then an exactly similar method of smoke detection has been



Illumination Effects at
Constant Temperature
of 70°F.

Curve Sheet No. 1.

Arthur Stert

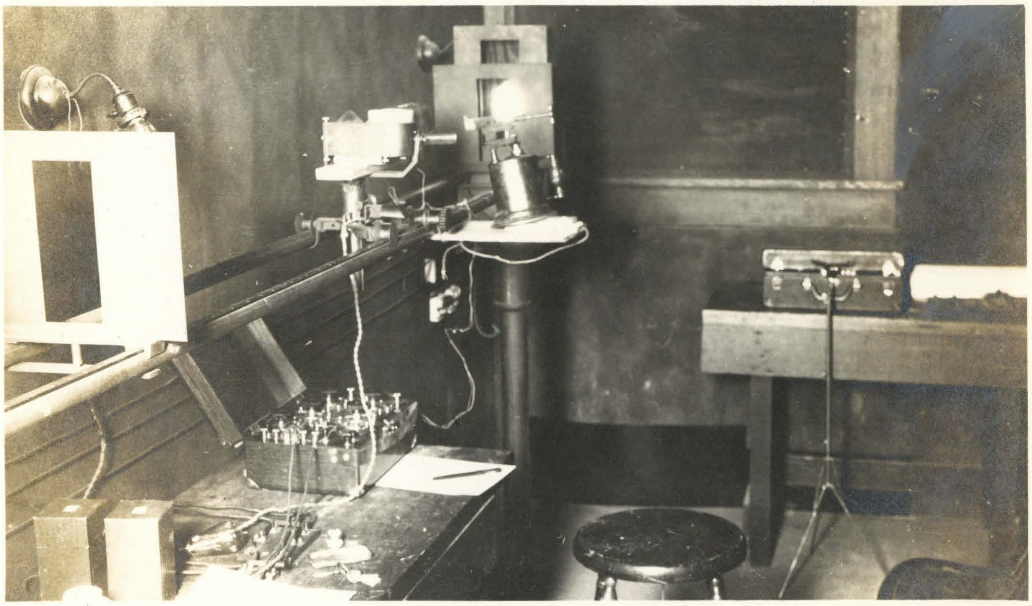


Temperature Effects
at Zero Illumination.

E.I. Co. Selenium Cell.

Curve Sheet No. 2.

Arthur Stert.



Apparatus for Testing Selenium Cell

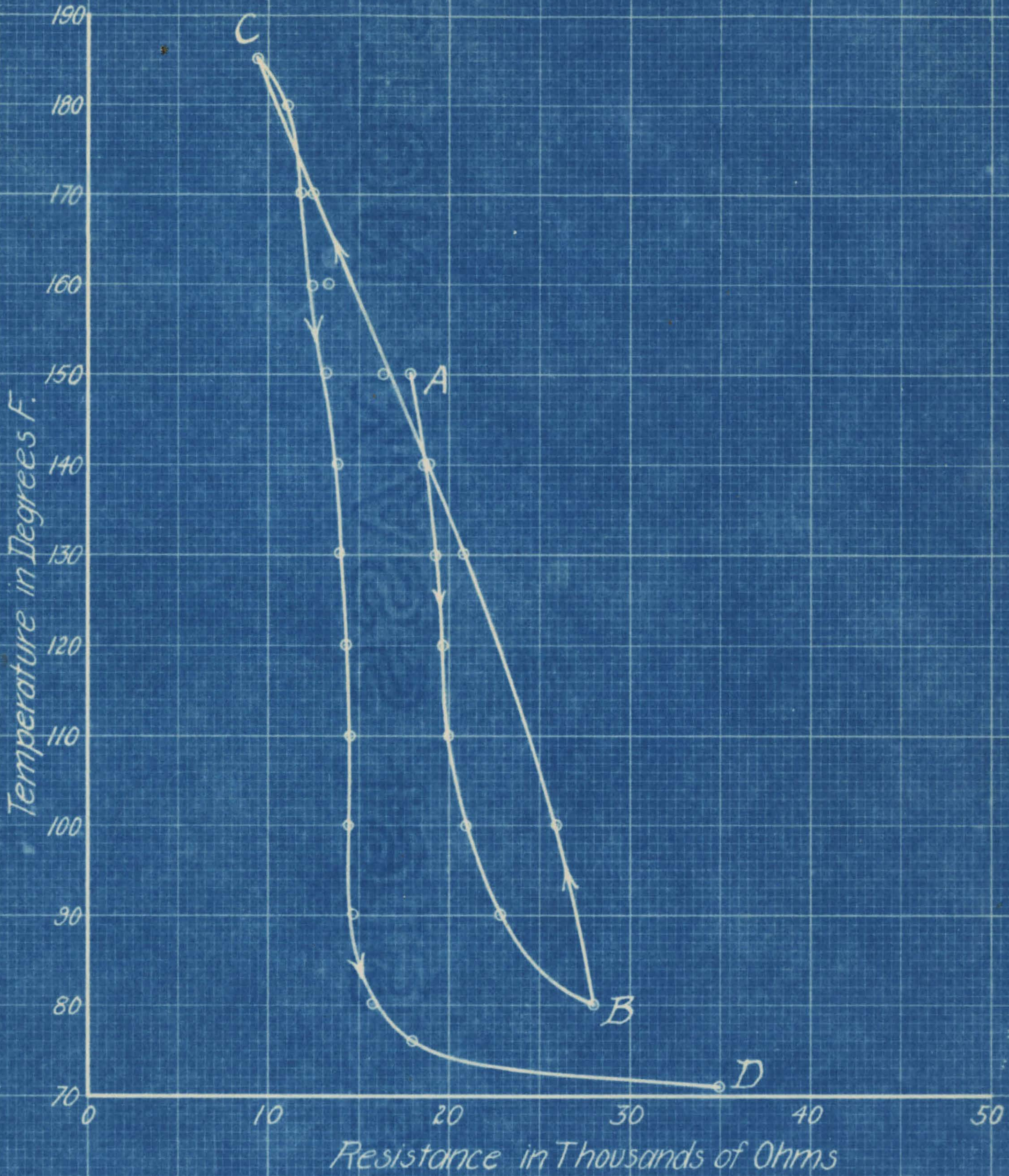
successfully used on the U.S.S. Conyngham, and has been the subject of a paper by Rear Admiral R. T. Hall, U.S.N. read before the twenty-fourth annual meeting of the Society of Naval Architects and Marine Engineers, held in New York Nov. 16 & 17, 1916. A review of this paper occurs in Power, Vol. 44, page 767.

This apparatus consists of a simple selenium cell located as at D in Diagram No. 1. This was connected in series with a source of power, a galvanometer and a resistance for adjustment. The adjustable resistance was a very essential part of this apparatus and as we shall soon see, it was probably much overworked.

A selenium cell, such as is put out by the Electro Importing Co., was tested under several conditions. Curve Sheet No. 1 shows the effect at constant temperature of varying illumination on the resistance. This curve shows that a maximum illumination of about ten foot-candles will probably give the best results.

The cell was then placed in the dark and the change of resistance with temperature was noted within the normal working range. The results were plotted on Curve Sheet No. 2. Curve AB is the original rising temperature curve. After that, conditions became constant and four successive ascensions and descensions of temperature followed the curve BC.

Curve Sheet No. 3 shows the "hysteresis" loop

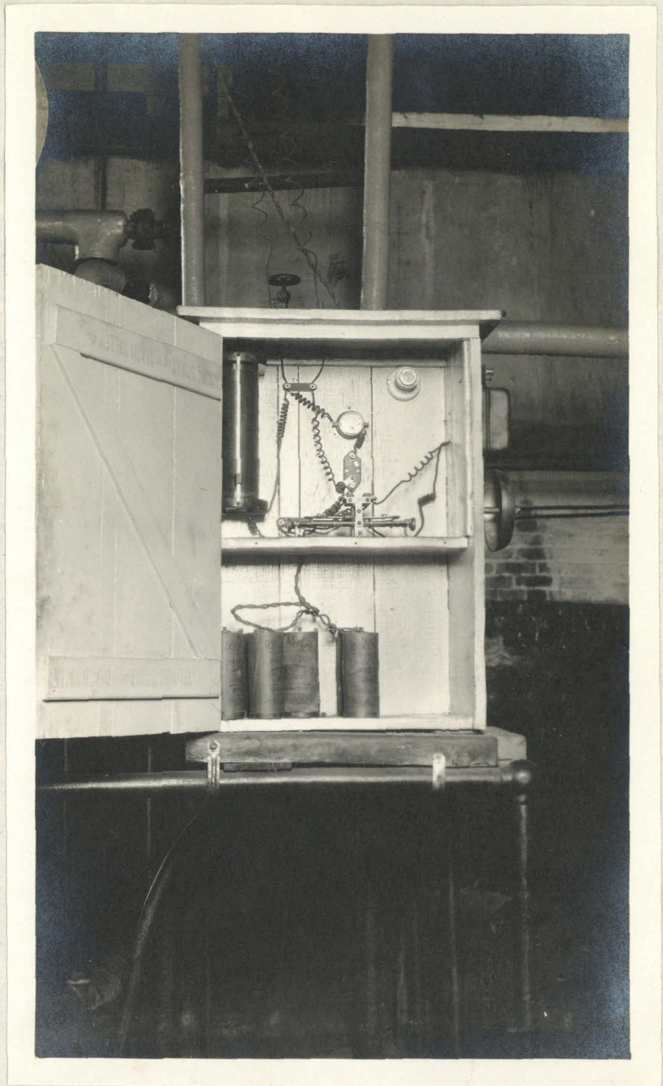


Temperature Effects at 60 Foot-Candles Illumination.

E. I. Co. Selenium Cell.

Curve Sheet No. 3.

Arthur Stert.

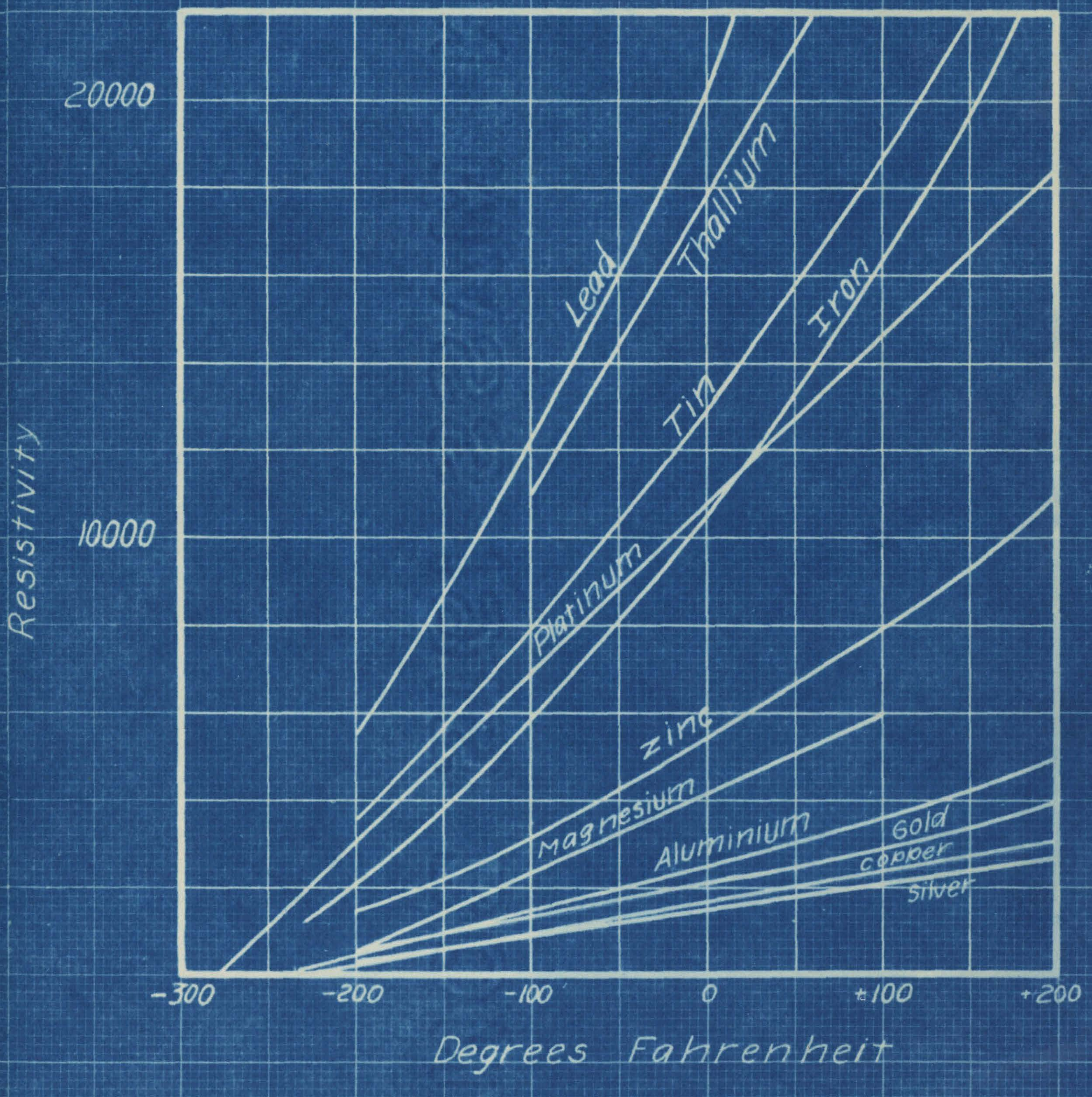


Instruents Used With

Selinum Cell Smoke Indicator

Change of Resistance with Temperature.

(Taken from Carhart's Physics.)



Curve Sheet No. 4.

Arthur Stert.

which will occur if rapid temperature changes take place. These curves were made at constant illumination of sixty foot-candles.

Curve Sheets 2 and 3 both show that a very material resistance change with temperature takes place; that within the normal working range and with comparatively slow temperature changes, the temperature resistance curve is very nearly a straight line; and that the resistance decreases with rise of temperature.

Varying load conditions on a furnace cause varying flue gas temperatures. Climatic conditions would also affect the temperature of the selenium cell. Hence, if the selenium cell smoke detector is to be trustworthy and untroublesome, some method must be devised to automatically compensate for change of resistance with temperature.

Curve Sheet No. 4, taken from Carhart's College Physics, shows the change of resistivity with temperature for the more common metals. From this we see that the resistance of most metals increases with increase of temperature -- just the opposite from selenium. Hence it is evident that if the correct amount of metal wire be connected in series with the selenium cell and be located near it so as to be subject to the same temperature changes, the resistance of the circuit will remain constant with varying temperatures. Thus the selenium cell will be compensated for temperature and will be sensitive to light variation only. This is the ideal condition.

The larger the temperature coefficient, the less wire will be required for the compensating resistance. Curve Sheet No. 4 shows that of the common metals, ~~of which~~ iron has the highest temperature coefficient.

In order to determine the temperature coefficient of the selenium cell we are interested in the slope of the line BC, Curve Sheet No. 2. BC will be considered as a straight line determined by the points B and C.

At B $\quad t = 170$

$\qquad\quad R = 17000$

At C $\quad t = 80$

$\qquad\quad R = 47000$

$$R = mt + k$$

$$17000 = 170m + k$$

$$47000 = 80m + k$$

$$30000 = -90m$$

$$m = -333.$$

$$17000 = -170 \times 333 + k$$

$$k = 17000 + 56600$$

$$= 73600$$

$$R = 73600 - 333t$$

Therefore the resistance of the selenium cell decreases 333 ohms per degree temperature rise (Fahrenheit).

The fundamental equation for resistance of metallic wire is:

$$R_t = R_o(1 + Bt)$$

Where R_t = resistance after a temperature rise of t^o F.

R_o = resistance at original temperature.

B = temperature coefficient of the wire per ^{o} F.

= .0165 per ^{o} F. for iron wire.

$$R_t = R_o + R_oBt$$

The variable R_oBt must equal 333 ohms per degree F.

$$R_oBt = 333$$

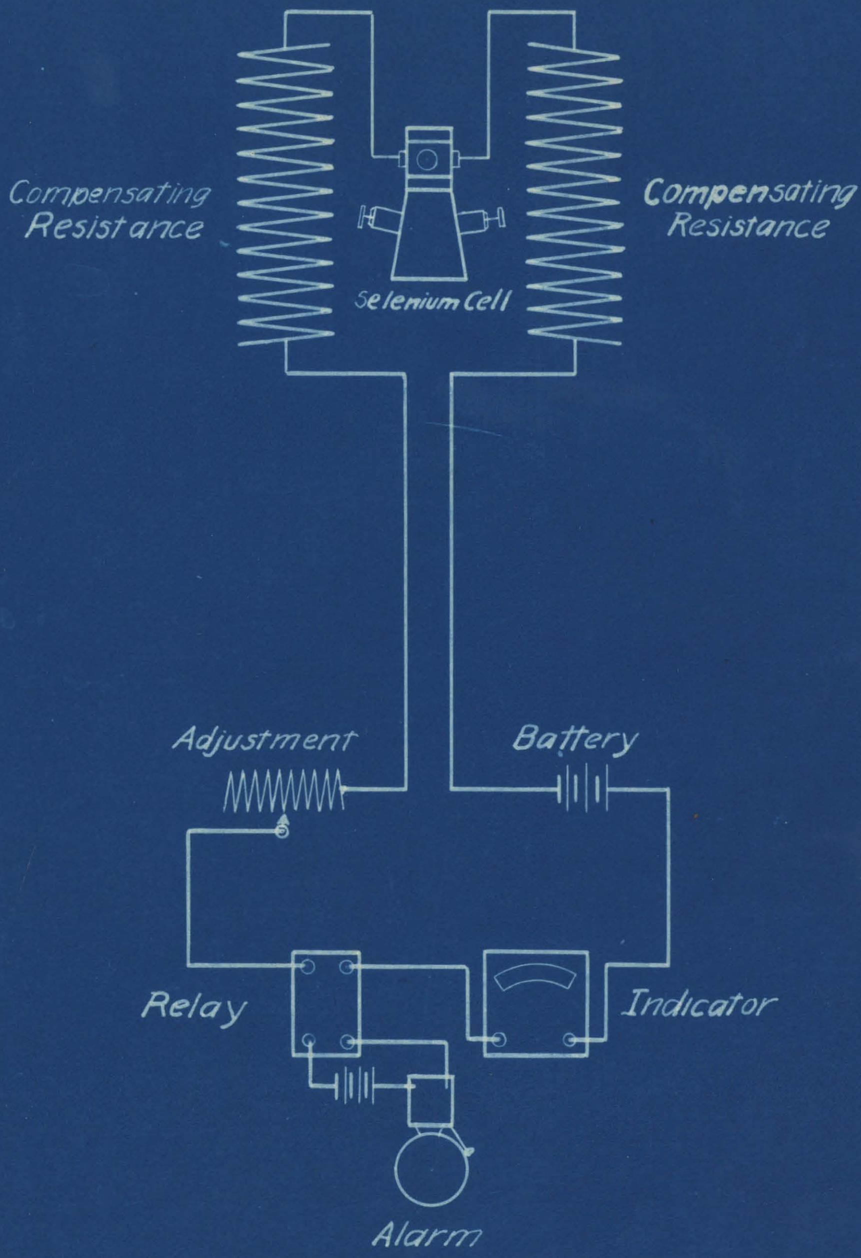
$$R_o \times .0165 \times 1 = 333$$

$$R_o = \frac{333}{.0165}$$

$$= 20200 \text{ ohms.}$$

No. 36 B. & S. Iron wire will be used in the compensating coils. Its resistance at 75^o F. is 2940 ohms per 1000 feet. Hence 20200/2940 = 6870 feet will be required. Weight of No. 36 B.& S. Iron wire = .457 lb.

The dark resistance of the circuit will then be 140000 ohms, and will vary from there to 78000 ohms at 10 foot-candles illumination.



Selenium Cell Indicator

Diagram of Electrical Connections

Diagram No. 2.

Arthur Stert.

Diagram No. 2 shows the connections for a selenium cell smoke detector to act both as an indicator and as an alarm. A recording galvanometer would make the apparatus into a smoke alarm, indicator and recorder.

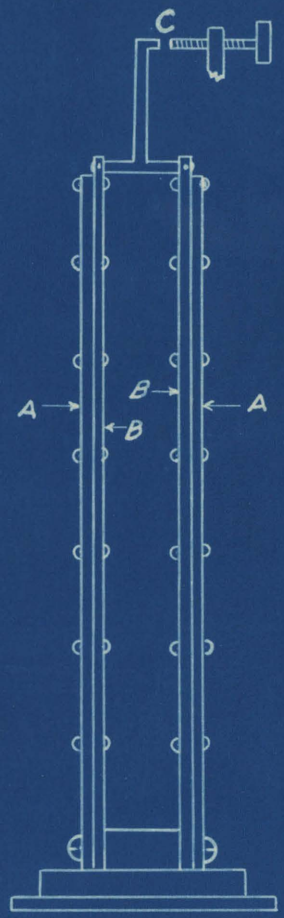
(c) The effect of light on the bromides of certain metals is well known in connection with photography. The Wattles Smoke Register, described in Power for Aug. 16, 1910, projects a beam of light across the stack and permits it to fall thru a slit onto a clock-operated sensitized chart. As the light intensity varies due to smoke, it affects successive portions of the chart accordingly. The disadvantages of this instrument are that the chart must be carefully guarded from stray light; that the resulting record is not very legibile; and that no audible alarm can notify the fireman of the sudden smoking.

(d) Light energy is readily changed into heat energy by permitting it to fall on a non-reflecting surface.

Since the temperature of the instruments of any smoke detector will vary thru a range of approximately 100° F., any apparatus for determining smoke by measuring the heat of absorbed light must be a differential arrangement which will measure merely the extra temperature due to the absorbed light.

There are many ways in which this temperature difference may be determined. For temperature measurements, one naturally thinks first of the thermometer. Two thermometers might be used. One with blackened bulb placed at D, Diagram No. 1. The other placed beside the first but screened from the light. Ordinary temperature fluctuations would cause their threads to rise and fall together. The presence of light would cause the exposed thermometer to be hotter. The difference of readings of the two would determine the amount of smoke present. This arrangement could not record nor actuate an alarm. Suppose, however, slight modifications are made. Select two exactly similar thermometers. Fasten them to a stick, bulbs together and stems pointing in opposite directions. Balance the stick over a knife edge and let the light be focused on the blackened bulb. If no light is present and the temperature varies, the threads of the two thermometers will run in and out together, thus maintaining the balance. If, however, light strikes the blackened bulb, the thread on that side will run out further than the other, the balance will be disrupted and the stick will tilt, indicating the presence of light. Thus a tilted stick means no smoke while a level stick means smoke. This method is impractical for obvious reasons, but is merely cited as an example of how the changing center of gravity of a thermometer might be made use of.

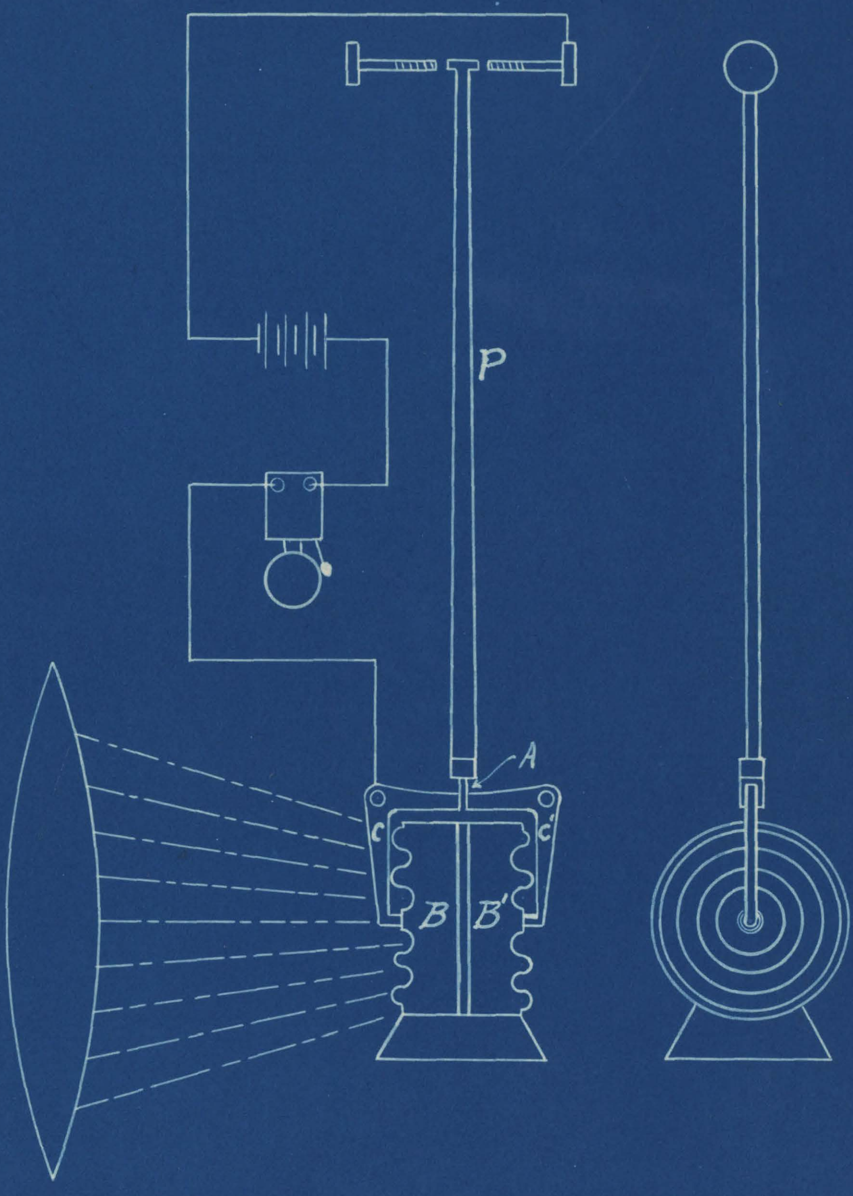
The common steel-and-ebonite-strip thermostat is one of the first mechanical temperature change alarms to suggest itself. Two such thermostats placed back to back with



Steel and Ebonite Thermostat Smoke Alarm.

Diagram No. 3

Arthur Stert.



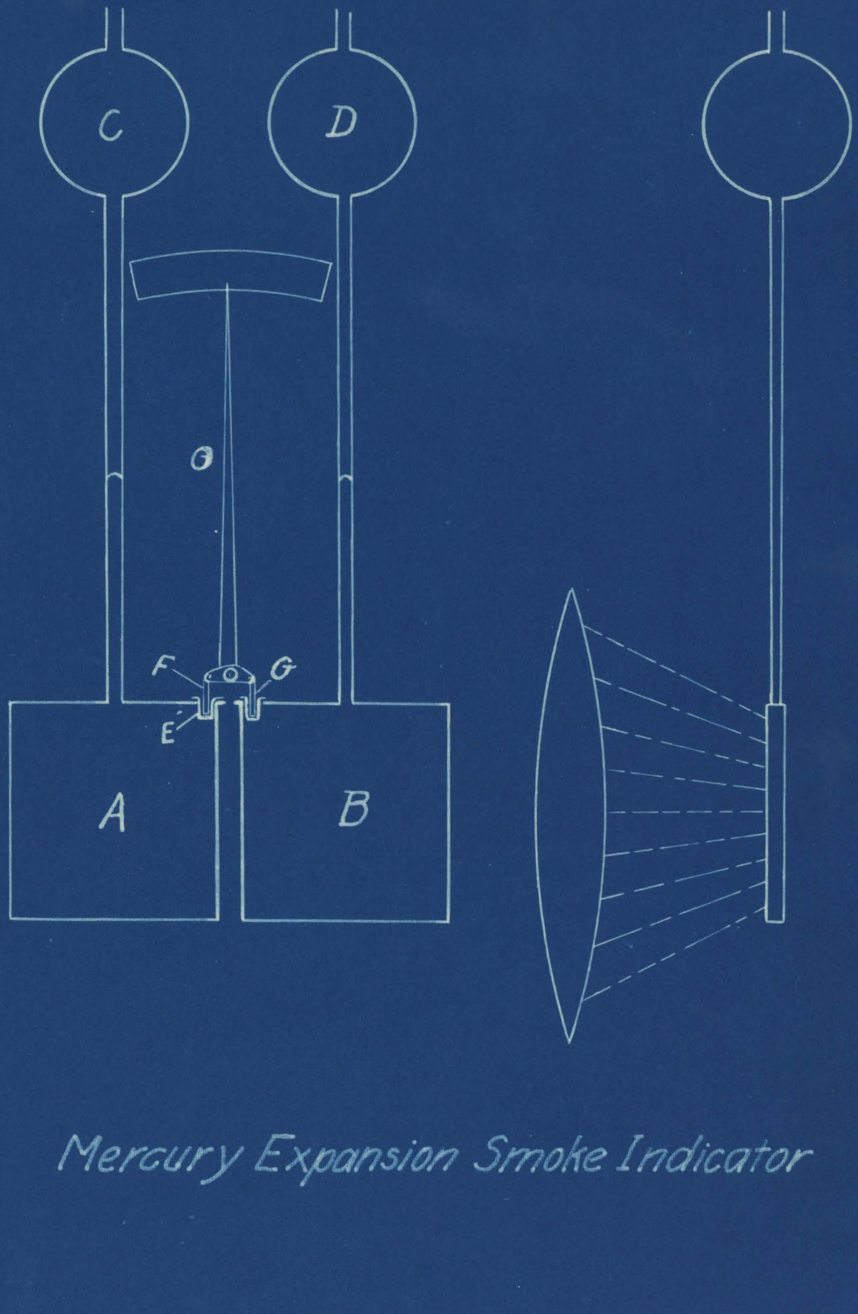
Air Expansion Smoke Alarm.

Diagram No. 4

Arthur Stert.

the light falling on one ebonite strip would make a satisfactory differential temperature alarm and could be used as a smoke detector. The arrangement is shown in Diagram No. 3. A-A are Ebonite strips. B-B are steel strips. C is the electrical contact. As the temperature of the stack changes, both compound strips tend to become concave inward because of the extra high coefficient of expansion of the ebonite. However, the forces are balanced against each other and contact C cannot move. When light is projected from the right, the right-hand complex strip tends to become more concave because hotter and hence the contact C is separated. When smoke cuts off the light the temperature of both strips becomes the same, the contact closes and the alarm rings. This apparatus is not practical because it is too slow in its operation. The necessarily large mass of the parts requires too long to undergo an appreciable temperature change under the action of light of any reasonable intensity.

Diagram No. 4 shows a method of using the expansion of a gas to produce the required results. B and B' are air chambers with corrugated diaphragms. As the air expands due to rise of temperature, the diaphragms are forced outward, thus the bell cranks C and C' are actuated and their inner extremities are given a downward motion together. Thus the pointer P moves downward but parallel to itself. At A are two small flat springs. One end



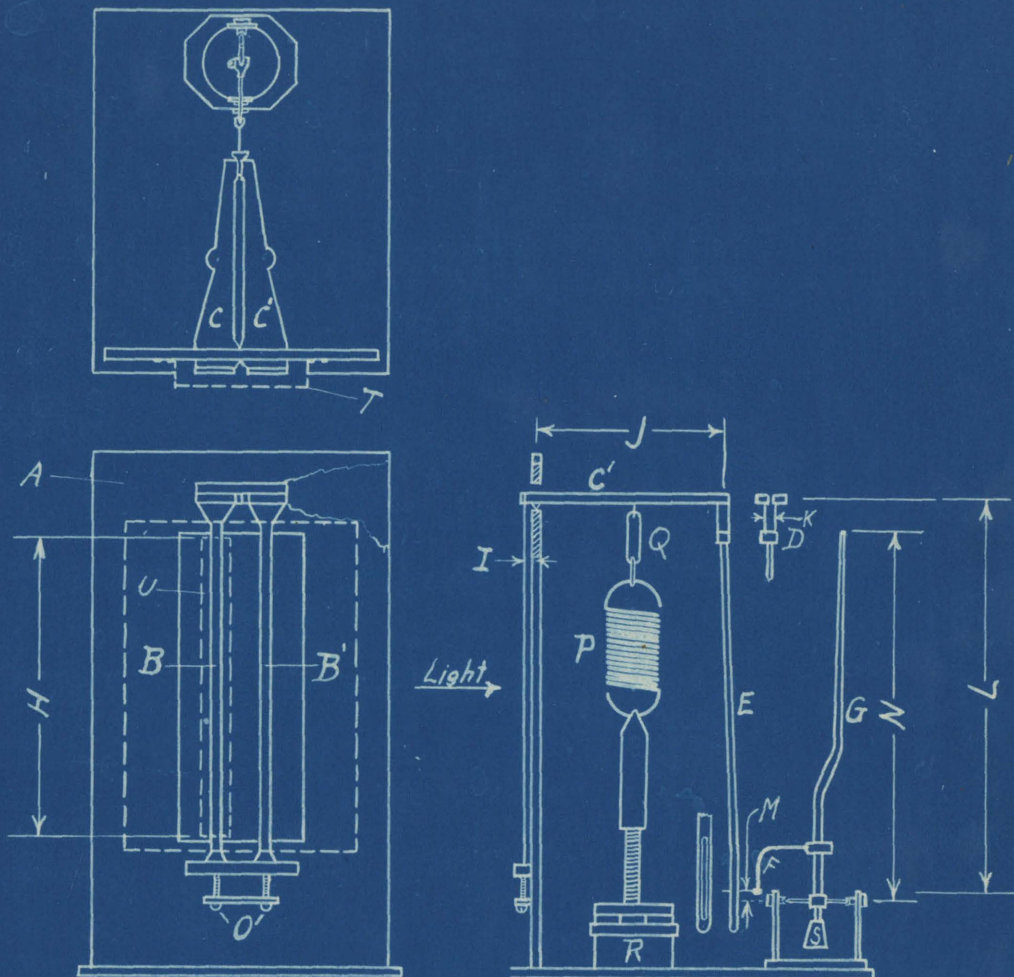
Mercury Expansion Smoke Indicator

Diagram No 5.

Arthur Stert.

of each is fastened to the pointer P. The other end of each is respectively fastened to one of the bell cranks. This gives a flexible joint with no lost motion or parts to stick. Suppose light falls on the blackened diaphragm at B. It becomes hotter, producing greater expansion in the air, making the bell crank move more and hence the pointer P is tipped to the left. When the smoke cuts off the light, the pointer returns, contact is made and the alarm rings. This apparatus would probably work very satisfactorily as a smoke alarm.

The expansion of mercury is utilized in the apparatus shown in Diagram No. 5. Two flat, thin mercury tanks A and B have risers C and D and small leather pockets E fitted with small plungers F, at the inner corners. The front surface of A is blackened and the light falls on it. When no light strikes the instrument, the mercury expands equally in each of the two tanks, with changing temperature. Thus the mercury heads on the two tanks remain the same and the forces on the two plungers F and G are the same. Hence pointer O does not move. If light strikes on A, the mercury in it is heated more and expands more, increasing the head on the plunger F and the pointer moves to the right, thus indicating the amount of smoke passing. This instrument would be slow in action because of the amount of light energy required to change the temperature of the mercury perceptibly.



Aluminum Expansion Smoke Indicator

Diagram No. 6.

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The instrument shown in Diagram No. 6 was constructed and tested. It worked very satisfactorily when an electric arc was used as the source of light. Thus it was proven impracticable, as too much energy was required for its operation.

The principle of operation is as follows:- Two thin aluminum strips B and B' are fastened at their lower ends by the screws O. Their upper ends are fastened to two levers C and C' which are pivoted on knife edges as shown. The spring P, fastened to the two levers C and C' thru the equalizing bar and linkage Q, keeps the same tension in each of the two strips. This may be adjusted by the screw R. At the outer ends of the two levers C and C' are two thin flat german silver springs K, which are also inserted into the block D to which is fastened the arm E. When the stack temperature changes, the aluminum strips expand equally and hence the two levers C and C' move together. Thus the spring joint K does not come into action and the arm E merely moves vertically up and down. If, however, light falls on the blackened strip B thru the slot U in the metal shield T, then it expands more, the lever C moves more and the arm E is deflected to one side. In the lower end of E is a slot in which works the small pin M. This is connected to pointer G thru the arm F. S is a weight to keep the pointer balanced. When the arm E is deflected it moves the pin M and the pointer G is moved across the scale.

The mechanical multiplication of motion from aluminum strip to pointer tip is

$$\frac{N}{M} \times \frac{L}{K} \times \frac{J}{I}$$

The dimensions used were:

N = 3.375"	K = .0515"
M = .0625"	J = 1.25"
L = 2.875"	I = .0937"

Then the multiplication is

$$\frac{3.375}{.0625} \times \frac{2.875}{.0515} \times \frac{1.25}{.0937} = 40300 : 1$$

The pointer must move 1 3/8 inches.

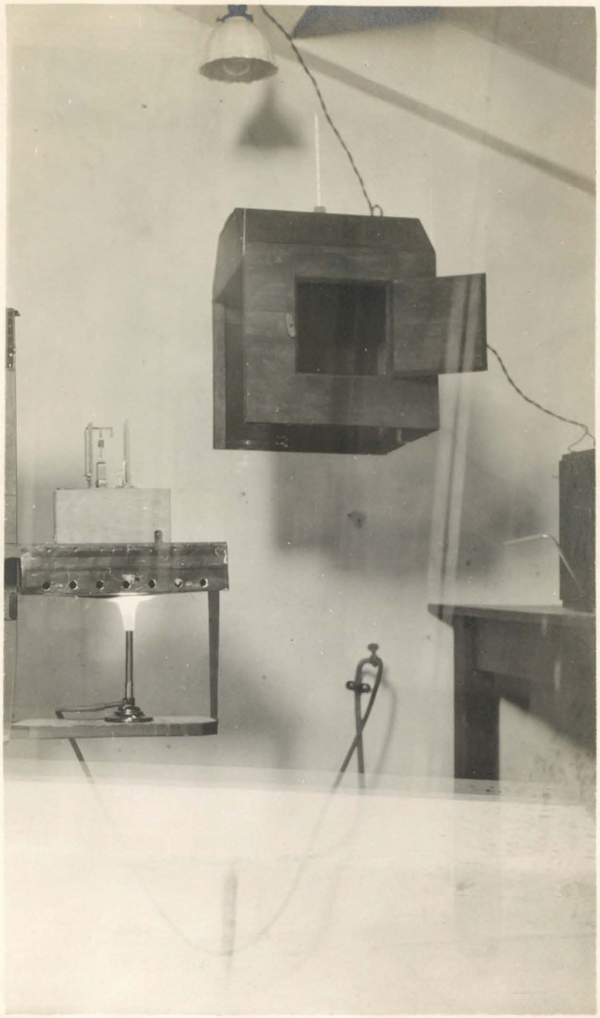
Length of exposed aluminum strip is 2 1/4 inches.

Coefficient of expansion of aluminum = .000013 per $^{\circ}$ F.

Temperature rise in aluminum strip must be:

$$\frac{\dfrac{1.375}{40300 \times 2.25}}{.000013} = 1.17^{\circ} \text{ F.}$$

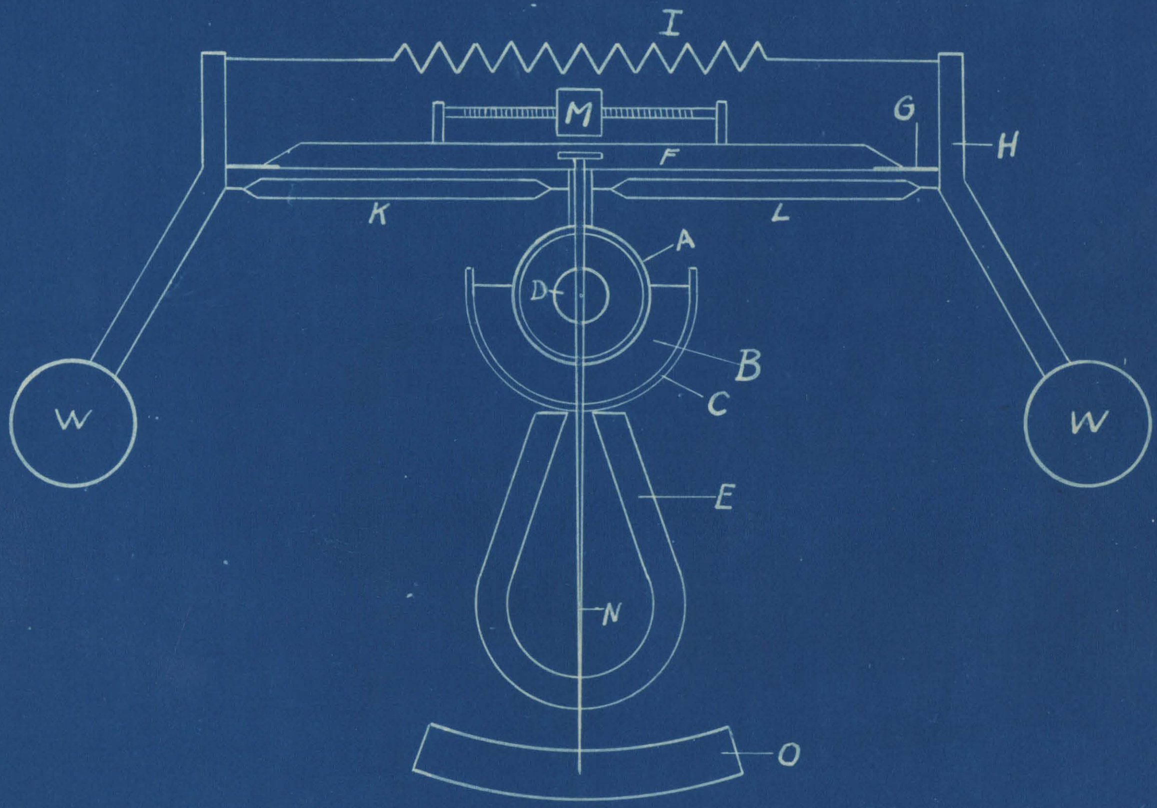
The above results are based on dimensions as finally constructed and adjusted. A one degree F. rise was used as the basis of the original calculation of dimensions and then adjustment at F and M provided for final adjustment.



Testing the Aluminum Expansion

Smoke Indicator

(Showing Instrument Box Removed)



Mercury Pivot Balance Smoke Indicator

Diagram No 7.

Arthur Stert.

Aluminum was chosen as the material of the strips because of its extreme suitability. Zinc and Ebonite, of the materials that are at all suitable, have higher coefficients of expansion. Zinc has the disadvantage of corroding easily, while ebonite is brittle and tends to warp when in thin pieces.

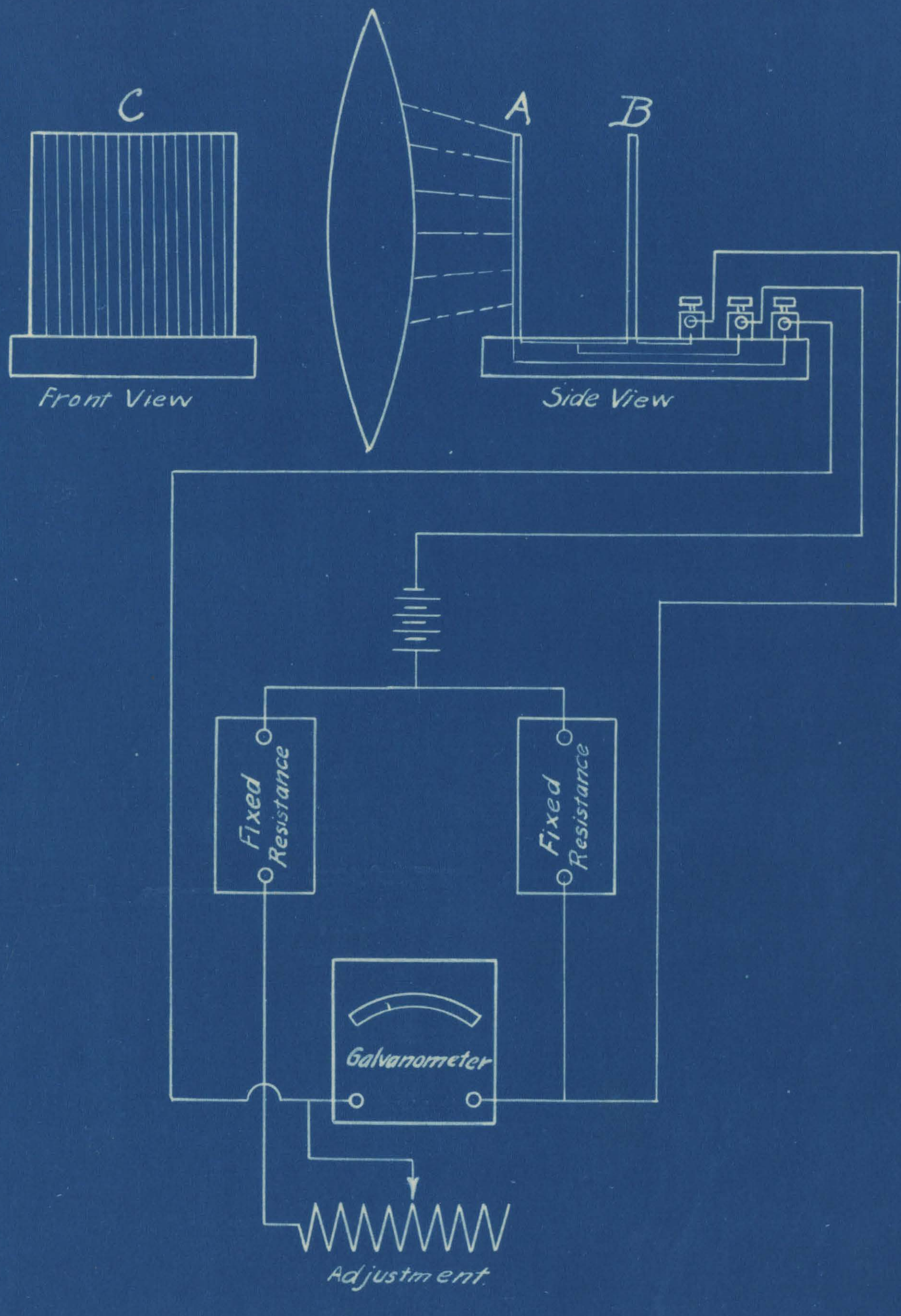
A very sensitive instrument using the expansion of aluminum strips is shown in Diagram No. 7. It is unique insofar as it contains a bearing which, when acting as a balance pivot, is in effect absolutely frictionless.

The instrument is fastened to a glass cylinder shown sectioned at A, which floats in mercury B contained in the trough C. Located concentrically in the glass cylinder A is an iron core D. Thus the magnet E retains the cylinder A centrally located in the trough C.

This pivot is frictionless when at rest because it is impossible for the system to come to rest with the center of gravity at any but its lowest position.

A frame F is fastened to the pivot and has flat springs G at its extremities which are attached to arms H. Weights W are held out equally by spring I. Aluminum strips K and L restrain the outward motion of the weights W. Weight M is for adjusting the balance.

When the instrument temperature changes, strips K and L expand equally, letting the weights W move outward



Resistance Smoke Indicator

Electrical Connections

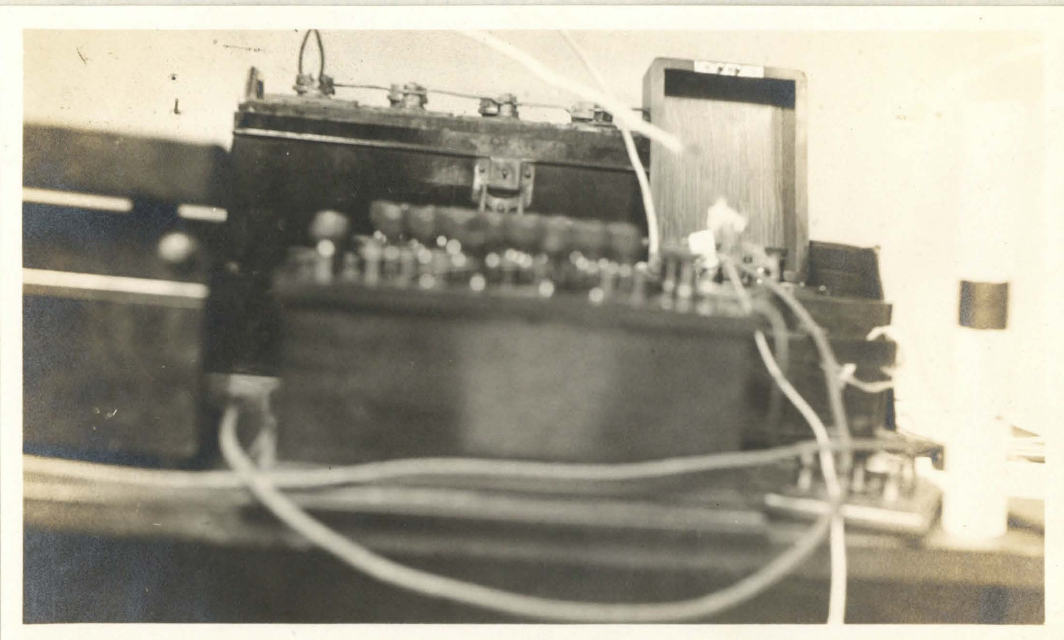
Diagram No. 8

Arthur Stert.

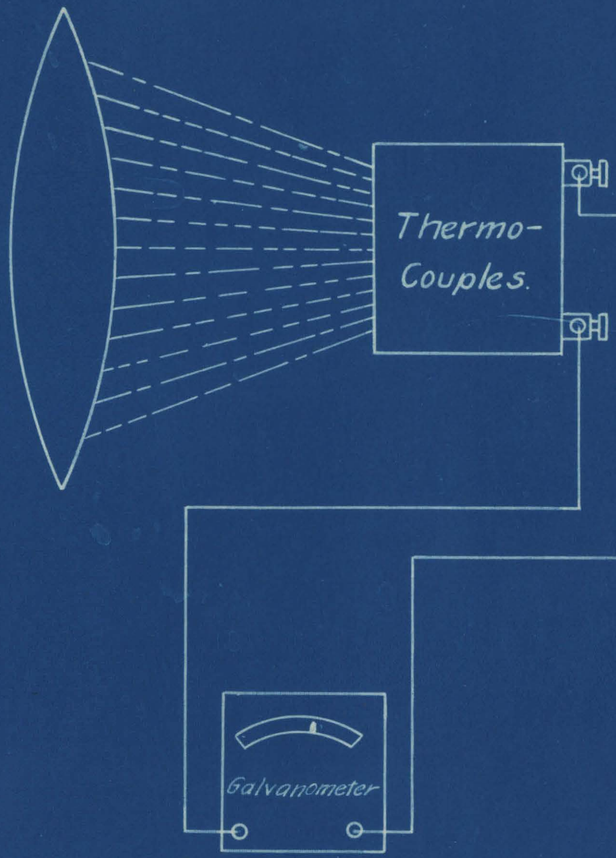
equally and the balance is maintained. Strip K is blackened and light allowed to fall on it. It expands more than does L so the weight at the left goes out more, so that the balance is disturbed, the instrument tips, and the pointer N moves over the scale O.

In actual practice such an instrument as this would have to be arranged with means of adjusting the center of gravity vertically and with some method of dampening oscillations.

The heat of absorbed light might well be used to change the resistance of a coil of wire, which, when measured, would be an indication of the light intensity. Of course, in this, as in other similar instruments, compensation for temperature changes must be affected. Diagram No. 8 shows a simple method of accomplishing the desired results. Two exactly similar coils A and B are wound with iron wire as shown at C. These are set up and connected as shown in the diagram. This hook-up is nothing more or less than the Wheatstone Bridge connection. A variation in the ratio of resistance A to resistance B will cause a current to flow thru the galvanometer. This will occur only where A is hotter than B due to the light falling on it. This method of smoke detection was tried out, but proved unsuccessful, principally because a galvanometer of the necessary sensitiveness was not obtainable. The method is probably impracticable because of the very slight change of resistance with the



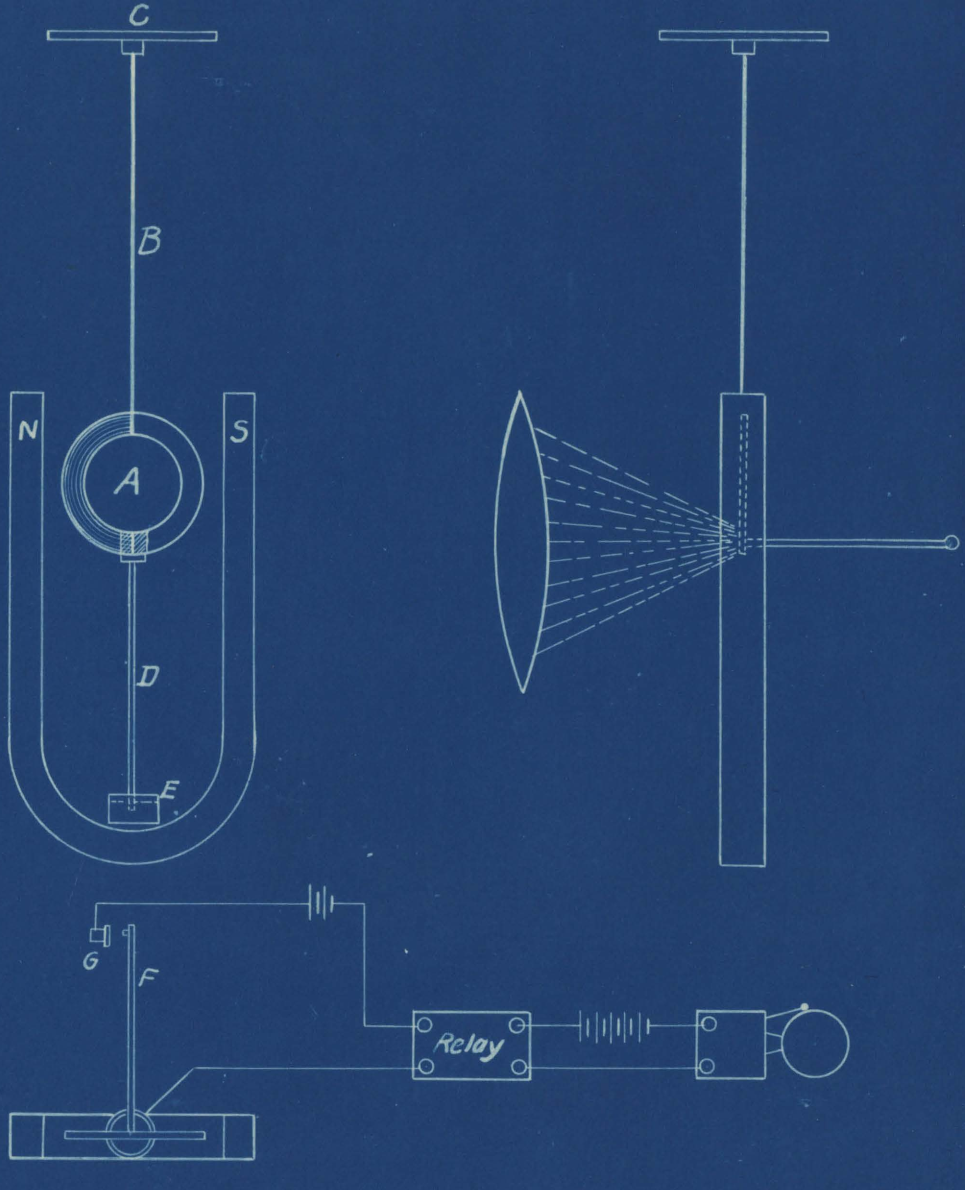
Testing Restance Type Smoke Indicator.



Thermo-Couple Smoke Indicator
Electrical Connections

Diagram No. 9.

Arthur Stert.



Thermo Couple Galvanometer Smoke Alarm.

Diagram No. 10

Arthur Stert.

small temperature change obtainable by light absorbtion.

A thermocouple is composed of two different metals soldered together at the end. When this joint is heated more than the rest of the wire, a small potential is created and an electric current will flow which can be detected by a galvanometer suitably located in the circuit. An arrangement of this sort is shown in Diagram No. 9. The disadvantages are that action would be slow because of the amount of light energy necessary to raise the temperature of the comparatively large mass of the Thermocouple.

Diagram No. 10 shows a combination of a thermocouple, a galvanometer and a relay. A bimetallic ring A hangs by a quartz fiber B from a torsion head C. The wire dips in mercury at E and by means of arm F contact is made at G when rotation takes place. Variation of instrument temperature cannot produce any results because both joints in the ring A are at the same temperature. If, however, the light is concentrated on one of the joints which has been previously blackened, that joint will become warmer, and a current will flow, which, circluating around the ring will produce a magnetic field tending to turn the ring into a position at right angles to the position shown. This will make contact and operate the alarm thru a relay.

This instrument is a modification of an apparatus that has been used successfully for measuring the energy of light radiation emanating from distant stars. Hence, it should be delicate enough to make a very good smoke detector.

The interesting instrument known as Crooke's Radiometer operates in the presence of light. The blackened sides of the vanes become warmer due to the absorbed light and hence air molecules which strike the black and the shiny vane surfaces equally are thrown back with greater velocity from the warm black side. This produces a reaction which rotates the vanes. This reaction might be used to actuate contacts and hence operate the alarm.

To calculate the mean force exerted per square inch of blackened vane surface, the Radiometer was placed in light of definite strength and its rate of rotation noted. Then the light was cut off and the revolutions and time required to stop were noted. As the rotating part is enclosed in a vacuum bulb, it was impossible to get the weights of the different parts directly, so their sizes were estimated and as the materials used were known, the moment of inertia and the radius of gyration were readily calculated with an error of not over 100%.

After the force exerted was calculated it was then possible to calculate the temperature difference between the two sides of the vanes. This was done on a basis of a pressure in the bulb of 1 centimeter of mercury.

MEASUREMENTS ON A CROOKE'S RADIOMETER.

Diameter of Glass bulb = 3 1/2 inches.

Estimated mean thickness of mica vanes = .0045 inch.

4 vanes each 5/8" square.

Mean radius to center of vane = 13/16".

Framework of aluminum, thickness = .015".

4 Arms 1/16" high and 5/8" long.

Moment of Inertia.

$$\text{Wt. Mica} = 4 \times \frac{(.625)^2}{144} \times \frac{.0045}{12} \times 183.$$

$$= .000745 \text{ lbs. at. } \frac{13}{16 \times 12} = .0677'$$

$$\text{Wt. Arms} = .625 \times \frac{1}{16} \times .015 \times 4 \times \frac{1}{1728} \times 162.$$

$$= .00022 \text{ lbs. at. } \frac{13}{16 \times 12 \times 2} = .0338'$$

$$\text{Moment of Inertia} = .000745 \times (.0677)^2 + .00022 \times (.0338)^2$$

$$= .0000034 + .0000003$$

$$= .0000037 \text{ lbs.} \times \text{ft}^2.$$

Radius of Gyration.

$$\rho = \sqrt{\frac{I}{W}}$$

$$= \sqrt{\frac{.0000037}{.000965}}$$

$$\rho = \sqrt{.00383}$$

$$= .062 \text{ ft.}$$

$$= .742 \text{ inches.}$$

Vanes rotated at 24 r.p.m. in light of the intensity used.

They made 1.00 turns after the light was shut off.

They required 8.0 seconds to come to rest after the light was shut off.

Acceleration based on Velocity and Time.

$$V = \frac{24\pi \times 2 \times .062}{60} = .156 \text{ ft./sec.}$$

$$M = \frac{.000965}{32.2} = .00003 \text{ Poundals.}$$

$$s = 2\pi \times .062 = .39 \text{ ft.}$$

$$t = 8 \text{ secs.}$$

$$v = at$$

$$a = \frac{v}{t} = \frac{.156}{8} = .0195 \text{ ft/sec}^2.$$

Acceleration based on Distance and Time.

$$s = \frac{1}{2} at^2$$

$$a = \frac{2s}{t^2}$$

$$= \frac{2 \times .39}{64} = .0122 \text{ ft/sec}^2.$$

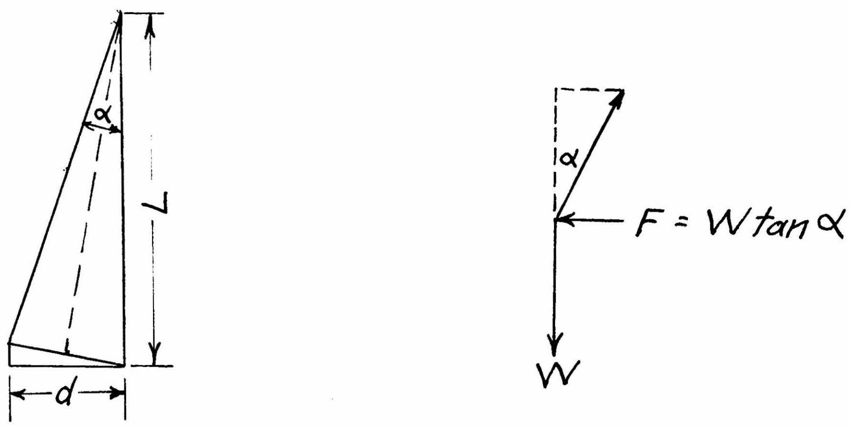
Mean acceleration = .0158 ft/sec^2.

Force exerted.

$F = Ma = .00003 \times .0158$

$= .00000047$ lbs. Total force.

$\frac{.00000047}{(.625)^2} = .0000012$ lbs/sq. in. of Black surface.



Consider vane 1/2 inch sq. = 1/4 sq. inch hanging from silk threads 1/2" long.

L = .75"

Wt of Aluminum = $\frac{.007 \times .25}{1728} \times 162$

$= .000164$ lbs.

$F = \frac{1}{4} \times .0000012 = .0000003$ lbs.

$\tan\alpha = \frac{F}{W} = \frac{.0000003}{.000164} = .00183$

$\alpha = 6.5'$

$$d = L \tan\alpha \text{ approx.} = .75 \times .00183$$
$$= .00137'' \text{ Deflection.}$$

If deflection of .005" is needed then

$$L = \frac{.005}{.00183} = 2\ 3/4''$$

The deflection possible increases approximately directly as the length of suspending threads and inversely as the weight of the vane.

Mica would be a much better material for the vane because of its low heat conductivity.

With a mica vane, say .001 inch thick and suspended from silk threads six inches long, the deflection would be about fifteen times that calculated for the aluminum as above.

It will be interesting to calculate the temperature rise on the black side of the vane.

TEMPERATURE RISE IN RADIOMETER VANES.

Assume a pressure in the bulb of one centimeter of mercury. Pressure varies directly as the absolute temperature.

$$\text{Normal pressure} = \frac{14.7}{76}$$
$$= .193 \text{ lbs/in}^2.$$

Temp.-= 75° F. = 535° Abs.

$$\text{Pressure on Black side} = \frac{.0000012}{.193} \times 100$$

$$= .000622\% \text{ High.}$$

The molecules strike the discs with the same velocity on each side because the same temperature exists in the medium surrounding each side of the disc, but they rebound from the black side with a greater velocity because they are heated after contact with the hot surface. Hence the extra pressure exerted on the black side is equivalent to half that due to the temperature of the disc.

Therefore temperature must be 2 x .000622% High.

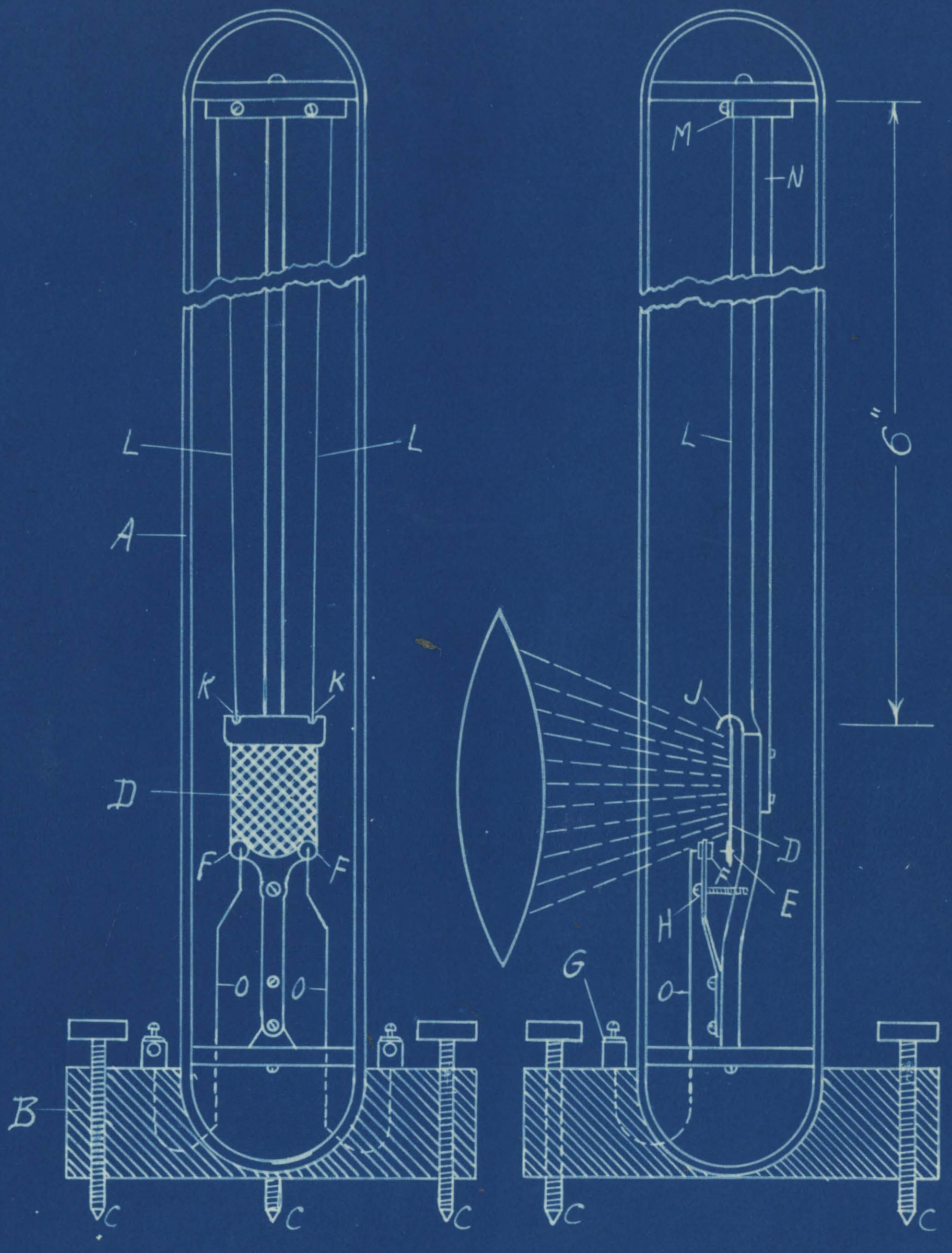
= 2 x .00000622 x 535 = .00665° F. higher on the black side than on the shiny side of the vanes.

It was decided to suspend a thin mica disc with an exposed area 1/2 inch square from two silk threads each six inches long. The weight of the disc with its double platinum contact points was .00011 lbs.

$$\tan\alpha = \frac{F}{W} = \frac{.0000003}{.00011} = .00273$$

$$d = L \tan\alpha \text{ approx.} = 6 \times .00273 = .0164 \text{ inches.}$$

Hence in a light of intensity such as was used in testing the Radiometer, a suspended disc of the size and weight assumed would be deflected .0164 inches from the normal position. This would be sufficient to break an



Radiometer Smoke Alarm.

Scale Full Size

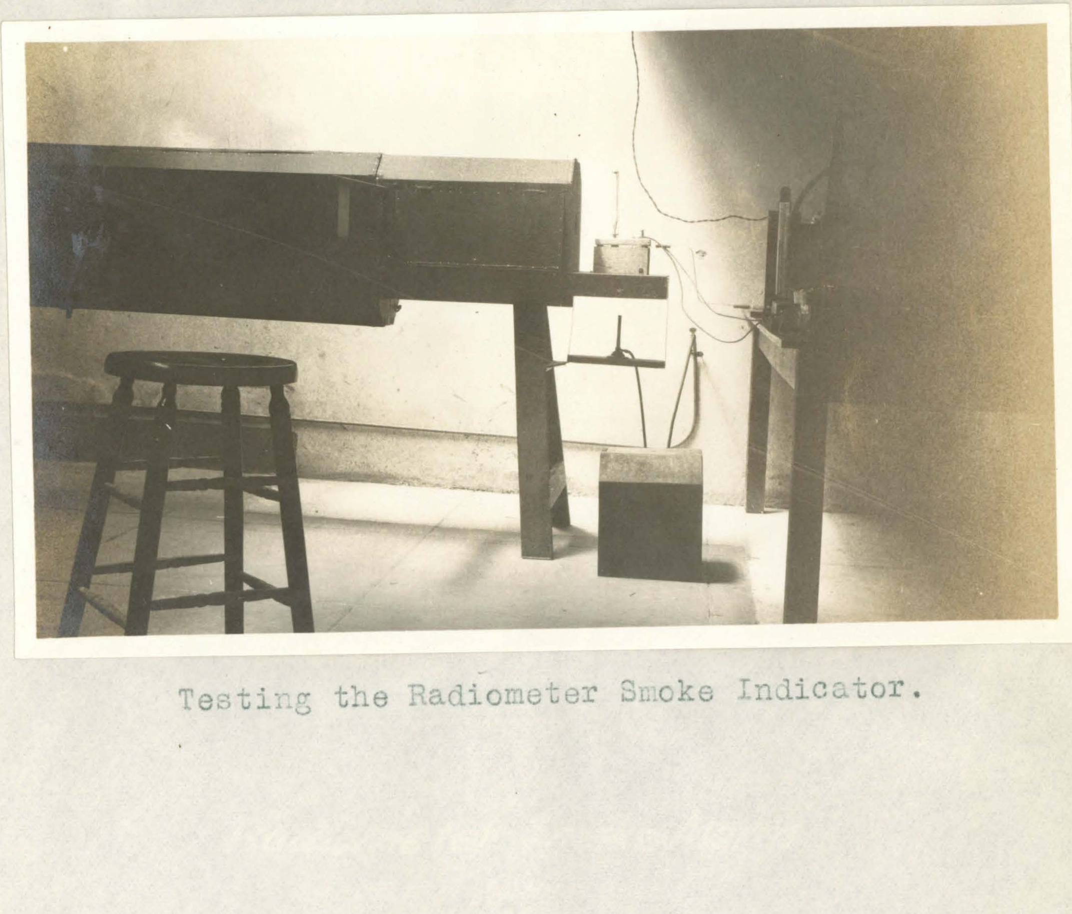
Diagram No. 11.

Arthur Stert.

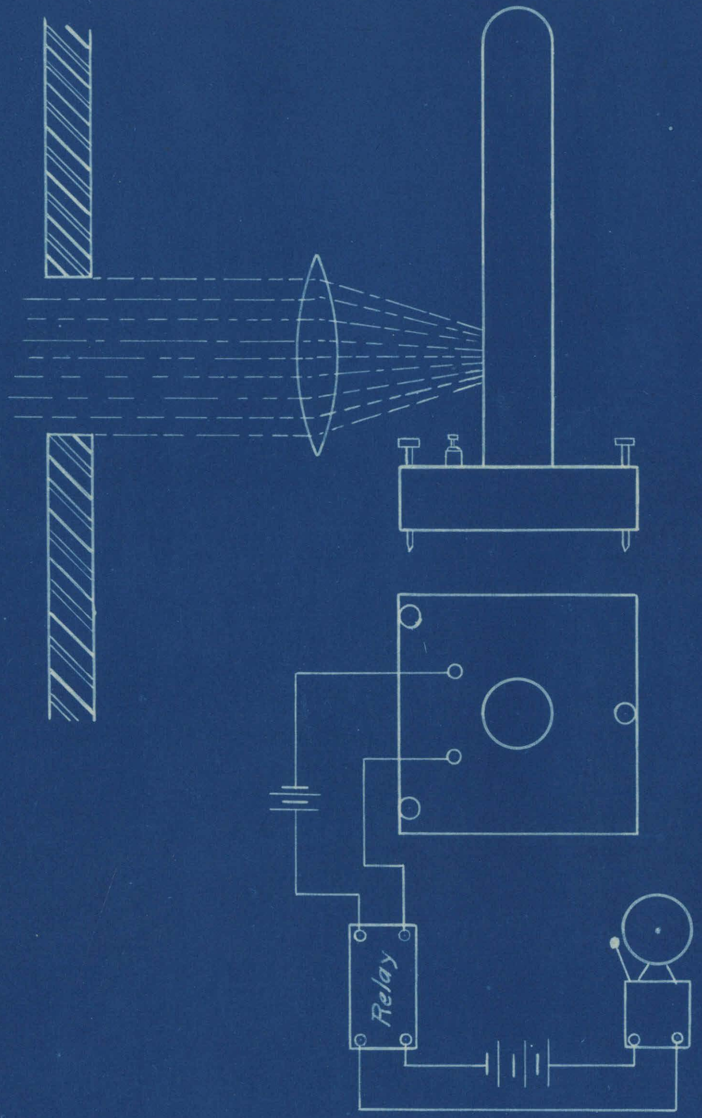
electrical contact.

The instrument as designed and constructed is shown in Diagram No. 11. A is a glass tube in which a low pressure exists. B is a wooden base. Screws C-C-C are for leveling the instrument so that the disc may hang perfedtly freely from the silk threads. D is the mica disc, blackened on the front side and carrying double contacts E which complete the circuit thru the stationary contacts F-F. Leads O-O, run from F-F to the binding posts G-G. Screw H is for adjusting contacts F-F. Extending over the top and down the rear of the disc is a stationary metal shield J which is for the purpose of deflecting the air currents which rise from the warm black front of the disc around and down the back side so that the draft may keep the rear of the disc cool. Slots K-K are provided in shield J for passing silk threads L-L which suspend the disc D. The silk threads are clamped by the arm M which is held up by the frame member N.

The operation is as follows: When no smoke is being emitted the light falls on the disc D, forcing it back and breaking the contacts at F-F. When the smoke cuts off the light the disc swings forward by its own weight, contact is made and the smoke alarm rings. Electrical connections for the apparatus are shown in Diagram No. 12.



Testing the Radiometer Smoke Indicator.

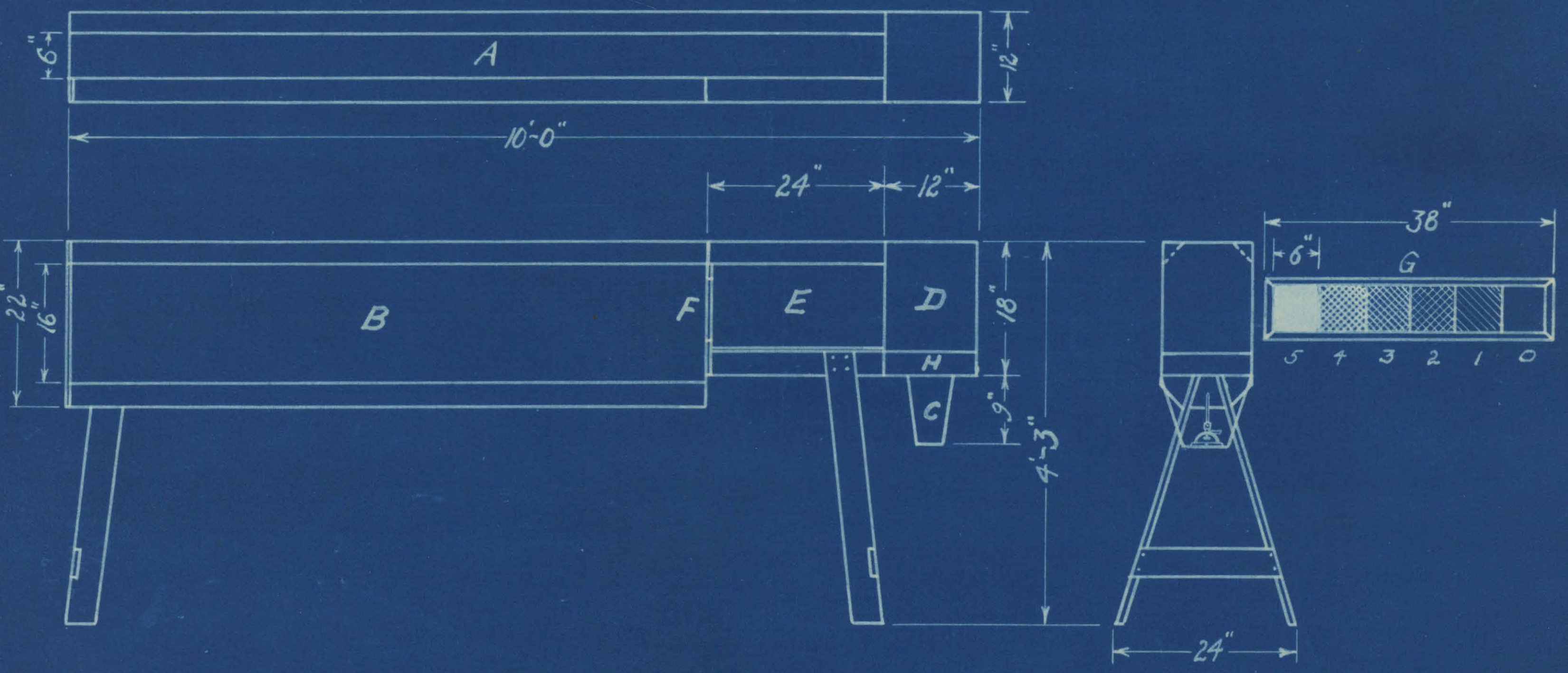


Radiometer Smoke Alarm

Electrical Connections

Diagram No 12.

Arthur Stert.



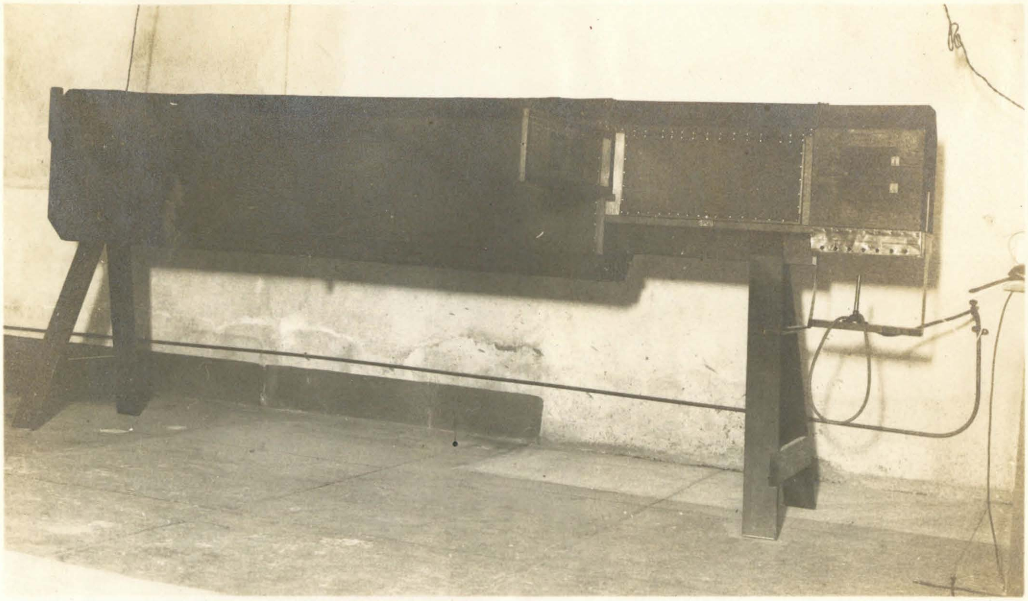
Apparatus for Testing
Smoke Indicator.

Diagram No. 13

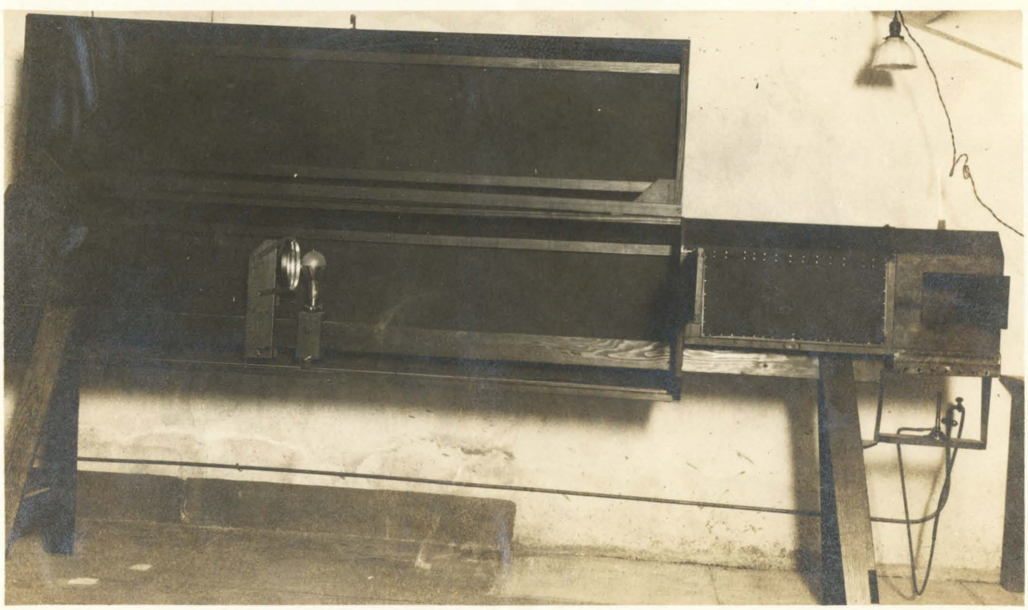
Arthur Stert.

When this machine was tested it worked unsatisfactorily because the only relay available required a current to operate it which sufficient to cause sticking of the contact points to such an extent that the minute weld formed would be able to hold up the entire weight of the disc.

It would have been inconvenient to have tried out the instruments that were constructed by actually installing them on a stack, as control of the smoke and stack temperature would have been difficult. Accordingly, the apparatus shown in Diagram No. 13 was built. The source of light was located in the compartment B. This light passed thru an aperture at F, thru the dead space E into the instrument box D. The light could be located any distance back from F in the space B, corresponding to different stack diameters. Across the aperture at F, a glass screen G could be slid. This glass screen was divided into six sections that were stained in even gradations from clear to dead black, corresponding approximately to the Ringlemann scale of smoke densities. With this arrangement the light which reached the instrument could be diminished at will to correspond to the intensity of light beam that would penetrate any given density of smoke. The instrument box D was capable of being kept at any desired temperature by a bunsen burner located at C and heating up the abestos lined tin box H which had air vents



Apparatus for Testing Smoke Indicators.



Showing Interiors of Light Compartment and Instrument Box.

to give a hot air draught into D. The accompanying photos show the testing apparatus and the method of using it

CONCLUSIONS.

In all, four different types of instruments were constructed and tested with the following results:-

1. A machine based on the principle of differential expansion of two pieces of metal. See Diagram No. 6. This instrument required an arc light to operate it. It worked very satisfactorily when the light intensity used was sufficiently great. The time lag to indicate the presence of smoke averaged about ten seconds. When the smoke stopped the time lag was about four seconds. More careful workmanship and better bearings would probably increase the sensitiveness materially. In testing, the multiplication was adjusted to be as great as compatable with assured action. From the results of the tests this type of instrument must be branded as commercially impractical in its present stage of development.

2. An apparatus based on the principle of unbalancing a Wheatstone Bridge network by differential heating of corresponding fixed resistances. See Diagram No. 8. This apparatus was entirely unsatisfactory as it was impossible to find a galvanometer sufficiently delicate to indicate the presence of light. In fact, the coil on which the light fell had to be heated with a

bunsen burner to get a visible deflection of the galvanometer.

3. An instrument using the principle of the excess reaction of gaseous molecules rebounding from a heated surface over those rebounding from an equal cooler surface. See Diagrams Nos. 11 and 12. This instrument has good possibilities tho it did not show up very well under test. Two essential conditions are, that the pressure in the tube be just right and, that an exceedingly delicate relay and low current be used so as to prevent sticking of the contact points. At best, this instrument would require a comparatively intense source of light and is, for that reason alone, probably commercially impractical.

4. Use of a Selenium Cell. The results obtained are very encouraging. Action is practically instantaneous. With accurate compensation for temperature, the selenium cell is the most satisfactory smoke detector. There are no moving parts, nothing exposed to get out of order, and no intricate construction. Very good selenium cells can be purchased for about five dollars.

In conclusion it may be said that a selenium cell smoke detector arranged as in Diagram No. 2 and equipped with a galvanometer smoke indicator and relay actuated audible alarm would be a very desirable and satisfactory auxiliary to every coal or oil fired furnace and could be produced commercially comparatively cheaply and marketed readily and profitably.