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Form 26
ABSORPTION OF GASES
BY CHARCOAL IN VACUA

by

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Submitted in partial fulfilment of the requirements for the degree of Master of Arts in the Graduate School of the University of Missouri

1917
Historical Introduction

Work of Dewar and Others.--That charcoal is a good absorbent of gases has long been known. The subject was first investigated by Saussure, and a detailed examination of this property of charcoal was made by Hunter (Phil. Mag. 4, vol. XXV, p. 364. 1863). Of all the charcoals he examined that made from cocoa-nut had by far the greatest absorbing power, one volume of charcoal absorbing 171.7 volumes of ammonia, 17.9 of oxygen, and 4.4 of hydrogen. It was not until 1874 that Sir James Dewar began his investigations on charcoal absorbing power. He found that when charcoal is first heated and then exhausted to expel gases already absorbed, and finally cooled in liquid air, 450 cc. of gas is absorbed by each volume of charcoal. While cocoa-nut charcoal functions best, any kind will do—even that of blood.

Besides charcoal other substances, such as alumina when cooled in liquid air are effective. A small quantity of alumina will absorb 400 cc. of air in a few minutes, but will not retain it as well as charcoal does. This lack of retaining power is characteristic of most metals. F. Soddy found that heated calcium is a univer-
sal absorbent of all chemically valent gases (Roy. Soc., 

From his results with liquid air and cocoa-nut 
charcoal Professor Dewar obtained the following laws:

At constant pressure, the curve of volume absorbed 
to temperature has a hyperbolic form.

At constant temperature, the pressure-volume curve 
is also hyperbolic.

The law connecting the pressure of the gas ocluded 
by the charcoal with the concentration of the gas, in 
a short range, is a fairly simple logarithmic one. The 
concentration enters into the formula with a power index 
of about 2.5. Through large ranges, however, the 
formula becomes very complicated.

The following table, I¹, shows volumes of helium 
absorbed by charcoal at different temperatures (Engineer-
ing, 81, p. 796, 1906).

TABLE I¹

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Helium</th>
<th>Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>-185° C.</td>
<td>2.5</td>
<td>137</td>
</tr>
<tr>
<td>-210</td>
<td>5.0</td>
<td>180</td>
</tr>
<tr>
<td>-252</td>
<td>160.0</td>
<td>250</td>
</tr>
<tr>
<td>-258</td>
<td>195.0</td>
<td>---</td>
</tr>
</tbody>
</table>

For a variation in pressure table II¹ shows the 
amount of hydrogen absorbed by 6.5 grams of cocoa-nut
charcoal at -190°C. (Engineering, 81, p.796, 1906).

Table I:

<table>
<thead>
<tr>
<th>Pressure in Atmospheres</th>
<th>Volume in c.c.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>620</td>
</tr>
<tr>
<td>5</td>
<td>925</td>
</tr>
<tr>
<td>10</td>
<td>1050</td>
</tr>
<tr>
<td>15</td>
<td>1000</td>
</tr>
<tr>
<td>20</td>
<td>975</td>
</tr>
<tr>
<td>25</td>
<td>925</td>
</tr>
</tbody>
</table>

From the results given in table I, Dewar concluded that the hypothetical density of any gas absorbed in charcoal is practically equal to the liquid density of the gas, and that whatever charcoal does, it behaves similarly to all gases, considering comparative temperatures. Knowing the amount of carbon dioxide gas absorbed by charcoal, he could estimate that 100 grams of charcoal contained about 15 cc. of pore space. He could compare the density of that absorbed carbon dioxide to the real density of the liquid carbon dioxide. Similar deductions had been made for other gases (See table III).

Table III:

Theoretical Mean Density of Gases in the Pores of Charcoal. Available Space 15 cc. per 100 Grams of Charcoal

<table>
<thead>
<tr>
<th>Gas</th>
<th>Temperature</th>
<th>Density of Gas in Charcoal</th>
<th>Fluid Density of Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>15°C.</td>
<td>.7</td>
<td>.8</td>
</tr>
</tbody>
</table>
Table III continued.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Temperature</th>
<th>Density of Gas in Charcoal</th>
<th>Fluid Density of Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>-183°C</td>
<td>1.33</td>
<td>1.12</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>-193</td>
<td>1.00</td>
<td>.84</td>
</tr>
<tr>
<td>Electrolytic gas</td>
<td>~58</td>
<td>.58</td>
<td>?</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>-193</td>
<td>.06</td>
<td>.07</td>
</tr>
<tr>
<td>&quot;</td>
<td>-210</td>
<td>.08</td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>-252</td>
<td>.11</td>
<td></td>
</tr>
</tbody>
</table>

Charcoal has a certain selective absorption.

This is shown in the case of air consisting of four volumes of nitrogen and one of oxygen, which if passed over cocoa-nut charcoal escaped with three volumes of nitrogen and two of oxygen. Again, if charcoal was cooled in liquid air it drank in air-gas very rapidly. When this charcoal was heated afterwards, the gas given off was much richer in oxygen than ordinary air. Considerable use has already been made of the graded absorption of charcoal in scientific work.

Applications of Dewars Methods:-- The following are some examples of the use of graded absorption of charcoal with liquid air for analytical purposes. The general law of selective absorption is that the more volatile the gas the less it is absorbed at a given temperature. If it is required to separate the helium which is found in the gases given off by a thermal spring, these gases are subject to the action of charcoal with liquid air. The result is the absorption
of the less volatile constituents, i.e. all except hydrogen and helium. The gaseous residue, with the addition of oxygen, is then sparked and the water thus formed is removed along with the excess of oxygen, when helium alone remains. Or the separation may be effected by a method of fractionation. To separate the most volatile constituents of the atmosphere an apparatus such as shown in Figure 8, p. 54 may be used. In one experiment with this apparatus 200 cc. of air was supplied from the graduated gas-holder, F, to the vessel D which contained charcoal cooled in liquid air. When unabsorbed parts of the air passed on to the sparking tube AB, which had a small charcoal bulb, C, attached, it showed the C and F lines of hydrogen, the yellow and some orange lines of neon, and the yellow and green of helium. By using a second charcoal vessel, E, with stop-cocks at H, I, J, K, and L to facilitate the manipulation, considerable quantities of the most volatile gases can be collected. After the charcoal in E has been saturated the stop-cock K is closed and I and J are opened for a short time. This allows the less condensable gas in E to be sucked into the second condenser, D, along with a portion of air. The condenser E is then taken out of the liquid air, heated quickly at 15°C, to expel occluded air and then replaced. More air is then passed in and by repeating the operation several times 50 liters of air can be treated in a short time,
supplying sparking tubes which will show the complete spectra of the volatile constituents of the air (Roy. Soc. Proc. 74, pp. 127-131, 1904).

The less volatile constituents of the atmosphere, krypton and xenon, may be obtained by leading a current of air, purified by passage through a series of tubes cooled in liquid air, through a charcoal condenser also cooled in liquid air. The condenser is then removed and placed in solid carbon dioxide at -78°C. The gas that comes off is allowed to escape, but what remains in the charcoal is liberated by heating and exhaustion. The carbon and oxygen are removed and the residue, consisting of krypton and xenon, is separated into its constituents by condensation and fractionation. Another method is to cover a few hundred grams of charcoal with old liquid air, which is allowed to evaporate slowly in a silvered vacuum vessel. The gases remaining in the charcoal are then treated in the manner described above. (Roy. Inst. Proc. 1894).

Charcoal enables a mixture containing a high percentage of oxygen to be extracted from the atmosphere. In one experiment 50 grams of it, after being heated and exhausted were allowed to absorb air at -185°C. Some 5 or 6 liters were taken up in 10 minutes, and it then presumably contained air of the composition of the atmosphere, i.e. 20% oxygen and 80% nitrogen as shown in the following figure:
But when air was passed over it, the portion that was not absorbed was found to consist of about 98% nitrogen. This showed that an excess of oxygen was being absorbed. In the course of a few hours the ocluded gas attained a new and apparently definite composition exhibited by the figure:

\[
\begin{array}{cc}
\text{N} & \text{N} \\
\text{O} & \text{N} \\
\text{N} & \text{N}
\end{array}
\]

Using charcoal methods such accurate quantitative results have been obtained that the percentage of rare gases in our atmosphere have been recently determined (Engineering, 81, p. 797, 1906).

The high absorption by charcoal at very low temperatures is shown in the following experiment. The electric discharge through a helium tube is not altered when the charcoal bulb attached to it is cooled in liquid air, because there is hardly any condensation of helium at that temperature. On the other hand, when the tube is cooled in liquid hydrogen the gas pressure is so much reduced that the discharge can no longer pass through the tube.

Professor Dewar has been able to make vacuum jacket
vessels out of metals instead of glass. He improves the vacuum between the walls by partly filling the space with well exhausted charcoal. When the liquid air or any other substance at very low temperature is placed in the vessel the charcoal absorbs practically all the air remaining between the walls after the preliminary exhaustion.

Pressure Changes in Vacuum Tubes.—Blythwood and Allen (Phil. Mag. 10, pp. 497-512, Oct. 1905) performed some experiments upon the rate of absorption of charcoal cooled in liquid air. They found that if \( p \) be the original pressure, and \( p_0 \) the pressure after time \( t \), the relation holds good that \( \log (p-p_0) = A-kt \), where \( A \) and \( k \) are constants. From this they deduce the velocity of absorption \( \frac{dx}{dt} = k(e-x) \), where \( x \) is the total amount of air the charcoal takes up and \( e \) the amount absorbed when equilibrium is produced.

The capacity for condensing gases is limited mainly to porous surfaces. The enormous increase of absorption at low temperatures in the case of charcoal is not found with palladium, according to H. Baerwald (Ann. d. Physik 23, 1, pp. 84-106, 1907). Nevertheless, Valentier finds that palladium does absorb hydrogen at low temperatures and that this absorption increases with the pressure to 5 mm. (Deutch. Phys. Gesell. Verh. 13, 22, pp. 1003-22, 1911).

The density of the carbon and the gas are the
decisive factors in the absorption of gases. Charcoal powder shows less absorption than the solid material. Moreover, the lighter the charcoal the more rapidly is the absorption completed. Charcoal prepared from elder pith takes up nitrogen as cocoanut charcoal absorbs hydrogen. Bergter found that at pressures .5 to 10 mm. pure oxygen is absorbed by cocoanut charcoal 30 to 40 times as much as pure nitrogen (Ann. d. Physik. 37, 3, pp. 475-510, 1912). Absorption, as a rule, is most rapid in the lightest charcoal and for the lightest gases. Baerwald concluded that regards the initial state of the carbon, no complete elimination of the original occluded gas is as yet feasible. Gases are given off beyond 500°C. All that can be done at present is to note the absorption after maintaining the temperature for some time at any given point. He believes that it is probable that all gases are absorbed to the same extent at their boiling points by the same kind of charcoal. The amount so absorbed is 240 cc. in the case of cocoanut charcoal, and 300 cc. in the case of elder pith charcoal. I. F. Homfray (Roy. Soc. Proc. Ser. A 84, pp. 99-106, 1910) finds that when amorphous charcoal is converted into crystalline graphite it entirely loses its absorptive power. Claud (Comptes Rendus 158, pp. 861-864, Mar. 1914) found that as a general rule the more easily a gas is liquified, the more readily it is absorbed by charcoal.
Theories of the Gas Absorption.-- J. Duciaux

(Comptes Rendus, 153, pp. 1217-1219, 1911) thinks that two very small equal volumes of definite shape placed in a gaseous medium are not in general in the same state, the irregularities of the movements of the molecules and their chances of collision will cause one of these volumes to contain more molecules than the other. These local differences of pressure and temperature he believes play a part in the absorption of gas by porous bodies.

A. Eucken (Deutch. Phys. Gesell. Verh. pp.345-362, 1914) using the assumption that gas absorption on a solid body represents the formation of a layer of compressed gas owing to physical forces of attraction, was able to deduce formulae for the absorption of an ideal gas. He found, in agreement with experiment, that the absorbed amount is for low pressure proportional to the gas pressure. Moreover his formula shows the influence of temperature. In the case of a real gas saturation takes place at high compression owing to the diminution of the compressibility. With vapors saturation can, as a rule, be effected only on strongly pitted surfaces.

In his paper, "The Mechanism of the Absorption ('Sorption") of Hydrogen by Charcoal" (Phil. Mag. S. 6, 18, pp. 916-934, 1909) James W. McBain sums up the various theories of absorption: (1) True chemical absorption, (2) True solid absorption. (3) A modified solid solution in which practically only the outer layers become
saturated owing to the difficulty of diffusion in solids. (4) Condensation on the outside of the surface of the solid. These, his experiments show him, do not account for what really occurs. He concludes that absorption of hydrogen by charcoal consists of a surface condensation and a diffusion (solid solution) into the interior of the carbon. Moreover, he finds that the surface condensation is nearly instantaneous at the temperature of solid air, whereas, the diffusion requires about 12 hours.

R. J. Strutt (Roy. Soc. Proc. Ser. A. 87, pp. 381-382, 1912) found that upon sending a silent discharge through a Siemens ozone tube containing phosphorous helium was absorbed. This helium could be liberated again when the tube was heated. When nitrogen or hydrogen was absorbed it could not be liberated by heating. He, therefore, concluded that the absorption by phosphorus seemed to be mechanical in the case of helium, but chemical in the case of hydrogen and nitrogen.

Hardening of X Ray Bulbs.--When a discharge is first sent through a new X ray bulb considerable gas is given off. This is caused chiefly by the gas ejected from the cathode and that given off by the anticathode (Kaye, X Rays, p. 71). After some time however, the gas pressure becomes continuously lower as the tube runs. This decrease in pressure is known as hardening. The same is true of any vacuum tube when a discharge is
passed through it. Ever since the days of Plücker (1858) attempts have been made to explain this action and thereby obtain methods for its control. Hodson, among others, believed that the hardening is due to the occlusion of the gases by the electrodes (Phys. Zet., 1912). But Hill (Proc. Phil. Soc., 1912) has shown that a marked absorption of gases occurs even with an electrodeless discharge. He concurs in belief with Willows (Phil. Mag. 1, p. 517, 1901) that hardening of the discharge tube is due to chemical action between the glass and the gas. Willows concluded that if tubes are desired in which the pressure remains constant they should be made of Jena-glass in preference to lead-glass, and of lead-glass rather than soda-glass; and finally that in the first two cases hydrogen is absorbed to a far less extent than air or nitrogen, the last two gases showing little differences.

Campbell-Swinton (Proc. Roy. Soc. 1907-'08) concluded from experiments that the gas is actually driven into the glass by the discharge. This, Kaye thinks, could be only a partial explanation for it does not, for instance, explain the marked differences in the behavior of different kinds of glass. Kaye suggests also that the action is stimulated by a species of electrolysis of the glass produced by the high tension discharge playing over the surface. In consideration of the results of Soddy and Mackenzie (Proc. Roy. Soc. p. 1906-'07)
showing that helium was absorbed by aluminium sputtered from the cathode of a discharge tube, and the fact that hardening of an X ray tube is well known to be pronounced with tubes whose walls have been blackened with metal sputtered from the electrodes, Kaye (Kaye, X Rays, p. 74) concluded that the finely divided metal behaves like spongy platinum in its absorptive properties for gases. In such a case the gas may be trapped by a contact film of metal.

For softening X ray tubes there are several well known methods used as, (1) the occlusion method, (2) "osmosis" method due to Prof. Villard, and (3) the use of the Bauer valve.

When a bulb becomes too soft about the only method used for hardening, besides exhaustion, is by prolonged running with as large a coil as obtainable. It is often beneficial to send the hardening discharge in the reverse direction, disconnecting the anticathode.

Kaye, in his book on X rays, speaks of the "finishing-off" processes to follow the pump for increasing the vacuum. One such process is to use cocoa-nut charcoal as anode with a feeble discharge. The gas absorbed by the charcoal is retained long after the discharge ceases. This is not the case when the gas has been absorbed by charcoal cooled in liquid air.

The gas absorbed by the electric process can be liberated if a heavier discharge is used. So that with
an evacuator of this type one should be able to regulate
the vacuum in a tube or bulb by simply varying the discharge
sent through the attached evacuator, or by reversing the
direction of the discharge. This charcoal evacuator
(name due to A. H. Pfund) should prove valuable for con-
trolling the degree of vacuum in an audion, in tubes
used for spectroscopic work, portable radiometers and
vacuum thermal junctions, and even in X ray bulbs if high
enough evacuation can be produced. In this connection
it is interesting to note that Pfund (Phy. Rev. 34, p.
230, 1912) used a charcoal evacuator to regulate the
vacuum for his black-body-vacuum thermal junction with
which he measured the radiation from Jupiter and other
planets.

The following is a description of Pfund's charcoal
evacuator with some of the results he has been able to
obtain:

Description of Pfund's Charcoal Evacuator.-- Take
the shell of an ordinary cocoa-nut, break up into pieces
about one inch square, place these pieces upon a sheet
iron strip and cover them with another piece of the
same material. Heat over a Bunsen burner until you
have charcoal. Next place these pieces of charcoal into
a mortar and crush them into granules of the size of
granulated sugar particles. Do not pulverize them. Re-
heat the mass to redness. When cool place this granular
charcoal into the evacuator and attach the pump.
Exhaust the pump until about 1 mm. pressure and send so heavy a discharge through the tube that the upper electrode is raised to a red heat (this electrode should be made of oxidized sheet iron). The current must not be kept on too long at a time since the glass near the electrode is liable to get soft. Repeat the process of sending heavy discharges through the tube until the greenish (i.e., the color of discharge) hydro-carbon vapors are no longer given off freely. This process of evacuation can be carried out with an ordinary good Gaede "Vorpumpe" alone. Next, the mercury pump is thrown in and the charcoal evacuator (not traversed by discharge) is pumped out for 15 minutes to the limit of the pump. The charcoal evacuator may now be sealed off from the pump and is ready for use.

If it is desired to remove the small quantities of air that may subsequently have leaked into the apparatus, connect the charcoal evacuator to a small transformer of about 2500 volts (for full primary voltage) in the secondary and send a very feeble discharge through the tube. The gases will be absorbed quite rapidly and shortly the discharge will cease. In order to carry the evacuation further, a small Wehnelt cathode connected to the battery B and K2, is inserted at W (Fig. 1). Upon closing the keys K1 and K2 and heating this cathode to incandescence, a vigorous discharge is again started and gases are again absorbed.
In a later experiment Dr. Pfund used the apparatus as shown in Figure 3 where

A indicates an iron electrode (cylindrical and hollow)
B indicates charcoal
C indicates small tungsten lamp
D indicates tinfoil externally applied after the gases have been driven out of charcoal by heavy discharge.

His method differed in some places, however. He describes it as follows:

To prepare this charcoal evacuator, connect A and B to a transformer and drive off gases. Continue this process (together with pumping) until gases are no longer freely given off. Stop discharge, work pump alone, light up lamp C and heat bulb with Bunsen flame for about 15 minutes. Then seal off from pump. When gases have leaked in or have been admitted (after charcoal evacuator is cold), connect A and B and send feeble discharge through until this practically stops. Next, light up C to white heat and connect it to A. This starts up discharge again, causing absorption of much gas. When discharge no longer passes, connect A and D to one side of transformer and incandescent lamp C to the other. This last connection, gives the highest vacuum attainable with the charcoal evacuator.
All waxes, such as bee's wax and rosin, stop-cock grease, etc. give off hydrocarbons. These in turn, react with incandescent tungsten wire and, in consequence interfere seriously with the proper functioning of the charcoal evacuator.

Using this method Dr. Pfund produces a degree of evacuation such that the discharge from a large induction coil will jump over an air-gap greater than 12 cm. in preference to passing between two electrodes (6.5 cm. apart) in a vacuum tube sealed to the charcoal evacuator.
The Purpose of the Experiments.--The purpose of the writer's experiments is to learn how effective the electrical process can be made. Also how useful it may be for controlling vacua where moderately low pressures are desired without the extra trouble of the more cumbersome processes. Another purpose is to study how readily various gases are absorbed by different kinds of charcoal. It is known, for instance, that with liquid air elder-pith charcoal absorbs nitrogen as cocoa-nut charcoal absorbs hydrogen. This suggests that probably the most efficient combination has not yet been found.

Preparation of Charcoal.--In the first experiments Pfund's method of preparing the charcoal was used, page 14. As a result of crushing there was always much pulverized material present. In order to remove this powder the entire mass was poured on one half of a piece of cheese cloth, the other half being folded over it. Now by catching hold of both ends of the cloth a sieve was formed with a cover so that it could be shaken with convenience until practically all the powder was gone. This mass of granular charcoal was then heated on a piece of sheet iron until it glowed (red heat) for a few minutes, after which it was allowed to cool. This cool charcoal was now placed into a hard glass tube, about 11 inches long and one inch in diameter (Fig. 2). At each of its
tapering ends wire electrodes were sealed in, picene and red sealing wax being used for the final sealing. To the upper wire a sheet iron cylinder was attached. This formed the cathode. The lower wire was surrounded by charcoal which formed the anode. A side tube was attached making connection with an air pump. The discharge tube was connected with an induction coil which in turn was connected with a Wehnelt interrupter as shown in Figure 4. A heavy discharge was sent through the tube for a few minutes at a time until the hydrocarbon vapors ceased coming off freely. These vapors glow with a greenish color when a discharge is passed through them. The pump was operated all the time, even during the intervals when the discharge was not passing. After this process was completed the charcoal was placed in a softer glass tube (Fig. 3) where a lighter discharge from the induction coil, connected to a rotary mercury interrupter (Fig. 4), was sent through for some time as above, only for longer intervals, ten or fifteen minutes at a time. When no more hydrocarbons were given off freely the charcoal was ready for use. This tube (Fig. 3) was built like the hard glass tube except for the method of sealing in the wire electrodes and for the fact that an ordinary nail was used for the cathode in the place of the cylinder.

At this place it might be well to mention a few precautions to be observed. It is necessary to
start the mechanical pump a minute before opening
the stop-cock passage into the tube to be evacuated.
When using an aspirator it is well to place a beaker of
water under the nozzle to prevent leakage. Moreover,
remove the tube before turning off the water. While
sending discharges through the tube care must be taken
that it does not get hot enough to break.

At another time the charcoal was prepared by imbed­
ding the clean shells in the sand in an earthen ware
vessel. This was then placed over a Bunsen flame and
heated until the charring was complete. The remainder
of the preparation was the same as in the previous case.

The second step in the preparation was varied in
the third process when after charring between two sheets
of iron the shells were placed in a long hard glass
tube, 32 cm. long and 1 cm. in diameter. One end of the
tube was closed while the other was connected to the
Vorpumpe of a Gaede rotary (mercury) pump. A plug of
glass wool was placed a short distance above the level
of the charcoal so as to prevent the latter going over
into the pump. With the pump running the charcoal
was heated for an hour or more over a double burner
Bunsen flame. The double burner was used to give
an even intensity distribution of heat. At this stage
a ring of dark green viscous substance, probably tar,
appeared on the walls of the tube. The heating was
continued until this no longer increased. Then,
with the pump still running, the charcoal was allowed to cool. In this condition it was placed in the final tube. Here a heavy discharge from an induction coil interrupted by a Wehnelt or mercury turbine break was sent through at intervals for about three hours. This was continued until there was no more lightning like discharge from within the mass of charcoal, and until the characteristic green discharge through hydrocarbons ceased.

Methods of Charcoal Preparation not yet tried.--
In some future experiments different methods of charcoal preparation will be tried. Brown wood-charcoal has some peculiar properties in connection with high explosives. For this reason it may lead to some interesting results when used in an evacuator. It will be prepared by prolonged gradual charring in a vacuum tube surrounded by a bath. Another arrangement to be tried is charring a piece of elder pith by making it an electrode in an exhausted tube and passing a discharge.

Method of Testing Vacuum.--An increase in the degree of evacuation can be very easily detected when the pressure in the tube is low enough to give the distinct cathode dark space, because this becomes larger as the pressure decreases until finally it fills the entire tube and the discharge ceases. If the potential is increased the discharge will again appear and a similar process takes place. This process was used only as
an indicator.

For determining the actual decrease of pressure in the tube the parallel spark method was relied upon. It is known that if a spark gap (in air) is in parallel with a vacuum tube through which a discharge is passing the gap must be made smaller as the pressure in the tube is decreased down to a certain point if the discharge is to pass only occasionally across the gap. After this point has been reached the spark gap must be made larger as the pressure in the tube diminishes.

It is these facts which are made use of in these experiments for determining the degree of evacuation. Through the two poles (A and A, Fig. 4) are two sharply pointed wires (f) and (g). The ends of these can be placed at different distances apart, thus giving the various spark gaps desired.

When the vacuum is being tested, the wires (f) and (g) are placed at such distances apart that the spark just jumps across the gap when hardly any discharge takes place through the tube. The distance between the near ends of the wire (f) and (g) was measured and this used to give the relative degree of evacuation. In these no pressures were taken which were not below those for which the discharge in the tube is more vigorous the nearer (f) and (g) are together. The distance was measured with a vernier caliper.

In the first experiment a Millikan pump was connected at (A) (Fig. 2) to evacuate the tube. This
pump proved unsatisfactory. for this work because
the pump could not be operated and at the same time
the current regulated. It was finally broken. Then
a Gaede rotary (mercury) pump was substituted for it.
This was joined to a Vorpumpe which was operated by
the same motor which drove the Gaede pump. In all
cases the Vorpumpe was run for a few minutes before
the Gaede pump was thrown in. This was done to produce
a vacuum low enough for the operation of the latter.

Description of Apparatus.--The tube used with this
arrangement was exactly as shown in Figure 2. Here
(A) is a side tube leading to a pump, (B) is the cylinder
of oxidized iron forming the cathode, and (C) is the mass
of charcoal which is the anode. The tube was made by
drawing down the ends of a glass tube 2 cm. in diameter
and 20 cm. long. The lead wires at (B) and (C) were
sealed in with red sealing wax and picene. It proved
as the experiment advanced that this method of sealing
in wires was not suitable because at times the tube became
too hot for these sealing materials to hold. It is
probably due to this fact that no positive results were
obtained with this tube.

The apparatus supplying the current was arranged
as shown in Figure 4, except that the pump at (H) was
not present. In this figure (R) and (L) are the taps
from the direct current generator (110 volts); (YZW)
is a doublethrow double pole switch; (DBC) is a
double throw single pole switch; (R) and (R) are
variable resistances; (T) is a rotary (mercury) interrupter; (W) is a Wehnelt interrupter; (Z) is a condenser; (I) is an inductance; (M) is an induction coil of which (A) and (A1) are the poles carrying the rods (f) and (g). The distance apart of (f) and (g) could be adjusted.

The direction of the current supplied by the generator was such that if (Y) was connected to (R) the terminal (A) was an anode when (W) was connected to (Z), and (A) was the cathode when (W) was connected to (Y). When (B) and (C) were joined the current passed through the Wehnelt (W) and when (B) and (D) were joined the current passed through the mercury interrupter (T).

Methods of Operating the Evacuator.--For the first part of the operation where a heavy discharge was sent through the vacuum tube in order to free the charcoal of the gases it contained, (W) was connected to (Z) and (B) to (C). The strength of the current passed through Wehnelt interrupter was regulated by varying the resistance (R). After the tube had cooled down the switches were thrown so that (B) was connected to (D). (W) remained connected to (Z), thus keeping the charcoal the anode. With the first observations (f) and (g) were kept far enough apart so that a spark could not jump from one to the other. In order to make the actions of the discharge observable a black screen was placed behind the vacuum tube. Moreover, all observations were made in a dark room.
With the preliminary exhaustion completed a very light discharge from the induction coil (using mercury interrupter) was sent through the tube. The strength of this discharge was regulated by varying the resistance (R). At this time the entire tube was filled with the characteristic green cathode glow, except the small dark space around the cathode. In a very short time the dark space increased in size. Then the current was increased in small steps until there was no resistance in the primary of the induction coil. In each case the increase of the cathode dark space was observed, but the total increase was not very great. It is a well known fact that with a vacuum of this degree the size of the cathode dark space is a gauge of the degree of evacuation in the tube. The increase in the size of the dark space indicates that the pressure in the tube has been decreased but not to any marked degree. It was for this reason that this method of evacuation was abandoned.

The apparatus was changed some for the next experiments. In the first place the vacuum tube was changed. This time the tube had the appearance of Figure 6 where (m) was an iron nail, (n) was a mass of charcoal (anode) surrounding some "seal in" wire which extended through the glass of the tube, (c) was a tungsten filament automobile lamp, (f) was a double way stop-cock leading to the air pumps. This time the wires at (m) and (n) were sealed in by first drawing out the ends of the large tube then plac-
ing the "seal in" wires through small capillary glass tubes (.5 cm. in diameter and 3 cm. long) allowing the wires to extend about 3 cm. beyond each end. The capillary tubes were now melted so as to make air tight contact with the ends of the large tube where they were sealed on. Also the automobile lamp was sealed on to the end of the side tube.

Further changes were made as follows. Since results with the induction coil had proved unsatisfactory, a Thor-dersen transformer was introduced, and the induction coil was used only for determining the length of the parallel spark-gap. Also, an arrangement was introduced for heating the tungsten filament.

Figure 5 shows the new arrangement, the dotted lines indicating in outline the direct current part of the apparatus which was exactly the same as in Figure 4. The 110 volt alternating current (EP) led into the coil (b) which surrounded a laminated iron core. Above the core was another coil (a) with leads to the automobile lamp (c). The tube leading to the air pumps was at (p). The key (k) was up when testing with the parallel spark through (fg). Another 110 volt alternating current (GJ) led to the primary (Pr) of the transformer (T). In this circuit was a variable resistance (r) and three lamps in parallel with each other and in series in the circuit. The leads from the secondary (Se) of the transformer terminated in the key (k) and at the point (x).

After the tube had been pumped down as stated before and the apparatus arranged as described above enough.
Resistance was inserted, with key (k) down, to allow a feeble discharge to pass through the tube. The current was left on until the discharge ceased. Then some resistance was taken out at (r) until a fairly vigorous discharge was again obtained and the same process was repeated. After a few trials in this manner the discharge was started again when (a) was placed over (b) (other parts connected as before) so as to make (c) glow dull red. (a) was now left in this position until the discharge ceased. Then (a) was placed a little nearer (b) which made the lamp glow more brilliantly and the discharge increase. When this change was not too great the discharge would again cease. Next, (a) was taken away from (b) at the same time that the resistance was taken out at (r) and the above procedure repeated. The results at this point were encouraging but not good enough to warrant taking measurements.

At another time a similar procedure was used with a longer time devoted to heating the charcoal. With full voltage on the transformer a current was sent through the (m) and (n) terminals (connections as in Figure 5) for intervals of five minutes with intermissions of two minutes. The tube was flushed with air before sending the current through it again. This process was repeated until very little green discharge remained. After the last time that the heavy current was sent through the pumps were allowed to run for 15 minutes to carry
away as much as possible of the gas liberated. Then the tube was sealed off by means of a stop-cock and the evacuator was ready for use. Next with connections left exactly as they were an attempt was made to pass a current through the tube by gradually varying the resistance in the primary. No results were obtained even with the full voltage on the primary, indicating a high degree of evacuation. When the automobile lamp was lighted by an induced current a sudden vigorous discharge appeared. This doubtless indicated that gas was liberated, so all the current was cut off and the pumps turned on to exhaust the tube. Connections were then made with the freshly exhausted tube at (x) and (n) (Fig. 5) so that the lamp filament could be made the cathode. The resistance at (r) was removed a little at a time. After each step the lamp (c) was lighted and left on for a minute or so. This was continued until suddenly a vigorous discharge appeared and the lamp (c) lighted without the induced current being on. The lamp lighted because the filament as cathode was heated by the high voltage current from the secondary of the transformer. To cut this voltage down a little more resistance was thrown in at (r) until a very feeble discharge was passing through the tube. Then the lamp (c) was again lighted with the induced current from (a) and left on about one minute. The resistance at (r) was reduced a little at a time using the lamp (c) after each change of resistance
as before. Next the transformer was cut off by lifting the key \((k)\). The induction coil \((M)\) was connected to \((m)\) and \((n)\) so as to give a parallel spark gap at \((f_3)\) for testing the degree of evacuation. By this method the spark gap was increased from a few mm. to 23 mm.

At this point it may be well to mention two of the most serious sources of error which had to be carefully guarded against. In the first place if the discharge through the vacuum tube is too heavy the tube will crack because of heating. This would necessitate repeating all the work. The other serious source of error was the appearance of grease in the tube from the stopcock. It is known that grease gives off gas freely when under the influence of an electric discharge.

Results and Discussions.---For the next set of experiments a new supply of charcoal was used. To drive off the occluded gas the charcoal was first placed between metal sheets and heated with a Bunsen burner. Then it was placed in a tube where it was heated by a current from an induction coil with a Wehnelt interrupter. The automobile lamp was gloved for a few minutes after currents for freeing the charcoal of gas were turned off, but while the lamps were still running. This was done to free the Tungsten filament of any occluded gases. After the pump had been sealed off a rather heavy current was sent through the tube long enough to get as long a parallel spark as desired. The following are some of the results obtained. The first column gives the length of the parallel spark gap; the second, its length at the end of the time that is duration
of discharge given in the third column; the last gives
the resistance in the circuit at (r) Figure 5, here a
- indicates that the resistance was decreased over that
of the preceding reading.

**TABLE I**

Air and Cocoa-nut Charcoal

<table>
<thead>
<tr>
<th>Length of parallel spark gap</th>
<th>Beginning</th>
<th>End</th>
<th>Duration of discharge</th>
<th>Resistance middle of (R)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>44 mm.</td>
<td>45 mm.</td>
<td>2 min.</td>
<td></td>
</tr>
<tr>
<td>45 &quot;</td>
<td>50 &quot;</td>
<td>4 &quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 &quot;</td>
<td>50 &quot;</td>
<td>3 &quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 &quot;</td>
<td>55 &quot;</td>
<td>2 &quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>55 &quot;</td>
<td>64 &quot;</td>
<td>4 &quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 &quot;</td>
<td>68 &quot;</td>
<td>2 &quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>63 &quot;</td>
<td>68 &quot;</td>
<td>2 &quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>68 &quot;</td>
<td>70 &quot;</td>
<td>2 &quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>70 &quot;</td>
<td>71 &quot;</td>
<td>5 &quot;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total increase in spark gap 27 mm.

After this only an occasional spark could be made
to jump the gap. The resistance was further varied in
small steps and with increase of the time interval but no
further increase in the length of the parallel spark
could be obtained.

Switches were placed in the circuit leading to
the transformer and the circuit carrying the current which
lighted the lamp (c). This was done to break up the
capacity effects in these two circuits. It is likely
that the transformer and the coil (a) might be charged
by the high frequency current leaking off by way of the lamp filament.

While testing with the parallel spark gas must have been liberated in the tube as the gas changed from 71 mm. to 26 mm. where the next set of observations began.
Table II
Air and Cocoa-nut Charcoal

<table>
<thead>
<tr>
<th>Length of parallel spark</th>
<th>Time</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning</td>
<td>End</td>
<td></td>
</tr>
<tr>
<td>26 mm.</td>
<td>27 mm.</td>
<td>5 min.</td>
</tr>
<tr>
<td>27 &quot;</td>
<td>29 &quot;</td>
<td>10 &quot;</td>
</tr>
<tr>
<td>29 &quot;</td>
<td>33 &quot;</td>
<td>10 &quot;</td>
</tr>
<tr>
<td>33 &quot;</td>
<td>34 &quot;</td>
<td>10 &quot;</td>
</tr>
<tr>
<td>34 &quot;</td>
<td>36 &quot;</td>
<td>10 &quot;</td>
</tr>
</tbody>
</table>

Total increase of spark gap 10 mm.

Next the heavy discharge was sent through the tube at intervals of 15 minutes. The pumps were connected for 10 minutes and the following results were obtained.

Table III
Air and Cocoa-nut Charcoal

<table>
<thead>
<tr>
<th>Length of parallel spark</th>
<th>Time</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning</td>
<td>End</td>
<td></td>
</tr>
<tr>
<td>43 mm.</td>
<td>45 mm.</td>
<td>10 min.</td>
</tr>
<tr>
<td>45 &quot;</td>
<td>50 &quot;</td>
<td>15 &quot;</td>
</tr>
<tr>
<td>50 &quot;</td>
<td>54 &quot;</td>
<td>20 &quot;</td>
</tr>
</tbody>
</table>

Total increase of spark gap 11 mm.

The arrangement of the apparatus was now changed somewhat. One of the most important changes was the introduction of a water resistance in the secondary circuit at $R_2$ (Fig. 6). In Figure 6 the lettering for those parts which occur in the preceding figures is as nearly the same as it could be conveniently made.
A key \((K_5)\) was inserted so that the lamps \((LLL)\) could be easily cut out. The resistance at \(R_1\) was of the type shown in Figure 7, where the lettering is the same as that of Figure 6.

When the apparatus was arranged as shown in Figure 6 the parallel spark between \((f)\) and \((g)\) was obtained by disconnecting at \((K_3)\), and connecting at \((K_2)\) with the double pole switch \((W_1)\) open. To get all the resistance at \((R_1)\) in the circuit it was necessary to disconnect \((K_5), (K_2),\) and \((K_4)\); and then after connecting at \((K_1)\) and \((K_3)\) bring \((R_1)\) to \((N_1)\). This resistance could be varied (lessened) by sliding \((R_1)\) toward \((M_1)\). The lamps \((LLL)\) could be cut out by connecting at \((K_5)\). When \((K_1)\) was disconnected and \((K_4)\) connected all the resistance at \((R_1)\) was cut out. In order to glow the lamp \((a)\) the switch \((W_1)\) was closed. The secondary resistance \((R_2)\) was thrown in by connecting \((K_1)\) and disconnecting \((K_4)\). The remainder of the connections and operations were the same as those with apparatus shown in Figure 4 and Figure 5. The transformer contained a magnetic shunt which could be regulated by a thumb screw.

With the apparatus as described above three sets of readings were taken with results as given in Table 4, Table 5, and Table 6. The first three columns in these tables are the same as those of the preceding tables. The third column gives the resistance at \((R_1)\) with the
same notation as before, while the last column gives the change of resistance using lamps (LLL) and resistances \(R_1\) and \(R_2\).

**TABLE IV**

Air and Cocoa-nut Charcoal

<table>
<thead>
<tr>
<th>Length of parallel spark gap</th>
<th>(R_1)</th>
<th>Character of resistance change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beginning</strong></td>
<td><strong>End</strong></td>
<td><strong>Time</strong></td>
</tr>
<tr>
<td>37 mm.</td>
<td>41 mm.</td>
<td>17 min.</td>
</tr>
<tr>
<td>41 &quot;</td>
<td>52 &quot;</td>
<td>15 &quot;</td>
</tr>
<tr>
<td>52 &quot;</td>
<td>61 &quot;</td>
<td>15 &quot;</td>
</tr>
</tbody>
</table>

Total increase in spark gap 24 mm.

**TABLE V**

Air and Cocoa-nut Charcoal

<table>
<thead>
<tr>
<th>Length of parallel spark gap</th>
<th>(R_1)</th>
<th>Character of resistance change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beginning</strong></td>
<td><strong>End</strong></td>
<td><strong>Time</strong></td>
</tr>
<tr>
<td>22 mm.</td>
<td>24 mm.</td>
<td>2 min.</td>
</tr>
<tr>
<td>24 &quot;</td>
<td>26 &quot;</td>
<td>2 &quot;</td>
</tr>
<tr>
<td>26 &quot;</td>
<td>32 &quot;</td>
<td>2 &quot;</td>
</tr>
<tr>
<td>32 &quot;</td>
<td>40 &quot;</td>
<td>6 &quot;</td>
</tr>
<tr>
<td>40 &quot;</td>
<td>45 &quot;</td>
<td>10 &quot;</td>
</tr>
</tbody>
</table>

Total increase in parallel spark 23 mm.
TABLE VI
Air and Cocoa-nut Charcoal

<table>
<thead>
<tr>
<th>Length of parallel spark</th>
<th>R₁</th>
<th>Character of resistance change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning 20 mm.</td>
<td>End 28 mm.</td>
<td>20 min.</td>
</tr>
<tr>
<td>28 mm.</td>
<td>40 mm.</td>
<td>20 min.</td>
</tr>
<tr>
<td>40 mm.</td>
<td>49 mm.</td>
<td>20 min.</td>
</tr>
</tbody>
</table>

Total increase in parallel spark 29 mm.

With another trial the voltage leaped to a high value very suddenly, liberating so much gas in the tube that it was not profitable to try to absorb it again. Incidentally the alternating current fluctuated very much at times thus causing much trouble in these experiments.

The next experiments were undertaken to see what effect (1) different arrangement to resistance, that is whether in primary or secondary circuit; (2) changing resistance gradually or in jumps, would have on the absorption. The apparatus as shown in Figure 6 was used for all sets of readings. The same time intervals were used for all sets of readings. The results were as follows:

Gradual change in resistance beginning with R₂ and LLL in, ending R₂, LLL, and R₁ out.
Table VII
Air and Cocoa-nut Charcoal
Parallel spark gap length

<table>
<thead>
<tr>
<th>Beginning</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 mm.</td>
<td>25 mm.</td>
</tr>
<tr>
<td>25 &quot;</td>
<td>28 &quot;</td>
</tr>
<tr>
<td>28 &quot;</td>
<td>34 &quot;</td>
</tr>
<tr>
<td>34 &quot;</td>
<td>40 &quot;</td>
</tr>
</tbody>
</table>

Total increase in spark gap 21 mm.

Table VIII
(Like Table VII except change in jumps)

Air and Cocoa-nut Charcoal
Parallel spark gap length

<table>
<thead>
<tr>
<th>Beginning</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>29 mm.</td>
<td>37 mm.</td>
</tr>
<tr>
<td>37 &quot;</td>
<td>40 &quot;</td>
</tr>
<tr>
<td>40 &quot;</td>
<td>42 &quot;</td>
</tr>
<tr>
<td>42 &quot;</td>
<td>45 &quot;</td>
</tr>
</tbody>
</table>

Total increase in spark gap 16 mm.

Table IX
Air and Cocoa-nut Charcoal
Gradual change in resistance beginning with R₂, LLL in, R₁ out; ending with R₂ and R₁ out, LLL in
Parallel spark gap length

<table>
<thead>
<tr>
<th>Beginning</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>22 mm.</td>
<td>30 mm.</td>
</tr>
</tbody>
</table>
Table IX continued

<table>
<thead>
<tr>
<th>Beginning</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 mm.</td>
<td>34 mm.</td>
</tr>
<tr>
<td>34 &quot;</td>
<td>41 &quot;</td>
</tr>
</tbody>
</table>

Total increase in spark gap 19 mm.

Table X

(Like Table IX except resistance changed in jumps)

<table>
<thead>
<tr>
<th>Parallel spark gap length</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beginning</strong></td>
</tr>
<tr>
<td>21 mm.</td>
</tr>
<tr>
<td>28 &quot;</td>
</tr>
<tr>
<td>31 &quot;</td>
</tr>
</tbody>
</table>

Total increase in spark gap 12 mm.

Table XI

Air and Cocoa-nut Charcoal

Gradual change in resistance, beginning with $R_1$ and LLL in, $R_2$ out; ending $R_1$, LLL, and $R_2$ out

<table>
<thead>
<tr>
<th>Length of parallel spark gap</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beginning</strong></td>
</tr>
<tr>
<td>22 mm.</td>
</tr>
<tr>
<td>26 &quot;</td>
</tr>
<tr>
<td>30 &quot;</td>
</tr>
</tbody>
</table>

Total increase in spark gap 13 mm.

Table XII

(Like Table XI except resistance change gradual)

Length of parallel spark
Table XIII

Air and Cocoa-nut Charcoal

Gradual decrease in resistance beginning with $R_2$, LLL, and $R_1$ in; ending with $R_1$, $R_2$, and LLL out.

Length of parallel spark

<table>
<thead>
<tr>
<th></th>
<th>Beginning</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>22 mm.</td>
<td>41 mm.</td>
<td></td>
</tr>
<tr>
<td>41 &quot;</td>
<td>52 &quot;</td>
<td></td>
</tr>
<tr>
<td>52 &quot;</td>
<td>61 &quot;</td>
<td></td>
</tr>
<tr>
<td>61 &quot;</td>
<td>73 &quot;</td>
<td></td>
</tr>
</tbody>
</table>

Total increase in spark gap 51 mm.

For the last reading of this table the magnetic shunt of the transformer was taken out.

Table XIV

(Same as for Table XIII except lamp (c) glowed brighter)

Length of parallel spark

<table>
<thead>
<tr>
<th></th>
<th>Beginning</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>23 mm.</td>
<td>43 mm.</td>
<td></td>
</tr>
<tr>
<td>43 &quot;</td>
<td>55 &quot;</td>
<td></td>
</tr>
<tr>
<td>55 &quot;</td>
<td>82 &quot;</td>
<td></td>
</tr>
<tr>
<td>82 &quot;</td>
<td>86 &quot;</td>
<td></td>
</tr>
<tr>
<td>86 &quot;</td>
<td>95 &quot;</td>
<td></td>
</tr>
</tbody>
</table>
Total increase in spark gap 72 mm.

Here again it was not possible to run the current in the primary of the transformer to the limit because of a sudden voltage change.

Upon observing the results it can be seen that the greatest increase in parallel spark gap is obtained under conditions of Tables VII, IX, XI, XIII, and XIV; that is, when the resistance is removed gradually.

The arrangement for VII was the same as for VIII, for IX the same as X, and XI the same as XII except that in each case there is a difference in the manner in which the resistance is removed. Moreover, it can be seen that the best arrangement of resistance is that given in Tables XIII and XIV.

In the next table (Table XV) the arrangement was the same as for Table XIV, but now the time for each reading was the same while the pressure in the tube was different for each one.

<table>
<thead>
<tr>
<th>Table XV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length of parallel spark</strong></td>
</tr>
<tr>
<td><strong>Beginning</strong></td>
</tr>
<tr>
<td>12 mm.</td>
</tr>
<tr>
<td>29 &quot;</td>
</tr>
<tr>
<td>82 &quot;</td>
</tr>
<tr>
<td>99 &quot;</td>
</tr>
</tbody>
</table>

This table shows that for air and cocoa-nut
charcoal the smallest increases were obtained at the lower pressures. This condition is typical for all the results obtained. Another point noticeable is that the greatest amount of absorption in a single step took place when most of R₁ was out. This was also the time when most care had to be taken to avoid sending too heavy a discharge with too sudden an increase, thus releasing gas instead of absorbing it. Moreover when beginning with vacuum of about 104 mm. parallel spark (or even lower at times) the pressure could not be brought down enough to be measured. This was probably due to the fact that when a voltage was used which was high enough to cause a discharge to pass through the tube a back discharge took place in the coil which lighted the lamp (e).

An attempt was made to see how hydrogen would be absorbed. Hydrogen was prepared by electrolysis of water. The apparatus consisted of two glass tubes about 1 cm. in diameter and 20 cm. long. At the top of each tube was a stopcock, while platinum electrodes were sealed into the bottom of each. The bottom of the tubes were connected by a tube which had a side tube into which the water was poured. When a current was sent through the water hydrogen collected in one tube and oxygen in the other.

After the hydrogen had been prepared it passed through a drying agent (phosphorous pentoxide). Here it was necessary to observe two precautions. In the first place care was taken to open slowly the stopcock on the tube
in which hydrogen was collected. This allowed the water to rise gradually so that it could be stopped easily before being able to enter the drying tube. When the tube containing hydrogen again filled with this gas the process could be repeated. This prevented the water getting over into the vacuum tube. Moreover, the tube containing the drying agent should lie in an horizontal position, or if in any other position some substance such as glass wool should be mixed with the pentoxide to prevent clogging of the tube. It might have been well also to have passed the hydrogen through sulphuric acid.

The first gas passing over the drying agent was allowed to escape into the air. This was done to clear the delivery tube of air, thus preventing any contamination in the tube. When the supply was pure it was admitted to the vacuum tube through a stop cock. After the vacuum tube had been filled with hydrogen it was reexhausted. This was repeated several times until it was evident that the tube contained only hydrogen. The same process was used with oxygen.

The apparatus was that of Figure 6 and the process of operation the same as that for which Table XIV was obtained. For some reason the behavior was not as is usually the case where hydrogen is absorbed by cocoa-nut charcoal. With liquid air hydrogen is very readily absorbed by cocoa-nut charcoal, but this was not the
case in these experiments as is shown in the following table:

Table XVI
Hydrogen and Cocoa-nut Charcoal
Length of parallel spark gap

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Begin</td>
<td>End</td>
</tr>
<tr>
<td>24 mm.</td>
<td>36 mm.</td>
</tr>
<tr>
<td>36 &quot;</td>
<td>42 &quot;</td>
</tr>
</tbody>
</table>

Total increase in spark gap 18 mm.

The difference in the way various kinds of charcoal absorb when cooled in liquid air suggests that a similar difference might be found with the process previously described. It was with this in view that walnut and hickory nut charcoals were tried. Time prohibited further experiments along this line. However, in another set of experiments which is to be carried on later elder pith charcoal, brown wood charcoal and others will be tried.

Air and Walnut Charcoal.-- In this case the preliminary preparation of the walnut charcoal was the same as the last method (page 18) used for preparing cocoa-nut charcoal. The apparatus and operation was the same as that for hydrogen and cocoa-nut charcoal. The results were of the type given in the following table:
Table XVII
Air and Walnut Charcoal

Length of parallel spark

<table>
<thead>
<tr>
<th>Beginning</th>
<th>End</th>
<th>Trial</th>
<th>Total increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>26 mm.</td>
<td>30 mm.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>30 &quot;</td>
<td>34 &quot;</td>
<td>8 mm.</td>
<td></td>
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This table shows that walnut charcoal does not absorb air as well as cocoa-nut charcoal does. Hickory nut was tried like walnut, but oil was continually appearing in the tube so that no satisfactory results were obtained with it. Elder pith charcoal was prepared but was not tried on account of lack of time. It would have been very interesting to try the combination of this charcoal with nitrogen for two reasons, (1) because it absorbs gas with liquid air very readily, (2) because it absorbs abnormally nitrogen when immersed in liquid air as cocoa-nut charcoal absorbs hydrogen. Nitrogen and oxygen were not tried on account of lack of time and because they are constituents of air, thus indicating that they should be absorbed rather readily—more
particularly if combined with the proper charcoal.

One variation of the above experiments was used with the same apparatus. This time connection was made so that a feeble discharge passed between m and n (Figure 6). This very soon refused to pass. The process was repeated with variance in $R_1$, being careful not to send too heavy a discharge. Now (c) and (n) were connected while (c) was caused to glow to incandescence when the discharge again passed and the actions of the first arrangement were repeated. In each of these cases no tests were made with parallel spark because too much resistance ($R_1$) was taken out thus finally causing gas to be given off instead of being absorbed.

The arrangement with tin foil externally applied at Q (as suggested by Dr. Pfund) was not tried on account of lack of time. This is supposed to give the most efficient arrangement.

Some Pronounced Effects.--When the apparatus (Fig. 6) was connected so that a discharge from the induction coil with Wehnelt interrupter passed between (m) and (n) a dark brown deposit appeared on the walls of the glass tube around the cathode. It is probable that this brown deposit was influential in the absorption later, in accordance with the suggestion of Kaye (Kaye, X Rays, p. 74) that this finely divided metal behaves like spongy material in its absorptive properties for gases.
Inverse Effect.—The following phenomenon, new so far as the writer knows, was observed while operating the tube with the induction coil, actuated by the mercury turbine interrupter. On reversing the primary of the coil by the use of the double throw switch, YWZ (Fig. 4) it was found that the current through the tube was not correspondingly reversed, the tube seeming to act as a rectifier with the charcoal always an anode. When the switch was thrown to the left WY (Fig. 4) gas was given off as shown by the presence of heavy striations which slowly filled the tube. When the switch YWZ (Fig. 4) was thrown to the right these striations slowly moved into the anode, showing an increase in the absorption or at least a large decrease in the amount of gas given off. This action is probably due to the inverse discharge being greater with the current in one direction than it was with the current in the other direction. When three striations were forced out of the anode with the switch in the WY direction all three could be drawn back into the anode when the switch was in the WZ direction. The pump was operating during this process.

Absorption upon cooling even when only down to room temperature was observed as the striations would shift nearer the anode after the charcoal had been given time to cool. This was done with the pump shut off.
CONCLUSIONS

There are several sources of error which doubtless influenced the results materially. In the first place it is probable that the charcoal was not heated long enough or steady enough to drive off all the occluded gases before it was placed in the evacuator. Willows (Phil. Mag. 1, p. 517, 1901) heated the charcoal he used for absorption for as much as three days and longer in order to drive off all the gases. In no case was the charcoal heated for such a long period in these experiments. Moreover, the stop cock used in these experiments was greased and sometimes the grease was forced into the evacuator. It is known (A. H. Pfund, letter) that all waxes, such as bee's wax and rosin, stop cock grease, etc. give off hydrocarbons. These in turn, react with the incandescent tungsten wire and in consequence interfere with the proper functioning of the evacuator. Again the method of sealing off with a stop cock might be ineffective in itself at these low pressures. It is possible that the air taken into the tube was not perfectly dry. This is probably one of reasons why hydrogen acted so peculiarly. It might have been well to have the hydrogen bubble through hydrogen sulfate after passing through the phosphorous pentoxide drying tube. Again the tube used for the
evacuator might have been too large for best results.
The large and sudden fluctuations in the supply current
caused much trouble at places where small changes were
absolutely essential. An attempt was made to overcome
this by working late at night when the load on the supply
circuit was not subject to abrupt changes. This trouble
can doubtless be minimized by using storage batteries
as the source of supply.

These experiments show that as far as the investiga-
tions have been carried the lighter charcoals are
better absorbers of air than the heavier ones. Cocoa-
nut charcoal is better than that from either walnut or
hickory nut. In the experiments with liquid air
Baerwald (Ann. d. Physik 37, 3, pp. 84-106, 1907)
found elder pith charcoal better than any of the others
for rapid action. Moreover, powdered charcoal will
not absorb well. The grains should be as large as
those of granulated sugar.

Air acted more favorably with cocoa-nut charcoal
than did hydrogen, the only other gas used. There
are reasons to believe that the action of hydrogen was
not normal. Oxygen and nitrogen were not tried sepa-
rately because of lack of time and because they are con-
stituents of air. It is known (Ann. d. Physik. 37, 3,
pp. 84-106, 1907) that the lighter gases are absorbed
most rapidly. These experiments were not carried far
enough to prove this point. The fact that only air

? How much?
was tried with different kinds of charcoal prevents any definite conclusion as to the relation between the absorbing power and the density of the charcoal and gas combined; although it appears likely that the lighter gases combined with lighter charcoals would make the evacuator of most rapid action.

It was also found that the most marked absorption took place when the tube had a vacuum equivalent to about 20 cm. parallel spark. For the best results the strength of the discharge sent through the evacuator should be varied gradually. Most absorption took place near the limit when a very small excess current would cause a rapid evolution of gas.

The results so far obtained indicate that the absorption is not great enough at very low pressures to make the method suitable for regulating the vacuum in an X ray tube. However, they do indicate that it may be possible to obtain an evacuator that will be useful for this purpose if the proper combination of gas and charcoal is found. For instruments like audions, radiometers, spectrumtubes, thermo-junctions, etc. which do not require such a high degree of evacuation this evacuator would prove valuable.

**Proposed Additional Experiments**—Further experiments are to be carried out with the purpose of eliminating the above mentioned sources of error and of getting data for a wider range of gases and charcoals.
Moreover, the arrangement with the tin foil applied to the tube externally after the gases have been driven out of the charcoal by heavy discharges will be used. The position of application is shown at Q (Fig. 6). This, according to Dr. Pfund gives the highest vacuum attainable with the charcoal evacuator.

In conclusion I wish to thank Dr. H.C.Rentschler for suggesting the problem and for his valuable assistance in constructing the apparatus as well as for his important advice concerning the methods of carrying out the experiment.
BIBLIOGRAPHY

20. Travers, Gases.
May 2, 1917.

Professor Walter Miller,
Dean of the Graduate Faculty,
University.

Dear Sir:

I am sending herewith the thesis of Mr. E. C. Blom. It has been accepted, so far as the Department of Physics is concerned, as satisfying the thesis requirements for the degree of Master of Arts. Since the thesis is entirely experimental in character, I should suggest that, if it is to be referred to someone outside this department, it be to some member of the Department of Chemistry and the Professor of Electrical Engineering.

Respectfully,

[Signature]

Ch'm'n Physics Dept.
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