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ABSORPTION OF GASES

BY CHARCOAL IN VACUA

or

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

ABSORPTION OF GASES BY CHARCOAL IN VACUA

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., Proc., Ser. A, 78, pp. 429-458, 1907).

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 occluded by the charcoal with the concentration of the gas, in a short range, is a fairly simple lograthmic 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, I[1], shows volumes of helium absorbed by charcoal at different temperatures (Engineering, 81, p. 796, 1906).

TABLE I[1]

Cocoa-nut Charcoal and Liquid Air

Temperature	Helium	Hydrogen
-185° C.	2.5	137
-210	5.0	180
-252	160.0	250
-258	195.0	---

For a variation in pressure table II[1] shows the amount of hydrogen absorbed by 6.5 grams of cocoa-nut

charcoal at -190°C. (Engineering, 81, p.796, 1906).

Table II[1]:

Pressure in Atmospheres	Volume in c.c.
1	620
5	925
10	1050
15	1000
20	975
25	925

From the results given in table III[1] Dewar conclud-
ed 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 sim-
ilarly to all gases, considering comparative temperatures.
Knowing the amount of carbon dioxide gas absorbed by char-
coal, he could estimate that 100 grams of charcoal con-
tained 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[1]).

Table III[1]:

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

Gas	Temperature	Density of Gas in Charcoal	Fluid Density of Gas
Carbon dioxide	15°C.	.7	.8

Table III[1] continued.

Gas	Temperature	Density of Gas in Charcoal	Fluid Density of Gas
Oxygen	-183°C.	1.33	1.12
Nitrogen	-193	1.00	.84
Electrolytic gas		.58	?
Hydrogen	-193	.06	.07
"	-210	.08	
"	-252	.11	

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 Dewar's 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 suppli-
ed 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 manip-
ulation, 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 allowes the less condens-
able 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 $15^{\circ}C$.
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, con-
sisting of krypton and xenon, is separated into its con-
stituents 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 per-
centage 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 atmos-
phere, i. e. 20% oxygen and 80% nitrogen as shown in the
following figure:

```
         N          N
              O
         N          N
```

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 occluded gas attained a
new and apparently definite composition exhibited by
the figure:

```
         O          N
              O
         N          O
```

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 tempera-
tures is shown in the following experiment. The elec-
tric 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 parctically all the air
remaining between the walls after the preliminary ex-
haustion.

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 orig-
inal pressure, and p_0 the pressure after time t, the re-
lation holds good that log $(p-p_0)$ = A-kt, where A and k
are constants.   From this they deduce the velocity of
absorption dx/dt = k(e-x), where x is the total amount
of air the charcoal takes up and e the amount absorbed
when equilibrum 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 cocoa-nut 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 prob-
able 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 cocoa-nut
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 char-
coal.

Theories of the Gas Absorption.-- J. Duclaux
(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 vari-
ous theories of absorption: (1) True chemical absorption,
(2) True solid absorption.   (3) A modified solid solu-
tion in which practically only the outer layers become

saturated owing to the difficulty ~~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 Siemen's 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) attemps 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 (Phy. 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) con-
cluded 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 be-
havior of different kinds of glass.   Kaye suggests
also that the action is stimulated by a species of elec-
trolysis of the glass produced by the high tension dis-
charge 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 upoh 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
granulatedsugar particles.   Do not pulverize them.   Re-
heat the mass to redness.   When cool place this granular
charcoal into the evanuator and attach the pump.

Exhaust ∧with the pump ~~until~~ to 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 con-
nected to the battery B and K_2, is inserted at W (Fig. 1).
Upon closing the keys K_1 and K_2 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. Them seal off from pump. Whem 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 incandescant 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 incandescant tungsten wire and, in
consequence interfere seriously with the proper function-
ing 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.

WRITER'S EXPERIMENTS

The Purpose of the Experiments.--The purpose of the
writer's experiments is to learn how effective the elec-
trical 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 vari-
ous gases are absorbed by different kinds of charcoal.
It is known, for instance, that with liquid air elder-
pith charcoal absorbes nitrogen as cocoa-nut charcoal
absorbes hydrogen.   This, suggests that probably the
most effecient 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 dis-
charge 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 ^rubber 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 earthern 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 explos-
ives.   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 surround-
ed by a bath.   Another arrangement to be tried is char-
ring 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 paralled 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^1 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^1) and (R) are

variable resistances; (T) is a rotary (mercury) inter-
rupter; (V) is a Wehnelt interrupter; (K) is a condenser;
(I) is an inductance; (M) is an induction coil of which
(A) and (A^1) 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 (V) 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 re-
sistance (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 resistnace
(R^1).   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 increas-
ed 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 guage of the degree of evacuation in the
tube.   The increase in the size of the dark space in-
dicates 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 ex-
periments.   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, (P) 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
(.3 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-
darsen 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 al-
ternating current (EF) 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 al-
ternating current (GJ) lead to the primary (Pr) of the trans-
former (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 pro-
cess 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 near-
er (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 repeat-
ed 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 resist-
ance 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 ex-
haust the tube.   Connections were then made with the fresh-
ly 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 fila-
ment as cathode was heated by the high voltage current
form 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 min-
ute.   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 lift-
ing the key (k).   The induction coil (M) was connected
to (m) and (n) so as to give a parallel spark gap at (fg)
for testing the degree of evacuation.   By this method
the spark gap was increased form a few mm. to 25 mm.

At this point it may be well to mention two of
the most serious sources of error which had to be care-
fully 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 appear-
ance 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 experi-
ments 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
coul with a Wehnelt interrupter.   The automobile lamp was
glowed 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 filla-
ment 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 preceeding reading.

TABLE I

Air and Cocoa-nut Charcoal

Length of parallel spark gap

Beginning	End	Duration of discharge	Resistance
44 mm.	45 mm.	2 min.	middle of (R)
45 "	50 "	4 "	--
50 "	50 "	3 "	-
50 "	55 "	2 "	-
55 "	64 "	4 "	-
58 "	68 "	2 "	-
68 "	68 "	2 "	-
68 "	70 "	2 "	-
70 "	71 "	5 "	-

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.

Swithches 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 11

Air and Cocoa-nut Charcoal

Length of parallel spark		Time	Resistance
Beginning	End		
26 mm.	27 mm.	5 min.	middle of (r)
27 "	29 "	10 "	-
29 "	33 "	10 "	-
33 "	34 "	10 "	-
34 "	36 "	10 "	-

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

Length of parallel spark

Beginning	End	Time	Resistance
43 mm.	45 mm.	10 min.	-
45 "	50 "	15 "	-
50 "	54 "	20 "	-

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 preceeding 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 (c) 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 preceeding 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

Length of parallel spark gap			R_1	Character of resistance change
Beginning	End	Time	Beginning	R_2 in, gradual decrease in R_1
37 mm.	41 mm.	17 min.	all in	
41 "	52 "	15 "	-	" "
52 "	61 "	15 "	-	" "

Total increase in spark gap 24 mm.

TABLE V

Air and Cocoa-nut Charcoal

Length of parallel spark gap			R_1	Character of resistance charge
Beginning	End	Time	Beginning	
22 mm.	24 mm.	2 min.	half in	R_2 in, grad. change R_1
24 "	26 "	2 "	-	" " " "
26 "	32 "	2 "	-	" " " "
32 "	40 "	6 "	all out	" " " "
40 "	45 "	10 "	all in	R_2 out, lamps on

Total increase in parallel spark 23 mm.

TABLE VI

Air and Cocoa-nut Charcoal

Length of parallel spark			R_1	Character of resistance change
Beginning	End	Time	Beginning	
20 mm.	28 mm.	20 min.	all in	lamps on, R_2 in
28 mm.	40 mm.	20 min.	all in	lamps on, R_2 out
40 mm.	49 mm.	20 min.	all in	lamps out

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 R_2 and LLL in, ending R_2, LLL, and R_1 out.

Table VII

Air and Cocoa-nut Charcoal

Parallel spark gap length

Beginning	End
19 mm.	25 mm.
25 "	28 "
28 "	34 "
34 "	40 "

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

Beginning	End
29 mm.	37 mm.
37 "	40 "
40 "	42 "
42 "	45 "

Total increase in spark gap 16 mm.

Table IX

Air and Cocoa-nut Charcoal

Gradual change in resistance beginning with R_2,

LLL in, R_1 out; ending with R_2 and R_1 out, LLL in

Parallel spark gap length

Beginning	End
22 mm.	30 mm.

Table IX continued

Beginning	End
30 mm.	34 mm.
34 "	41 "

Total increase in spark gap 19 mm.

Table X

(Like Table IX except resistance changed in jumps)

Parallel spark gap length

Beginning	End
21 mm.	28 mm.
28 "	31 "
31 "	33 "

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

Length of parallel spark gap

Beginning	End
22 mm.	26 mm.
26 "	30 "
30 "	35 "

Total increase in spark gap 13 mm.

Table XII

(Like Table XI except resistance change gradual)

Length of parallel spark

Beginning	End
26 mm.	27 mm.
27 "	31 "
31 "	35 "

Total increase in spark gap 11 mm.

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

Beginning	End
22 mm.	41 mm.
41 "	52 "
52 "	61 "
61 "	73 "

Total increase in spark gap 51 mm.

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

Table XIV

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

Length of parallel spark

Beginning	End
23 mm.	43 mm.
43 "	55 "
55 "	82 "
82 "	86 "
86 "	95 "

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 XV

Length of parallel spark

Beginning	End	Increase
12 mm.	34 mm.	22 mm.
29 "	46 "	17 "
82 "	95 "	13 "
99 "	106 "	7 "

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 R_1 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 (c).

An attempt was made to see how hydrogen would be ab-
sorbed. 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 pour-
ed. 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 contamina-
tion 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

Beginning	End
24 mm.	36 mm.
36 "	42 "

Total increase in spark gap 18 mm.

The difference in the way various kinds of char-
coal 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 pre-
liminary 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 re-
sults were of the type given in the following table:

—

Table XVII

Air and Walnut Charcoal

Length of parallel spark

Beginning	End	Trial	Total increase
26 mm.	30 mm.	1	
30 "	34 "		
34 "	34 "		8 mm.
21 "	27 "	2	
27 "	37 "		
37 "	40 "		19 mm.
20 "	26 "	3	
26 "	34 "		14 mm.

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 incandesence 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 incandescant 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 investi-
gations 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

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 char-
coal evacuator.

Fig. 1.

Fig. 2.

Fig. 3

Fig. 4

Fig. 5.

As in Fig. 4

110 D.C.

110 A.C.

Fig. 6.

Fig. 7.

Fig. 8

C
A
B
H
D
I
F
E
K
J
L
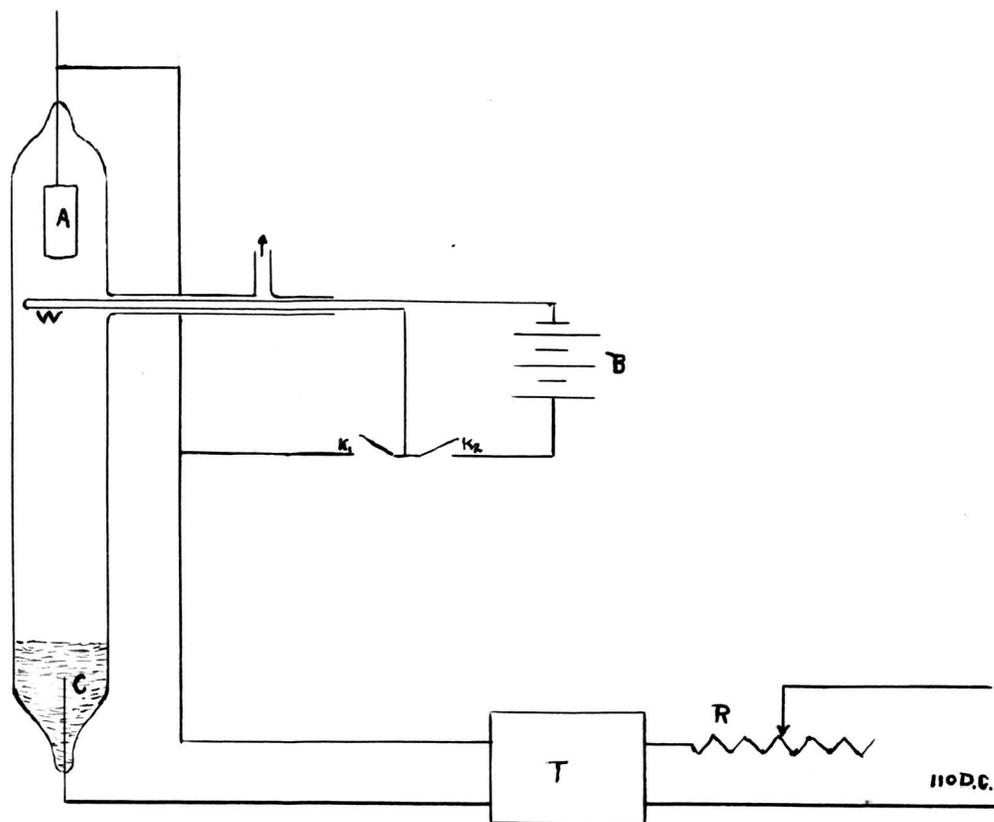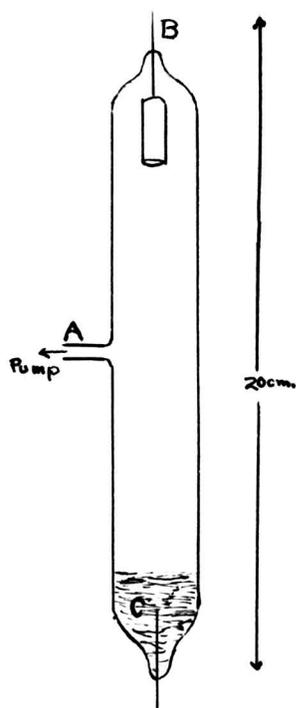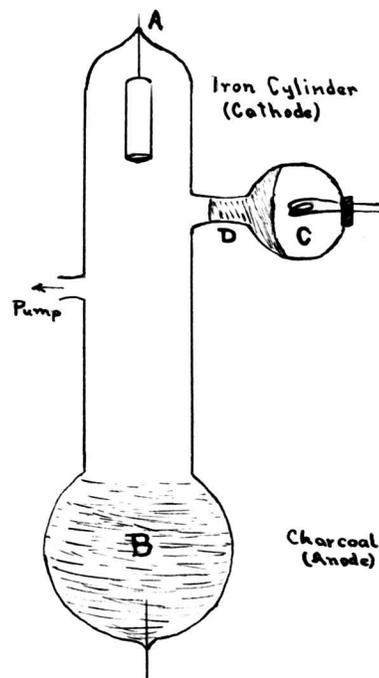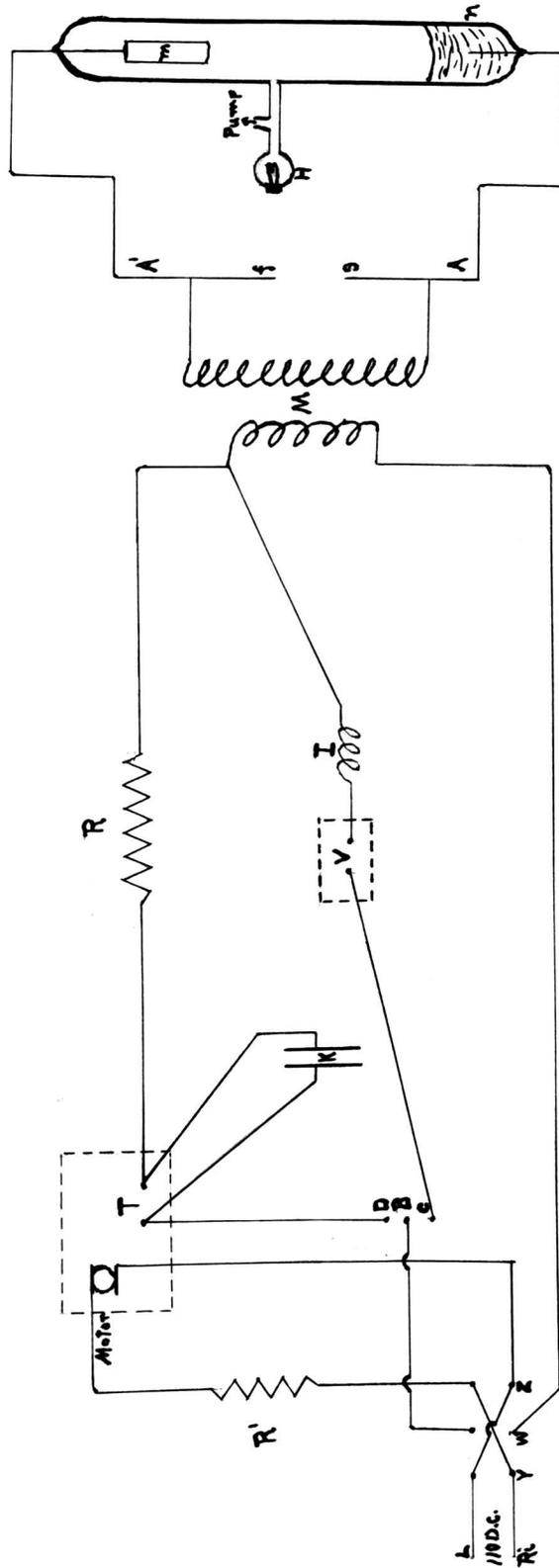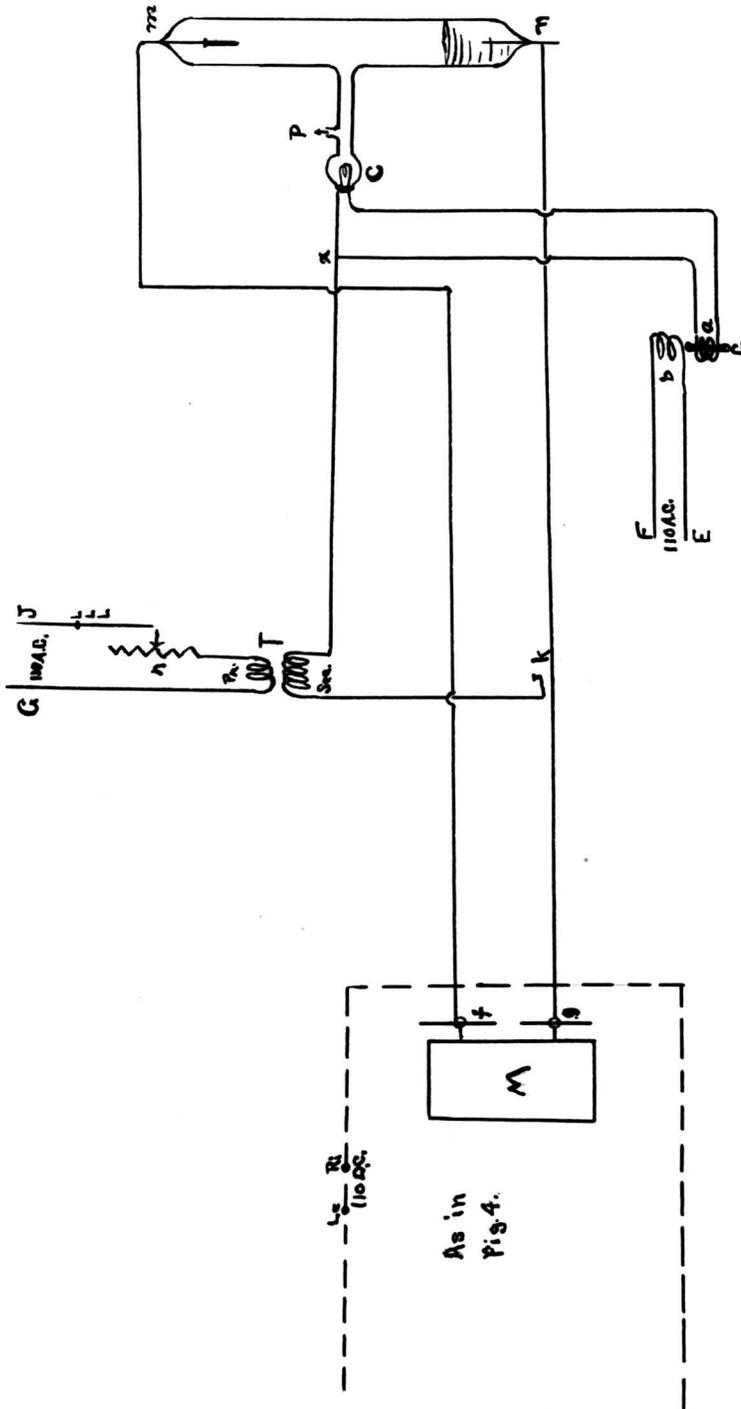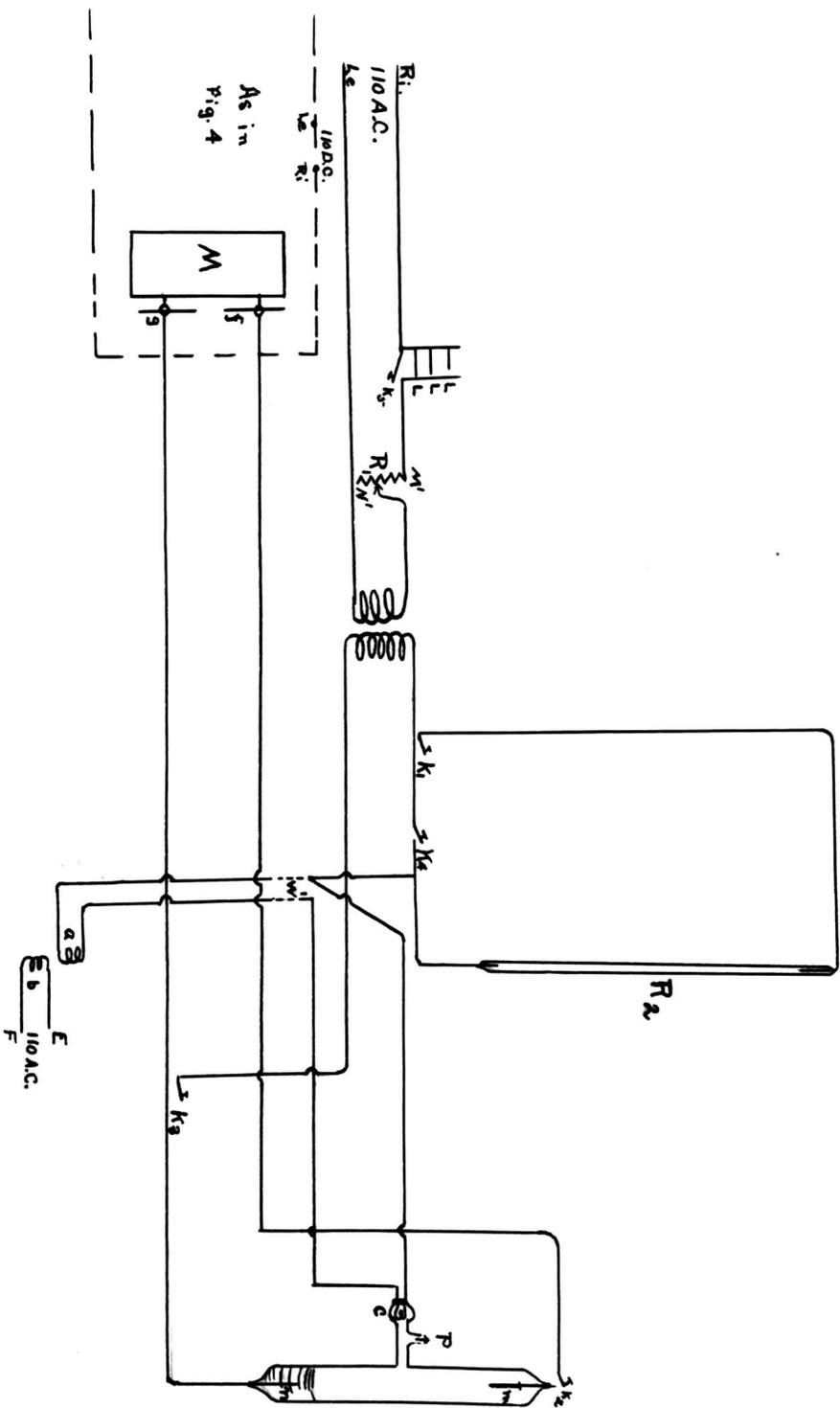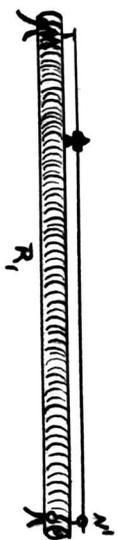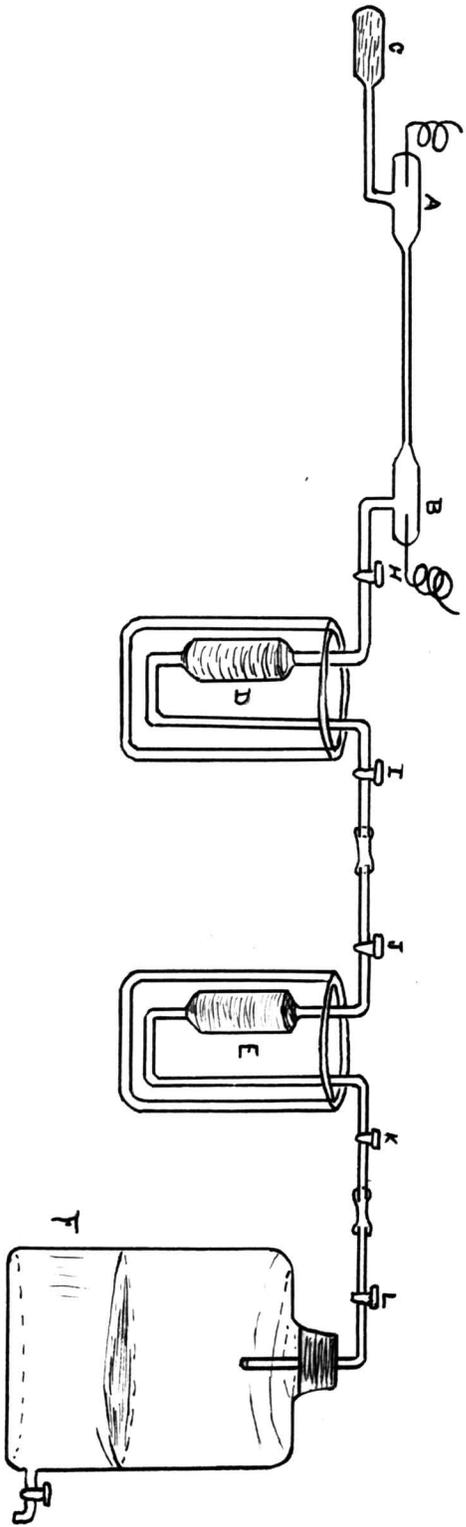
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DEPARTMENT OF PHYSICS

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 ~~Department~~ and the Professor of Electrical Engineering.

Respectfully,

[signature]

Ch'm'n Physics Dept.

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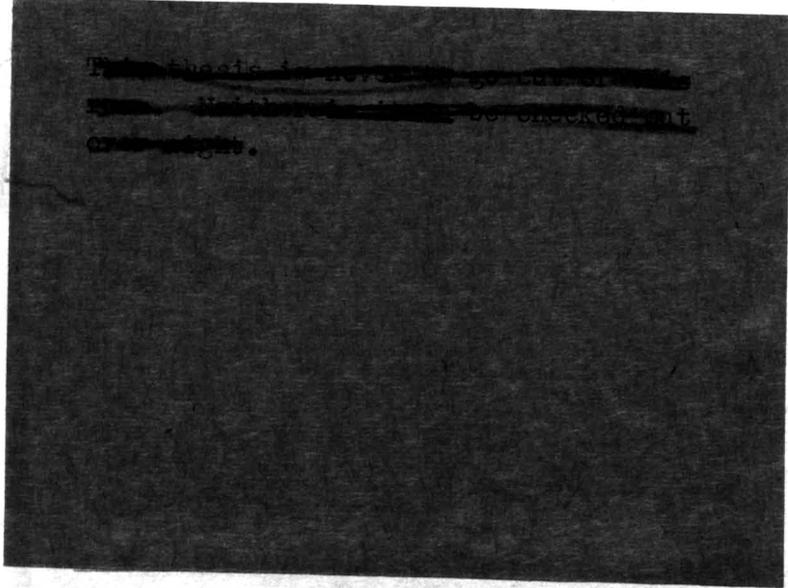
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