# THESIS

## AN INVESTIGATION OF CHEMICAL MEANS OF PRODUCING ELECTRICITY FROM COAL

R. B. KLING R. W. NODDINS

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# AN INVESTIGATION OF CHEMICAL MEANS OF PRODUCING ELECTRICITY FROM COAL.

A Thesis Submitted to

The Faculty of

MICHIGAN AGRICULTURAL COLLEGE

By

R. B. Kling R. W. Noddins

Candidates for the Degree of

Bachelor of Science.

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"I THINK THE MOST IMPORTANT LINE OF INVESTIGATION

IS THE PRODUCTION OF ELECTRICITY DIRECT

FROM THE COMBUSTIBLE".

Thomas A. Edison.

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# ELECTRICAL ENERGY DIRECT FROM CARBON.

By A. C. Kennelly.

A pound of good coal when burned in air liberates about five and seven tenths horsepower hours of energy.

In ordinary fairly large engines it takes from two to three pounds of coal per boiler horsepower hour.

If coal were converted to coke and if coke could be consumed in a galvanic battery in the same way in which zinc is consumed there would be no such necessary waste of energy as there is in a thermo-dynamic process, and theoretically almost all of the energy of combination of coke carbon and oxygen could be liberated in the electrical circuit of the apparatus.

This would represent the direct generation of the energy of coke carbon into electrical energy. Unfortunately, however, carbon refuses to behave like zinc and burn in a voltaic cell.

The only known means by which carbon could be made to give out its energy in a voltaic cell in competition with the use of coal in a steam engine, is by the formation of either carbon monoxide or carbon dioxide: in other words the same oxidation which yields the energy of carbon in the process of combustion must take place electro-chemically. The oxygen for the

purpose must be obtained from some cheap electrolyte containing oxygen and cannot so far as known be obtained from the atmosphere directly. In other words it is necessary to rob an electrolyte of oxygen in order that carbon shall combine with it electrolytically. If the oxygen of the electrolyte were but feebly held, that is to say, if the electrolyte consisted of a chemical combination with oxygen so unstable as to require but a negligibly small amount of energy to tear the oxygen away, and if moreover the substance or substances with which oxygen was unstably linked were capable of entering into combination with the other plate of the voltaic couple with but little absorption of energy: then it might be possible for the voltaic cell to work with a power output theoretically approaching that of the combustion valve of carbon and oxygen.

The union of carbon and oxygen in the cell would take place without sensible elevation of temperature, the electrolyte would give up its oxygen for the formation of carbon dioxide and the products of the cell would have to be chemically eliminated in some continuous manner, to be replaced by fresh electrolyte.

All this requires the existance of an electrolyte possessing properties of small chemical stability, together with the capability of forming suitable chemical combinations at both plates of the couple. Moreover the

electrolyte must be so abundant as to be very cheap.

An examination of thermo-chemical data confirms the results of the very large amount of experimental inquiry made during the past century and leads to the conclusion that there is no cheap electrolyte available for the burning of carbon in a voltaic cell at ordinary temperatures with an efficiency that can compete with that of a steam engine.

Prospects from thermo-chemical data seem equally unfavorable. The hot voltaic cell is complicated by the introduction of thermo-electric effects.

If a cell is a mere thermo-electric couple it must do work in the circuit by receiving heat at a high temperature at one contact and rejecting heat at a lower temperature at the other contact.

The prospects are not encouraging for the hot voltaic cell but there is hope that it may be found.

Apart from the solution of the problem by improvements in heat engines, or by the discovery of a suitable working substance in the voltaic cell, there is always the possibility of finding some new mechanism by which the heat energy of carbon atoms can be converted into the energy of mass rotation. We are still so profoundly ignorant of how the energy of carbon is stored relatively to that of oxygen that a discovery of the hidden

mechanism of the storage principle might lead to a discovery of a new means of releasing it. In other words there is something in a lump of carbon in conjunction with a lump of oxygen which corresponds either to a bent spring or to the motion of a gyrostat. All we know is that when the two substances are brought into sufficiently intimate contact with the aid of a high temperature either the spring is released or the gyrostatic motion is arrested with the production of the jostle energy among the molecules of a substance, or of that particular kind of rapid oscillatory motion which we assume heat to be. It is conceivable that if we had a clear idea of the nature of the invisible gyrostats, we might discover some means by which the springs might be released without the production of jostle energy and with the direct production of some kind of utilizable force.

The fact that by chemical processes we are able to transfer a part of the energy to a different substance in chemical form without first liberating it in heat should encourage hope that we may find a means of transferring it in some other form than chemical or thermal.

Except in localities where water power is available coal is the main source from which we derive our electrical power.

Unfortunately in the process of converting the potential energy of coal into electrical energy, a series

of heavy losses is incurred.

There is firstly a loss of heat in the stack, heat which should have gone to the boiler; secondly power is lost through the fact that a heat engine at best can transform into useful work only a define fraction of the heat supplied; thirdly we have the losses due to friction in the engine, dynamo, etc. These losses could be avoided if we could construct an efficient galvanic cell in which carbon is consumed instead of some costly materials usually employed in galvanic cells now in use.

The problem of constructing a carbon cell is therefore one of peculiar interest and resolves itself into that of constructing a cell of the type C/electrolyte/$O_2$.

## JUNGER'S CARBON CELL.

Carbon burns in sulphuric acid of more than fifty percent, which, to improve its conductivity, should be heated. In sulphuric acid of 95%, carbon is electrically almost as active at 95 or 100° C. as zinc is in dilute sulphuric acid. The acid is decomposed, the products being CO, $H_2$, $SO_4$, and depolarisers are required in such carbon cells. E. W. Junger combines an anode of amorphous carbon with a cathode of graphite, depolarised by air or in other ways.

The cathode is a perforated tube made of graphite powder and solium silicate, which is afterwards rendered insoluble, by dipping the mass in magnesium salts, and compressed; powdered glass may also be fused with the graphite. The anode consists of pieces of coke, covered by a heavy perforated horisontal anode plate. The cell box stands within another cell box, the space between the two being charged with steam; the outer box is packed with heat-insulating material. Air is forced through the cathodes. The electrolyte, concentrated sulphuric acid, may be charged with NO, $N_2O_3$, $NO_3$, oxygen compounds of chlorine, or sulphates of metals which form several sulphates; then a diaphragm of brick graphite or asbestos is applied. The working electromotive force is 0.5 volt. Several arrangements are proposed.

The two chief reactions on which this new carbon cell is based are $SO_2 + O + H_2O = H_2SO_4$; and $2\ H_2SO_4 + C = SO_2 + 2\ H_2O$.

The first step is carried out in cells built up of earthen-ware vessels, with a vertical diaphragm of the same material both compartments being sealed by the cover, and vertical electrode slabs of graphite, the anode packed with porous graphite moistened with nitrosyl-sulphuric acid (depolariser) and the cathode with very small grains of coke and porous coal in order to secure a large surface.

Through pipes air and suphurous acid are blown into the compartments; sulphuric acid trickles down the cathode compartments, from which it is drawn off, while the current generated flows through the circuit. The electromotive force varies with the concentration of the acid (generally 80%) from 0.5 to 0.5 volts (in more concentrated acid). The second step, the reconversion of sulphuric into sulphurous acid is effected by heating the sulphuric acid with coal or coke.

# JACQUES' CARBON CELL.

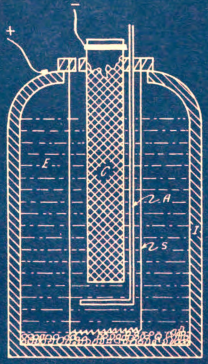
The Jacques Cell which produces Electricity from Coal and Atmospheric Oxygen at Three-hundred Degrees Centigrade.

The iron crucible which is the outer part of the Jacques cell serves as a positive electrode. It is heated to about three-hundred degrees centigrade and filled with caustic soda. The bottom is covered with a layer of granulated quicklime which acts as a diaphragm as a sheet iron cylinder is set with its serrated lower edge resting upon this layer. The cylinder divides the contents of the crucible into a cathode chamber and anode chamber.

Into the anode chamber depends a carbon rod while into the cathode chamber a wuantity of manganese dioxide is added to the caustic soda. The dioxide dissolves in the fused alkali and takes up oxygen from the air forming a green melt containing sodium manganate and having approximately the same potential as oxygen.

On closing the circuit the manganate becomes reduced to magnetite which is in turn reoxidized by the air.

The carbon reacts with the caustic soda with




C- Carbon Rod.
I- Iron Crucible.
E- Electrolyte.
A- Depolarizing Air Tube.
S- Sheet Iron Cylinder.
Q- Quicklime.

The Jacques Cell.

formation of sodium carbonate and hydrogen, and it is really this latter which furnishes the electromotive force, so that to be precise, this cell is not a carbon cell but an ox-hydrogen cell. And in point of fact the voltage is approximately that corresponding to oxygen and hydrogen electrodes.

It was reported that with a battery of 100 pots each 12 inches deep and 1 1/2 inches in diameter a current averaging 90 volts and 16 amperes was obtained for 19 hours. Eight pounds of carbon was consumed in the pot, representing 94% efficiency. (Coal for heat or air not mentioned).

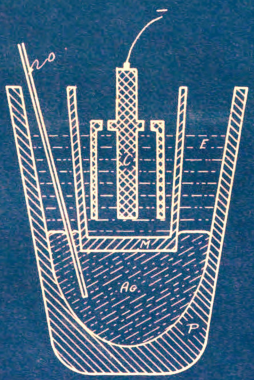
## BAUR'S CARBON-OXYGEN CELL.

To avoid wasteful secondary reactions it is necessary to use high temperatures. Only at bright red heat where carbon burns vigorously in air, can we hope to avoid these wasteful secondary reactions, and to thus obtain a cell practically free from polarization effects over wide ranges of working conditions. The difficulty which now presents itself is to find a suitable oxygen electrode.

Looking around for an appropriate material we finally hit upon molten silver.

When the molten metal is allowed to cool at the surface so as to form a semi-solid crust, little craters are formed upon the crust which present the appearance of a boiling mass.

This effect is due to the liberation of oxygen which is dissolved in the molten silver and which is liberated as the metal cools. One cubic inch of silver dissolves in the molten state, ten cubic inches of oxygen measured at ordinary temperature. Such a mass of molten silver should form a very effective oxygen electrode capable of furnishing a considerable current, in view of the high diffusion velocities prevailing at red heat.




C- Carbon.
E- Electrolyte.
O- Tube for Oxygen.
M- Magnesia Diaphragm.
P- Porcelain Crucible.
Ag - Molten Silver.

Baur's Cell.

Experience has in fact confirmed this expectation. All that is necessary is to combine such an electrode with a fused electrolyte and a carbon electrode, and we obtain a cell whose electromotive force is practically that calculated from thermo-dynamics data - a cell furthermore which shows very little polarisation when properly handled.

The construction of such a cell is shown below:

When working, this cell must of course be placed in a suitable furnace.

A carbon electrode C. which is formed into an inverted bell to present a large surface, hangs down into a porcelain crucible P, whose bottom is covered with silver (AG). Into this dips a porcelain tube O through which air or oxygen is introduced. A stout nickle wire (not shown) forms the second electrode. The space between the carbon and the silver is occupied by the fused electrolyte E. In order to prevent particles of coal from falling into the silver it is well to provide a magnesia diaphragm M as shown. The electrolyte must be an oxy-salt which is fixed at a thousand degrees centigrade, which does not decompose at this temperature, and also is unattacked by carbon, or at least not sufficiently attacked to cause any inconvenience.

Fortunately there are a number of salts which satisfy these requirements and which present the further

advantage of cheapness. Molten glass is one such substance, also borax, potassium and sodium carbonate, or cryolite and alumina.

Theory demands that the electromotive force of the carbon-oxygen cell must be independent of the nature of the electrolyte, and this is indeed found to be very nearly true: the electromotive force is in all cases close to one volt.

The differences are due in fact to accidental variations in the conditions of the experiment, and are in fact ascribable to the fact that the gas liberated at the carbon electrode is not pure carbon dioxide but contains more or less carbon monoxide - in some cases as much as 99%.

The presence of carbon monoxide is attended by an increase in the electromotive force of the cell, in fact calculation gives the following figures:

| | |
|---|---|
| For pure $CO_2$ | E.M.F. = 0.997 |
| For 99% CO, 1% $CO_2$, | E.M.F. = 1.129 |

The problem of constructing a reversible carbon cell is therefore solved.

An important circumstance from a technical point of view, is the fact that the cell is capable of furnishing a considerable current without losing

appreciably its electromotive force and furthermore, the internal resistance of the cell is relatively small.

The prospects of the commercial exploitation of the carbon cell are therefore good. The principal question which now faces us is whether the shaped coke electrodes can be made sufficiently cheaply.

If a ton of coke costs $5.00 and the carbon is burned to CO in the cell, furnishing an electromotive force of one volt the kilowatt-hour costs 1.25 cents. But the electrodes used at the present day in the electro-chemical and steel furnaces cost $45.00 to $50.00 per ton. With these it would not be possible to work economically.

The carbon monoxide we cannot look upon as a by-product, for at least a part of it could be consumed in heating up the cell.

The cost of silver might at first be thought prohibitive. But it is not impossible that by economical use of the metal the investment of a large amount of capital might be avoided.

As regards the recovery of waste heat and the durability of the vessels employed, modern glass industry is quite able to take care of this. Lastly a number of minor difficulties of construction remain to be disposed of. They are however no more serious than those

commonly met in developing a new process.

# ELECTROLYTIC DEPOSITION OF CARBON

By Dr. Coehn.

Editorial from London Electrician, April 3, 1896.

A noteworthy paper by Dr. Alfred Coehn was recently read before the German Electro-technical Association and printed in the Electro-technische Seitschrift from which we transcribe its essential argument. It deals primarily with the question whether carbon is competent to form ions and thus take active part in an electrolytic circuit, in other words, can carbon be caused to dissolve from an anode in the manner characteristic of a metal? An observation bearing on the point was made by Bartoli and Papasogli, who found that on passing current between carbon electrodes immersed in dilute sulphuric both carbon monoxide and carbon dioxide appear at the anode in addition to oxygen, whence it follows that the anode takes an active part and suffers oxidation. Dr. Doehn has attempted to extend this result by varying the concentration, temperature, and current density so as to induce complete suppression of the oxygen at the anode and its replacement by products of the oxidation of carbon, and he has so far succeeded that the gas escaping at the anode may consist of substantially 70% $CO_2$ and 30% CO. A small quantity of oxygen (about one percent) is however usually present.

In these researches it was noticed that at moderate temperatures disintegration of the anode occurs and particals of carbon appear in suspension in the electrolyte.

At higher temperatures this disintegration does not take place but a signigicant coloration of the acid is perceptible. The liquid is at first yellow, and in longer trials, be comes dark red and red brown in color. If this color be due to dissolved carbon, it may be fairly concluded that the carbon is in the ionic state and dirigible by the current.

Seeing that the carbon thus present is not capable of decomposing water, the solution containing it should be in a condition to deposit the carbon at the cathode. Experiment bears out this deduction, for on substituting a platinum for a carbon cathode, carbon is deposited thereon in a manner characteristic of a metal. The first film of carbon exhibits the color of thin plates, but as the deposit thickens it becomes black and graphic. The phenomena of solution and precipitation can be obtained with various forms of carbon, including carbon rods for arc lighting and blast-furnace coke.

After obtaining this remarkable result, Dr. Coehn took care to ascertain that the deposits formed in the manner described are really carbon and not some metallic impurity derived from the anode. The deposited

material is insoluble in hydrochloric acid, slightly soluble in nitric acid - recalling in that respect the behavior of carbon in steel upon which is based the Eggertz colorimetric method of determining carbon.

The film disappears completely on heating in contact with air. Determination by combustion (such as is practiced in ultimate organic analysis) suffices to establish the belief that the deposit is chiefly carbon, associated, however, with oxygen and hydrogen in the proportions to form water and thus to be regarded as hydrated. This hypothesis is borne out by the behavior of the film with strong sulphuric acid which acts upon it much as if it were a carbohydrate.

The establishment of these facts led Dr. Coehn a step further. To construct a cell capable of yielding electrical energy by the oxidation of carbon, it is necessary to find a cathode electro-negative to the carbon, which has to function as anode.

Lead peroxide in the form of a plate from a secondary cell fulfills this need. When such a cathode is opposed to carbon anode in a bath of sulphuric acid of the right temperature and concentration a primary cell is obtained in which carbon is the material attacked: a cell made in this manner gives a voltage of 1.03 on a circuit having an external resistance of 100 ohms.

Dr. Coehn does not state what fraction of the total energy appears as electrical energy.

The question now arises, how far the results recorded are really due to carbon acting as a soluble anode? Platinum when exposed to lead peroxide in sulphuric acid electrolyte becomes an anode, and gives a current which however decreases to a vanishing point as soon as the platinum electrode has acquired its complement of oxygen. No such arrest of the output of a carbon-lead peroxide cell takes place. The current is obtained until the cathode is exhausted, and the cell regains its efficiency when a fresh plate of lead peroxide is supplied.

Dr. Coehn ends his paper by the following conclusions:

1. It is possible to prepare a solution of carbon by electrolytic means,

2. Carbon can be separated from such a solution at the cathode.

3. A cell may be made having its soluble electrode of carbon.

# A NEW PRIMARY BATTERY IN WHICH CARBON IS CONSUMED.

By Willard E. Case.

The high cost of zinc consumed in the primary battery has always stood in the way of its more general adoption as a source of electricity, and hence it has been the endeavor of many to find a substitute less costly. Carbon in its different forms evidently presents a number of advantages, principal among which is its cheapness. Electric currents have been produced by the union of carbon and oxygen in the past, but the methods employed have required a high temperature and hence entailed considerable loss of energy in the form of heat.

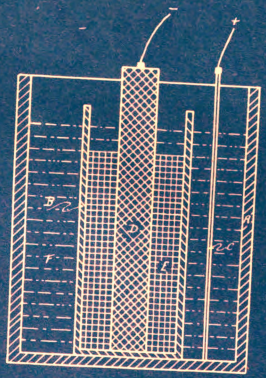
In the usual styles of batteries carbon constitutes the insoluble or negative electrode, but in the new cell carbon is a positive or soluble electrode.

The accompanying illustration shows one form of the cell, which consists of the glass jar A, containing a porous cup V, in which is placed a conducting body of hard carbon D, such as coke. The negative electrode is a sheet of platinum C.

In the porous cup is placed a quantity of carbon E, in comminuted form, previously moistened with sulphuric acid. In the outer vessel A, is placed sulphuric acid. A cell thus arranged will give substantially no current,

inasmuch as both elements resist the action of the acid, however, chlorate of potash is gradually added in small quantities. The result of the reaction of the sulphuric acid and the chlorate of potash is the formation (among other things) of peroxide of chlorine, $ClO_2$, which is a yellowish-red gas and which permeates the liquid, gradually turning it to a red color. For practical purposes it is sufficient to cease adding chlorate of potash when the acid turns a distinct red. A reaction between the carbon and the peroxide of chlorine will, however, begin as soon as the oxygen permeates the porous cell and reaches the carbon, and if the addition of chlorate be suspended, this reaction will continue until the acid loses its red hue, when probably the chemical affinities between the oxygen and the carbon are satisfied. More chlorate must then be added. ($ClO_2$ is a very unstable oxygen compound, decomposing under the action of sunlight and exploding at about 140° F.) The cell should be covered to prevent the escape of gas and the jar made opaque.

The peroxide of chlorine formed apparently decomposes into chlorine and oxygen. The oxygen attacks the carbon producing apparently carbonic acid. The other products of the reaction of chlorate of potash and sulphuric acid are seemingly inert in the cell. A certain amount of polarization occurs which may be reduced by agitating the liquid.




A- Opaque Jar.
B- Porous Cup.
C- Platinum Sheet.
D- Hard Carbon.
E- Comminuted Carbon.
F- Electrolyte.

Willard E. Case.

'98.

The electromotive force of this cell is approximately 1.25 volts.

Note-

The porous cup is not essential. It merely prevents the carbon of the anode from spreading through the whole of the electrolyte.

## EXPERIMENTS.

Nearly all the experiments were performed with the sulphuric acid type of cell. It was stated in the article on Junger's cell that carbon was as active in sulphuric acid of more than 95% concentration as zinc in weak sulphuric acid.

The first necessity was to find some substance which could be used as the negative electrode of the battery; carbon being the negative.

The material used in almost all the previous experiments was platinum but this material was not available.

Dr. Alfred Coehn used lead peroxide in his cell as the positive electrode. This was the material used in all the experiments as it was available in the form of plates from secondary cells.

Experiment No. 1.

The object of this experiment was to determine whether or not carbon was active in concentrated sulphuric acid and the temperature at which it was most active if any chemical action took place.

The electrodes were a small piece of lead peroxide plate from a storage cell and a carbon rod from an exhausted dry cell.

These were dipped in electrolyte of 75 c.c. of concentrated sulphuric acid which was contained in a 250 c.c. beaker.

DATA

| Time | E.M.F. volts. | Current milli-amps | Temp. °F. | Time | E.M.F. volts. | Current milli-amps | Temp. °F |
|---|---|---|---|---|---|---|---|
| 2:45 | 1.010 | 00 | 87 | 3:41 | .225 | 80 | 168 |
| 3:00 | .66 | 00 | 88 | 3:43 | .220 | 75 | 168 |
| 3:08 | .260 | 50 | 88 | 3:45 | .200 | 65 | 164 |
| 3:10 | .256 | 50 | 88 | 3:47 | .195 | 60 | 160 |
| 3:11 | .200 | 65 | 88 | 3:49 | .240 | 90 | 184 |
| 3:13 | .180 | 60 | 88 | 3:53 | .250 | 100 | 201 |
| 3:15 | .170 | 53 | 88 | 3:56 | .240 | 90 | 202 |
| 3:17 | .160 | 50 | 88 | 3:58 | .210 | 75 | 201 |
| 3:19 | .157 | 50 | 88 | 4:02 | .320 | 130 | 280 |
| 3:23 | .114 | 45 | 88 | 4:05 | .320 | 125 | 300 |
| 3:25 | .200 | 65 | 120 | | | | |
| 3:27 | .195 | 63 | 121 | | | | |
| 3:29 | .180 | 58 | 120 | | | | |
| 3:31 | .168 | 50 | 120 | | | | |
| 3:33 | .172 | 50 | 120 | | | | |
| 3:35 | .265 | 100 | 155 | | | | |
| 3:37 | .260 | 100 | 168 | | | | |
| 3:39 | .230 | 85 | 161 | | | | |

## CONCLUSION.

Increasing the temperature increased the activity of the substances to a very slight extent. The greatest current and voltage was obtained at 155° F; showing a slight advantage in increasing the temperature.

## Experiment No. 2.

The object of this experiment was to determine whether a difference in the degree of concentration would make the cell more active and to determine the degree of concentration which would give the greatest output.

The electrodes and other apparatus was the same as used in Experiment No. 1.

DATA

| Time | E.M.F. volts. | Current milli-amps | Temp. °F | $H_2SO_4$ c.c. | $H_2O$ c.c. | % Concentration |
|---|---|---|---|---|---|---|
| 1:55 | .58 | 0.00 | 86. | 75. | 11. | 87.2 |
| 2:00 | .70 | | 152. | | 17. | 81.5 |
| | .74 | | 155. | | 20. | 79.5 |
| | .77 | | 158. | | 24. | 75.7 |
| | .82 | | 164. | | 31. | 71.7 |
| | .85 | | 170. | | 33. | 69.5 |
| | .88 | | 170. | | 36. | 67.5 |
| | .92 | | 172. | | 41. | 64.6 |
| | .94 | | 175. | | 47. | 61.5 |
| | .96 | | 172. | | 49. | 60.5 |
| | .98 | | 169. | | 56. | 57.2 |

| Time | E.M.F. volts | Current milli-amps. | Temp. °F | $H_2SO_4$ c.c. | $H_2O$ c.c. | % Concentration |
|---|---|---|---|---|---|---|
| | 1.00 | 0.00 | 163. | | 62. | 54.7 |
| | | | | | 66. | 53.2 |
| 3:45 | .60 | . | 87. | 80. | | 55.5 |
| 3:48 | .48 | 50. | 85. | | | |
| 3:49 | .40 | 50. | 84. | | | |
| 3:60 | .25 | 50. | 80. | | | |

Cell was shorted until 1:15 p.m. April 26. upon opening the circuit the following results were obtained.

1:15 .15

Weight of Electrodes

| | Carbon | Lead peroxide |
|---|---|---|
| Before experiment | 77.3 | 88.3 |
| After experiment | 81.7 | 89.3 |

The increase in weight was due to the absorption of the electrolyte by the electrodes. They were nearly dry at the beginning of the experiment.

CONCLUSION.

The greatest output was obtained with a concentration of 54.7%. During the last part of the experiment the cell was short circuited for 69 hours. After being shorted for this length of time the cell still gave an E.M.F. of .15 volt as soon as the circuit was opened.

The electrodes were weighed before and after the experiment but they were both practically dry when placed in the electrolyte so both absorbed acid and were heavier after being used than before.

No change or evidence of action could be observed on the carbon electrode.

## Experiment No. 3.

The object of this experiment was to determine whether any electromotive force could be obtained from a cell consisting of lead peroxide and a carbon rod as electrodes and nitric acid for the electrolyte. In the later part of the experiment the effect of adding hydrogen peroxide to the cell was noted.

**DATA**

| Time | E.M.F. volts. | Current milli-amps. | Nitric acid c.c. | Hydrogen peroxide c.c. | |
|---|---|---|---|---|---|
| 3:28 | .54 | 00. | 55. | 15. | |
| 3:31 | .66 | 00. | | | |
| 3:32 | .34 | 125. | | | |
| 3:33 | .32 | 135. | | | |
| 3:35 | .51 | 130. | | | |
| 3:40 | .31 | 125. | | | |
| 3:45 | .23 | 80. | | 20. | |
| 3:50 | .30 | 90. | | | |
| 3:52 | .24 | 70. | Gas collects around carbon and | | |
| 3:55 | .24 | 70. | lowers E.M.F. | | |
| 4:05 | .21 | 60. | | | |
| 4:10 | .18 | 50. | | 25. | |
| 4:20 | .19 | 55. | | | |
| 4:25 | .22 | 60. | | | |
| 4:30 | .22 | 65. | | | |
| 4:35 | .20 | 65. | | 32. | |
| 4:37 | .28 | 100. | | | |
| 4:40 | .24 | 75. | | | |
| 4:45 | .25 | 80. | | | |
| 4:50 | .24 | 80. | | | |

Data on second part of experiment with Nitric acid and hydrogen peroxide.

| E.M.F. volts open circuit | E.M.F. volts across 22 ohms. | | | | |
|---|---|---|---|---|---|
| .54 | .40 | 00. | 25. | 0.00 | No action |
| .52 | .37 | 50. | | 5. | gas evolved |
| | .14 | | | 7. | from both |
| | .16 | | | 10. | electrodes. |
| | .18 | 50. | | 13. | |
| | .20 | 50. | | 14. | |

The action of the hydrogen peroxide and nitric acid on the lead peroxide plate rapidly reduded it to white lead oxide; so another cell was made which had a porous cup to keep the solution containing the hydrogen peroxide from the lead peroxide. This made the reduction of the lead peroxide much slower and increased the E.M.F. of the cell.

With 30 c.c. of nitric acid and 10 c.c. of hydrogen peroxide an open circuit voltage of .63 volt was obtained. When short circuited thru a milliammeter a voltage of .20 and current of 75 milliamperes were obtained.

When this cell was left short-circuited for about twenty hours the lead peroxide was partially decomposed to white lead oxide. The carbon did not show any evidence of decomposition.

The experiments with this type of cell were all performed at room temperature.

From these experiments it was concluded that the E.M.F. and the current obtained were due to the chemical action within the electrolyte and the decomposition of the lead peroxide plate.

## EXPERIMENTS WITH SULPHURIC ACID CELL WHOSE ELECTROLYTE CONTAINS PEROXIDE OF CHLORINE

The object of these experiments was first to determine the effect of adding potassium chlorate to the sulphuric acid electrolyte of the cell and to test a cell whose electrolyte was sulphuric acid containing peroxide of chlorine and whose electrodes were carbon rods and a lead peroxide plate.

When potassium chlorate is added to concentrated sulphuric acid chlorine gas is given off and the acid turns red due to the presence of peroxide of chlorine which is a powerful oxidising agent.

Peroxide of chlorine is decomposed by sunlight and explodes at about 140° F.

DATA

| Time | E. M. F. volts | Current milli-amps. | $H_2SO_4$ | |
|---|---|---|---|---|
| 2:40 | .17 | 50. | 50. | One carbon rod. |
| 2:43 | .19 | 60. | | |
| 2:47 | .20 | 55. | | |
| 2:48 | .23 | 90. | 75. | Two carbon rods $PbO_2$ |
| 2:53 | .22 | 90. | | same size. |
| 2:55 | .26 | 100. | | Three carbon rods $PbO_2$ |
| 3:14 | .28 | 125. | 125. | same size. |
| | .26 | 200. | | |
| | .26 | 200. | | |
| 4:00 | .3 | Short circuited. | | |

DATA

| E. M. F. volts | Current milli-amps. | $H_2SO_4$ | |
|---|---|---|---|
| .17 | 80. | 60. | One carbon rod. |
| .19 | 60. | | |
| .20 | 50. | | |
| .23 | 40. | 75. | Two carbon rods $PbO_2$ same size. |
| .32 | 20. | | |
| .36 | 100. | | Three carbon rods $PbO_2$ same size. |
| .38 | 138. | 145. | |
| .38 | 200. | | |
| .39 | 800. | | |
| .8 | Short circuited. | | |

The reostat was then adjusted for an E.M.F. of .3 volt and the cell left connected across the rheostat for 20 hours.

At the end of this time the polarity was reversed and the cell had an E.M.F. of .2 volt on open circuit. The carbon rod was partially decomposed and the lead peroxide plate seemed to have changed to lead sulphate.

Tests were then made to determine which plate had given out or whether it was the electrolyte.

With the same electrolyte and carbon rods but a new lead peroxide plant an E.M.F. of .3 volt was obtained.

With old electrodes but new electrolyte an A.M.F. of .34 volt and current of 90 milliamperes were obtained.

With old plates and electrolyte but adding more potassium chlorate to the electrolyte gave the following results, An E.M.F. of .4 volt on open circuit and when short circuited through the milli-amperes.

The results indicate that the electrolyte had given out.

The results of the first experiment using a small amount of potassium chlorate in the sulphuric acid were encouraging so a large cell was built.

This cell consisted of seventeen carbon rods weighing 4.25 lb., a lead peroxide plate weighing 1 ½lb., 925 c.c. concentrated sulphuric acid which with the battery jar weighed 6.75 lb. A small amount of potassium chlorate probably about 10 gms. was added to the electrolyte.

DATA

| Time | E.M.F. volts | Current milli-amps. | Temperature °F |
|---|---|---|---|
| 9:57 | .84 | 00. | 70. |
| 10:26 | .59 | 475. | |
| 10:27 | .56 | 465. | 81. |
| 10:29 | .55 | 460. | |
| 10:45 | .53 | 422. | 81. |
| 1:15 | .47 | 380. | |
| 2:15 | .48 | 400. | 72. |
| 3:15 | .47 | 390. | 71. |
| 4:15 | .48 | 400. | |
| Circuit left open between April 29, when cell was built to April 30, when next readings were taken. | | | |
| 1:25 | 1.06 | | 70. |
| 1:28 | .78 | 650. | |
| 1:30 | .73 | 610. | |
| 1:31 | .70 | 580. | |
| 1:37 | .62 | 510. | |
| 1:45 | .58 | 480. | 70. |
| 2:00 | .56 | 469. | |
| 2:10 | .55 | 455. | |
| 2:30 | .52 | 445. | |
| 3:00 | .54 | 440. | |
| May 4. | | | |
| Circuit was open from April 30 to May 4. | | | |
| 1:46 | 1.15 | 50. | |
| 1:47 | 1.2 | 420. | |
| 1:50 | .96 | 390. | |

| Time | E.M.F. volts | Current milli-amps | Temperature °F |
|---|---|---|---|
| 1:55 | .92 | 370. | |
| 2:00 | .89 | 358. | |
| 2:10 | .87 | 345. | |
| 2:15 | .85 | 340. | |
| 2:20 | .84 | 335. | |

May 10.

The cell was left open from May 4 to May 10.

| | | | |
|---|---|---|---|
| 2:00 | 1.42 | 000. | |
| 2:03 | 1.37 | 55. | |
| 2:05 | 1.10 | 750. | |
| 2:10 | 1.02 | 620. | |
| 2:15 | .88 | 575. | |
| 2:20 | .84 | 540. | |
| 2:25 | .82 | 480. | |
| 2:30 | .72 | 620. | |
| 2:35 | .70 | 590. | |
| 2:40 | .68 | 540. | |
| 2:45 | .66 | 530. | |
| 2:50 | .64 | 510. | |
| 2:55 | .63 | 500. | |
| 3:00 | .61 | 490. | |
| 3:05 | .62 | 490. | |
| 3:10 | .61 | 490. | |
| 3:15 | .60 | 480. | |
| 3:20 | .59 | 475. | |
| 3:25 | .58 | 470. | |
| 3:30 | .58 | 468. | |
| 3:35 | .57 | 460. | |
| 3:40 | .56 | 460. | |
| 3:45 | .56 | 455. | |
| 3:50 | .56 | 450. | |
| 3:55 | .55 | 445. | |

When the circuit was opened the E.M.F. of the cell came up to .8 volt within a half minute.

May 12.

The circuit was left open from May 10 to May 12.

| | | | |
|---|---|---|---|
| 2:04 | 1.40 | 000. | |
| 2:04 | 1.10 | 750. | |
| 2:05 | 1.03 | 750. | |
| 2:10 | .90 | 630. | |
| 2:15 | .82 | 620. | |
| 2:20 | .78 | 590. | |
| 2:25 | .75 | 560. | |
| 2:30 | .71 | 540. | |
| 2:35 | .69 | 530. | |
| 2:40 | .67 | 510. | |
| 2:45 | .64 | 500. | |
| 2:50 | .62 | 480. | |

From May 12 until the time this data was taken which was about a week the cell was left open circuited.

| Time | E.M.F. volts | Current milli-amps. |
|---|---|---|
| 1:30 | 1.46 | 000. |
| 1:31 | 1.44 | 000. |
| 1:31 | 1.2 | 650. |
| 1:32 | 1.12 | 580. |
| 1:40 | 1.1 | 430. |
| 1:45 | .95 | 445. |
| 1:50 | .90 | 460. |
| 1:55 | .83 | 530. |
| 2:00 | .75 | 575. |
| 2:05 | .70 | 550. |
| 2:10 | .68 | 532. |
| 2:15 | .65 | 520. |
| 2:20 | .63 | 500. |
| 2:25 | .61 | 460. |
| 2:30 | .60 | 475. |
| 2:35 | .59 | 460. |

After taking this data the cell was short circuited until May 21.

When at this time the circuit was opened and a voltage reading taken, which was 0.32 volt.

The electrodes were then weighed again to determine whether there had been any noticable change.

Carbon rods = 4.5 lb.

Acid and Jar = 6.5 lb.

Plate of lead peroxide = 1.0 lb.

This indicates an increase in weight of the carbon but this must have been due to the absorption of acid by them. The acid and the jar weigh .25 lb. less than at the beginning of the experiment. There is no apparent change in weight of the lead peroxide plate.

A large amount of the lead peroxide was however off the plate and in the bottom of the jar was a grey deposit which was probably lead sulphate with some carbon. The carbon rods were partially decomposed from the action of the electrolyte although the results by weight show an increase.

These experiments indicate that electricity can be obtained from a cell in which carbon is one of the active materials. Sulphuric acid in which was peroxide of chlorine was the only electrolyte found which would affect carbon.

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