Subject: Carbon Arc Lighting and how to make electrodes
Sent: 7 July 05

Over all Summary:

Using hard graphite carbon rods (made like pencil leads) and a voltage of 45 to 60 volts with about 2 to 10 amps DC in a Simi closed environment (behind glass, with controlled air flow) consumes the least amount of carbon rod. DC work best but AC can be used. Current is limited by use of resistor (DC) or Inductance (Ac). This is necessary because of the negative resistance characteristic of the arc.

The electrodes when in use need to be in a slow continuous motion toward each other in order to maintain a given arc length and to compensate for the carbon burned up. All kinds of electro-mechanical setups are possible. Hissing of the arc indicates electrodes are too close or too much current. Carbon electrodes are classified as molded carbons and forced carbons depending on how they are manufactured. Forced carbons are higher quality then molded carbons. Good electrodes of average size average about .15 ohm/foot. Positive electrode is consumed twice as fast as the negative.

Electrodes can be made from other types of carbon (petroleum coke, charcoal, certain types of coal, lampblack and carbon black from oil or natural gas) but it is not easy or likely in a primitive environment. Self-baking electrodes are used a lot in electric furnaces used to refined metals. The technique has promise if it can be setup see patents on this subject.

Note: I promised Nancy a few years ago I would look into this subject. Every time I picked up the subject up to research I ran into a brick wall of complexity with much development done in the past that had dived out of site and was not readily available. Finally after much looking... I realized this was not going to be something the normal primitive survival person would be able to accomplish. In other words it took until nearly modern times to develop the

processes and techniques to make these electrodes. It is as much an art as it is an engineering effort at extremely high temperatures and currents. I tried several experiments at making electrodes from ground up charcoal to no avail. They would not conduct electricity. I couldn't get them hot enough and compacted enough in a no air environment to make a graphitized conducting electrode.

I think if one has naturally occurring graphite available then it might be possible using the pencil making technique. This would be to fine grind the graphite and 5-10% clay and water, then heated to fuse clay making an electrode. See write up on making pencil leads. If one can find big enough graphite chunks use them as-is for electrodes. The highlights of what I found are attached below. For more information see the all the patents and reference materials included in the primitive survival CD-ROM set.

The following goes into more detail on the possibilities and techniques.

Electrode making details from reference material:

A small amount of cerium (rare-earth group) is used in a core of a carbon electrode to make the light output stronger in the visible spectrum. Normally carbon by it’s self is stronger in the ultraviolet region. If carbons having cores made up a number of metals, among them iron, nickel and aluminum are used it results in a minimum visible light and high production of ultraviolet light. This is from a book called Illumination engineering.

Artificial Manufacture of Graphite. The alteration of carbon at high temperatures into a material resembling graphite has long been known. In 1893 Girard and Street patented a furnace and a process by which this transformation could be effected. Carbon powder compressed into a rod was slowly passed through a tube in which it was subjected to the action of one or more electric arcs. E. G. Acheson, in 1896, patented an application of his carborundum process to

graphite manufacture, and in 1899 the International Acheson Graphite Co. was formed, employing electric current from the Niagara Falls. Two procedures are adopted: (1) graphitization of molded carbons; (2) graphitization of anthracite en masse. The former includes electrodes, lamp carbons, sc. Coke, or some other form of amorphous carbon, is mixed with a little tar, and the required article moulded in a press or by a die. The articles are stacked transversely in a furnace, each being packed in granular coke and covered with carborundum. At first the current is 3000 amperes at 220 volts, increasing to 9000 amperes at 20 volts after 20 hours. In graphitizing en masse large lumps of anthracite are treated in the electric furnace. A soft, unctuous form results on treating carbon with ash or silica in special furnaces, and this gives the so-called "deflocculated" variety when treated with gallotannic acid. These two modifications are valuable lubricants. The massive graphite is very easily machined and is widely used for electrodes, dynamo brushes, lead pencils and the like.
see http://encyclopedia.jrank.org/GOA_GRA/GRAPHITE.html

Gas carbon is produced by the destructive distillation of coal in the manufacture of illuminating gas (see Gas: Manufacture), being probably formed by the decomposition of gaseous hydrocarbons. It is a very dense form of carbon, and is a good conductor of heat and electricity. It is used in the manufacture of carbon rods for arc lights, and for the negative element in the Bunsen battery. see
http://encyclopedia.jrank.org/CAL_CAR/CARBON_symbol_C_atomic_weight_.html

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Patent research:

The fourth manufacturing method of a carbon material for a negative electrode comprises the steps of applying a heat treatment to a carbonaceous material containing at least one material selected from the group consisting essentially of the carbonized material and the graphitized material under a gaseous atmosphere selected from the group consisting of a first gaseous atmosphere containing at least 10% by volume of CO_2, a second gaseous atmosphere containing at least 1% by volume of H_2O and a third gaseous atmosphere containing at least 10% by volume of CO_2 and at least 1% by volume of H_2O, and bringing the carbonaceous material into contact with a gaseous acid.

It is desirable to apply a heat treatment to the carbonaceous material in order to maintain a gaseous state of the acid when the gaseous acid is brought into contact with the carbonaceous material having the heat treatment applied thereto. It is desirable for the heat treating temperature to fall within a range of between the vaporizing temperature of the inorganic acid or organic acid and 800.degree. C. If the heat treating temperature exceeds 800.degree. C., the reaction proceeds rapidly, with the result that it is possibly difficult to apply a uniform acid treatment to the surface of the carbonaceous material. It is more desirable for the heat treating temperature to fall within a range of between the vaporizing temperature of the inorganic acid or the organic acid and 500.degree. C. Where, for example, nitric acid is used as the inorganic acid, it is desirable for the heat treating temperature to fall within a range of between 130.degree. C. and 500.degree. C.

One of 30 sample methods was prepared by spinning a petroleum pitch used as a carbon precursor, followed by applying a heat treatment to the spun sample at 300.degree. C. for one hour so as to make the spun sample infusible. Then, a heat treatment was applied to the carbon precursor at 900.degree. C. for 3 hours in the presence of an atmosphere gas consisting of 100% by volume of a carbon dioxide gas so as to obtain a carbonized material. The carbonized material thus obtained belonged to an amorphous carbon or a soft carbon. Further, a heat treatment was applied to the carbonized material at 2800.degree. C. for 3 hours in the presence of an atmosphere gas consisting of 100% by volume of a carbon dioxide gas so as to obtain a fibrous carbon material. Before the heat treatment, an atmosphere gas was introduced into the furnace so as to completely substitute the gas within the furnace, followed by stopping the gas supply and subsequently starting the heat treatment.

The average particle diameter, the interplanar spacing d.sub.002 derived from (002) reflection, which was determined by the X-ray diffractometry, the specific surface area determined by the BET method, and the immersion heat ratio .DELTA.H.sub.i.sup.n /.DELTA.H.sub.i.sup.h of the carbon material were measured under the conditions equal to those employed in Example 24 in respect of the carbon material thus obtained. Table 8 shows the results. 6,623,889 23 Sep 2003 Various processes have been developed over the years for the production of high performance carbon fiber materials. One of the leading processes for producing high performance carbon fibers is the so-called PAN process wherein polyacrylonitrile is used as a precursor fiber. The PAN process typically starts with a highly prestretched PAN fiber and involves three steps. First is a stabilization treatment wherein the PAN fiber is heat treated in air at a temperature from about 200.degree. to 300.degree. C. for one or more hours. In the second step, the fiber is carbonized at a temperature above about 1100.degree. C. in a non-oxidizing atmosphere. Last is a post heat treatment at temperatures up to about 2500.degree. C. to graphitize the fiber and give it high performance properties. It is in this post heat treatment step that the chemical composition, the crystalline structure, and the mechanical properties are strongly influenced.

There has been an intense effort to develop methods of spinning and carbonizing hydrocarbon pitch fiber to reduce precursor filament cost and weight loss. However, such processes require pitch pretreatment, spinning conditions, and post-treatments to insure correct orientation of carbon atoms in the final products. As a result, use of spun and carbonized hydrocarbon pitch has been nearly as expensive as using the previously noted methods involving organic polymers. Both methods require use of continuous filaments to achieve high orientation and good properties. There is a practical fiber diameter lower limit of 6 to 8 micrometers. Thinner fibers break during spinning and require excessive post-treatment.

Above is from patent: 5,643,670 date: July 1, 1997

This fine carbon power is required to have properties comparable to normal graphite powder, more specifically, good electrical conductivity as an electrode and in the case of a battery, electrical or chemical properties such that the carbonaceous member is resistant against a corrosion by an acid.

Carbon black is a material having properties satisfying these requirements to a certain extent and is used over a wide range. In general, carbon commonly obtained from coke is graphitized, for example, by heating at a high temperature with an attempt to stabilize chemically and improve the corrosion resistance. However, carbon black is a material difficult to graphitize and can be hardly graphitized by mere heating.

Therefore, for example, JP-A-62-246813 (the term "JP-A" as used herein means an "unexamined published Japanese patent application") discloses a technique of adding boric acid to carbon black and heating the obtained slurry at a temperature of 1,000 to 2,000.degree. C. to reduce the d.sub.002 of carbon crystal, which is an index of showing the graphitization, even to 3.41 .ANG. (0.341 nm), thereby attaining the graphitization. However, according to the study by the present inventors, d.sub.002 of carbon black cannot be lowered to less than 3.40 .ANG. which is by far larger than the theoretical value for complete graphite (i.e. 3.354 A). Furthermore, mere heating for the graphitization fails in elevating the electrical conductivity as demanded.

Therefore the first object of the present invention is to obtain graphitized fine carbon powder having excellent crystallinity and thereby increased in the resistance against chemical corrosion and at the same time, improved in the electrical conductivity, and to provide a high performance catalyst for polymer electrolyte fuel battery and polymer electrolyte fuel battery using the catalyst.

As a result of extensive investigations by taking account of the above-described problems, the present inventors have found that by using carbon black that was considered to be hardly graphitized, submicron fine graphitized carbon powder having an X-ray plane spacing C.sub.0 value (double of d.sub.002) of less than

0.680 nm (namely, d.sub.002 is less than 3.40 .ANG.) can be obtained. Furthermore the present inventors succeeded to obtain a high-performance fuel battery by using the powder as a catalyst support for fuel battery.

12. The electrically conducting carbon composite powder for supporting a catalyst as described in 11 above, wherein from 1 to 7% by mass of vapor grown carbon fiber is mixed with carbon powder.

13. The electrically conducting carbon composite powder for supporting a catalyst as described in any one of 10 to 12 above, wherein the carbon powder is heat-treated at a temperature of 2,500.degree. C. or more.

14. The electrically conducting carbon composite powder for supporting a catalyst as described in any one of 11 to 13 above, wherein the vapor grown carbon fiber is graphitized at a temperature of 2,500.degree. C. or more and boron content in the fiber is in a range of 0.001 to 5% by mass.

DETAILED DESCRIPTION OF THE INVENTION

To begin with, the first group of the present invention: fine graphitized carbon powder having good crystallinity, production method thereof, an electrically conducting carbon composite powder for supporting a catalyst using the carbon powder, a catalyst for polymer electrolyte fuel battery, polymer electrolyte fuel battery cell, and polymer electrolyte fuel battery, will be described in detail below.

The raw material used for obtaining the carbon powder of the present invention is a submicron fine particle comprising an amorphous carbonaceous material called carbon black. Examples of the carbon black include oil furnace black (e.g., Ketjen Black, Valcan, both are trade names) obtained by incompletely combusting aromatic hydrocarbon oil such as creosote oil; acetylene black (e.g., Denka-Black, trade name) obtained by complete combusting method using acetylene as a raw material; thermal black obtained by complete combusting method using natural gas as a raw material; and channel black obtained by incomplete combusting method using natural gas as a raw material. Any of these can be used.

Among these carbon blacks, oil furnace black and acetylene black are preferred.

The reasons that the two are preferred are explained as follows. One of important factors determining the performance of carbon black as an electrically conducting material is a primary particle chain structure (aggregation structure) called structure. The structure of carbon black have generally this aggregation structure where fine spherical primary particles are gathered and form irregular chained branches. As the number of primary particles is larger and as the chained branches are more complicated (called high structure state), the effect of imparting electrical conductivity is higher. This high structure state can be easily formed in the oil furnace black and acetylene furnace black and therefore, these carbon blacks are preferred.

The carbon powder of the present invention can preferably contain boron. This carbon powder containing boron can be produced, for example, carbon black and boron compound such as boron carbide (B.sub.4 C), boron oxide and boron nitride are mixed, and the mixture is heat-treated at 2,500.degree. C. or more in a non-oxidative atmosphere.

Among these methods, one preferable method where the carbon black is mixed with boron carbide (B.sub.4 C) and heated at a high temperature, that is not described in a literature, is explained below.

The boron carbide is ground to a particle size of 40 .mu.m or less and then mixed with carbon black. The average particle size of boron carbide is preferably 20 .mu.m or less. If the average particle size exceeds this range, the effect by the addition is small and also the yield and productivity decrease.

In the grinding, a commercially available general impact-type grinder (e.g., roller mill, ball mill, pulverizer) can be used. The boron carbide is difficult to grind and therefore, is preferably ground in advance to the mixing with carbon black.

The amount of boron carbide added is suitably from 0.01 to 7% by mass, preferably from 0.5 to 7% by mass as calculated in terms of boron. If the amount added is less than this range, the graphitization barely proceeds, whereas even if the amount added exceeds 7% by mass, the graphitization does not proceed any more and this is useless. The boron added in this range comes to be present in the carbon powder in an amount of 0.001 to 5% by mass, preferably 0.1 to 5% by mass and by virtue of this, the above-described graphitization effect can be brought out.

The boron carbide and carbon black may be mixed by any method without using any special machine as long as these are uniformly mixed.

The mixture of carbon black and boron carbide is preferably placed in a graphitic container and heat-treated in a non-oxidative atmosphere by passing an inert gas such as argon. The heat-treatment temperature must be 2,500.degree. C. or more. If the temperature is less than this range, the graphitization does not proceed and the graphitic fine carbon powder having a plane spacing of a unit lattice (C.sub.0 value) of less than 0.680 nm, furthermore 0.6730 nm or less for use in the present invention cannot be obtained.

The heat-treatment furnace for the graphitization may be any furnace as long as the heat-treatment can be performed at a desired temperature in a non-oxidative atmosphere and for example, an Acheson furnace utilizing carbon powder particles for the heat generation, a high frequency furnace and a furnace using a solid graphite heating element may be used. The non-oxidative atmosphere can be obtained by burying the material to be graphitized in the carbon powder or purging the inside of the furnace with an inert gas such as nitrogen gas or argon gas.

In the heating, after the entire material to be heated reaches a predetermined temperature, holding for a certain time is not particularly necessary. The heat-treated material is allowed to cool in the same non-oxidative atmosphere and ground by lightly stirring it.

If a boric acid which is in general easily available is mixed and heat-treated, instead of using boron carbide as the raw material of boron, enough reduction in the C.sub.0 value cannot be attained by the graphitization, and it is difficult to make the C.sub.0 value of less than 0.680 nm.

By the above-described method of the present invention, carbon black which is said usually non-graphitizable and difficult to graphitize, can be graphitized.

When the carbon fine powder of the present invention is measured by an X ray, the C.sub.0 crystallite plane spacing (double of d.sub.002) generally used as an index for showing the graphitization degree is less than 0.680 nm, furthermore 0.6730 nm or less. C.sub.0 value as low as this level can not be attained using the submicron carbon powder.

The fine carbon powder of the present invention uses carbon black having a primary particle size of about several nm to about 100 nm as the raw material and is obtained by the partial aggregation of the carbons and therefore, after the graphitization, the particles having this primary particle size are aggregated as they are.

Even after the heat-treatment and grinding, the aggregated particles are estimated to have almost the same average particle size and distribution as those before the heat-treatment.

The primary particle size can be directly measured by the observation through TEM (transmission electron microscope), but the particle size distribution is mostly fixed by the manufacturing standard of carbon black. In the present invention, carbon powder having a primary particle size of 100 nm or less is suitably used and the graphitization product thereof also has a primary particle size within this range. N.sub.2 absorption specific surface area (BET), which is decreased by graphitization, is preferably in a range of 50 to 400 m.sup.2 /g in the present invention.

The particle size of the aggregated particle cannot be precisely measured because of the aggregation form such that primary particles are branched. When the average particle size is measured, for example, by the centrifugal precipitation method, the aggregated particles of the present invention are considered to be submicron particles having an average particle size of less than 1 .mu.m.

Since the fine carbon powder of the present invention is heat-treated together with boron carbide, the graphitization can successfully proceed and the electrical conductivity can be improved as compared with ordinary carbon powder which is not subjected to a heat-treatment or subjected to a heat-treatment by not adding boron carbide.

Above is From Patent#: 6,780,388 B2 Date: 24 Aug 04

Coating for carbon electrodes can consist of 50% by weight of finely ground graphite and silica. Hardened in a furnace.

Casting electrodes: mix ground coke with coal tar. Pressurize at 60-140 deg C (plastic paste) and using continuous jolts or vibration to increase density. Then baking it for several hours up to a temperature of about 1500 deg C.

A paste mixture of carbon coal particles fired to the point of Graphitizing the Agglomerated Carbon particles.

Heat the carbon particles first to drive off vapors then mix with binder. Important that each particle is coated with the binder. Ground up petroleum coke and pitch coke to about .3mm or smaller then separated and the larger particles mixed with the pitch (tar) first and the smaller second until it makes a dense paste that still wets the full surface of each practical.

Above is from Patent#: 2,645,583

Bake carbon electrodes used in electric furnaces consist of calcined petroleum coke other cokes, charcoal, certain types of coal and lampblack. They are all amorphous carbon structure. The binders are petroleum pitch which is the residue of the refining of an asphalt-base petroleum, other pitches and various tars. Other binders include molasses, resins, turpentine and various products which are produced by distilling organic substances. The volatile material is largely eliminated by the baking process. The residue left consists of elemental carbon which bonds the particles of the body material. All binders are designated as carbonaceous.

Old method: petroleum coke is crushed and calcined and the resultant carbon body material is ground and this is mixed with the warm binder, which is in the form of small particles. This mixture is cooled crushed and ground to produce the electrode-forming composition. The ground electrode-forming composition is heated in a mold until it becomes pasty. The mold is then removed from the heating oven, and the material in the mold is subjected to high pressure while still in the mold. The molded shape is then removed from the mold and is baked in a furnace, with the exclusion of air, in order to remove the volatile matter. Due to the low thermal conductivity of the molded shape, the baking process requires great care, and the finished electrodes are often warped and have low conductivity and low mechanical strength due to improper baking. Also, a long baking period of one to two weeks is required, especially if the electrode is large size. Also, a long cooling period of the furnace is required. The maximum temperature of the furnace is about 1050° C. in a gas-fired furnace.

Above is from Patent# 2,764,539

Carbon Arc Lighting and making of electrodes -- a good general write up:
See http://encyclopedia.jrank.org/LEO_LOB/LIGHTING.html

The electric arc may be produced between any conducting materials maintained at different potentials, provided that the source of electric supply is able to furnish a sufficiently large current; but for illuminating purposes pieces of hard graphitic carbon are most convenient. If some source of continuous electric current is connected to rods of such carbon, first brought into contact and then slightly separated, the following facts may be noticed: With a low electromotive force of about 50 or 6o volts no discharge takes place until the carbons are in actual contact, unless the insulation of the air is broken down by the passage of a small electric spark. When this occurs, the space between the carbons is filled at once with a flame or luminous vapor, and the carbons themselves become highly incandescent at their extremities. If they are horizontal the flame takes the form of an arch springing between their tips; hence the name arc. This varies somewhat in appearance according to the nature of the current, whether continuous or alternating, and according as it is formed in the open air or in an enclosed space to which free access of oxygen is pre-vented. Electric arcs between metal surfaces differ greatly in color according to the nature of the metal. When formed by an alternating current of high electromotive force they resemble a lambent flame, flickering and producing a some-what shrill humming sound.

Electric arcs may be classified into continuous or alternating current arcs, and open or enclosed arcs, carbon arcs with prior chemically impregnated carbons, or so-called flame arcs, and arcs formed with metallic or oxide electrodes, such as magnetite. A continuous current arc is formed with an electric current flowing always in the same direction; an alternating current arc is formed with a periodically reversed current. An open arc is one in which the carbons or other material forming the arc are freely exposed to the air; an enclosed arc is one in which they are included in a glass vessel. If carbons impregnated with various salts are used to color or increase the light, the arc is called a chemical or flame arc. The carbons or electrodes may be arranged in line one above the other, or they may be inclined so as to project the light downwards or more in one direction. In a carbon arc if the current is continuous the positive carbon becomes much hotter at the end than the negative, and in the open air it is worn away, partly by combustion, becoming hollowed out at the extremity into a crater. At the same time the negative carbon gradually becomes pointed, and also wears away, though much less quickly than the positive. In the continuous-current open arc the greater part of the light proceeds from the highly incandescent positive crater. When the arc is examined through dark glasses, or by the optical projection of its image upon a screen, a violet band or stream of vapor is seen to extend between the two carbons, surrounded by a nebulous golden flame or aureole. If the carbons are maintained at, the right distance apart the arc remains steady and silent, but if the carbons are impure, or the distance between them too great, the true electric arc rapidly changes its place, flickering about and frequently becoming extinguished; when this happens it can only be restored by bringing the carbons once more into contact. If the current is alternating, then the arc is symmetrical, and both carbons possess nearly the same appearance. If it is enclosed in a vessel nearly air-tight, the rate at which the carbons are burnt away is greatly reduced, and if the current is continuous the positive carbon is no longer cratered out and the negative no longer so much pointed as in the case of the open arc.

Davy used for his first experiments rods of wood charcoal which had been heated and plunged into mercury to make them better conductors. Not until 1843 was it carbons. Proposed by J. B. L. Foucault to employ pencils cut from the hard graphitic carbon deposited in the interior of gas retorts. In 1846 W. Greener and W. E. Staite patented a process for manufacturing carbons for this purpose, but only after the invention of the Gramme dynamo in 187o any great demand arose for them. F. P. E. Carle in France in 1876 began to manufacture arc lamp carbons of high quality from coke, lampblack and syrup. Now they are made by taking some specially refined form of finely divided carbon, such as the soot or lampblack formed by cooling the smoke of burning paraffin or tar, or by the carbonization of organic matter, and making it into a paste with gum or syrup. This carbon paste is forced through dies by means of a hydraulic press, the rods thus formed being subsequently baked with such precautions as to preserve them perfectly straight. In some cases they are cored, that is to say, have a longitudinal hole down them, filled in with a softer carbon. Sometimes they are covered with a thin layer of copper by electro-deposition. They are supplied for the market in sizes varying from 4 to 30 or 40 millimeters in diameter, and from 8 to 16 in.

in length. The value of carbons for arc lighting greatly depends on their purity and freedom from ash in burning, and on perfect uniformity of structure. For ordinary purposes they are generally round in section, but for certain special uses, such as lighthouse work, they are made fluted or with a star-shaped section. The positive carbon is usually of larger section than the negative. For continuous-current arcs a cored carbon is generally used as a positive, and a smaller solid carbon as a negative. For flame arc lamps the carbons are specially prepared by impregnating them with salts of calcium, magnesium and sodium. The calcium gives the best results. The rod is usually of a composite type. The outer zone is pure carbon to give strength, the next zone contains carbon mixed with the metallic salts, and the inner core is the same but less compressed.

In addition to the metallic salts a flux has to be introduced to prevent the formation of a non-conducting ash, and this renders it desirable to place the carbons in a downward pointing direction to get rid of the slag so formed. Bremer first suggested in 1898 for this purpose the fluorides of calcium, strontium or barium. When such carbons are used to form an electric arc the metallic salts deflagrate and produce a flame round the arc which is strongly colored, the object being to produce a warm yellow glow, instead of the somewhat violet and cold light of the pure carbon arc, as well as a greater emission of light. As noxious vapors are however given off, flame arcs can only be used out of doors. Countless researches have been made on the subject of carbon manufacture, and the art has been brought to great perfection. Special manuals must be consulted for further information (see especially a treatise on Carbon making for all electrical purposes, by F. Jehl, London, 1906).

The physical phenomena of the electric arc are best examined by forming a carbon arc between two carbon rods of the above description, held in line in a special apparatus, and arranged so as to be capable of being moved to or from each other with a slow and easily regulated motion. An arrangement of this kind is called a hand-regulated arc lamp (fig. 4). If such an arc lamp is connected to a source of electric supply having an electromotive force preferably of 100 volts, and if some resistance is included in the circuit, say about 5 ohms, a steady and continuous arc is formed when the carbons are brought together and then slightly separated. Its appearance may be most conveniently examined by projecting its image upon a screen of white paper by means of an achromatic lens. A very little examination of the distribution of light from the arc shows that the illuminating or candle-power is not the same in different directions. If the carbons are vertical and the positive carbon is the upper of the two, the illuminating power is greatest in a direction at an angle inclined about 40 or 50 degrees below the horizon, and at other directions has different values, which may be represented by the lengths of radial lines drawn from a centre, the extremities of which define a curve called the illuminating curve of the arc lamp (fig. 5). Considerable differences exist between the forms of the illuminating-power curves of the continuous and alternating current and the open or enclosed arcs.

It will be found that, beginning at the lowest current capable of forming a true arc, the potential difference of
the carbons (the arc P.D.) decreases as the current increases. Up to a certain current strength the arc is silent, but at a particular critical value P.D. suddenly drops about 10 volts, the current at the same time rising 2 or 3 amperes. At that moment the arc begins to hiss, and in this hissing condition, if the current is still further increased, P.D. remains constant over wide limits. This drop in voltage on hissing was first noticed by A. Niaudet (La Lumiere electrique, 1881, 3, p. 287). It has been shown by Mrs Ayrton (fount. Inst. Elec. Eng. 28, 1899, p. 400) that the hissing is mainly due to the oxygen which gains access from the air to the crater, when the latter becomes so large by reason of the increase of the current as to overspread the end of the positive carbon. According to A. E. Blondel and Hans Luggin, hissing takes place whenever the current density becomes greater than about 03 or o5 ampere per square millimeter of crater area.

It will thus be seen that the arc, considered as a conductor, has the property that if the current through it is increased, the difference of potential between the carbons is decreased, and in one sense, therefore, the arc may be said to act as if it were a negative resistance.

Violle also, in 1893, supported the opinion that the brightness of the crater per square millimeter was independent of the current density, and from certain experiments and assumptions as to the specific heat of carbon, he asserted the temperature of the crater was about 350o C. It has been concluded that this constancy of temperature, and therefore of brightness, is due to the fact that the crater is at the temperature of the boiling-point of carbon.

As the current can be interrupted for a moment without extinguishing the arc, it is possible to work the electric arc from an alternating current generator without apparent intermission in the light, provided that the frequency is not much below 50.

If a continuous-current electric alternating-current arcs is formed in the open air with a positive carbon having a diameter of about 15 millimetres, and a negative carbon having a diameter of about 9 millimetres, and if a current of 10 amperes is employed, enclosed the potential difference between the carbons is generally from 40 to 50 volts. Such a lamp is therefore called a S00-watt arc. Under these conditions the carbons each burn away at the rate of about 1 in. per hour, actual combustion taking place in the air which gains access to the highly-heated crater and negative tip; hence the most obvious means of preventing this disappearance is to enclose the arc in an air-tight glass vessel. Such a device was tried very early in the history of arc lighting. The result of using a completely air-tight globe, how-ever, is that the contained oxygen is removed by combustion with the carbon, and carbon vapor or hydrocarbon compounds diffuse through the enclosed space and deposit themselves on the cool sides of the glass, which is thereby obscured. It was, however, shown by L. B. Marks (Electrician 31, p. 502, and 38, p. 646) in 1893, that if the arc is an arc formed with a small current and relatively high voltage, namely, 8o to 85 volts, it is possible to admit air in such small amount that though the rate of combustion of the carbons is reduced, yet the air destroys by oxidation the carbon vapor escaping from the arc. An arc lamp operated in this way is called an enclosed arc lamp (fig. 8). The top of the enclosing bulb is closed by a gas check plug which admits through a small hole a limited supply of air. The peculiarity of an enclosed arc lamp operated with a continuous current is that the carbons do not burn to a crater on the positive tip or mushroom on the negative, but preserve nearly flat surfaces. This feature affects the distribution of the light. The illuminating curve of the enclosed arc, therefore, has not such a strongly marked maximum value as that of the open arc, but on the other hand the true arc or column of incandescent carbon vapor is less steady in position, wandering round from place to place on the surface of the carbons. As a compensation for this defect, the combustion of the carbons per hour in commercial forms of enclosed arc lamps is about one-twentieth part of that of an open arc lamp taking the same current.

For the purpose of public illumination it is very usual to employ a lamp taking 10 amperes, and therefore absorbing about 500 watts. Such a lamp is called a 500-watt arc lamp, and it is found that a satisfactory illumination is given for most street purposes by placing 5oo-watt arc lamps at distances varying from 40 to l00 yds., and at a height of 20 to 25 ft. above the roadway. The maxi-mum candle-power of a 5oo-watt arc enclosed in a roughened or ground-glass globe will not exceed 1500 candles, and that of a 6.8-ampere arc (continuous) about 900 candles. If, how-ever, the arc is an enclosed arc with double globes, the absorption of light would reduce the effective maximum to about 200 c.p. and 120 c.p. respectively.

One early devised form of arc-lamp mechanism was a system of clock-work driven by a spring or weight, which was started and stopped by the action of an electromagnet; in modern lighthouse lamps a similar mechanism is still employed. W. E. Staite (1847), J. B. L. Foucault (1849), V. L. M. Serrin (1857), J. Duboscq (1858), and a host of later inventors, devised numerous forms of mechanical and clock-work lamps. The modern self-regulating type may be said to have been initiated in 1878 by the differential lamp of F. von Hefner-Alteneck, and the clutch lamp of C. F. Brush. The general principle of the former may be explained as follows: There are two solenoids, placed one above the other. The lower one, of thick wire, is in series with the two carbon rods forming the arc, and is hence called the series coil. Above this there is placed another solenoid of fine wire, which is called the shunt coil. Suppose an iron rod to be placed so as to be partly in one coil and partly in another; then when the coils are traversed by currents, the iron core will be acted upon by forces tending to pull it into these solenoids. If the iron core be attached to one end of a lever, the other end of which carries the upper carbon, it will be seen that if the carbons are in contact and the current is switched on, the series coil alone will be traversed by the current, and its magnetic action will draw down the iron core, and therefore pull the carbons apart and strike the arc. The moment the carbons separate, there will be a difference of potential between them, and the shunt coil will then come into action, and will act on the core so as to draw the carbons together. Hence the two solenoids act in opposition to each other, one in-creasing and the other diminishing the length of the arc, and maintaining the carbons in the proper position. In the lamp of this type the upper carbon is in reality attached to a rod having a side-rack gearing, with a train of wheels governed by a pendulum. The action of the series coil on the mechanism is to first lock or stop the train, and then lift it as a whole slightly. This strikes the arc. When the arc is too long, the series coil lowers the gear and finally releases the upper carbon, so that it can run down by its own weight. The principle of a shunt and series coil operating on an iron core in opposition is the basis of the mechanism of a number of arc lamps. Thus the lamp invented by F. Krizik and L. Piette, called from its place of origin the Pilsen lamp, comprises an iron core made in the shape of a double cone or spindle (fig. 13), which is so arranged in a brass tube that it can move into or out of a shunt and series coil, wound the one with fine and the other with thick insulated wire, and hence regulate the position of the carbon attached to it. The movement of this core is made to feed the carbons directly without the intervention of any clock-work, as in the case of the Hefner-Alteneck lamp. In the clutch-lamp mechanism the lower carbon is fixed, and the upper carbon rests upon it by its own weight and that of its holder. The latter consists of a long rod passing through guides, and is embraced somewhere by a ring capable of being tilted or lifted by a finger attached to the armature of an electromagnet the coils of which are in series with the arc. When the current passes through the magnet it attracts the armature, and by tilting the ring lifts the upper carbon-holder and hence strikes the arc. If the current diminishes in value, the upper carbon drops a little by its own weight, and the feed of the lamp is thus effected by a series of small lifts and drops of the upper carbon (fig. 14). Another element sometimes employed in arc-lamp mechanism is the brake-wheel regulator. This is a feature of one form of the Brockie and of the Crompton-Pochin lamps. In these the movement of the carbons is effected by a cord or chain which passes over a wheel, or by a rack geared with the brake wheel. When no current is passing through the lamp, the wheel is free to move, and the carbons fall together; but when the current is switched on, the chain or cord passing over the brake wheel, or the brake wheel itself is gripped 665 in some way, and at the same time the brake wheel is lifted so that the arc is struck.

Although countless forms of self-regulating device have been invented for arc lamps, nothing has survived the test of time so well as the typical mechanisms which work with carbon rods in one line, one or both rods being moved by a controlling apparatus as required. The early forms of semi-incandescent arc lamp, such as those of R. Werdermann and others, have dropped out of existence. These were not really true arc lamps, the light being produced by the incandescence of the extremity of a thin carbon rod pressed against a larger rod or block. The once famous Jablochkoff candle, invented in 1876, consisted of two carbon rods about 4 mm. in diameter, placed parallel to each other and separated by a partition of kaolin, steatite or other refractory non-conductor. Alternating currents were employed, and the candle was set in operation by a match or starter of high-resistance carbon paste which connected the tips of the rods. When this burned off, a true arc was formed between the parallel carbons, the separator volatilizing as the carbons burned away. Although much ingenuity was expended on this system of lighting between 1877 and 1881, it no longer exists. One cause of its disappearance was its relative inefficiency in light-giving power compared with other forms of carbon arc taking the same amount of power, and a second equally important reason was the waste in carbons. If the arc of the electric candle was accidentally blown out, no means of relighting existed; hence the great waste in half-burnt candles. H. Wilde, J. C. Jamin, J. Rapieff and others endeavored to provide a remedy, but without success.

It is impossible to give here detailed descriptions of a fraction of the arc-lamp mechanisms devised, and it must suffice to indicate the broad distinctions between various types. (I) Arc lamps may be either continuous-current or alternating-current lamps. For outdoor public illumination the former are greatly preferable, as owing to the form of the illuminating power-curve they send the light down on the road surface, provided the upper carbon is the positive one. For indoor, public room or factory lighting, inverted arc lamps are sometimes employed. In this case the positive carbon is the lower one, and the lamp is carried in an inverted metallic reflector shield, so that the light is chiefly thrown up on the ceiling, whence it is diffused all round. The alternating-current arc is not only less efficient in mean spherical candle-power per watt of electric power absorbed, but its distribution of light is disadvantageous for street purposes. Hence when arc lamps have to be worked off an alternating-current circuit for public lighting it is now usual to make use of a rectifier, which rectifies the alternating current into a unidirectional though pulsating current. (2.) Arc lamps may be also classified, as above described, into open or en-closed arcs. The enclosed arc can be made to burn for 200 hours with one pair of carbons, whereas open-arc lamps are usually only able to work, 8, 16 or 32 hours without recarboning, even when fitted with double carbons. (3) Arc lamps are further divided into focusing and non focusing lamps. In the former the lower carbon is made to move up as the upper carbon moves down, and the arc is therefore maintained at the same level. This is advisable for arcs included in a globe, and absolutely necessary in the case of lighthouse lamps and lamps for optical purposes. (4) Another subdivision is into hand-regulated and self-regulating lamps. In the hand-regulated arcs the carbons are moved by a screw attachment as required, as in some forms of search-light lamp and lamps for optical lanterns. The carbons in large search-light lamps are usually placed horizon-tally. The self-regulating lamps may be classified into groups depending upon the nature of the regulating appliances. In some cases the regulation is controlled only by a series coil, and in others only by a shunt coil. Examples of the former are the original Gulcher and Brush clutch lamp, and some modern enclosed arc lamps; and of the latter, the Siemens “band“ lamp, and the Jackson-Mensing lamp. In series coil lamps the variation of the current in the coil throws into or out of action the carbon-moving mechanism; in shunt coil lamps the variation in voltage between the carbons is caused to effect the same changes. Other types of lamp involve the use both of shunt and series coils acting against each other.

A further classification of the self-regulating lamps may be found in the nature of the carbon-moving mechanism. This may be some modification of the Brush ring clutch, hence called clutch lamps; or some variety of brake wheel, as employed in Brockie and Crompton lamps; or else some form of electric motor is thrown into or out of action and effects the necessary changes. In many cases the arc-lamp mechanism is provided with a dash-pot, or contrivance in which a piston moving nearly air-tight in a cylinder prevents sudden jerks in the motion of the mechanism, and thus does away with the “hunting" or rapid up-and-down movements to which some varieties of clutch mechanism are liable. One very efficient form is illustrated in the Thomson lamp and Brush-Vienna lamp. In this mechanism a shunt and series coil are placed side by side, and have iron cores suspended to the ends of a rocking arm held partly within them. Hence, according as the magnetic action of the shunt or series coil prevails, the rocking arm is tilled back-wards or forwards. When the series coil is not in action the motion is free, and the upper carbon-holder slides down, or the lower one slides up, and starts the arc. The series coil comes into action to withdraw the carbons, and at the same time locks the mechanism. The shunt coil then operates against the series coil, and between them the carbon is fed forwards as required. The control to be obtained is such that the arc shall never become so long as to flicker and become extinguished, when the carbons would come together again with a rush, but the feed should be smooth and steady, the position of the carbons responding quickly to each change in the current.

The introduction of enclosed arc lamps was a great improvement, in consequence of the economy effected in the consumption of carbon and in the cost of labor for trimming. A well-known and widely used form of enclosed arc lamp is the Jandus lamp, which in large current form can be made to burn for two hundred hours without re-carboning, and in small or midget form to burn for forty hours, taking a current of two amperes at l00 volts. Such lamps in many cases conveniently replace large sizes of incandescent lamps, especially for shop lighting, as they give a whiter light. Great improvements have also been made in inclined carbon arc lamps. One reason for the relatively low efficiency of the usual vertical rod arrangement is that the crater can only radiate laterally, since owing to the position of the negative carbon no crater light is thrown directly downwards. If, however, the carbons are placed in a downwards slanting position at a small angle like the letter V and the arc formed at the bottom tips, then the crater can emit downwards all the light it produces. It is found, however, that the arc is unsteady unless a suitable magnetic field is employed to keep the arc in position at the carbon tips. This method has been adopted in the Carbon arc, which, by the employment of inclined carbons, and a suitable electromagnet to keep the true arc steady at the ends of the carbons, has achieved considerable success. One feature of the Carbon arc is the use of a relatively high voltage between the carbons, their potential difference being as much as 85 volts.

Arc lamps may be arranged either (i.) in series, (ii.) in parallel or (iii.) in series parallel. In the first case a number, say 20, may be traversed by the same current, in that case a magnetic cut-out, so that if the carbons stick together or remain apart the current to the other lamps is not interrupted, the function of such a cut-out being to close the main circuit immediately any one lamp ceases to pass current. Arc lamps worked in series are generally supplied with a current from a constant current dynamo, which maintains an invariable current of, say 10 amperes, independently of the number of lamps on the external circuit. If the lamps, however, are worked in series off a constant potential circuit, such as one supplying at the same time incandescent lamps, provision must be made by which a resistance coil can be substituted for any one lamp removed or short-circuited. When lamps are worked in parallel, each lamp is independent, but it is then necessary to add a resistance in series with the lamp. By special devices three lamps can be worked in series of 100 volt circuits. Alternating-current arc lamps can be worked off a high-tension circuit in parallel by providing each lamp with a small transformer. In some cases the alternating high-tension current is rectified and supplied as a unidirectional current to lamps in series. If single alternating-current lamps have to be worked off a 100 volt alternating-circuit, each lamp must have in series with it a choking coil or economy coil, to reduce the circuit pressure to that required for one lamp. Alternating-current lamps take a larger effective current, and work with a less effective or virtual carbon P.D., than continuous current arcs of the same wattage.

The cost of working public arc lamps is made up of several items. There is first the cost of supplying the necessary electric cost. energy, then the cost of carbons and the labor of recarboning, and, lastly, an item due to depreciation and repairs of the lamps. An ordinary type of open Io ampere arc lamp, burning carbons 15 and 9 mm. in diameter for the positive and negative, and working every night of the year from dusk to dawn, uses about 600 ft. of carbons per annum. If the positive carbon is 18 mm. and the negative 12 mm., the consumption of each size of carbon is about 70 ft. per 1000 hours of burning. It may be roughly stated that at the present prices of plain open arc-lamp carbons the cost is about 15s. per 1000 hours of burning; hence if such a lamp is burnt every night from dusk to midnight the annual cost in that respect is about I, ros. The annual cost of labor per lamp for trimming is in Great Britain from 2 to 3; hence, approximately speaking, the cost per annum of maintenance of a public arc lamp burning every night from dusk to midnight is about 4 to 5, or perhaps 6, per annum, depreciation and repairs included. Since such a 10 ampere lamp uses half a Board of Trade unit of electric energy every hour, it will take r000 Board of Trade units per annum, burning every night from dusk to midnight; and if this energy is supplied, say at r 2d. per unit, the annual cost of energy will be about 6, and the upkeep of the lamp, including carbons, labor for trimming and repairs, will be about 10 to 11 per annum. The cost for labor and carbons is considerably reduced by the employment of the enclosed arc lamp, but owing to the absorption of light produced by the inner enclosing globe, and the necessity for generally employing a second outer globe, there is a lower resultant candle-power per watt expended in the arc. Enclosed arc lamps are made to burn without attention for zoo hours, singly on 100 volt circuits, or two in series on 200 volt circuits, and in addition to the cost of carbons per hour being only about one-twentieth of that of the open arc, they have another advantage in the fact that there is a more uniform distribution of light on the road surface, because a greater proportion of light is thrown out horizontally.

It has been found by experience that the ordinary type of open arc lamp with vertical carbons included in an opalescent globe cannot compete in point of cost with modern improvements in gas lighting as a means of street illumination. The violet color of the light and the sharp shadows, and particularly the non-illuminated area just beneath the lamp, are grave disadvantages. The high-pressure flame arc lamp with inclined chemically treated carbons has, however, put a different complexion on matters. Although the treated carbons cost more than the plain carbons, yet there is a great increase of emitted light, and a 9-ampere flame arc lamp supplied with electric energy at 1-d. per unit can be used for 1000 hours at an inclusive cost of about 5 to 6, the mean emitted illumination being at the rate of 4 c.p. per watt absorbed. In the Carbon arc lamp, the carbons are worked at an angle of 15 or 200 to each other and the arc is formed at the lower ends. If the potential difference of the carbons is low, say only 50-6o volts, the crater forms between the tips of the carbons and is therefore more or less hidden. If, however, the voltage is increased to 9o-roo then the true flame of the arc is longer and is curved, and the crater forms at the extreme tip of the carbons and throws all its light downwards. Hence results a far greater mean hemispherical candle power (M.H.S.C.P.), so that whereas a so-ampere 6o volt open arc gives at most r200 M.H.S.C.P., a Carbon 10-ampere 85 volt arc will give 2700 M.H.S.C.P. Better results still can be obtained with impregnated carbons. But the flame arcs with impregnated carbons cannot be enclosed, so the consumption of carbon is greater, and the carbons themselves are more costly, and leave a greater ash on burning; hence more trimming is required. They give a more pleasing effect for street lighting, and their golden yellow globe of light is more useful than an equally costly plain arc of the open type. This improvement in efficiency is, however, accompanied by some disadvantages. The flame arc is very sensitive to currents of air and therefore has to be shielded from draughts by putting it under an "economizer" or chamber of highly refractory material which surrounds the upper carbon, or both carbon tips, if the arc is formed with inclined carbons. (For additional information on flame arc lamps see a paper by L. B. Marks and H. E. Clifford, Electrician, 1906, 57, P. 975.)

----------------------------- my notes ----------

If this is not available then try 50% ground up charcoal and 50% lamp black (soot from chimney or incomplete burning), and 10% clay or pitch or tar or molasses. Heat it in middle of a .5” SS tube. Pack in more from other end (use a packing rod) as heat dries and fuses it into a rod that comes out the other end. If done slow enough it may work to from a rod. If it gets hot enough it will then conduct electricity if not hot enough with no air then it won't conduct. This is all from my current understanding from the above.