May 21, 1929. C. G. SMITH 1,714,406

METHOD AND APPARATUS FOR CAUSING ELECTRICAL CONDUCTION

Filed July 30, 1923

Fig. 1

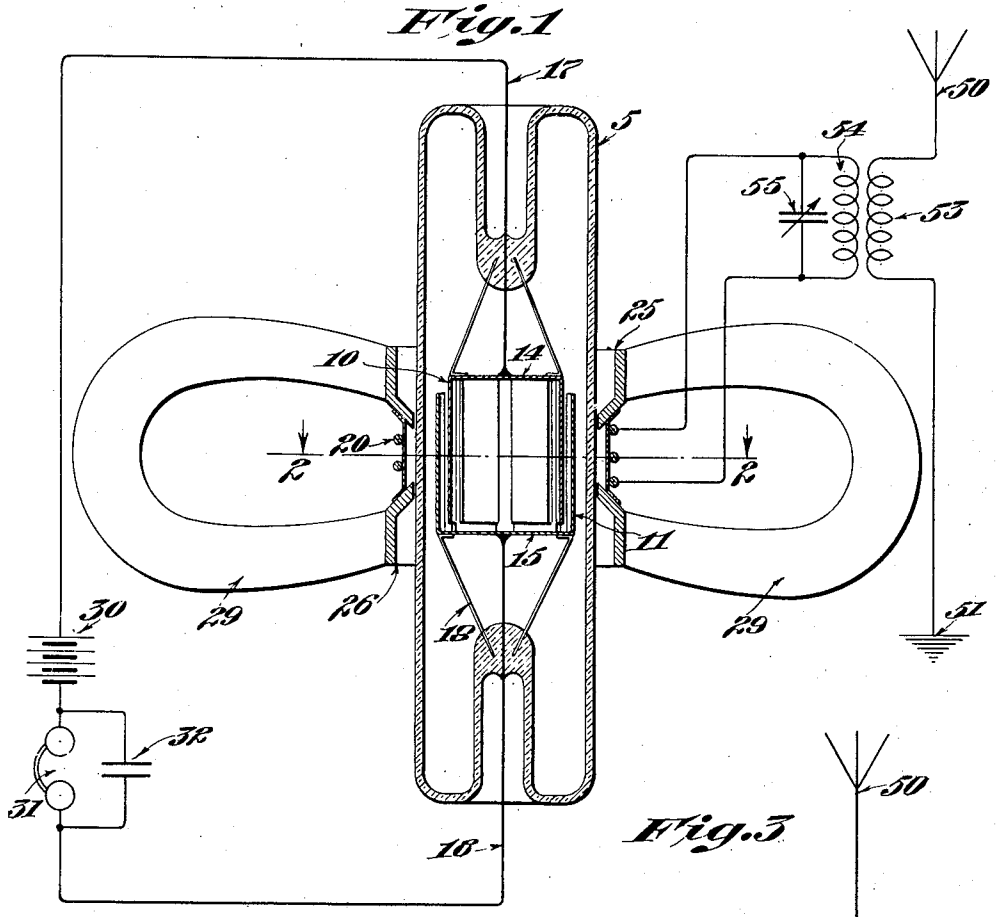


Fig. 2

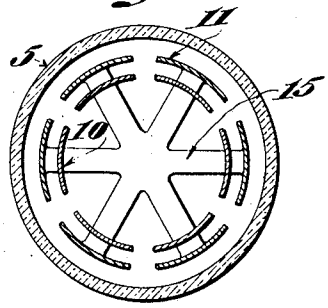
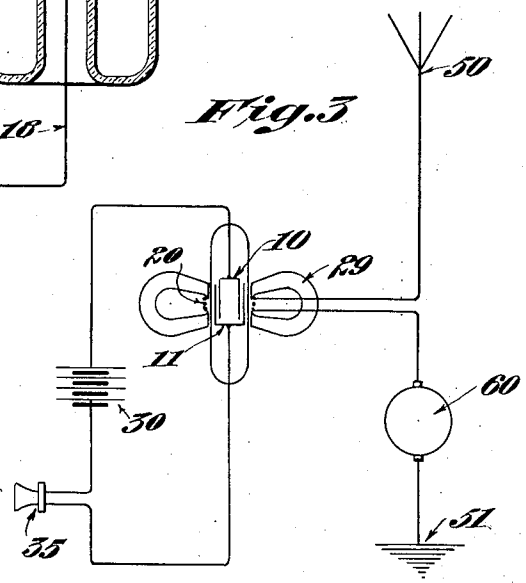


Fig. 3



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UNITED STATES PATENT OFFICE.

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METHOD AND APPARATUS FOR CAUSING ELECTRICAL CONDUCTION.

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The present invention relates to a method and apparatus for causing electrical conduction and is more particularly concerned with a method and apparatus involving electrical conduction through a highly rarefied gaseous medium.

The conduction of electrical current through space subjected to an electrical field depends, according to recently accepted theories, upon the presence in the region of a sufficient number of carriers of electricity, which may take the form of negative electrons or positive ions. Heretofore such electrical conduction has been caused to take place in either one of two distinct manners, namely (1) by subjecting a gaseous medium to an electrical potential gradient sufficiently large to cause ionization of the gas molecules and (2) by causing electronic or ionic emission from an electrode immersed in the region. The first method assumes the presence of at least one free electron in the gas which, when impelled by the electric field, is enabled to collide with and ionize one or more gas molecules, thereby forming further electrons and positive ions. These electrons and ions are in themselves able to ionize further gas molecules, thereby setting up cumulative ionization, which results in electrical conduction through the gas. The second method ordinarily employs an incandescent filament to produce a supply of electrons by emission. By this means, it is possible to drive fairly large currents through a gaseous medium having a pressure even less than one thousandth of a millimetre of mercury, which for all practical purposes is designated in the art as a "perfect vacuum". Each of the above methods possesses its peculiar advantages, the former obviating the necessity of employing a fragile filament together with means for heating the same to incandescence and the latter ordinarily allowing a more complete control of the conduction for the purpose of modulating, amplifying or otherwise operating upon electrical oscillations.

The principal object of this invention is to provide a method and apparatus for causing and controlling electrical conduction in a highly rarefied gaseous region without recourse to incandescent electrodes.

With this object in view, one feature of the present invention provides for the cumulative production of negative electrons in a highly evacuated region. This is carried out by accelerating electrons in the region and causing them to impinge against a surface of conducting material with sufficient velocity to liberate further electrons. The electrons so liberated are in themselves enabled to strike the conducting surface and give rise to still more electrons. This accelerating effect may be carried out in a number of ways as, for example, by passing a beam of radiation through the region traversed by the electrons. In its preferred form, however, the invention contemplates the provision of a pair of electrodes separated by a substantially perfect vacuum which is subjected to the action of an electric field directed substantially parallel to the electrode surfaces. This parallel electric field acts upon the electrons and increases their velocity so that they may impinge upon one of the electrodes with sufficiently high velocity to liberate further electrons. This effect is cumulative and in a very short time the space between the electrodes is filled with such a large number of electrons that conduction is caused to take place between the electrodes if a sufficiently high electro-motive force is impressed in a normal direction therebetween.

This invention, involving as it does features of broadly new and useful character, has numerous practical applications, particularly in connection with the amplification, modulation and production of electrical oscillations. It is to be pointed out that the space separating the electrodes may be considered to be traversed by two electron streams or electric currents, one of which travels progressively in a direction substantially parallel to the electrode surfaces, and the other of which consists of those electrons which are enabled to traverse the entire distance between the electrodes themselves. These currents, together with the voltages producing them, are all mutually dependent one upon the other, so that variations in one of them will alter the characteristics of the others. Such a property makes the present invention adaptable for use in modulating or otherwise operating upon electrical oscillations.

Other features of the invention consists of novel features of construction and operation hereinafter described and claimed, the advantages of which will be obvious to those

skilled in the art from the following description.

In the accompanying drawings, Fig. 1 is a sectional elevation of an apparatus embodying the features of the present invention used in connection with a circuit for the detection of radio signals; Fig. 2 is an enlarged sectional view of the receptacle and electrodes on line 2—2 of Fig. 1; and Fig. 3 is a diagram illustrating the use of the apparatus of the present invention for modulating the output of an electrical generator.

The illustrated embodiment of the invention comprises a receptacle of insulating material having supported therein a pair of electrodes, preferably of tubular or cylindrical form. The receptacle is evacuated as far as possible, preferably to less than one thousandth of a millimetre of mercury. There is impressed in the region separating the electrodes a magnetic field having a large constant component and a smaller variable component of high frequency. The constant component is for the deflection of electrons in a sidewise direction between the electrodes (i. e., transversely of the direct path between the electrodes and, in the illustrated embodiment, circumferentially of the annular space between the electrodes;) and the latter variable component gives rise to the accelerating electro-motive force which acts to increase the velocity of the electrons. This apparatus may be conveniently included in a system for the reception of radio signals. In this case, the high frequency magnetic field is produced by a solenoid upon which are impressed the oscillations received by the antenna. The variations in the conductivity between the electrodes is then in direct accordance with the variations of energy received by the antenna.

In the drawings 5 represents the enclosing receptacle which is constructed preferably of glass. Electrodes 10 and 11 which are supported therein are provided with cylindrical opposing surfaces and are longitudinally slotted to prevent the occurence of eddy currents in a peripheral direction. As shown in Fig. 2, the electrode 11 is mounted upon a suitable spider 15 which, for convenience, may be made integral with the portions of the electrodes. The electrode 10 is mounted upon a similar spider 14. The electrodes are maintained in the receptacle by suitable straps 18 attached to the respective spiders and sealed into the glass. Suitable lead wires 17 and 18 are also sealed in the glass and are connected with electrodes 10 and 11, respectively. The magnetic field is produced by two annular magnetic poles 25 and 26 which are excited for the constant component by suitable permanent magnets 29 arranged at intervals around the circumference of the poles. The poles are so arranged that the lines of magnetic flux pass into the region separated by the electrodes and cut the external electrode 11 in two places. This curving or arching of the magnetic field is advantageous as it tends to concentrate the electrical discharge in a region close to the median plane of the poles as pointed out in my Patent 1,617,177 granted February 8, 1927. The alternating component of the magnetic field is supplied by a suitable winding 20 which, when high frequencies are employed, may consist of only a few turns. In the operation of this device it is preferred, when possible, to have the external electrode 11 act as a cathode. When a potential difference is applied between anode 10 and cathode 11 any free electrons existing in the region of cathode 11 will be impelled toward the anode, but due to the action of the constant component of the magnetic field, they are deflected sidewise and caused to have a component of direction parallel to the electrode surfaces (circumferentially of the annular space between the electrode surfaces in the illustrative embodiment). If now the winding 20 is energized by a high frequency electric current an electro-motive force is set up in the region surrounded by the winding. This electro-motive force produces no currents in the electrodes because they are slotted to prevent it, but its action is to apply forces to the electrons. When these forces act in the same direction as the deflecting force of the constant magnetic field, the electrons are accelerated and caused to impinge upon the cathode 11 with increased velocities, thereby liberating other electrons which in turn are also caused to strike the cathode with high velocity. When the space between the electrodes is filled with electrons, a large number of electrons will reach the anode, and the space between the electrodes may be said to have become conducting. However, when the electro-motive force generated by the winding 20 tends to force the electrons in a direction opposite to that caused by the constant magnetic field their velocities are decreased to such a low value that they are either unable to return to the cathode at all or cannot liberate more electrons. Thus it will be seen that this apparatus damps out one half of the high frequency alternation, thereby acting to rectify it.

In Fig. 1, the receiving system in which the conduction apparatus is embodied comprises a wireless receiving antenna 50 connected to ground 51 through an inductance 53. This inductance is coupled to a resonant input circuit consisting of an inductance 54 and a variable condenser 55 connected to the winding 20. Leads 17 and 18 are connected to an output circuit containing a battery 30, a pair of telephone receivers 31 and a by-pass condenser 32. Because of the controlling effect of winding 20 upon the region separating the electrodes, the current through the telephone

31 is caused to be many times larger than the current passing directly in the input circuit. Furthermore, the rectifying action of the device which has been previously explained obviates the use of a separate detector. It is to be pointed out that this combined amplifying and detecting action is a feature not to be found in any prior device, since it is well-known that in the ordinary thermionic tube, for example, the amplifying and detecting effects take place by virtue of the variations in the characteristic curve, so that the one effect can be usually obtained only at the expense of the other.

The amplifying action explained in the preceding paragraph depends upon the fact that electronic conduction between the electrodes 10 and 11 is dependent upon the current passing through winding 20. It has been found that an effect of substantially the reverse character can also be obtained, namely, that the current in winding 20 can be made dependent upon the voltage impressed between electrodes 10 and 11. This effect has an important application in the modulation of the output of a high frequency generator by periodically absorbing energy from the generator. It has been previously explained that there may be considered to be two distinct electron streams passing in the region between the electrodes. The system of modulation to be presently explained operates merely upon the steam which is considered to pass in a direction substantially parallel to the surfaces of the electrodes (circumferentially of the annular space between the surfaces in the illustration). It has been found that the velocity with which electrons impinge upon the cathode depends materially upon the potential difference existing between the electrodes. For example, a very high voltage between anode 10 and cathode 11 causes electrons to pass very near the anode. Such electrons have a long trajectory and strike the cathode with a high velocity, liberating large numbers of secondary electrons. If the voltage between electrodes is low, the electrons have a shorter trajectory and strike with a much decreased velocity. This principle is made use of in the modulator system shown in Fig. 3, in which 50 is a wireless sending antenna connected through winding 20 and high frequency generator 60 to ground 51. The electrode circuit comprises a battery 30 or other constant source of potential and a telephone transmitter 35. Upon speaking into the transmitter, the voltage between electrodes 10 and 11 is caused to fluctuate in accordance with fluctuations of the voice. The electron trajectories thereby fluctuate in length, causing an electron stream of alternating strength around the electrodes (circumferentially of the annular space between the electrodes in the embodiment illustrated). It will be seen that this electron stream forms, in effect, the primary of a transformer of which winding 20 is the secondary, and that variations in current strength in the region between the electrodes must cause similar variations in the current passing through winding 20. A part of the energy generated by the high frequency generator 60 may, therefore, be considered to be absorbed by the electron stream, thereby modulating the emitted wave in accordance with the voice variations impressed upon the transmitter 35. The high frequency generator 60 may be of any type, such as a mechanical generator, an oscillating thermionic tube or a device such as that shown in Fig. 1 with coupled input and output circuits.

Although this device is designed to have especial utility in connection with extremely high vacua, it is to be pointed out that such extreme rarefaction is not necessary for the operation of the apparatus. The device may be used with gas pressures of fairly large value, and its principle of operation will not be changed except through the possible presence of positive ions caused by collision of electrons against gas molecules.

Other features of the apparatus, especially those concerning the size and spacing of electrodes, and the means for producing the magnetic field or the accelerating electromotive force should not be considered as limited to the specific construction described herein, except as limited in scope by the appended claims.

The invention having been described, what is claimed is:

1. The method of causing electrical conduction in a highly rarefied gaseous medium between a cathode and anode, which comprises impelling electrons from the region of the cathode and accelerating the electrons through the medium, and causing some of the accelerated electrons to impinge upon the cathode with sufficient velocity to liberate additional electrons.

2. The method of causing electrical conduction in a highly rarefied gaseous medium between a cathode and anode, which comprises impelling electrons from the region of the cathode and accelerating the electrons through the medium, and causing some of the accelerated electrons to impinge upon the cathode with sufficient velocity to liberate additional electrons, while causing some of the electrons to travel to the anode.

3. The method of causing electrical conduction in a highly rarefied gaseous medium between a cathode and anode, which comprises impelling electrons from the region of the cathode and accelerating the electrons through the medium transversely of the direct path between cathode and anode, and causing some of the accelerated electrons to impinge upon the cathode with sufficient velocity to liberate additional electrons.

4. The method of causing electrical conduction in a highly rarefied gaseous medium between a cathode and anode, which comprises impelling electrons from the region of the cathode and accelerating the electrons through the medium transversely of the direct path between cathode and anode, and causing some of the accelerated electrons to impinge upon the cathode with sufficient velocity to liberate additional electrons, while causing some of the electrons to travel to the anode.

5. An electrical apparatus comprising a pair of electrodes in a substantially perfect vacuum, means for impressing an electric field in the space between the electrodes to impel electrons from the region of one electrode toward the other electrode, means for deflecting electrons impelled by the electric field in a sidewise direction between the electrodes, and means for accelerating the electrons so deflected to cause them to impinge on the first electrode with sufficient velocity to liberate additional electrons.

6. An electrical apparatus comprising a highly evacuated receptacle, an anode and a cathode therein, means for impressing an electric field in the space between the anode and the cathode to impel electrons from the region of the cathode, and means for accelerating the electrons in a sidewise direction between the anode and the cathode to cause electrons to strike against the cathode with sufficient velocity to liberate additional electrons.

7. An electrical apparatus comprising an anode and a cathode immersed in a highly evacuated region, means for impressing an electrical potential difference between the anode and the cathode to impel electrons from the region of the cathode, means for deflecting the electrons in a direction substantially parallel to the electrode surfaces, and means for accelerating electrons to cause them to strike the cathode with sufficient velocity to liberate additional electrons.

8. An electrical apparatus comprising a highly evacuated receptacle, a pair of electrodes immersed therein, means for impressing a magnetic field in a region between the electrodes, the magnetic field having a constant component for deflecting electrons in a sidewise direction, and a variable component for inducing in the region an electromotive force to accelerate the electrons in a sidewise direction against one of the electrodes.

9. An electrical apparatus comprising an anode and a cathode in a vacuous region, means for bombarding the cathode with electrons produced by the cathode to liberate additional electrons, means to form a progressive electron stream around the cathode, and means for applying a potential difference between the anode and the cathode to attract to the anode a varying number of electrons in accordance with the characteristics of the electron stream.

10. An apparatus for modulating the output of a high frequency generator comprising a pair of electrodes in a vacuous region, a winding surrounding the electrodes and adapted to cooperate with the generator to induce in the vacuous region a high frequency electro-motive force for the purpose of accelerating electrons from one electrode against the same electrode to form a progressive electron stream in the region, means for impressing a low frequency potential difference between the electrodes to alter the characteristics of the electron stream and to absorb a varying amount of the energy from the generator.

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