Jan. 22, 1963 H. O. G. ALFVÉN 3,074,875

GENERATION OF EXTREMELY HIGH TEMPERATURE

Filed Sept. 29, 1959 2 Sheets-Sheet 1

Fig. 1

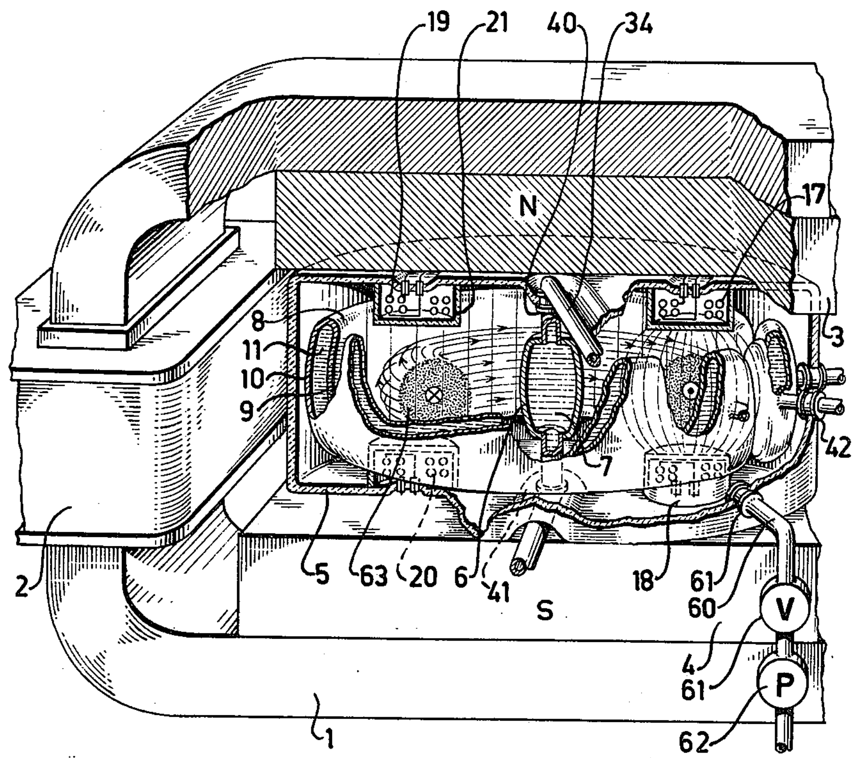

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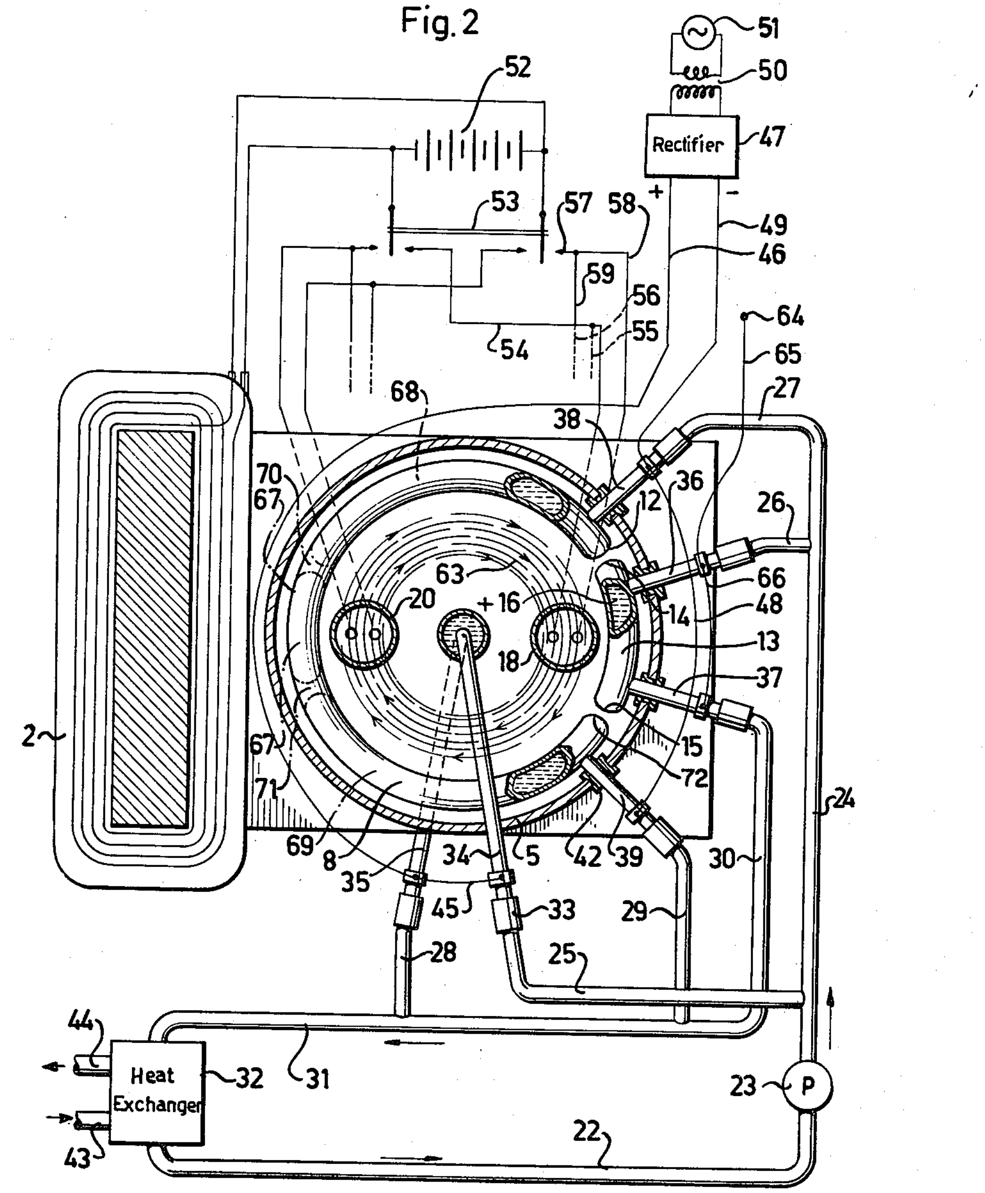
Fig. 2



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GENERATION OF EXTREMELY HIGH TEMPERATURE

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The present invention has for its object to render possible the generation of extremely high temperatures, such as those required to initiate and maintain nuclear fusion reactions, e.g. with hydrogen isotopes, for research or other such purposes as are known to those skilled in the art of extremely high temperature plasmas. For different purposes, inter alia, in connection with thermonuclear reactors it is necessary to heat the gas concerned to such a high temperature, as a rule above 10^{6}° K., and to maintain it at such elevated temperature for a period of time of the order of size of one second.

It is known that such temperatures may be obtained by conducting a heavy electric current impulse through a rarefied gas confined in a straight or annular discharge tube having a diameter of about 1 meter.

One object of the invention is to produce a concentrated gas plasma having a longer life than the current impulse impressed. A further object is to obtain a higher temperature than has been hitherto possible and to establish the prerequisites for a technical utilisation of the heat developed at the high temperature through nuclear fusion.

To realize these objects and obtain other advantages the present invention is concerned with an apparatus comprising a receptacle, the interior of which is isolated from the atmosphere, outer and inner electrode means insulated for high voltage and dimensioned for heavy currents and arranged in said receptacle, said outer electrode means surrounding said inner electrode means and being excited to a voltage opposite to that of said inner electrode means and providing between said outer and inner electrode means an annular discharge space, first magnetizing means for producing a substantially uniform magnetic field in an axial direction through said annular space, second magnetizing means for producing at least one local additional field also in substantially the same axial direction through said annular space and being of a several times higher intensity than said uniform field, evacuation means for rarefying gas included in said receptacle and ionisation means for initiating a discharge through said annular space. The ionisation means may principally consist of any known device able to ionize a gas. Thus the electrodes may themselves be so shaped or connected to such a voltage source that the electric field between them produces, e.g., a corona discharge which ionizes the gas. It may be found suitable to provide a special electric arc or glow discharge device, such as a heated cathode or a so called electrode gun, in the discharge space. In the present instance it has been found satisfactory to include in said means a high voltage source, any further specific means for this purpose being, in fact, not necessary, it being understood that a powerful electric direct current producer, such as a rectifier, will have to deliver a voltage of from 10 kv. up to 200 kv. to produce an instantaneous discharge current of the order of 10^{5} amperes through a gas filling of deuterium, D_2, and/or tritium, T_2, rarefied to a pressure of 10^{-5} to 10^{-2} torr. The output of such a rectifier will thus serve the twofold purpose of ionizing the gas in the receptacle and delivering the subsequent heavy discharge current.

Said outer electrode means may be composed of at least one primary outer electrode and at least one secondary outer electrode, said secondary electrodes being electrically insulated from said primary electrodes and connected to exterior terminals separate therefrom.

The invention will now be more specifically described with reference to the accompanying drawings on which

FIG. 1 is a perspective view, partly in section, and

FIG. 2 a central horizontal section with associated circuit and pipe diagrams.

In the drawings a heavy soft iron yoke 1 is provided with a magnetizing winding 2 and heavy pole shoes 3 and 4, the pole shoe No. 3 of which may be a north pole and No. 4 a south pole, as indicated. In the gap between said pole shoes there is inserted a cylindrical airtight receptacle 5 of a non-magnetic substance, such as copper. The inner electrode means is provided in the form of a single electrode constituted by a hollow metal tube 6 with a vertical axis placed centrally in the receptacle. Its inner cavity 7 is included in an oil pipe circulation system described below. The outer electrode means comprises in this case a single primary outer electrode 8 being of a nearly annular form concentric to the electrode 6. Its inner operative surface is concave not only in a horizontal section but also in a vertical section as shown. Between an inner wall 9 and an outer wall 10 there is provided an oil jacket 11 included in the oil circulation system. This primary outer electrode does not encircle the inner electrode 6 completely but is interrupted at the points 12 and 72. In the interspace between said points there is provided a secondary outer electrode 13 substantially conforming to the electrode 8 but having a considerable less peripheral extension so that gaps are formed between its extremes 14 and 15 and the points 12 and 72 respectively. Also this electrode is provided with an oil jacket 16 included in the oil circulation system.

In this embodiment the second magnetizing means is constituted by two pairs of magnet coils 17, 18 and 19, 20 respectively, provided inside the receptacle 5 and covered by protecting boxes, such as indicated at 21, preferably of heat proof material. Each pair of magnetic coils is arranged in an axial arrangement and the coils are dimensioned for producing a considerable number of ampere-turns. The pair 17, 18 of the second magnetizing means is placed adjacent the second outer electrode 13 whereas the other pair 19, 20 of the additional magnetizing means are provided peripherally displaced in relation thereto, e.g., diametrically opposed as indicated on the drawings.

As seen from FIG. 2 the oil pipe circulation system includes a main supply pipe 22, a pump 23 and a further pipe main 24 from which a number of branches 25, 26 and 27 are tapped off. A number of outgoing pipes 28, 29 and 30 are united to a comon return pipe 31. This pipe is connected to the input side of an heat exchanger 32, the output side of which is connected to pipe main 22. Each pipe has an electrically insulating tube section, such as indicated at 33, and the continuation of the pipe forms then an electrically insulated pipe section which may be associated with the corresponding electrode, while passing through insulating bushings, such as 40 and 41, at the inner electrode 6 and bushings, such as 42, at the outer electrodes. Thus, the insulated pipe section 34 is in communication with the top of the oil cavity 7 of the electrode 6 and the insulated pipe section 35 with the bottom of said cavity. The insulated pipe section 36 is in communication with the oil jacket 16 of the electrode 13 at the one end thereof whereas the insulated pipe section 37 is associated with the opposite end thereof. The insulated pipe 38 communicates with the oil jacket of the electrode 8 at the one end thereof whereas the insulated pipe 39 communicates with the opposite end thereof.

The low temperature side of the heat exchanger may have an intake 43 and an outtake 44 for the gas or fluid to be heated by the oil.

The electric circuits of the system are as follows. The insulated pipe sections may conveniently serve as parts of the leads for connecting the electrodes to the outside of the receptacle. Thus, the pipe sections **34** and **35** are interconnected through a conductor **45** and, via the conductor **46**, connected to the positive terminal of the rectifier **47**. The pipes **38** and **39** associated with the main outer electrode **8**, are interconnected through the conductor **48** and, via the conductor **49**, connected to the negative side of the rectifier **47**. The rectifier may be fed with high tension alternating voltage via a transformer **50** from an alternator **51**.

The field coil **2** is fed from a direct current source diagrammatically indicated as a battery **52**. To this battery is connected a two pole double throw switch **53**. In its one position it connects the negative pole via the conductor **54** and the branch wire **55** to the coil **18** and the positive pole via a conductor **57** and the branch wire **58** to the opposite terminal of the coil **18**. At the same time the branch wires **56** and **59** connect the negative poles of the battery to the coil **17**. The intensity of the local magnetic field produced between the coils will then be of the order of 10,000 to 100,000 gauss.

It is evident that in a similar way the switch **53** in its opposite position will connect the two coils **19** and **20** into circuit via corresponding conductors indicated on the drawing. The switch **53** has a function to energize the two pairs of coils **19**, **20**, and **17**, **18**, respectively, in alternation.

An evacuation pipe **60** is connected to the interior of the receptacle **5** through an insulating bushing **61**. This pipe is connected to a valve **61** and an evacuation pump **62**.

The system operates substantially as follows. A gas filling of the receptacle **5** of deuterium, D_2, and/or tritium, T_2, is rarefied by means of the pump **62** to a pressure of 10^{-5} to 10^{-2} torr. The coil **2** is energized so that there will be a practically uniform magnetic field in the gap between the pole shoes **3** and **4** passing through the receptacle **5**. The intensity of this field should be in the order of 1,000 to 10,000 gauss. In the right hand position of the switch **53** the pair of coils **17** and **18** will produce a local additional magnetic field also in substantially the same axial direction through the annular space formed between the inner and outer electrodes. This local field should be considerably stronger than the uniform field and the magnetic induction thereof should be at least ten times that of the uniform field. This local field will, however, not be as uniform as the field between the shoes **3** and **4**, it being understood that the magnetic induction will be considerably higher close to the coils than in the central space between the coils. The pump **23** is put into operation whereby oil is forced to circulate through the cavities and jackets respectively of the electrodes **6**, **8** and **13** and through the heat exchanger **32**. Through the intake **43** and outtake **44** of the heat exchanger a fluid or liquid to be heated is caused to circulate in any conventional way.

The rectifier **47** is then put into operation and delivers a voltage from 10 kv. up to 200 kv. and the gas filling is thereby ionized and a violet discharge is started between the inner and outer electrodes causing the formation of a hot circulating plasma as indicated at **63**. The plasma will move perpendicular to the electric field between the electrodes **6** and **8** with a velocity of E/B in which E indicates the voltage and B the magnetic induction. The temperature of the plasma is very high and particularly that of its ions. This will be the case particularly if the degree of ionisation is high which is obtained by making the voltage between the inner and outer electrodes very high, such as from 20 kv. to 200 kv. Through the so called pinch effect the plasma is kept together as a rotating ring. When this plasma ring meets the local magnetic field between coils **17** and **18** having an intensity of from 10,000 to 100,000 gauss, its temperature will be increased very considerably and reach such high values that thermo-nuclear reactions take place. Thereby the entire plasma will be further heated.

The thermo-nuclear development of energy will heat the electrodes and this heat is withdrawn via the heat exchanger **32**.

If the switch **53** is switched over to its left hand position the pair of coils **19** and **20** will be energized and the coils **17** and **18** deenergized. This shifting of the coils is convenient because there will be an intense heating of them in view of the considerable energizing currents necessary to produce the high number of ampere turns. By switching over the energizing current from one coil pair to another the device may operate continuously. The number of pairs of coils may, of course, be more than two.

In order to obtain a maximum heating of the plasma it is necessary that this does not contain impurities of heavy elements. As the heavier ions are moving in larger trochoidal paths they will more easily reach the negative electrode which may be adapted to absorb and remove the impurities.

When the movement of the plasma is braked by the intense magnetic field from one of the coils **17**, **18** or **19**, **20**, respectively, the electric field will be intensified due to space charges caused by the inertia effect. The electrode **13** close to the local magnetic field between coils **17** and **18** will then be charged to a higher negative voltage than the main electrode **8** surrounding the weaker uniform field. This renders it possible to take out electric energy at a higher voltage between the terminal **64** and the conductor **46** than between the conductors **49** and **46**, the terminal **64** being connected via conductors **65** and **66** and pipes **36** and **37** to the electrode **13**.

For similar reasons it may be found of advantage to provide more than one local electrode **13**, as indicated at **67** with dashed and dotted lines in which case there will be two main electrodes **68** and **69** separated therefrom by gaps **70** and **71**. The necessary oil pipes will then have to be attached according to the same principle as that laid down in connection with the embodiment of FIG. 2 shown in full lines.

What is claimed is:

1. An apparatus for producing gaseous plasma with extremely high temperature and comprising a receptacle, the interior of which is isolated from the atmosphere, outer and inner electrode means insulated for high voltage and dimensioned for heavy currents and arranged in said receptacle, said outer electrode means surrounding said inner electrode means and being excited to a voltage opposite to that of said inner electrode means and providing between said outer and inner electrode means an annular discharge space, first magnetizing means for producing a substantially uniform magnetic field in an axial direction through said annular space, second magnetizing means for producing at least one local additional magnetic field in said annular space along an axis traversing said uniform magnetic field, said local magnetic field being of a several times higher intensity than said uniform field, evacuation means for rarefying gas included in said receptacle and ionisation means for initiating a discharge through said annular space.

2. The apparatus of claim 1 in which said ionisation means include a high voltage source connected across said outer and inner electrode means.

3. The apparatus of claim 1 in which said outer electrode means is composed of at least one primary outer electrode and at least one secondary outer electrode, said secondary electrodes being electrically insulated from said primary electrodes and connected to exterior terminals separate therefrom.

4. The apparatus of claim 1 in which at least two second magnetizing means are provided for producing at least two local additional magnetic fields peripherally

spaced in the annular discharge space, and switch means are provided to energize said coils sequentially.

5. The apparatus of claim 3 in which said secondary outer electrode is provided adjacent to one of said second magnetizing means.

6. The apparatus of claim 1 in which said second magnetizing means are of a sufficient strength to produce a local additional magnetic field of an intensity at least ten times that of said substantially uniform field.

7. The apparatus of claim 1 in which said electrodes means are provided with cooling means for withdrawing heat energy from the electrodes.

8. The apparatus of claim 1 in which said second magnetizing means is accentrically disposed relative to said first magnetizing means.

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