Feb. 1, 1955 | T. M. DICKINSON | 2,701,304

CYCLOTRON

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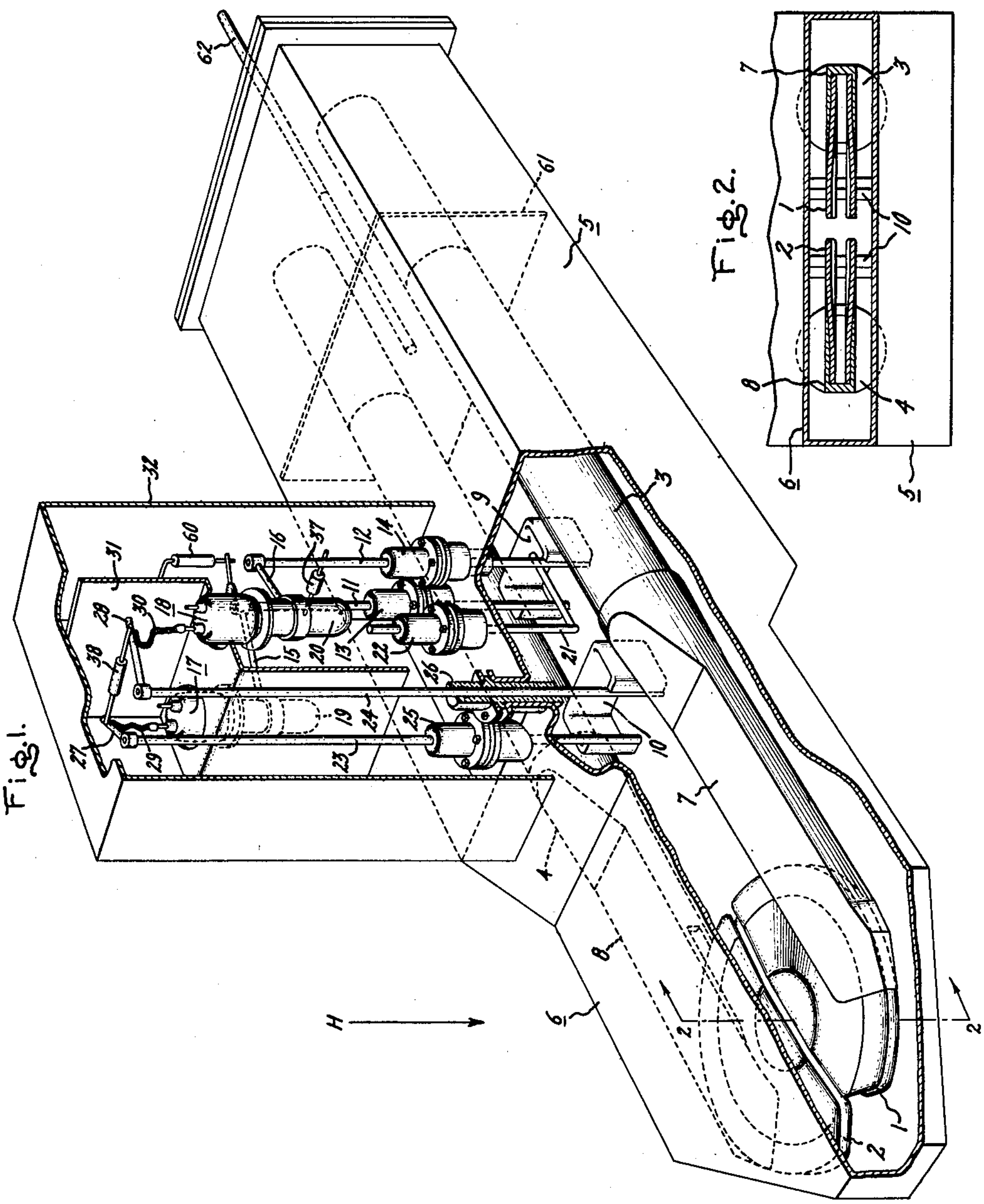

Fig. 1.

Fig. 2.

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Fig. 3.

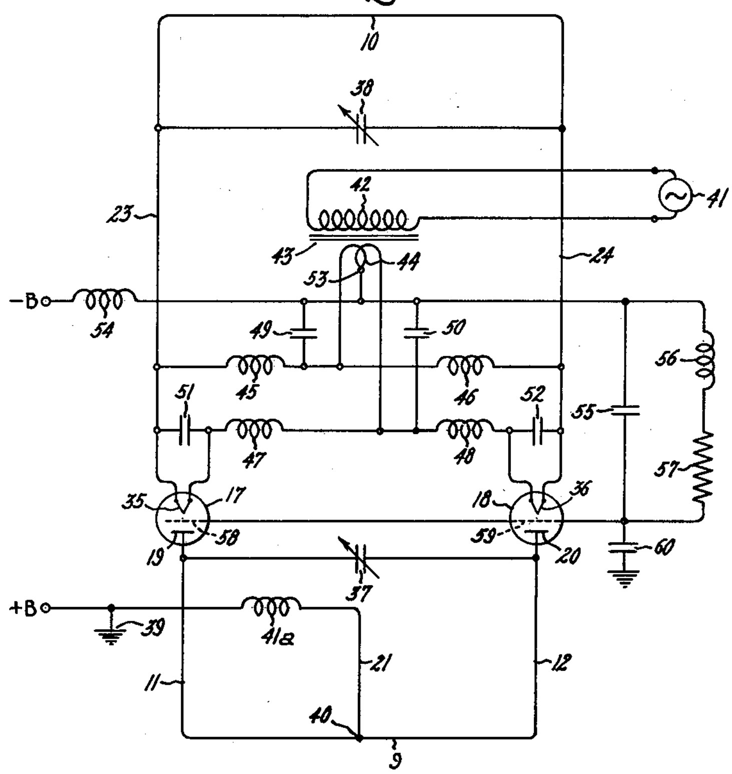


Fig. 4.

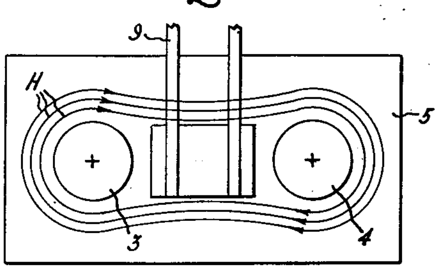
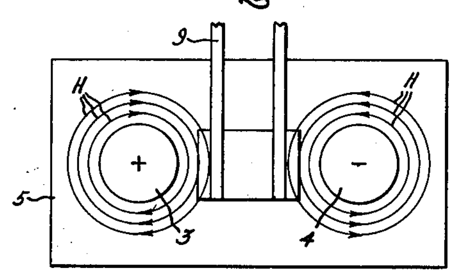


Fig. 5.



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CYCLOTRON

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Application May 31, 1951, Serial No. 229,077

5 Claims. (Cl. 250—27)

This invention relates generally to cyclotron apparatus for accelerating charged particles in spiral paths, and particularly to means for energizing such apparatus.

In cyclotron apparatus, ions are accelerated to high energy levels in spiral paths by the combined action of a cyclically reversible electric field and a unidirectional magnetic field. One of the most familiar forms of this apparatus comprises a pair of opposed hollow, D-shaped electrodes, called dees, enclosed by an evacuable tank and energized by a suitable source of oscillatory power. Ions formed in the central space between the dee electrodes are accelerated intermittently by the reversible electric field appearing between the dee electrodes, while they are simultaneously constrained to outwardly spiraling paths by the unidirectional magnetic field which is oriented to be essentially normal to the plane of extension of the dee electrodes.

One of the primary problems encountered in the construction of cyclotron apparatus has been that of obtaining suitable means for energizing the dee electrodes. In order to secure the required high voltage and frequency stability, the dee electrodes are usually supported at the ends of transmission lines, whereby the lines with the dee electrodes connected thereto serve as a high Q tank circuit for an electron discharge tube oscillator. While this expedient has provided adequate high voltage and frequency stability, the coupling of the oscillator to the transmission lines has caused considerable difficulty, since the transmission lines have a tendency to oscillate in such a mode that no electric field appears between the dee electrodes. Therefore, it is a principal object of the present invention to provide improved means for energizing the dee electrodes in cyclotron apparatus.

According to one aspect of the invention, more fully described and delineated hereinafter, there is provided cyclotron apparatus having a pair of dee electrodes connected to a parallel wire transmission line. The dee electrodes are energized by an electron discharge tube oscillator which is inductively coupled to the transmission line in such manner as to assure the production of the desired electric field between the dee electrodes.

The aspects of my invention which I desire to protect herein are pointed out with particularity in the appended claims. The invention itself, together with further objects and advantages thereof, may best be understood by reference to the following description, taken in connection with the accompanying drawings, in which Fig. 1 is a schematic, partially broken away, perspective view of cyclotron apparatus suitably embodying the invention; Fig. 2 is a fragmentary sectional view taken along line 2—2 of Fig. 1; Fig. 3 is a circuit diagram illustrating preferred connections for the energization of the apparatus of Fig. 1; and Figs. 4, 5 are diagrammatic representations useful in explaining the invention. To facilitate the description of the invention, like numerals will be employed to identify similar elements in the various figures of the drawings.

Referring now to Figs. 1 and 2, there is shown cyclotron apparatus which comprises opposed, hollow, dee electrodes **1** and **2**, suitably supported at the ends of hollow transmission lines **3** and **4**, within an evacuable, hollow tank **5**. Portion **6** of tank **5** and portions **7**, **8** of transmission lines **3**, **4**, respectively, are reduced in the height dimension in order to facilitate the insertion of this section of the apparatus between the pole pieces of an electromagnet, not shown, whereby a magnetic field having a direction as indicated by the arrow H, essentially normal to the plane of extension of dee electrodes **1** and **2**, may be provided. According to well known principles of cyclotron operation, if the dee electrodes are energized such that a cyclically reversible electric field appears therebetween and if ions are generated in the central space within the dee electrodes, the ions will be repetitively accelerated in outwardly spiraling paths as they traverse the space between dee electrodes **1** and **2**. In such fashion, ions may be accelerated to high energy levels and utilized for various purposes well known to those skilled in the art. A more detailed description of the principle of operation of cyclotron apparatus may be found in U. S. Patent 1,948,384—E. O. Lawrence, dated February 20, 1934, or in the monograph entitled "The Cyclotron" by W. B. Mann, published by Methuen & Company, Ltd., London, England.

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In order to energize dee electrodes **1** and **2** according to the invention to produce the desired cyclically reversible electric field therebetween, an electron discharge tube oscillator is coupled to transmission lines **3** and **4** by means of an anode loop **9** and a cathode feedback loop **10**. Anode loop **9** is adjustably supported between transmission lines **3** and **4** by means of conductive rods **11** and **12**, which are slidably inserted through hermetic sealing insulators **13** and **14**. At the upper ends of rods **11** and **12** respectively are attached clamp members **15** and **16**, which serve as electrical connections for the anodes **19** and **20** of electron discharge devices **17** and **18** respectively. For a purpose that will be more fully described hereinafter, a center tap is provided for anode loop **9** by means of right-angle conductive rod **21**, which is introduced to tank **5** in slidable hermetic relationship by means of an insulator **22**. Cathode loop **10** is supported in a manner similar to anode loop **9** by means of conductive rods **23**, **24** and insulators **25**, **26**. Affixed to the upper ends of conductive rods **23**, **24** respectively are rods **27** and **28**, the former of which is connected through a flexible lead **29** to one side of the filament of discharge tube **17** and the latter of which is connected through a flexible lead **30** to one side of the filament of discharge tube **18**. In order to decrease the likelihood of undesired oscillations during operation of the apparatus, an electrostatic shield **31** is provided as shown; and the discharge tube oscillator is surrounded by a shield **32** to prevent the generated oscillations from radiating and disturbing nearby equipment.

A better understanding of the electrical interconnections of the electronic oscillator of the invention may be had by reference to the circuit diagram of Fig. 3. As has been mentioned heretofore, anode loop **9** is connected at one end to the plate electrode **19** of discharge tube **17** and at the other end to the plate electrode **20** of discharge tube **18**; while cathode loop **10** is connected at one end to one side of the filament **35** of discharge tube **17** and at the other end to one side of the filament **36** of discharge tube **18**. Anode loop **9** and cathode loop **10** are respectively shunted by variable tuning capacitors **37** and **38**; and the positive terminal of the B voltage supply, which is connected to ground as indicated conventionally at **39**, is introduced into the oscillator circuit at the approximate mid-point **40** of anode loop **9** through an isolating high frequency choke **41***a*. Alternating heating current is supplied to filaments **35** and **36** from a source of alternating current **41** connected to the primary winding **42** of a filament transformer **43**. Current induced in secondary winding **44** of filament transformer **43** is directed to filaments **35** and **36** through a network including high frequency choke coils **45**, **46**, **47**, **48**, and bypass capacitors **49**, **50**, **51**, **52**. The center tap **53** of secondary winding **44** is connected through a high frequency choke **54** to the minus terminal of the B voltage supply and also through a parallel network, including a capacitor **55**, a high frequency choke coil **56**, and a resistor **57**, to the grids **58** and **59** of discharge tubes **17** and **18** respectively. Grids **58** and **59** are maintained at high frequency ground potential by means of a capacitor **60** connected as shown.

As will now be understood by those skilled in the art, the above described circuit of Fig. 3, when considered in conjunction with the transmission lines **3** and **4** having the dee electrodes **1** and **2** connected thereacross, will operate to generate sustained oscillations within the tank circuit formed by transmission lines **3**, **4**, and dee electrodes **1**, **2**. Tuning bar **61**, which may be electrically connected through sliding contacts, not shown, to transmission lines **3** and **4** and the inside conducting surface of tank **5** as represented schematically in Fig. 1, may be adjusted through an operating rod **62** such that a desired condition of resonance obtains at the operating frequency of the cyclotron apparatus, whereby transmission lines **3** and **4** may be considered as a shielded parallel wire transmission line having effectively a foreshortened quarter wavelength. Tuning capacitors **37** and **38** may be employed to adjust the relative phases of voltages induced in anode loop **9** and cathode loop **10**. By varying the height of anode loop **9** in conjunction with the adjustment of tuning capacitor **37**, the anode loop may be tuned for an impedance match to the load impedance reflected thereinto; and by varying the height of cathode loop **10** in conjunction with the adjustment of tuning capacitor **38**, the cathode loop may be tuned for the proper amplitude of feedback voltage to sustain tank circuit oscillation.

It will be realized from the foregoing that, in order to obtain the desired cyclically reversible electric field between dee electrodes **1** and **2**, oscillations must occur whereby transmission lines **3** and **4** oscillate in the opposite phase, i. e., electron discharge devices **17** and **18** must operate in push-pull to produce coincident, relatively opposite polarities of transmission lines **3** and **4**. The diagrammatic illustrations of Figs. 4 and 5 show that, with the arrangement of anode loop **9** and cathode loop **10** relative to transmission lines **3** and **4** according to the invention as hereinbefore described, oscillations can occur only in the desired mode with transmission lines **3** and **4** having opposite phases. If, for example, transmission lines **3** and **4** tend to oscillate in phase, the currents in both transmission lines travel in the same direction as is indicated in Fig. 4. In this instance, the magnetic field lines encircle both transmission lines **3** and **4** somewhat as represented by the lines labeled H in Fig. 4, whereby there is no changing magnetic field linking anode loop **9** or cathode loop **10** (not shown), and power can neither be transferred to transmission lines **3**, **4** from anode loop **9** nor can power be removed for grid-cathode excitation by cathode loop **10**. Consequently, when transmission lines **3** and **4** tend to oscillate in phase, oscillations cannot persist. However, when transmission lines **3** and **4** oscillate in the out-of-phase mode, the magnetic field lines will appear somewhat as represented by the lines labeled H in Fig. 5. In this situation, the magnetic field encircling transmission line **3** has a clockwise direction, while that encircling transmission line **4** has a counterclockwise direction, whereby the two fields are additive in between the lines. Therefore, the magnetic field lines link both anode loop **9** and cathode loop **10**, and oscillations will be built up as desired. Moreover, by placing both loops **9** and **10** in essentially the same plane as shown in Fig. 1, tendency for oscillation to occur by virtue of magnetic coupling between them is eliminated, and oscillation can only occur by virtue of coupling through the resonant line and dee system.

It will be understood by those skilled in the art that the invention may be modified substantially without departing from the spirit of the invention. For example, instead of maintaining grids **58** and **59** at a high frequency ground potential, filaments **35** and **36** may be maintained at substantially high frequency ground potential. With such a circuit modification, a grid feedback loop would be substituted for the cathode feedback loop of the circuit of Fig. 3 and the orientation would be such that open ends of the anode and grid loops are adjacent each other. However, the grounded grid circuit of Fig. 3 is preferred because difficult neutralization of undesired oscillations is necessary in the grounded cathode circuit. As another exemplary modification, a hermetically sealed partition may be utilized within tank **5** to seal off the dee electrodes from the remainder of tank interior in order to reduce the volume requiring evacuation.

What I claim as new and desire to secure by Letters Patent in the United States is:

1. Cyclotron apparatus comprising a pair of dee electrodes between which a cyclically reversible electric field may be developed for accelerating charged particles in spiral paths, means for energizing the dee electrodes comprising a parallel wire transmission line connected to said dee electrodes, and an electron discharge tube oscillator inductively coupled to said parallel wire transmission line, said transmission line with said dee electrodes connected thereto being a foreshortened quarter wavelength at the operating frequency of said oscillator, said inductive coupling of said oscillator including an anode loop and a feedback loop both extending in planes essentially parallel to the plane of extension of said transmission line and positioned intermediate said parallel wire transmission lines.

2. Cyclotron apparatus comprising a pair of dee electrodes between which a cyclically reversible electric field may be developed for accelerating charged particles in spiral paths, means for energizing the dee electrodes comprising a shielded parallel wire transmission line connected to said dee electrodes, and an electron discharge tube oscillator inductively coupled to said parallel wire transmission line, said transmission line with said dee electrodes connected thereto being a foreshortened quarter wavelength at the operating frequency of said oscillator, said inductive coupling of said oscillator including an anode loop and a feedback loop both extending in planes essentially parallel to the plane of extension of said transmission line and positioned intermediate said parallel wire transmission lines.

3. Apparatus as in claim 1 in which said feedback loop comprises a cathode loop, said anode and cathode loops being positioned with the open end of one of the loops adjacent the closed end of the other of the loops.

4. Cyclotron apparatus for accelerating charged particles comprising a pair of dee electrodes, an electron discharge tube oscillator for energizing said dee electrodes, a pair of hollow conductors each of which is connected at one end to one of said pair of dee electrodes, said conductors and said dee electrodes being enclosed by an evacuable tank of conductive material, said pair of conductors with said dee electrodes connected thereto being a foreshortened quarter wave-length at the operating frequency of said oscillator and means hermetically introduced into said tank for coupling said oscillator to said hollow conductors including an anode loop and a feedback loop both extending in planes essentially parallel to a plane including the longitudinal axes of said conductors and positioned intermediate said pair of hollow conductors.

5. Cyclotron apparatus for accelerating charged particles comprising a pair of dee electrodes, a push-pull electron discharge tube oscillator for energizing said dee electrodes, a pair of hollow conductors each of which is connected at one end to one of said pair of dee electrodes, said conductors and said dee electrodes being enclosed by an evacuable tank of conductive material, means coupled to said conductors for tuning said conductors and said dee electrodes to a foreshortened quarter wave-length at the operating frequency of said oscillator and means for coupling said oscillator to said conductors including an anode loop and a feedback loop both extending in planes essentially parallel to a plane including the longitudinal axes of said conductors and positioned intermediate said pair of hollow conductors.

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