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[21] Appl. No. **740,243**
[22] Filed **June 26, 1968**
[45] Patented **Feb. 2, 1971**

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June, 1965; 250-41.9(2)

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[54] **QUADRUPOLE MASS FILTER WITH FRINGING-FIELD PENETRATING STRUCTURE**
13 Claims, 3 Drawing Figs.

[52] U.S. Cl..... **250/41.9,**
313/83

[51] Int. Cl..... **H01J 39/34**

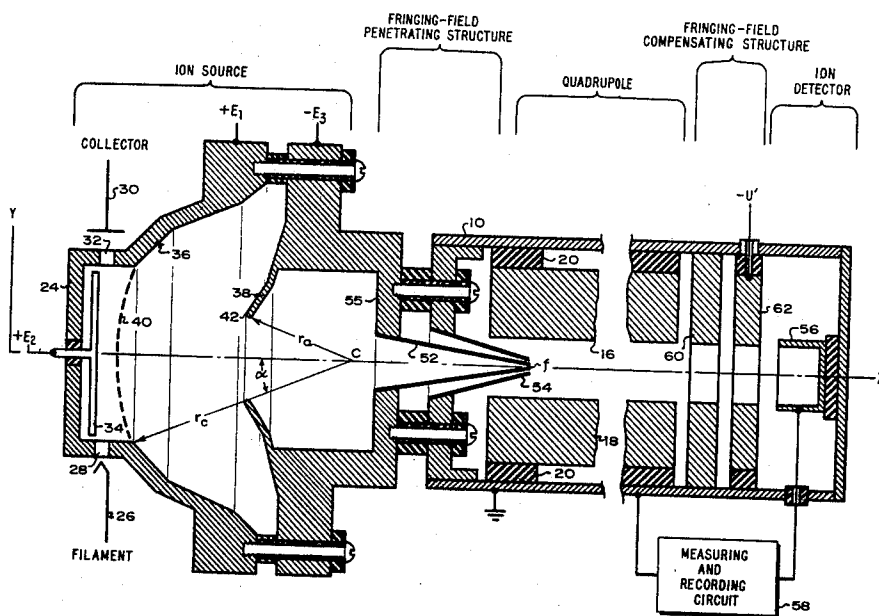
[50] Field of Search..... 250/41.9(2),
41.9ISB; 313/83, 85; 330/4.7, 4.5

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ABSTRACT: An ion source positioned near the entrance of a quadrupole mass filter focuses a beam of positive ions at a point inside the quadrupole where the defocusing effect of the fringing field is substantially reduced. This beam of ions passes into the quadrupole through two concentric conical electrodes operated at different potentials and positioned with their larger ends outside the quadrupole near the ion source and their smaller ends inside the quadrupole near the focal point of the ion beam. An ion detector positioned near the exit of the quadrupole receives ions transmitted by the quadrupole. These ions pass through two concentric cylindrical electrodes operated at different potentials and positioned between the exit of the quadrupole and the ion detector.



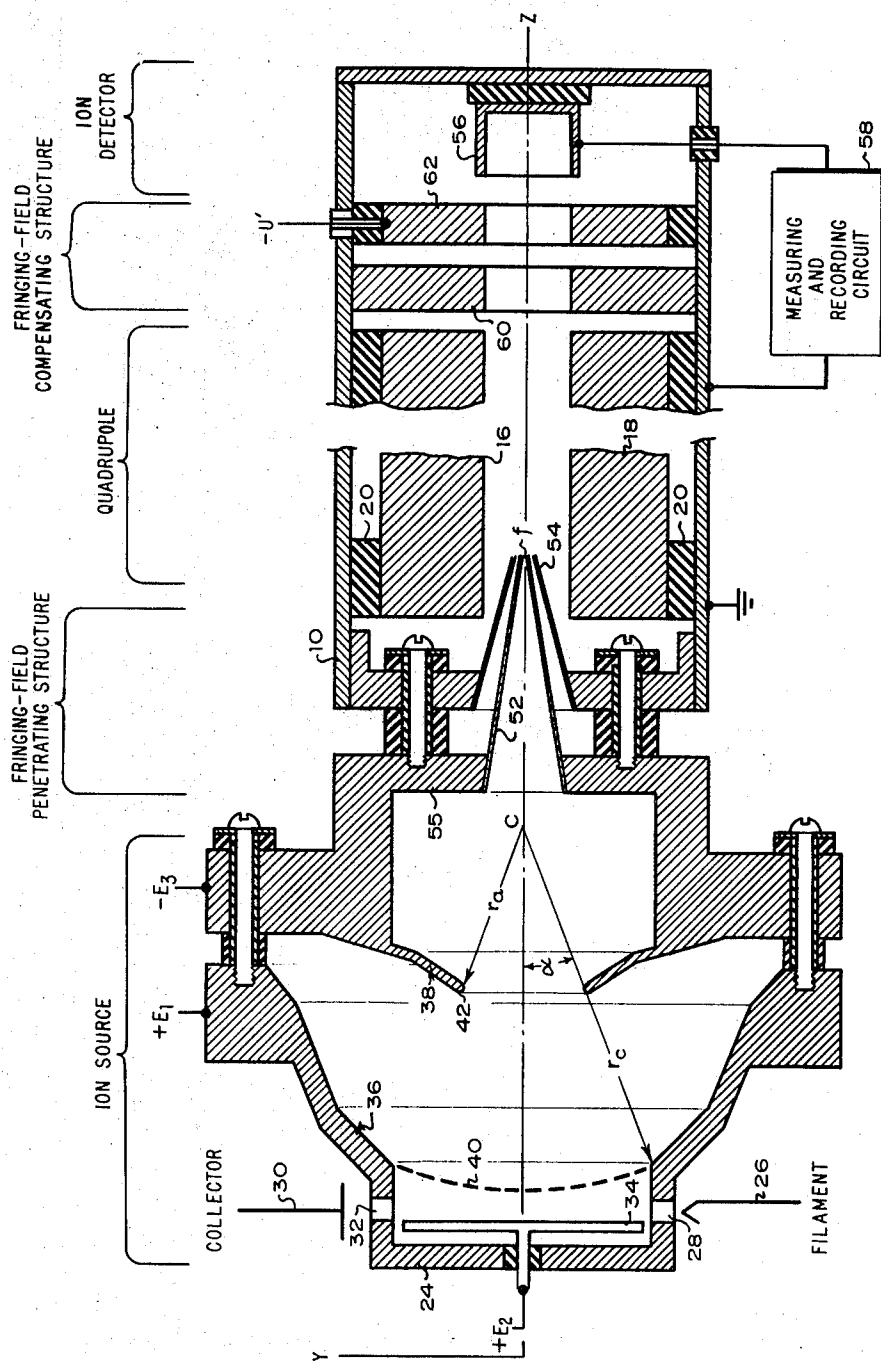


Figure 1

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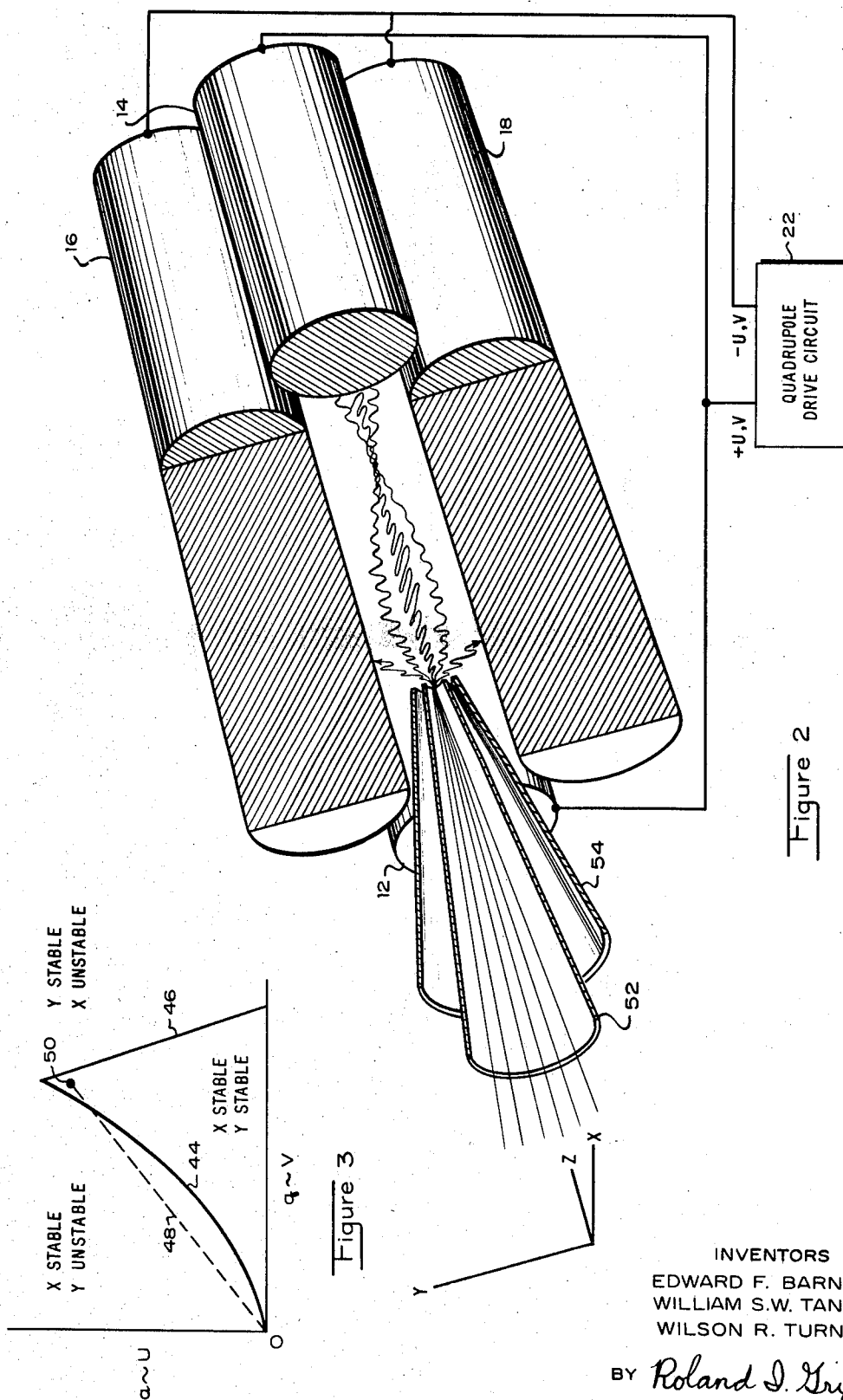


Figure 2

Figure 3

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QUADRUPOLE MASS FILTER WITH FRINGING-FIELD PENETRATING STRUCTURE

BACKGROUND AND SUMMARY OF THE INVENTION

This invention relates to quadrupole mass spectrometers and, more particularly, to the entrance construction of quadrupole mass filters used therein.

The fringing fields near the entrance of a quadrupole mass filter have a serious defocusing effect upon ions approaching and entering the quadrupole. This defocusing effect reduces the ion transmission efficiency and hence the sensitivity of the quadrupole. Accordingly, it is the principal object of this invention to provide a fringing-field penetrating structure for increasing the ion transmission efficiency and hence the sensitivity of the quadrupole.

This object is accomplished in accordance with the illustrated embodiment of this invention by concentrically mounting two conical electrically-conductive tubes about the central axis of the quadrupole with their larger ends lying outside the quadrupole adjacent to an ion source and with their smaller ends lying inside the quadrupole in a region where the defocusing effect of the fringing fields is substantially reduced. The inner tube is operated at a negative DC voltage with respect to quadrupole ground, which is hereinafter defined for purposes of this specification and the claims appended hereto as the mean potential of the primary electrodes. This produces an equipotential region inside the inner tube through which ions from the ion source drift with a higher velocity than they have further inside the quadrupole. The inner tube therefore serves two purposes. First, it injects ions from the ion source into the quadrupole at a point where the defocusing effect of the quadrupolar fringing fields is substantially reduced. Secondly, it shields the ions from the defocusing effects of the quadrupolar fringing fields until they reach the point of injection. The outer tube is operated at quadrupole ground and also serves two purposes. First, it terminates the quadrupolar fields in a desirable manner at the point of ion injection. Secondly, it shields the quadrupole from the perturbing effect of the high negative voltage on the inner tube.

DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic sectional view of a quadrupole mass spectrometer constructed in accordance with the preferred embodiment of this invention.

FIG. 2 is a fragmentary perspective view of the fringing-field penetrating structure at the entrance of the quadrupole mass filter.

FIG. 3 is a stability diagram illustrating the operating characteristics of a quadrupole mass filter.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIGS. 1 and 2, there is shown a quadrupole mass spectrometer including a cylindrical electrically-conductive housing 10 operated at quadrupole ground and having four primary electrodes 12, 14, 16 and 18 mounted therein on electrically insulating supports 20. Housing 10 is positioned within an evacuated enclosure when the quadrupole mass spectrometer is to be employed in the laboratory. However, this evacuated enclosure is unnecessary when the quadrupole mass spectrometer is to be employed for upper atmospheric research in the vacuum of space. Primary electrodes 12, 14, 16 and 18 comprise coextensive, electrically-conductive, cylindrical rods extending parallel to one another and symmetrically disposed about a central axis Z. Diametrically opposed rods 12 and 14 have their centers in the X-Z plane and are hereinafter referred to as the X-rods, whereas diametrically opposed rods 16 and 18 have their centers in the Y-Z plane and are hereinafter referred to as the Y-rods. As shown in FIG. 2, X-rods 12 and 14 are electrically connected together and Y-rods 16 and 18 are electrically connected together. An excitation voltage comprising both a balanced AC component V and a balanced DC component $\pm U$ is applied between the X-rods and the Y-rods by a drive circuit 22,

all voltages being referred to quadrupole ground. This creates a quadrupole electric field having both AC and DC components between the X-rods and the Y-rods. The positive DC excitation voltage component +U is applied to the X-rods, and the negative DC excitation voltage component -U is applied to the Y-rods.

An ion source is mounted at one end of housing 10 and is symmetrically disposed about the central axis Z. The ion source may comprise, for example, an ionization chamber 24 operated at a positive voltage E_1 of about 5 volts. A filament 26 is mounted adjacent to an aperture 28 in one side of the ionization chamber, and a collector 30 is mounted adjacent to an aperture 32 in the opposite side of the ionization chamber. Positive ions are produced by operating the filament and the collector to provide an electron flow of about 10 milliamperes through a gas sample injected into the ionization chamber by means of a sample inlet (not shown) in one side thereof. A beam of these ions is forced out of the ionization chamber by a pusher electrode 34 operated at a positive voltage E_2 of about 5½ volts.

The ion source further comprises an ion gun having a first electrode 36 operated at the positive voltage E_1 and a second electrode 38 operated at a negative voltage $-E_3$ of about 700 volts. First electrode 36 includes a spherical mesh 40 of radius r_c . This spherical mesh protrudes into the ionization chamber and intersects an imaginary conical surface of revolution generated by rotating a line that intersects the central axis Z at the center of curvature C of mesh 40 about the central axis Z at an angle α of about 20° or less. A circular aperture 42 in second electrode 38 intersects this imaginary conical surface of revolution at a distance r_a of about one-half r_c from the center of curvature C. Electrodes 36 and 38 are shaped to obtain a radial potential distribution between their inner field-forming surfaces. This may be accomplished while providing the electrodes 36 and 38 with a convenient size and shape by the conventional electrolytic tank method. The ion beam forced out of the ionization chamber is focused by the ion gun at a point f on the central axis Z inside the quadrupole where the defocusing effect of the fringing fields is substantially reduced. Focal point f lies on the central axis Z a distance Δ behind the center of curvature C. This distance Δ may be determined with the aid of the graph of FIG. 15.35 on page 461 of Karl R. Spangenberg's book entitled "Vacuum Tubes" and published by McGraw-Hill Book Company, Inc., 1948. For example, Δ equals 1½ inches where the ratio r_c/r_a equals 2.

The defocusing action of the quadrupolar fringing fields upon the beam of positive ions from the ion source can be explained with reference to the stability diagram of FIG. 3, where the abscissa q is proportional to the AC excitation voltage component V and the ordinate α is proportional to the DC excitation voltage component U. In this diagram, the triangularly-shaped region defined by solid lines 44 and 46 represents stable ion motion in both the X and the Y directions. The region to the left of solid line 44 represents unstable ion motion in the Y direction, and the region to the right of solid line 46 represents unstable ion motion in the X direction. If the ratio of the DC excitation voltage component U to the AC excitation voltage component V is held constant, the locus of the operating point of an ion passing through the quadrupole fringing fields is the dashed straight line 48. The ratio of U to V is adjusted so that this line passes just below the apex of the triangularly-shaped region of stability to maximize the resolution of the quadrupole mass filter. Along dashed line 48 the ion motion is stable everywhere in the X direction and is unstable in the Y direction until nearly the final operating point 50 is reached. This instability in the Y direction reduces the ion transmission efficiency and hence the sensitivity of the quadrupole mass filter.

A fringing-field penetrating structure is provided for injecting the ion beam from the ion source through the fringing fields near the entrance of the quadrupole with a substantially improved efficiency. This structure comprises two concentric,

conical, electrically-conductive tubes 52 and 54, symmetrically disposed about the central axis Z with their larger ends lying outside the quadrupole adjacent to the ion source and with their smaller ends lying inside the quadrupole in a plane containing the focal point f of the ion beam. Inner tube 52 is supported by an annular flange 55 of electrode 38 and is operated at the same negative voltage $-E_3$ as electrode 38. Thus, the ion beam from the ion source is shielded from the fringing fields near the entrance of the quadrupole until it reaches a region inside the quadrupole and close to the central axis Z where the defocusing effect of the fringing fields is substantially reduced. Ions leaving the inner tube have a greater axial velocity than they have further inside the quadrupole. This minimizes their exposure to the fringing fields inside the quadrupole and to the higher order perturbations of the quadrupolar fringing fields produced by the high negative potential on the inner tube.

Outer tube 54 is insulatingly supported out of contact with inner tube 52 and is operated at quadrupole ground. This shields the quadrupole from the inner tube and thereby minimizes the perturbing effect of the inner tube upon the fields inside the quadrupole. The above-described fringing-field penetrating structure may improve the ion transmission efficiency and hence the sensitivity of the quadrupole mass filter by as much as one or two orders of magnitude. For greatest effectiveness the ion source and the conical tubes 52 and 54 should be designed to inject an ion beam of the highest possible density through the fringing fields to the furthest possible point on the central axis Z inside the quadrupole that can be reached without degrading the resolution of the quadrupole.

An ion detector 56, such as a conventional electron multiplier or Faraday cup is mounted at the other end of housing 10 and is symmetrically disposed about the central axis Z. Positive ions entering and traversing the quadrupole impinge upon ion detector 56 and thereby produce an electrical current that may be measured by a conventional measuring and recording circuit 58. The DC excitation voltage component $-U$ applied to the Y-rods also has a defocusing effect in the Y-Z plane upon the positive ions approaching and leaving the exit of the quadrupole. A fringing-field compensating structure similar to that described in a copending patent application entitled QUADRUPOLE MASS FILTER WITH ELECTRODE STRUCTURE FOR FRINGING-FIELD COMPENSATION and filed on or about June 19, 1968 by Edward F. Barnett, Donald L. Hammond and William S.W. Tandler may be disposed along the central axis between the exit of the quadrupole and the detector 56 to compensate for this defocusing effect and thereby further increase the ion transmission efficiency and hence the sensitivity of the quadrupole mass spectrometer. This structure comprises a pair of cylindrical electrodes 60 and 62. The electrode 60 nearest the exit of the quadrupole is operated at quadrupole ground, and the electrode 62 nearest the ion detector is operated at a negative DC voltage $-U'$ referred to quadrupole ground and maintained directly proportional to the DC excitation voltage component U applied to the quadrupole.

We claim:

1. A multipole mass filter comprising:

- a plurality of substantially parallel primary electrodes spaced symmetrically about a central axis and provided with terminal means for receiving an excitation voltage including AC and DC components balanced with respect to a reference potential to produce alternating and static multipole electric field components in the central region between the primary electrodes; and
- a tubular electrode disposed about the central axis adjacent to one end of the primary electrodes, said tubular elec-

trode being positioned with one end lying outside the central region between the primary electrodes and with the other end lying inside the central region between the primary electrodes.

2. A multipole mass filter as in claim 1 including another tubular electrode at least partially enclosing the first-mentioned tubular electrode, said tubular electrodes being conically shaped and concentrically mounted about the central axis for operating at different potentials with their larger openings lying outside the central region between the primary electrodes and with their smaller openings lying inside the central region between the primary electrodes.

3. A multipole mass filter as in claim 2 including means positioned near the larger opening of the inner conical tubular electrode for focusing a beam of ions at a region along the central axis near the smaller opening of the inner conical tubular electrode.

4. A quadrupole mass filter as in claim 3 wherein said last-mentioned means comprises an ion source for focusing the ion beam at a point on the central axis inside the quadrupole where the defocusing effect of the multipole electric field components is substantially reduced.

5. A quadrupole mass filter as in claim 4 wherein the smaller openings of the inner and outer conical tubular electrodes lie in a plane normally intersecting the central axis substantially at the focal point of the ion beam from the ion source.

6. A quadrupole mass filter as in claim 5 wherein the inner conical tubular electrode is operated at a potential of greater magnitude than both the outer conical tubular electrode and the ion source and of a sign for accelerating ions to a higher axial velocity within the inner conical tubular electrode than they have further inside the quadrupole.

7. A quadrupole mass filter as in claim 1 wherein said tubular electrode is conically shaped and concentrically mounted about the central axis with its larger opening lying outside the central region between the primary electrodes and with its smaller opening lying inside the central region between the primary electrodes.

8. A multipole mass filter as in claim 1 including an ion source positioned adjacent to said one end of the tubular electrode for focusing a beam of ions at a region along the central axis adjacent to said other end of the tubular electrode.

9. A multipole mass filter as in claim 1 including another tubular electrode disposed adjacent to said first-mentioned tubular electrode, said tubular electrodes being concentrically mounted about the central axis for operating at different potentials.

10. A multipole mass filter as in claim 9 wherein one of said tubular electrodes is operated at said reference potential and the other of said tubular electrodes is operated at a negative potential referred to said reference potential.

11. A multipole mass filter as in claim 10 wherein said last-mentioned tubular electrode at least partially encloses said first-mentioned tubular electrode.

12. A quadrupole mass filter as in claim 10 including:

- an ion source positioned adjacent to said one end of said first-mentioned tubular electrode for focusing a beam of ions at a region along the central axis adjacent to said other end of the first-mentioned tubular electrode; and
- an ion detector disposed along the central axis adjacent to the other end of the primary electrodes.

13. A quadrupole mass filter as in claim 12 wherein said tubular electrodes are concentrically disposed about the central axis adjacent to said one end of the primary electrodes, each of said tubular electrodes being positioned with one end lying outside the central region between the primary electrodes and with the other end lying inside the central region between the primary electrodes.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,560,734 Dated February 2, 1971

Inventor(s) Edward F. Barnett, William S.W. Tandler & Wilson
Turne

It is certified that error appears in the above-identified patent
and that said Letters Patent are hereby corrected as shown below:

Column 2, line 52, cancel " α " and insert -- a --.

Signed and sealed this 19th day of October 1971

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Acting Commissioner of Pat