Nov. 21, 1950 R. G. E. HUTTER 2,531,050

ION TRAP

Filed Nov. 30, 1946

FIG. 1

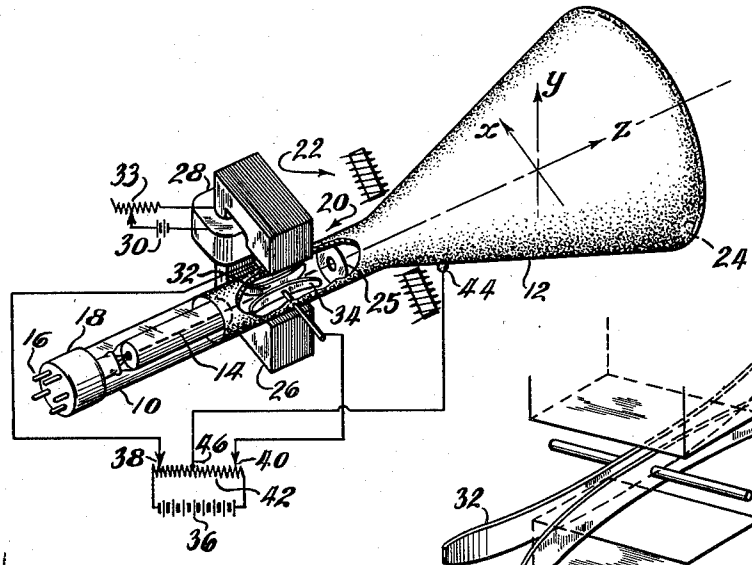


FIG. 5

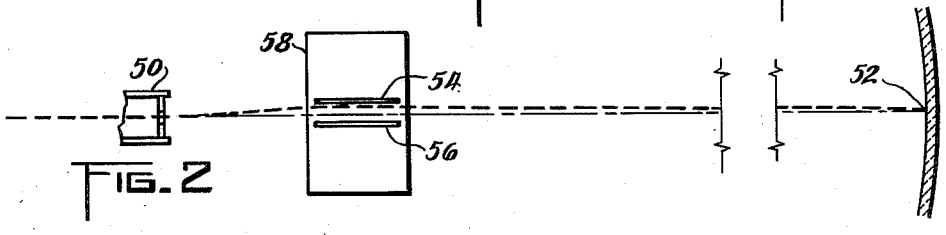


FIG. 2

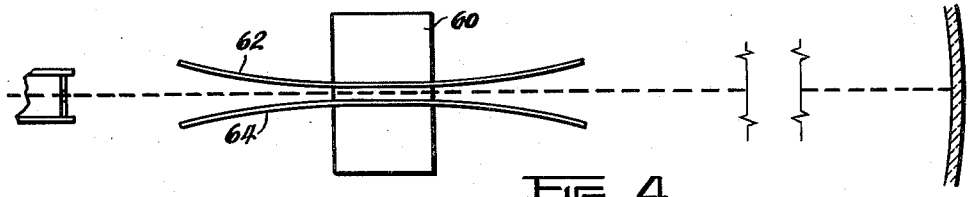


FIG. 4

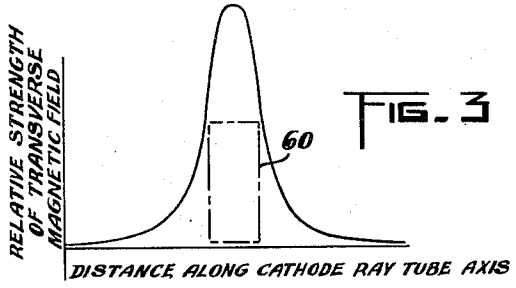


FIG. 3

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Patented Nov. 21, 1950 2,531,050

UNITED STATES PATENT OFFICE

2,531,050

ION TRAP

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Application November 30, 1946, Serial No. 713,243

9 Claims. (Cl. 250—158)

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This invention relates to apparatus which in its operation produces a beam of charged particles; and more particularly to the separation of a desired type of particles from undesired types. The invention is conceived as having primary application to ion traps in cathode-ray devices and also to mass spectrometers.

Various forms of ion traps have been devised to prevent the formation of an "ion spot" in the target or fluorescent screen of cathode-ray tubes of the magnetic deflection type. These traps separate the ions from the electrons before the beam enters the deflection zone by subjecting the combined ion and electron beam to a relatively strong magnetic field. The ions are not appreciably deflected, but the electron beam is bent through a relatively wide angle. The neck of the cathode-ray tube, according to one prior art arrangement, is bent so that the deflected electron beam passes along the bent "axis" of the tube after being separated from the combined ion and electron beam. This arrangement is disclosed in the U. S. Patents 2,211,613 and 2,211,614 issued on August 13, 1940, to R. M. Bowie. Alternatively, the electron stream can be maintained nearly in its original course despite the magnetic field by means of an electrostatic deflection field, acting in the zone of the magnetic field, which affects both the electrons and the ions substantially to the same extent. The electric field disposes of the ion stream by deflecting it away from anything approximating the straight axis of the cathode-ray tube, and has the overall effect of maintaining the electron beam on a course approximately coinciding with the axis of the tube. This arangement is also described in the Bowie patents cited above.

In cathode-ray tubes having a known form of ion trap the electron beam which is initially circular in cross-section passes through an ion-separation field that affects one part of the electron beam differently from other parts because of differences in the composite field at various cross-sectional parts of the beam, and as a consequence the initially circular electron beam tends to become roughly elliptical as it leaves the ion trap.

An object of this invention is to provide an ion trap for cathode-ray devices wherein this beam distortion is minimized and image deflection is improved. A further object is to provide a method of separation of electrons from ions such that a minimum of distortion of the electron beam is caused. A further object is to provide a method of producing the improved type of ion trap.

As applied to mass spectrometers, the invention

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contemplates separation of the ions of a given charge-to-mass ratio from all other particles emanating from an ion gun together, whether of larger or smaller charge-to-mass ratios. Mass spectrometers have long been known wherein ions of various charge-to-mass ratios have been projected into a magnetic field that caused the various particles to described semi-circular paths of various radii. By adjustment of the magnetic intensity, particles of any desired charge-to-mass ratio can be collected at a given point. Another type of mass spectrometer is disclosed by Oliphant, Shire, and Crowther in "Proceedings of the Royal Society" for 1934 at pages 922–929. The mass spectrometer there described involves a generally linear path for the desired type of ion, which is achieved by impelling a heterogeneous stream of ions from an "ion gun" through a transverse magnetic field and a coextensive transverse electrostatic field, these fields being mutually perpendicular. All of the ions except those of a given charge-to-mass ratio from a straight path are deflected in one direction or another. In that spectrometer it is necessary to adjust the direction of the "gun" or focusing system for the ion beam in relation to the ion-separation fields, so that desired particles would emerge from the system at a given collection point.

The "linear" characterization is only roughly proper since the ions enter, leave, or both enter and leave off the axis of symmetry of the electrostatic and magnetic fields. The prior art linear mass spectrometer depends on achieving an overall balance between the tendency to deflection of the beam components into a curved path by the magnetic field, and a correction of that curvilinear tendency for ions of a given charge-to-mass ratio by means of the electrostatic field. That overall balance is definitely not a point-to-point balance, with these two difficulties resulting: First, the initially sharp focus of the desired beam is impaired; secondly, the gun must be so directed in relation to the separation-field tube as to introduce an error compensating for the non-linearity of the "linear" mass spectrograph.

It is accordingly a further object of the present invention to provide an improved linear mass-spectrometer. A more general object of the invention is to provide an improved system for separation of particles of a given charge-to-mass ratio from others.

In the illustrated embodiment of my invention a beam formed in a gun and containing both ions and electrons in a cathode ray device, or

containing ions of various charge-to-mass ratios in a mass spectrometer, is passed through a composite electrostatic and electromagnetic field. The joint effect of the electric and magnetic fields on particles of a given charge-to-mass ratio when established in accordance with this invention is not to deflect them appreciably at any point along their straight-line path through the separation fields. The discovery that such a system is possible is an underlying feature of the present invention, and the system itself yields notable advantages in both the mass-spectrometer and in the cathode-ray device.

The amount of deflection of a beam of charged particles depends on the charge-to-mass ratio of the particles in the case of magnetic deflection but is independent of this ratio in case of electrostatic deflection. By establishing a magnetic and an electric field in such a way that the deflection of certain particles at all points along the axis of symmetry of the system is zero, there will be a minimum of dispersion or transverse distortion of the beam which is to be isolated. The objectionable particles are nonetheless deflected.

A better understanding of the invention together with its further objects and features will be gained from the following detailed disclosure of a specific embodiment thereof, and from the drawings wherein:

Fig. 1 is a cathode-ray tube to which my invention is applied;

Fig. 2 is a diagram indicating the operation of a prior-art form of ion trap;

Fig. 3 is a graph of the transverse magnetic field strength of an ion-trap magnet as it is distributed along the axis of a cathode-ray tube to which the trap is applied;

Fig. 4 is a diagram similar to Fig. 2 showing the operation of an ion trap improved in accordance with the present invention; and

Fig. 5 is an enlarged perspective view of the improved ion trap which is also shown in Fig. 1.

The invention is illustrated as applied to a cathode-ray television tube. The envelope of the cathode-ray tube in Fig. 1 includes a cylindrical portion **10** and a funnel-shaped portion **12**, the wide end of which constitutes the image area. Within cylindrical portion **10** is an assembly **14** for generating and focusing an electron beam. This assembly commonly termed a "gun" is suitably energized at terminals **16** on the base **18** of the cathode-ray tube. All the particles of the beam are accelerated to the extent measured by the "gun" potential. Ion trap **20** is positioned between gun **14** and deflection system **22** (schematically illustrated) which deflection system is located near the junction of portions **10** and **12** of the envelope. The electron beam when suitably deflected produces an image on screen **24**, conventionally of fluorescent material. This invention is applicable to cathode-ray tubes having any other kind of target likely to be deleteriously affected by ions. The ion beam, deflected from the electron path, impinges against apertured metal disc **25**.

Ion trap **20** comprises an iron core **26** and a coil **28** outside the envelope which are energized from a suitable D.-C. supply **30** through rheostat **33**, and are shaped to provide a field symmetrical about the x—z plane. A pair of plates **32** and **34** are supported inside the envelope in the gap of core **26**. These plates are so shaped and oriented as to produce an electrostatic field symmetrical about the y—z plane of the cathode-ray tube and generally parallel to the x axis. The energizing potential for the plates is supplied by D.-C. source **36** and by adjustable contacts **38** and **40** on potentiometer **42**.

It is desirable, though not absolutely essential, that the ion trap be located in a zone of uniform potential. This simplifies design, as will be gathered from the specific discussion which follows. In order to provide this uniform-potential field and for other known reasons, the internal surface of the cathode ray tube is coated, except in the zone of gun **14** and at its screen, with a conductive material such as "aquadag." The potentials of plates **32** and **34** advantageously are above and below the potential of this coating, and to this end terminal **44** of the coating is connected to the center tap **46** of potentiometer **42**.

To the extent described, the cathode ray tube is entirely conventional, being much the same as that in Fig. 5 of the Bowie patents mentioned above. It is the purpose in this prior-art type of ion trap to maintain a substantially straight path for the desired type of particles. It is my conclusion, however, this desired linearity has been merely an overall consideration. Thus (see Fig. 2 herein illustrating a prior art ion trap) an electron beam emerging from gun **50** might ultimately reach a part of target **52** which is along the axis of the gun, after passing through the composite electric and magnetic field of electrostatic plates **54**, **56**, and of poles **58** of an electromagnet. However, due to edge effects of the poles and plates the electron beam departs from the true axis of the system, and travels off the axis of symmetry of the composite electric and magnetic field. In Fig. 2 the heavy dashed line indicates a probable path of electrons, while the dot-dash line represents the axis of symmetry of the gun and the fields. The path of the ions is omitted to avoid confusion.

Along that part of the axis of the cathode ray tube which is opposite rectangular poles **58** of the magnet the field may be taken as nearly uniform and of relatively high intensity. Outside the edges of pole pieces **58** and along the axis there is a magnetic field which tapers in intensity but which nevertheless has an important effect on the electron path. There is a similarly slight extension of the transverse electric field along the axis of the cathode ray tube beyond the edges of plates **54** and **56**. As a result, while there is an overall approximate balance between the effects of the magnetic field and of the electric field on the electron beam, this beam is deflected from the axis of the tube somewhat as indicated, and travels through an asymmetric part of the field. It is a known fact that a beam is distorted when traveling in this manner. A beam which is circular in section on entering the gun may become elliptical or flat after traveling asymmetrically through an ion trap. Where the beam travels a long the axis of symmetry of the composite field, the distortion is at a minimum.

The remainder of this specification is devoted to the development of suitable means for producing optimal electric and magnetic fields to minimize beam distortion by balancing the effects of those fields on the desired particles, electrons in the case of the cathode ray tube, so that there will be zero deflection at each point along the axis of the tube.

In this "ideal" ion trap the condition sought to be achieved is that the effect of the electric field on electrons of charge e_0 having a mass M_0 at every point along the z axis of the cathode-ray tube, and where the electrons are accelerated to

a potential ϕ, shall be the same as the effect of the transverse magnetic field at that point but opposite in sense. Expressing this mathematically, we have the following equation:

$$(1) \qquad E(z)=\sqrt{\frac{2e_0\phi}{M_0}}H(z)$$

Thus at each point along the axis (z), the electric (E) and the magnetic (H) field strengths are to be related to each other by a constant. There remains the problem of devising magnetic poles and electrostatic electrodes which shall have mutually compensating effects on an electron beam of uniform speed entering along their axis of symmetry. With respect to the ions, which have other ratios of charge-to-mass, the deflection required for separation will still be achieved, and the deleterious effect of the ions on the screen is avoided as in the prior art.

In Fig. 3 there is shown the distribution curve of the magnetic field strength of a pair of unsaturated rectangular pole pieces **60** (Fig. 4) forming part of the improved ion trap, from point to point along the z axis of the cathode-ray tube. The separation between the magnetic poles in this example is equal to the extent of the pole facing along the axis of the cathode-ray tube and is four centimeters. From the foregoing discussion of the electric field in relation to the magnetic field, it will be apparent that the distribution of the transverse electric field along the axis should have a curve like that in Fig. 3. A field of this desired distribution will result when the electrostatic "plates" of an ion trap are made the same in spacing, size, and shape as the poles and are charged to the proper potential difference, provided that the related magnetic poles are not saturated. Such a pair of charged electrodes cannot in practice be associated with the magnetic poles of the same shape in an ion trap because the poles would affect the electrostatic field, because prohibitively high voltages would be required, and because the poles are preferably mounted outside the cathode-ray tube whereas the electrostatic plates preferably are mounted internally.

It is possible to use electrodes shaped like pole pieces in order to determine the necessary shape of the electrostatic plates of practical dimensions, that is, narrow enough to fit within the cylindrical portion of the cathode ray tube and between the magnetic poles. By immersing the electrodes shaped like the poles in an electrolyte and establishing an A.-C. voltage between them, it is possible to plot numerous unipotential surfaces constituting the field pattern. The electrodes used in making these unipotential plots may be replaced by other electrodes having the configurations of unipotential surfaces, insofar as the field pattern between them is concerned. Equipotential plots on opposite sides of the axis of symmetry can be used as the model for shaping the desired electrostatic plates. Since the plates are close to each other they may be made narrower than the widely separated electrostatic replicas of the poles. Where the plates diverge, as they do under the practical requirements of the improved ion trap, the equipotential plot is not a perfect model since the plates cannot be as wide as the equipotential surface; they are narrow enough for enclosure within the cathode-ray tube and taper as they curve toward the cylindrical envelope portion **10** (Fig. 5). Allowance for these factors may be realized either by computation or by cut-and-try shaping and testing, as in an electrolytic plotting tank.

Where the pole-pieces are significantly saturated, they cannot serve as models for the electrolytic plotting procedure described above. The lines of magnetic force should instead, be plotted directly and from these lines a pattern of equipotential magnetic lines can be derived by known techniques. The equipotential lines can be extended laterally of the plot to constitute surfaces which will serve as models for the desired electrostatic surfaces. The shapes of plates so determined are correct for only the one degree of pole-piece saturation used in their design, so that significant saturation is preferably avoided if practical, unless constant field-strength can be maintained during use.

It was mentioned above that the problem of shaping the plates is simplified where the ion trap is to operate in an electrostatically equipotential space. Just as in the case of the narrow diverging portions of the electrodes it is possible to allow for non-uniformity in the ion-trap space by critical shaping of the electrostatic plates, checked by computation or by electrolytic plotting or both. However, unipotential spaces may be found both in the electron gun and between the gun and the deflection system, and therefore the allowance for ambient non-uniformity of electrostatic field is not of great concern.

When electrodes are shaped so as to compensate for the tendency of the magnetic field to deflect the electrons at all points in the zone of the ion trap, both between the poles and in the fringe region, a pair of closely spaced and nearly parallel plates generally result for the region directly between the poles, and these plates diverge in regions outside the poles, whether the poles are saturated or not. A typical assembly utilizing rectangular-faced poles is shown in Fig. 5, and in Fig. 1 on a much smaller scale.

The desired beam may be maintained on the initial course by plates and poles properly shaped in relation to each other using another approach: the electrostatic surfaces can first be arbitrarily chosen, and the shape of the magnetic system can then be found which is required to compensate, at each point along the straight-line course, for the tendency of the electric field to deflect the electrons. This is an equivalent procedure to the one discussed in detail above, but is by far the more difficult from a practical standpoint. As a compromise, the pole-pieces may be judiciously shaped to simplify the problem of shaping the plates.

In operation of the cathode-ray tube it is necessary to charge the ion-trap plates to a voltage difference which is properly related to the magnetic field strength. The respective potentials of the electrostatic plates may be determined from the related equipotential plots, with the equation given above.

The foregoing discussion on the shaping of electrodes to achieve true linearity of the electron path in a cathode-ray tube also applies to linear mass spectrometers. By properly shaping the electrostatic p'ates in relation to the pole pieces, it becomes possible to have a truly linear mass spectrometer. The necessity for providing an adjustable coupling between the gun and the composite electric and magnetic field structure can thus be avoided, and the spectrometer can be adjusted for separation of any desired ion simply by adjusting the charges on the electrostatic plates or the magnetic field strength or both.

Having thus described a specific embodiment of my invention and what I believe to be the operative principles thereof, what I claim is:

1. The method of separating desired particles of a given charge-to-mass ratio from a composite beam containing particles of other ratios of charge to mass which comprises the steps of subjecting the composite beam to magnetic field generally transverse of the initial axis of the beam and electrostatically substantially nullifying the deflecting influence of the transverse component of said magnetic field on the desired particles at each point along the axis.

2. The method of separating desired particles of a given charge-to-mass ratio from a composite beam containing particles of other ratios of charge to mass which comprises the steps of subjecting the composite beam to a magnetic field transverse of and symmetrical to the initial axis of the beam and substantially nullifying the deflecting force of the transverse component of said magnetic field on the desired particles at each point along said axis with a transverse electrostatic field symmetrical about said axis and at right angles to said field.

3. Apparatus for separating particles of a given type from particles of another type comprising common means for accelerating both types of particles and forming a beam thereof, and mutually perpendicular pairs of elements for establishing electric and magnetic fields transverse to the initial course of said beam, the elements for establishing the electric field being shaped substantially in accordance with an equipotential surface of said magnetic field.

4. Apparatus according to claim 3 wherein said electric elements lie between said magnetic elements.

5. Apparatus according to claim 3 wherein said electric elements are narrow plates supported edgewise between said magnetic elements, and have extensions diverging outside the gap between said magnetic elements.

6. An ion trap for cathode-ray tubes and the like which comprises an electron gun, a deflection system, and an ion trap all arranged along a common axis, said ion trap comprising means for producing a magnetic field transverse to said axis which varies along said axis, and means for producing a transverse electrostatic field having substantially the same variation along the axis.

7. An instrument for separation of charged particles according to their relative charge-to-mass ratios comprising means for producing a beam of charged particles, means symmetric about the initial course of said beam for establishing a magnetic field transverse to said beam, and means for maintaining an electrostatic field transverse of the initial course and varying in strength from point to point along the course in such manner as substantially to counterbalance the effect of said magnetic field on particles of a given charge-to-mass ratio, whereby particles of the given ratio will travel a linear path from said source through the separation system.

8. Means for establishing mutually perpendicular electric and magnetic fields jointly causing no appreciable deflection of charged particles of a given ratio of charge to mass at each point along a linear path comprising a pair of poles symmetric about the path and a pair of electrostatic plates symmetric about said path, the central portions of the plates being generally parallel and the end-portions in the direction of the path being divergent.

9. The method of making a tube for separating undesired charged particles from a beam containing desired particles by means of mutually perpendicular electric and magnetic fields established symmetrically about an ideally linear path of the desired particles comprising the steps of providing a magnet proportioned to embrace said tube symmetrically, determining the field pattern corresponding to the shape of said magnet, shaping a pair electrostatic plates essentially according to equipotential lines on opposite side of the plane of symmetry of said field, and arranging said plates and said magnet in relation to said tube to yield fields as aforesaid.

RUDOLF G. E. HUTTER.

REFERENCES CITED

The following references are of record in the file of this patent:

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2,211,613	Bowie	Aug. 13, 1946

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