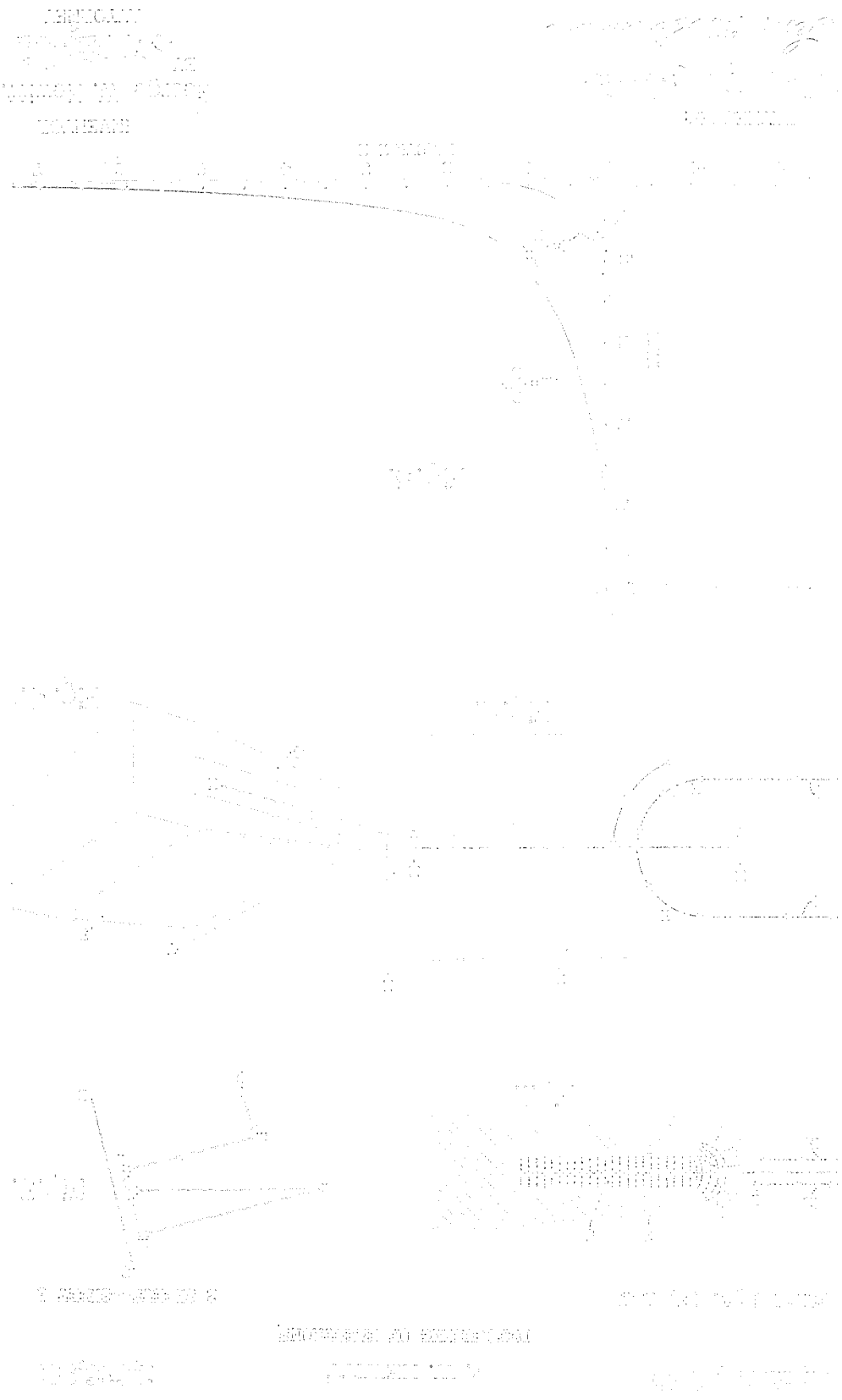

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DEFLECTING OF ELECTRONS

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My invention relates to electrical discharge devices and, in particular, relates to arrangements for focusing beams of electrically charged moving particles which pass through magnetic fields in the course of their movement.

As is well known, an electrified particle moving perpendicular to a magnetic field undergoes an acceleration in a direction perpendicular to the plane containing the direction of the magnetic field and the direction of its movement. Since this fact offers a way of applying force in a desired direction to such particles, arrangements in which these particles are caused to move in paths through magnetic fields find many uses in electrical discharge devices. By the use of magnetic fields, it is thus possible to cause the direction of motion of a moving electrified particle to undergo predetermined changes; to take one example, an electrified particle having a velocity along the X axis of a set of rectangular coordinates will, upon entering a magnetic field parallel to the Z axis, be accelerated along the Y axis. By the use of this expedient, it is possible to reverse the direction of movement of the particle and cause it to travel in the opposite direction from that in which its motion started. Another instance of the employment of magnetic fields in conjunction with moving electrified particles is found in the mass spectrometer. Still further instances are found in cyclotrons and betatrons.

Where an electrified particle moves through a field-free space, its velocity remains unaltered in magnitude and direction from second to second. When the particle moves with a constant speed perpendicular to the lines of force of a magnetic field of constant intensity and direction, the path described by the particle is an arc of a circle lying in a plane perpendicular to the lines of force. For many purposes, it is desirable to impose on moving electric particles one or the other of the two types of motion just mentioned; i. e. rectilinear movement or movement along a circular arc of constant radius. It would be possible to achieve motions of the type just mentioned if it were possible to cause the particle to move from a portion of space where the magnetic intensity was zero instantaneously into another portion of space where the magnetic field was of constant intensity; but such magnetic conditions would involve a discontinuity in the magnetic field, and such a thing is physically impossible. An approximation to such conditions can be arrived at by projecting an electrified particle into a narrow gap between a pair of magnetic plates of large area, forming pole-faces lying in parallel planes, from a point sufficiently distant so that the magnetic field due to the plates is almost zero; but such an arrangement is only an approximation since the space adjacent the edges of the magnetic plates is traversed by a "fringing" magnetic field which it is impossible to eliminate. An electrified particle moving in a plane exactly midway between the aforesaid planes would follow a path, the whole of which lay in that central plane; but it is impossible to produce a beam of electrons all of which lie exactly in such a central plane. In other words if the central plane be considered the X—Y plane of a set of rectangular coordinates, the beam must have a substantial dimension in the Z coordinate. In any actual apparatus, some of the electrons follow paths which, while they may lie in planes parallel to the X—Y plane, are slightly displaced above or below the latter. It can be shown that these particles are accelerated along the Z axis by the "fringing" field; so that all the moving particles except those which follow paths lying exactly in this X—Y plane undergo accelerations along the Z axis.

One of the objects of my invention is to provide an improved form of magnet arrangement in which the movements of the particles normal to the central plane between the pole pieces are reduced to a minimum.

Another object of my invention is to provide an improved arrangement in which the resulting motion of the moving particles in a direction perpendicular to the central plane between the magnetic pole pieces is reduced to zero by the time the moving particle has left the vicinity of the magnetic pole pieces.

Still another object of my invention is to provide an improved type of magnet for deflecting moving electrified particles in such a way that the direction of their motion after leaving the field of the magnet lies in the same plane with the direction of their motion before entering the magnet field.

Other objects of my invention will become apparent upon reading the following description, taken in connection with the drawings, in which:

Figure 1 shows a cross-sectional view of the pole pieces of a magnetic structure embodying the principles of my invention along the plane I—I in Fig. 2;

Fig. 2 is a view of the same structure at right angles to Fig. 1;

Figs. 3 and 4 are diagrammatic views which are useful in explaining the principles of my invention and which show the directions of move-

ment of a particle in the region of the magnetic structure;

Fig. 5 is a plot of magnetic intensity near the magnet structure;

Fig. 6 is a plot of certain quantities derived from Fig. 5 and useful in designing the magnet of Figs. 1 and 2;

Fig. 7 is a plan view and Fig. 8 a sectional elevation along plane VIII—VIII in Fig. 7 of a magnet structure provided with an ancillary magnetic shielding arrangement; and

Fig. 9 is a plan view and Fig. 10 an elevation in section along the plane X—X in Fig. 9 of a magnetic structure provided with an ancillary electric field.

Referring to Fig. 1 in detail, an electrified particle may be considered to be moving along a path 1 from a region which is substantially free from electric and magnetic fields, and to be carried by its movement directly in the central plane lying between a pair of iron or other suitable magnetic pole plates 3 and 4. The contiguous faces of the plates 3 and 4 lie in parallel planes. The pole plates 3 and 4 are maintained at different magnetic potentials by any means conventional in the art and produce in the space directly between them magnetic lines of force 5 which are substantially perpendicular to their plane faces. In accordance with well known magnetic principles, the density of the lines of force 5 over most of the surface of the plates 3 and 4 is substantially constant. The pole faces of the plates 3 and 4 may be considered to be parallel to, and equidistant from, the X—Y plane of a set of rectangular coordinate axes in which the path 1 lies parallel to the X axis. Along the edges of the pole plates 3 and 4, however, the magnetic lines of force 6 to 10 are shown in Fig. 1 to illustrate the "fringing" effect which has been mentioned above. The lines of force 6 to 10 lie in planes perpendicular to the X—Y plane and to the edges of the plates 3 and 4. They are less closely spaced than the lines of force 5 and are curved; but all are perpendicular to the X—Y plane where they pass through it. A particle moving along the path 1 in this X—Y plane will, accordingly, always encounter lines of magnetic force which are normal to the direction of movement of the particle and, in accordance with well known electromagnetic principles, will be moved in a curve lying in the X—Y plane; i. e. a curve such as A—E—B in Fig. 2. The magnetic field produces on the moving particle a force which is proportional to the product of the velocity of the particle at any instant and the magnetic field through which it is passing. This force is directed perpendicularly to the instantaneous direction of motion of the particle and constitutes a centripetal force which is related to the radius of curvature r of the curve being followed by the particle at any instant by the well known formula:

$$F=m\frac{v^2}{r}$$

for centripetal force, m being the mass of the particle and v its velocity.

While the particle is passing transverse to the lines of force 6 to 10 where the intensity of the magnetic field is changing as the particle moves, the radius of curvature r similarly changes; but when the particle has reached the magnetic lines of force 5 where the magnetic intensity is constant, the particle follows a circular arc. By

properly designing the shape of the plates 3 and 4 in the X—Y plane, their edges may be made to cross this circular path of movement at any desired point, thus determining the direction in which the particle will be moving at the time it re-enters the field-free space.

However, it is impossible as a practical matter to project electrified particles lying always exactly in the X—Y plane above described, and in any actual electrical discharge device, some of the particles will follow paths such as 12 which lie above the X—Y plane, while others follow paths 13 which lie below the X—Y plane. Particles following either of the paths 12 and 13 will cross the lines of magnetic force 6 to 10 at points where their direction is not normal to the X—Y plane. The directions of the lines of force 6 to 10 where the particle following the path 12, for example, intersects it can be resolved into two components, one along the Z axis normal to the X—Y plane and the other lying parallel to the X—Y plane.

If the electrified particle continued to follow a path parallel to the X axis, the last-mentioned component of the magnetic force being along the X axis also would produce no deflecting force on it. However, the component of the magnetic field lying along the Z axis causes the particle to follow a curve path having a component parallel to the Y axis. This component of velocity parallel to the Y axis, together with the above-mentioned component of magnetic field parallel to the X axis, will produce a force accelerating the particle along the Z axis. Such a movement of the particles along the Z axis tends to defocus the electron beam and creates considerable practical difficulty in the use of magnets for the purpose here under discussion. The object of my invention is, in fact, to minimize the effect of this defocusing movement imparted to the particle along the Z axis.

It will be noted that once the particles following the paths 12 and 13 have passed into the region of the magnetic lines 5, all lines of magnetic force which they encounter lie along the Z axis and they will correspondingly receive no further accelerations along the Z axis. They will, however, retain any velocity along the Z axis with which they left the "fringing" field as long as they remain in the portion of the magnetic field between plates 3 and 4 which is not subject to "fringing." However, when the particles, after following a circular arc between the plates 3 and 4, reach the edge of these plates at another point than that at which they entered, they again encounter the "fringing" field. It can be shown that the effect of the "fringing" field at the point of egress produces accelerations in the same direction along the Z axis as those encountered by the particle in the "fringing" field at entrance. Thus the effects of the "fringing" at the entrance and the egress points in producing velocity along the Z axis are cumulative.

As I will now proceed to show, it is possible to substantially reduce to zero the velocity along the Z axis of the particle leaving the "fringing" field, by the expedient of forming the edges of the pole pieces 3 and 4 as planes normal to the X—Y plane, but which make an angle α with the X axis along which the particle is moving in field-free space before entering the magnetic field due to plates 3 and 4. Referring in detail to Fig. 3, the edge of the pole pieces 3 and 4 may be represented by the line SB making an

angle α with the H' axis. The velocity of the moving particle along the path 1 may be represented in magnitude and direction by the vector *op*. The velocity *op* may be resolved into two components, one *on* normal to the direction SE and the other *om* parallel to SE.

A line of magnetic force in the "fringing" field, such, for example, as 10, will lie in a plane normal to the line SE and to the H—V plane and may be resolved into a component *mh* perpendicular to the line SE and a second component along the E axis. The magnetic component along the E axis will, of course, combine with the velocity of the particle in the H—V plane to produce a curvature of the path such as has already been described as occurring in particles moving in path 1. The magnetic component *mh*, however, is in the same direction as the velocity component *om*, so the two will produce no accelerating force on the charged particle. But the magnetic component *mh* and the velocity component *mp* are at right angles to each other in the H—V plane and will produce an acceleration along the E axis. In short it is the velocity component parallel to the pole face SE, and the magnetic intensity normal to it which combine to produce accelerations of the particle along the E axis.

Turning now to Fig. 2, the moving particle may be considered to travel along the path 1 which is rectilinear and parallel to the H axis until it enters the "fringing" field comprising the magnetic lines 9 to 10 of Figs. 1 and 2.

The particle moving along the path 1 has a velocity V, and since the magnetic field can neither transfer energy to the particle nor abstract energy from it, the particle will retain this velocity V while it moves along the curved path AEB, and in fact throughout the period of its traverse through the magnetic field of plates 3 and 4. Beyond the point B and up to point H, the path will, of course, be a circular arc of smaller radius of curvature than any of the radii of curvature in the portion AEB in view of the greater intensity of the magnetic field directly between the plates 3 and 4.

The intensity of the magnetic field *f* at points along the path 1 is, of course, a maximum between the plates 3 and 4, starts at zero while the moving particle is far away from the plates 3 and 4, and increases very little until the particle reaches a point which is distant from the ends of the plates 3 and 4 by an amount of the order of magnitude of the spacing between them. The variation of intensity of this magnetic field can, of course, be calculated by methods known in the art and has a form of the type plotted in Fig. 5. While it would be theoretically possible to calculate the exact form of the path of the particle in the H—V plane by applying known differential equations for the movement of an electrified particle in a magnetic field to the analytical function which precisely expressed the value of the magnetic field *f* at all points in the H—V plane, this function is so complex that, as a practical matter, the exact solution of these differential equations would be extremely difficult, if not impossible. However, a very close approximation may be arrived at by graphical methods. The correct angle α required to minimize defocusing (i. e. introduction of a velocity component in the E-direction) may be calculated in a similar graphical manner. I have found by a mathematical analysis of the forces and resulting accelerations of the moving particle due to the various components of the magnetic field through which it passes, that the velocity Va of the particle perpendicular to the pole-faces 3 and 4 when it has reached a position where the magnetic field between pole pieces 3 and 4 is exactly normal to their faces (i. e. has no H component in Figs. 3 and 4), will be zero if

$$\cos\alpha = \frac{\int_{x'}^{\infty}\left(\frac{Bx}{B}\int_{x}^{\infty}\frac{Bz}{B}dx\right)dx}{R\int_{x'}^{\infty}\frac{Bx}{B}dx} \qquad (1)$$

where B is the magnetic flux well within the air gap, Bx and Bz the components on the coordinate system of Fig. 4, R the radius of the circular path described by the particle between the pole-pieces 3 and 4 at points where the field has no x or y component; i. e. at points far enough inside the air gap so that there is no magnetic fringing; and α the desired angle to be found for the pole-edge in Fig. 2.

The integrations in the foregoing equation may be performed graphically by the following procedure. A scale model of the pole-pieces 3, 4 may be subjected to electrolytic tank methods well known for determining by direct measurement the potential gradients of a given field distribution, and the resulting quantities

$$\frac{Bx}{B} \quad \text{and} \quad \frac{Bz}{B}$$

appearing in the foregoing integrals may then be plotted. Fig. 5 shows a typical pair of curves obtained in this way. The value of the integral

$$\int_{x}^{\infty}\frac{Bz}{B}dx$$

is then obtained by determining the area (e. g. by planimeter) under curve M lying between each abscissa x and infinity. For abscissas greater than 5 times the air gap width G the value of

$$\frac{Bz}{B}$$

may be taken as

$$0.75\frac{G}{x}$$

hence it is sufficient to measure the area under curve M for abscissas up to x=5G.

The values of the integral thus found for each point x is plotted against x. Curve P in Fig. 6 shows such a curve derived as described above from curve M in Fig. 5. A third set of values is then plotted by multiplying, for each abscissa H, the ordinate of curve M in Fig. 5 multiplied by the ordinate for the same value of H on curve P in Fig. 6. These product values are then plotted against x, point-by-point, to obtain a fourth curve. The curve marked NP in Fig. 6 was thus obtained from curve N of Fig. 5 and curve P of Fig. 6. The area under the curve NP in Fig. 6 is then measured by the above-described methods and gives the value of the numerator in Equation 1. The area under curve N in Fig. 5 is similarly measured and, when multiplied by R, gives the denominator for Equation 1. The angle α is thus determined.

The lines of force of the magnetic field due to the plates 3 and 4 will lie in planes perpendicular to the H—V plane and to SE, the edge of the pole faces. As has previously been explained, these lines of force, at the point where they pass through the H—V plane, have no horizontal com-

ponent, but at points above and below this plane have horizontal components which are normal to the line SB and may accordingly be represented by a vector such as *mh* in Fig. 3.

Referring now to Fig. 2 (in which the X-axis is chosen differently than in Fig. 4), it will be noted that at the point A, the velocity of the moving particle may be represented by the vector NP (Fig. 3) parallel to the X axis, and this velocity may be resolved into two components *nm* which is normal to the line SB and *mp* parallel to the line SB. Since the velocity *nm* is parallel to the components *mh* of the magnetic field in Fig. 2, it will cause no deflection of the moving particle, but the velocity component *mp* which is parallel to the line SB, and hence to the edge of the magnet plates 3 and 4, lies in the X—Y plane perpendicular to the magnetic component *mh* and will cause a force equal to the product *mh* times *mp* to produce accelerations of the moving particle along the Z axis. It will be noted that the magnetic component *mh* for points above the X—Y plane is opposite in direction from that for points below the X—Y plane, while the direction of *mp* is the same; hence particles moving in paths above the X—Y plane are accelerated in one direction and particles moving below the X—Y plane are accelerated in the opposite direction along the Z axis.

While the velocity *np* in Fig. 3 was referred to as the velocity of the particle to the left of point A in Fig. 2, it will be noted that similar resolutions of the velocity at other points on the AEB portion of the curve could be made in directions similar to *nm* and *mp*, but that, in general, the component *mp* would decrease as the particle moved from A and soon reach a point at which it would become zero. Calling the latter point E, the component *mp* would be of the reverse direction for points beyond E. This means that at the point E the acceleration of the particle along the Z axis has fallen to zero, although its velocity along the Z axis is not zero. Thus the particle is being accelerated in the opposite direction along the Z axis while in the EB portion of the path, to that while in the AE portion. For the correct value of angle *a*, the retardation along the last-mentioned path EB will counter-balance the Z axis acceleration imparted along the path AE and the particle will enter the uniform field inside the pole pieces 3, 4 with zero velocity along the Z axis. In short, the particles which left the field-free space moving in the X—Y plane will enter the space between the plates 3, 4 moving along a curved path in a plane parallel to the X—Y plane, although displaced from the latter.

It will be evident from the foregoing that this elimination of velocity along the Z axis by the time the particle fully enters the space between pole-plates 3 and 4 is effected by giving the edge SB of the plates 3, 4 a particular angle *a* relative to the direction of movement of the particle in field-free space, where *a* may be determined from the Equation 1 as previously described.

As has previously been stated, the particle moves beyond the point B along a circular arc determined by the density of the magnetic field between the plates 3, 4 and will continue to follow this curve until it arrives close to another edge of the plates 3, 4 at which it leaves the dense portion of the magnetic field therebetween. The fringing field adjacent this other edge of the plates 3, 4 will be similar to that already described in connection with Fig. 3, and the particle will accordingly follow a curve similar to AEB after leaving the space between the plates. If it is desired that the particle upon again reaching field-free space shall move in a direction directly parallel to the path f in Fig. 2, a mirror image of the path fAEB may be applied at a point K having the same X coordinate as point B in Fig. 2. The point K is, accordingly, a point of exit on the other edge of the plates 3, 4 corresponding to the point of entry B.

When it is desired that the path of the particle on re-entering field-free space should have some angle, differing by angle U from 180 degrees relative to the original field-free path f, it will be obvious that the point K should be displaced along the curve KB by an angle U, the radius of curvature of the path through the "fringing" field in the regions of emergence being retained unaltered.

A moment's consideration will show that the velocity of the particle emerging from the space directly between the plates 3, 4 has a component parallel to the magnet edge which is similarly directed along that edge to the homologous component on entrance; i. e. the vectors *mp* in the diagrams corresponding to Fig. 3 are the same for homologous points in the "fringing" fields at both entrance and exit paths of the particle. Likewise, the magnetic component *mh* is the same as that shown in Fig. 3 for homologous points in both "fringing" fields; hence the forces and accelerations along the Z axis are exactly the same, point by point along the exit path, to those existing along the entering path AEB. Hence the particle, while it experiences a displacement along the Z axis in passing through the "fringing" field, will emerge from the "fringing" field with zero velocity along the Z axis. Its path in field-free space will, accordingly, be parallel, to, and so coplanar with, the path f which which it entered the magnet field.

The foregoing describes a way in which the position of the edges of the plates 3 and 4 may be determined in order to minimize defocusing of the electron beam as a result of accelerations of the particles along the Z axis in the fringing flux. I may point out that where anyone desires to avoid the plotting and integrations described above, it will be possible to make up a number of specimen magnets having edges lying at various values of angle *a* in Fig. 2. These may then be tried successively and the degree of defocusing plotted against the various values of the angle *a*. In this way, a curve may be plotted from which an optimum angle *a* may be determined by inspection.

An arrangement which may be applied either alternatively, or as a supplement, to that described in the foregoing, for improving the magnetic field distribution of the plates 3, 4 and reducing the "fringing" field distant from the edges of the plates 3 and 4 is shown in Figs. 7 and 8. It comprises providing a pair of magnet poles like those of Figs. 1 and 2 with a series of plates 31, 32, 33 of magnetic material such as iron, which are perpendicular to the mid-plane between the pole plate 3, 4 and parallel to the edges of poles. These plates have openings or windows to permit passage of the beam, forming closed loops around the beam, so that the lower halves 34, 35 and 36 are at the same magnetic potential as the corresponding upper halves 31, 32, 33. While such magnetic plates may increase the component of magnetic force along the X axis (i. e. the component *mh* in Fig. 3) directly in front of the pole

plates 3 and 4, the amount by which they reduce the "fringing" field at greater distances from the edges of the poles more than compensates this latter effect so that a net improvement in the focusing is found to result. This arrangement can be used in combination with the acute incidence angle α method. The angle α is computed by the use of Equation 1 from the flux distribution of the magnet with the magnetic shields in place. It has been found that α is much nearer 90° when shields are used, than when none are used. For example, in one case 86.5° with shields compared with 73.7° without shields were calculated values for angle α.

In Figs. 9 and 10 I have disclosed an arrangement which may be applied either separately or in combination with magnetic shields. Thus, a magnet having plates 3, 4 substantially similar to those already described in connection with Fig. 1, and having its pole edges perpendicular to the initial beam direction, may be provided with means for producing an electric field in the space immediately in front of the edges of the pole pieces 3, 4, and, if desired, extending somewhat into the air gap which electric field will produce forces equal and opposite to the forces along the Y axis described as arising from the fringing field. For example, a series of non-magnetic electrodes 21 to 30 and 31A to 32A may be positioned on each side, in the Y direction, of the entering and emerging beams as shown in Figs. 9 and 10 may be used. These electrodes are shaped and spaced so as to produce an electrostatic field of the same distribution as the Z-component of magnetic flux in the "fringing" region. The correct shape and spacing of these electrodes may be obtained from the flux map of the magnetic intensity in the "fringing" field of the magnet structure to be used. Since the distribution of the electrostatic flux should be the same as that of the magnetic flux, the electrodes 21 to 30 and 31A to 32A should have the same shape (in the X—Y plane) as the equipotential lines of the magnetic field (in the X—Z plane), at the corresponding positions with respect to the beam. Various sections of different equipotential lines may be chosen to be replaced by electrodes. For example, in Fig. 10, electrodes 25, 30, 31A and 32A have the shape and position of magnetic equipotential lines which, when extended within the magnet are spaced apart by one-half the air gap width. Similarly, electrodes 23, 24, 25 and 30 lie on portions of equipotential lines which, extended within the magnet, are spaced apart by one quarter the air gap width, and electrodes 21, 22, 27 and 28 lie on portions of equipotential lines, which extended within the magnet, are spaced apart by one-eighth the air gap width. To produce the desired electric field distribution, this set of electrodes would have potentials applied as follows: If the beam particles are negatively charged (such as an electron beam) then a negative potential $-\frac{1}{4}Q$ would be applied to electrodes 22 and 27, and a potential of $+\frac{1}{4}Q$ to electrodes 21 and 28, with respect to the electrostatic potential of the magnet poles. A potential of $-\frac{1}{2}Q$ would be applied to electrodes 24 and 26, and a potential of $+\frac{1}{2}Q$ to electrodes 23 and 29. Electrodes 23 and 31A would be operated at $-Q$, and electrodes 25 and 32A at $+Q$. The magnitude of Q can be calculated from well-known relations involving the magnetic field strength inside the air gap, and the particle velocity as follows: The magnitude of potential Q must be such that the electrostatic gradient E' between electrodes 25 and 26 (also 31A and 32A) if extended inside the magnet gap would satisfy the equation

$$E'e' = VBe \qquad (2)$$

where

E'=electrostatic gradient in stat. volts per cm.
e'=particle charge, stat. coulombs.
e=particle charge, ab. coulombs.
V=particle velocity, cm. per second.
B=flux density inside magnet in gausses.

But

$$\frac{e}{e'} = \tfrac{1}{3}(10)^{-10}$$

$$E' = \tfrac{1}{3}(10)^{-10}VB$$

Let

S=spacing in cm. between electrodes 25 and 26 when extended within the air gap
Q=potential in volts.

Then

$$E' = \frac{Q-(-Q)}{300S}$$

and

$$Q = \tfrac{1}{2}(300)SE'$$
$$= \tfrac{1}{2}(10)^{-8}VBS$$

or, substituting

$$V = BR\left(\frac{e}{m}\right)$$

$$Q = \tfrac{1}{2}(10)^{-8}B^2RS\left(\frac{e}{m}\right)$$

In the example, illustrated in Fig. 9, the spacing S equals one-half the gap width,

$$S = \frac{G}{2}$$

An advantage of this means of minimizing defocusing is that adjustment can be made easily for various radii of curvature within the magnet, by varying the magnitude of Q and by moving one set or both sets of electrodes (one set consisting of those around the entering beam, and the other set consisting of those around the energizing beam) along the pole edges, in the Y direction. This arrangement will produce electric fields which may be made to produce electric forces equal and opposite to those produced by the "fringing" field of the magnet by adjusting the potentials applied, respectively, to the electrodes. The proper values for these potentials to impart accelerations on the electrified particles equal and opposite, point-by-point, to the Y axis accelerations produced by the Z component of the fringing magnetic flux can be calculated by methods well-known in the art; or these potentials may be adjusted by experiment until the defocusing of the electron beam is observed to be a minimum.

I claim as my invention:

1. An arrangement for altering the direction of movement of an electrified particle moving in field-free space along the X axis of a set of rectangular coordinates comprising a pair of pole pieces of having a uniform air gap with faces in the X—Y plane and edges normal thereto, and having a magnetic field between them which is parallel to the Z axis, the plane of said edges making angles with said X axis which is

$$\cos^{-1}\frac{\int_x^\infty\left(\frac{Bx}{B}\int_x^\infty\frac{Bz}{B}dx\right)dx}{R\int_x^\infty\frac{Bx}{B}dx}$$

where B is the magnetic flux, Bx and Bz are x and z components of said magnetic field at any point x on the particle's path, and R is the radius of the circular arc followed by said particle when well within said magnet gap.

2. An arrangement for altering the direction of movement of an electrified particle comprising a pair of pole pieces having a magnetic field between them which is normal to the path of movement of said particle in field-free space before entering said magnetic field, and electrodes for producing an electric field in the fringing magnetic field of said pole pieces where said particles enter the space between said pole pieces, said electric field having a magnitude substantially equal to the product of the magnitude of the magnetic field and the velocity of the particle along the path of the particle, said electric field having a direction so as to produce a force on said particle opposite to that produced by said fringing magnetic field.

3. An arrangement for altering the direction of movement of an electrified particle comprising a pair of pole pieces of magnetizable material having a magnetic field between them which is normal to the path of movement of said particle in field-free space before entering said magnetic field, and a set of plates of magnetic material for each pole piece positioned adjacent the edges of said pole pieces in the region where said particle passes between them forming closed magnetic paths around said path, said plates being normal to the mid plane between said plates.

4. Means for operating upon an electrified particle moving without acceleration along the X axis of a set of rectangular coordinates, means for producing a magnetic field along the Z axis of said coordinates and which is substantially uniform over an area in the X—Y plane having predetermined boundaries, and which is in the path of movement of said particle, said boundaries having a rectilinear portion which makes with the X axis at a point where said path intersects said area an angle of

$$\cos^{-1}\frac{\int_x^\infty\left(\frac{Bx}{B}\int_x^\infty\frac{Bz}{B}dx\right)dx}{R\int_x^\infty\frac{Bx}{B}dx}$$

where B is the magnetic flux well within said area, Bx and Bz are the x and z components of said magnetic field at any point being traversed by the particle and R is the radius of the circular arc followed by said particle when well within said area.

5. Means for operating upon an electrified particle moving without acceleration along the X axis of a set of rectangular coordinates, means for producing a magnetic field along the Z axis of said coordinates and which is substantially uniform over an area in the X—Y plane having predetermined boundaries, and which is in the path of movement of said particle, said boundaries having a rectilinear portion which makes with the X axis at a point where said path intersects said area an angle of 90 degrees, a pair of electrically charged sheets of conducting material symmetrically positioned relative to said X axis and perpendicular to the X—Y plane, and intersecting said X—Y plane in curves which duplicate the curves formed by the intersection of the X—Z plane with magnetic equipotential surfaces of said magnetic field.

GEORGE W. HEWITT.

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