

Feb. 25, 1941.

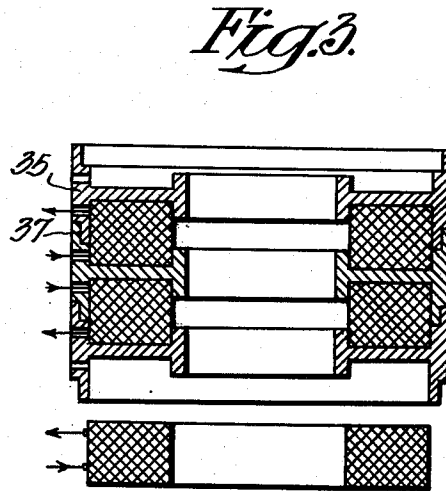
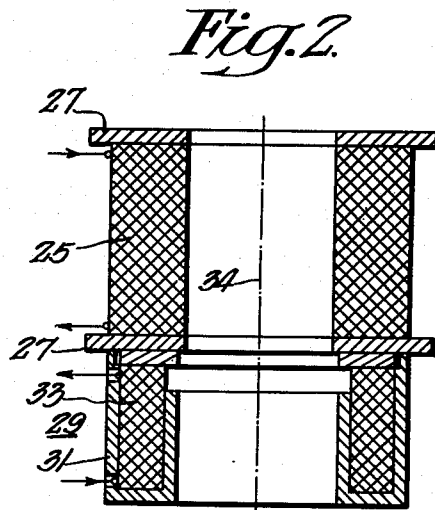
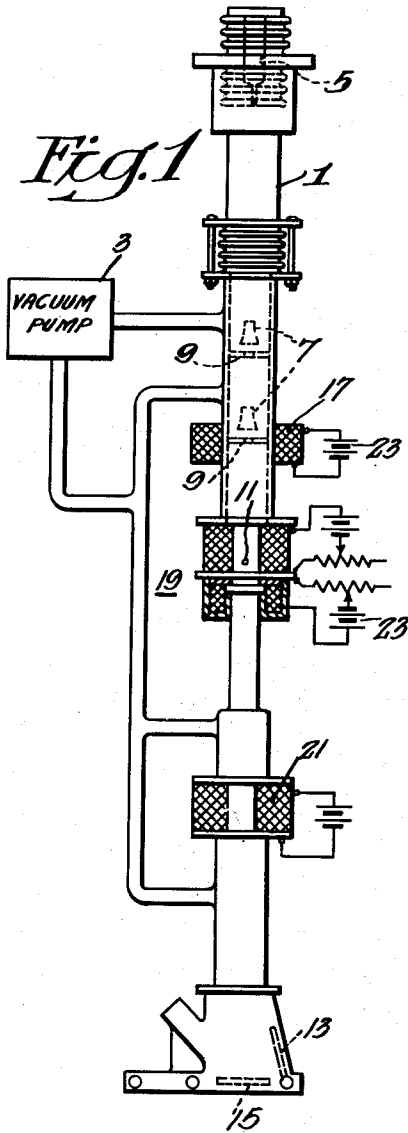
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2,233,264

ELECTRON LENS

Filed Dec. 27, 1938

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

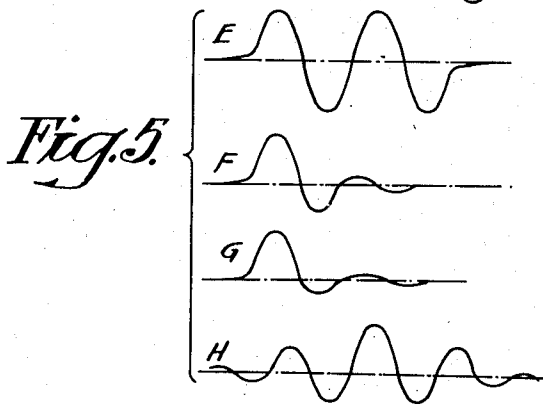
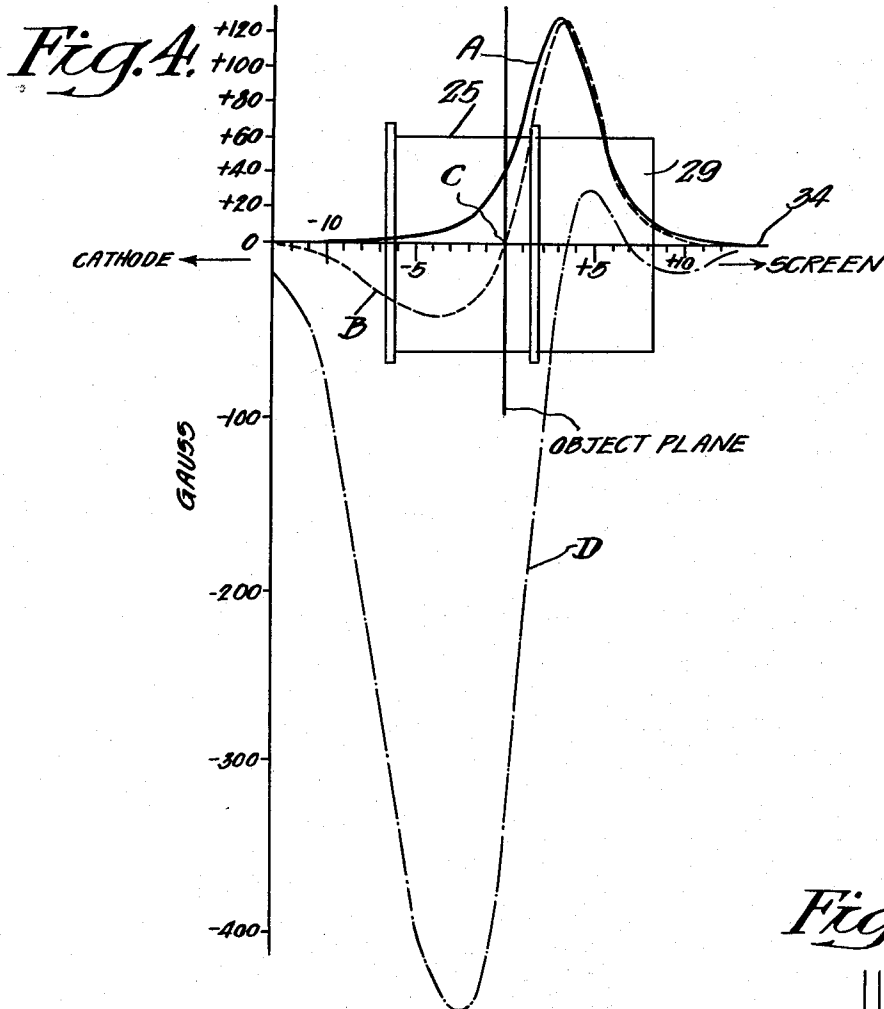
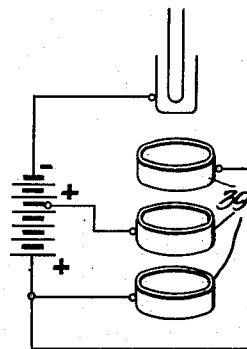


Fig. 6.



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UNITED STATES PATENT OFFICE

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ELECTRON LENS

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11 Claims. (Cl. 250—27.5)

This invention relates to electron lenses and in particular to an electron lens which is made up of opposing fields.

In optical microscopes it is well known that compensation must be made for spherical aberrations. An electron microscope also employs lens systems for focusing the electrons which are subject to similar aberration. In a short focus lens, the aberrations may be especially objectionable and therefore compensation is essential. The conventional electron lens consists of means for establishing a field which acts as a lens with respect to the electrons traveling through the field. The field may be established by electric or magnetic forces.

While a simple field will focus electrons, if high magnification is desired, and spherical aberrations are to be minimized, compensation must be employed. It is therefore one of the objects of this invention to provide means for establishing an electron lens which is capable of focusing electrons. Another object is to provide means for correcting for spherical aberration in an electron lens. A further object is to provide a field of force for focusing electrons and an opposing field to correct aberration in said focusing. A still further object is to provide means for creating an electron focusing field and for opposing said field so that the resultant field changes sign along the axis.

The invention will be described by reference to the accompanying drawings in which Figure 1 is a schematic diagram of an electron microscope embodying the invention; Figures 2 and 3 are sectional views of compensated magnetic electron lenses; Figure 4 is a graph indicating the distribution of the magnetic fields of force in one embodiment of the invention; Figure 5 is a graph illustrating different field arrangements for focusing electrons; and Figure 6 is a view partly in perspective illustrating an electric compensation lens.

Referring to Fig. 1, an envelope 1 is exhausted by a vacuum pump 3. The envelope includes a cathode 5, deflecting electrodes 7, diaphragms 9, an object or specimen positioned at 11, a fluorescent screen 13, and means for inserting a photographic plate 15. Incorporated with the outside of the envelope are a condensing lens 17, a compensated objective lens 19, and an eye-piece lens 21. The lenses are energized by currents from batteries 23 or the like.

One suitable embodiment of the compensated objective lens is shown in Fig. 2. A coil 25 is arranged on a spool or other suitable support 27.

A second or compensating field is established by the electromagnet 29 which consists of a shell 31 of magnetic material and a coil 33 which is disposed within the shell. The two coils are coaxially arranged with respect to their axis of symmetry 34. By way of example, the inside diameter of the first coil may be 6 centimeters and the outside diameter 12 centimeters. The length may be 7 to 8 centimeters. The shell of the compensating coil is approximately $\frac{1}{2}$ centimeter thick and includes an annular space approximately 5 centimeters long and 1.7 centimeters wide. The smaller diameter of the annular space is approximately $7\frac{1}{2}$ centimeters.

The foregoing dimensions have been given by way of illustration rather than limitation. Referring to Fig. 4, if the metal-clad coil 29 is energized, its field of force along the axis will be represented by the curve A. It has been found that this distribution of force, while it will focus electrons, is subject to appreciable aberration. If the first coil 25 is poled so that its field will oppose the field of the metal-clad coil 29, a resultant field of force represented by the broken line B may be obtained. It will be noted that the resultant field changes its sign along the axis of symmetry 34. It will be observed that the intersection of B with the axis, as indicated by C, represents in this particular case the location for the object or specimen to be examined. However, the object may be located at any point between the planes in which the field or the axis reaches a maximum value. It has been found by experiment that a compensated lens of this type is much superior to an uncompensated lens.

The theory of the operation of the lens is as follows: It has been recognized that a steep gradient of the field of force is desirable along the axis of symmetry. It is difficult to obtain in a single field a distribution of the lines of force which does not decrease gradually to zero along the axis. By applying a second field in the opposite sense the gradually decreasing field may be cut off and replaced by a field with constant gradient over the desired region. The resultant field with its steep gradient shows a greatly diminished spherical aberration. While the spherical aberration may be diminished by means of a single lens, the aberration may be further decreased by the use of several fields of alternately opposite sign, either of equal strengths and shapes or of unequal strengths diminishing in accordance with any desired law, as shown in Fig. 5E, F, G.

If the compensating field is greatly increased

so that it becomes several times stronger than the original field, and therefore over-compensation is obtained, as indicated by the curve D, the magnification greatly increases without any substantial increase in the spherical aberration. It is a matter of some surprise that a satisfactory image may be obtained when the object is placed at the point of the field where the gradient is negative. Ordinarily no satisfactory image may be observed under such conditions. The existence of a satisfactory image of the object located on the negative gradient portion of the field may be explained by analogy.

In the front lens of a microscopic objective a virtual image is formed. In the compensated electron lens in which the first field is made very strong and in which the object is placed on the negative gradient side of the field, the image formation conditions are similar to the case of the microscopical objective. The electron image formed by the first field is a virtual one which is transformed into a real one by the subsequent weaker fields. An inspection of the curve D will indicate that a portion of the field precedes the object. This portion of the field may be combined with weaker fields in a manner similar to the foregoing description so that it becomes a part of the condensing lens system. These effects are in close analogy to the light optical systems used in microscopes in which it is well known that a good condenser lens corresponds to an inverted objective lens. Thus the total field distribution of the condenser and objective system corresponds to the curve H of Fig. 5.

Numerous distributions of the magnetic fields may be obtained, as indicated by the graph of Figure 5, in which the change of sign along the axis of symmetry is indicated for fields of equal and unequal strengths. While the invention has been described by reference to one arrangement of a magnetic lens system, other arrangements have been devised. For example, in Fig. 3 a series of magnetic shells have been arranged with interlocking joints so that any number of successive fields may be assembled. If desired, the magnetic shells of some or all the coils may be omitted. In the event that electric fields are employed, hollow cylindrical electrodes may be employed, as indicated in Fig. 6, the various electrodes being differently polarized to obtain compensation effects already illustrated with respect to the magnetic fields.

Thus the invention has been described as an electron lens in which fields of force are used for focusing electrons and in which opposing fields are employed to reduce the spherical aberration. Either magnetic or electric fields may be used in the lens. It is desirable that the fields be of different magnitudes changing in sign and decreasing in magnitude along the axis of symmetry in the direction of the electron movement.

I claim as my invention:

1. An electron lens for imaging an object including in combination, means for creating an electron focusing field and means for creating a second electron focusing field opposing said first field along its axis, said object to be imaged being located substantially in the plane in which said fields change sign so that the field on the object side of the lens extends past the object and forms part of a condensing lens system and so that the field at said plane is substantially zero.

2. An electron lens for imaging an object in-

cluding in combination, means for creating an electron focusing field, and means for creating a second electron focusing field opposing said first field so that its strength changes sign along its axis of symmetry, said object to be imaged being substantially in the plane in which zero field exists so that the field on the object side of the lens extends past the object and forms part of a condensing lens system.

3. An electron lens for imaging an object including in combination, means for creating an electron focusing field having an axis of symmetry, and means for creating an opposing electron focusing field so that said fields are in opposition along their axes and their resultant field changes sign along said axes, said object to be imaged being located in a plane normal to said axis and in which plane said fields change sign.

4. An electron lens for imaging an object, including in combination, means for creating an electric field having an axis of symmetry, and means for creating an opposing electric field so that said fields are overlapping and are in opposition along their axes and their resultant field changes sign along said axes, said object to be imaged being located at the point along said axes where the resultant field is substantially zero.

5. An electron lens for imaging an object, including in combination, means for creating a magnetic field of force having an axis of symmetry, and means for creating an opposing magnetic field of force so that said fields are overlapping and are in opposition along their axes and their resultant field changes sign along said axes, said object to be imaged being located at the point along said axes where the resultant field is substantially zero.

6. The method of forming an image of an object which consists of emitting electrons, condensing said electrons on an object by means of a first electron focusing field, focusing said electrons to form a virtual image of the object by means of a second electron focusing field, transforming said virtual image into a real image by means of a third field, and adjusting said first and second fields so that they overlap and change in sign in the region including the object whose image is to be formed.

7. The method described by claim 6 in which the condensing and focusing is effected in part by a common electron focusing field.

8. The method of forming an image of an object which includes establishing a first electron focusing field, establishing a second opposed electron focusing field, adjusting the ratio of the strengths of said fields so that they overlap and change sign in the position substantially including the object to be imaged, emitting electrons, directing said emitted electrons through the object, and focusing electrons leaving the object to form an image of said object.

9. The method of forming an image of an object which includes establishing a first electron focusing field, establishing a second opposed electron focusing field, adjusting the ratio of the strengths of said fields so that they overlap and change sign in the position substantially including the object to be imaged, emitting electrons, condensing said emitted electrons upon the object, and focusing electrons leaving the object to form an image of said object.

10. The method of forming an image of an object which includes establishing a first electron focusing field, establishing a second opposed electron focusing field, adjusting the ratio of

the strengths of said fields so that they overlap and change sign in the position substantially including the object to be imaged, emitting electrons, directing said emitted electrons through the object, and focusing the electrons leaving the object by varying the strengths of said fields while maintaining said ratio to form an image of said object.

electron emitting object which includes establishing a first electron focusing field, establishing a second opposed electron focusing field, adjusting the ratio of the strengths of said fields so that they overlap and change sign in the position substantially including the electron emitting object to be imaged, and focusing electrons leaving the object to form an image of said object.

11. The method of forming an image of an

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