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CORRECTION FOR SPHERICAL AND CHROMATIC ABERRATIONS IN ELECTRON LENS

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Fig. 1.

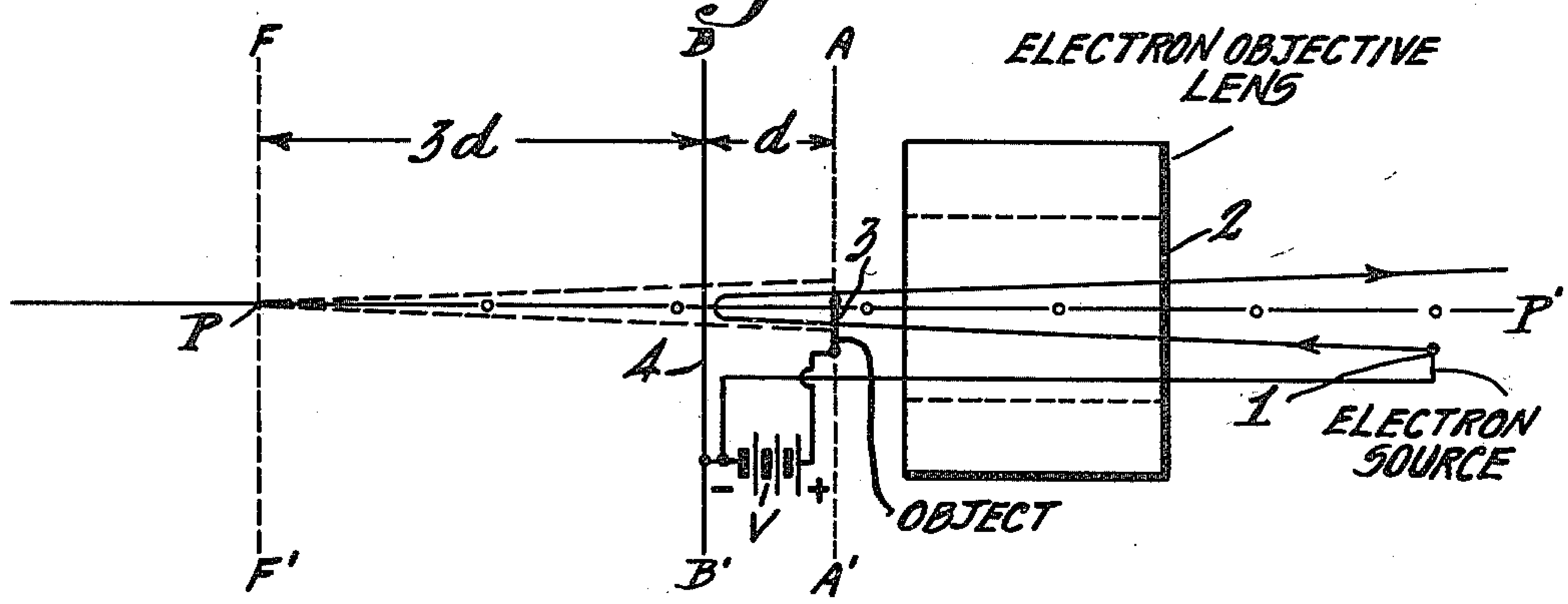


Fig. 2.

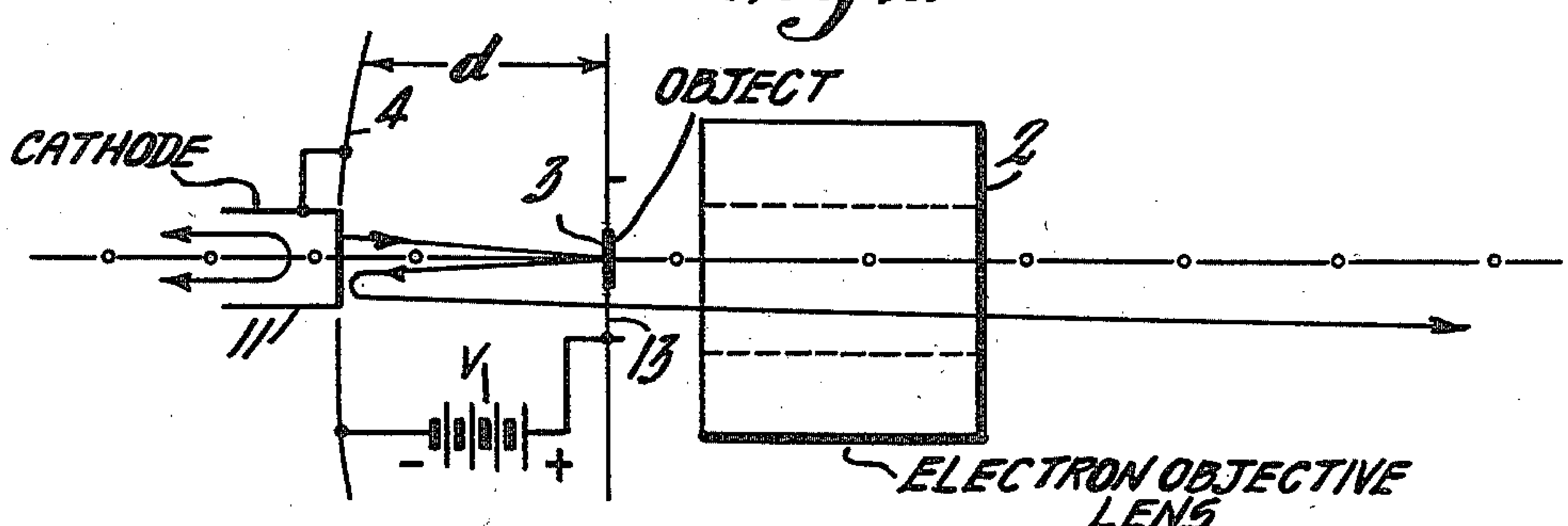
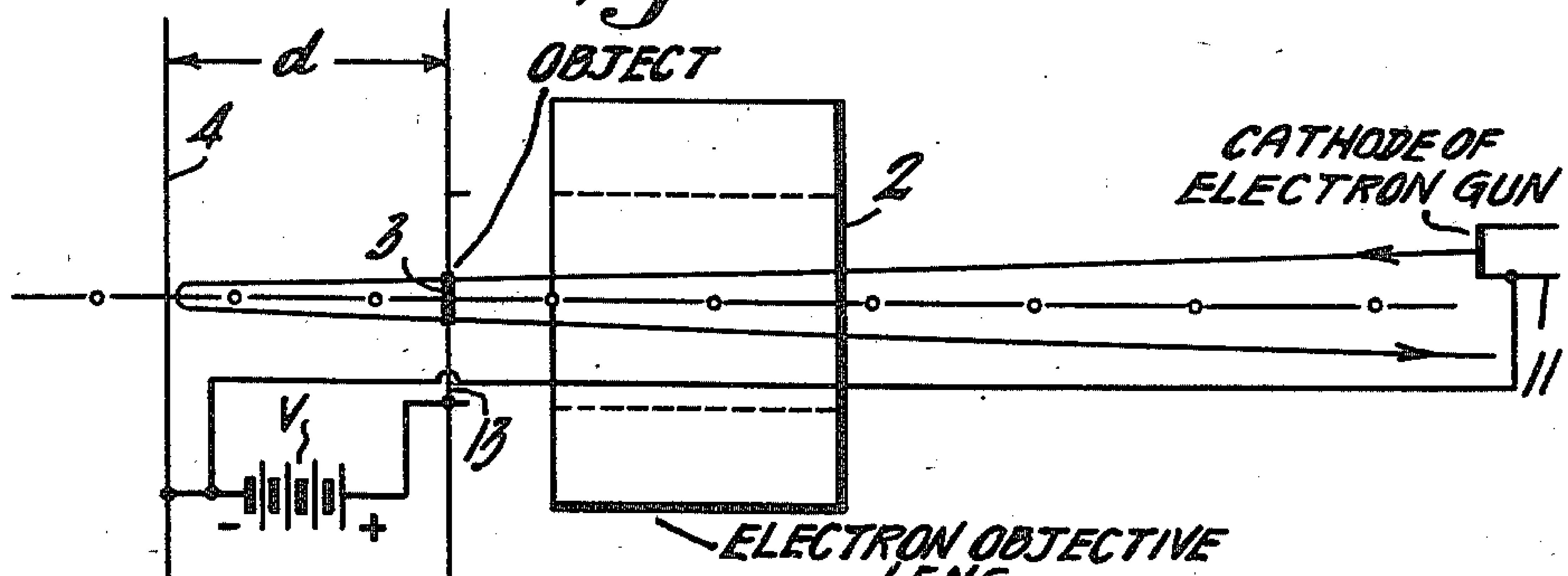


Fig. 3.



INVENTOR.
Edward G. Ramberg

BY [signature]

ATTORNEY

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CORRECTION FOR SPHERICAL AND CHROMATIC ABERRATIONS IN ELECTRON LENS

Edward G. Ramberg, New York, N. Y., assignor to Radio Corporation of America, a corporation of Delaware

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6 Claims. (Cl. 250—49.5)

1

This application is a division of applicant's copending U. S. application, Serial No. 459,814, filed September 26, 1942, upon which Patent 2,401,315 was granted June 4, 1946, entitled Correction for spherical and chromatic aberrations in electron lens, and assigned to the same assignee as the instant application.

This invention relates generally to electron lens systems and particularly to the correction of spherical and chromatic aberrations of electron lenses.

Heretofore various methods have been devised for correcting only for chromatic aberration in electron lenses. Such systems have included no means for correcting simultaneously for inherent spherical aberration. In an article by Otto Scherzer in Zeitschrift für Physik, vol. 114, November 18, 1939, pages 427 to 434, entitled "The theoretically attainable resolving power of the electron microscope," a system is described for correcting only for spherical aberration, in which the aperture defect (spherical aberration) is supposedly compensated with electron mirrors or screen lenses by changing the sign of the aperture defect of the projection lens of the microscope focusing system. This method disclosed by Scherzer has not been found very practical.

The instant invention contemplates the simultaneous correction for both chromatic and spherical aberrations of an electron lens by subjecting an electron beam to a decelerating electron field within the focus of the lens to be corrected.

The simultaneous correction for both types of aberration has been found to be dependent upon a predetermined relation between the depth of the electron decelerating field and the focal length of the lens to be corrected. While simultaneously complete correction of both spherical and chromatic aberrations is difficult in practice, complete correction of spherical, and partial correction of chromatic aberration is feasible by the method and means herein disclosed for an electron objective lens. Likewise, the method and means disclosed may be utilized for correcting only for spherical, or only for chromatic aberration.

Among the objects of the invention are to provide an improved means for and method of correcting simultaneously for spherical and chromatic aberration in an electron lens system. Another object is to provide an improved means for and method of correcting simultaneously for spherical and chromatic aberrations in an electron lens system which includes a decelerating

2

electron field. Another object is to provide an improved means for and method of correcting simultaneously for spherical and chromatic aberrations in an electron lens system which includes a decelerating electron field forming an electron reflector, wherein the inherent aberrations of the electrons lens are substantially neutralized by aberrations of equal value and opposite sign provided by the decelerating field. Another object is to provide an improved means for and method of correcting spherical and chromatic aberrations of an electron lens wherein electrons irradiating an object are subjected to the action of a decelerating field which reflects electrons received from the object and applies them to an electron lens. A further object of the invention is to provide an improved means for and method of correcting for spherical and chromatic aberrations of an electron lens wherein a source of electrons is focused upon an object, electrons transmitted by the object are subjected to a decelerating field, and said field reflects said transmitted electrons back through the electron lens, whereby the inherent aberrations of the lens are substantially neutralized by the aberrations of the decelerating field. Another object is to provide a curved electrode for forming one boundary of the above mentioned decelerating field.

The invention will be described by reference to the accompanying drawing, of which Figure 1 is a schematic diagram for the purpose of explaining theoretically the operation of the system; Figure 2 is a schematic diagram of one embodiment of the invention; and Figure 3 is a schematic diagram of a second embodiment of the invention. Similar reference numerals are applied to similar elements throughout the drawing.

Referring to Figure 1, an electron beam from a source **1** is focused by an electron objective lens **2** on an object **3** disposed in the field thereof. The positive terminal of a source of potential V is connected to the object **3**. The negative terminal of the potential source V is connected to a plane electrode **4** disposed in the path of the electron beam and in a plane BB' substantially normal thereto. The negative terminal of the potential source V is also connected to the electron source **1**. The distance d between the electrode **4** and the object **3** is somewhat less than ¼ of the focal length of the objective lens **2**. The electric field formed between the object **3** and the decelerating electrode **4** provides an electron mirror. A virtual image of the object will be formed in the plane FF' at a distance $3d$ from the plane BB' of the decelerating electrode 4.

The spherical aberration (the radius of the circle of confusion about the image point P at the intersection of the plane FF' with the lens axis PP') is

$$\Delta r_s = 4d\theta^3 \quad (1)$$

where θ is the angle of inclination of the incident electrons to the axis at the object and image.

Similarly, the chromatic aberration of the decelerating field (the circle of confusion for electrons of kinetic energy $V+\Delta v$ at the plane AA' of the object 3) is

$$\Delta r_c = 4d\theta \frac{\Delta v}{V} \quad (2)$$

If we suppose that the focal point of the lens 2 falls in the plane FF' (that is, the focal length is somewhat larger than $4d$), the spherical aberration of the lens will be

$$\Delta r_s = Cf\theta^3 \quad (3)$$

where C may be any value larger than one-quarter. (See R. Rebsch, Ann. d. Physik, 31, 551, 1938.)

Likewise, the chromatic aberration of the electron lens will be

$$\Delta r_c = Kf \frac{\Delta V}{v} \theta \quad (4)$$

where K is less than one but very close to unity. Since f is slightly larger than $4d$, it is apparent that the aberrations may be made to substantially neutralize each other.

Referring to Figure 2, a source of electrons, comprising a cathode 11, irradiates an object 3, comprising a substantially opaque material supported by a conducting film 13. The positive terminal of the source of potential V is connected to the object support 13. The negative terminal of the potential source V is connected to a reflecting electrode 4 disposed substantially normal to the beam of the emitted electrons and in the same plane as the electron emitting cathode 11. The distance d is derived in the same manner as described for the theoretical system of Figure 1. Electrons striking the object 3 are reflected therefrom in the decelerating field between the object support 13 and the reflecting electrode 4 and are again reflected by the electron mirror, formed by the decelerating field, away from the cathode 11 and reflecting electrode 4. The last mentioned reflected beam passes through the object support 13 and is focused by the electron lens 2 to form a desired image. It is to be understood that the electron lens 2 may be of either the electromagnetic or electrostatic types well known in the art. When the distance d, between the object and the reflecting electrode 4, is suitably related to the focal length of the electron lens 2, the resultant spherical and chromatic aberrations of the decelerating field will substantially neutralize the inherent spherical and chromatic aberrations of the electron lens 2. The system described has particular utility in the observation of substantially electron-opaque surfaces. In a system of this type, correction for chromatic aberration is particularly desirable.

Figure 3 comprises a system, similar to the theoretical system described in Figure 1, wherein an electron source comprising a cathode 11 is focused by an electron lens 2 upon an electron permeable object 3 in the field of the lens. The positive terminal of a source of potential V is connected to the object 3 through the object support 13. The negative terminal of the potential source V is connected to a reflecting electrode 4 disposed at a distance d from the object and substantially normal to the axis of the electron lens. The negative terminal of the potential source V is likewise connected to the cathode 11. Electrons transmitted by the object 3 are reflected by the reflecting electrode 4 by means of the decelerating field between the object 3 and the reflecting electrode 4. The reflected electrons are again transmitted either by the object 3, or its support 13, and again focused by the electron lens 2. In a system of the type of Figure 3, correction for spherical aberration is primarily important, while correction for chromatic aberration is of secondary importance.

In each of the systems described heretofore, the correction for aberrations may be somewhat improved by curving the reflecting electrode 4, as shown in Figure 2, to provide additional compensation for electrons at higher angles of incidence, and to adapt the aberrations of the reflector to those of a given lens. Furthermore, the distance d may be increased, if desired, by increasing its negative potential with respect to the potential at the plane AA' of the object 3. With this arrangement, the distance between the object plane and the plane of reversal of the electrons becomes somewhat less than ¼ of the focal length of the lens, while the distance d is merely dependent upon the value of the potential V.

Thus the invention described comprises a method of and means for correcting simultaneously for spherical and chromatic aberrations of an electron lens, by subjecting electrons focused by the lens to the compensating effects of electronic arrays of the required strength and phase derived from an electron decelerating field. Substantially perfect correction of the chromatic and spherical aberrations of the lens may be obtained by a predetermined relation between the depth of the decelerating field and the focal length and aberration constants of the electron lens.

I claim as my invention:

1. In an electron beam focusing system for imaging an object including an electron lens and a decelerating electric field, the method of correcting simultaneously for spherical and chromatic aberrations comprising adjusting the depth of said field to have a predetermined relation to the focal length of said lens, irradiating said object, subjecting electrons reflected from said object to said field to again reflect said electrons and to derive an electronic image having aberrations of equal value and opposite sign to the aberrations of said lens, and focusing said reflected electrons by said lens to form a corrected image of said object.

2. Apparatus for correcting simultaneously for spherical and chromatic aberrations of an electron beam by an electron lens including means for supporting an object, means for irradiating said object, means for forming a decelerating field, an electron lens, means for subjecting electrons reflected from said object to said field to again reflect said electrons and to derive an electronic image having aberrations of equal value and opposite sign to aberrations in said lens, and means for applying said reflected electrons to said lens to form a corrected image of said object.

3. Apparatus for correcting simultaneously for spherical and chromatic aberrations of an elec-

tron beam by an electron lens including means for supporting an object, means for irradiating said object, means for forming a decelerating field, an electromagnetic electron lens, means for subjecting electrons derived from said object to said field to reflect said electrons and to derive an electronic image having aberrations of equal value and opposite sign to aberrations in said lens, and means for applying said reflected electrons to said lens to form a corrected image of said object.

4. Apparatus for correcting simultaneously for spherical and chromatic aberrations of an electron beam by an electron lens including means for supporting an object, means for irradiating said object, means including a curved reflector and a source of potential connected between said reflector and the plane of said object for forming a decelerating field, an electron lens, means for subjecting electrons derived from said object to said field to reflect said electrons and to derive an electronic image having aberrations of equal value and opposite sign to aberrations in said lens, and means for applying said reflected electrons to said lens to form a corrected image of said object.

5. Apparatus for correcting substantially for chromatic aberration and simultaneously partially for spherical aberration of an electron beam by an electron lens including means for supporting an object, means for irradiating said object, means for forming a decelerating field, an electron lens, means for subjecting electrons reflected from said object to said field to again reflect said electrons and to derive an electronic image having aberrations of equal value and opposite sign to aberrations in said lens, and means for applying said reflected electrons to said lens to form a corrected image of said object.

6. Apparatus for correcting simultaneously spherical and chromatic aberrations of an electron beam in an electron lens system including means providing an electron decelerating field, an electron lens, means for successively applying said beam to said field and to said lens, and means for adjusting the depth of said field to have a predetermined relation to the focal length of said lens to correct simultaneously for the inherent spherical and chromatic aberrations in said lens.

EDWARD G. RAMBERG.

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