United States Patent [19]

Akahori et al.

[11] **3,715,582**

[45] **Feb. 6, 1973**

[54] **METHOD OF AND APPARATUS FOR ATTAINING FOCUSING FOLLOWING VARIATION IN MAGNIFICATION IN ELECTRON MICROSCOPE**

[75] Inventors: **Hiroshi Akahori; Morioki Kubozoe; Toshihiro Furuya; Sadayasu Ueno,** all of Katsuta, Japan

[73] Assignee: **Hitachi, Ltd.,** Tokyo, Japan

[22] Filed: **Aug. 21, 1970**

[21] Appl. No.: **65,996**

[30] **Foreign Application Priority Data**

Feb. 13, 1970 Japan 45/40945
May 15, 1970 Japan 45/12377

[52] **U.S. Cl.** ..... **250/49.5 A,** 250/49.5 D
[51] **Int. Cl.** **H01j 37/10**
[58] **Field of Search** ..... 250/49.5 A, 49.5 C, 49.5 D

[56] **References Cited**

UNITED STATES PATENTS

3,509,275	4/1970	Deeley	250/49.5 A
3,535,514	10/1970	Cardile	250/49.5 A
2,406,974	9/1946	Vance	250/49.5 A
3,504,176	3/1970	Thon	250/49.5 D
3,509,275	4/1970	Deeley	250/49.5 A

Primary Examiner—Archie R. Borchelt
Assistant Examiner—C. E. Church
Attorney—Craig, Antonelli, Stewart & Hill

[57] **ABSTRACT**

A method of and apparatus for attaining the focusing following a variation in the magnification in an electron microscope having an image producing lens system consisting of three or more lenses or generally *n* lenses including at least an objective lens, an intermediate lens and a projective lens. Means are provided in the apparatus so that, when the value of excitation current for the magnification varying lens is varied to vary the magnification, the excitation current supplied to the focus adjusting lens can be set at a value corresponding to the variation in the magnification, whereby the focusing following the variation in the magnification by the magnification varying lens as well as the adjustment of the intensity of illumination can be achieved by a single regulating operation.

8 Claims, 7 Drawing Figures

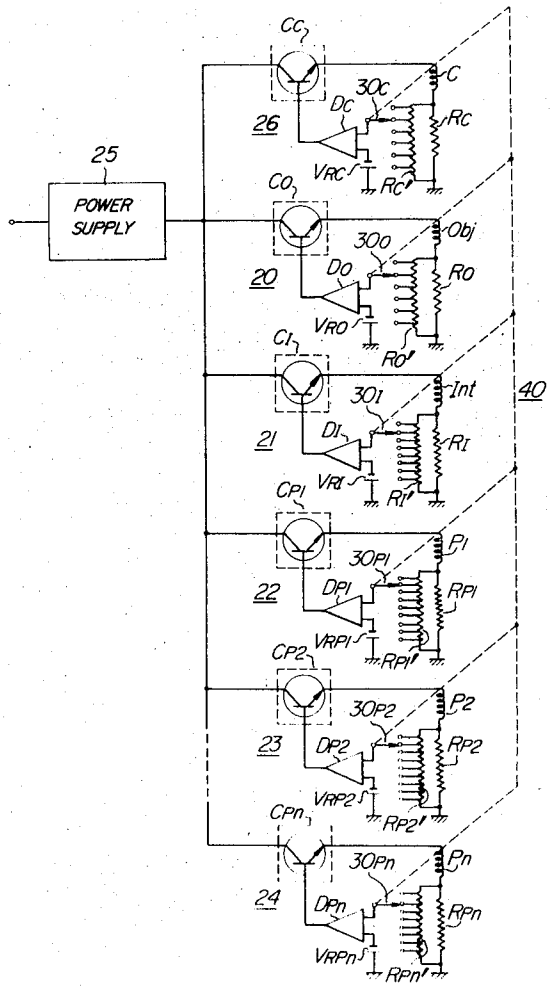


FIG. 1

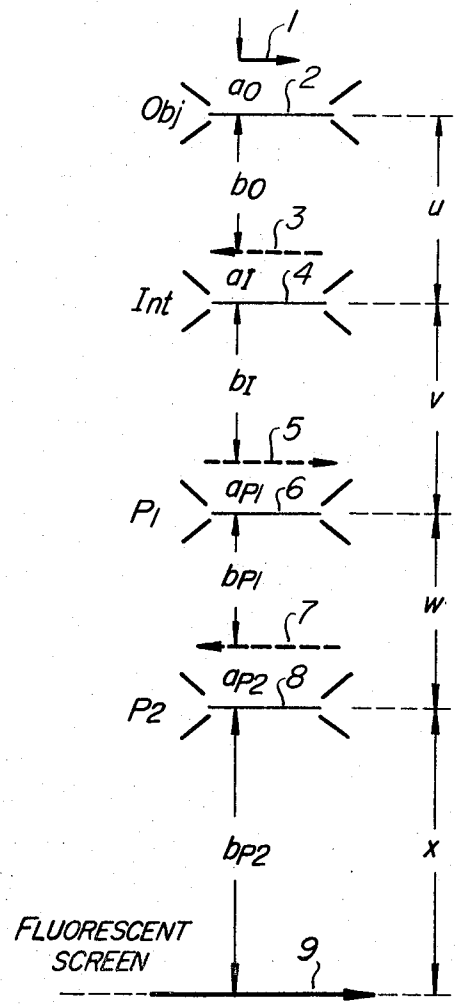
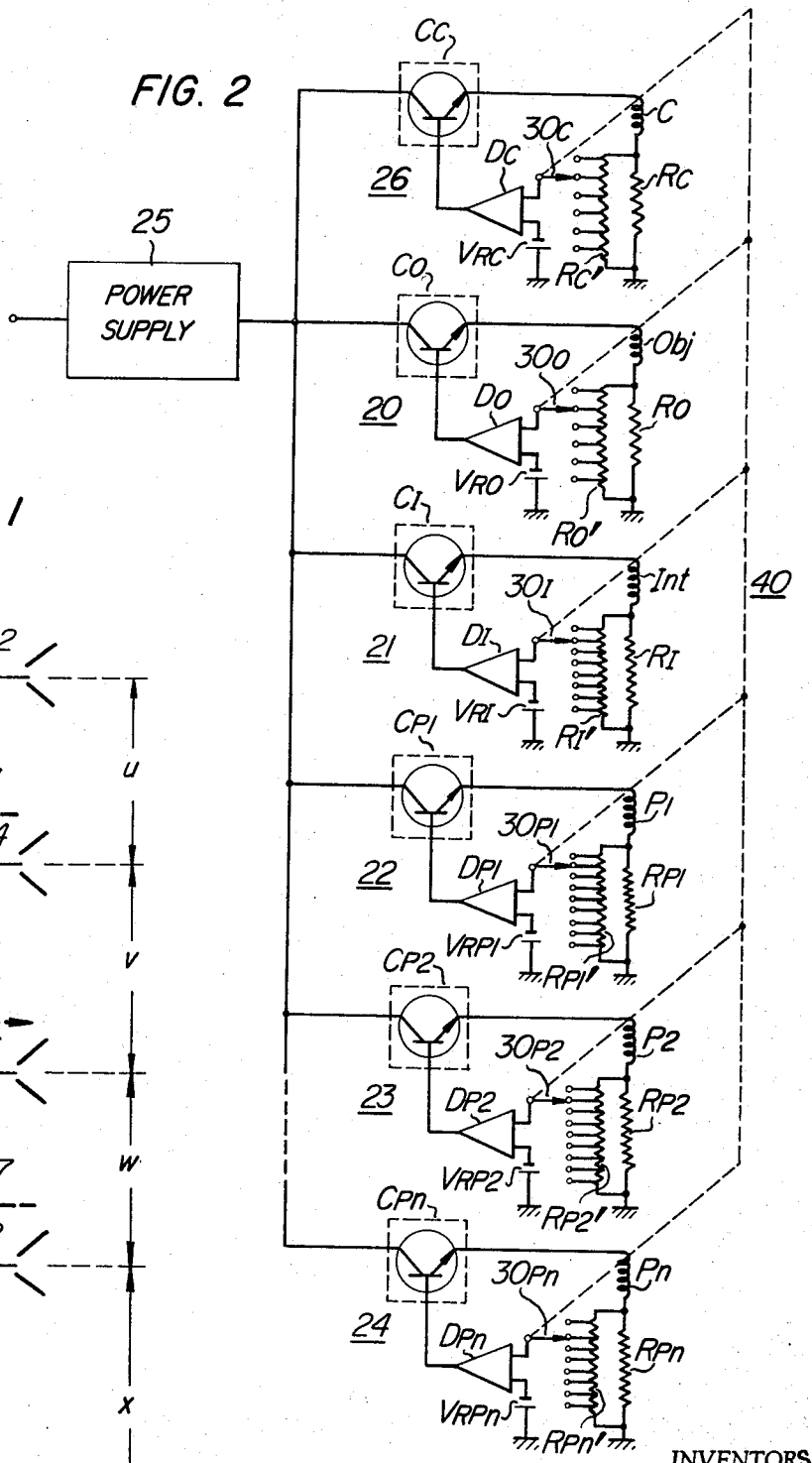


FIG. 2



INVENTORS
HIROSHI AKAHORI, MORIOKI KUBOZOE,
SADAYASU UENO & TOSHIHIRO FURUYA

BY Craig, Antonelli, Stewart & Hill
ATTORNEYS

FIG. 3

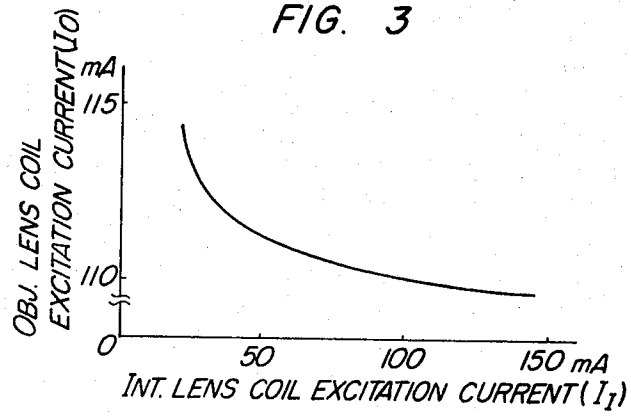
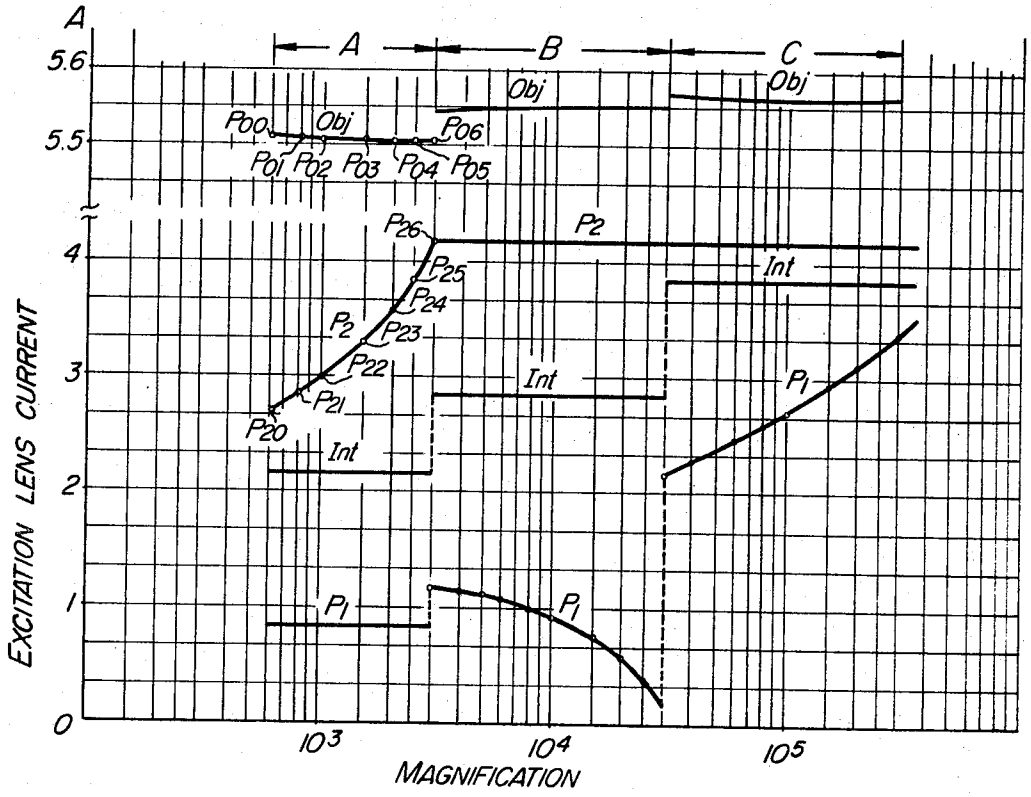


FIG. 4



INVENTORS

HIROSHI AKAHORI, MORIOKI KUBOZOE,
SADAYASU UENO & TOSHIHIRO FURUYA

BY Craig, Antonelli, Stewart & Hill

ATTORNEYS

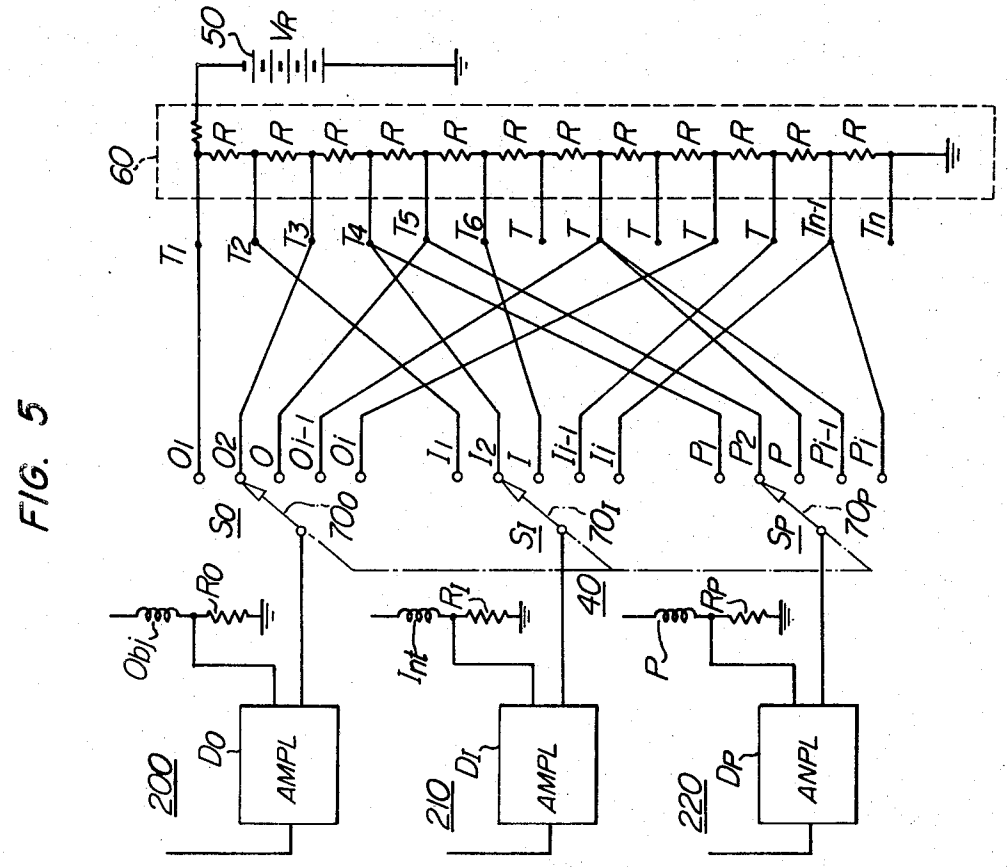


FIG. 5

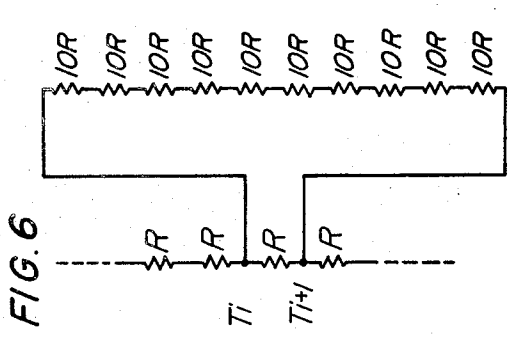


FIG. 6

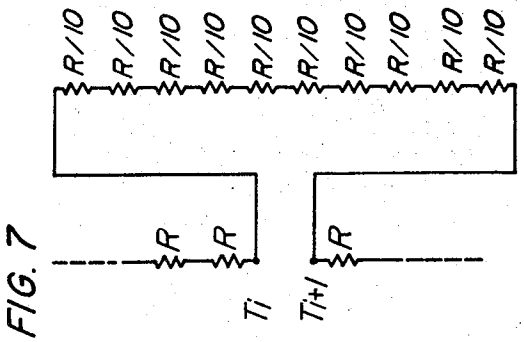


FIG. 7

INVENTORS

HIROSHI AKAHORI, MORIOKI KUBOZOE,
SADAYASU UENO & TOSHIHIRO FURUYA

BY Craig, Antonelli, Stewart & Hill

ATTORNEYS

METHOD OF AND APPARATUS FOR ATTAINING FOCUSING FOLLOWING VARIATION IN MAGNIFICATION IN ELECTRON MICROSCOPE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to electron lens systems of electron microscopes. More particularly, it relates to a method and apparatus for attaining the focusing and adjustment of the intensity of illumination in response to a variation in the magnification when the magnification is varied by varying the value of excitation current supplied to the magnification varying lens in an electron microscope.

2. Description of the Prior Art

In an electron microscope, the magnification must be suitably varied for the observation of various kinds of specimens or for the observation of those specimens under various states. The manipulation for the variation in the magnification in an electron microscope includes varying the value of excitation current supplied to the magnification varying lens for varying the magnification and then varying the value of excitation current supplied to the focus adjusting lens for attaining the focusing thereby to produce an enlarged image of a specimen on a final image screen. In the electron microscope, the intensity of illumination of the final image must be kept constant since the intensity of illumination of the image varies in inverse proportion to the square of the magnification with an increase or decrease in the magnification.

By way of example, in an electron microscope having a three-stage image producing lens system consisting of an objective lens, an intermediate lens and a projective lens, the intermediate or projective lens acts as the magnification varying lens, while the objective lens acts as the focus adjusting lens. Heretofore, a microscopist has manually adjusted the value of excitation current supplied to the focus adjusting lens and condenser lens while observing the final image produced on the fluorescent screen.

However, such a focusing system has been defective in that an elongated period of time is required for the focus adjusting manipulation and, since the specimen is exposed to the electron beam for such a long period of time, the surface of the specimen is damaged to such an extent that it is no longer possible to observe the specimen under ordinary conditions. This defect has been especially marked in the case of a specimen such as a high molecular compound which is easily affected by heat. Further, it has been very difficult with the prior art focusing system to attain the focusing following a variation in the magnification in the case of observation of a specimen such as a piece of tissue with a so-called low magnification of the order of several thousand times or less, and the manipulation for the proper focusing has required an elongated period of time. Thus, this defect has aggravated the above-described defect.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a novel method of attaining the focusing following a variation in the magnification in an electron microscope which overcomes the defects described above, and an apparatus for carrying out such a method.

Another object of the present invention is to provide an apparatus for attaining the focusing following a variation in the magnification in an electron microscope in which means are provided so that, when the value of excitation current supplied to the magnification varying lens is varied to vary the magnification, the excitation current supplied to the focus adjusting lens can be set at a value corresponding to the above variation in the magnification to attain the focusing in simultaneous relation with the manipulation for the variation in the magnification, and at the same time, the excitation current supplied to the condenser lens can also be set at the value corresponding to the above variation in the magnification to adjust the intensity of illumination, whereby the variation in the magnification can be always carried out in the state in which the focusing is properly attained and the intensity of illumination is completely adjusted.

A further object of the present invention is to provide an electron microscope having an image producing lens system consisting of three or more lenses or generally n lenses including at least an objective lens, an intermediate lens and a projective lens, in which means are provided to set the excitation current supplied to the focus adjusting lens at a value corresponding to a variation in the value of excitation current supplied to the magnification varying lens so that the focusing following the variation in the magnification can be carried out by a single regulating operation thereby to eliminate the troublesome manipulation involved in the handling of the electron microscope.

A yet further object of the present invention is to provide, in an electron microscope having an image producing lens system consisting of three or more lenses or generally n lenses including at least an objective lens, an intermediate lens and a projective lens, a method of varying the magnification of the electron lens comprising fixing the focal length of the intermediate lens and varying the value of excitation current supplied to the lens or lenses disposed in the stage or stages lower than the intermediate lens for carrying out the variation in the magnification.

A still further object of the present invention is to provide, in an electron microscope having an image producing lens system consisting of three or more lenses or generally n lenses including at least an objective lens, an intermediate lens and a projective lens, a method and apparatus for varying the magnification of the electron microscope in which the value of excitation current supplied to the intermediate lens is varied stepwise while the value of excitation current supplied to the lens or lenses disposed in the stage or stages lower than the intermediate lens is continuously varied at a portion corresponding to the stepped portion of the intermediate lens excitation current so as to carry out the variation in the magnification.

A common object of the present invention is to provide a novel method of varying the magnification of an electron microscope and an apparatus capable of attaining the focusing following the variation in the magnification by a single regulating operation in simultaneous relation with the above variation in the magnification.

Other objects, features and advantages of the present invention will be readily apparent from the following detailed description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic view showing the relative position of electron lenses and the positional relation between image planes in an electron microscope having a four-stage image producing lens system consisting of an objective lens, an intermediate lens, a first projective lens and a second projective lens.

FIG. 2 is a block diagram of an embodiment of the present invention having interlocking control means for the simultaneous control of the values of excitation current supplied to electron lenses in an electron microscope having an image producing lens system consisting of four or more lenses or generally n lenses including at least an objective lens, an intermediate lens, a first projective lens and a second projective lens.

FIG. 3 is a graph showing the relation between objective lens excitation current and intermediate lens excitation current when, in an electron microscope having an image producing lens system consisting of three or more lenses or generally n lenses including at least an objective lens, an intermediate lens and a projective lens, the value of excitation current supplied to the electron lens or lenses disposed in the stage or stages lower than and including the projective lens is kept constant.

FIG. 4 is a graph showing the manner of variation in the values of excitation current supplied to electron lenses for illustrating an embodiment of the method of varying the magnification according to the present invention when it is applied to an electron microscope having a four-stage image producing lens system consisting of an objective lens, an intermediate lens, a first projective lens and a second projective lens.

FIG. 5 shows a modification of the embodiment shown in FIG. 2.

FIGS. 6 and 7 are modifications of parts of the embodiment shown in FIG. 5.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The relative position of electron lenses and the positional relation between image planes in an electron microscope having a four-stage image producing lens system consisting of an objective lens, an intermediate lens, a first projective lens and a second projective lens will be described with reference to FIG. 1. In FIG. 1, a specimen to be observed is designated by the reference numeral 1. The objective lens O_{bj} has a principal plane 2 and an image forming plane 3. The intermediate lens I_{nt} has a principal plane 4 and an image forming plane 5. The image forming plane 5 of the intermediate lens Int corresponds at the same time to the object plane for the first projective lens P_1 disposed in the next stage. The first projective lens P_1 has a principal plane 6 and an image forming plane 7. The image forming plane 7 of the first projective lens P_1 corresponds at the same time to the object plane for the second projective lens P_2 disposed in the next stage. The second projective lens P_2 has a principal plane 8 and an image forming plane 9. Generally, a fluorescent screen for the image observation or the emulsion surface of a photographic plate or film is disposed at the image forming plane 9 of the second projective lens P_2.

Suppose that f_o, a_o and b_o are the focal length of the objective lens O_{bj}, the distance between the specimen 1 and the principal plane 2 of the objective lens O_{bj}, and the distance between the principal plane 2 and the image forming plane 3 of the objective lens O_{bj}, respectively. Suppose further that f_I, a_I, b_I; f_{P1}, a_{P1}, b_{P1}; and f_{P2}, a_{P2}, b_{P2} are those of the intermediate lens I_{nt}, first projective lens P_1 and second projective lens P_2, respectively, and u, v and w are the distances between the principal planes of the four lenses. Then, the following equations hold:

$$1/a_o + 1/b_o = 1/f_o \quad (1)$$

$$1/a_I + 1/b_I = 1/f_I \quad (2)$$

$$1/a_{P1} + 1/b_{P1} = 1/f_{P1} \quad (3)$$

$$1/a_{P2} + 1/b_{P2} = 1/f_{P2} \quad (4)$$

$$a_I + b_o = u \quad (5)$$

$$a_{P1} + b_I = v \quad (6)$$

$$a_{P2} + b_{P1} = w \quad (7)$$

Suppose further that M_o, M_I, M_{P1} and M_{P2} are the magnification of the objective lens O_{bj}, that of the intermediate lens I_{nt}, that of the first projective lens P_1 and that of the second projective lens P_2, respectively. Then, the total magnification M_T is given by

$$M_T = b_o/a_o \times b_I/a_I \times b_{P1}/a_{P1} \times b_{P2}/a_{P2}$$
$$= M_o \cdot M_I \cdot M_{P1} \cdot M_{P2}$$

In the electron microscope, the variation in the magnification is generally carried out by varying the value of excitation current supplied to the intermediate lens I_{nt} thereby varying the focal length f_I of the intermediate lens I_{nt}, that is, by shifting the position of the object plane 3 for the intermediate lens I_{nt}. More precisely, when the distance a_I is varied to $a_I + \alpha_I$, the magnification of the intermediate lens I_{nt} is now given by $M_I' = b_I/(a_I + \alpha_I)$, and the magnification of the objective lens O_{bj} is given by $M_o' = (b_o - \alpha_I)/a_o$. Thus, the magnification at the portion including the objective lens O_{bj} and the intermediate lens I_{nt} is varied from $M_o \cdot M_I$ to $M_o' \cdot M_I' = (b_o - \alpha_I)/a_o \cdot b_I/(a_I + \alpha_I)$. However, due to the fact that the image forming plane 3 of the objective lens O_{bj} is shifted by $-\alpha_I$, the image would be out of focus unless the focal length f_o of the objective lens O_{bj} is varied correspondingly provided that the distance a_o is fixed.

Thus, with the system described above, the variation in the magnification by the intermediate lens results in blurring of the image, and therefore, the value of excitation current supplied to the objective lens must be adjusted for attaining the proper focusing each time the magnification is varied. Modern electron microscopes have a widened range of variation in the magnification. In such an electron microscope, the focusing operation must be done quite frequently and a lot of time is required for the focusing operation, resulting in troublesome and inconvenient handling of the electron microscope. Other drawbacks involved in the prior art system include damage to the specimen due to exposure to the electron beam for a long period of time.

With a view to overcome the above drawbacks, the present invention contemplates the provision of an electron microscope which is provided with means for setting the excitation current supplied to the focus adjusting lens at a value corresponding to a variation in the magnification in simultaneous relation with the variation in the magnification by the magnification varying lens. The present invention contemplates also the provision of a novel method of carrying out the variation in the magnification.

The method of varying the magnification according to the present invention will be described in detail hereunder.

1. At first, the variation in the focal length f_o of the objective lens O_{bj} when the magnification is varied by varying the value of excitation current supplied to the intermediate lens I_{nt} in the relative position shown in FIG. 1 will be discussed. In this case, the focal length f_I of the intermediate lens I_{nt} is solely subject to variation. Thus, the focal lengths f_{P1} and f_{P2} are fixed and the distances a_o, a_I, a_{P1}, b_{P1}, a_{P2} and b_{P2} are kept constant. The total magnification M_T in this case is given by

$$M_T = M_o \cdot M_I \cdot M_{P1} \cdot M_{P2}$$
$$= (b_o/a_o) \cdot (b_I/a_I) \cdot (b_{P1}/a_{P1}) \cdot (b_{P2}a_{P2})$$
$$= K_1 (b_o/a_I) \quad (8)$$

where $K_1 = (b_I/a_o) \cdot (b_{P1}/a_{P1}) \cdot (b_{P2}/a_{P2})$.

Substituting a_I and b_o in the equation (8) by those obtained from the equations (2) and (5), M_T is expressed as

$$M_T = K_1 [u(b_I - f_I) - b_I f_I / b] f_I \quad (9)$$

The focal length f_I is sought from the equation (9) as

$$f_I = \frac{ub_I}{u + b_I + \frac{b_I}{k_I} M_T} = \frac{ub_I}{K_2 + K_3 M_T} \quad (10)$$

where $u + b_I = K_2$ and $b_I/K_1 = K_3$. From the equation (1), f_o is given by

$$f_o = a_o b_o (a_o + b_o)$$

Thus, from this equation and the equations (2) and (5), f_o is expressed as

$$f_o = \frac{a_0\{ub_I - (u + b_I)f_I\}}{(a_0 + u)b_I - (a_0 + u + b_I)f_I} \quad (11)$$

Substituting f_I in the equation (11) by that in the equation (10), f_o is expressed as

$$f_o = a_0 u \frac{K_3 M_T}{(a_0 + u)K_3 M_T + a_0 b_I} = \frac{a_0 u}{a_0 + u + \frac{a_0 K_1}{M_T}} \quad (12)$$

The equation (12) is differentiated with M_T to find the variation Δf_o of f_o when f_I is varied to vary M_T. The result is given by

$$(\Delta f_o)_{fI} = (K_1/u) \cdot f_o^2 \cdot M_T^{-2} \cdot \Delta M_T \quad (13)$$

The above equation represents the variation Δf_o of the focal length f_o of the objective lens O_{bj} when the total magnification is varied by ΔM_T by varying the value of excitation current supplied to the intermediate lens I_{nt}.

2. The next discussion is directed to the case in which the magnification is varied by varying the value of excitation current supplied to another lens, for example, the first projective lens P_1 instead of the intermediate lens I_{nt}. In this case, the focal length f_{P1} is solely subject to variation. Thus, the focal lengths f_I and f_{P2} are fixed and the distances a_o, b_{P1}, a_{P2} and b_{P2} are kept constant. The total magnification M_T in this case is given by

$$M_T = M_o \cdot M_I \cdot M_{P1} \cdot M_{P2} = (b_o/a_o) \cdot (b_I/a_I) \cdot (b_{P1}/a_{P1}) \cdot (b_{P2}/a_{P2})$$
$$= k_1 (b_o/a_I) \cdot (b_I/a_{P1}) = k_1 (u - a_I/a_I) \cdot (v - a_{P1}/a_{P1}) \quad (14)$$

where $k_1 = (b_{P1}/a_0 \cdot b_{P2}/a_{P2}$

From the equations (1) through (7), M_T is expressed as

$$M_T = \frac{k_1}{f_I b_{P1}} \cdot \frac{-\{uv - (u+v)f_I\}b_{P1}}{f_{P1}} \cdot \frac{\{uv - (u+v)f_I + (u+f_1)b_{P1}\}f_{P1}}{k_3 f_{P1}} = \frac{k_2 b_{P1} - (k_2 + k_4)f_{P1}}{k_3 f_{P1}} \quad (15)$$

where $uv - (u+v)f_I = K_2$, $(u - f_I)b_{P1} = k_4$ and $f_I \cdot b_{P1}/h_1 = k_3$.

The focal length f_{P1} is sought from the equation (15) as

$$f_{P1} = k_2 b_{P1}/(k_2 + k_4 + k_3 M_T) \quad (16)$$

The focal length f_o is given by

$$f_o = \frac{a_o b_o}{a_o + b_o} = a_o \frac{k_2 b_{P1} - (k_2 + k_4)f_{P1}}{(a_o v + k_2)b_{P1} - \{a_o(v + b_{P1}) + k_2 + k_4\}f_{P1}}$$

Substituting f_{P1} in the above equation by that in the equation (16), f_o is expressed as

$$f_o = a_o \frac{k_2 k_3 M_T}{a_o(vk_4 - b_{P1}k_2) + (a_o v + k_2)k_3 M_T} = a_o k_2 \frac{1}{a_o v + k_2 + \frac{a_o u k_1}{M_T}} \quad (17)$$

The equation (17) is differentiated with M_T to find the variation Δf_o of f_o when M_T is varied by varying f_{P1}. The result is given by

$$(\Delta f_o)_{f_{P1}} = (k_1/k_2) \cdot u f_o^2 \cdot M_T^{-2} \cdot \Delta M_T \quad (18)$$

The above equation represents the variation Δf_o of the focal length f_o of the objective lens O_{bj} when the magnification is varied by varying the value of excitation current supplied to the first projective lens P_1.

3. The ratio between the equations (13) and (18) is sought to seek the ratio between the variations Δf_o of the focal length f_o of the objective lens O_{bj} when the magnification is varied to the same value.

For the sake of simplicity, it is assumed that $u \approx v$ and $(b_{P1})_{f_{P1}} \approx (b_I)_{f_{P1}}$ since such conditions hold in most cases.

$$\frac{(\Delta f_o)_{f_I}}{(\Delta f_o)_{f_{P1}}} = \frac{\frac{K_1}{u} \cdot f_o^2 \cdot M_T^{-2} \cdot \Delta M_T}{\frac{k_1}{k_2} \cdot u \cdot f_o^2 \cdot M_T^{-2} \cdot \Delta M_T} = \frac{1}{u^2} \cdot \frac{k_2}{k_1} \cdot K_1 \frac{uv - (u+v) \cdot (f_I)_{f_{P1}}}{u^2} \cdot \frac{a_o \cdot (b_I)_{f_I} \cdot (b_{P1})_{f_I}}{(b_{P1})_{f_{P1}} \cdot a_o \cdot (aP_1)_{f_I}} \cdot (M_{P1})_{f_I}$$

The above equation can be simplified as

$$\frac{(\Delta f_o)_{f_I}}{(\Delta f_o)_{f_{P1}}} \left(\neq 1 - \frac{2(f_I)_{f_{P1}}}{u} \right) \cdot (M_{P1})_{f_I} \quad (19)$$

when $u \approx v$, f_{P2} is constant and $(b_{P1})_{f_I} \approx (b_{P1})_{f_{P2}}$. Since the focal length f_I of the intermediate lens I_{nt} is used in the range in which it is smaller than u and the relation $f_I << u$ holds at a high magnification, the following equation can be obtained:

$$\frac{(\Delta f_o)_{f_I}}{(\Delta f_o)_{f_{P1}}} \doteqdot (M_{P1})_{f_I} \quad (20)$$

The above equation shows the fact that, when the magnification is varied by varying the focal length f_I of the intermediate lens I_{nt}, the variation Δf_o of the focal length f_o of the objective lens O_{bj} is greater by the magnification of the first projective lens P_1 than when the magnification is varied by varying the focal length f_{P1} of the first projective lens P_1.

In other words, the above equation implies that the variation f_o in the focal length f_o of the objective lens for the variation in the magnification is smaller when the magnification is varied by varying the focal length f_{P1} of the first projection lens than when the magnification is varied by varying the focal length f_I of the intermediate lens. The ratio between the two cases is about $1/M_{P1}$. Ordinarily the value of M_{P1} is 10 to 20. Consequently, when the magnification is varied by varying the focal length f_{P1} of the first projection lens, the

image falls within the depth of focus of the objective lens O_{bj} to become a focused or distinct image even without varying the focal length f_o of the objective lens.

This applies also to an electron microscope having a three-stage image producing lens system consisting of an objective lens, an intermediate lens and a projective lens. In this case too, the variation in the magnification can be carried out in a substantially sharply focused state by varying the magnification by the projective lens while fixing the value of excitation current supplied to the intermediate lens.

However, the variation in the magnification solely by the first projective lens is not practical because its magnification varying range is narrow.

In such a case, as will be described later with reference to FIG. 4, the entire magnification range of the electron microscope is divided into N sections, at the boundaries of which the excitation current of the intermediate lens is varied discontinuously, but within each of which it is kept constant. Within each section the excitation current of the lens of a subsequent stage to the intermediate lens, that is, of the first or second projection lens is finely varied so that the magnification is varied without a substantial variation in the focal length f_o of the objective lens, that is, in the substantially focused state.

In order to keep the focal length of the objective lens substantially constant irrespective of the variation in the magnification, the variation in the excitation current of the objective lens corresponding to the variation in the excitation current of the intermediate lens, which has been calculated or measured in advance, is imparted to the excitation current of the objective lens in coordination with the switching of the excitation current of the intermediate lens. In this manner the magnification can be varied over its entire range in a substantially focused state.

The above description has referred to the method of varying the magnification of an electron microscope having a three-stage image producing lens system consisting of an objective lens, an intermediate lens and a projective lens.

FIG. 2 is a block diagram of means for controlling the excitation current supplied to electron lenses in an electron microscope having an image producing lens system consisting of four lenses or generally n lenses including at least an objective lens, an intermediate lens, a first projective lens and a second projective lens. As for the means for controlling the excitation current supplied to electron lenses in an electron microscope having a three-stage image producing lens system, the case in which the excitation current supplied to the lenses disposed in the stages lower than the third stage is fixed at a predetermined value in FIG. 2 may be considered.

Referring to FIG. 2, the reference numerals **20**, **21**, **22** and **23** designate an objective lens excitation current control system, an intermediate lens excitation current control system, a first projective lens excitation current control system, and a second projective lens excitation current control system, respectively. The reference numeral **24** designates generally an nth projective lens excitation current control system. The electron lens control systems **20**, **21**, **22**, **23** and **24** are supplied with current from a common stabilized power supply **25**.

The objective lens excitation current control system **20** includes an objective lens coil O_{bj}, a detecting resistor R_o for detecting the excitation current flowing through the objective lens coil O_{bj}, a voltage-dividing resistor R_o' for the detecting resistor R_o, an error amplifier D_o such as a balanced DC amplifier for detecting and amplifying the difference between a voltage detected by the voltage-dividing resistor R_o' and a reference voltage V_{Ro}, and an output control means C_o which is controlled by the output from the amplifier D_o for controlling the excitation current flowing through the coil O_{bj}. The lens excitation current flowing through the objective lens coil O_{bj} is converted into a voltage by the combination of the current detecting resistor R_o and the voltage-dividing resistor R_o', and the difference between this voltage and the reference voltage V_{Ro} is detected and amplified by the error amplifier D_o. The output from the error amplifier D_o is supplied to the output control means C_o for stabilizing the current flowing through the excitation coil O_{bj}. That is, the lens excitation current is maintained at a predetermined value depending on the value of the detecting resistor R_o. The setting of the lens excitation current flowing through the objective lens coil O_{bj} can be varied by varying the resistance of the detecting resistor R_o or the voltage division ratio of the voltage-dividing resistor R_o'. In the present embodiment the value of the excitation current flowing through the objective lens coil O_{bj} is varied by varying the voltage division ratio of the voltage-dividing resistor R_o' connected in parallel with the detecting resistor R_o. For this purpose, the voltage-dividing resistor R_o' may have a variable resistance so that it may be varied continuously or the voltage-dividing resistor R_o' may be divided stepwise as shown in FIG. 2 so that its resistance may be changed over by a changeover switch 30_o.

The operation of the remaining electron lens excitation current control systems **21**, **22**, **23** and **24** is similar to the operation of the objective lens excitation current control system **20**, and suffixes I, P_1, P_2 and P_n are attached to the corresponding components of the intermediate lens excitation current control system **21**, first projective lens excitation current control system **22**, second projective lens excitation current control system **23**, and nth projective lens excitation current control system **24**, respectively.

The variation in the values of excitation current in the electron lens excitation current control systems is carried out by an interlocking change-over means **40** such as a rotary switch which changes over the voltage division ratios R' of the detecting resistors which are preset to supply required current values in a fixed relationship with each other. As an example, when the excitation currents for the electron lenses disposed in the stages lower than and including the first projective lens P_1 are kept at respective fixed values and the focal length f_l of the intermediate lens I_{nt} is varied to vary the magnification of the electron micriscope shown in FIG. 2, a corresponding variation Δf_o of the focal length f_o of the objective lens O_{bj} will be as shown in the equation (13). It is known that the focal length of a magnetic lens generally varies in inverse proportion to the square of the excitation current. Suppose, in this case, that I_o and I_l are the excitation current for the objective lens O_{bj} and the excitation current for the intermediate lens I_{nt}, respectively. Then, the following equation is derived from the equation (12):

$$I_o^2 = C_1 + [1/(C_2 I_I^2 + C_3)] \quad (21)$$

where C_1, C_2 and C_3 are constants. This relation is illustrated in FIG. 3.

Therefore, the voltage division ratio of the voltage-dividing resistor R_I' for the detecting resistor R_I in the intermediate lens excitation current control system **21** and the corresponding voltage division ratio of the voltage-dividing resistor R_o' for the detecting resistor R_o in the objective lens excitation current control system **20** may be determined on the basis of the relation between the intermediate lens excitation current I_I and the objective lens excitation current I_o shown in FIG. 3, and the change-over switches 30_I and 30_o for the change-over of these voltage division ratios may be mechanically coupled to each other by the interlocking change-over means **40** as to attain the focusing following the variation in the magnification by a single regulating operation. The interlocking change-over means **40** may be disposed between the objective lens excitation current control system **20** and the intermediate lens excitation current control system **21** or it may be arranged to simultaneously control the values of all the electron lens excitation currents as shown in FIG. **2**. In this latter case, the change-over of the values of excitation current for the lenses disposed in the stages lower than the intermediate lens I_{nt} may be such that the excitation currents are kept at the same values in spite of change-over of the steps for varying the voltage division ratio of the voltage-dividing resistors R'. For example, the change-over steps may be connected to the same voltage-dividing point so as to show the same resistance.

A condenser lens excitation current control system **26** is so arranged that the excitation current for a condenser lens coil C is set at a value corresponding to the variation in the value of excitation current for the intermediate lens coil O_{bj} in the intermediate lens excitation current control system **21** in order to adjust the intensity of illumination of the image following the variation in the magnification. Since the intensity of illumination of the final image can be kept always constant in spite of the variation in the magnification, photographing, especially continuous photographing can be done without any fear of underexposure or overexposure.

The above description has referred to the simultaneous control means for the electron lens excitation currents on the basis of the discussion given in paragraph 1.

The following description is directed to a method and apparatus for varying the magnification on the basis of the discussion given in paragraphs 2 and 3.

FIG. **4** is a graphic illustration of one form of the method of varying the magnification in an electron microscope having a four-stage image producing lens system consisting of an objective lens O_{bj}, an intermediate lens I_{nt}, a first projective lens P_1 and a second projective lens P_2. In FIG. **4**, the horizontal and vertical axes represent the magnification and the lens excitation current, respectively. As will be apparent from FIG. **4**, the value of excitation current for the intermediate lens I_{nt} is varied stepwise and the value of excitation current for the first projective lens P_1 or second projective lens P_2 is varied continuously or stepwise at portions corresponding to the stepped portions of the intermediate lens excitation current for varying the magnification. Points bearing the marks on the characteristic curves for the first and second projective lenses P_1 and P_2 represent the current values varied stepwise.

In the magnification range A of from 600 to 3,000 times, the values of excitation current for the intermediate lens I_{nt} and first projective lens P_1 are fixed at about 2.17A and 0.83A, respectively, while the value of excitation current for the second projective lens P_2 is varied continuously or discontinuously (stepwise) from about 2.67A to 4.17A. P_{20}, P_{21}, . . . P_{26} represent the stepwise varying values of excitation current for the second projective lens P_2, and P_{oo}, P_{o1}, . . . P_{o6} represent the settings of excitation current for the objective lens O_{bj} corresponding to the stepwise varying values of excitation current for the second projective lens P_2.

Therefore, the voltage division ratios of the voltage-dividing resistors R' for the detecting resistors R in the respective electron lens excitation current control systems may be set to have a relation as described above and these voltage-dividing resistors may be mechanically coupled to each other by the interlocking change-over means **40** shown in FIG. **2**. The above arrangement applies also to the magnification ranges described below.

In the magnification range B of from 3,000 to 30,000 times, the values of excitation current for the intermediate lens I_{nt} and second projective lens P_2 are kept constant, while the value of excitation current for the first projective lens P_1 is varied continuously or stepwise. In this range, the value of excitation current for the objective lens O_{bj} is varied in a manner as shown.

In the magnification range C of from **30,000** to **300,000** times, the values of excitation current for the intermediate lens I_{nt} and second projective lens P_2 are kept constant, while the value of excitation current for the first projective lens P_1 is varied continuously or stepwise. In this range, the value of excitation current for the objective lens O_{bj} is varied in a manner as shown.

It will be apparent from FIG. **4** that the value of excitation current for the objective lens O_{bj} is varied stepwise in a relation similar to the stepped variation of the value of excitation current for the intermediate lens I_{nt}, but the variation in the value of excitation current for the objective lens O_{bj} at the portions corresponding to the stepped portions of the excitation current for the intermediate lens I_{nt} is very little compared with the variation in the value of excitation current for other electron lenses.

It will be understood that the variation in the magnification according to the so-called Zoom lens system can be carried out by an arrangement in which the values of excitation current for the respective electron lenses are varied in a relation as shown in FIG. **4** and an interlocking change-over means **40** as shown in FIG. **2** is used for the simultaneous control of the variation of these current values.

While the above description has referred to the case of varying the values of excitation current by varying the resistances of the detecting resistors or the voltage division ratios of the voltage-dividing resistors in the respective excitation current control systems, such may be carried out by varying the voltage value of the reference voltage source V_R.

Another embodiment of the present invention in which the value of reference voltage is varied to vary the value of excitation current will be described with reference to FIG. **5**. Although a three-stage image producing lens system consisting of an objective lens

O_{bj}, an intermediate lens I_{nt} and a projective lens P is shown in FIG. 5 by way of example, it will be apparent for those skilled in the art that the present embodiment is also applicable to an n-stage lens system. The suffixes O, I and P are attached to components belonging to excitation current control systems **200**, **210** and **220** for the objective lens O_{bj}, intermediate lens I_{nt} and projective lens P, respectively. The reference numerals **50** and **60** designate a source of reference voltage and a voltage-dividing resistor group, respectively, which are common to the electron lens excitation current control systems **200**, **210** and **220**. A change-over means S_o for the objective lens excitation current control system **200** includes a change-over switch 70_o and a plurality of stationary contacts $O_1, O_2, \ldots O_i$. A change-over means S_I for the intermediate lens excitation current control system **210** includes a change-over switch 70_I and a plurality of stationary contacts $I_1, I_2, \ldots I_i$. Similarly, a change-over means S_P for the projective lens excitation current control system **220** includes a change-over switch 70_P and a plurality of stationary contacts $P_1, P_2, \ldots P_i$. The voltage-dividing resistor group **60** has a plurality of voltage-dividing terminals $T_1, T_2, \ldots T_{n-1}, T_n$.

The precision of the setting of the value of excitation current is different in each electron lens, but a very high degree of precision is required for every electron lens. For example, in order to eliminate any fluctuation in the intensity of illumination of the image as well as in the focal point when the magnification is varied in a lens system consisting of a plurality of stages, the values of excitation current must not deviate beyond 0.001 percent in the case of the objective lens and 1 percent in the case of the condenser and projective lenses. Therefore, the voltage-dividing resistor group **60** used for the setting of the current value requires such a number of resistors which will correspond to the very finely divided units of the current value and the individual resistors must also be of high precision. Taking the above point into consideration, the voltage-dividing resistor group **60** is composed of a series connection of n unit resistors having the same rated resistance R, and the stationary contacts $O_1, O_2, \ldots O_i$; $I_1, I_2, \ldots I_i$; and $P_1, P_2, \ldots P_i$ of the respective change-over means S_o, S_I and S_P are connected to the voltage-dividing terminals corresponding to the desired current settings in a manner as, for example, shown in FIG. 5. When, for example, the change-over switch 70_P of the change-over means S_P for the projective lens excitation current control system **220** is brought into contact with the stationary contact P_2, the input terminals of an error amplifier D_P is connected through the change-over switch 70_P and stationary contact P_2 to the voltage-dividing terminal T_5 of the voltage-dividing resistor group **60** connected to the reference voltage source **50**. Thus, a reference voltage which is $5/n$ of the voltage V_R of the reference voltage source **50** is applied to the error amplifier D_P. Similarly, a voltage which is any desired division of the reference voltage V_R can be obtained when each of the change-over switches 70_o and 70_I is brought into contact with a suitable stationary contact. Therefore, the variation in the magnification can be always carried out in a sharply focused state when these stationary contacts are previously connected to give respective fixed voltages as described in the first embodiment and the change-over switches 70_o, 70_I and 70_P are simultaneously changed over by an interlocking change-over means **40**. Two or three of the stationary contacts in the change-over means S_o, S_I and S_P are connected to the same voltage-dividing terminal of the voltage-dividing resistor group **60** as shown in FIG. 5. In order to deal with possible fluctuation in the reference voltage value applied to the error amplifier D_o, D_I or D_P when these stationary contacts are connected to the same terminal, the input resistors for the error amplifiers must have a sufficiently large resistance.

When it is required that the divided voltage of the reference voltage V_R applied to the error amplifier has a more precise value lying intermediate between the divided voltage values appearing at the adjacent terminals T_i and T_{i+1} of the voltage-dividing resistor group **60**, a series circuit including ten resistors each having a resistance of **10R** may be connected in parallel with the resistor R lying between the voltage-dividing terminals T_i and T_{i+1} as shown in FIG. **6** or a series circuit including ten resistors each having a resistance of R/10 may be connected in series across the terminals T_i and T_{i+1} as shown in FIG. 7. By this arrangement, the excitation current can be set at a value which is one place higher in precision than that obtained with the arrangement shown in FIG. 5.

We claim:

1. In an electron microscope comprising a three-stage image forming electron lens system consisting of an objective lens, an intermediate lens and a projection lens arranged in this order in the direction of an electron beam axis, and excitation current sources each connected to each of said electron lenses for supplying excitation currents thereto and for stabilizing said excitation currents, each of said excitation current sources including means for adjusting said excitation currents; a focusing apparatus comprising means for mechanically coupling said excitation current adjusting means to simultaneously control said excitation currents, so that when the magnification of said electron microscope is varied by varying the excitation current of said intermediate lens while keeping the excitation current, of said projection lens constant, the excitation current of said objective lens is set at the value compensating for the variation of said excitation current of said intermediate lens to provide proper focusing.

2. In an electron microscope having a three-stage image producing electron lens system consisting of an objective lens, an intermediate lens and a projective lens which are disposed in the above order in the direction of the electron beam axis, an apparatus for attaining the focusing following a variation in the magnification comprising an excitation power supply connected to each of said electron lenses for supplying excitation current to said electron lenses and stabilizing the excitation current, each said excitation power supply including an excitation current control means for controlling the excitation current flowing through the lens coil, a detecting resistor for detecting the excitation current flowing through said lens coil, means for varying the resistance of said resistor, a source of reference voltage for supplying a reference voltage for comparison between it and the voltage detected by said detecting resistor, and an amplifier for detecting and amplifying the difference between said detected volt-

age and the voltage of said reference voltage source, said amplifier having its first input terminal connected to said detecting resistor, its second input terminal connected to said reference voltage source and its output terminal connected to said excitation current control means, and means mechanically coupling said resistance varying means for said detecting resistors in said excitation power supplies for the simultaneous control of the resistances of said detecting resistors so as to set the excitation current for said objective lens at a value corresponding to a variation of the value of excitation current for said intermediate lens when the value of excitation current for said intermediate lens is varied while maintaining the excitation current for said projective lens at a constant value.

3. An apparatus for effecting focusing dependent upon the variation in magnification of an electron microscope, comprising: an electron source for producing electrons; an irradiation electron lens system including a plurality of condenser lenses for converging said electrons into an electron beam to direct said electron beam to a specimen; a three-stage image forming electron lens system consisting of an objective lens, an intermediate lens and a projection lens; excitation current sources each connected to each of said lenses for supplying excitation currents thereto and for stabilizing said excitation currents, each of said excitation current sources including means for adjusting each respective excitation current; and means for mechanically coupling said excitation current adjusting means to simultaneously control said excitation currents, so that when the magnification of said electron microscope is varied by varying the excitation current of said intermediate lens while keeping the excitation current of said projection lens constant, the excitation current of said objective lens is set at the value compensating for the variation of said excitation current of said intermediate lens to provide proper focusing necessitated by the variation in the magnification and at the same time the excitation currents of said condenser lenses are set at the values corresponding to the variation of said magnification to adjust the brightness dependent upon said variation in magnification.

4. In an electron microscope comprising a three stage image forming electron lens system including an objective lens, an intermediate lens, and a projection lens arranged sequentially in the direction of the electron beam axis, and excitation sources connected to each respective electron lens for supplying excitation currents thereto and for stabilizing said excitation currents, each of said excitation sources including means for adjusting said excitation currents, an improved focusing apparatus comprising:

control means, coupled to each of said current sources and said lenses, for simultaneously maintaining the excitation current of said projection lens constant,

for varying the excitation current of said intermediate lens, and

for adjusting the excitation current of said objective lens to a predetermined value to provide proper focusing in response to said variation of the excitation current of said intermediate lens, wherein each of said excitation sources comprises a power supply, a switching transistor connected between said power supply and a respective electron deflection element associated with each lens and a control circuit responsive to said control means for appropriately energizing said switching transistor to control the flow of current to said deflection element, and wherein

said deflection element comprises a lens coil and wherein said control circuit comprises a voltage dividing circuit, connected to said lens coil, and a differential amplifier having one input connected to a respective source of reference potential and another input adjustably connected to said voltage dividing circuit, the output of said differential amplifier being connected to control the operation of said switching transistor.

5. An improved focusing apparatus according to claim 4, wherein said control means further includes a mechanically ganged switching arrangement having respective switches connected between each voltage divider and the corresponding input to each of said differential amplifiers.

6. A method of varying the magnification of an electron microscope having a four-stage image forming electron lens system consisting of an objective lens, intermediate lens, and first and second projection lenses arranged in this order in the direction of an electron beam axis, excitation current sources each connected to each of said electron lenses for supplying an excitation current thereto and for stabilizing said excitation current, each of said excitation current sources including means for adjusting said excitation current, and means for mechanically coupling said excitation current adjusting means to simultaneously control said excitation currents in a predetermined relation therebetween, comprising the steps of:

a. dividing the entire magnification range into a plurality of sections and varying the excitation current of said intermediate lens discontinuously at the boundaries of said sections while keeping said excitation current of said intermediate lens constant within each section;

b. varying the excitation current of one of the electron lenses disposed downstream of said intermediate lens within said each section to vary the magnification of said electron microscope; and

c. keeping the excitation current of said objective lens, within said each section, substantially constant at a value compensating for the variation of the excitation current of said intermediate lens.

7. A method of varying the magnification of an electron microscope according to claim 6, in which said one electron lens of the step (b) is said first projection lens.

8. A method of varying the magnification of an electron microscope according to claim 6, in which said one electron lens of the step (b) is said second projection lens.

* * * * *