International Academic Institute for Science and Technology

International Academic Journal of Science and Engineering
Vol.10, No.2, 2023, pp.89-95.

ISSN 2454-3896

International Academic Journal of Science and Engineering

www.iaiest.com

Effect of the Outer Pole Length on the Optical Properties in Gemini Lens

Emad Abdul-majeed Othman [a], Mohammed A. Hussein [b]

[a] *College of Science, University of Kirkuk, Iraq. E-mail: scphm001@uokirkuk.edu.iq*
[b] *Assistant Professor, College of Agriculture / Hawija, University of Kirkuk, Iraq. E-mail: mohdphy@uokirkuk.edu.iq*

Abstract

In order to get some of the most important optical and geometrical properties of scanning electron microscope lens, Such as focal length, lens aberration (spherical and chromatic aberration), Axial magnetic field distribution, trajectory of the electron beam, diameter of the electron probe in this work. A computer programs used to achieve the results in objective lens which called Gemini lens.by changing the outer pole length of lens to get a better optical property. The results under constant lens excitation (NI=1000 A-t) and accelerating voltage (Vr=8 KV) are (f=3.93mm, Cs=2.59mm, Cc=2.87mm) and the magnetic field distribution Bz =1.72 tesla

Keyword: Objective Lens, Lens Aberrations, Diameter of Electron Probe, Gemini Lens, Optical Properties of Gemini Lens.

DOI:10.71086/IAJSE/V10I2/IAJSE1012
Received: 15 March 2023/Revised: 20 April 2023/Accepted: 11 May 2023/Published: 29 June 2023

Introduction

The scanning electron microscope (SEM) is a branch in Electron Optics (EO) which deals with electron beam in magnetic fields to form an image at the surface of the specimen. The first SEM was invented by (knoll) in 1935 by evaluating the surface of specimen and the defects on it [1]**.**In 1942 the first scanning electron microscope (SEM) was developed by Zworykin, he showed that the secondary electron (SE) gives us image for features and properties of surface (surface topography) and the electronic multiplier tube used was used as magnifier for secondary electron [2]**,** it follows the development in 1965 by smith who laid the theoretical foundation to calculate the electron probe and lens aberration and brightness**.** [3]**.** A few years ago the SEM has been manufactured as size of human finger and a magnetic lens used in it[4]**.**The SEM consists of many parts (Electron Gun (EG) ,Illuminating System , Imagining System),the Electron Gun (EG) consider as the most important parts in SEM ,which consists of Electrostatic lens and accelerator of electron ,and it is source of electron beam[5] .The optical performance of any electron microscope depends on electron gun types, there is two types of Electron Gun, Thermionic Emission Gun (TEG), Field Emission Gun (FEG) [6] **.**The illuminating system consists of several magnetics lenses which comes directly after the electron gun and it is responsible for lighting the specimen, The first two lenses known as (Condenser Lenses) which works on assembling the electron beam, And the third one called (Objective Lens) which is responsible for focusing the beam on specimen surface [7]**.** Imaging system consists of detectors and image reviewer devices, the image formed by assembling the emitted electrons from specimen surface ,This happens by different detectors depending on electron energy and the energy of converting them into an image through single-transformation to image device displayed on the screen [8]

The objective magnetic lens is consider as important part in SEM because its works on reducing the defects and distortion that effect on clarity and filtering of a forming image ,also to achieve a highest peak of magnetic flux density distribution (Bz) and better optical properties such as focal length (f) and spherical with chromatic aberrations (Cs),(Cc) respectively [9]

The main target in this work to get a best possible geometrical and optical properties in Gemini lenses and discuss how the lens get affected by changing its outer pole length

Designing the Objective Lens and Computers Programs

The objective magnetic lens is designed by using finite element method(FEM) which become one of the main ways to design electron lenses ,this Gemini lens described as (26*50)mesh size .With different length in outer pole side of the lens , when L1 represent a Gemni lens with 13 mm length above a optical axis and L2=10 mm , L3=7mm , L4=4 mm all of them under constant Excitation (NI=1000 A-t), in this work (Flux M31) program used to draw the magnetic flux density lines, these lines is draw by attaching the magnetic flux points at each points of the clamp which has the same voltage while these lines takes circular form concentrated around the iron poles ,and the lines are convergent in high density areas and sparse in low density areas [10], figure 1 show the magnetic flux density lines.

Axial Magnetic Flux Density Distribution (Bz)

(AMAG) program is manufactured by Munro in 1975 and developed by (Lencova) in 1986 , this program used to calculate the axial magnetic flux density distribution (Bz) [11] . It has high accuracy because of using many gridlines [12] figure 2 describe the axial magnetic flux density (Bz) to the distance (Z) for designed Gemini objective lenses with different length of its outer pole.

Optical Focal Properties of Objective Lenses

And to evaluate the efficiency of any magnetic lens, the optical focal properties should be found and tested, also this work use M21 which was invented also by Munro in 1975 , this program used to get a focal properties like spherical and chromatic aberration (Cs, Cc) and focal length (f), the chromatic aberration represent the ability of the lens to focus the electron beam with uniform wave lengths and the spherical aberration represent the lens ability to produce the electron beam that configured as point form with least opportunities of confusion and the focal length represent the power of the lens to focusing the electron beam. Figures (3-1),(3-2),(3-3) shows Chromatic aberrations (Cc) and Spherical aberrations (Cs) and focal length (f) as function of accelerating voltage Vr=8 KV all under same excitation factor (NI=1000 A-t).

Trajectory of Electron beam Inside the Objective Lenses

Also, the trajectory of electron beam inside the objective lens is calculated by M21 program. The fourth order of (Runge-Kutta) method used to solve the paraxial ray function and achieve the path of the beam[9]. At constant excitation (NI=1000 A-t) and accelerating voltage Vr=8 KV as shown in figure 4

The Diameter of the Electron Probe of Objective Lenses calculation

The probe is defined as source image of electron which is consider as an important factor that tests the ability of resolving and also helping to accurate formation of chromatic and spherical aberrations coefficient and aperture angle [13], the total effective diameter (dp) was calculated with all other (ds, dc, dg, dd) due to spherical and chromatic aberration as function of aperture angle αp, for all four changes in objective Gemini lens (L1,L2,L3,L4) in constant excitation NI=1000 A-t and potential voltage Vr=8 KV, to find an ideal value of aperture angle α opt and achieve the lowest value of probe diameter dp as shown in figure 5

Results

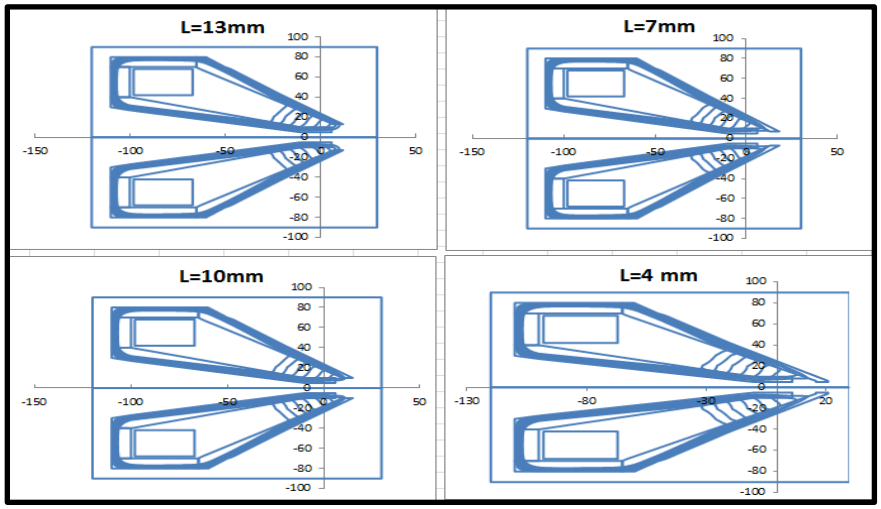


Fig. 1: Objective Lenses with Magnetic Flux Line of Four Lenses (L1, L2, L3, L4)

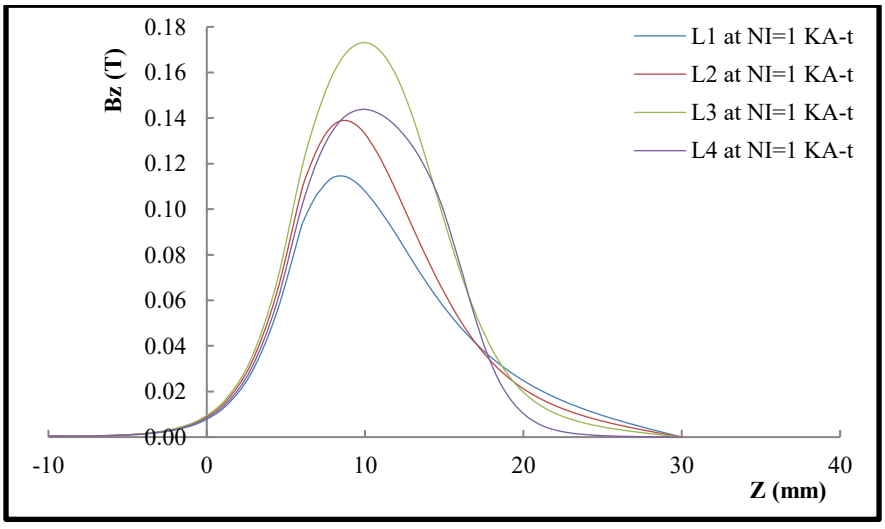


Fig. 2: Gemini Lenses Axial Magnetic Flux Density Distribution at Excitation =1000 A-t for (L1, L2, L3, L4)

The axial magnetic flux density distribution is calculated by (AMAG) program for all designed objective lenses (L1, L2, L3, L4) under same excitation (NI=1000 A-t), clearly, we can notice that L3 has a highest peak of magnetic flux density (B_{max}) and that give it the best focal properties.

Table 1: Electromagnetic Analyses for 4 Types of Objective Gemini Lenses at Constant Excitation (NI=1000 A-t)

Lens Icon	Peak Site Z(mm)	B_{max} (T)
L1	8.66	0.14
L2	8.5	0.13
L3	9.5	0.17
L4	9.75	0.44

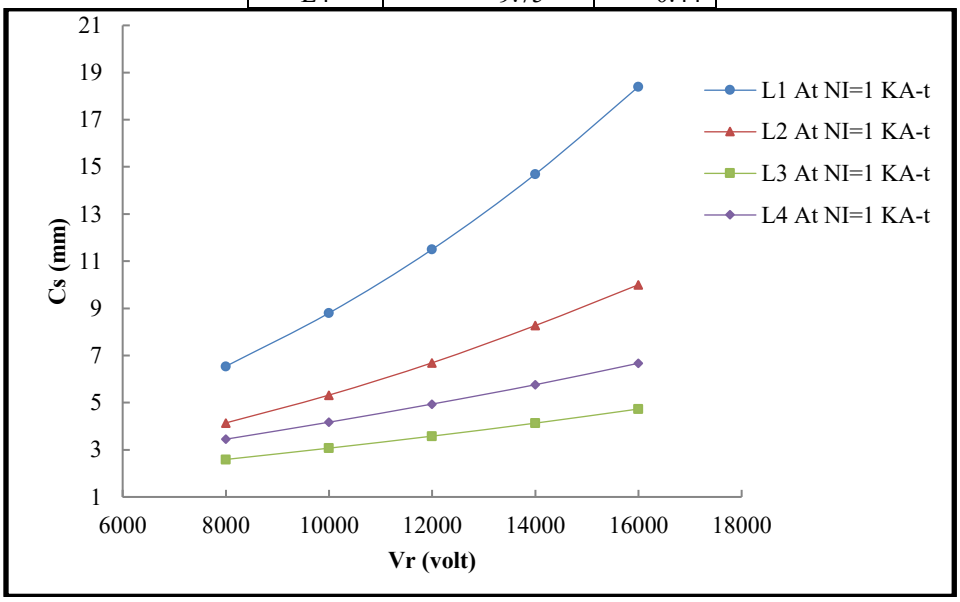


Fig. 3-1: The Spherical Coefficient Values to Accelerating Voltage Vr at Constant Excitation NI =1000 (A-t) for Four Lenses (L1, L2, L3, L4)

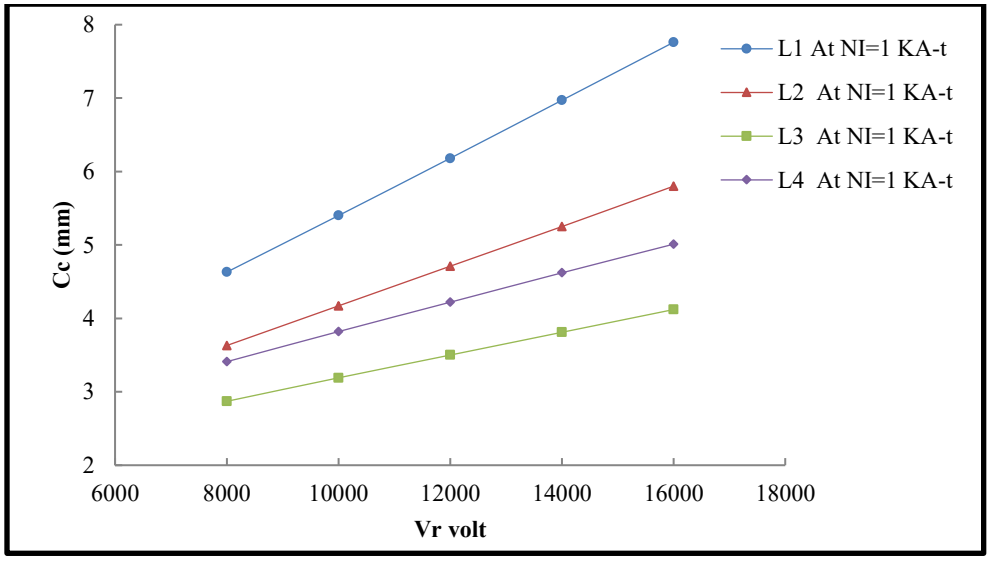


Fig. 3-2: The Chromatic Coefficient Values to Accelerating Voltage Vr at Constant Excitation NI =1000 (A-t) for Four Lenses (L1, L2, L3, L4)

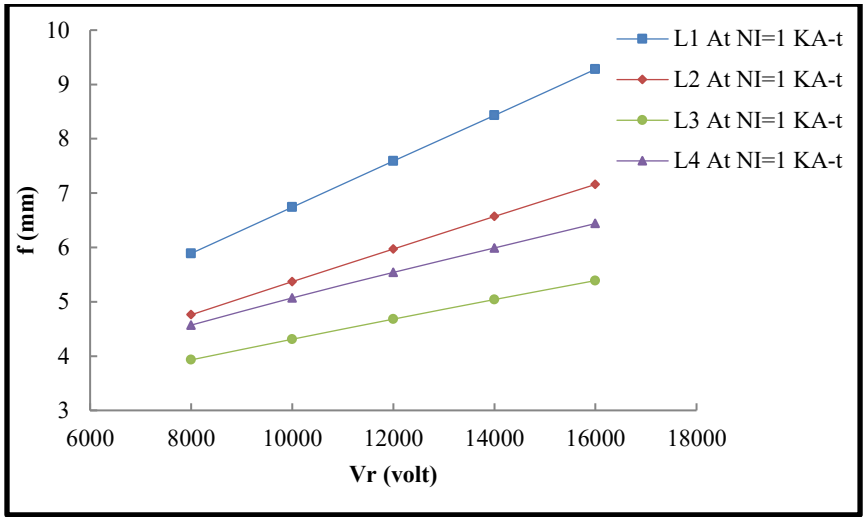


Fig. 3-3: Focal Length Values to Accelerating Voltage Vr at Constant Excitation NI =1000 (A-t) for Four Lenses (L1, L2, L3, L4)

From the last three figures (3-1) (3-2) (3-3) we notice that the chromatic and spherical aberrations (Cc) (Cs) respectively also focal length are increasing when the accelerating voltage (Vr) increased and lens L3 has a better focal property than other objective lenses.

Table 2: Shows the Values of Chromatic and Spherical Aberration and Focal Length Under Constant Excitation Factor (NI=1000 A-t) with Accelerating Voltage Vr= 8000 Volt

Lens Icon	Focal length (mm)	Chromatic aberration coefficient **Cc** (mm)	Spherical aberration coefficient Cs (mm)
L1	5.89	4.64	6.54
L2	4.76	3.63	4.14
L3	3.93	2.87	2.59
L4	4.13	3.01	2.70

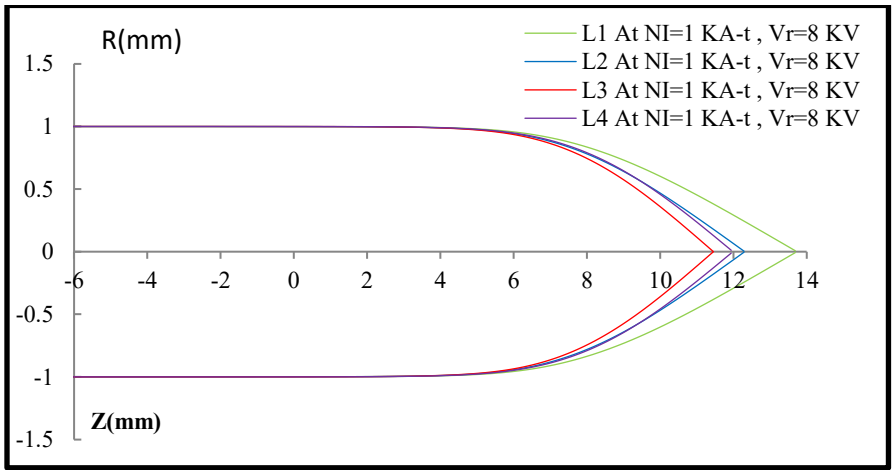


Fig. 4: Trajectory of Electron Beam in Gemini Objective Lenses at Constant Excitation NI=1000 (A-t) and Voltage Vr=8 KV

The trajectory of electron beam calculated for all four magnetic lenses (L1, L2, L3, L4), All under same excitation (NI=1000 A-t) and same accelerating voltage (Vr=8000 Volt), it notices that L3 has lowest value of focal length and that give it the focusing power and least aberrations comparing to other lenses.

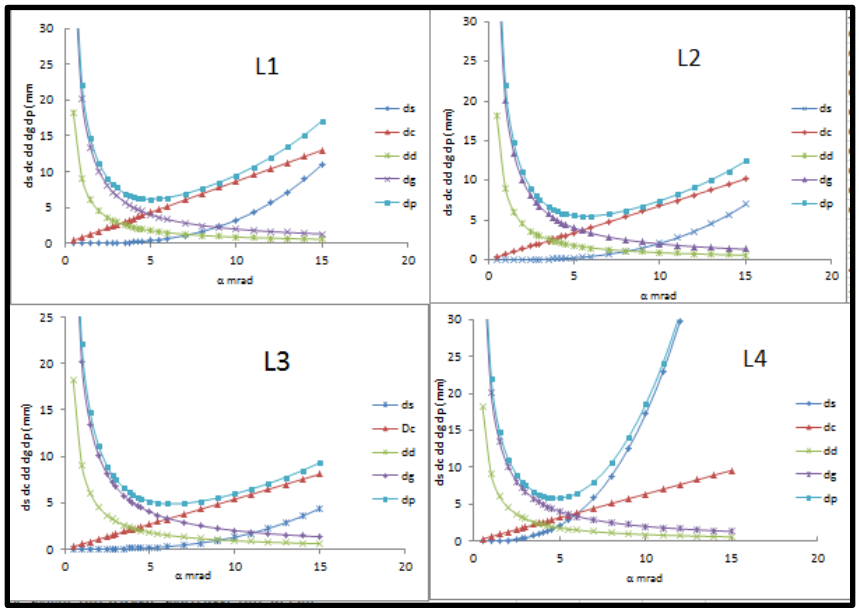


Fig. (5-1)

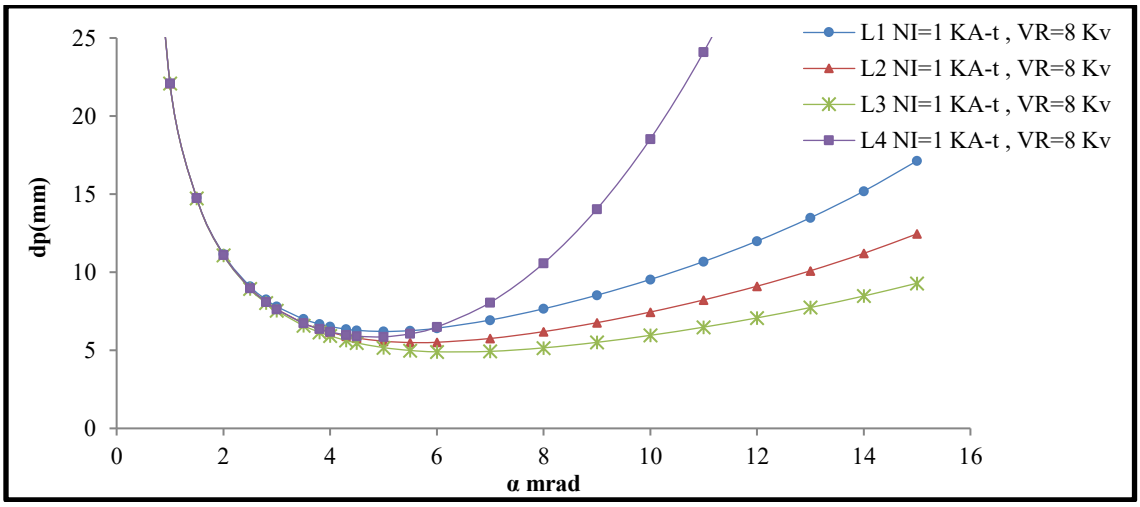


Fig. (5-2)

Fig. 5: (a) and (b) The Change in Aberrations (dc, ds, dd) and Final Effective Probe Diameter dp as Function to Aperture Angle α

Table 3: Represent the Ideal Aperture Angle Values α_{opt} (mrad) Which Meets with Minimum Values of Final Effective Probe Diameter dp min

Lens Icon	αopt (mrad)	dp min (mm)
L1	5	6.2
L2	5.5	5.49
L3	6	4.9
L4	5	5.86

The final effective probe diameter dp for incident electron beam on the specimen surface accompanied by contribution of three aberrations (chromatic and spherical, diffraction) that the objective lens suffered from them, all calculated as function of aperture angle for (L1, L2, L3, L4), we can notice from figures 5shows that the contribution of spherical and chromatic aberrations decreases when the angle of aperture decreases, and the aperture angle increase when dp increase.

Conclusions

With four design of magnetic objective lenses (Gemini Lens) in this work, L3 Gemini lens has a better results comparing to other three lenses for scanning electron microscope system, evaluating the axial magnetic flux density and electron trajectory with constant excitation (NI=1000 A-t) and accelerating voltage Vr= 8000 Volt it is clear that L3 has a highest peak for magnetic flux density distribution and also has a lowest values of chromatic and spherical aberration (Cc=2.87mm, Cs=2.59 mm) and a lowest focal length (f=3.93 mm), it noted that changing the outer pole side of magnetic lens has good impact on the optical and focal properties of the objective lenses.

Reference

McMullan, D. (1995). Scanning electron microscopy 1928–1965. *Scanning*, *17*(3), 175–185.

Southworth, H.N. (1975). Scanning electron microscopy and microanalysis. In *Physicochemical Methods of Mineral Analysis* (pp. 421-450). Boston, MA: Springer US.

Rishton, S. A. (1984). *Resolution limits in electron beam lithography (PhD thesis, University of Glasgow*). University of Glasgow.

Nelliyan, K., & Khursheed, A. (2011). Permanent magnet finger-size scanning electron microscope columns. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *645*(1), 41-45.

Hussein, M. A., & Kareem, M. Q. (2016). Behaviors and Characteristics Study of the Electron Beam for Lens System in a Scanning Electron Microscope. *International J. Res.*, *03*(13), 193–203.

Khursheed, A. (2011). *Scanning electron microscope optics and spectrometers*. World scientific.

Alamir, A.S.A. (2001). Magnetic electron lenses performance. *Optik*, *112*(11), 507-510.

Paluszyński, J., & Slówko, W. (2006). Compensation of the shadowing error in three-dimensional imaging with a multiple detector scanning electron microscope. *Journal of microscopy*, *224*(1), 93-96.

Podbrdský, J. (1986). High current density magnetic electron lenses in modern electron microscopes. *Scanning Electron Microscopy*, *1986*(3), 887-896.

Al-Khashab, M.A., & Al-Khaldey, T.J. (2018). The Design of the Iron Shroud Geometrical Shape in the Condenser-Objective Electromagnetic Lens. *Rafidain Journal of Science*, *27*(1), 277-289.

Hussein, M.A. (2016). Numerical analysis to verifying the performance of condenser magnetic lens in the scanning electron microscope. *Adv. Phys. Theor. Appl.*, *58*, 44–49.

Lencová, B., & Lenc, M. (1986). A finite element method for the computation of magnetic electron lenses. *Scanning Electron Microscopy*, *1986*(3), 9, 897–915,.

Hawkes, P.W. (1972). *Electron optics and electron microscopy*. london: Taylor and Francis, 1972.