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ION BEAM SIMULATION USING A THREE-ELECTRODE DIAPHRAGM EINZEL LENS SYSTEM

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In this paper, design and optimization for three diaphragm lens system were done by using SIMION computer program. An oxygen ion beam of diameter 3 mm with energy of 5 keV was extracted from an ion source and the ion beam entered the lens system from a distance of 100 mm. Seven design parameters were identified as variable parameters in the presence of space charge current of 0.1 mA. These parameters are the separation between each electrode of the lens, the aperture diameter of the outer electrodes of the lens system, the aperture diameter of the intermediate electrode, the focusing points at different distances for singly charged oxygen ion trajectories, the applied voltage to the intermediate electrode and the influence of space charge on beam quality and also study of the influence of the mass for the different elements has been investigated. Beam quality was significantly improved when the applied voltage to the intermediate electrode was optimized and found at V_2 = - 4500 V, separation distance (gap between each electrode) = 20 mm, the aperture diameter of the lens system = 40 mm and finally the best focused point was found at a distance of 550 mm from the end of the lens system.

***Keywords**: Oxygen ion trajectories, beam emittance and beam diameter, focusing voltage and space charge.*

INTRODUCTION

Computer analysis and design first came into effective use in electron and ion optics in the early 1969s [1]. The development of computer programs was accompanied by the need of more applications for such ion and electron instruments in various kinds [2-4]. Simulation packages have become the world standard for particle physics experiments. SIMION [5] is an electrostatic lens analysis and design program capable of modeling charged particle optics problems in experiments covering many fields of applications [6].

In this paper, design of the three diaphragm lens system has been done by using SIMION computer program, where different parameters for this lens system have been studied and investigated without and with space charge current of 0.1 mA.

DESIGN OF THE THREE DIAPHRAGM LENS SYSTEM

This kind of lenses is used in particle accelerators, ion implantation and mass spectrometers [7], [8]. If the voltage of an intermediate electrode (V_2) is adjusted to be out from the range of the voltages of the outer electrodes (V_1) to (V_3), then we get a ‘Saddle field lenses’, because the potential distribution becomes saddle shaped, in which the three potentials are different for the three electrodes, but the voltage of the intermediate electrode is larger than the outer electrodes. The focal length of this lens is shortened gradually as the potential (V_2) of the intermediate electrode either increases beyond (V_3) or decreases below (V_1). When the potential of the two outer electrodes is of the same value ($V_3 = V_1$), this type of electrostatic lenses is called an einzel lens. The einzel lens with particle trajectories is shown in Fig 1a,b. A particle moving through this lens at a given distance from the axis experiences first a defocusing force, then a focusing force, then again a defocusing force. The net effect is always positive focusing (converging lens). Because, the field between the two first electrodes is retarding, the particle moves more slowly through of focusing forces than through the region of a defocusing forces. Also, the particle on the average is farther away from the axis in the focusing part and therefore experiences larger focusing forces. This lens system consists of three electrodes with dimensions and lens system geometry assumed for the SIMION calculations by contours as shown in Fig. 1a, b.

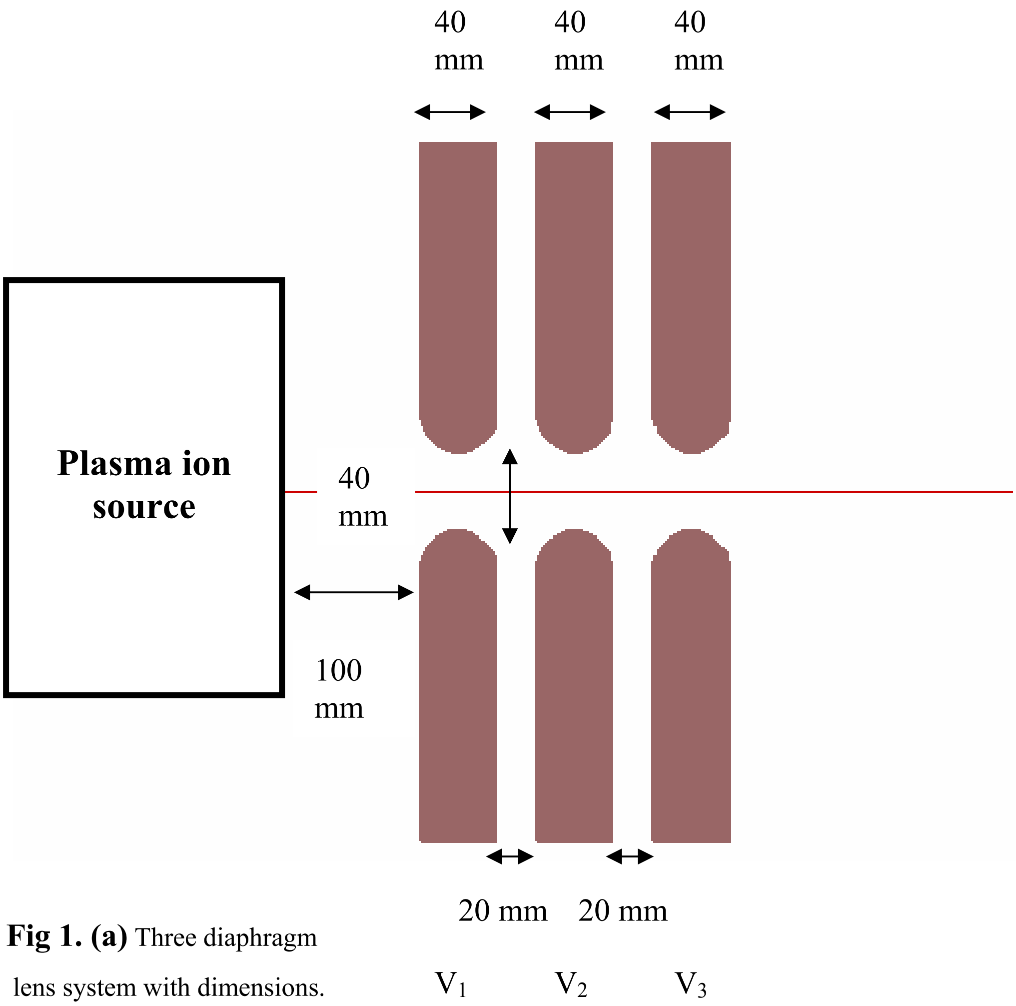

Fig 1. (a) Three diaphragm lens system with dimensions.

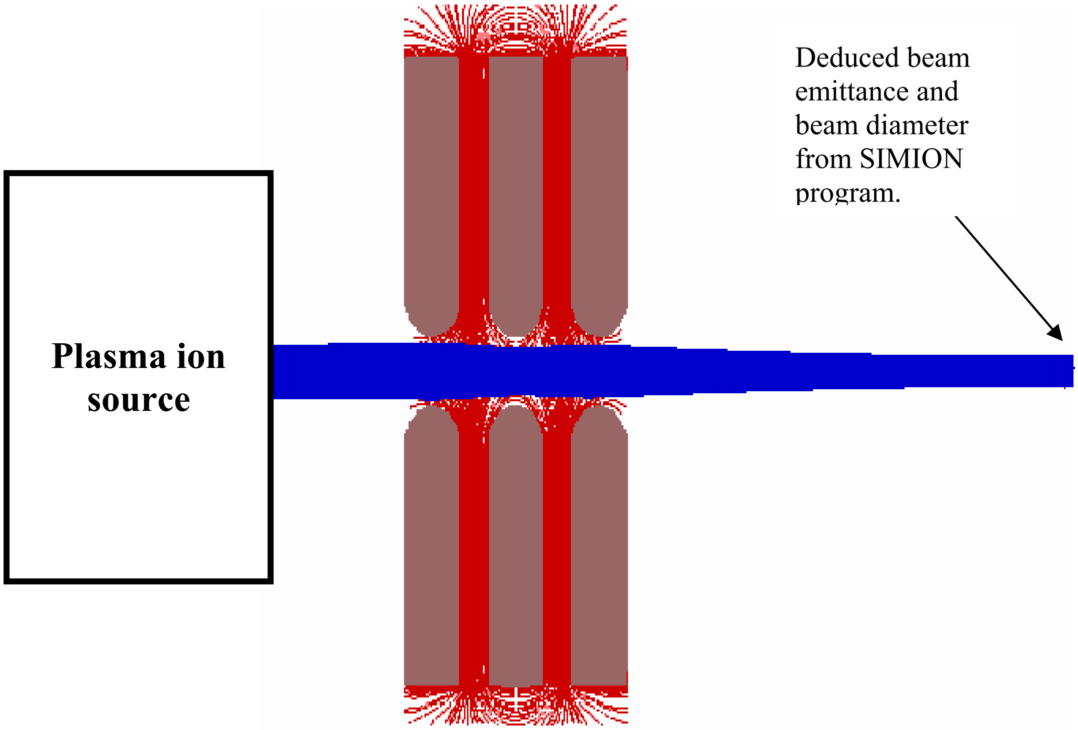

Figure 1. (b) Lens system geometry assumed for the SIMION calculations by contours.

The simulation process was done with a space charge current of 0.1 mA for a singly charged oxygen ion trajectories of diameter 3 mm with energy of 5 keV. The first and third electrodes of the lens system were set each at zero volts. The applied voltage to the second electrode of the lens system (intermediate electrode) was varied from 0 to – 9 kV. Beam emittance and beam diameter were deduced downstream of 70 mm from the exit of the lens system. Influence of the focusing voltage on beam emittance and beam diameter for the three diaphragm lens system has been studied, (Fig. 2).

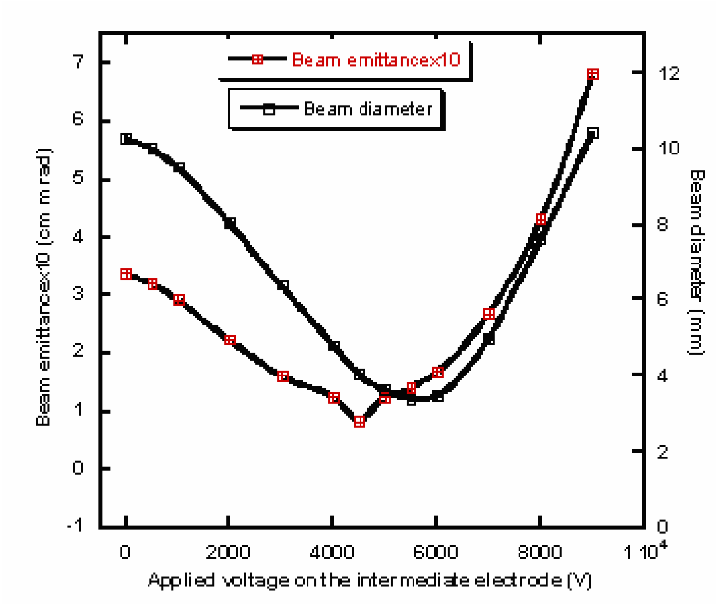

Figure 2. Influence of the focusing voltage on both beam emittance and beam diameter for three diaphragm lens system of singly charged oxygen ion trajectories with space charge current of 0.1 mA.

Minimum beam emittance and minimum beam diameter were found at a focusing voltage applied to the second electrode (intermediate electrode) of the lens system of -4500 and – 5500 V, respectively.

Beam emittance and beam diameter as a function of the diameter of the lens system were investigated (Fig. 3). Minimum beam emittance was found at a diameter of 40 mm and gap width of 20 mm. Minimum beam diameter for the three diaphragm lens system was found at 20 mm, whereas an increase of the tube diameter was accompanied by an increase of the beam diameter at a focusing voltage applied to the intermediate electrode V_2 = - 4500 V.

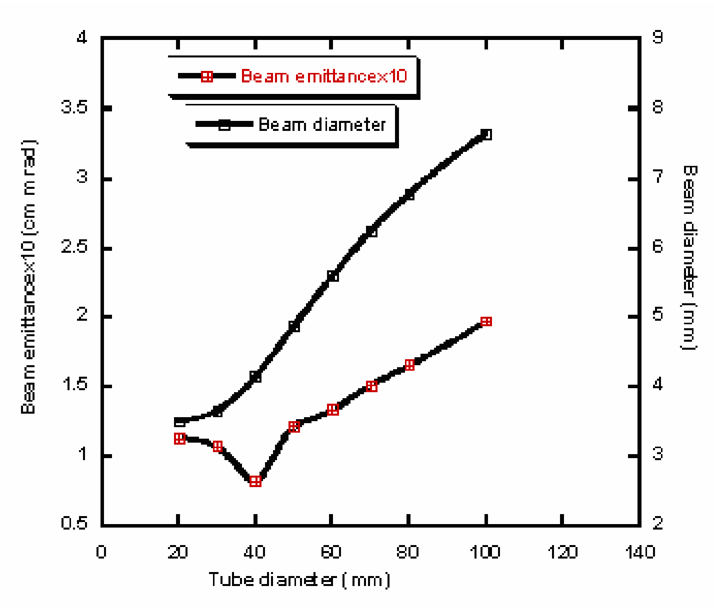

Figure 3. Beam emittance and beam diameter as a function of the diameter of three diaphragm lens system at V_2 = - 4500 V, V_2 = - 5500 V, gap width = 20 mm and current = 0.1 mA.

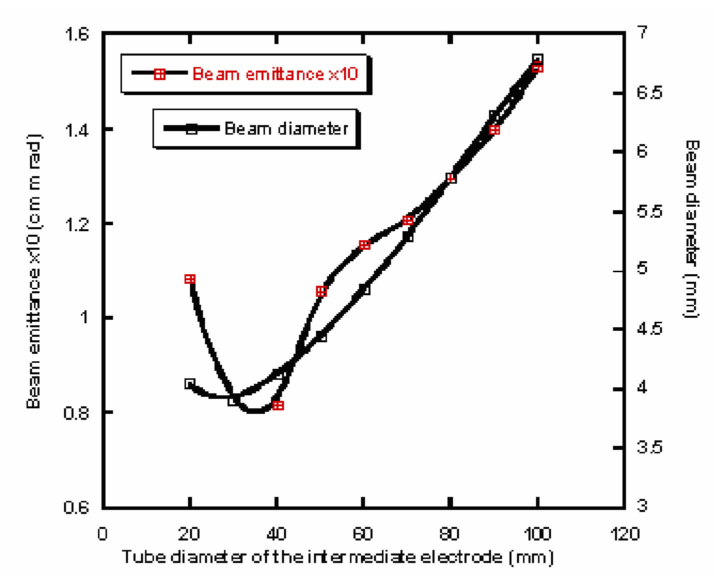

Figure 4. Beam emittance and beam diameter as a function of the diameter of the intermediate electrode for the three diaphragm lens system at V_2 = - 4500 V, gap width = 20 mm and current = 0.1 mA.

Beam emittance and beam diameter as a function of the diameter of the intermediate electrode for the lens system were studied for singly charged oxygen ion trajectories with a space charge current of 0.1 mA (Fig. 4). Minimum beam emittance was found at a diameter of 40 mm and gap width of 20 mm. Minimum beam diameter for the intermediate electrode of the three diaphragm lens system was found at 30 mm, and at a focusing voltage applied to the intermediate electrode V_2 = - 4500 V.

Beam emittance and beam diameter as a function of the gap width were also studied for the three diaphragm lens system (Fig.5). It was found that an increase of the gap width is accompanied by an increase of the beam diameter, and minimum beam diameter was found at a gap width of 10 mm for the lens system at a focusing voltage V_2 = - 5500 V applied to the intermediate electrode and measured at 70 mm from the end of the lens system and tube diameter = 40 mm. Minimum beam emittance for the three diaphragm lens system was found at a gap width of 20 mm. It was found that the optimum gap width is 20 mm, where at this gap; the ion beam envelope was best passed through the focusing region (Fig. 5).

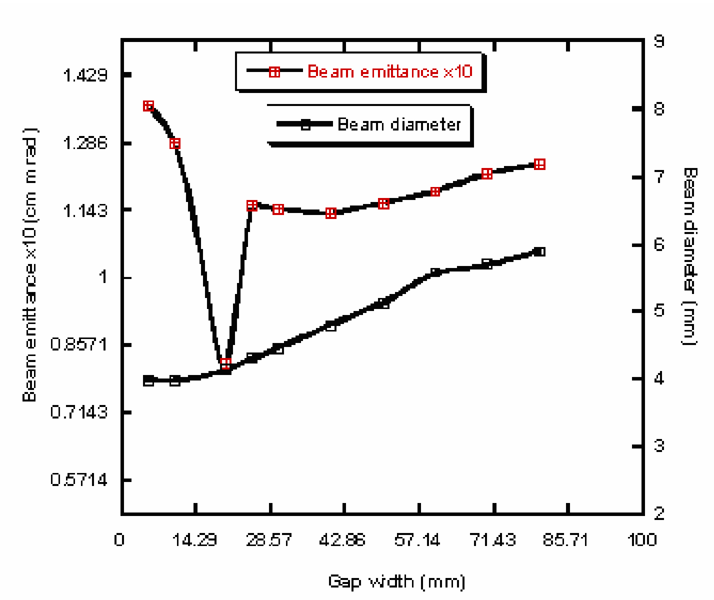

Figure 5. Beam emittance and beam diameter as a function of the gap width for the three diaphragm lens system at V_2 = - 4500 V for a singly charged oxygen ion trajectories with space charge current of 0.1 mA.

Beam emittance and beam diameter as a function of the focusing points at different distances for singly charged oxygen ion trajectories of the three diaphragm lens system were investigated (Fig. 6). Minimum beam emittance was found downstream of 550 mm for the lens system. Minimum beam diameter was found at 553 mm at a focusing voltage V_2 = - 5500 V and gap width = 20 mm and tube diameter = 40 mm.

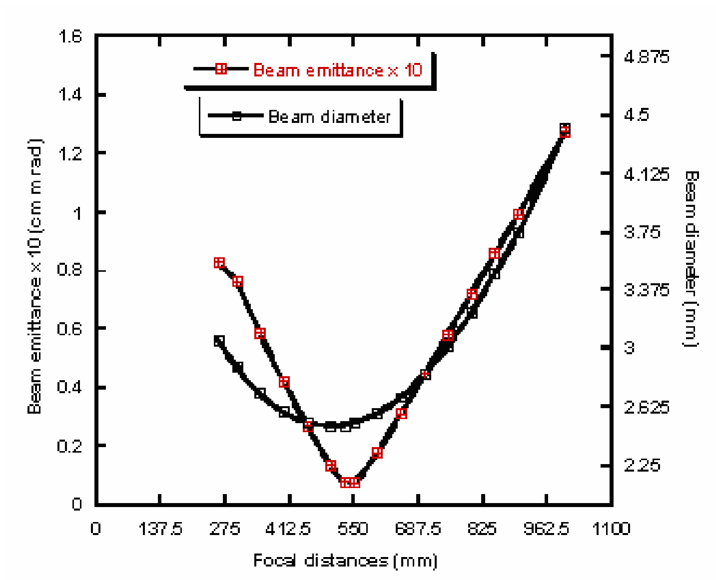

Figure 6. Beam emittance and beam diameter as a function of the focusing points measured from the end of the three diaphragm lens systems.

In high current ion sources and in transport systems for protons or heavier ions the repulsive force due to the space charge carried out by the beam itself plays an important role for the design of the focusing system and for conservation of beam emittance. The influence of space charge on both beam emittance and beam diameter was studied for the three diaphragm lens system (Fig.7). Simulation process was done as follows: the applied voltage to the intermediate electrode was set V_2 = - 4500 V, while the voltage applied to the outer electrodes was zero volts. The gap between each electrode was 20 mm and the diameter of the lens system = 40 mm, where at these parameters, minimum beam emittance was obtained. It was found that; the space charge has a large effect on the beam emittance at current higher than 10^{-4} A. Minimum beam emittance for the lens system was found at a current of 10^{-4} A, and started to have a large effect at current higher than10^{-3} A. Minimum beam diameter was found at a current of 10^{-6} A, and started to have a large effect at current higher than10^{-5} A.

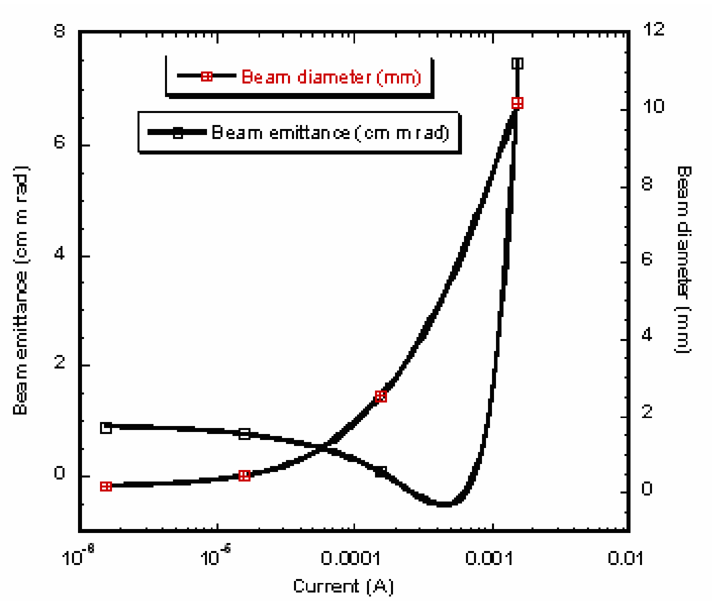

Figure 7. Influence of space charge on both beam emittance and beam diameter for three diaphragm lens system of singly charged oxygen ion trajectories.

Influence of atomic masses of different elements on both the beam emittance and beam diameter for the three diaphragm lens system was investigated with current of 0.1 mA for singly charged oxygen ion trajectories (Fig.8). Minimum beam emittance was obtained for nitrogen (m = 14). An increase of atomic mass for some elements was accompanied by an increase of the beam diameter for three diaphragm lens system.

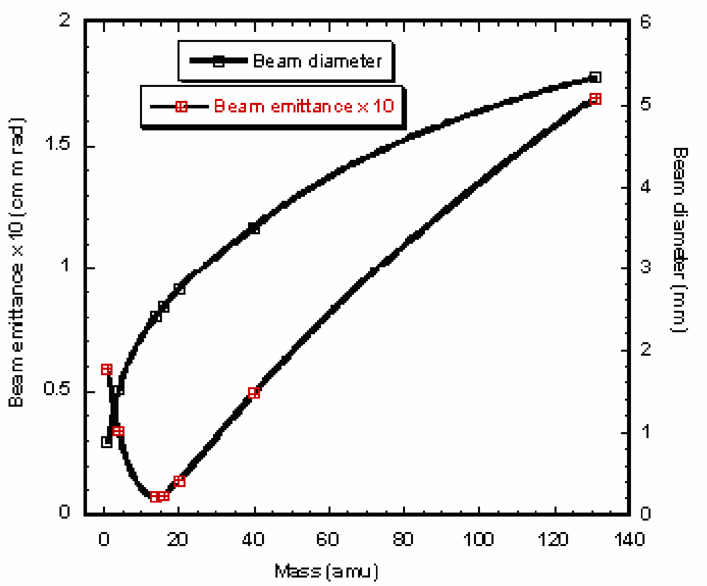

Figure 8. Beam emittance and beam diameter as a function of atomic mass for different elements of three diaphragm lens system of singly charged oxygen ion trajectories with space charge current of 0.1 mA.

CONCLUSION

In this work, beam emittance and beam diameter were deduced downstream of 70 mm from the exit of the lens system. Beam emittance and beam diameter were found at a focusing voltage applied to the second electrode (intermediate electrode) of the lens system of V_2 = -4500 and – 5500 V, respectively. Minimum beam emittance was found at a diameter of 40 mm and gap width of 20 mm. Minimum beam diameter for the three diaphragm lens system was found at 20 mm, whereas an increase of the tube diameter was accompanied by an increase of the beam diameter at a focusing voltage applied to the intermediate electrode V_2 = - 4500 V. It was found that an increase of the gap width is accompanied by an increase of the beam diameter, and minimum beam diameter was found at a gap width of 10 mm for the lens system at a focusing voltage V_2 = - 4500 V applied to the intermediate electrode and measured at 70 mm and tube diameter = 40 mm. It was found that the optimum gap width = 20 mm, where at this gap; the ion beam envelope was best passed through the focusing region. Minimum beam emittance was found downstream of 550 mm for the lens system, whereas, minimum beam diameter was found at 553 mm at a focusing voltage V_2 = -4500 V, gap width = 20 mm and tube diameter = 40 mm. It was found that; the space charge has a large effect on the beam emittance at current higher than 10^{-4} A. Minimum beam emittance for the lens system was found at a current of 10^{-4} A, and started to have a large effect at current higher than10^{-3} A. Minimum beam diameter was found at a current of 10^{-6} A, and started to have a large effect at current higher than10^{-5} A. Minimum beam emittance has been obtained for nitrogen (m = 14). An increase of atomic mass for elements was accompanied by an increase of the beam diameter for three diaphragm lens system.

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محاكاة الحزم الأيونية باستخدام نظام عدسة إينزل ذات ثلاثة أقطاب مثقوبة

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في هذه الدراسة تم عمل محاكاة لتصميم عدسة ذات ثلاثة أقطاب مثقوبة وذلك باستخدام أحد برامج المحاكاة المعروفة بإسم (سيميون). تمت هذه الدراسة باستخدام حزم أيونية من التيار الأيونى لغاز الأوكسجين ذات طاقة 5 كيلو إلكترون فولت و قطر3 مم و مبتدأه من مسافة 100 مم قبل دخول نظام العدسة. ولكي نصمم نظام العدسة تم عمل دراسة العوامل المختلفة في وجود شحنة الفراغ. وهذه الدراسة تشمل تصميم وتعيين أفضل بارامترات التشغيل لنظام عدسة إينزل ذات ثلاثة أقطاب مثقوبة . وفي نظام العدسة يتم توصيل القطب الأول و الثالث بجهد يساوي صفر فولت بينما القطب الثاني (المتوسط) فقد تم تطبيق جهد متغير من صفر إلي – 9 كيلو إلكترون فولت.

وقد تم دراسة تأثير وتطبيق جهد سالب علي القطب الثاني (المتوسط) لنظام العدسة علي قطر وانبعاثية مسار حزم الأوكسجين أحادية الشحنة. وكذلك تم دراسة قطر وانبعاثية الحزم الايونية كدالة في قطر العدسة المصممة. وأيضا تم دراسة قطر وانبعاثية الحزم الأيونية كدالة في قطر القطب الثاني (المتوسط) للعدسة المصممة.

كما تم تعيين نقطة التركيز (التجميع) لحزم الأوكسجين أحادية الشحنه كدالة في قطر وانبعاثية الحزمة. وايضا تم دراسة تأثير الأوزان الذرية للعناصر المختلفة علي كل من قطر وانبعاثية الحزم الأيونية. كما تم دراسة تأثير وتغيير الفجوة بين أقطاب العدسة المصممة علي كل من قطر وانبعاثية الحزمة الأيونية.

وجد أن أفضل وأحسن حزم أيونية من التيار الأيونى لغاز الأوكسجين تم دراستها و محاكاتها عند تطبيق جهد سالب علي القطب الثاني (المتوسط) لنظام العدسة = - 4500 فولت وعند أفضل مسافة للفجوة بين الأقطاب الثلاثة = 20 مللمتر و قطر العدسة = 40 مللمتر و كذلك افضل نقطة تجميع للحزم الأيونية عند مسافة 550 مللمتر من نهاية نظام العدسة المصممة.