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# The design of electrostatic quadrupole zoom lens for fixed multi-collector system at mass spectrometer

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ABSTRACT

In order to measure different isotopes with fixed multi-collectors at a Mass Spectrometer conveniently, a zoom lens with two electrostatic quadrupoles is chosen to adapt the dispersions from different isotopes. A design method of such a zoom lens is introduced in this paper. Based on theoretical modelling results, validation of zoom effect and focusing performance has been carried out through SIMION simulation of two different electrostatic quadrupole devices: pole-type and segment-type. Then, electric voltage corrections have been applied considering the inconsistencies. Finally, the design requirements are satisfied.



## 1. Introduction

The multi-collector mass spectrometer with magnetic mass analyzer has recently improved its precision and accuracy, which is better than that with conventional peak jump measurement [1,2]. However, the change in dispersion as the ion beams' mass number varies remains a great challenge for this system. Neptune Plus developed by Thermo Science, contains several groups of detectors, one of which is chosen when measuring a given element [3]. The Phoenix equipped with 9 individually motorized Faraday collectors, moves the detector to the correct position for a given element, which may result in mechanical instability [4]. SPECTRO MS adopted a newly designed Direct Charge Detection (DCD) with 4800 dual-stage channels mounted in the mass spectrometer's focal plane. The system can cover the full mass range from 5 to 240 amu[1] [5]. However, the drawback of the DCD with multiple channels is that its interference may affect accuracy. An ion optical electrostatic zoom lens was firstly adopted to adapt the ion beam dispersion by a multiple collector plasma source mass spectrometer produced by Nu Instruments Ltd, which is more stable and easier to operate since it is controlled by an electric field [6].

To avoid the isobaric interference and strong peak tail interference from other elements, a Laser Resonance Ionization Mass Spectrometer (LRIMS) with high element selectivity covering the long-lived isotopes with mass ranging from 50 to 300 amu has been developed [7–9]. An array of fixed independent detectors equipped with a zoom lens including two electrostatic quadrupoles [10,11] to adapt the dispersion has been widely adopted because of its better accuracy, controllability, stability and convenience.

In this paper, a design method of electrostatic quadrupole zoom lens for fixed multi-collector system at mass spectrometer is proposed and reported in the following sections. Generally, a theoretical model of such a lens has been established and its numerical solution has also been realized. Based on theoretical modelling results, validation of zoom effect and focusing performance has been carried out through simulation of two different electrostatic quadrupole devices: pole-type and segment- type. Then, electric voltage corrections have been applied considering the inconsistencies. Finally, the design requirements have been satisfied.

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[1] Atomic mass unit, which refers to $^{16}O = 16$ based mass scale (Definitions of terms relating to mass spectrometry (IUPAC Recommendations 2013), Pure Appl. Chem., 2013, Vol. 85, No. 7, pp. 1515–1609. http://dx.doi.org/10.1351/PAC-REC-06-04-06).

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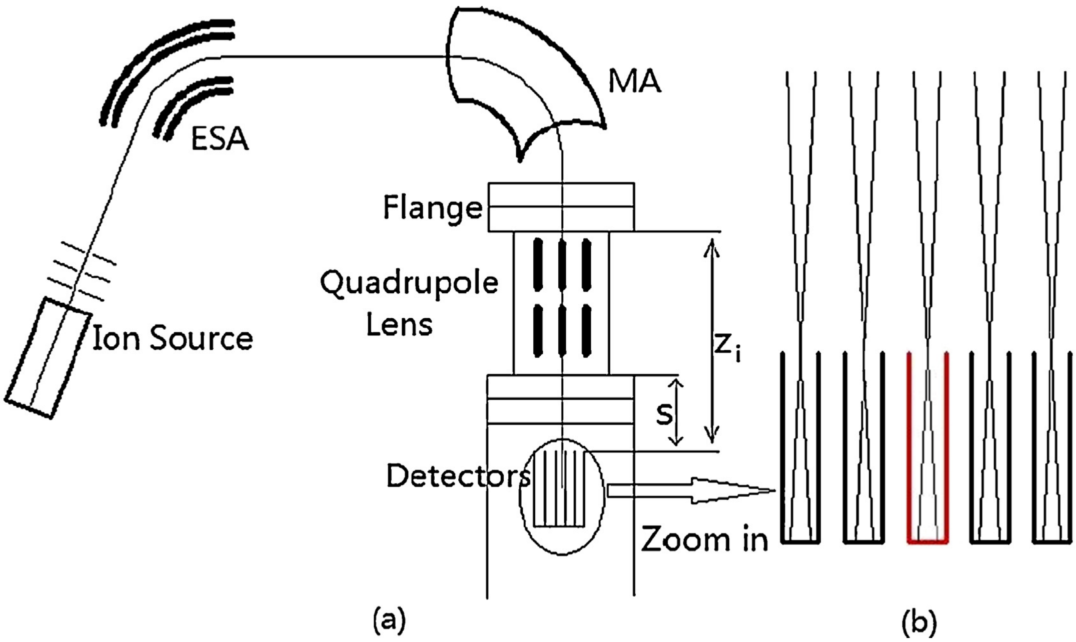


**Fig. 1.** The schematic layout of the mass spectrometer.

## 2. Theoretically modelling

### 2.1. Requirements and constraints

Generally, a LRIMS contains a Nier-Johnson mass analyzer equipped with an ElectroStatic Analyzer (ESA) and a Magnetic Analyzer(MA), both of which can direct and focus the ion beams with different masses [12]. Here, we will introduce the design method using the LRIMS at northwest institute of nuclear technology, illustrated in Fig. 1. The incident ion beams, which are initially perpendicular to the ESA cylindrical electric field, are deflected by 65° in the ESA, and later by 90° in the MA. The focal plane of the beams without zoom lens is 400 mm from MA exit. For ion measurement, an array of five Faraday cups, whose entrances are all at the focal plane, is deployed in the separation of adjacent isotope ions whose middle mass number is 150.

As we know, the separation between the two adjacent ion beams D is determined by the following formula:

$$D = \frac{1}{2} \times \frac{\Delta A}{A} \times K_m \quad (1)$$

where A is the mass number of ions, ΔA is mass difference of the two ions and $K_m$ is determined by the LRIMS [13]. In this case, ΔA is 1.0 considering the adjacent isotope ions, and $K_m$ is 1000 mm for the LRIMS at northwest institute of nuclear technology.

In order to measure the isotopes with mass number ranging from 75 to 300, an electrostatic quadrupole zoom lens is planned to be placed between MA and Faraday cups, considering space limitation. Considering the flange and other connecting parts, the distance $z_i$ between the quadrupole lens entrance and the focal plane is limited to 260 mm, and the gap $s$ between quadrupole lens exit and the focal plane is preset to 120 mm.

$$z_i = 260mm \quad (2)$$

$$s = 120mm \quad (3)$$

According to Eq. (1), the separation multiplication $m$ can be expressed by

$$m = \frac{A}{150} \quad (4)$$

where A is the middle mass number of the five adjacent measured isotope ions.

Since the separation of ion detector array is fixed at 3.33 mm for ion beams with a middle mass number of 150, the separation multiplication $m$ should be in the range [0.5, 2.0] in order to measure isotopes with mass numbers ranging from 75 to 300. Obviously, separation should be magnified (de-magnified) if the middle mass number, A, is greater (or less) than 150.

It is worth noting that we can make use of three non-adjacent detectors to measure three adjacent ion beams with middle mass number ranging from 38 to 75, if m is set to A/75.

### 2.2. Modelling

In order to ensure good focusing of ion beams, the electrostatic quadrupole zoom lens consists of two electrostatic quadrupoles [6], both of which are opposite in polarity. This kind of combination is referred as electrostatic quadrupole doublet.

#### 2.2.1. Transfer matrix of electrostatic quadrupole doublet

The rectangular model, in which the electric field's distribution in the z-axis is rectangular, was adopted to calculate electric field of electrostatic quadrupole [14] under the following assumptions:

1) The effective electric filed length of electrostatic quadrupole $l_{ej}$ is long enough compared to inner radius of quadrupole $a_0$. Namely, the following condition needs to be satisfied.

$$l_{ej}/a_0 \geq 3, (j = 1, 2) \quad (5)$$

2) The ion beams travel paraxially, which is called as paraxial approximation and means the higher order effect is negligible.

Under the above conditions, the first order approximation is accurate and the modeling is simplified for possible solving. If the paraxial approximation can not be satisfied well, the deviation may be decreased by adjusting the voltages on the electrodes to an acceptable level for satisfactory detection considering the proper slit width of Faraday cups.