Find the Distribution of Charge-to-Mass Ratio in Low-Pass Region by Quadrupole Mass Spectrometer

YAO-XUAN LI(李曜亘), JYUN-TING CHEN(陳雋庭) and CHIA-CHIA CHAO(趙家加)
TA: ZHAO-HUI HUANG(黃朝暉) Advisor: YUNG-FU CHEN(陳永富)
Experimental Physics II, Department of Physics, National Center University

Introduction:

Different from other spectrometers, QMS has ability of filter by electric field only. This characteristics interest us to learn how the voltage of AC and DC affect the motion of particles, and why particles can pass the QMS or why particles can not pass. We would like to find the distribution of e/m in certain region in the end.

Theory:

On the x-axis and y-axis of quadrupole(Fig. 1), we add DC and AC source. The DC voltage on both axis are opposite but their magnitude is the same, and the AC voltage on x-axis is 180° out of phase with the ac voltage on y-axis. This will form a saddle potential to trap the particles and let it pass the quadrupole mass spectrometer, but if the charge-to-mass ratio of the particles is not suitable, the particles will be thrown out from the quadrupole mass spectrometer.
The equation of motion of the particle in the quadrupole mass filter:

$$\frac{d^2x}{dt^2}+\frac{\omega^2}{4}[a+2q\cos(\omega t)]x=0 \qquad a=\frac{4eU}{mr_0^2\omega^2}$$
$$\frac{d^2y}{dt^2}-\frac{\omega^2}{4}[a+2q\cos(\omega t)]y=0 \qquad q=\frac{2eV}{mr_0^2\omega^2}$$

e/m: charge to mass ratio
U: voltage of DC
V: voltage of AC
ω: angular frequency of AC
r_0 distance from the center of the quadrupole to the electrode

By a and q, we can get a stable table. The stable table of the quadrupole mass spectrometer can tell us whether the particles pass the quadrupole. If q/m of a particle lies in the shadow of the table, it will pass; otherwise it will not pass(Fig. 2).

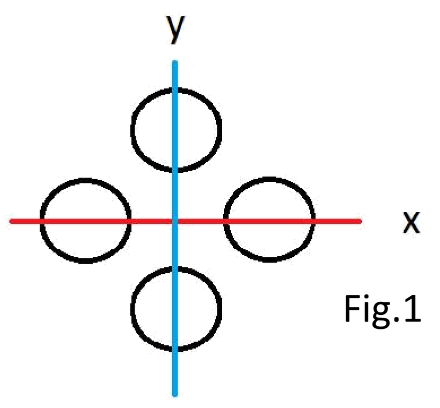

Fig.1

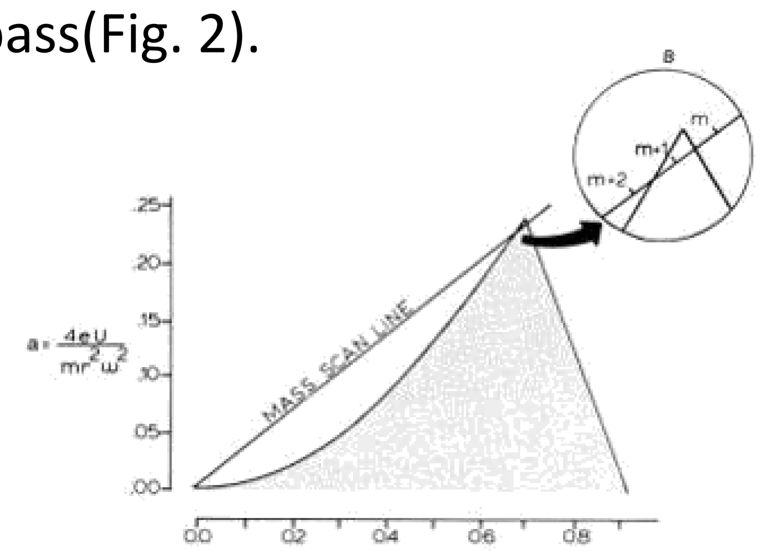

Fig.2 stable table[1]

Experiment setup:

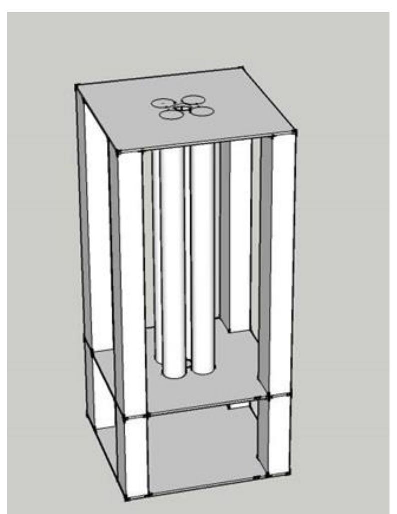
Fig. 3 experiment setup

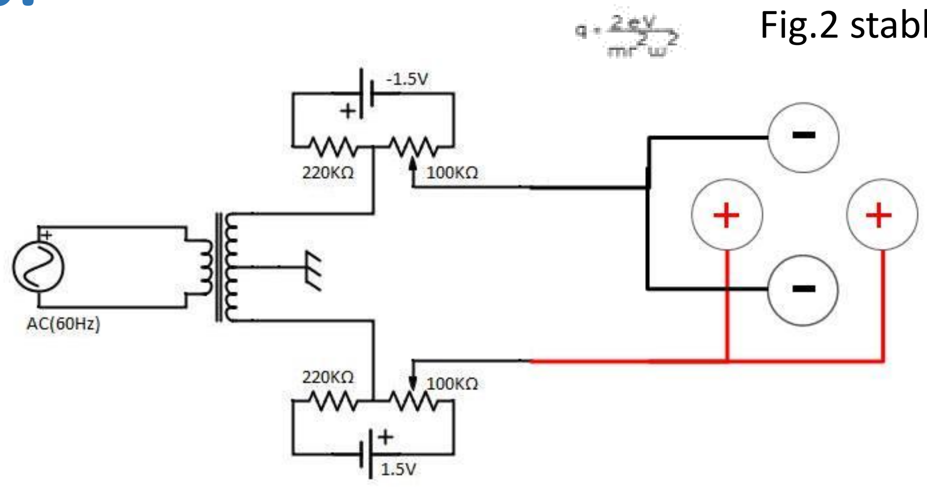

Fig.4 circuit diagram of the setup

Particles:

- Styrofoam (weight:1e-4×g, diameter:2.9e-3×m)
- Bulleted Breech(weight: 1.15e-3×g, diameter:6e-3×m)
- Light clay(weight: 4.8e-3×g, diameter: 2.8e-3×m)

Discussion:

We use the ideal stable table to simulate the motion of particles in the quadrupole. We fix the value of q and change the value of a, then we can get different situations. One is the situation that particles pass the quadrupole(Fig. 5), the other is the situation that particles are thrown out from the quadrupole(Fig. 6). By these result, we can simulate our own stable table which is according to the setup.

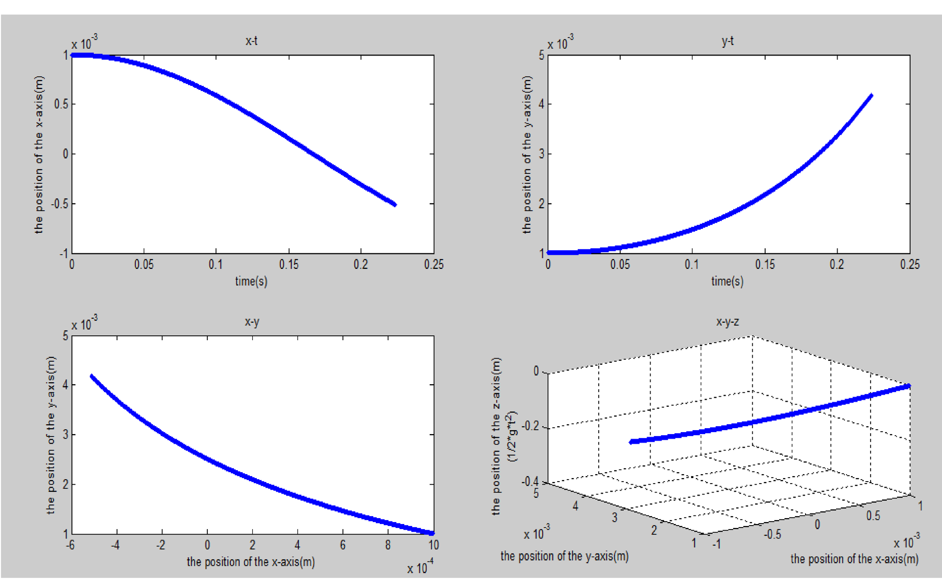
Fig.5 Particle passes through
a=0.002 q=3.71e-5 e/m=1e-7 r_0=0.0087(m)
V=2000(v) U=53920(v) $\omega=120\pi$

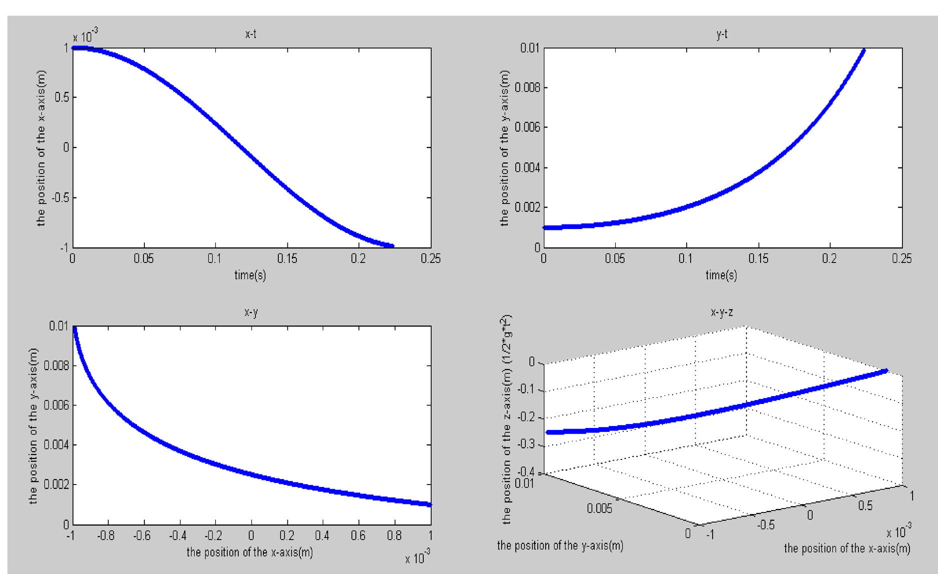
Fig.6 The particle is thrown out
a=0.005 q=3.71e-5 e/m=1e-7 r_0=0.0087(m)
V=2000(v) U=134800(v) $\omega=120\pi$

Because the length of our quadrupole is not long enough, some particles which can not finish a cycle would pass the quadrupole and be thought that its e/m is suitable. So we simulate a experimental stable table which is different from theoretical one on paper. (Fig. 7)

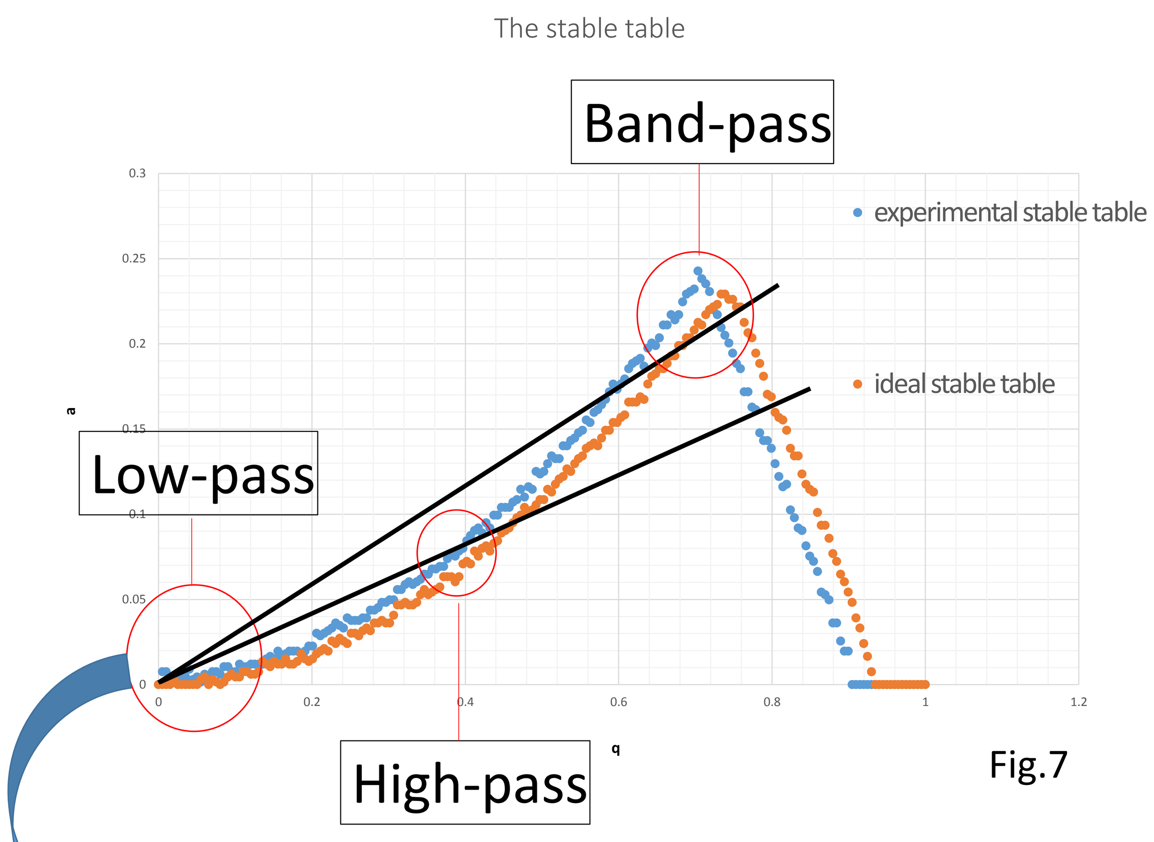

Fig.7

In the beginning, we tend to reach the band-pass region which has the most effective ability of filter. However, the AC and DC voltage is not high enough to reach the band-pass region, and we change our gold to reach low-pass region. After comparing the real table and theoretical one in the low-pass region we choose, we find that the theoretical table would not has the low-pass region. However, the limitation of the length of quadrupole make the real table produce the low-pass region which has ability of filter we need.(Fig. 8)

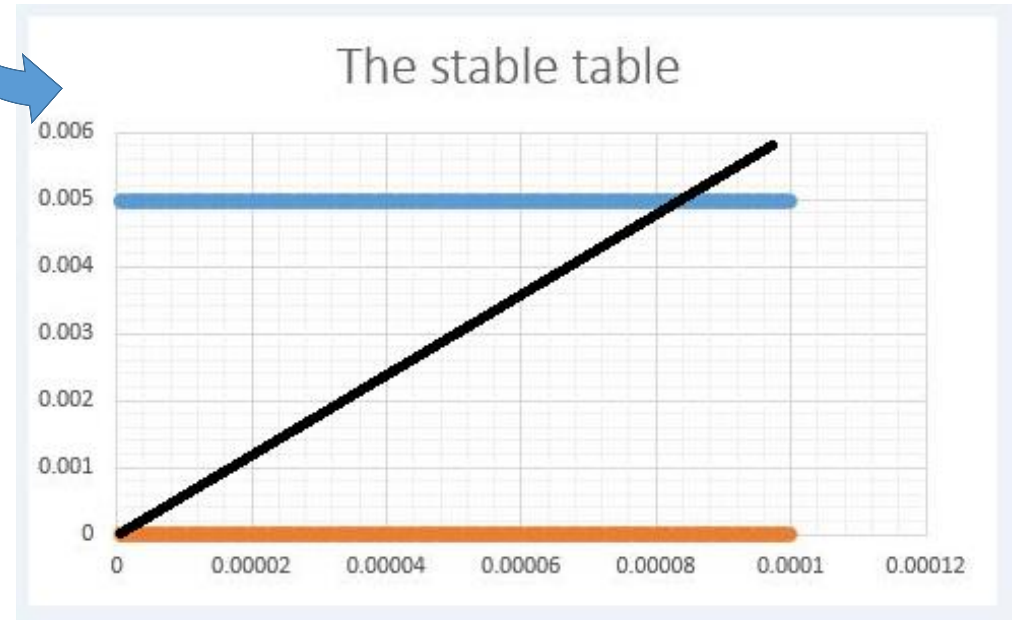

Fig.8

We tend to find the distribution of e/m by adjusting DC voltage in low-pass region and predict it will be a normal distribution.(Fig. 9) The motion of particle would be controlled by only electric field theoretically. However, the particle would be affected by air resistance as well and the trajectory of particle is unpredictable. This problem makes us difficult to find the accurate distribution of e/m.

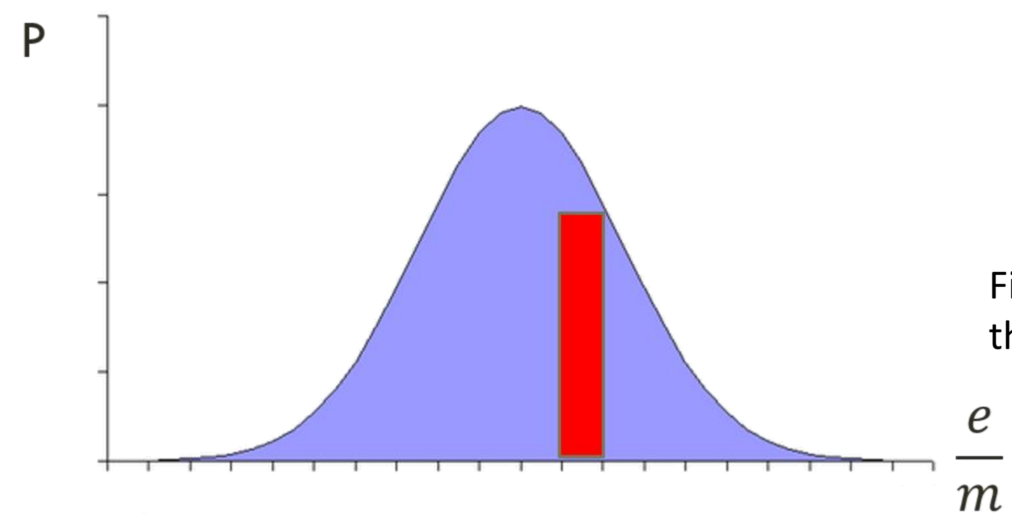

Fig.9
the distribution of the e/m

To avoid the influence of air resistance, we conduct the experiment in vacuum environment. However, the chamber cannot be sealed up perfectly so that airflow influence the motion of particles more seriously.

Summary:

Because the limitation of length of quadrupole, the experimental stable table would have low-pass region in the situation a and q is extremely small. However, the theoretical stable table would not.

Reference:

[1] The Quadrupole Mass Filter: Basic Operating Concepts-Philip E. Miller' and M. Bonner Denton--University of Arizona, Tucson, AZ 85721 Volume 63 Number 7 July 1986
[2] Operating Parameter of a Quadrupole in a Grounding Cylindrical Housing-D. R. Denison-University Instruments Corporation, Boulder, Colorado 80301 THE JOURNAL OF VACUUM SCIENCE AND TECHNOLOGY VOL. 8 NO. 1