A SMALL CYCLOIDAL MASS SPECTROMETER WITH VACUUM VIBRATOR ARC SOURCE

P. T. RAJAGOPALAN
(*Central Instruments and Services Laboratory*)
AND
V. S. VENKATASUBRAMANIAN
(*Central Instruments and Services Laboratory and Department of Physics, Indian Institute of Science, Bangalore 560012*)

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ABSTRACT

The advantages of the cycloidal mass analyser for heteroenergetic ion sources such as the vacuum vibrator arc source are described. The constructional details of a small cycloidal mass analyser and some results obtained with the vacuum vibrator source are presented. The results indicate that this analyser, compared to other mass analysers of similar dimensions, gives a much higher resolved ion current and therefore is suitable for ion sources with moderate energy spread.

Key words : Cycloidal mass analyser; Vacuum vibrator arc; Mass spectrometer.

INTRODUCTION

The use of the vacuum vibrator as an ion source for the analysis of solids has been suggested by Dempster [1] and its characteristics have been studied in detail by Venkatasubramanian and Duckworth [2], Franzen and Schuy [3] and Hintenberger [4]. It has been observed that this ion source has an energy spread of about 100 to 200 volts which is quite small compared to that of the RF spark source where the spread is of the order of 1000 to 2000 volts. Yet, because of the spread in energy, the vibrator source generally requires the use of a double focusing mass spectrometer for obtaining direction focusing as well as velocity focusing. A Nier-Johnson type mass spectrometer is preferable to other types as it gives double focusing of the first order and direction focusing of the second order.

The cycloidal mass spectrometer originally developed by Bleakney and Hipple [5] is of the perfect focusing type and so can yield a better luminosity than a double focusing mass spectrometer. In fact in the very first instrument developed by Bleakney and Hipple, perfect focusing was achieved for ions having an energy spread of 50% of the accelerating voltage and having a half-angular divergence of about 6°. The total path length will also be smaller than a double focusing mass spectrometer where the ion beam has to travel through an electrostatic analyser and then through a magnetic analyser. It would thus appear that the cycloidal analyser would be eminently suitable for the vibrator ion source, but no reports are available in the literature on the performance of the cycloidal analyser with the hetero-energetic arc sources. It was therefore decided to construct a cycloidal mass spectrometer and study its performance with the vibrator arc source.

In this paper we describe the design and constructional aspects of a small cycloidal mass spectrometer ($b = 9\cdot5$ cm) and present some results obtained with an arc source.

Principle of operation

The design of the cycloidal mass spectrometer was carried out on the lines given by Bainbridge [6]. The basic diagram (Fig. 1) shows the (prolate) cycloidal path of an ion beam when subjected to crossed electric and magnetic fields. The cycloidal path is generated by point P, distant ρ from the centre O of a rolling circle of radius a. a is known as the primary radius and ρ is known as the secondary radius. $\rho > a$ results in the prolate cycloidal path which is generally used in mass spectrometry applications. Ions which have crossed a plane $Y =$ Constant at a point A ($x = x'$) will again cross this plane at a point $x = x' + nb$ where

$$b = 2\pi a = 2\pi E \cdot \frac{mc^2}{eH^2} \tag{1}$$

where e is the charge on ion of mass m, c is the velocity of light, E is the electric field strength in esu and H is the magnetic field strength in emu.

Thus the focal line at a distance nb beyond the initial point x' is independent of the velocity and direction of the ions at the source. The focusing achieved here is said to be perfect, as no higher order aberration terms, characteristic of the deflection type instruments appear in the expression for b.

From eqn. (1) it is seen that b is proportional to m/e and thus a linear mass scale is obtained. The resolving power is given by

$$RP = \frac{m}{\triangle m} = \frac{b}{\triangle b} \text{ for photographic detection}$$

and

$$RP = \frac{m}{\triangle m} = \frac{b}{s_1 + s_2} \text{ for electrical detection} \tag{2}$$

where s_1 and s_2 are the source and collector slit widths respectively. When the resolving power of a cycloidal mass spectrometer is compared with that available from a magnetic deflection type instrument ($Rp = b/2\triangle b$), it is seen that the resolving power of the cycloidal instrument is twice that of the deflection type instrument.

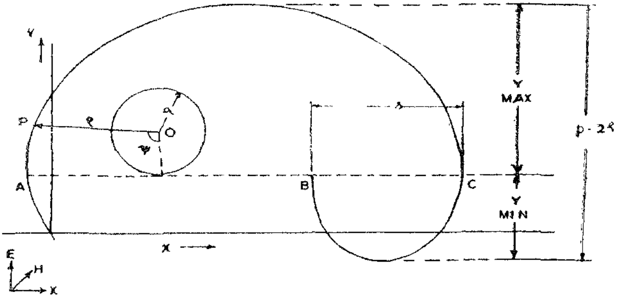

FIG. 1. The prolate cycloid.

Design

In designing the cycloidal mass spectrometer, the following steps were adopted:

1. Depending on the resolving power required at the maximum mass number, the value of b is calculated from eqn. (2). For example, when the resolving power required is 1 in 45 at mass number 45, and $s_1 = s_2 = 1$ mm, then $b = (s_1 + s_2)\ RP = 0{\cdot}2 \times 45 = 9$ cm. Once b is known, the value of a can be calculated.

2. Different values of ρ are tried out to give the desired cycloidal trajectory. Then for a particular value of ρ, s is given by

$$s = 2\left[(\rho^2 - a^2)^{\frac{1}{2}} - a \cos^{-1}\left(\frac{a}{\rho}\right)\right] \tag{3}$$

3. The magnetic field should extend at least over dimensions $(b + s)$ along ox and $p = 2\rho$ along oy directions. The electric field must be uniform between two planes at a distance $(\rho - a)$ and $(\rho + a)$ from the source-collector plane (that is, in effect over a distance of $p = 2\rho$).

4. The secondary radius ρ is related to β through the relation $4a\,\rho\beta = (\rho^2 - a^2)$ from which β is calculated.

5. The acceleration voltage, V_0, is given by

$$V_0 = V_\beta = pE\beta = ap\beta\,\frac{eH^2}{mc^2} \times 300 \text{ volts.}$$

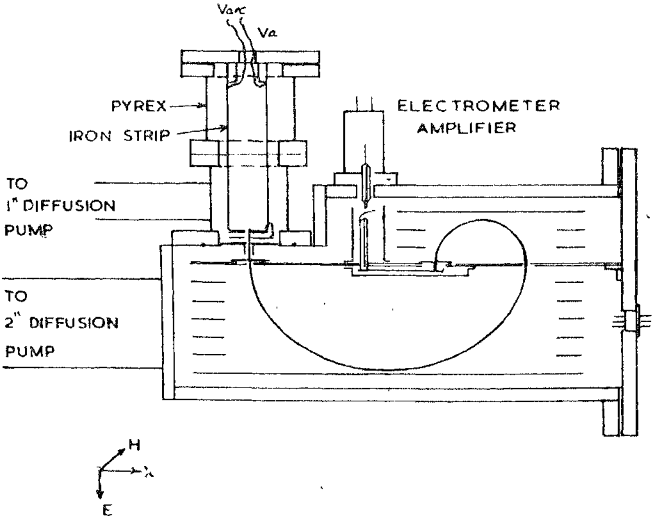

FIG. 2. Schematic diagram of a cycloidal mass spectrometer.

It should be remembered that very small values of β will mean that low values of V_0 will have to be used, which is not desirable for ion sources having an appreciable energy spread. Thus the values of ρ and a have to be selected properly to yield the desired value of β. Table I gives values of b, s, β and MV_0 ($H = 4000$ Gauss) for various values of a, namely, 0·5, 1·0, 1·5 and 2·0 cm. It is found that for $a = 1{\cdot}5$ cm, $b = 9{\cdot}42$ cm. So the value of $a = 1{\cdot}5$ cm is selected. Either $\rho = 4$ cm or 5 cm can be selected, but in the present instrument $\rho = 4$ cm is used. For this case $MV_0 = 11000$, so that when $M = 27$, V_0 is nearly equal to 400 volts.

TABLE I

a (cm)	b (cm)	s (cm)	bs (cm)	ρ (cm)	p (cm)	β	MV_0
0·5	3·14	8·36	11·50	5	10	2·48	19810
1·0	6·28	7·06	13·34	5	10	1·20	19210
2·0	12·56	4·52	17·08	5	10	0·50	16000
0·5	3·14	6·49	9·63	4	8	1·20	12600
1·0	6·28	5·11	11·39	4	8	0·94	12000
1·5	9·42	3 96	13·28	4	8	0·57	11000
2·0	12·56	2·73	14·79	4	8	0·38	9603

Construction and testing of the instrument

The minimum size of the pole face should be $(b + s)$ along the ox and $p = 2\rho$ along the oy directions. So soft iron pieces of slightly larger size (22×13 cm instead of $13{\cdot}3 \times 8$ cm) are selected to serve as the pole faces. They also form parts of the two sides of the analyser chamber, all the remaining sides being made of brass sheets of about 6 mm thickness. The pole faces have been shaped as shown in Fig. 2, so that there is a much smaller magnetic field in the source region compared to the region of the analyser. Silver brazing was done to keep the pieces in their normal positions. The gap between the pole pieces was fixed to be 3 cm.

The electric field $V = Ep$ is obtained by applying a potential of V volts to two stainless steel plates held at a distance of slightly greater than 2ρ (10 cm instead of 8 cm). For making the field very uniformly over the distance, several rectangular rings are spaced uniformly between these plates and applied suitable voltages from a potentiometric network arranged outside the analyser, through a 9 pin glass to metal seal fixed in a circular flange. The Faraday cup collector is connected to a glass to metal seal through a copper spring contact and externally an electrometer amplifier is connected to the glass to metal seal.

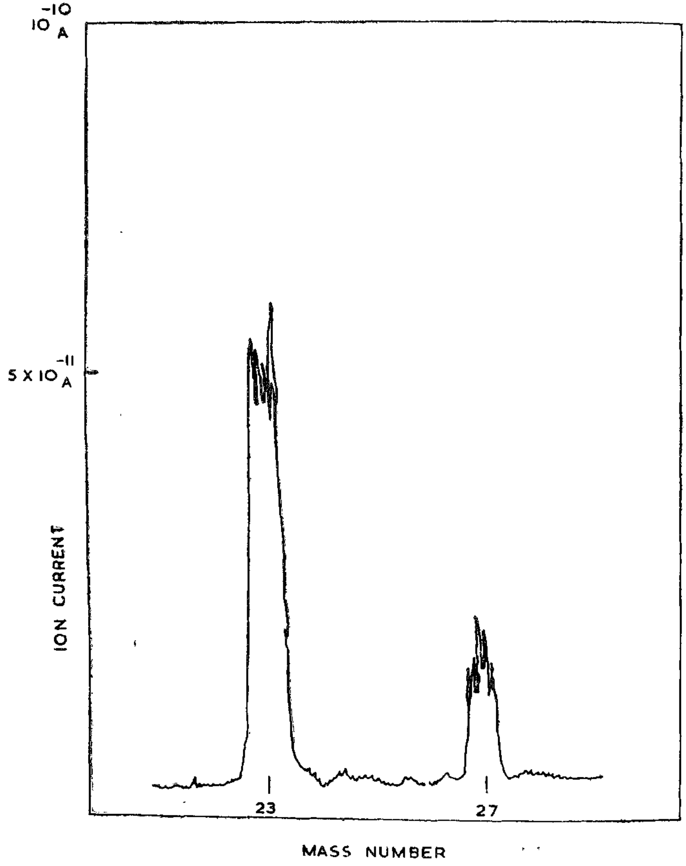

FIG. 3. Mass spectra of $Al_2O_3 + Na_2CO_3$.

The source and the analyser regions, pumped separately by 1" and 2" oil diffusion pumps respectively, are connected only through the source slit of about 1 mm width and 6 mm length, so that the source can be operated at pressures as high as 10^{-4} torr while the pressure in the analyser is maintained at about 10^{-7} torr (with a liquid nitrogen trap). A single rotary vacuum pump is used to back the two diffusion pumps.

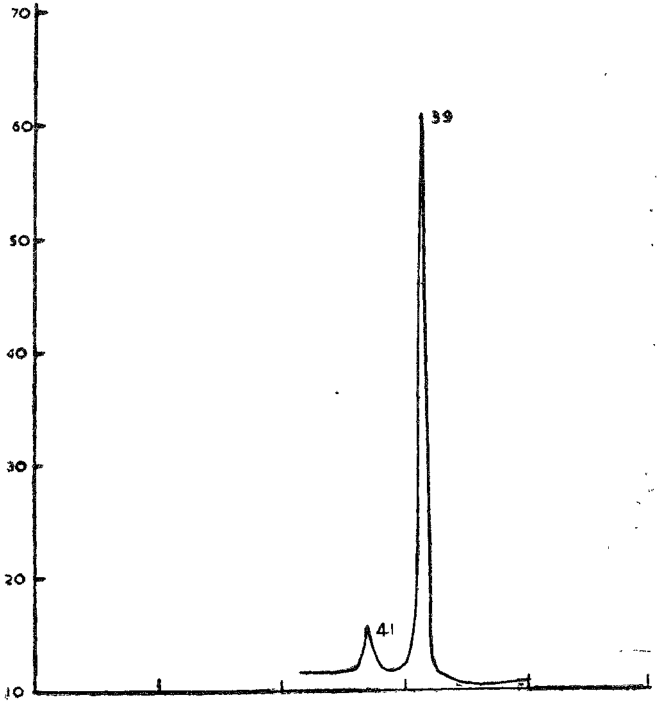

FIG:- 3 a MASS SPECTRUM OF POTASSIUM

The electromagnet, capable of giving a field of about 4000 Gauss, is fed by a current regulated power supply capable of providing 1 amp at 300 volts with a regulation of 0·025%. Voltages are applied to the field plates through a potentiometer network connected across a standard electronically controlled voltage supply unit giving upto 1500 volts at 5 mA. A similar unit was used for accelerating the ion beam. The electrometer output is applied to a conventional high gain d.c. amplifier and the overall amplifier system gain can be varied to give full scale deflection for currents of 10^{-10}, 10^{-11} and 10^{-12} amp.

Initial testing and adjustment of the instrument was carried out with a thermal ionization source coated with a lithium salt. The field voltages and the acceleration voltage were optimized and it was found that $\beta = V_0/V = 0{\cdot}6$, very close to the initially assumed value of 0·57. The instrument was able to resolve the two isotopes of lithium without any overlap. The half width of the peaks and the separation between them corresponds to a resolution of about 1 in 40. Fig. 3 *a* shows the spectrum of potassium with thermal ionization source.

Next, the instrument was fitted with the vibrator arc source in which iach of the contact members carried a pellet containing Al_2O_3 and Na_2CO_3 in a graphite matrix. The observed spectrum with 1·5 mm slits is shown en Fig. 3. Using narrower slits, the expected resolution of 1 in 40 has been achieved. The ion currents of the order of 10^{-10} amp are obtained when the ions are initially accelerated through a potential of as low as 400 volts. Even this resolved ion current is about one order of magnitude larger than is available with a double focusing mass spectrometer of similar dimensions, where generally much larger accelerating potentials are employed. It is obvious that much larger currents can be obtained with the cycloidal mass spectrometer at correspondingly higher accelerating potentials.

The suitability of the eycloidal analyser for use with the vibrator source thus appears to have bnable thlished. Further work is in progresss to modify the instrument to cnable ese use of higher accelerating voltages with a view to increasing the luminority and the resolving power.

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