IV. ELECTRONIC INSTRUMENTATION*

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A. DETECTION OF HEAVY MASS POSITIVE IONS USING THE CONTINUOUS-CHANNEL ELECTRON MULTIPLIER

1. Introduction

Several authors have studied the characteristics of the continuous-channel electron multiplier, such as its gain for input of electrons as a function of applied voltage, pressure, time, its mode of operation, and its detection efficiency for positive ions H^+, He^+, Ne^+, A^+ which are of relatively low mass.[1-6] This paper presents an investigation of the gain of a continuous-channel electron multiplier for very heavy mass positive ions at various applied voltages. These important characteristics would enable the continuous-channel electron multiplier to find application in the field of mass spectrometry.

2. Apparatus and Description of Measurements

The experimental apparatus is shown in Fig. IV-1. It consists mainly of a Hitachi Perkin-Elmer RMU-6D mass spectrometer operating at pressure in the 10^{-6} mm Hg range, a preamplifier whose gain can be varied from 1 to 1000 in steps of decades, a DC amplifier and a recorder.

A removable Faraday cup is installed between the collector slit of the mass spectrometer and the input end of the electron multiplier. It can be connected to the preamplifier to provide a "control signal" on the recorder to be compared with the output signal of the electron multiplier.

Figure IV-2 shows the test fixture for the electron multiplier which can be moved to line up with the stream of incoming ions by means of a graduated mechanical stage.

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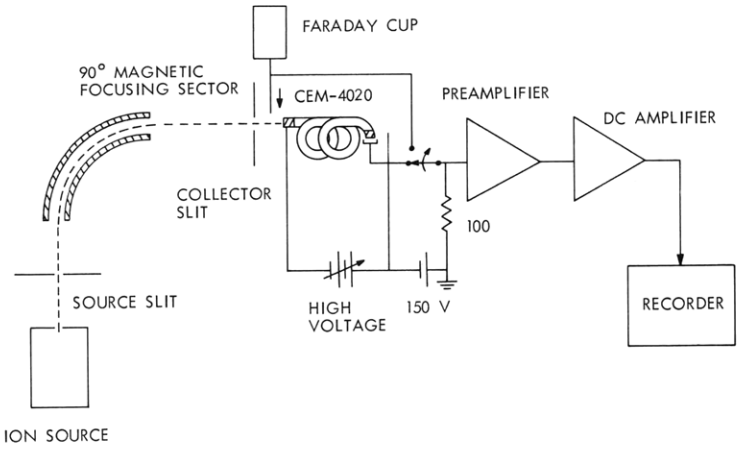

Fig. IV-1. Experimental apparatus for testing the CEM-4020 electron multiplier with ions as input.

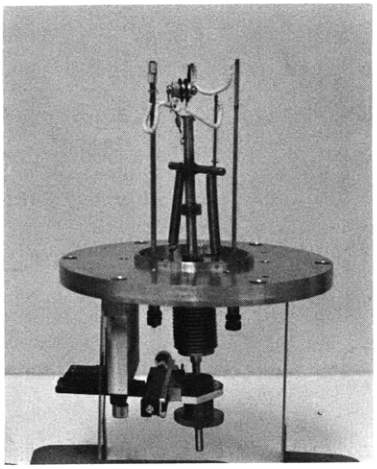

Fig. IV-2.

Test fixture for testing the electron multiplier in the Hitachi 90°-sector mass spectrometer.

The electron multiplier that was tested was a CEM-4020 obtained from the Bendix Corporation, Michigan.

The input ions used were Ne^+ ($m \approx 20$), Ar^+ ($m \approx 40$), Xe^+ isotopes ($m \approx 128$-136) and a compound called Perfluoro-tributyl-amine $C_{10}F_{27}N$ ($m \approx 647$).

3. Results and Discussion

The electron multiplier gain as a function of the applied voltage for Ar^+, Xe^+ and ions of lighter mass is shown in Figs. IV-3 and IV-4. The electron multiplier gain as a function of the ion mass for various applied voltages is shown in Fig. IV-5.

For the purpose of comparison, the multiplier gain as a function of the applied voltage with electrons as input is shown in Fig. IV-6.

From Figs. IV-4 and IV-6, it can be seen that for applied voltages below 2400 V, the

electron multiplier gain is almost the same with both electrons and xenon ions as input. Nevertheless, as the voltage is increased beyond 2400 V, the gain for xenon ions

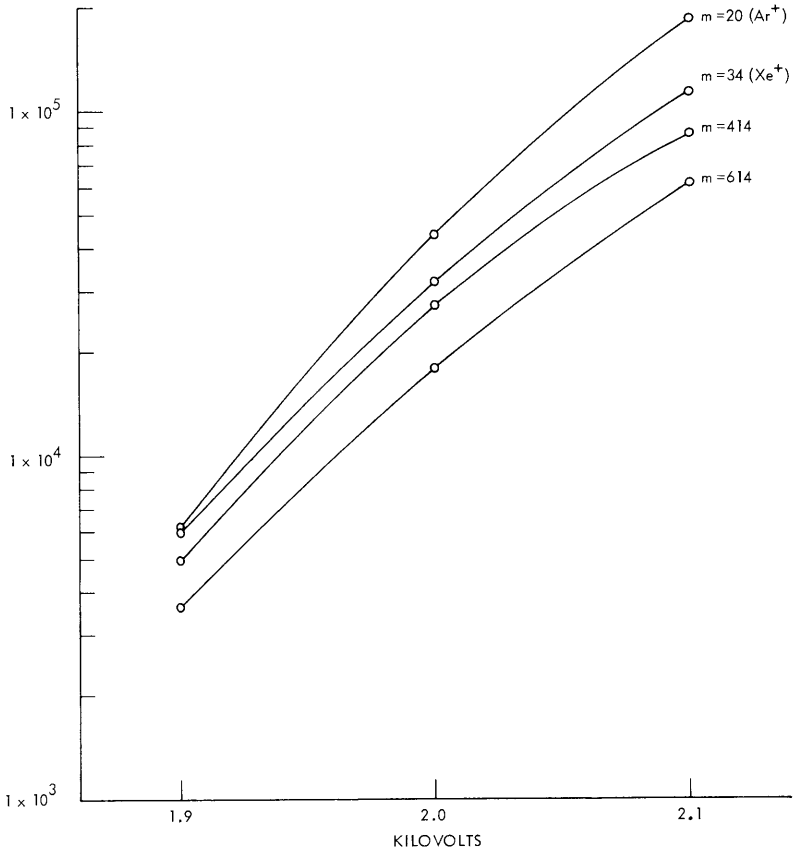

Fig. IV-3. Electron multiplier gain vs applied voltage for various ion masses.

appears to become less than that for electrons; in other words, the electron multiplier gain for ions becomes saturated earlier than that for electrons.

Furthermore, from Figs. IV-3 and IV-5, the electron multiplier gain decreases further and further for heavier and heavier ions.

It should be kept in mind that not all of the ions that were collected by the Faraday cup entered the input end of the electron multiplier because, even though the width of the ion beam was set to be somewhat smaller than the inside diameter of the multiplier, the height of the ion beam could not be adjusted. At any rate, this error could not be large because of the two-dimensional Gaussian distribution of the ions at the input plane of the electron multiplier. In this respect, it could be ensured that the gain was actually somewhat larger than was measured.

Furthermore, the very small 60-Hz noise picked up by the preamplifier and the noise

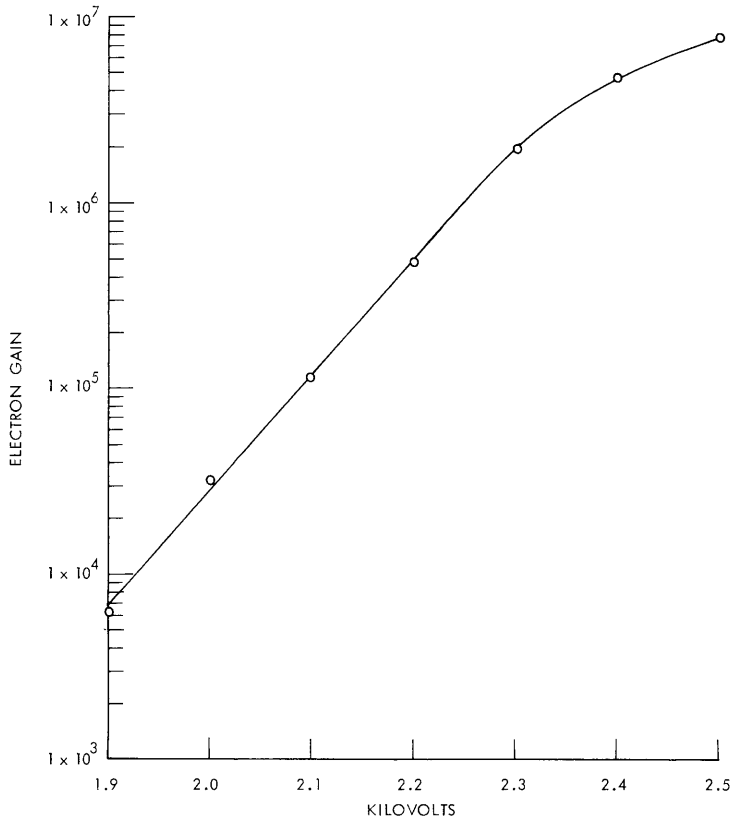

Fig. IV-4. Electron multiplier gain vs applied voltage with Xe^+ isotopes as input.

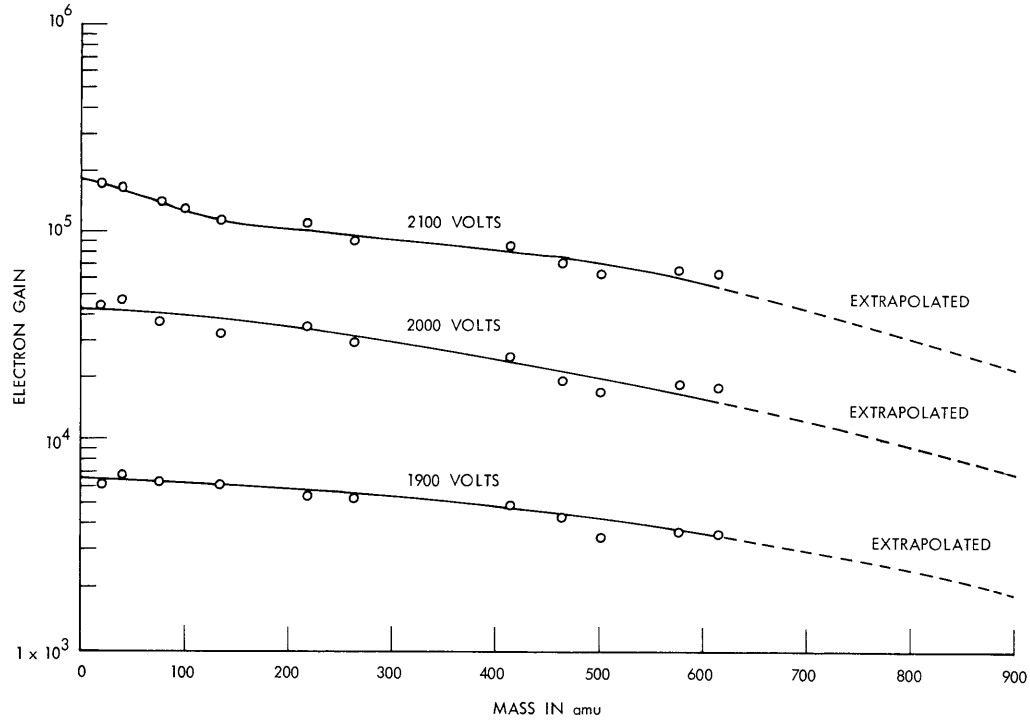

Fig. IV-5. Electron multiplier gain vs ion mass for different applied voltages.

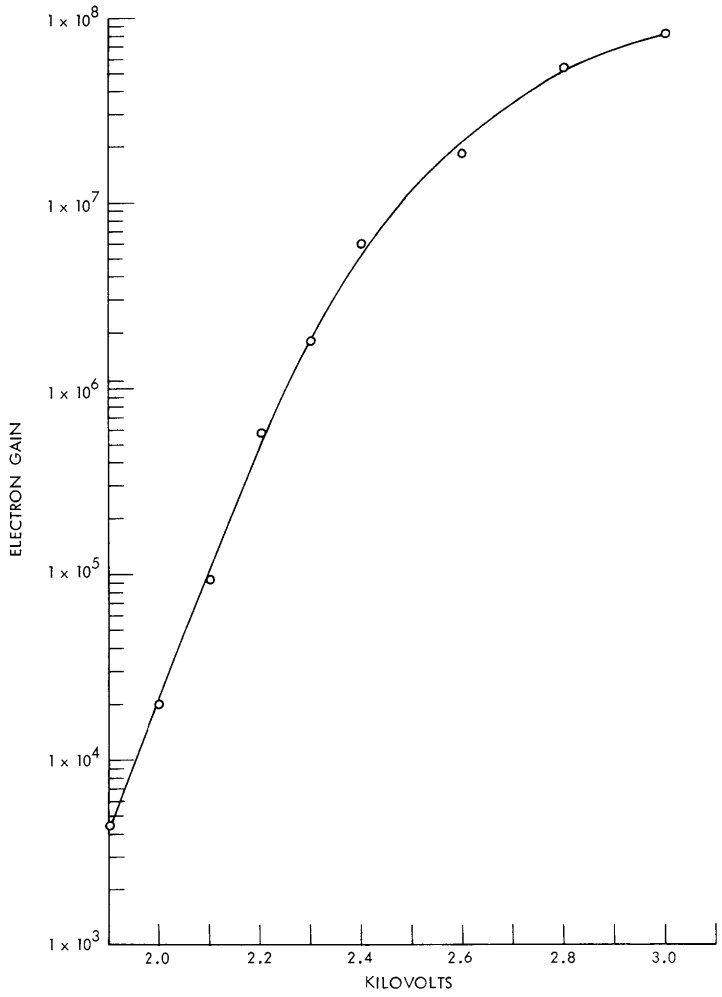

Fig. IV-6. Electron multiplier gain vs applied voltage with electrons as input.

caused by the strayed ions could have caused an error of as much as 10% in reading the recorder output.

Because of the limited dynamic range of the recorder, it was not possible to increase the applied voltage any further.

4. Application

The photographic detection system in the Consolidated Electrodynamics Type 21-110 double-focusing mass spectrometer can be replaced by an electronic detection system that consists mainly of a magnetically shielded array of 150 side-by-side continuous-channel electron multipliers. A suitable configuration of the electron multiplier for the array is shown in Fig. IV-7.

Since the inside diameter of the electron multiplier is extremely large compared with

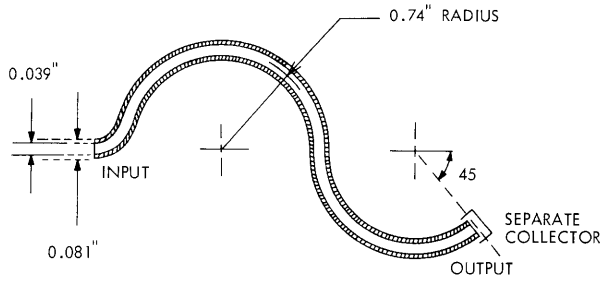

Fig. IV-7. Electron multiplier suitable for the detection array.

the distribution width of any kind of ion, it is necessary to place a slit of infinitesimal width in front of the multiplier input end to improve the resolution of the mass spectrometer.

Under the assumption that the distribution function of ions of a particular heavy mass is a Gaussian whose 10% amplitude width is 10 μ, the slit width or sample width should be 2.2 μ. In order to reconstruct the entire mass spectrum (1000 mass numbers), the detection array must be scanned incrementally along this focal plane of the mass spectrometer at distances of 2.2 μ in a scanning range of 1670 μ. To have negligible probability error in reconstructing the peak of the distribution function of ions, each sample period should be 0.068 sec, which results in a total sample-taking time of 52 sec. This results in a resolution of approximately 12,000. If, however, it were assumed that the 10% amplitude width of the distribution function was 3-6 μ, as it is with a normal exposure time of the photographic plate, the resolution would be between 20,000 and 40,000.

Mechanical scanning is found to have an advantage over either electric or magnetic scanning, since it does not disturb the distribution function of the incoming ions. This infinitesimal scanning process can be achieved by making use of the deflection of a $15 \times 1 \times \frac{1}{6.5}$ in. spring steel cantilever beam. This beam has one end bolted down solidly, while the other is acted upon by a precision micrometer.

For a micrometer scanning angle of 22.4°, the detection array connected to the beam 3 in. from its fixed end would have the desired scanning distance of 2.2 μ.

Incremental scanning can be done in many ways; for example, one way is to drive the field coil of a DC motor with a voltage supplied as shown in Fig. IV-8 while keeping the armature voltage constant.

The gain of the electron multiplier can be measured fairly accurately for all ion masses. This suggests that not only information on the exact locations of the ions but also information on the relative, if not absolute, intensities of the ions can be provided for the entire mass spectrum.

If the electron multipliers of the detection array are operated in the saturated modes, ions coming in would result in pulses of constant amplitude which can be counted. A

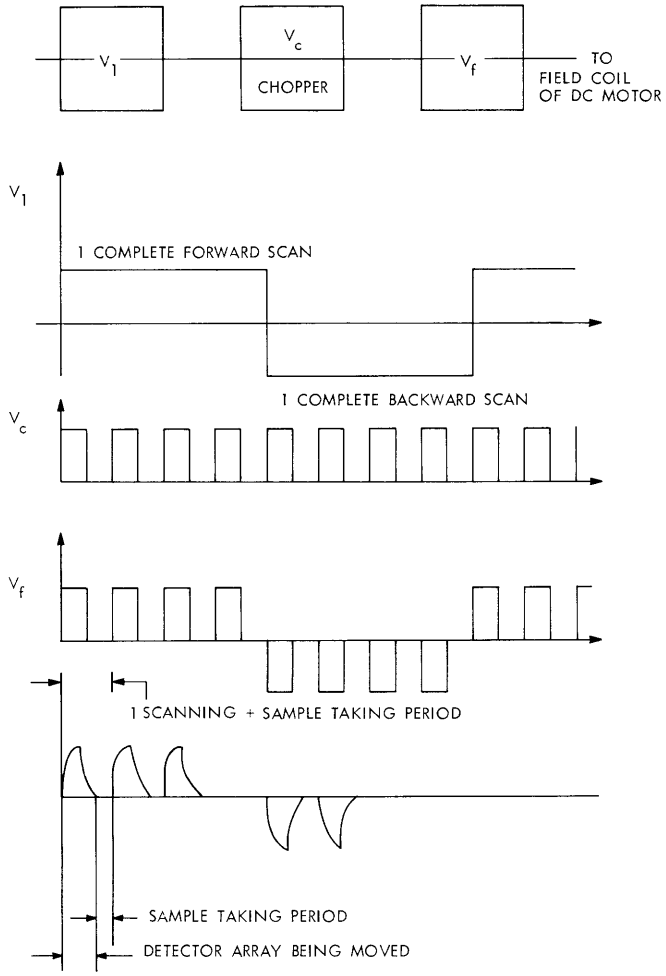

Fig. IV-8. DC motor field coil power supply.

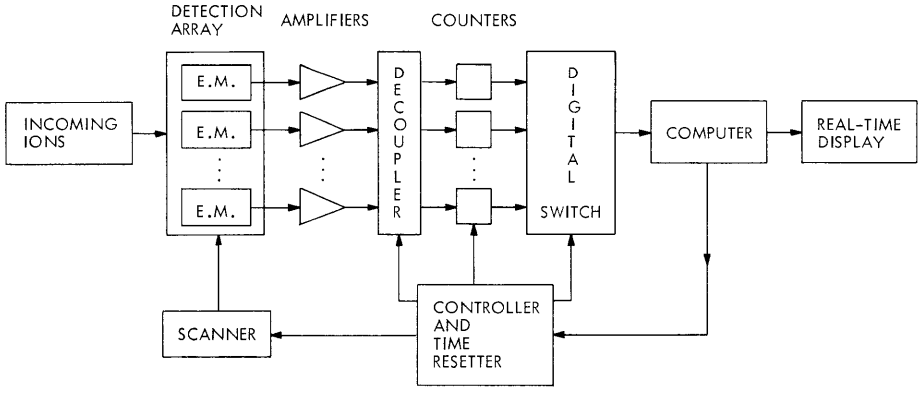

Fig. IV-9. Basic system using continuous-channel electron multipliers in saturated operating mode.

block diagram of the over-all detection system is given in Fig. IV-9.

This detection system is far superior to any of the detection systems that is capable of giving real-time output of the entire mass spectrum (ϕ to 1000 mass numbers), at the present time.

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