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ARKANSAS

Graduate Institute of Technology

BASIC EXPERIMENTAL RESEARCH LEADING TO IMPROVED

COLD ELECTRON SOURCES AND NEW TYPES OF

VELOCITY FILTER MASS SPECTROMETERS

The National Aeronautics and Space Administration

Research Grant NsG 153-61

(Final Report)

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UNIVERSITY OF ARKANSAS

GRADUATE INSTITUTE OF TECHNOLOGY

LITTLE ROCK, ARKANSAS

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FINAL REPORT

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Washington, D. C.

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M. K. Testerman, Head   Date
Electronics and Instrumentation

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PART I

LISSAJOUS MASS SPECTROMETER
Developmental Research

R. L. Bond

A. Introduction

A mass spectrometer that has many theoretical advantages over other spectrometers for space research has been experimentally investigated. It is a velocity filter device which derives its mass separation ability from the phase difference in ions traversing three stages of electrostatic deflection. Ions that have a pre-selected velocity, determined by a scan voltage, pass through a vertical and two horizontal deflection stages in phase with a 1.0 Mc sawtooth deflection potential applied between the plates of each stage. These resonant ions form a diagonal display (Lissajous pattern) on the collector. Non-resonant ions form similar displays on either side of the resonant ion display.

The chief advantage of the Lissajous mass spectrometer over radio-frequency types is its long duty cycle. The duty cycle is limited only by the flyback time of the sawtooth deflection potential and this is only about 3% of the sawtooth cycle. The duty cycle is at least twice that of the Bennett tube.

The Lissajous spectrometer has no low-mass discrimination as does the Bennett tube. Grids, one of the major causes of sensitivity loss in the Bennett tube, have been eliminated in the Lissajous. The diameter could be reduced to a fraction of that of the Bennett tube.

B. Theory of Analysis

All ions leaving the last electrode of the ion focusing guns are given an energy, eV, where e is the unit electrostatic charge in coulombs and V is the potential of the last electrode (scan potential) in volts. These ions have a velocity, v, in meters per second, given by

$$v = (\frac{2eV}{m})^{1/2} \tag{1}$$

where m = mass of the ion in kilograms

The ionic non-resonant to resonant velocity ratio, z, is given by

$$z = \frac{v}{v_0} = (\frac{m_0}{m})^{1/2} \tag{2}$$

where the subscript indicates the resonant ion. The volocity of m_0 is selected to maintain phase relationship with a sawtooth deflection potential applied to each of the deflection stages. If ions with masses m and m_0 enter the first set of deflection plates in phase and $m \neq m_0$ they will enter the second stage out of phase. The ion with mass m will also be out of phase with the sawtooth and therefore will be deflected more or less than the resonant ion with mass m_0. The phase difference between the two masses, θ_2, in fractions of a sawtooth cycle is given by

$$\theta_2 = \frac{a}{z} - a \tag{3}$$

where a is the equivalent length of drift space between sets one and two in cycles of sawtooth waveform. Between stages two and three this phase difference, θ_3, is

$$\theta_3 = \frac{a+b}{z} - (a+b) \tag{4}$$

where b is the equivalent length of the second drift space in cycles of sawtooth waveform.

The total difference of deflection on the screen, ΔY , can be given as

$$\Delta Y = \frac{Ed}{2sV} (\Theta_2 L_2 + \Theta_3 L_3) \qquad (5)$$

where: E = deflection potential in volts

s = plate separation in meters

d = plate length in meters

V = scan potential in volts

L_2 = distance from second deflection stage to screen in meters

L_3 = distance from third deflection stage to screen in meters

C. Experimental

1. Vacuum System

The vacuum system consists basically of a Consolidated Vacuum MCF-60 oil diffusion pump complemented by a Welch 1400B mechanical pump. The diffusion pump fluid is Octoil, CVC's brand of 2-ethyl hexyl phthalate. A water cooled optical baffle and liquid nitrogen trap help prevent pump oil from contaminating the vacuum chamber. The baffle, cold trap, and plumbing are made of stainless steel. The vacuum chamber consists of a series of four inch diameter, Double Tough Pyrex pipes sealed end to end with Teflon O-rings. The gate valve is a CVC two inch VCS-21 valve. Pressure in the micron region is measured by NRC Type 501 thermocouple gauge. The high vacuum is measured by an RCA 1949 ionization gauge.

2. The Mass Spectrometer Tube

A drawing of the mass spectrometer and associated circuitry is given in Figure 1. The tube is located in the Pyrex high vacuum chamber. The inside of the chamber is lined with brass mesh, s, to cut down the effects of stray fields and to eliminate part of the space charge. The stability of the beam is thereby increased. The tube consists of five major elements. Three of these (the electron formation and focusing region, A, the ion formation region, B, and the ion focusing and accelerating region, C), are compression mounted on an aluminum end cap. A fourth element, the collector assembly, D, is mounted on two rods which enter through a plate, P, at the opposite end of the system. The fifth element, E, consists of three sets of deflection plates introduced through metal spacers between the glass sections of the vacuum chamber. A scan element is also included in this section.

a. Electron Formation and Focusing

Electrons are emitted from a short section of rhenium ribbon, F. These electrons are focused into a small diameter, short focal length beam by an immersion lens, L. The lens consists of four Nichrome discs with concentric apertures. The control grid and the first accelerating electrode are five mils thick and the apertures are 0.0591 inches in diameter. The focusing and second accelerating electrodes are ten mils thick and their apertures are 0.0787 inches

in diameter. The distance between the filament and control grid is about 0.030 inches. The separation of the control grid and first accelerating electrode is 0.0197 inches and the separation of the other elements is 0.079 inches. Spacers used throughout the system are made of Supramica 500 (Mycalex Corporation). A short electron gun was necessary because the earth's magnetic field was strong enough (5×10^{-5} webers/m^2) to deflect the low energy electrons ($\sim 50eV$) in the long distances of a standard electron gun such as the Superior Electronics 3MP.

b. Ion Formation

The electrons are focused into the space between the first two elements of an equipotential ionization region, I. The sample is also introduced between these two elements. The third element, U, of the ionization region acts to pul out ions and to repel any electrons that are not captured by the other two elements.

The elements are made of ten mil Nichrome. The first two apertures are 0.063 inches in diameter; the last is 0.080 inches in diameter.

c. Ion Focusing and Acceleration

The ions from the pulling out region are collected by a three element aperture lens, Z. This lens has two outer elements with 0.063 inch diameter apertures. The center aperture is 0.156 inches in diameter. The ions are focused

into the first element of a three element cylindrical lens, Y.
The cylinders are all 0.375 inches long and 0.1875 inches in
diameter with variable spacing. They form a very weak lens
which focuses the ions on the collector 1.3 meters away.

d. Analyzer Region

The analyzer region consists of three stages of deflection
and a scan element. The scan element determines the resonant
mass. The last two stages are orthogonal to the first stage.
Each stage consists of two plates one centimeter in length.
In the first two stages the plates are three mm apart and
in the final stage they are three cm apart. The drift space
between the first and second stage is 50 cm. Between the
second and third stages the drift space is 30 cm and the
drift space from the third stage to the collector is 50 cm.
Ten centimeters is equivalent to one cycle of sawtooth
deflection potential.

The sawtooth generator is a constant current generator
with a relaxation oscillator. The oscillator uses a fast
rise time, short duration pulse to trigger a transistor
switch which shorts a capacitor. The total duration of the
sawtooth is one microsecond and the fly back time is about
twenty nanoseconds giving a duty cycle greater that 97%.
Nonlinearity of the sawtooth is about 10%.

e. Collector

Ion determination is by electrostatic collection. The current

is read directly into an electrometer. The collector consists of two sections. The one nearest the ion formation region is a .125 inch Nichrome ribbon. The second section is a solid brass plate that acts as a back-up plate to carry off non-resonant ions. The ribbon is almost coterminous with the cross section of the resonant ion beam.

The entire collector assembly is mounted on two rods which terminate on the outside of the vacuum system. By rotating these rods, two dimensional motion can be imparted to the collector. A third movement can be initiated by sliding the rods on dual O-ring seals. This provision was made to compensate for the difficulty of aligning the long beam on the axis of the system.

D. Conclusion

This mass spectrometer, in its present state of development, is not suitable for use as an analyzer in outer space because of its length. The length is established theoretically and cannot be reduced easily using present techniques. The minimum length of the deflection plates is about 1.0 cm due to fringing effects at shorter lengths. The transit time of particles through a set of deflection plates must not be more than one tenth of the deflection waveform period so the waveform must have an equivalent length of ten cm. The lowest practical number of cycles for the three drift spaces are five, three, and five in that order and therefore, the equivalent respective drift space lengths must be 50 cm, 30 cm, and 50 cm. This results in a minimum analyzer length of 130 cm.

This length would not be impractical in the laboratory and probably would not overshadow the desirable features of the tube.

The resolution of the Lissajous mass spectrometer is about five at the present time. The efficiency is about three percent. The duty cycle is around 95%. All three of these parameters can be increased by existing techniques.

50V

1.0 Mc
SAWTOOTH
GENERATOR

HP-211A
SQUARE WAVE
GENERATOR

50 cm   30 cm   50 cm

500 V

500 V

FIGURE I
LISSAJOUS MASS SPECTROMETER

PART II - A STUDY OF DIFFERENT DESIGNS OF COLD ELECTRON SOURCES CAPABLE
OF MASS SPECTROMETRIC APPLICATIONS

Submitted as publication with format to comply with editorial
regulations and therefore deviates from format of Part I.

A Study of Different Designs of Cold Electron Sources

Capable of Mass Spectrometric Applications

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ABSTRACT

Various methods of providing cold electrons for

ionizing neutral gas molecules in a mass spectrometer

have been studied. These devices all belong to the

general type in which a relatively weak current from

a primary emitter is amplified by an electron multi-

plier. The multipliers used in this study were either

conventional bucket-dynode or resistance-strip magnetic

types. The final designs of the cold sources described

here used tantalum photocathodes under ultraviolet

irradiation as primary electron sources. The sources

were found to be highly efficient, consume a negligible

amount of power using sunlight, have minimal outgassing and gettering effects, and produce considerably less short term emission fluctuations when compared with a temperature-limited thermionic emitter. These devices would lend themselves well to calibration work and space-flight instrumentation.

I   INTRODUCTION

The use of electrons with 50 to 100 electron volts of energy is one of the most commonly employed techniques for producing ions from neutral molecules in a mass spectrometer. In the past, thermionic emitters have been used almost universally as the source of the ionizing electrons. The presence of the hot wire in the proximity of the ionizing region gives rise to the vast majority of difficulties experienced in the use of mass spectrometry for precise quantitative analyses. The elimination of the hot body as an electron source could potentially minimize several problems such as: formation of insulating deposits on surrounding elements; variation in the mass spectrum cracking pattern due to thermal variations in the ionizing region; selective gettering of the entering sample, subsequently causing the composition of the sample to be modified; the very accurate and fast response of emission regulation required when operating the filament in a temperature limited mode; heat pumping or out gassing the ionizing region; and the elimination of carbon monoxide contribution to the 28 peak. The following is a description of an investigation of several cold techniques for producing electrons compatible for application in mass spectrometer ion sources, where the ion region may be operated at room temperature or below.

II   Experimental Apparatus and Techniques

   (1) Ten-stage Bucket Dynode Electron Multiplier

   This electron source consisted essentially of a photocathode, excited
by ultraviolet radiation, with an electron multiplier to amplify and direct
the photoelectrons into the ionization region of a radio-frequency mass
spectrometer (see Fig. 1). The ten-stage electron multiplier had bucket-
shaped silver-magnesium dynodes of the type used in the Dumont 6291 multi-
plier, but without cesium activation. The tantalum photocathode was identical
in size and shape to the multiplier dynodes. It was mounted adjacent to the
first dynode at a distance equal to the multiplier dynode spacings. The
photocathode faced a sapphire window (1 inch in diameter by 1/8 inch thick)
which transmitted ultraviolet light from a hydrogen arc lamp outside the
vacuum system. The final stage of the multiplier, from which the electron
beam emerged into the ionization region, was 1/8 inch from the first grid
of the mass spectrometer ion source. Studies using this source were
performed in a vacuum system capable of an ultimate pressure of 6.3×10^{-6}
Torr, being pumped by an Eimac HV-1 oil diffusion pump and having a liquid
nitrogen trap between the pump and the evacuated region.

   (2) Continuous Dynode Electron Multiplier

   Two resistance strip type multipliers, based on a design developed
by the Bendix Corporation[1] for use as an ion detector, were designed and
constructed at this laboratory. Of these two multipliers, one used an
electromagnet to create its magnetic field while the other had permanent
magnets. Whereas the Bendix multipliers were designed to amplify minute
ion currents, these multipliers were designed to produce microamperes of
electron current.

The resistance strip multiplier utilized thin films of tin oxide for dynode surfaces. Extremely clean microscope slides served as the substrate for the dynode strips. Of the many cleaning methods tested, the use of Aquet liquid detergent followed by vapor degreasing in trichloroethylene was found to be the most reliable cleaning technique. Preliminary preparation of a strip includes evaporating, in vacuo, a thin film of titanium onto the slide surface and oxidizing it until its measured resistance lies in the 1 to 10 megohm range. Finally, a thin film of tin is evaporated, in vacuo, over the titanium dioxide and activated (oxidized) by heating in air at an appropriate temperature until the resistance of the slide returns to that of the titanium dioxide film. Deposition work was conducted in an 18" diameter Pyrex belljar pumped by a Veeco EP4 oil diffusion pump equipped with a liquid nitrogen trap. The system was capable of maintaining pressures below 1×10^{-5} Torr during deposition.

Electrical contact to the dynode strip was made by soldering leads onto evaporated gold or silver-manganese contacts using indium solder. The silver-manganese contacts as described by Gould and Finnegan[2] have proven to be superior to gold contacts in adhesiveness, ruggedness, and ease of soldering.

These multipliers have been operated for test purposes, in vacuum systems capable of ultimate pressures of less than 1×10^{-6} Torr, being pumped by VEECO EP-4 oil diffusion pumps and having a liquid nitrogen trap between the evacuated region and the pump.

III Experimental Results

(1) Bucket Dynode Electron Multiplier

The electrons from this multiplier, because of its design configuration, are emitted in an unidirectional path over a short distance. This condition

gives rise to a higher ionization efficiency than that obtained from a
conventional thermionic emitter. In the case of the radio frequency mass
spectrometer, wherein the cold electron source was tested, the ionization
efficiency increased by a factor of 200 when the cold source was substituted
for the usual thermionic source.

The n-butane spectrum shown in Fig. 2 was typical of those obtained with
the cold electron source. There was no detectable loss of resolution and
the operational features of the RF mass spectrometer were not modified in
any way by the use of this electron source. There was the expected reduction
in the mass 28 peak, since the removal of the thermionic emitter eliminated
the usual formation of carbon monoxide.

The stability of the multiplier source was evaluated by comparing the
spectra peaks produced by the characteristic fragmentation of n-butane over
a five-day period. On the first day the ratio of the 43 peak to the 58 peak
was 5.94, while the ratio of the 43 peak to the 29 peak was 2.55. On the
fifth day, these ratios were the same, thus indicating that the energy
spectrum of the ionizing electrons was remaining constant, although the
overall gain of the multiplier assembly decreased during the period of
operation. The cold electron source did not display large short term
transients in electron emission in contrast to the temperature limited
thermionic emitter. With continuous use of the cold source, the ionizing
current will decrease gradually and approaches a constant value asymptotically,
thus simplifying electron emission regulation.

Of the several materials considered for the photocathode, tantalum
provided the highest emission current (see Fig. 3). Under the conditions
of an oil contaminated vacuum system, tantalum displayed the lowest rate
of electron emission decay. A film of lanthanum boride on a carburized

tantalum base gave an emission current approaching that of tantalum but much less durable, lasting less than 5 minutes. Electron current from unactivated silver-magnesium exceeded that of activated silver-magnesium but neither compared with that of tantalum.

Additionally, the tantalum has an advantage over the other materials tested in that its surface can be cleaned easily and repeatedly by flashing at 800-1000°C for approximately 1 minute. For this purpose, the tantalum photocathode was mounted on two heavy aluminum rods inserted through the end-cap walls of the mass spectrometer. These rods are shown in Fig. 1 (photocathode holder). Teflon seals made the inlets vacuum tight and insulated the rods electrically from the rest of the system. The large cross section of the rods permitted high currents to be fed to the photo-cathode without overheating the Teflon seals. Flashing is necessary after the tantalum has been exposed to air and may be used to restore full emissivity whenever the output current falls below an acceptable level.

The tantalum possesses good resistance to typical poisoning agents as indicated in Table I. The decrease in photoemission current during continuous ultraviolet radiation was gradual and very nearly linear, indicating again that emission regulation will be relatively simple. Flashing the photo-cathode restored full output in all cases, even after its extreme decline from long exposure to butane.

The ten-stage electron multiplier was capable of producing an ionizing electron current of 20-40 microamperes using an input current of 0.09 - 0.9 microamperes. Cases have very little poisoning effect on the silver-magnesium dynodes (see Table II).

After each of these tests the dynodes regained virtually all of their original secondary emission characteristics after a 24 hour recovery period under a vacuum of approximately 6.3×10^{-6} Torr.

The power consumed in producing one microampere of ionizing current was 160 microwatts for the cold source, which may be contrasted with 6 watts of power required by a thermionic emitter of comparable output current geometry.

In an additional test, the multiplier assembly was left in the vacuum system without a cold trap for 12 hours and then remained mounted in the system, exposed to room air without vacuum, for an additional 48 hours. The secondary emission coefficient was measured before removal of the cold trap and again, at the end of the 60 hour period, after replacement of the cold trap and restoration of a vacuum of 1.5×10^{-5} Torr. Comparison of the second measurement with the first showed a drop in secondary emission coefficient of only 25%.

(2) Continuous Dynode Electron Multiplier

The basic resistance strip multiplier, shown schematically in Fig. 5, consists of two plane-parallel, resistive surfaces. These surfaces ordinarily consist of a semiconducting coating over an insulating base wherein the active surface possesses the proper volume resistivity. Equal potential gradients are established along each surface by applying equal potential differences across the strip's long dimension. The potential of one surface (field strip) is maintained more positive than that of the other surface (dynode strip) at comparable lengths along the strip. Thus the equipotential lines are parallel to each other and slanted in the direction shown in the diagram. The entire structure is placed in a uniform magnetic field normal to the electrostatic field. An electron released from the dynode strip at any point will describe a trochoidal path whose initial direction is determined by the equipotential at its point of origin. It will return to the dynode strip with an impact energy corresponding to the difference in potential between its points of origin and impact. In a properly

designed multiplier this energy will be large enough to give a secondary emission ratio greater than unity. Thus each electron will release more electrons at its point of impact, and these electrons will continue along the strip in a similar fashion. The total gain in electron current along the strip will be a function of the magnetic and electrostatic field strengths and the length of the dynode[3].

An approximate analysis can be made of the path of an electron in the resistance strip multiplier by assuming the electron trajectory to be trochoidal and the initial electron energy to be negligible. The radius of curvature of the electron path is given by:

$$R = \sqrt{\frac{2mV}{eB^2}} \qquad (1)$$

where R = path radius, cm
 m = mass of charged particle, gm
 e = electronic charge, abcoulombs
 B = magnetic field intensity, gauss
 V = accelerating potential, abvolts

However, the accelerating potential is determined by the length of the jump of the electron and the electric field strength E along the dynode, or:

$$V = 2 RE \qquad (2)$$

Substituting equation (2) into equation (1) gives:

$$R = \frac{4mE}{eB^2} \qquad (3)$$

The effective number of stages is given by dividing the dynode length by the diameter of the individual jumps. This number can be altered by adjusting either the magnetic field intensity or the potential gradient along the dynode. For a given magnetic field intensity there exists a singular electrostatic field intensity at which maximum gain occurs, although this maximum is broad. The working parameters are chosen as the best compromise in performance between many low-gain stages and only a few high-gain stages.

The electromagnet multiplier has been used to study combinations of electrostatic and magnetic field strengths. These studies indicated an optimum magnetic field strength of approximately 180 Gauss in combination with electrostatic fields created by the application of 1000 - 1400 Volts across the dynode, for our particular multiplier configuration.

The parameters of the permanent magnet multiplier were chosen from the results of the electromagnetic multiplier tests. The permanent magnets greatly reduce the over-all size of the multiplier, require no power for operation as does the electromagnet, and do not generate heat.

As previously mentioned, the dynode surfaces of the resistance strip multipliers were thin films of tin oxide. These films, and films of tin in combination with other metals, have shown stability, ruggedness, high secondary emission ratios, and good resistivity to poisoning by atmospheric contaminants. The dynode strips have titanium dioxide coated glass microscope slides as their substrates. The incorporation of the titanium dioxide film between the glass substrate and the secondary emissive surface has improved dynode performance over the case where the final film was applied directly to the glass, in the following ways: bonding of the film to the substrate is improved; the resistance of the dynode remains constant during prolonged exposure to the atmosphere; a more uniform resistivity is obtained; and arcing over at the electrical contacts caused by film breakdown has been eliminated.

Tin oxide surfaces were selected because of their long lifetime under electron bombardment, relatively high gain, and their secondary emission yield was unaffected by long exposure to the atmosphere. The secondary emission characteristics of the films evaluated are presented in Table II. Several of these films exhibited higher yields than tin oxide but none even closely

approached the lifetime of tin oxide under continuous electron bombardment. The resistance strip multipliers are physically small, being only 3 in. in length, 1.5 in. wide and 1.5 in. high. Their small size is compatible with the installation requirements of a mass spectrometer ion source.

Sources of activating electrons have been studied from two points of view; use of beta-emitting radioactive materials and the use of photoelectrons, as previously discussed. Of the soft beta-emitting materials investigated, promethium^{147} was chosen for study because it produces no gamma rays, has a half-life of 2.6 years, a beta-ray energy of 0.0223 MeV, radio-chemical purity exceeding 99 percent, and it is relatively inexpensive. Because Pm^{147} emits only beta rays it is comparatively easy to shield. One curie of Pm^{147} yields 3.7×10^{10} disintegrations per second or a theoretical total electron current of approximately 6 nanoamperes per second. This is more than enough, when used with any multiplier having a total gain of at least 10^4, to furnish sufficient current for ionizing gas molecules, either in a mass spectrometer or in an ionization gauge.

The resistance strip multipliers were employed as ion gauges to test their sensitivity, response, and stability. The operation of electron multipliers as ionization gauges serves to show their feasibility as cold electron sources for mass spectrometric use. The use of an electron multi-plier as an ion source for a mass spectrometer was initially suggested in 1958 by Testerman[4]. In 1961, Riemersina, Fox and Lange[5] described a cold cathode ion gauge utilizing an electron multiplier. The resistance strip multiplier incorporating an electromagnet has been assembled using titanium dioxide field strips of approximately 100 megohms and tin oxide dynodes of at least one megohm (usually 10 megohms or greater). The multiplier showed gains of up to 10^4 for an applied potential of 1100 volts across the dynode and a magnetic field of 180 Gauss. The calculated effective number of

stages or jumps varied between 14 and 20 with a gain per jump of up to 1.69.

Figure 5 illustrates the pressure dependence of the ion gauge for two values of grid potential. For these measurements, the grid was connected through a meter to ground and a collector bias maintained at -25V with respect to the exit potential of the multiplier. The grid current was maintained at a constant 0.1 μa. The pressure/ion current relationship is linear below about 1×10^{-4} Torr. The maximum sensitivity of this gauge was 13.3 μA/μ/mA of grid current, for a grid voltage of +100 V, compared with 10 μ A/μ /mA of grid current for the RCA 1949 ionization gauge for a grid voltage of +100 V.

Gain-decay and output electron energy distribution studies have been conducted using the electromagnetic multiplier, in which both the magnetic field and the dynode voltages were variable. The multiplier, in the gain-decay study, using a dynode that had been exposed to the atmosphere for a considerable period of time, proved that the multiplier was capable of reasonably long periods of operation. The multiplier electron output current decreased from 8.1 μa for an input of 3 nA (gain of 2600) to 1.2 μA (gain of 400) after 47 hours of operation. This decay was also accompanied by a carbonaceous buildup, with the dynode resistance decreasing from 3.5 megohm to 0.9 megohm. The operating pressure varied from 5×10^{-5} to 1.2×10^{-6} Torr during this study.

Electron energy distribution studies conducted during this gain-decay period indicated that the energy distribution of the exiting electrons did not change with gain variations. Figure 6 shows a typical output electron energy distribution from the multiplier. The peak distribution energy of the electrons emerging from the multiplier is approximately equal to the energy gained by the electrons during individual jumps in the multiplier.

The broadness of the curve indicates that the points at which the electron finally departed from the dynodes were not all at the same potential, but rather distributed along the last few millimeters of the active surface of the dynode. Reflected primary electrons caused the high energy tailing of this curve.

Regulation of the emission current from these cold electron sources will be comparatively simple because the ionizing current gradually decreases with time and is not subject to the violent fluctuations found in thermionic emitters. Three methods are being considered for the regulation of the ionizing current from the cold sources. These are: (1) for photocathode excitation sources, variation of the current flowing to the hydrogen lamp through a closed-loop feedback system and, (2) for the photocathode and radioactive beta sources, variation of an adjustable iris between the source and the multiplier to vary the number of incident excitation electrons. A potential method of ionization current regulation by adjusting the dynode voltage through feedback techniques is also being considered. Although the over-all gain of the multiplier may vary, the relative energy distribution of the electrons leaving the multiplier has been shown to remain constant, assuring a constant and reproducible cracking pattern.

IV Summary

An electron multiplier, activated by photoelectrons or beta particles from a radioactive material, can be used as a source of ionizing electrons in ion gauge and mass spectrometric applications. Such a source is characterized by low temperature operation, high ionization efficiency, and an electron energy distribution that does not change with multiplier gain variations. Advantages of such a source over a thermionic emitter, including space applications, include: (1) appreciable decrease in power consumption

(2) reduced outgassing (3) no getter effect (4) more rugged construction
(5) high frequency modulation capability of the electron beams, and (6) comparatively little emission fluctuation. Test results show the source in mass
spectrometric applications to be highly efficient, to cause no deterioration
in resolution, and to eliminate many of the ambiguities directly attributable
to the presence of a thermionic emitter in the mass spectrometer.

FOOTNOTES

* This work was supported in part by the National Aeronautics and Space Administration, Goddard Space Flight Center, Grant NsG 153-61. Taken in part from thesis submitted for Master of Science Degree (1961)

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TABLE I

Decrease in Emission Current of Tantalum Photocathode

on Exposure to Poisoning Agents

Poisoning Agent	Time	Decrease in Current
Butane	23 hr.	75%
Diffusion Pump Oil	10 hr.	40%

TABLE II

Decrease in Secondary Emission Coefficient of Ag-Mg Dynodes

from Extended Exposure of Gases

Poisoning Agent	Time of Exposure	Decrease in Secondary Emission
Diffusion Pump Oil	8 hr.	6.0%
Butane	8 hr.	4.6%
Air	8 hr.	1.9%
Argon	8 hr.	1.4%
Helium	60 hr.	1.0%

TABLE III

Secondary Emission Characteristics of Thin Metal Film

Film	Activation Process	Maximum Secondary Emission Coefficient	Primary Electron Energy for maximum yield (electron volts)
SnO_2	Heated in air for 3.5 hours at 190°C	3.5	180
SnO_2	Heated in air for 10 minutes at 600°C	8.0	180
98% Sn-2% Sb	Heated in air for 5 minutes at 500°C	8.0	180
80% Sn-20% Al	Heated to 190°C in oxygen at 20 mm Hg	3.45	180
50% Sn-50% Ag	Heated to 190°C in oxygen at 20 mm Hg	3.45	180
50% Mg-50% Al	Heated to 280°C and exposed to atmosphere	2.56	100
Mg - Ag (Commercial)	Heated to 270°C and exposed to atmosphere	4.62	150
50% Be-50% Ag	Heated to 220°C and exposed to atmosphere	11.00	220

VACUUM-TIGHT CONNECTOR

PHOTOMULTIPLIER
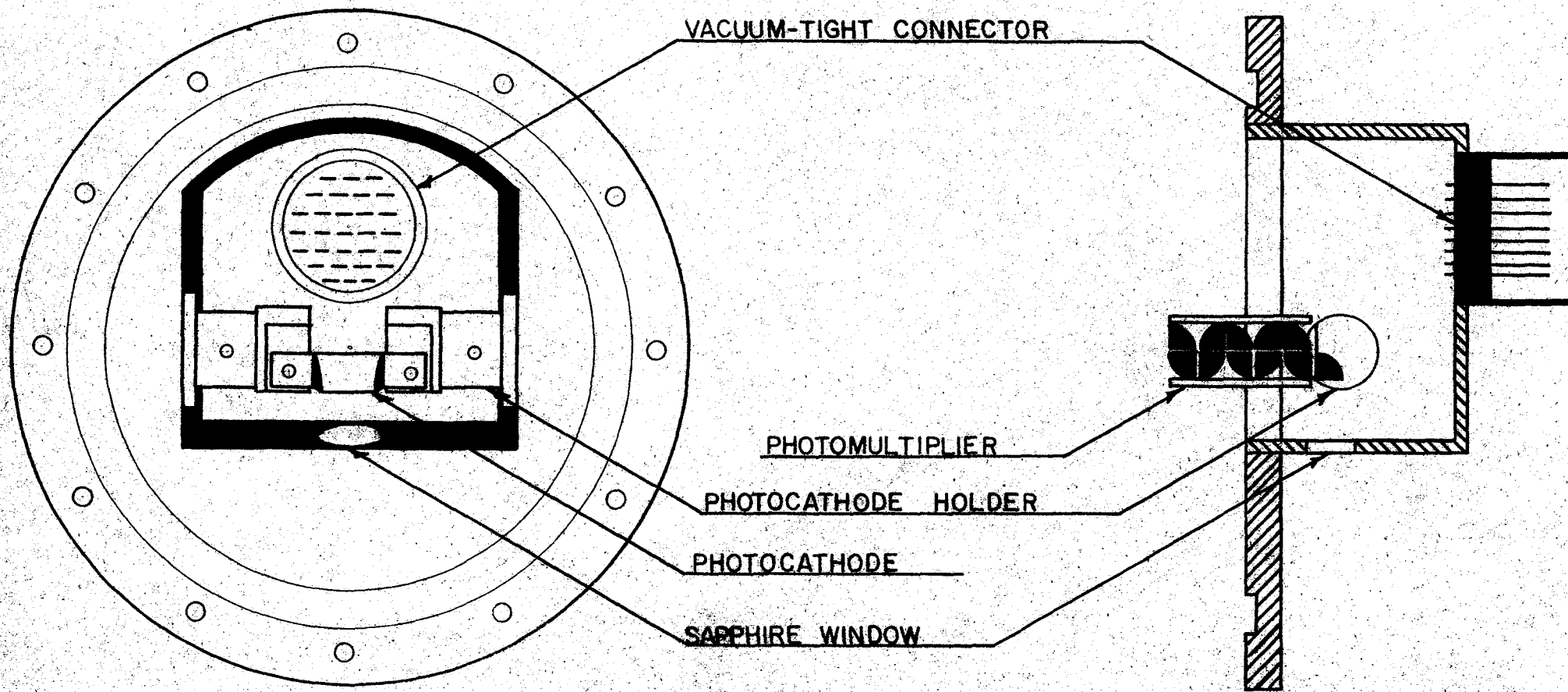
PHOTOCATHODE HOLDER

PHOTOCATHODE

SAPPHIRE WINDOW

Figure 1
ELECTRON MULTPLIER MOUNTED FOR USE IN
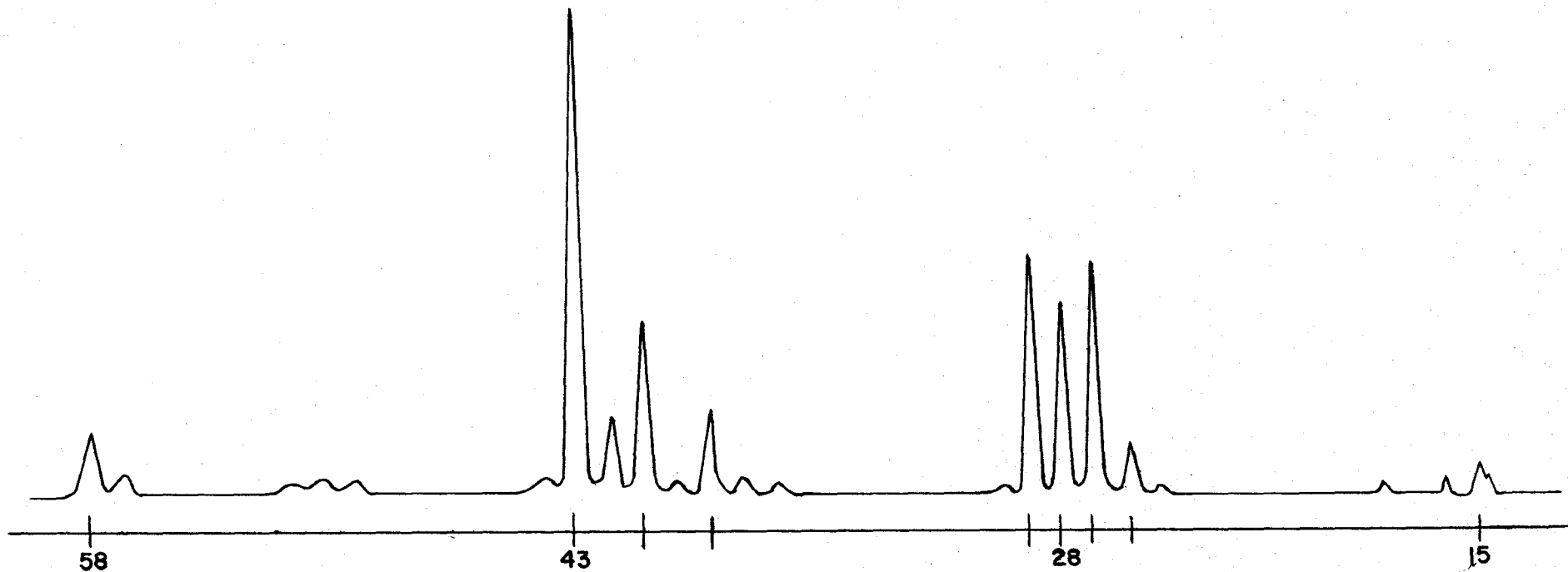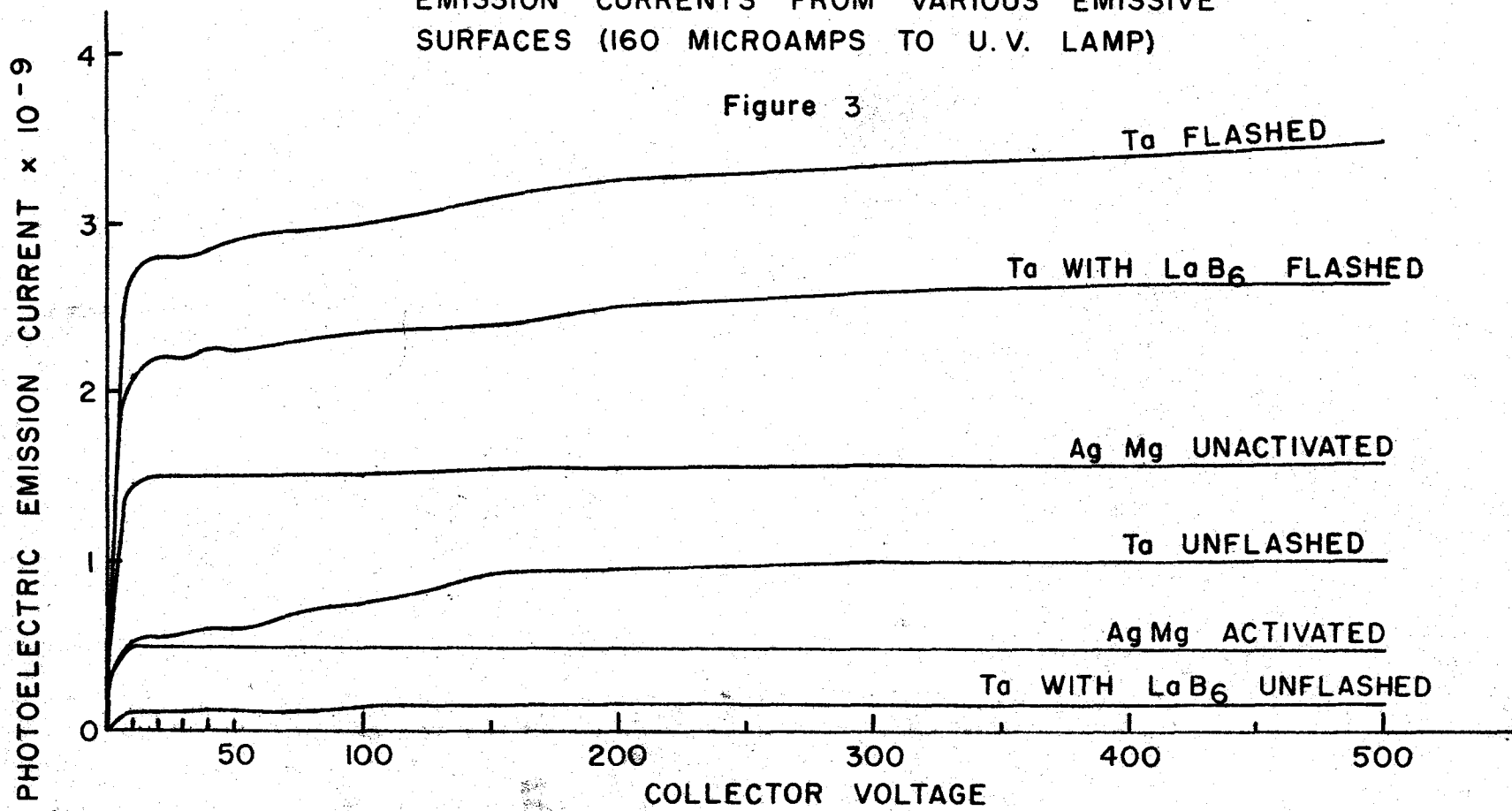R.F. MASS SPECTROMETER TUBE

Figure 2

n-Butane Spectrum from RF Mass Spectrometer
Using Cold Electron Source

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EMISSION CURRENTS FROM VARIOUS EMISSIVE SURFACES (160 MICROAMPS TO U.V. LAMP)
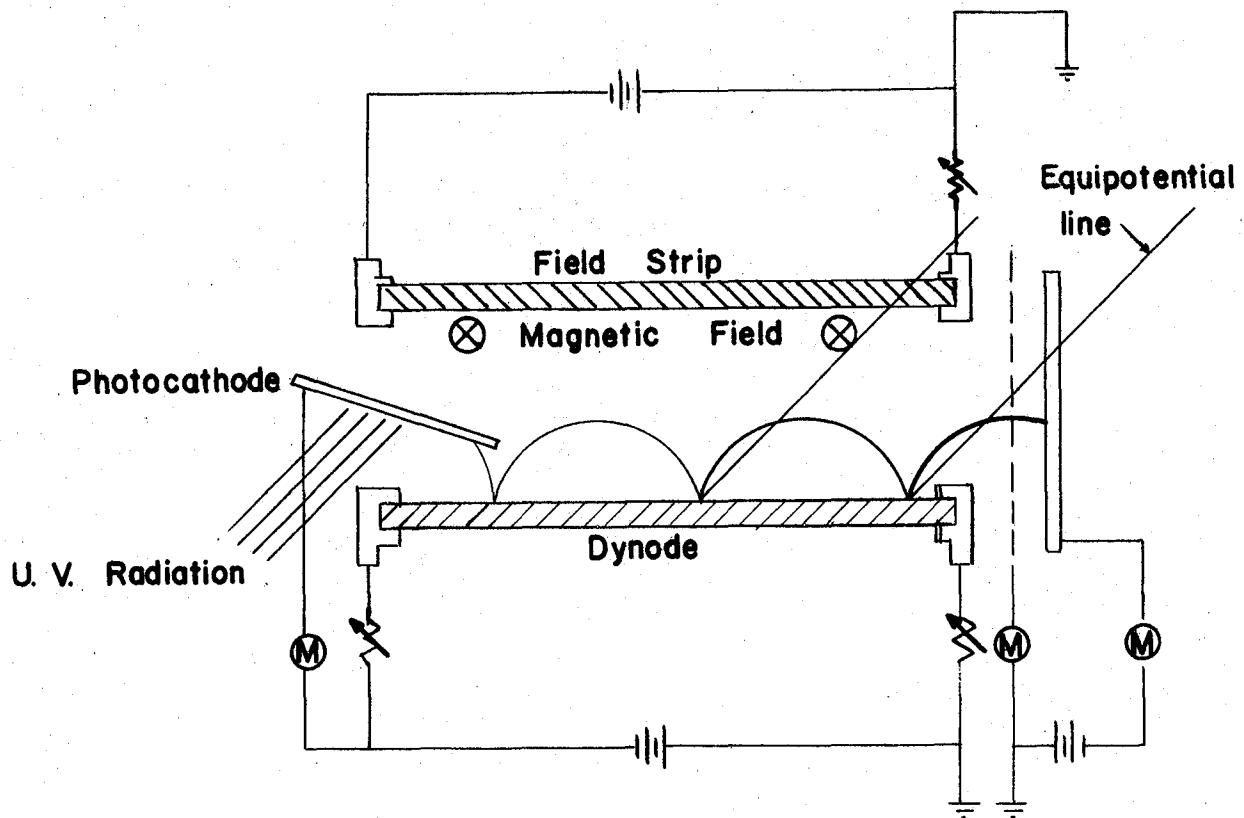
Figure 3

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Figure 4

SCHEMATIC OF MULTIPLIER

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Y-axis: Pressure, x 10^{-5} Torr

100
10
1.0
0.1

A
B

(A) Grid Voltage of 100 volts
(B) Grid Voltage of 125 volts

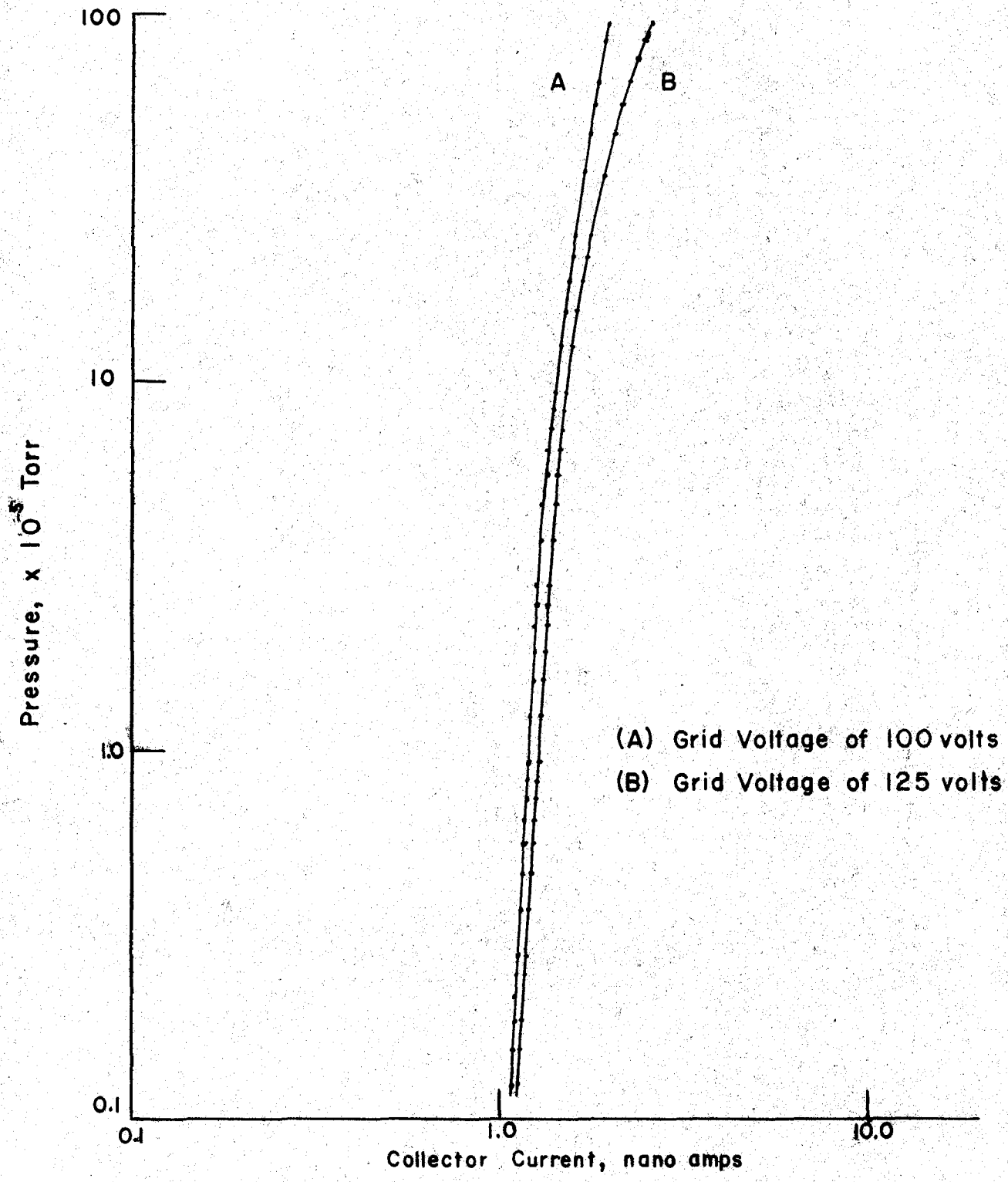**X-axis:** Collector Current, nano amps

0.1
1.0
10.0

Figure 5

Pressure Dependence of Multiplier Ion Gauge
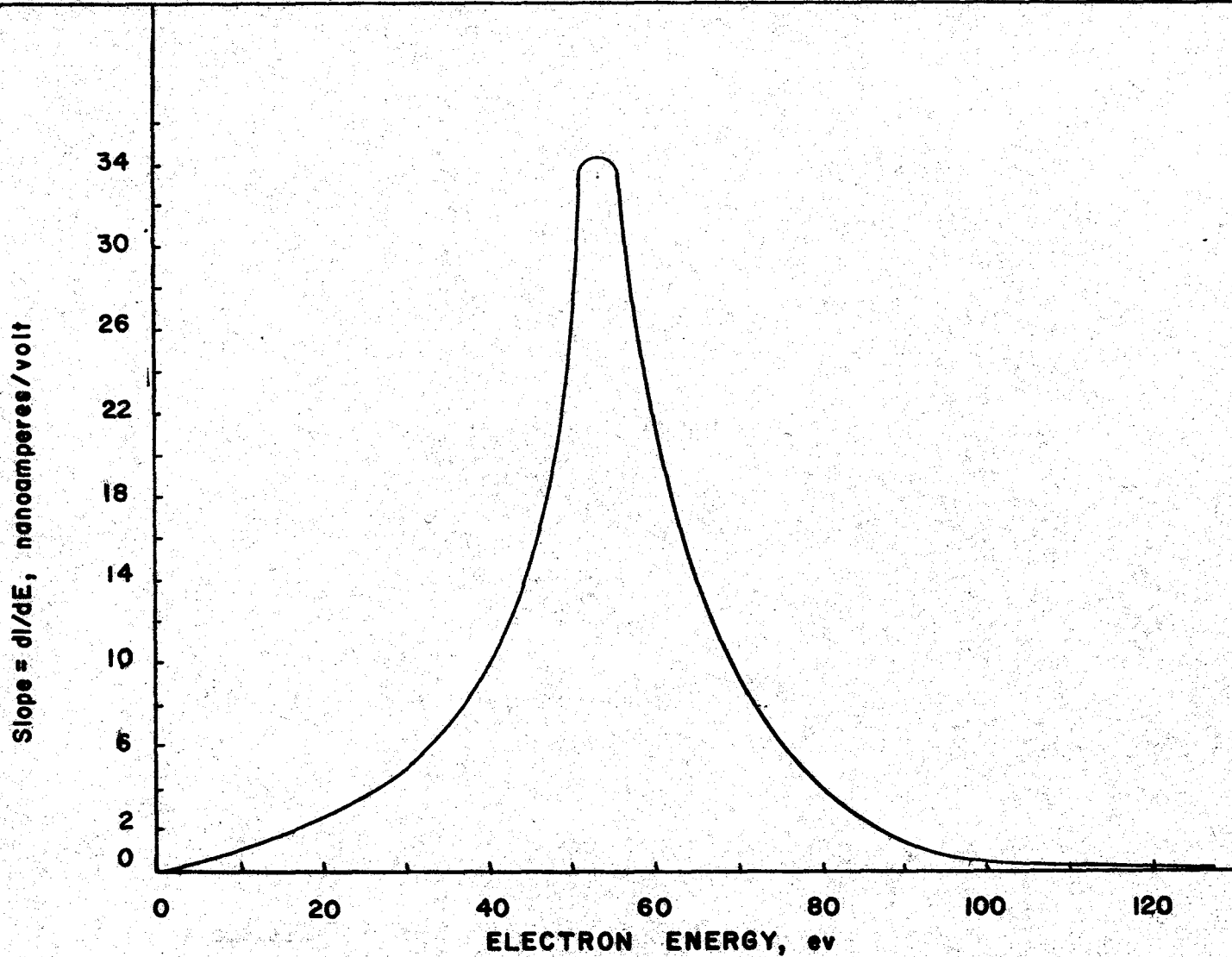
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Figure 6
ENERGY DISTRIBUTION OF MULTIPLIER OUTPUT

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