X-611-64-154

37p.

N65-35273
(ACCESSION NUMBER)
37
(PAGES)
TMX-[redacted]
(NASA CR OR TMX OR AD NUMBER)
55056
(THRU)
1
(CODE)
24
(CATEGORY)
FACILITY FORM 602

LOW ENERGY CHARGED PARTICLE DETECTION USING THE CONTINUOUS CHANNEL ELECTRON MULTIPLIER

BY

DAVID S. EVANS

GPO PRICE $ ______

CSFTI PRICE(S) $ ______

Hard copy (HC) 2.00

Microfiche (MF) .50

ff 653 July 65

MAY 1964

NASA — GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

Goddard Energetic Particles Preprint Series

[redacted]

ABSTRACT

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It has been found to be possible to operate the continuous channel electron multiplier, a recently developed type of windowless electron multiplier, in a gain saturated mode such that single, charged particles entering the input mouth of the channel will initiate output pulses whose amplitude and shape are both uniform and independent of the character of the excitation radiation. By suitable design of the channel this saturated pulse can be made stable against changes in such operating conditions as ambient pressure and applied voltage. When operated in this mode the efficiency of the channel for the detection of electrons over the energy range 250 eV to 10 keV is estimated to be greater than 50%.

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Introduction

The important contribution of low energy charged particles to outer radiation belt and auroral phenomena has become apparent in the course of their investigation. In the case of visual aurora in the auroral zone, it has been found that the major portion of the total energy input is supplied by charged particles having energies below 40 keV. In one example (McIlwain, 1960)[1], a virtually monoenergetic beam of 6 keV electrons was observed in association with a visual auroral display.

Comparison of data obtained from different detectors on Injun I in the outer belt has shown that the energy flux of electrons having energies between 1 keV and 40 keV was often tenfold greater than that of electrons having energies above 40 keV. (O'Brien, et al., 1962)[2] Very little, however, could be determined about the particle intensity or energy spectrum of this low energy component.

The efficient detection and energy analysis of these low energy particles has, in practice, posed a number of problems. It is critically important that the amount of material surrounding the active volume of the detector be minimized or, ideally, eliminated altogether. As an illustration, the Anton type 213 Geiger-Müller counter, having an entrance window of 1.2 mg/cm^2 thickness, requires a minimum energy of 40 keV for electrons and 500 keV for protons to trigger a count.

Scintillation counters, having only a very thin coating of material over the scintillator to reduce light sensitivity, have been used to detect electrons with energies as low as 3 keV. In the absence of refrigeration, however, the light output from such a small energy loss in a scintillator is too low to be resolved as a pulse above the thermal noise of a photomultiplier tube. Moreover, photomultiplier tube anode pulses, arising from the liberation of only one or a few electrons from a photocathode, have a very broad pulse height distribution and so are unsuitable for counting techniques. Under these circumstances, the anode output current, rather than individual pulses, is often monitored as a measure of the total energy flux incident upon the scintillator. This method, however, is too insensitive to detect weak particle fluxes and gives no direct information about the energy distribution of the incident particles.

Bare electron multipliers with a dynode structure similar to a photomultiplier tube have been used to detect directly charged particles allowed to strike the cathode. The absence of a photon-electron conversion process at the cathode permits the use of a cathode material of relatively high work function, thereby reducing thermal noise. The detector response extends to extremely low energy particles because of the complete elimination of an entrance window. Either the anode current or anode pulses from such a detector may provide a measure of the incident particle flux. As with the scintillation counter, however, the output pulse height distribution is very broad. In a typical case the pulses observed at the multiplier anode, due to a beam of monoenergetic electrons striking the cathode, ranged over a factor of 100 in amplitude (D. Mathews, private communication).

A recent development along the lines of a windowless electron multiplier is the Bendix continuous channel electron multiplier described by Wiley and Hendee (1962)[3]. The simplicity, small size, and ruggedness of this device make it ideal for use in sounding rocket and satellite research. Consequently, an investigation has begun at Goddard Space Flight Center to determine its characteristics as a detector for low energy charged particle radiation.

Description of the Channel Multiplier

In its simplest form, the channel multiplier is a straight glass capillary tube having dimensions such that the length-to-inside-diameter ratio is between 50 and 100. The inside diameter itself may be from less than a tenth of a millimeter to more than a millimeter. A layer of special semiconducting material, having secondary electron emission characteristics suitable for an electron multiplication process, is deposited over the interior surface of the tube.

When a potential difference is applied between the ends of the tube, an axial electric field is established down its length. Any electron ejected from the inside surface, for example by means of photoelectric or secondary emission processes, will thus be accelerated down the tube. Simultaneously, the electron will drift <u>across</u> the tube with whatever lateral velocity was acquired in the ejection process. The electron multiplication occurs when the potential difference and tube dimensions are such that these free electrons gain enough energy from the electric field between encounters with the surface that, on the average, more than one secondary electron is generated at each encounter.

In this manner (Figure 1) a single electron ejected at the low potential or input end of the tube can result in an electron cascade of some magnitude at the high potential or output end of the channel. A typical experimental channel multiplier gain curve obtained by Wiley and Hendee is shown in Figure 2.

The exact nature of the semiconducting surface has not been published, although it has been shown by Angel, et al. (1961)[4] that the relative spectral response of the material to the photoelectric effect is similar to that of tungsten, implying a work function of about 4 eV. Thus the channel has virtually no response to light of wavelengths longer than 1500A and essentially no background noise due to thermionic emission of electrons. The surface is, moreover, quite stable with respect to changes in the secondary emission ratio after extended and repeated exposure to the atmosphere. Hence, no special handling is necessary.

In Wiley and Hendee's investigations beta radiation, extreme ultraviolet light, and low energy photoelectrons from an illuminated photocathode were among the sources used to excite the channel. In all cases, the output current collected by a separate biased anode at the output end was compared to the input excitation current to obtain the electron gain data. In general, the channel was operated in these investigations at a gain which did not permit observation of the individual anode pulses arising from single events at the front end of the channel; hence, no work was done on this aspect of the channel multiplier.

The work reported here, on the other hand, concentrated upon the characteristics of the pulses appearing at the output end of the channel.

Description of the Present Work

For the initial, exploratory phase of the investigation, a number of straight channel electron multipliers were obtained. Most of these channels had a length-to-bore ratio of 50 and an inside diameter of 1 mm. For comparison, however, two channels with inside diameters of 1 mm and length-to-diameter ratios of 100, and two channels having inside diameters of approximately .5 mm and length-to-diameter ratios of 50 were also obtained. The measured ohmic resistance of the semiconducting layer was generally in the range 10^9 to 10^{10} Ohms. This resistance is the determining factor for both the power dissipated in the channel and any effects associated with its RC relaxation time.

The experimental scheme most often employed to investigate the channel's pulse output is illustrated in Figure 3. The output end of the channel was essentially covered by a foil to collect the total charge of the electron cascade. The voltage pulse developed across the shunt capacity of the collection circuit was displayed on both an oscilloscope and the output of a pulse height analyzer. With a knowledge of the collection circuit shunt capacity an electron gain could be determined from the voltage pulse amplitude on the assumption that the cascade was initiated by a single secondary electron.

Normally the collection end of the tube was operated at a potential between 1000 V and 4000 V with respect to both the input end and the surrounding stainless steel vacuum system. This procedure lessened the chance of stray positive ions being attracted into the mouth of the channel and causing anomalous counts. To expose any pressure sensitivity in the multiplication process, the channel multiplier was operated at ambient pressures ranging from 10^{-3} to 10^{-6} mm Hg. The excitation radiation was provided by Co^{60}, Fe^{55}, or S^{35} radioactive sources, or by the low energy charged particles produced by a Bayard - Alpert pressure gauge placed near the channel.

The first examination of the channel's output pulses was made at an applied potential of 1400 V and a pressure of less than 10^{-5} mm Hg. Under these conditions the channel gain was about 10^6 and a charge sensitive amplifier proved necessary in order to observe the output pulses at all. The pulse height dis-

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tribution of the output pulses was found to be very broad, the differential pulse height distribution displaying a tendency to continue rising with decreasing pulse height. It may be noted that the channel was operated in this case with a gain similar to the gains employed in the current output measurements of Wiley and Hendee.

Further investigation showed, however, that when the channel's electron gain was increased to more than about 10^7, the pulse height distribution of the output pulses became peaked; i.e., all of the output pulses had nearly the same amplitude which was independent of the character of the exciting radiation. Figure 4 shows an oscilloscope photograph of this effect. The appearance of this uniform output pulse is attributed to a saturation in the electron multiplication process basically caused by the magnitude of the electron cascade.

The high gain necessary for the appearance of the saturation effect was achieved through two separate but interdependent processes. The first was simply an increase in the potential difference applied across the tube. Up to a point, this procedure will increase the gain by increasing the average energy acquired by the individual electrons between collisions, and so increasing the secondary electron emission ratio.

The second mechanism depends on positive ion production by interaction between cascade electrons and residual gas molecules. These free ions are accelerated by the electric field toward the input end of the tube where they may interact with the wall to initiate a new cascade. This second, regenerative feedback effect dominates the behavior of the straight channel multiplier in the high electron-gain mode of operation.

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The clearest evidence of the role of ion feedback in controlling the multiplication process was the existence of a strong pressure dependence in both the amplitude and the character of the output pulse. If, for example, the potential difference was adjusted to yield a satisfactory output pulse at 10^{-4} mm Hg, a decrease in pressure to 10^{-6} mm Hg would cause the output pulse height distribution to revert to the low amplitude, broad, "washed out" type of distribution previously associated with electron gains on the order of 10^5. When the procedure was reversed and the applied potential set at a value sufficient to give a saturated output at 10^{-6} mm Hg, an increase in pressure to 10^{-4} mm Hg produced distortions in the output pulse shape, and instabilities in the form of spurious counts and often continuous, uncontrollable pulsing.

The contribution of ion feedback was also evidenced in the tube's response to penetrating radiation. Under exposure to gamma rays from Co^{60}, the channel output pulses exhibited the same peaked amplitude distribution as was found when the excitation was by low energy charged particles unable to initiate cascades except at the very mouth of the tube. The unsaturated pulses that would have resulted from gamma ray interactions liberating electrons well away from the input end of the tube were not seen because of the efficient ion feedback mechanism.

Perhaps, however, the most significant manifestation of the ion feedback mechanism was revealed in its effect on the leading edge of the output pulse. The rise time of the output pulse was observed to be typically 0.5 microsecond, which compares poorly with the few tens of nanoseconds estimated from the transit time

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down the tube of individual cascade electrons. Close examination of the leading edge of the pulse revealed a "staircase" appearance. This strongly suggested that the observed output pulse was the sum of numerous, successive electron cascades, each initiated by positive ions accelerated down the tube and striking the inner surface near the input end. The fact that this "staircase" effect was observed at ambient pressures less than 10^{-6} mm Hg indicates both the large number of electrons involved and the consequences of permitting relatively few ions to drift unobstructed to the input end of the tube to restart a cascade. Indeed, the appearance of the pulse's leading edge is felt to be the most sensitive guide as to the presence and extent of ion feedback in the multiplication process.

Discussion of the Saturation Effect

The tentative explanation of the gain saturation in the channel multiplier, which accounts for the appearance of output pulses of uniform amplitude, is based upon the alteration of the potential gradient within the tube by surface charges deposited on the interior walls of the tube during the multiplication process. The solid line in Figure 5 displays the voltage as a function of position within the tube in the absence of a pulse, the semiconducting surface being assumed to be uniform down the tube. During the electron multiplication process, a positive charge accumulates upon the walls of the tube because of a net loss of electrons from the surface. The potential vs. position curve may then be altered to the one depicted qualitatively by the dashed line in Figure 5. One will note that in the region BC (near the output end) the potential gradient has flattened, and the cascade electrons can no longer acquire the energy necessary to support the multiplication process. On the contrary, this portion of the tube will tend to become an electron sink, thereby limiting the gain.

Although no quantitative work has been done using this saturation model, observations on the nature of the multiplication process as a function of position in the tube provide a strong basis for believing that the gain limiting is indeed due to such a mechanism. In order to investigate this, a positively biased anode plate was placed at the output end of the tube to collect the cascade space charge and so insure that alterations of potential in the tube itself were due to only surface charges. The potential changes within the tube were observed by utilizing the capacitive coupling of a wire looped tightly around the outside of the tube.

It was found that when the pickup loop was positioned toward the input end of the channel a positive pulse was observed, indicating that electron multiplication was occurring. As the loop was moved toward the output end, a region was reached where the pulse was characterized by an initial positive phase followed by a negative phase. At a position still further toward the output, the pulse was entirely negative, indicating a net accumulation of electrons and a lack of multiplication. Whenever the channel was operated in the non-saturating mode, a positive pulse was observed at all points down the length of the channel, the entire tube apparently being utilized for electron multiplication.

The model predicts the existence of a period, while the surface charge is being redistributed, during which reduced amplitude or no pulses will be observed. Such a dead time, lasting about 100 microseconds, was observed at high count rates. This dead time is, in principle, connected with the RC relaxation time of the channel, and hence may be reduced by decreasing the ohmic resistance of the semiconductor strip. Such a procedure would be limited by the maximum allowable power dissipation of the device.

Discussion of the Instability

The investigations of the channel multiplier was primarily directed towards its use as a radiation detector in satellite and sounding rocket experiments. The pressure environment is uncontrollable in both systems; in the case of the sounding rocket changes in pressure over many orders of magnitude must be tolerated. Consequently, much of the investigation concerned itself with eliminating the dependence of the electron gain upon pressure and understanding the nature of the instability mentioned earlier.

If the channel multiplier gain was adjusted to yield a saturated, stable output pulse at 10^{-6} mm Hg and the pressure was then allowed to increase slowly as was described earlier, the instability first appeared as secondary after-pulses occurring 30-100 microseconds after the initial primary pulse (induced by a radioactive source, for example). Further pressure increases caused continuous pulsing, even in the absence of excitation radiation. The transition from after-pulsing to continuous pulsing was a smooth and reversible one, and both are believed to be aspects of the same fundamental instability.

The relatively long time delay before the appearance of an after-pulse suggested at first that, if charged particles were directly responsible, the process giving rise to the instability was taking place over a volume much larger than the interior volume of the channel itself. However, experiments performed with the open ends of the tube effectively blocked by aluminum, stainless steel, or copper foils demonstrated that the unstable after-pulsing arose from within the capillary itself.

Prospective models to explain the instability divided themselves into two crude catagories. Models in the first class were basically dependent upon the magnitude of the electron cascade. Among these was, for example, the thin-film field emission of electrons fron the semiconducting layer which had acquired a large surface charge density as a direct result of the electron multiplication process. The possibility exists that field emission of electrons could persist long after the termination of the primary pulse and thus cause after-pulsing. The effect of any ambient pressure variation would simply be to change the magnitude of the electron gain and hence the surface charge densities involved.

The second set of explanations is fundamentally connected with the existence of significant ion feedback in the channel. Referring to Figure 5, one observes that, although the potential alteration in the region BC effectively prevents an electron cascade developed in the region AB from arriving at the output, electron multiplication is still possible in the front portion. Hence, in this region of the tube, the regenerative ion feedback-electron multiplication process could constitute a means of self-perpetuating the presence of free charged particles until the back portion had recovered to the point of again allowing cascades to pass to the output.

A third "combination" model, based on the production of neutral metastable molecules by the electron cascade, depends upon both the presence of residual gas in the tube and the creation of a large electron cascade. However, attempts to accentuate such a process through the introduction of helium rather than air

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as the residual gas proved fruitless.

The strong interdependence between the magnitude of the electron cascade and extent of ion feedback in the straight channels did not allow a clear demonstration as to which of the alternative explanations of instabilities was valid.

The dominating influence of regenerative ion feedback in the straight channel is due essentially to the fact that ions, which are mostly produced at the back end of the tube where the electron cascade is largest, are permitted to move to the input end where the subsequent liberation of electrons has the most effect. Clearly a channel electron multiplier in the form of a curved capillary tube would contain these ions in the back end where their effect on the overall electron gain would be negligible. Such a channel multiplier would have the additional benefit of minimizing the regenerative ion-feedback-electron-multiplication process and thus give an indication of the basic cause of the instability.

Design of the Curved Channel

In order to design a curved channel multiplier a crude calculation of the loop gain of the ion feedback-electron multiplication mechanism was performed. The radius of curvature of the capillary tube was then chosen to reduce the loop gain enough to insure quenching of free charged particles well within the observed dead time.

Figure 6 shows a section of channel multiplier with a radius of curvature R_o. The path taken by an ion produced at the point A and moving under the influence of the axial electric field until striking the wall at B is shown schematically. The equations of motion governing the ion are:

$$m \frac{d^2 r}{dt^2} - mr \left(\frac{d\theta}{dt}\right)^2 = 0 \qquad (1)$$

$$mr \frac{d^2\theta}{dt^2} + 2m \frac{dr d\theta}{dt dt} = eE \qquad (2)$$

By neglecting the coriolis force term $\frac{dr dt}{dt dt}$ and approximating r by R_o in Eq. 1, one may integrate the equations to obtain

$$\mathcal{L} = \theta R_o = \sqrt{3R_o d} \qquad (3)$$

for the maximum possible distance through which an ion produced at A will pass before striking the wall at B.

Because the electron multiplication may be considered uniform along the length of the tube, it follows that the electron gain over a length x of the tube is related to the electron gain over the full tube length L by the expression

$$G(x) = G(L)^{x/L} \qquad (4)$$

G(L) being approximately 10^8 for a saturated pulse.

Given a number of electrons N passing a point P in the tube, the number of ions created as a function of the distance x further down the tube is given by

$$N_{ion}(x) = \alpha N \; G(L)^{x/L} dx \qquad (5)$$

where α is the first Townsend coefficient.

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We take the worst case and assume that all these ions move the maximum permissible distance ℓ before striking the interior wall of the tube and, with a probability of 1.0, eject a secondary electron. This electron is itself multiplied up to give a net gain at the point P of

$$dN' = \alpha N_o G(L)^{x/L} G(L)^{(\ell - x)/L} dx \qquad (6)$$

which, when integrated to obtain the contribution of all the ions of interest, gives

$$N' = \alpha N G(L)^{\ell/L} \ell \qquad (7)$$

as the total number of electrons arising through the feedback mechanism.

Recalling that $\ell = \sqrt{3R_o d}$ and using the maximum α at a design pressure of 10^{-3} mm Hg, one obtains for the loop gain

$$\frac{N'}{N} = 0.012 \sqrt{3R_o d}\; G(L)^{\sqrt{3R_o d}/L}$$

The time necessary for each oscillation of the ion-electron process is no more than a few tenths of a microsecond. Hence, assuming the peak number of electrons to be 10^8, a loop gain of .01 will insure that stray charged particles are completely eliminated within a few microseconds. Further, a loop gain of .01 would indicate that the contribution of ion feedback to the overall electron gain of the tube is no more than 1% at a pressure of 10^{-3} mm Hg. Hence, Eq. 8 becomes

$$\sqrt{3R_o d} \quad 10^{8\sqrt{3R_o d}/L} = .83$$

By setting the inside diameter d equal to 1 mm and the length L equal to 100 mm, the equation may be solved numerically to obtain

$R_o \approx 2.4$ cm.

A channel multiplier designed to such specifications would be in the form of a circular arc extending over about 2/3 of a circle having a radius of 2.4 cm.

In addition to the approximations made specifically in the calculation, the effect of gas adsorbed upon the inner walls has been neglected. The ionization of this adsorbed gas is probably most important at relatively low pressures and accounts for ion feedback observed below 10^{-6} mm Hg. The effect upon the gain function G(x) of altering the potential gradient inside the tube during a cascade has also been neglected. However, the choice of the loop gain is conservative to the point that if changes in G(x) occur, the electron cascade will in all probability still be quenched.

Characteristics of the Curved Channel Multiplier

The curved channel multiplier obtained from the Bendix Corporation, shown in Figure 7, had an inside diameter of 1 mm and a length-to-diamet ratio of 100. The capillary tube had the form of an arc extending over 3/4 of a circle having a radius of curvature of 2.0 cm. The experimental arrangement was identical to that used with the straight channel multipliers.

It was quickly established in the initial trial of the channel that the saturated pulse mode of operation was induced at an electron gain of about 5×10^7, roughly the same gain as was found necessary in the straight channel. In order to achieve this gain, an applied potential of 3000 V was required.

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To determine whether ion feedback was interfering with the electron gain mechanism, a careful examination was made of the leading edge and rise time of the output pulse. It was found that at all pressures below 10^{-3}mm Hg the rise time of the output pulse was less than 20 nanoseconds; moreover, the leading edge gave no evidence of distortion by ion feedback effects. Subsequent observations showed no variation in the electron gain of the channel multiplier during a change of more than two orders of magnitude in pressure, thus substantiating that there was no effective contribution from regenerative ion feedback to the electron multiplication process.

Determined efforts were made to excite the instability by increasing both the ambient pressure and the applied potential to the point where arcing became a danger. However, no instability was noted, either in the form of spurious or continuous pulsing or in the form of after-pulsing. The sole observable effect was a distortion in the shape of the output pulse evident at pressures above a few microns. This pressure, however, is well above the maximum pressure expected during the operation of the channel in sounding rocket or satellite experiments.

It is clear that either the ion feedback-electron multiplication process described earlier or another mechanism dependent upon ion feedback effects was the basic cause of the instabilities observed during investigations using the straight channel.

Figure 8 displays the output pulses from the curved channel in a case where the excitation was by 200 eV ions produced by a Bayard-Alpert type gauge. A comparison with the output pulses from a straight channel (Fig. 3) shows an apparent loss of resolution or "sharpness" in the pulses from the curved channel. The peaked pulse height distribution remains, however, entirely compatible with straightforward pulse-counting techniques. It should be pointed out that the rise time of the pulse shown in Figure 8 has been lengthened to about 0.1 microsecond by an emitter-follower circuit used at the output in order to drive the shunt capacity and thus obtain greater voltage amplitude.

Once a channel multiplier having a stable pulse mode of operation had been obtained, an examination of the efficiency of the channel for the detection of very low energy charged particles was begun. This efficiency, in principle, depends first upon the probability that the incoming primary particle will produce one or more secondary electrons when striking the input end of the channel, and secondly upon the probability that the initial secondary electron will result, after multiplication, in a saturated output pulse (collection efficiency).

Massey and Burhop[5] have pointed out that the energy distribution of secondary electrons emitted from a surface under impact from primary charged particles, is not strongly dependent upon the type or energy of the primaries, the secondaries in general being emitted with energies of only a few eV. Hence, it may be expected that the "collection efficiency" of the channel will remain more or less independent of the character of the incident radiation. One may conclude, then, that changes observed in the channel's counting efficiency due to changes in the incident radiation essentially reflect the variation in the secondary electron emission ratio with the energy or type of the incident particles. Therefore, by considering the general behavior of the secondary emission ratio exhibited by all materials, one may obtain a crude picture of the energy dependence of the detection efficiency of the channel.

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It would be expected, for example, that the channel responds initially to electrons having energies of about 10 eV. The relative efficiency should then increase with increasing primary electron energy, reaching a maximum for some energy in the range from a few hundred to a few thousand eV. As the primary electron energy is increased still further, the secondary emission ratio displays-in all materials-a long, very slow decline which will be mirrored in a similar decline in counting efficiency. In the case of tungsten, of interest because its photoelectric spectral response is similar to that of the material used in the channel, the secondary electron emission ratio has a maximum of 1.4 for an incident energy of 700 eV and declines to .12 for primary electron energies of 200 keV.

When ions (protons) are allowed to excite the channel, the counting response should first be observed with ions having an energy of a few hundred electron volts. Above this threshold the secondary emission ratio, and, therefore, the counting efficiency, rapidly increases with increasing ion energy, and, judging from typical secondary emission curves, this relative efficiency remains large for ion energies up to several hundred keV.

It should be pointed out that particles of these energies may directly initiate a count only by entering the channel through the open mouth. It is estimated that to penetrate the tube's glass walls and initiate a cascade at a point well down the tube from the input end, an electron must have about 0.5 MeV and a proton about 5 MeV. Excitation by x-ray bremsstrahlung from lower energy electrons is a possibility, of course.

The collection efficiency, acting in a sense as the normalizing factor for the relative response curve, is believed to be quite high; probably greater than 50% and perhaps as high as 80-90%. This conclusion is based on a measurement of the channel multiplier's absolute efficiency for the detection of beta rays from S^{35}. This particular beta spectrum has an end point at 169 keV and an average electron energy of about 60 keV. For incident electrons of this average energy, the secondary emission ratio for true, low energy secondary electrons is about 0.35, based upon the data for tungsten. The absolute efficiency for the detection of betas of the S^{35} spectrum was observed to be about 25%, from which one may infer a collection efficiency of around 75%. Uncertainties in the calibration of the radioactive source and possible error in using the properties of tungsten rather than those of the actual channel multiplier surface leave some doubt as to the exactness of this figure. However, the figure of 75% does not seem to be in great error. The fact that relatively few cascades are terminated during the first stages of multiplication by the complete loss of an electron into a wall is probably due to the cascade electrons being constrained to intersect the wall at a glancing angle. This insures that the secondary electrons are produced very near the wall surface and are thus able to leave the wall with very little possibility of absorption in the semiconducting material.

In addition to the efficiency measurement made with the aid of a radioactive source, attempts were made to obtain similar data by using a beam of low energy, monoenergetic particles from a Van de Graaff generator to excite the channel. These experiments were unsuccessful because of the inability to measure the very weak input particle flux that was necessary to avoid dead time effects in the channel. On the other hand, experiments of this kind are critically important in determining accurate detection efficiency vs. particle energy characteristics, and work has begun to solve the technical problems involved.

Of great interest also insofar as practical application is concerned, is the relative variation in detection efficiency with changes in either the ambient pressure of the applied potential. An investigation of such effects was easily carried out by using a stable radioactive source, in most cases S^{35}, and the results were very encouraging. It was noted, for example, that the count rate of the channel due to the radioactive source displayed no systematic variation that could be attributed to a change of two decades in ambient pressure. This result might have been expected from the pressure independence of the electron gain in the curved channel.

When the count rate was plotted against applied potential (Fig. 9), no significant change in efficiency was evident as long as the electron gain was sufficient to maintain the saturated mode of operation. During this phase of the experiment it was noted that if the applied voltage was increased rapidly by several hundred volts it required several minutes for the counting rate to stabilize to the nominal value from an initial somewhat higher value. The net variation in count rate during the stabilization amounted to only one to two percent and would not, in practice, give rise to any trouble.

The long term count rate stability of the channel multiplier was demonstrated in the course of these experiments in which no gross changes in count rate were observed during continuous operation lasting over several days. However, short term decreases in the electron gain of the channel were induced by operating the channel at very high count rates. This fatiguing would result in gain changes ranging as high as 50% and persisting for up to five hours. Fortunately, the fatigue in gain was not accompanied by any apparent effect upon the detection efficiency of the channel - provided, of course, that the degraded gain remained sufficient to result in a saturated output pulse.

The conclusion on the basis of these preliminary studies is that as long as the channel is operated with an electron gain of five to tenfold higher than that needed to insure a saturated pulse, it will provide a suitable and reliable low energy charged particle detector for space physics experiments. Of particular importance, the curved channel multiplier appears to exhibit excellent short and long term stability when operated in the counting mode, even in the presence of relatively large changes in applied potential, wide variations in ambient pressure, and gain fatigue effects occurring at excessively high counting rates.

Among the numerous further investigations that are contemplated are the determination of counting efficiency as a function of incident particle energy and a study to ascertain the effect, if any, of gas adsorbed upon the interior surface of the tube. This second phenomenon could cause very long term drifts in the efficiency of a channel multiplier in a satellite.

Because the output pulse from the channel multiplier carries no information concerning the type or energy of the primary radiation, knowledge of these parameters must be obtained by magnetic or electrostatic analysis of the incident radiation prior to its entering the channel. Fig. 10 displays one simple approach to the solution of this problem. The channel multiplier, its output end sealed with a protective cap, has been potted into a groove cut in a phenolic block. The rectangular area in the block contains the potted load resistor and output coupling capacitor. A small permanent magnet positioned behind the collimeter tube provides analysis of the type and energy of the radiation entering through the collimeter.

The quality of the energy discrimination for electrons is displayed in Fig. 11 where the relative response of the detector system has been plotted

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against the incident electrons. The magnet strength and position were chosen to obtain maximum response at 3.5 keV, and in this case a very constant response from 2.75 to 4.5 keV was obtained.

A number of units of this design, utilizing magnets of varying strengths to obtain a particle energy spectrum, were successfully flown on sounding rockets during the spring of 1964 to obtain information on the low energy portion of the auroral particle spectrum.

Figure Captions

1. Illustration of the electron multiplication process within the channel electron multiplier.

2. An experimentally determined electron gain curve (after Wiley and Hendee).

3. The experimental setup employed for the study of the output pulses.

4. Saturated pulse output from a straight channel multiplier. The pulse amplitude is 100 mV and the pulse width is about 4 μsec.

5. The potential plotted against position along the channel multiplier. The solid line is in the absence of a cascade. The dashed line illustrates the change to be expected at the height of the cascade.

6. A section of a curved channel multiplier displaying the quantities used in the calculation.

7. The curved channel multiplier used in the experimentation. The channel is mounted in a Kel-F block for ease of handling.

8. The saturated output pulses from the curved channel multiplier. .21 V/cm, .2 μsec/cm.

9. The count rate of the channel is a function of applied potential. The excitation was provided by a S^{35} source.

10. A flight model of a channel multiplier detector unit, with an unpotted channel beside for comparison.

11. The relative response of the detector system as a function of energy.

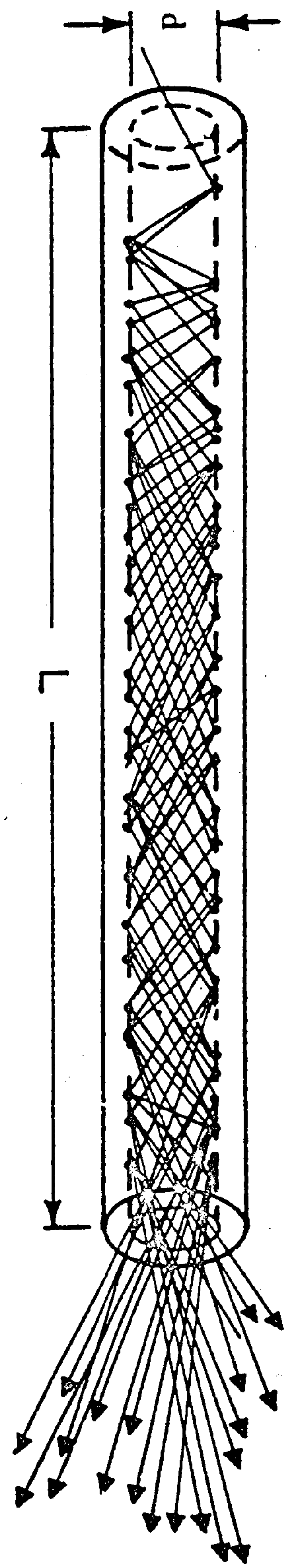
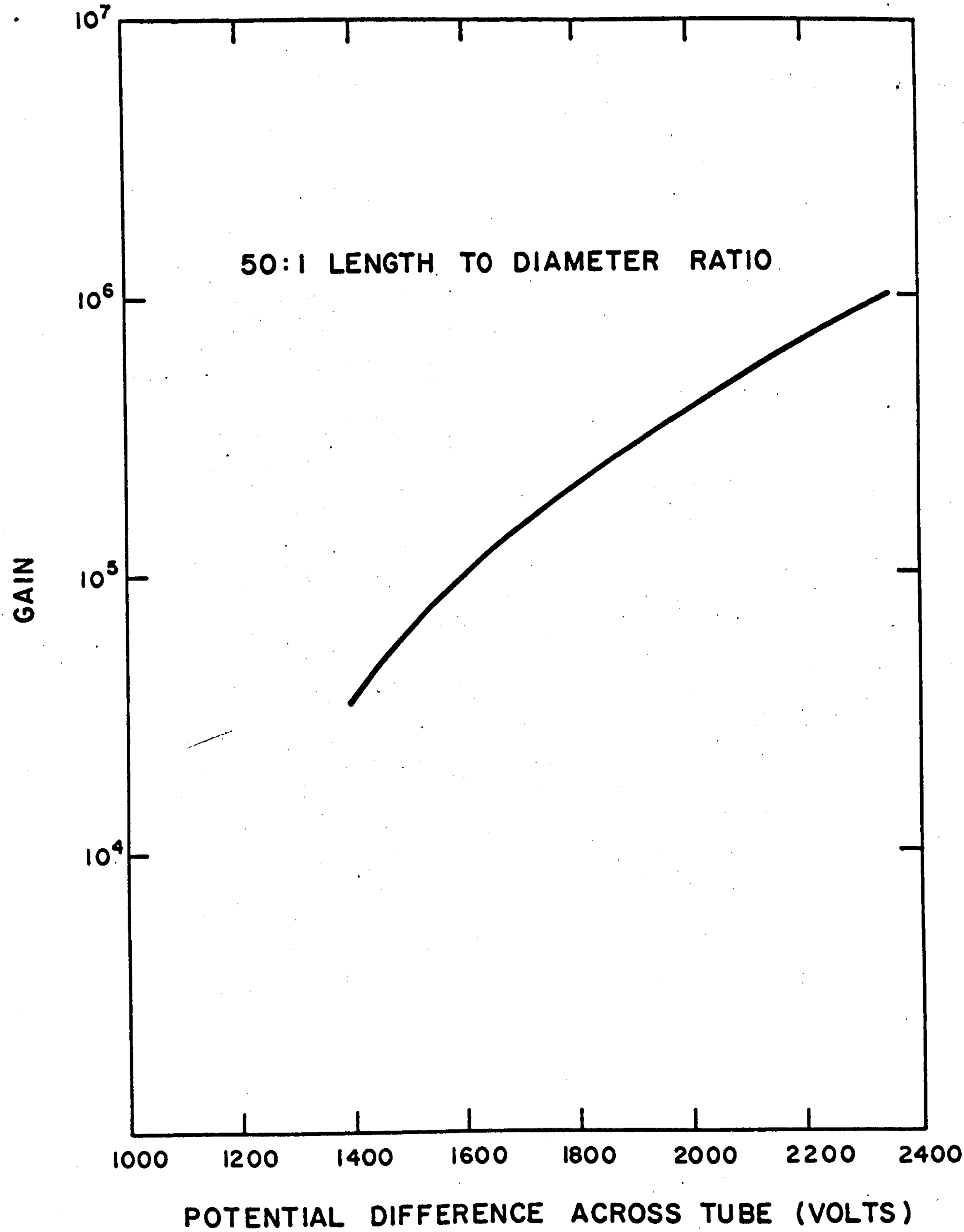


Fig. 1



10^7
50:1 LENGTH TO DIAMETER RATIO
10^6
10^5
10^4
GAIN
1000
1200
1400
1600
1800
2000
2200
2400
POTENTIAL DIFFERENCE ACROSS TUBE (VOLTS)

Fig. 2

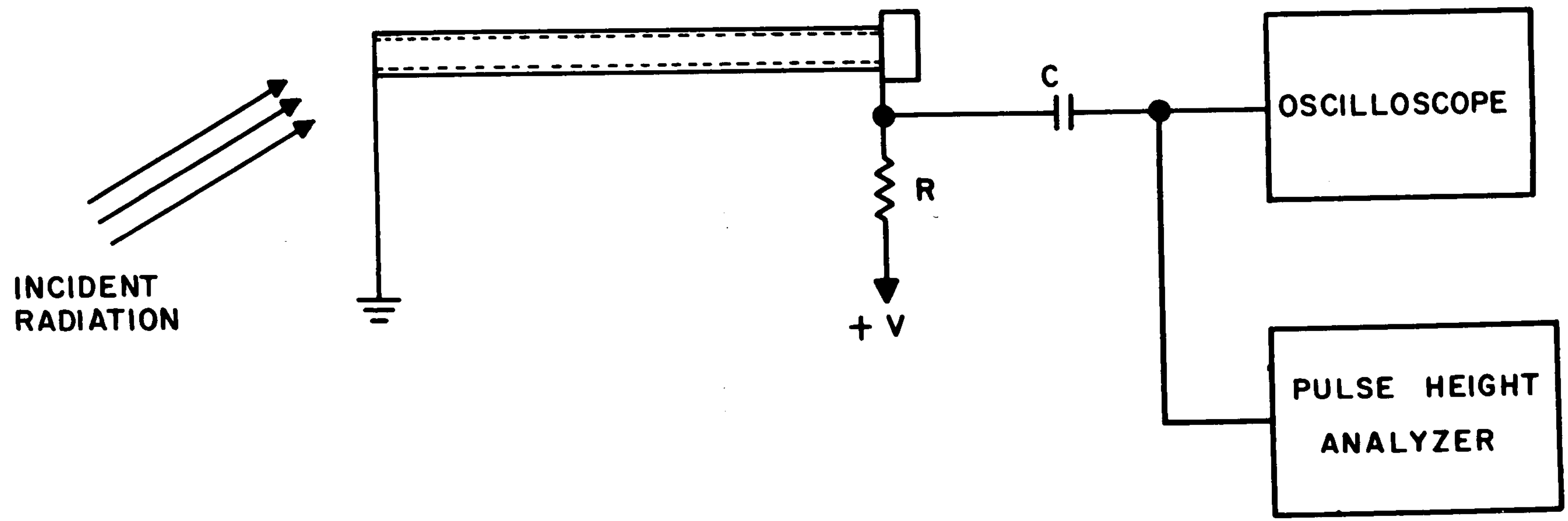

INCIDENT
RADIATION
C
R
+ V
OSCILLOSCOPE
PULSE HEIGHT
ANALYZER

Fig. 3

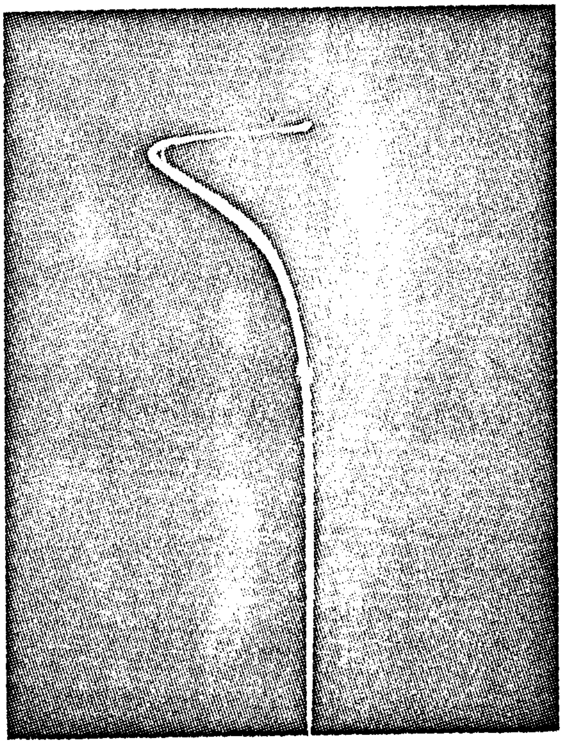


Fig. 4

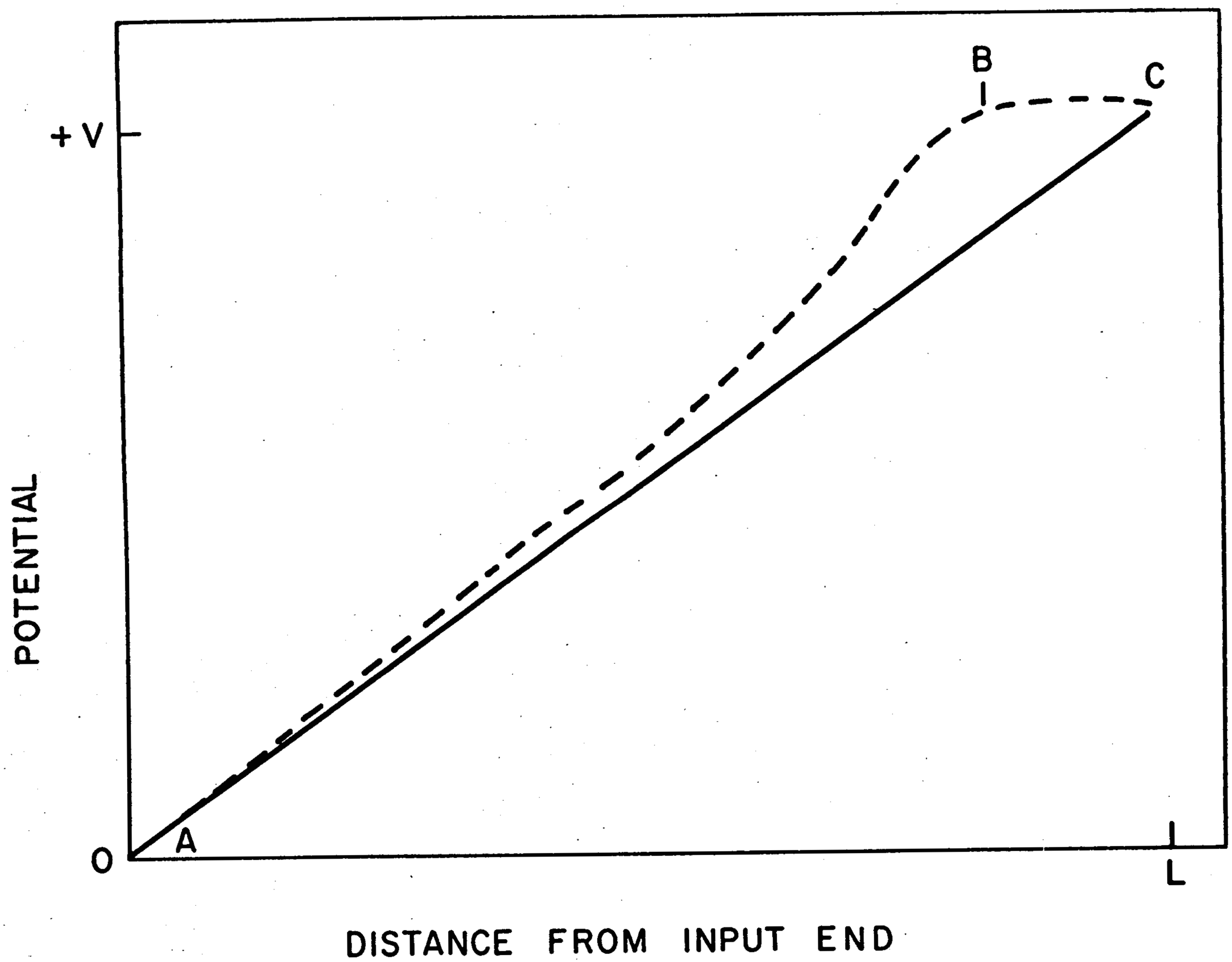


Fig. 5

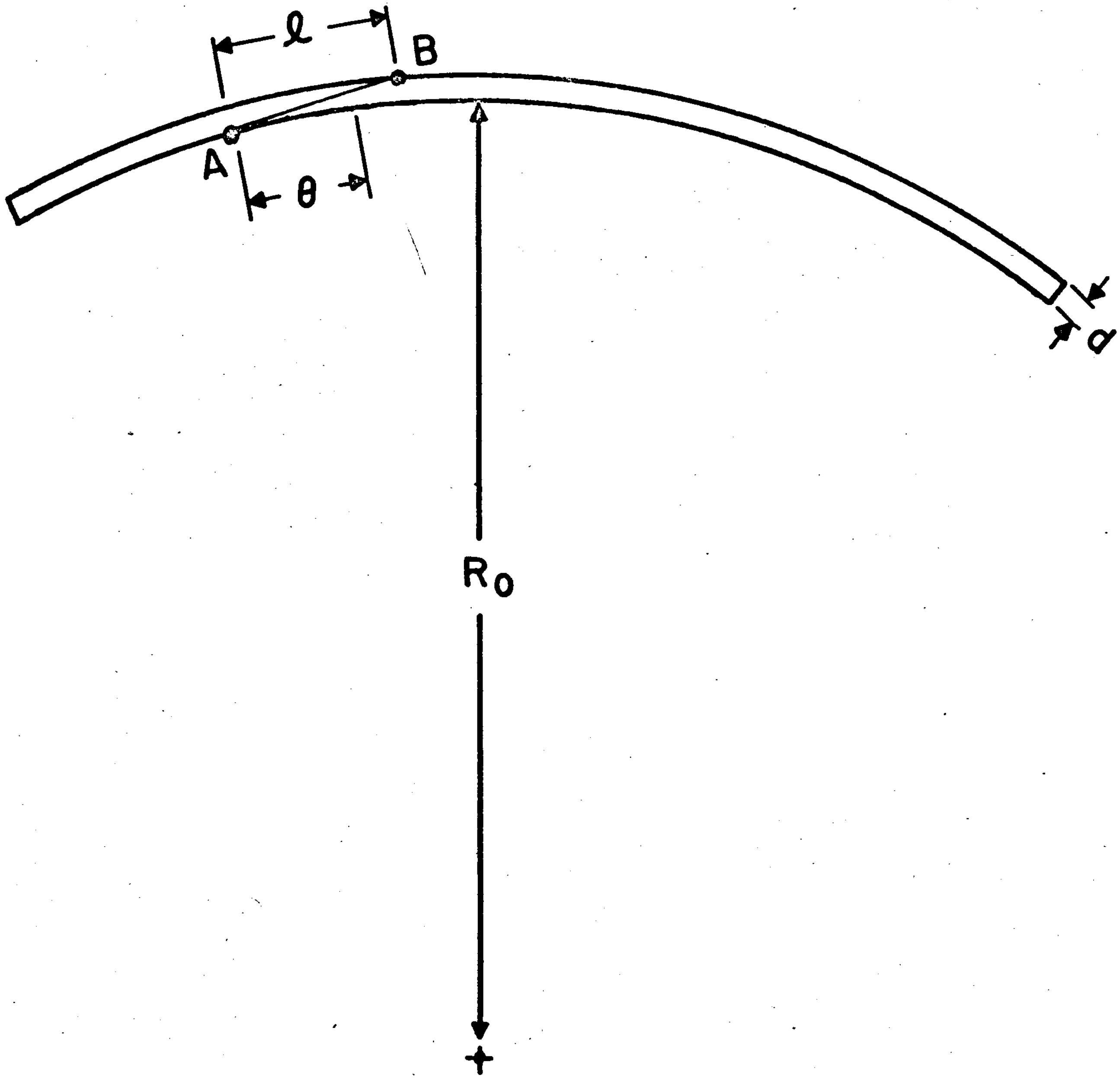


Fig. 6

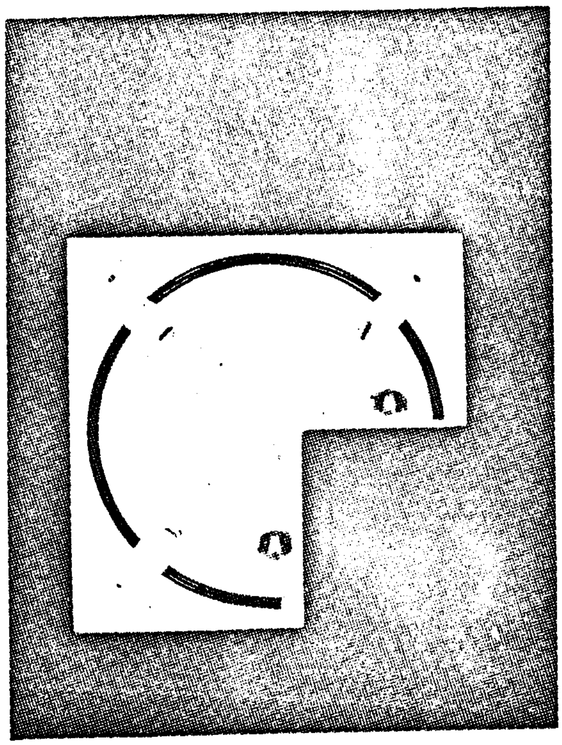


Fig. 7

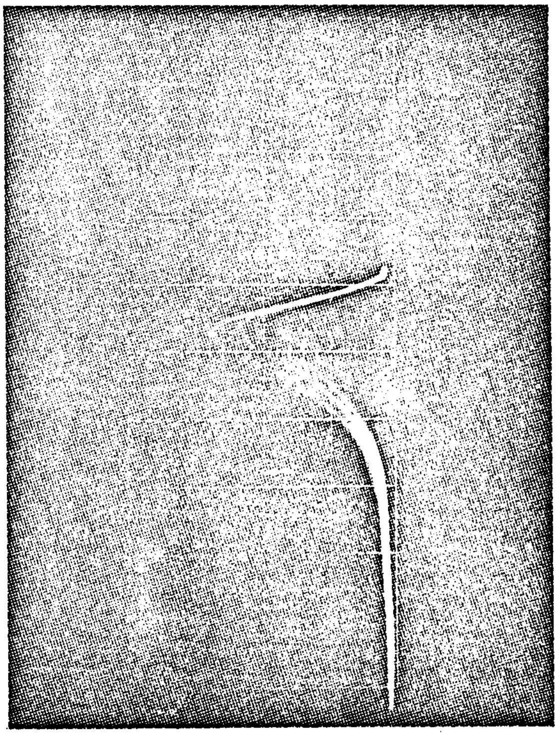
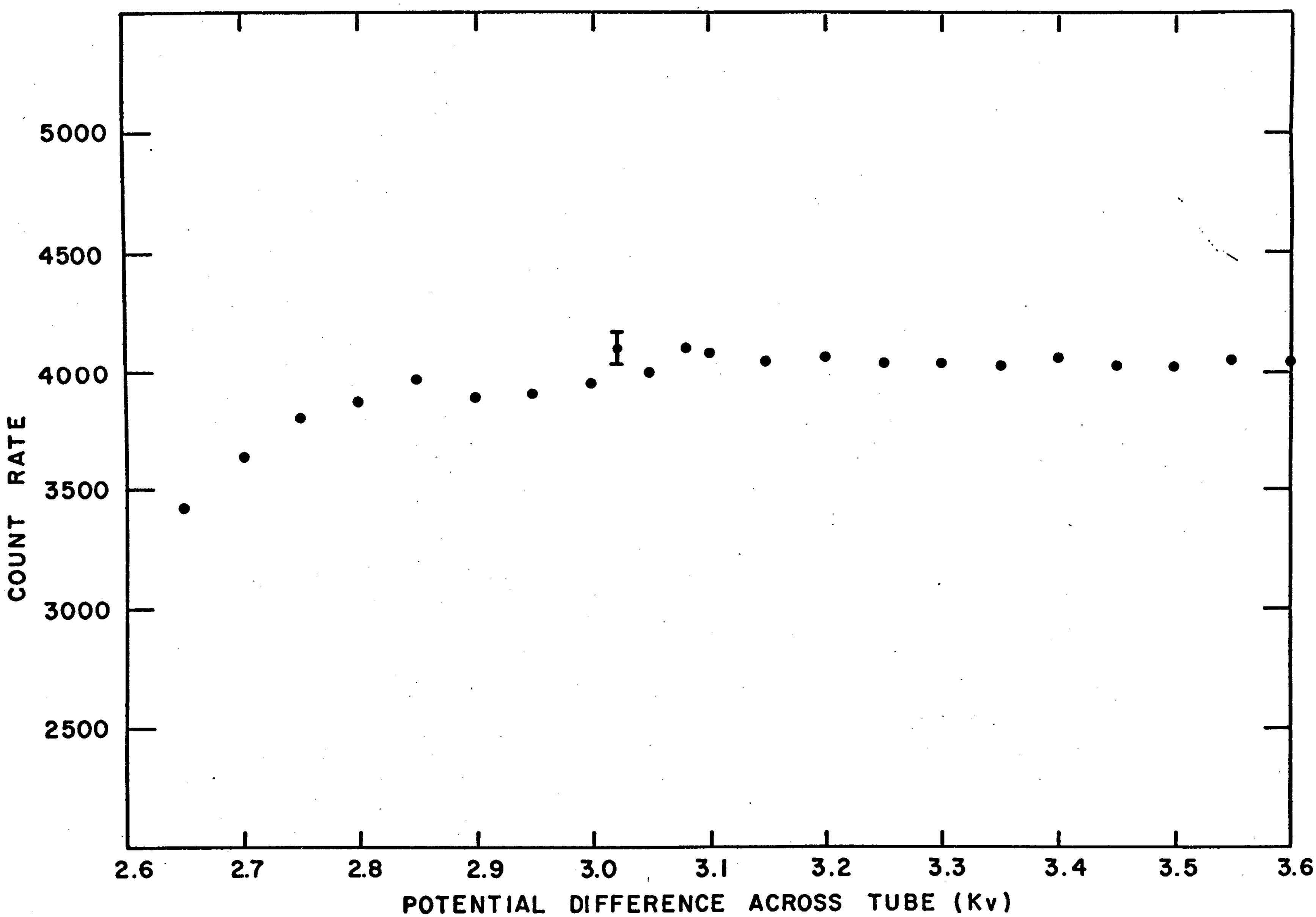


Fig. 8



5000
4500
4000
3500
3000
2500
COUNT RATE
2.6
2.7
2.8
2.9
3.0
3.1
3.2
3.3
3.4
3.5
3.6
POTENTIAL DIFFERENCE ACROSS TUBE (Kv)

Fig. 9

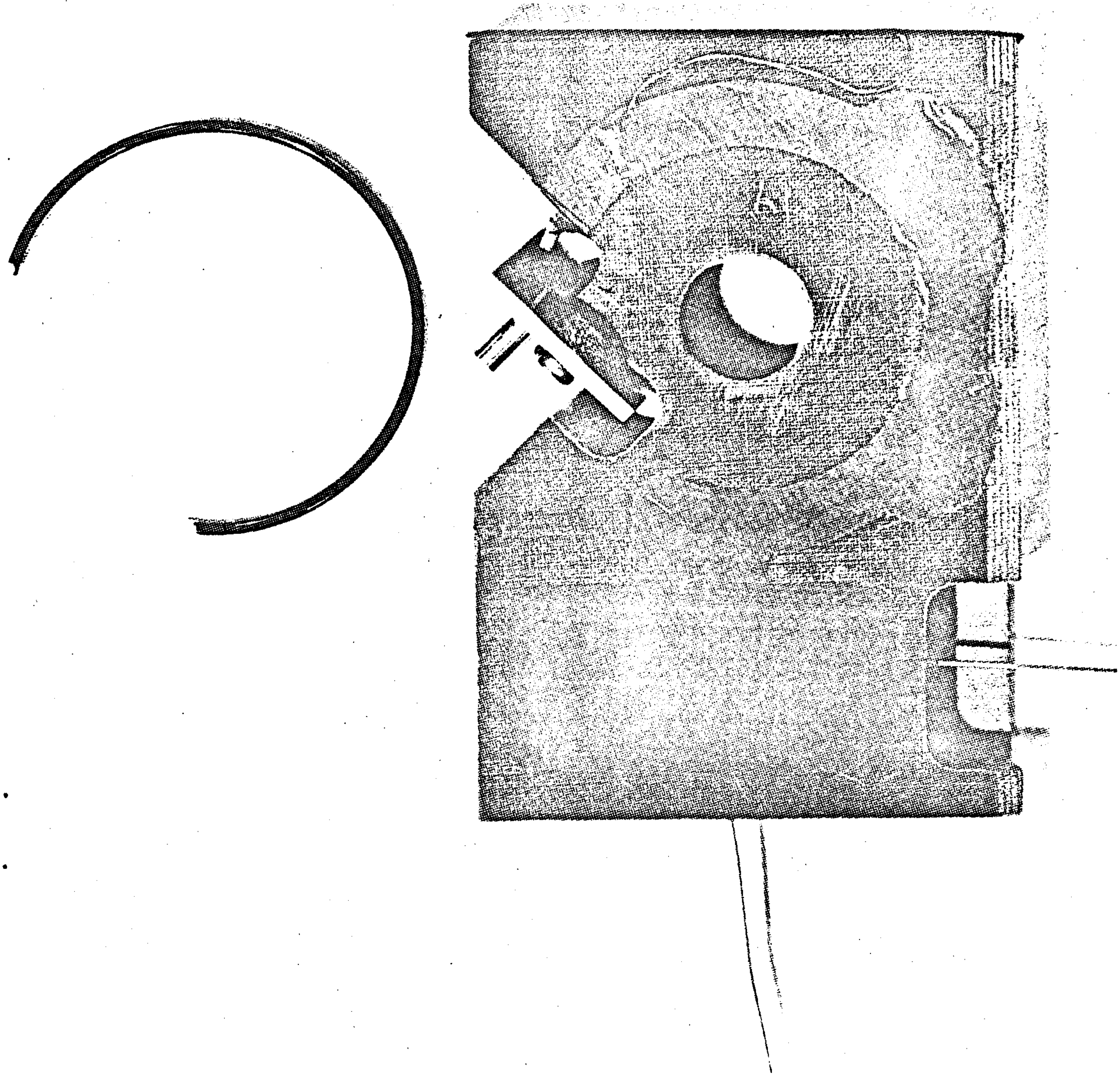
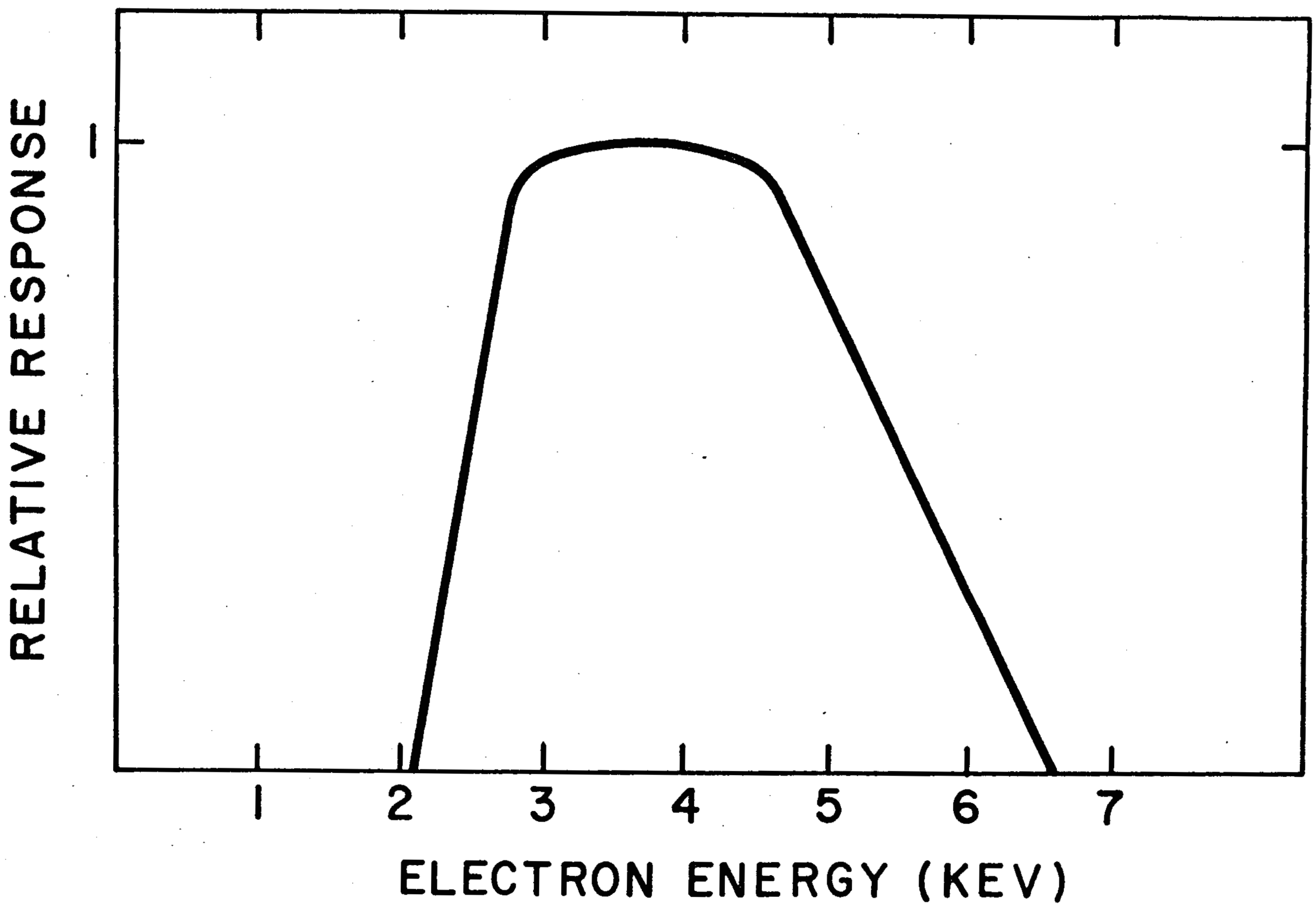


Fig. 10



RELATIVE COUNTING RESPONSE FOR A CHANNEL
MULTIPLIER DETECTOR UNIT

Fig. 11

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