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ELECTRONIC DEVICES FOR NUCLEAR  
PHYSICS

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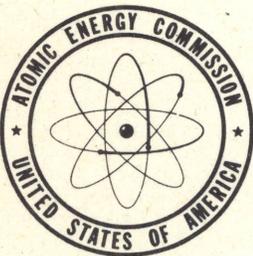
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ELECTRONIC DEVICES FOR NUCLEAR PHYSICS

(A report on photomultiplier tube development)  
November 1, 1955 - January 31, 1956

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## PART I

### MULTI-ALKALI PHOTOCATHODES

#### A. Multiplier Tubes

Further progress has been made in establishing a reproducible process for activating 10-stage tubes of the 6342 type with either Sb-K-Na or Sb-K-Na-Cs cathode and Ag-Mg dynodes. One three-alkali tube was tested by P. R. Bell in Oak Ridge and the improvement in performance over 6342 tubes with Sb-Cs cathodes was of the order expected from its higher blue response.

One Sb-K-Na multiplier was made with a cathode having 7.5 ua/lumen with a 5113 blue filter, i.e., the sensitivity was equal to the best Sb-Cs cathodes despite the absence of Cs. This tube is being investigated for dark current and stability with high voltages and currents.

It is felt that the processing of multi-alkali tubes is now far enough advanced to be taken over by the RCA Lancaster plant and some help has been given to the Lancaster development group to start on this project.

#### B. Measurements of Thermionic Emission

Considerable difficulty was encountered in previous attempts to measure thermionic emission from photocathodes at room temperature because of the interference from other dark currents in the range below  $10^{-14}$  amps/cm<sup>2</sup>. Therefore, a simpler method of determining the thermionic emission was tried, consisting of measurements at higher temperatures over a wide

enough range to permit extrapolation to room temperature. This method makes two assumptions; firstly, that the cathode surface at elevated temperature is the same as at room temperature, and, secondly, that the Richardson plot can be extrapolated down to room temperature as a straight line.

It is believed that the first assumption is justified as long as the cathode is not heated beyond the point at which the photoemission drops appreciably. Within the range in which measurements could be made, the Richardson plots were straight lines in all cases, so it is likely that a linear extrapolation to room temperature does not introduce a large error.

The measurements were made with standard Sb-Cs cathodes and with Sb-K-Na and Sb-K-Na-Cs cathodes; for comparison, an infrared sensitive Ag-O-Cs cathode was also included. Typical results are shown in the Table below:

<u>Temperature</u>	<u>Thermionic Emission</u> (amps/cm <sup>2</sup> )			
	<u>Sb-Cs</u>	<u>Ag-O-Cs</u>	<u>Sb-K-Na</u>	<u>Sb-K-Na-Cs</u>
150°C	2x10 <sup>-10</sup>	5x10 <sup>-8</sup>	< 5x10 <sup>-13</sup>	2x10 <sup>-10</sup>
22°C	10 <sup>-16</sup>	5x10 <sup>-13</sup>	(< 10 <sup>-18</sup> )	2x10 <sup>-16</sup>

These figures confirm two impressions previously gained from measurements with multipliers. Firstly, the thermionic emission of the Sb-K-Na-Cs cathode is of the same order as that of the Sb-Cs cathode, despite the longer threshold wavelength of the first. Secondly, the thermionic emission of the Sb-K-Na cathode is several orders of magnitude smaller than that of the Sb-Cs cathode, although the long wavelength threshold is about the same in both cathodes. The values for

the Sb-K-Na cathode in the Table require some comment. Even at 160°C, the thermionic emission was immeasurably small, i.e., below  $10^{-12}$  amps, but it was not considered safe to exceed this temperature because decomposition of the cathode was feared. With only this one maximum value at high temperature, a Richardson plot could not be drawn and the room temperature value is therefore an estimate based on the assumption that the slope of the Richardson plot is similar to that of the other cathodes. The Ag-O-Cs cathode, in agreement with past experience, had a thermionic emission more than three orders of magnitude larger than any other cathode.

The described measurements are only considered to be of a preliminary nature until more definite measurements can be made with a counter arrangement. However, they are believed to be reliable enough to justify a greater effort on making Sb-K-Na multiplier tubes to take advantage of the combination of high blue response and low thermionic emission.

PART IIPHOTOMULTIPLIER DEVELOPMENTA. Central Potential Photomultiplier

Design of the multiplying structure is reported here for a fast high-gain photomultiplier having its space-charge limited peak output current over 1 amp., utilizing central accelerating electrodes at a common high potential, and having a transit time dispersion substantially less than  $3 \times 10^{-9}$  secs.

A preliminary design of this tube is nearing completion. As previously reported, the work done includes extensive rubber model trajectory plotting, the construction of a small resistance network analog, field measurement from the analog, numerical improvement of the field by iteration and "over-correction", superposition of the several field components, and the beginning of numerical step-wise trajectory calculation.

Two major design activities are now under way, and will be continued simultaneously. These are (1) continuation of the trajectory calculations, and (2) construction of a large scale model of the preliminary design of multiplying structure, such that the bombarded portion of the dynodes is made visible by its phosphor coating. These two steps, in combination, should constitute a reliable check on the electron optics.

The trajectory calculation had been started "by hand" with the aid of a desk calculator. In recent weeks, our computation laboratory has put into operation improved computing equipment (IBM #650 card and drum machine) which lends itself to this problem more readily than the previous (CPC) machine.

The calculations will now be continued by our computation laboratory after an adequate statement of the problem has been completed for them.

The large scale model tube consists of a five stage electron multiplier of about four times the linear size of the proposed final tube. Only the symmetric portion of the multiplier is being tested here, and no high current collection system will be tested at this time. The electron source will be an electron gun, and deflection of the spot on the first dynode will reveal the focusing behavior at the phosphor coated second, and successive, dynodes. (See Fig. 1)

This large tube has been designed and parts preparation is well under way. It is expected that the testing of this tube may occur at about the same time as completion of the trajectory calculation, thereby providing a good basis for design decisions concerning the final tube.

#### B. Photoelectron Collector Systems

The photoelectron collector system between the photocathode and first dynode is one of the weakest links from the time resolution standpoint in nearly all present multipliers. The only exceptions to this are the H4646 with its small rectangular photocathode designed especially to have very strong fields in the vicinity of the emitting surface and the 1P21 where the cathode is very small and the distance between the cathode and first dynode is also small.

The reasons for the difficulty with most multipliers using a large cathode are two-fold. First, the electron lens systems are oversimplified to the point where the initial field strength to which electrons originating at some distance from the center of the cathode are subjected is considerably weaker than that for central electrons. This can be readily seen from the typical equipotential map shown in Fig. 2. With a two-inch cathode and one and one-quarter inch cathode to first dynode spacing, the time difference between zero velocity electrons originating at the center and those from the edge is nearly 6  $\mu$ secs. The second reason is that in general the fields in the neighborhood of the photocathode are weak and this, combined with the long path lengths, makes the time spread due to differences in the initial velocity fairly large. It can be estimated that the transit time of an electron leaving the center of the cathode and reaching the first dynode having an initial velocity of 1 ev is 3  $\mu$ secs. shorter than one originating at the same point at zero initial velocity. The time difference is even greater near the cathode edge. With most of the tubes in use at present, conditions are even less favorable because the aperture plate must be operated well below first dynode potential in order to obtain maximum photoelectron collection.

In line with the attempt to improve the resolving time of the multiplier, a new electron lens system is being investigated. This lens system consists of electrodes at very high potentials near the cathode so that the electrons are rapidly accelerated to a high velocity. As the electrons

approach the first dynode, they are slowed down so that they reach this element with a velocity corresponding to some 200 volts. In addition, the field strengths along trajectories between the center and the first dynode and between the edge of the cathode and first dynode are to be made much more uniform. It is probable that this will require photocathodes having relatively short radii of curvature. While this is undesirable from the standpoint of the optical coupling between crystal and cathode, nevertheless, it is felt to be necessary if the objective of very short resolving time is to be achieved. In the ultimate tube, it is probable that the outer surface of the cathode will be flat and the inner surface curved.

Paralleling the work on the inverse focus type of electron collector systems, some work will be done on the electron optical structures for conventional tubes in an effort to arrive at a lens system for the H5914 (RCA6810), giving better time resolution for the present cathode size and possibly permitting the use of a larger cathode.

#### C. Time Resolution Measurements of Secondary Emission Multiplier Structures

Work was continued on the system for measuring the time spread in multiplier structures using the same principle that was employed for measurement of the time spread of secondary emission itself. It is expected that this measurement can be reduced to a routine procedure in the near future.

Measurements on tube 6791-3 were concluded. This tube is designed to test the transit time dispersion in the

L16 dynodes (dynodes of the type used in the RCA6810 multiplier phototube). It was reported previously that the transit time dispersion for this type of dynode was less than  $9 \times 10^{-10}$  sec. In making this measurement it was observed that a satellite pulse accompanied each main pulse. Satellite pulses were observed in both tube 6791-3 and in tube 6791-2. Some study has been made of the possible origin of these satellite pulses. At present the most reasonable explanation appears to be that a certain small fraction of the secondary electrons from one dynode, instead of going to the next and being multiplied there, actually skips the next dynode in sequence and strikes the dynode following it. To check this hypothesis, the rubber model analog of the dynode structure was set up and further trajectory calculations were made. Fig. 3 shows some of the results obtained. For example, the path labeled (1) shows the calculated electron path for electrons with zero initial velocity. The path labeled (2) is the calculated trajectory for an electron which has 5 volts initial velocity in the direction indicated in the figure. From the point of impact of electrons in path (2), zero velocity secondary electrons can follow path (3), and it is conceivable that electrons with a finite initial velocity could cause secondary electron descendants which re-enter the multiplier chain. Some additional confirmation of this hypothesis is to be found in the distribution of fluorescence of the silver-magnesium dynode surfaces in a structure using L16 dynodes.

While the satellite pulses represent only a small fraction of the electrons passing through the structure,

nevertheless, they are undesirable both from the standpoint of time resolution and possibly pulse height distribution. Experiments directed toward eliminating the effect are to be made by reducing the secondary emission ratio of certain portions of the dynode surface.

Tube 6791-4, containing a DuMont dynode structure, was constructed. The hot cathode in this tube was unsatisfactory and had to be replaced. After this was done, the gain of the multiplier was very poor. A second tube, 6791-5, employing the same dynode structure was therefore built and activated. The performance of this tube was satisfactory. Upon comparison with tube 6791-3, its performance indicated a very much greater time spread. For example, when rf is put on only deflecting plates  $D_{5,6}$ , the auxiliary oscilloscope pattern is a secant  $\theta$  curve. From this condition, the application of rf to  $D_{1,2}$  should remove portions of the secant  $\theta$  curve leaving the pulse which is to be investigated. This is so when tube 6791-3 is used, but with tube 6791-5 the secant  $\theta$  curve merely changes in amplitude as the rf on  $D_{1,2}$  is varied. This would be the case if the transit time dispersion were such as to make the pulse longer than one-half cycle of the 50-megacycle oscillations used on the deflection system. In order to further test this point, the operating frequency was lowered to 20 megacycles by a readjustment of the 50-megacycle oscillator. The performance under this adjustment, however, was not very satisfactory. Therefore, an independent 10-megacycle oscillator was built. Measurements with this new oscillator are now in progress.

A tube was also built to test the 931-A type multiplier structure (tube 6791-6). This tube had only five dynodes rather than the six that had been used in the previous tubes. The secondary emission gain was found to be adequate. When tested at 50 megacycles, this multiplier showed a transit time dispersion which was at least as small as, if not smaller than, that of the L16 dynodes. Further measurements are to be made with this tube.

Fig. 4 shows the general construction of the tubes used for the measurements discussed above.

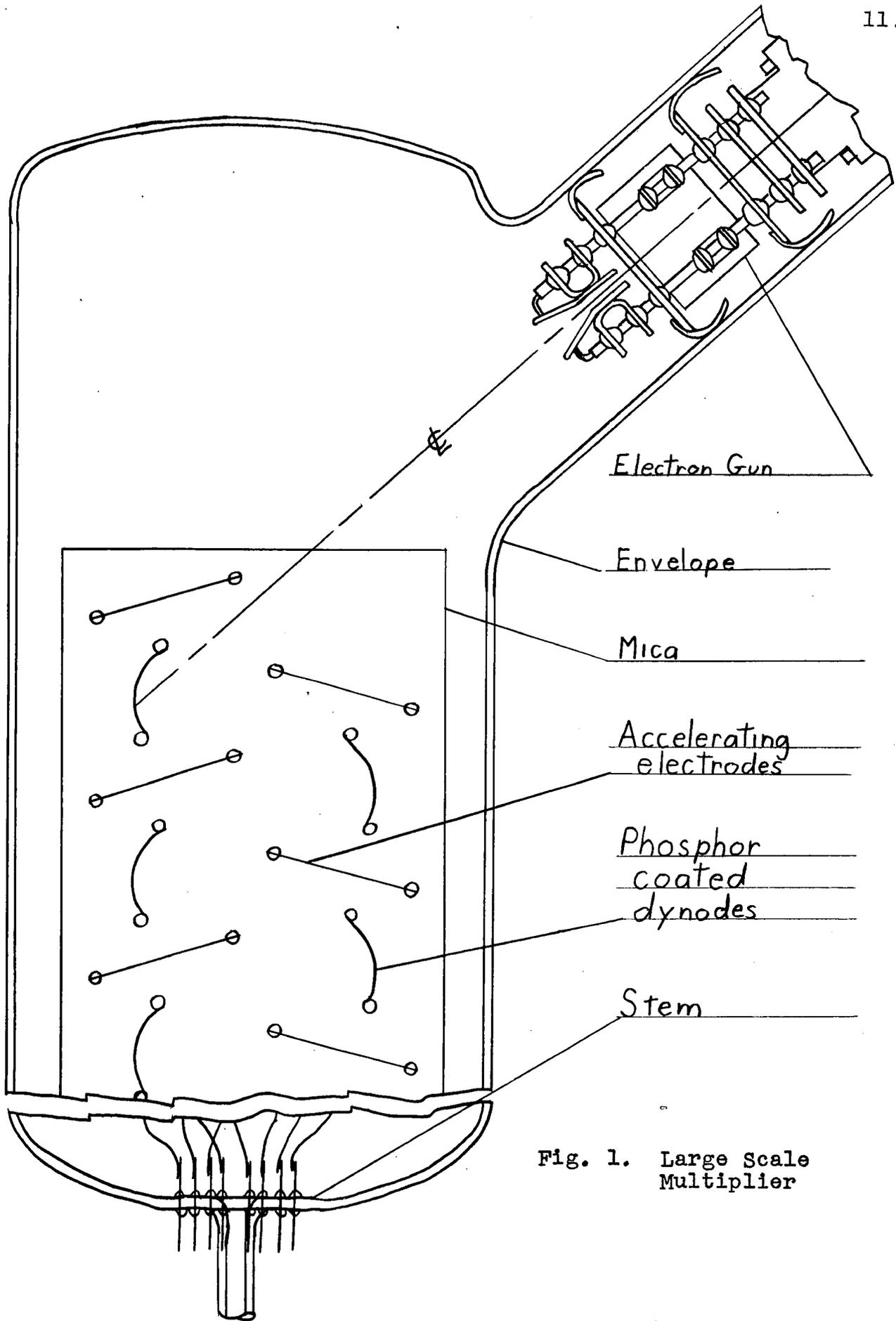


Fig. 1. Large Scale Multiplier



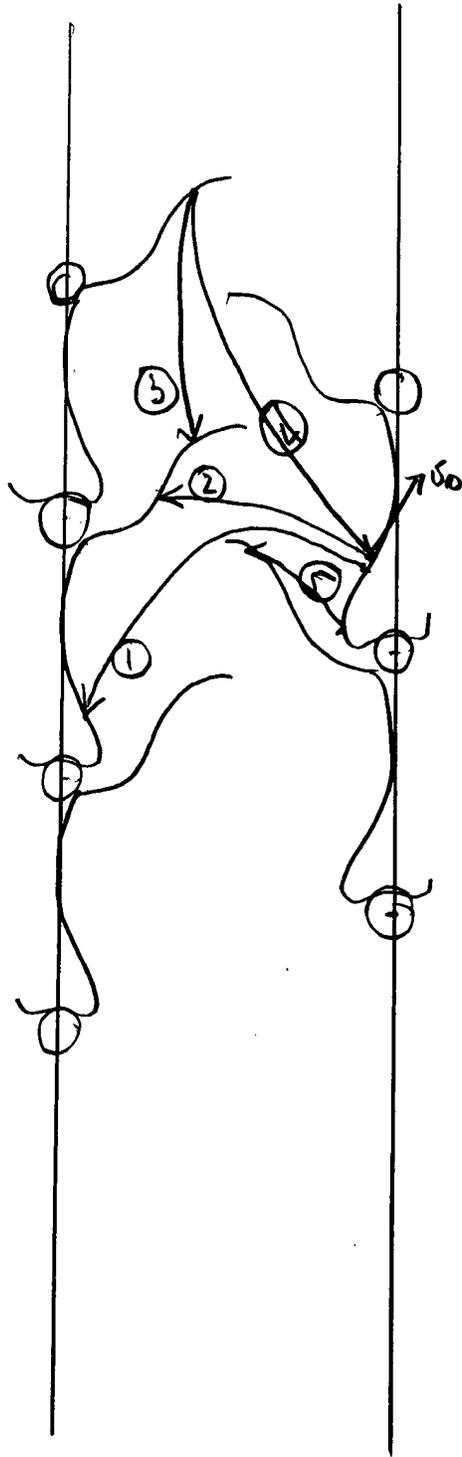
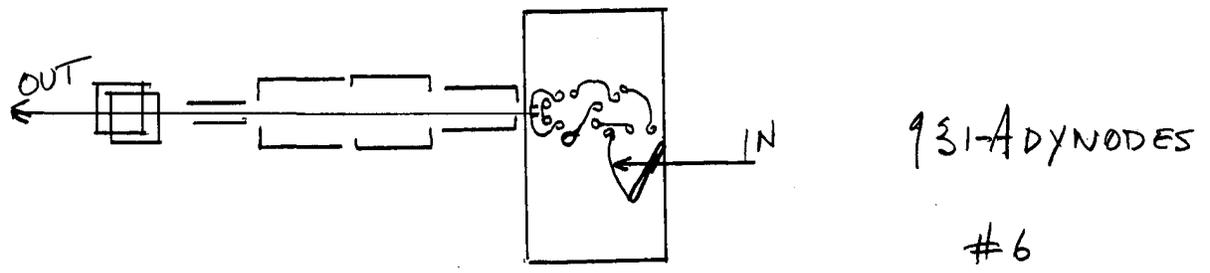
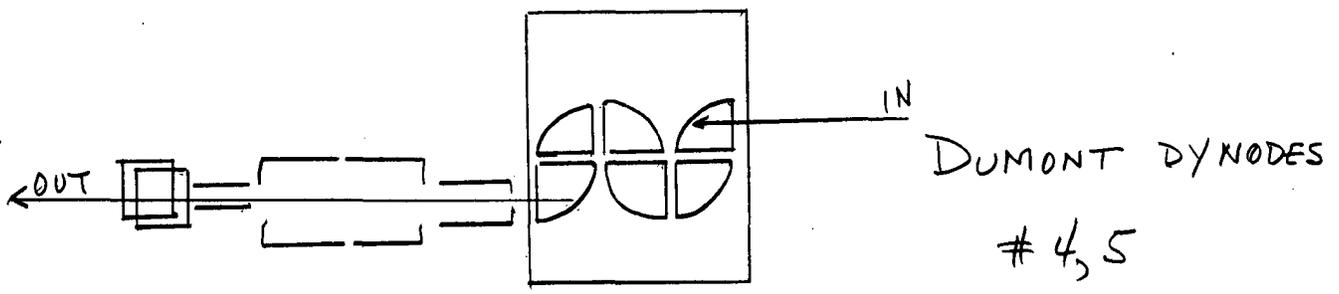
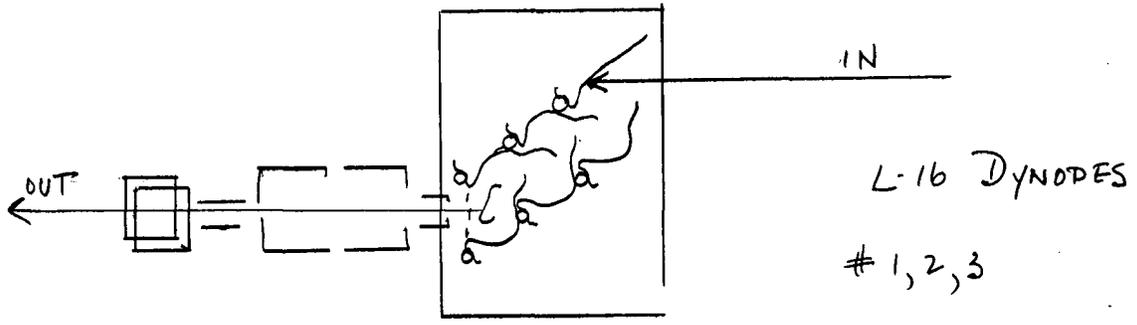


Fig. 3 Electron Paths in 6810 Tube



H-6791 TUBES

Fig. 4



