4516

Photomultiplier Tube

3/4-INCH DIAMETER, 10-STAGE, HEAD-ON TYPE BIALKALI PHOTOCATHODE OF HIGH QUANTUM EFFICIENCY IN-LINE ELECTROSTATICALLY-FOCUSED DYNODE STRUCTURE

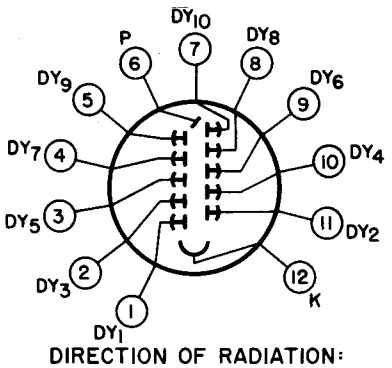
For Use in Pulse-Counting and Other Low-Light Level Detection and Measurement Systems

GENERAL

Spectral Response	**See accompanying** *Spectral Response Characteristics*
Wavelength of Maximum Response	**4000 ± 500 Angstroms**
Cathode, Semitransparent	**Cesium-Potassium-Antimony (Bialkali)**
Shape	**Spherical Section**
Minimum projected area	**0.2 sq. in**
Minimum diameter	**0.5 in**
Window	**Corning[a] No.0080, or equivalent**
Shape	**Plano-Concave**
Index of refraction at 4360 angstroms	**1.523**
Dynodes	
Substrate	**Copper-Beryllium**
Secondary-Emitting Surface	**Beryllium-Oxide**
Structure	**In-Line, Electrostatic-Focus Type**
Direct Interelectrode Capacitances (Approx.)	
Anode to dynode No.10	**2.4 pF**
Anode to all other electrodes	**3.2 pF**
Maximum Overall Length (Excluding semiflexible leads)	**3.94 in**
Maximum Diameter	**0.78 in**
Envelope	**T-6**
Magnetic Shield	**See footnote (b)**
Operating Position	**Any**
Weight (Approx.)	**0.9 oz**
Base	**Small-Button Thirteenar 12-Semiflexible Leads (JEDEC No.E12-72)**

TERMINAL DIAGRAM (Bottom View)

Lead 1 - Dynode No.1
Lead 2 - Dynode No.3
Lead 3 - Dynode No.5
Lead 4 - Dynode No.7
Lead 5 - Dynode No.9
Lead 6 - Anode
Lead 7 - Dynode No.10
Lead 8 - Dynode No.8
Lead 9 - Dynode No.6
Lead 10 - Dynode No.4
Lead 11 - Dynode No.2
Lead 12 - Photocathode



DIRECTION OF RADIATION: INTO END OF BULB

12BG

ABSOLUTE-MAXIMUM RATINGS

DC Supply Voltage		
Between anode and cathode	1800	V
Between anode and dynode No.10	300	V
Between consecutive dynodes	300	V
Between dynode No.1 and cathode	300	V
Average Anode Current[c]	0.5	mA
Ambient-Temperature Range[d]	-100 to +85	°C

CHARACTERISTICS RANGE VALUES

Under conditions with dc supply voltage (E) across a voltage divider providing electrode voltages shown in Table I, except as noted.

With E = 1500 volts except as noted

	Min	*Typ*	*Max*	
Sensitivity				
Radiant[e] at 4000 angstroms	-	3.2×10^{4}	-	A/W
Cathode Radiant[f] at 4000 angstroms	-	0.079	-	A/W
Luminous:				
With tungsten light source[g]	10	27	173	A/lm
With blue light source[h]	1.5×10^{-6}	4×10^{-6}	2.6×10^{-5}	A
Cathode Luminous:				
With tungsten light source[i]		6.7×10^{-5}	-	A/lm
With blue light source[k]	7×10^{-9}	1×10^{-8}	-	A
Quantum Efficiency at 4000 angstroms	-	24	-	%
Current Amplification	-	4×10^{5}	-	
Anode Dark Current[m]	-	2×10^{-10}	6×10^{-10}	A
Equivalent Anode-Dark-Current Input	-	2.9×10^{-11}[n]	-	lm
	-	2.4×10^{-14}[p]	-	W
Dark-Pulse Spectrum[q]	-	r	-	
Pulse-Height Spectrum with Fe^{55} Source[s]	-	t	-	
Pulse-Height Resolution[u]	-	8.5	-	%
Anode-Pulse Rise Time[v,w]	-	1.8×10^{-9}	-	s
Electron Transit Time[v,x]	-	2×10^{-8}	-	s

[a] Made by Corning Glass Works, Corning, New York 14830.

[b] Magnetic shielding in the form of foil or tape as available from the Magnetic Shield Division, Perfection Mica Company, 1322 North Elston, Chicago, Illinois 60622, or equivalent.

[c] Averaged over any interval of 30 seconds maximum.

[d] Tube operation at room temperature or below is recommended.

[e] This value is calculated from the typical luminous sensitivity rating using a conversion factor of 1190 lumens per watt.

[f] This value is calculated from the typical cathode luminous sensitivity rating using a conversion factor of 1190 lumens per watt.

[g] These values are calculated as shown below:

$$\text{Luminous Sensitivity (A/lm)} = \frac{\text{Anode Current (with blue light source)(A)}}{0.15 \times \text{Light Flux of } 1 \times 10^{-6} \text{ (lm)}}$$

The value of 0.15 is the average value of the ratio of the anode current measured under the conditions specified in footnote (h) to the anode current measured under the same conditions but with the blue filter removed.

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h Under the following conditions: Light incident on the cathode is transmitted through a blue filter (Corning C. S. No.5-58, polished to 1/2 stock thickness - Manufactured by the Corning Glass Works, Corning, New York) from a tungsten-filament lamp operated at a color temperature of 2870° K. The value of light flux incident on the filter is 1 microlumen.

i This value is calculated as shown below:

$$\text{Cathode Luminous Sensitivity (A/lm)} = \frac{\text{Cathode Current (with blue light source)(A)}}{0.15 \times \text{Light Flux of } 1 \times 10^{-3} \text{ (lm)}}$$

The value of 0.15 is the average value of the ratio of the cathode current measured under the conditions specified in footnote (k) to the cathode current measured under the same conditions but with the blue filter removed.

k Under the following conditions: Light incident on the cathode is transmitted through a blue filter (Corning C. S. No.5-58, polished to 1/2 stock thickness - Manufactured by the Corning Glass Works, Corning, New York) from a tungsten-filament lamp operated at a color temperature of 2870° K. The value of light flux incident on the filter is 0.001 lumen and 200 volts are applied between cathode and all other electrodes connected as anode.

m At a tube temperature of 22° C. Light incident on the cathode is transmitted through a blue filter (Corning C. S. No.5-58, polished to 1/2 stock thickness). The light flux incident on the filter is 1 microlumen. The supply voltage (E) is adjusted to obtain an anode current of 1 microampere. Sensitivity of the 4516 under these conditions is approximately equivalent to 7 amperes per lumen. Dark current is measured with no light incident on the tube.

n With supply voltage (E) adjusted to give an equivalent luminous sensitivity of 7 amperes per lumen.

p At 4000 angstroms. The value is calculated from the EADCI value in lumens using a conversion factor of 1190 lumens per watt.

q Measured under the following conditions: A Nuclear Data Model No.ND-180 Multichannel Pulse-Height Analyzer is used. The single-photoelectron pulse height is established by fully illuminating the photocathode with a weak light source, such as a tungsten-filament lamp operated at a low color temperature, to assure the high probability of single photoelectron emission from the photocathode of the 4516. The intensity of the light source is adjusted for approximately 50 per cent counting loss. The dark-pulse spectrum is then obtained, using the same gain setting of the Multichannel Pulse-Height Analyzer, with the light source removed.

r See accompanying *Typical Dark-Pulse Spectrum.*

s Measured using a Harshaw Type HG 0.005 " beryllium window NaI(Tl) scintillator, 0.04 " thick and 7/8 " in diameter and an isotope of iron having an atomic mass of 55 (Fe^{55}) and an activity rate of one microcurie. The Fe^{55} Source is in direct contact with the scintillator.

t See accompanying *Differential Fe^{55} Spectrum.*

u Pulse height resolution is defined as the quotient of the full width of the photopeak at half height by the pulse height at maximum count rate under the following condtions: The 662 ke V photon from an isotope of cesium having an atomic mass of 137 (Cs^{137}) and a cylindrical 3/4 " x 3/4 " thallium-activated sodium-iodide scintillator [NaI(Tl)-type 3D3] are used. This scintillator is manufactured by the Harshaw Chemical Corporation, 1945 East 97 Street, Cleveland 6, Ohio, and is rated by the manufacturer as having a resolution capability of 8.5%. The Cs^{137} source is in direct contact with the metal end of the scintillator. The faceplate end of the crystal is coupled to the 4516 by a coupling fluid such as Dow Corning Corp., Type DC200 (viscosity of 60,000 centistokes) - Manufactured by the Dow Corning Corp., Midland, Michigan, or equivalent.

v Under conditions with dc supply voltage (E) across a voltage divider providing 1/6 of (E) between cathode and dynode No.1; 1/12 of (E) for each succeeding dynode stage; and 1/12 of (E) between dynode No.10 and anode.

w Measured between 10 per cent and 90 per cent of maximum anode-pulse height. This anode-pulse rise time is primarily a function of transit time variation and is measured under conditions with the incident light fully illuminating the photocathode.

x The electron transit time is the time interval between the arrival of a delta function light pulse at the entrance window of the tube and the time at which the output pulse at the anode terminal reaches peak amplitude. The transit time is measured under conditions with the incident light fully illuminating the photocathode.

OPERATING CONSIDERATIONS

The *semiflexible leads* of the 4516 may be soldered into the associated circuit. If desired, the leads may be trimmed to within 1/4 inch of the protective plastic shell. When leads of reduced length are soldered, care must be taken to conduct excessive heat away from the lead seals. Otherwise, the heat of the soldering operation may crack the glass seals of the leads and damage the tube.

The *operating stability* of the 4516 is dependent on the magnitude of the anode current. The use of an average anode current well below the maximum rated value of 0.5 milliampere is recommended when stability of operation is important. When stability is of prime importance, the use of an average anode current of 1 microampere or less is recommended.

Electrostatic and magnetic shielding of the 4516 is ordinarily required. When a shield is used, it must be at cathode potential.

The *high voltages* at which the 4516 is operated are very dangerous. Care should be taken in the design of apparatus to prevent the operator from coming in contact with these high voltages. Precautions should include the enclosure of high-potential terminals and the use of interlock switches to break the primary circuit of the high-voltage power supply when access to the apparatus is required.

Accompanying Typical Voltage-Divider Arrangements are recommended for use with the 4516. Recommended resistance values for the voltage dividers range from 10,000 ohms per stage to 1,000,000 ohms per stage. The choice of resistance values for any voltage-divider network is usually a compromise. If low values of resistance per stage are utilized, the power drawn from the regulated power supply and the required power rating of the resistors increase. Phototube noise may also increase due to heating if the divider network is mounted near the photocathode. The use of high resistance values per stage may cause deviation from linearity if the voltage-divider current is not maintained at a value of at least 10 times that of the maximum value of anode current, and may limit anode-current response to pulsed light. The latter effect may be reduced by connecting capacitors between the tube socket terminals for dynodes No.7 and No.8, dynodes No.8 and No.9, dynodes No.9 and No.10, and between dynode No.10 and anode return. In addition to nonlinearity and pulse-limiting effects, the use of resistance values exceeding 1 megohm per stage make the 4516 more susceptible to leakage effects between terminals with possible resulting deviation in interstage voltage leading to a loss of current amplification.

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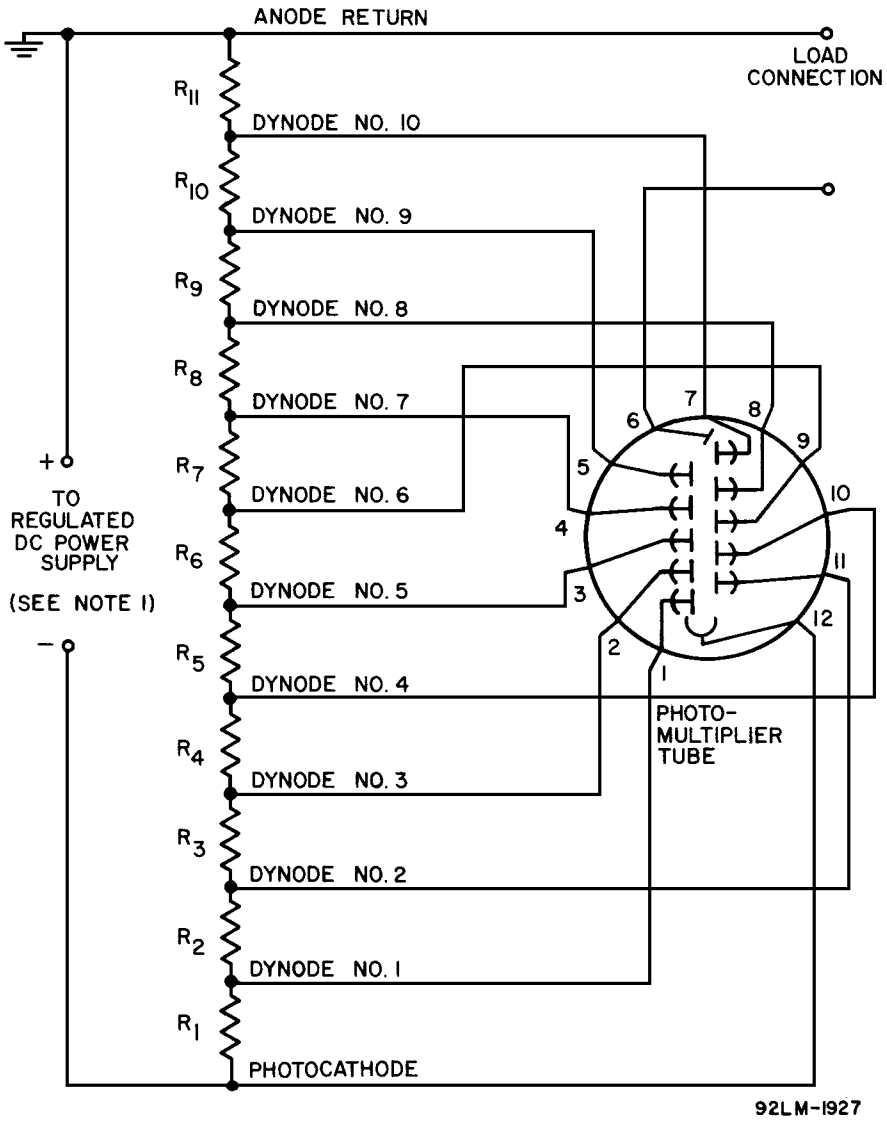
TYPICAL VOLTAGE-DIVIDER ARRANGEMENT WHICH PERMITS DIRECT COUPLING TO THE ANODE

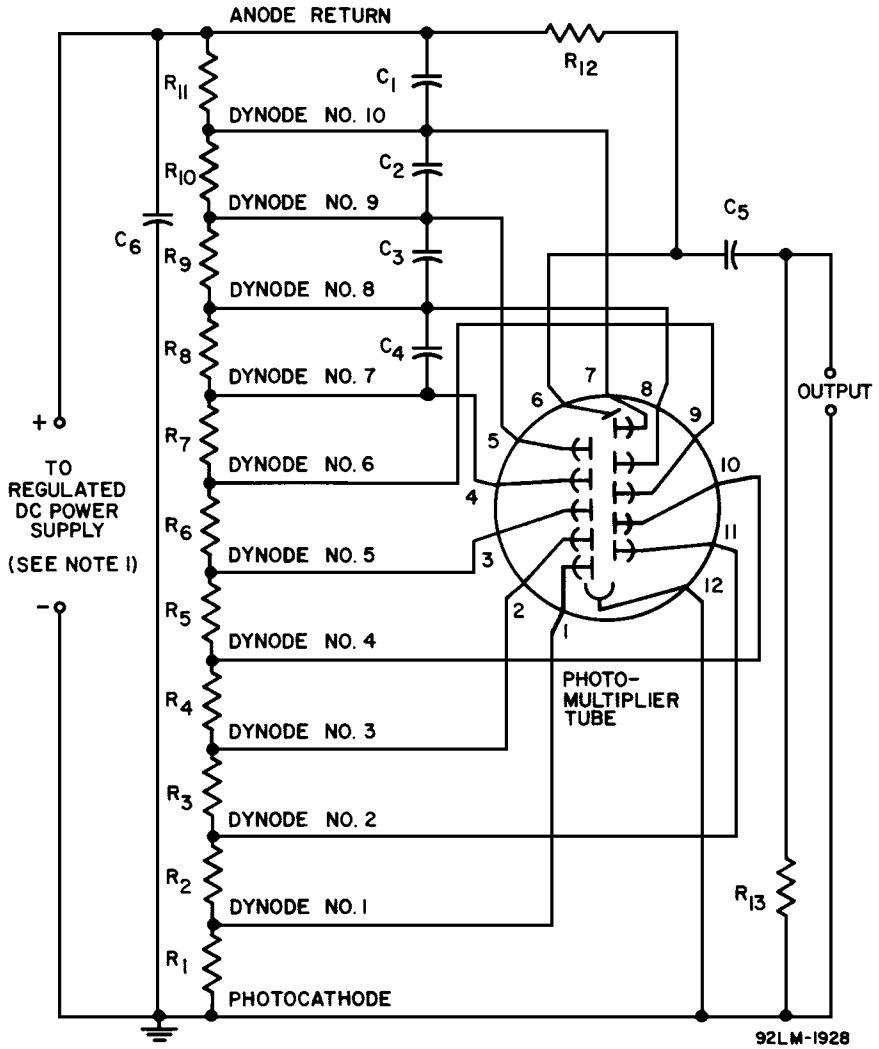


R_1 and R_2: 560,000 ohms, 1/2 watt
R_3: 820,000 ohms, 1/2 watt
R_4 through R_{11}: 470,000 ohms, 1/2 watt

Note 1: Adjustable between approximately 500 and 1800 volts dc.

Note 2: Component values are dependent upon nature of application and output signal desired.

TYPICAL VOLTAGE-DIVIDER ARRANGEMENT FOR USE IN SCINTILLATION-COUNTING APPLICATIONS



C_1: 0.05 μF, 500 volts (dc working)
C_2: 0.02 μF, 500 volts (dc working)
C_3: 0.01 μF, 500 volts (dc working)
C_4: 0.005 μF, 500 volts (dc working)
C_5 and C_6: 0.005 μF, 3000 volts (dc working)
R_1: 680,000 ohms, 1/2 watt
R_2:and R_3: 510,000 ohms, 1/2 watt
R_4 through R_{11}: 390,000 ohms, 1/2 watt
R_{12}: 1 megohm, 1/2 watt
R_{13}: 100,000 ohms, 1/2 watt

Note 1: Adjustable between approximately 500 and 1800 volts dc.

Note 2: Capacitors C_1 through C_6 should be connected at tube socket for optimum high-frequency performance.

Note 3: Component values are dependent upon nature of application and output signal desired.

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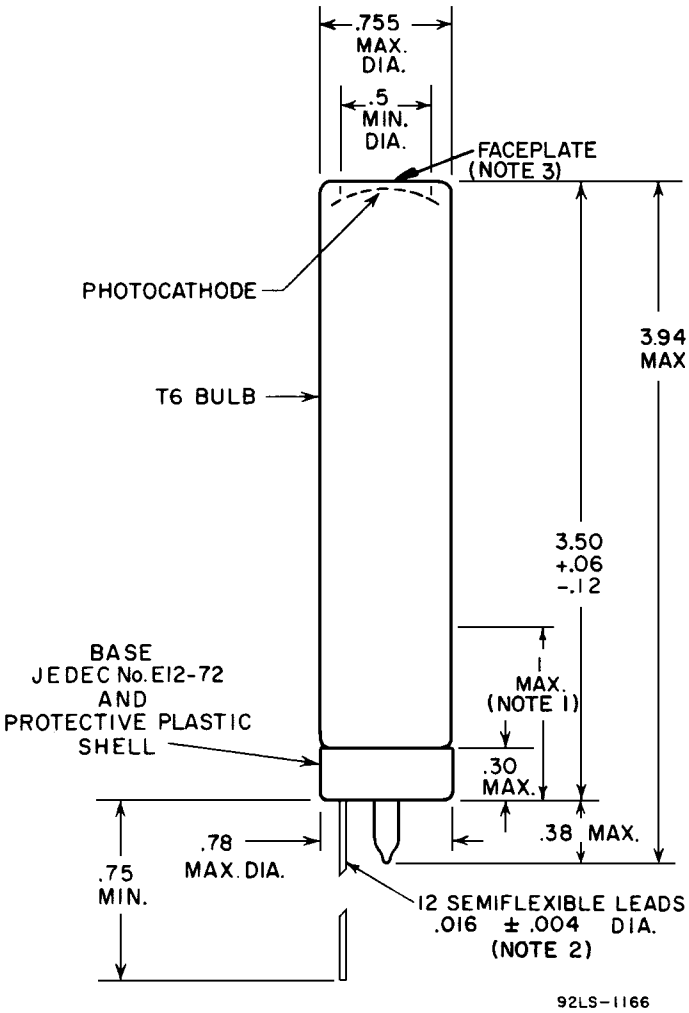
DIMENSIONAL OUTLINE



DIMENSIONS IN INCHES

Note 1: Within this length, maximum diameter of tube is 0.78".

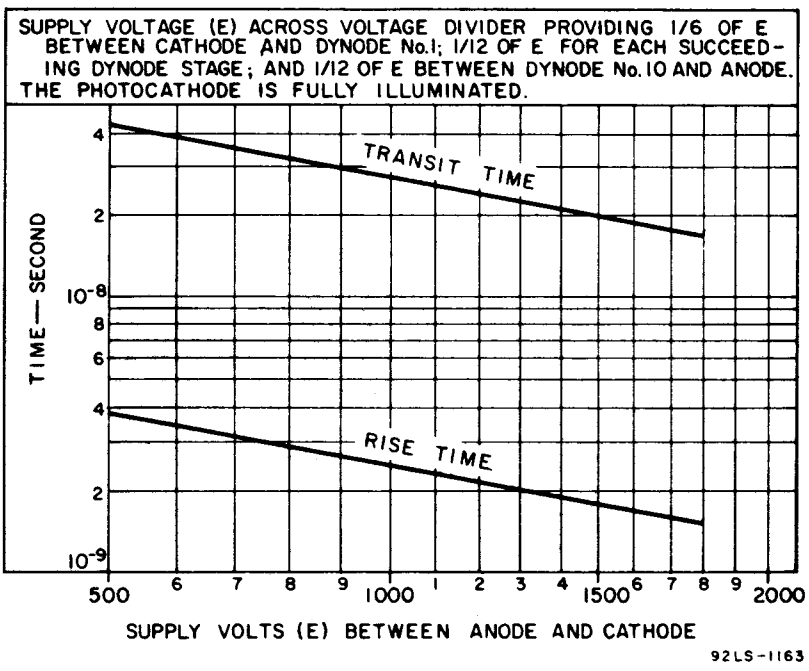
Note 2: The semiflexible leads of the 4516 may be soldered or welded into the associated circuit. If desired, the leads may be trimmed to within 1/4 inch of the protective shell. Care must be exercised when making such connections to prevent tube destruction due to thermal stress of the glass-metal seals. A heat sink placed in contact with the semiflexible leads between the point being soldered, or welded, and the protective shell is recommended. Excessive bending of the leads is to be avoided.

Note 3: Deviation from flatness within the 0.5"-diameter area will not exceed 0.006" from peak to valley.

TABLE I

TYPICAL POTENTIAL DISTRIBUTION	
Between	8.25% of Supply Voltage (E) multiplied by
Cathode and Dynode No.1	1.2
Dynode No.1 and Dynode No.2	1.2
Dynode No.2 and Dynode No.3	1.7
Dynode No.3 and Dynode No.4	1.0
Dynode No.4 and Dynode No.5	1.0
Dynode No.5 and Dynode No.6	1.0
Dynode No.6 and Dynode No.7	1.0
Dynode No.7 and Dynode No.8	1.0
Dynode No.8 and Dynode No.9	1.0
Dynode No.9 and Dynode No.10	1.0
Dynode No.10 and Anode	1.0
Anode and Cathode	12.1

Typical Time-Resolution Characteristics



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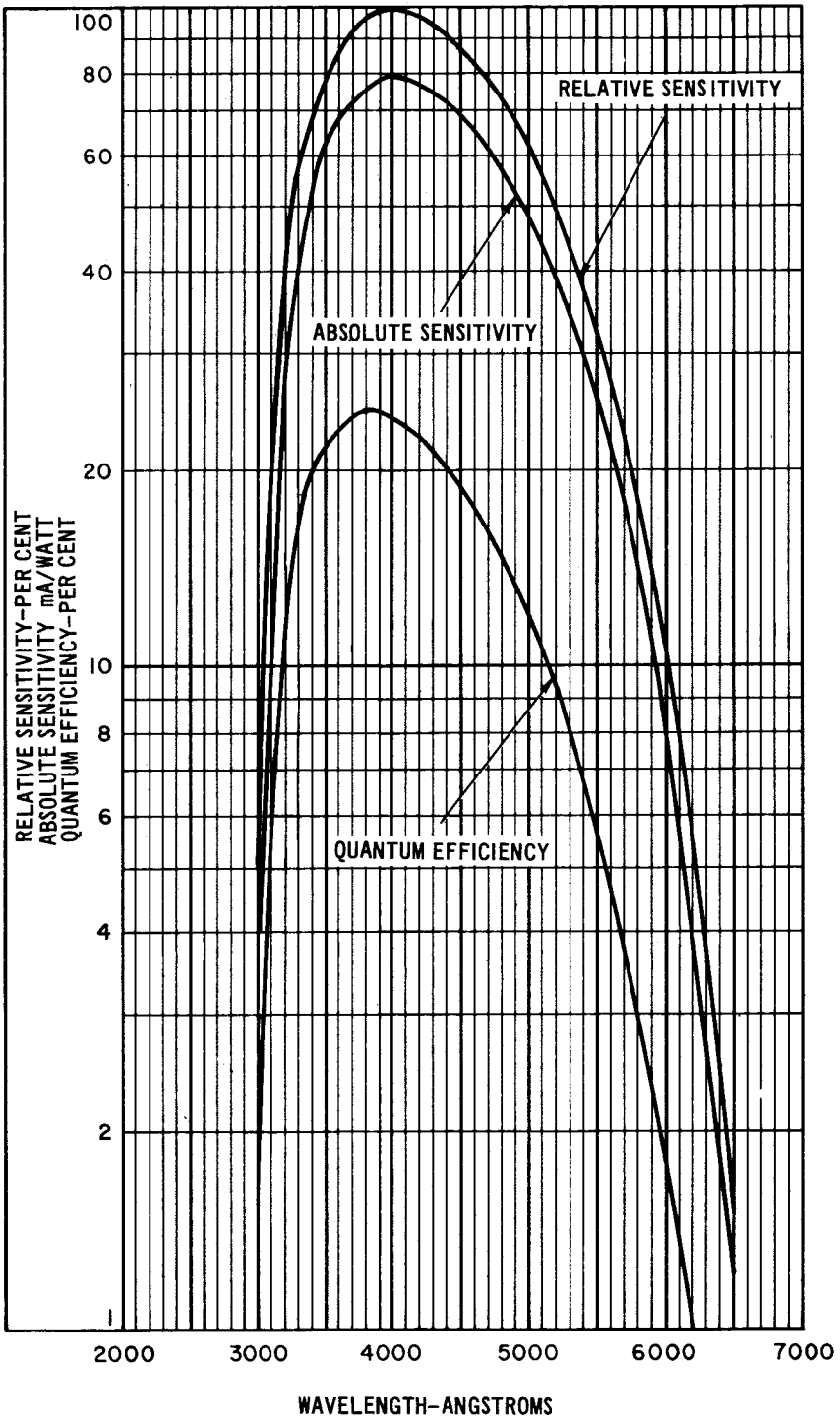
Typical Spectral Response Characteristics



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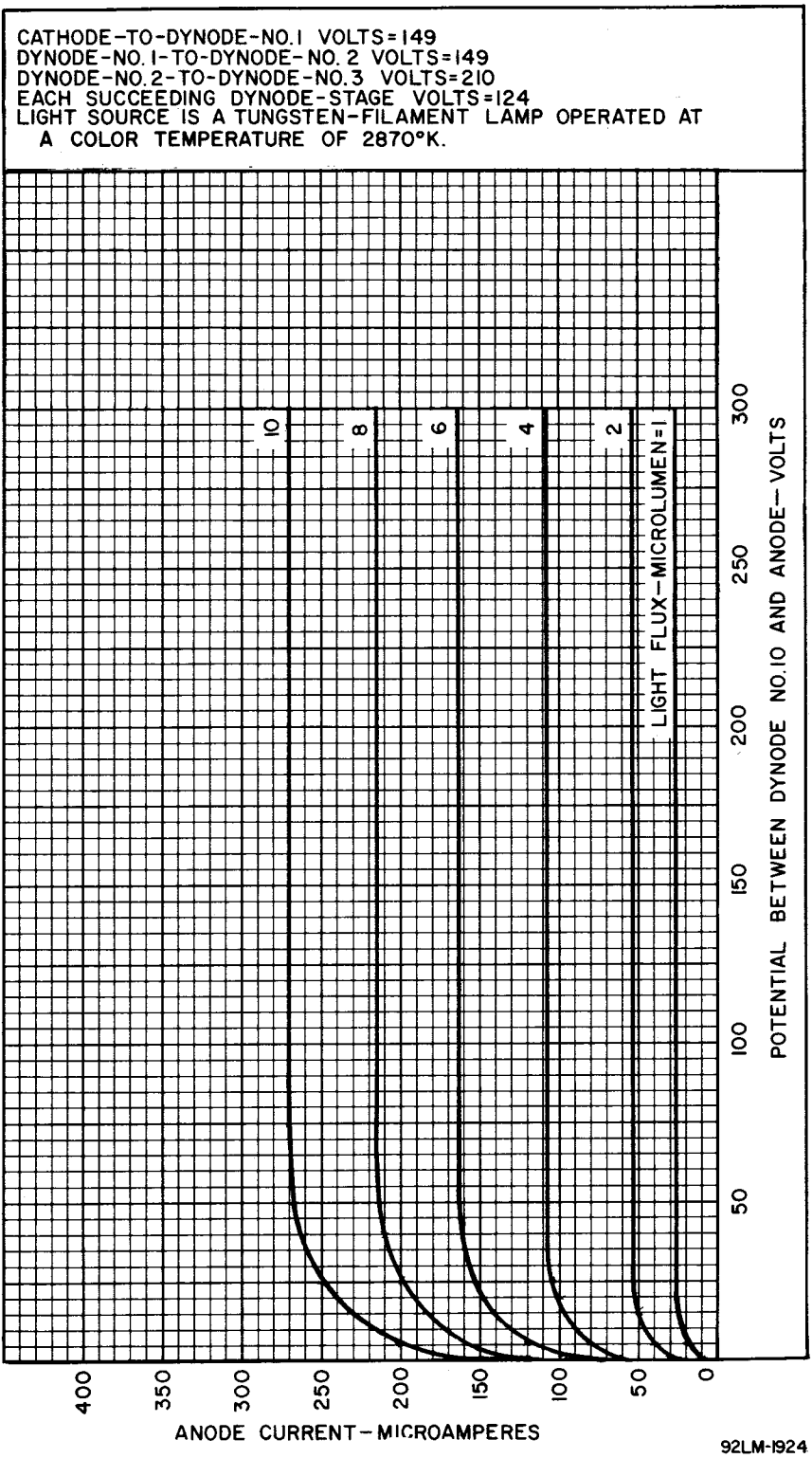
Typical Anode Characteristics



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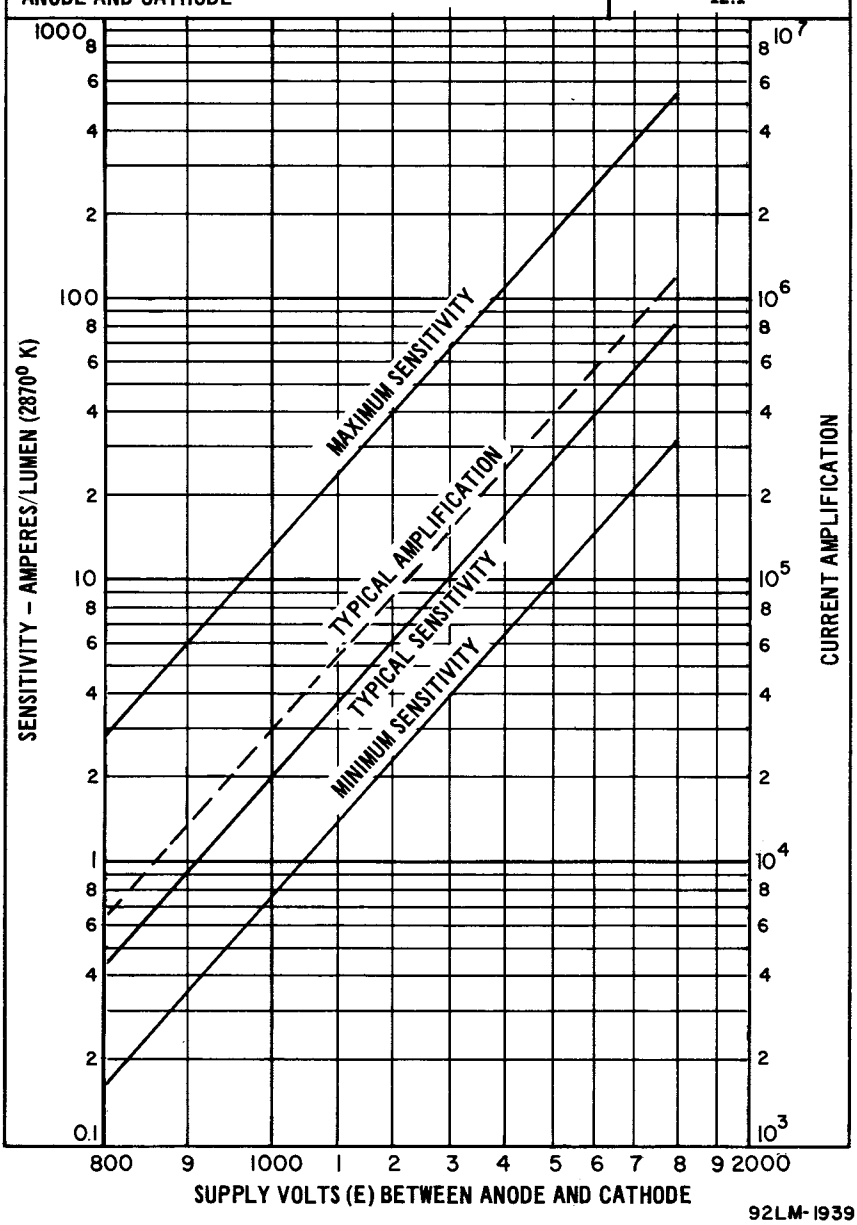
Typical Sensitivity and Current Amplification Characteristics

THE SUPPLY VOLTAGE (E) IS ACROSS A VOLTAGE DIVIDER WHICH PROVIDES VOLTAGES AS FOLLOWS:

BETWEEN	8.5% OF E MULTIPLIED BY
CATHODE AND DYNODE No.1	1.2
DYNODE No.1 AND DYNODE No.2	1.2
DYNODE No.2 AND DYNODE No.3	1.7
EACH SUCCEEDING DYNODE-STAGE	1.0
ANODE AND CATHODE	12.1



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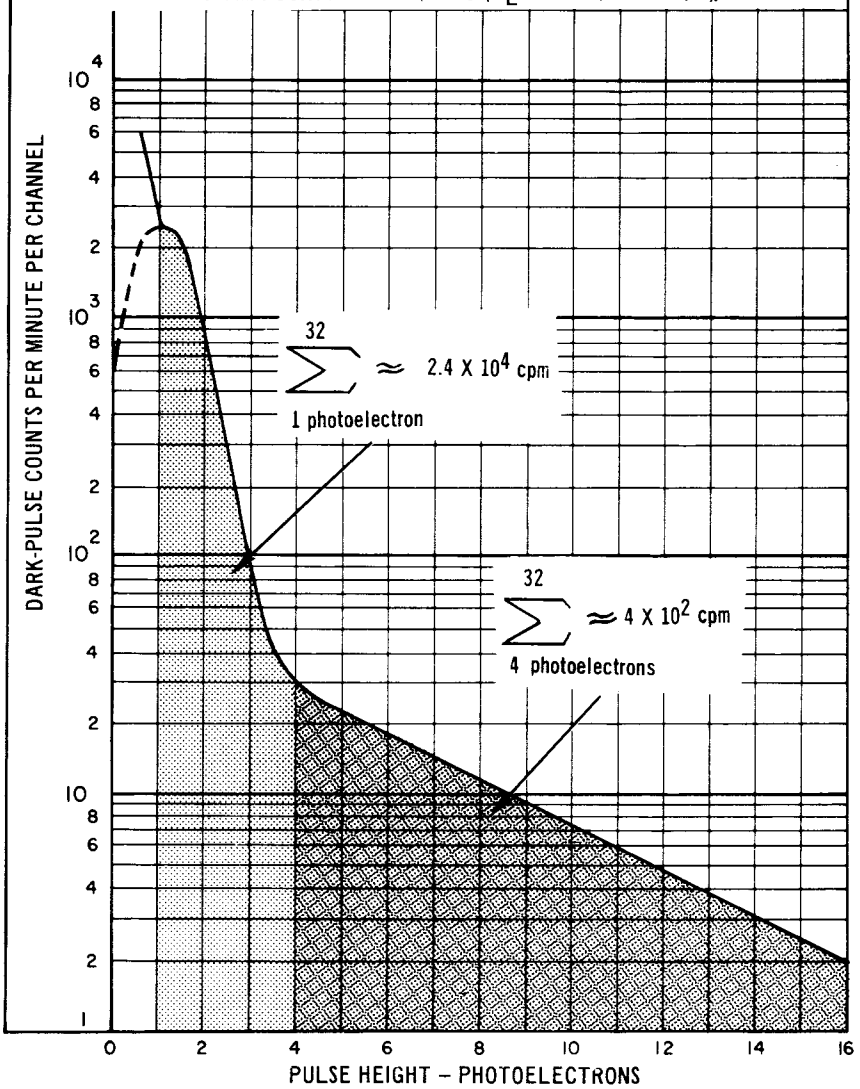
Typical Dark-Pulse Spectrum

CATHODE-TO-DYNODE-No. 1 VOLTS = 149
DYNODE-NO.-1-TO-DYNODE-NO. 2 VOLTS = 149
DYNODE-No. 2-TO-DYNODE-No. 3 VOLTS = 210
EACH SUCCEEDING DYNODE-STAGE VOLTS = 124
ANODE-TO-CATHODE VOLTS = 1500
DASHED PORTION INDICATES LOCATION OF SINGLE PHOTOELECTRON PEAK. THIS PORTION OF CURVE IS NORMALIZED TO COINCIDE WITH SINGLE PHOTOELECTRON PEAK OF DARK PULSE SPECTRUM AND IS OBTAINED WITH PHOTOCATHODE FULLY ILLUMINATED BY A TUNGSTEN-FILAMENT LAMP OPERATED AT A LOW COLOR TEMPERATURE. DARK PULSES ARE SUBTRACTED.
SOLID-LINE PORTION INDICATES DARK-PULSE SPECTRUM.
TUBE TEMPERATURE = 22^0 C.
ONE PHOTOELECTRON PULSE HEIGHT = 4 COUNTING CHANNELS.
INTEGRATING TIME CONSTANT = 30 μ SEC. (R_L = 300 kΩ, C = 100 pF).



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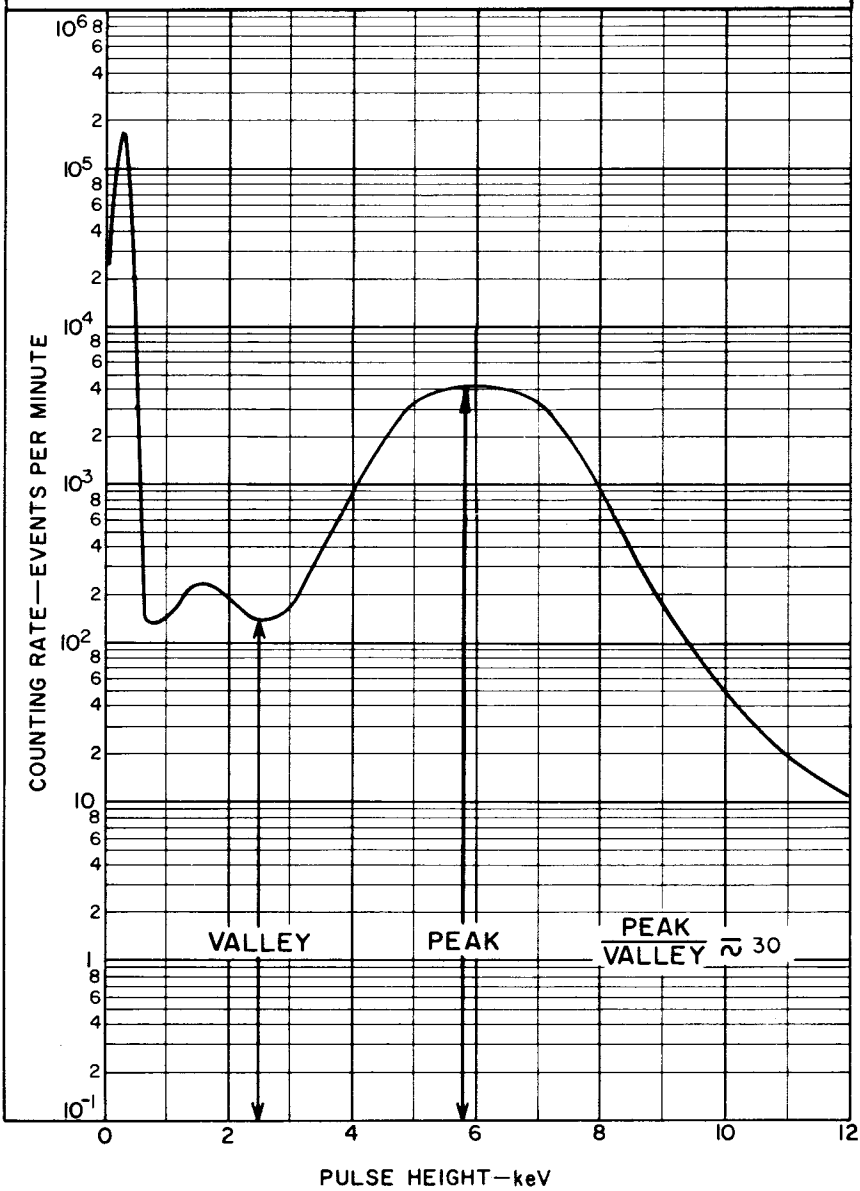
Differential Fe^{55} Spectrum

Fe^{55} SOURCE, IN CONTACT WITH SCINTILLATOR, ACTIVITY 1 μ CURIE
SCINTILLATOR: HARSHAW, TYPE HG, 0.005" BERYLLIUM WINDOW,
NaI(Tℓ), 7/8" DIAMETER, 0.040" THICK
CATHODE-TO-DYNODE-No. 1 VOLTS = 149
DYNODE-No. 1-TO-DYNODE-No. 2 VOLTS = 149
DYNODE-No. 2-TO-DYNODE-No. 3 VOLTS = 210
EACH SUCCEEDING DYNODE-STAGE VOLTS = 124
ANODE-TO-CATHODE VOLTS = 1500



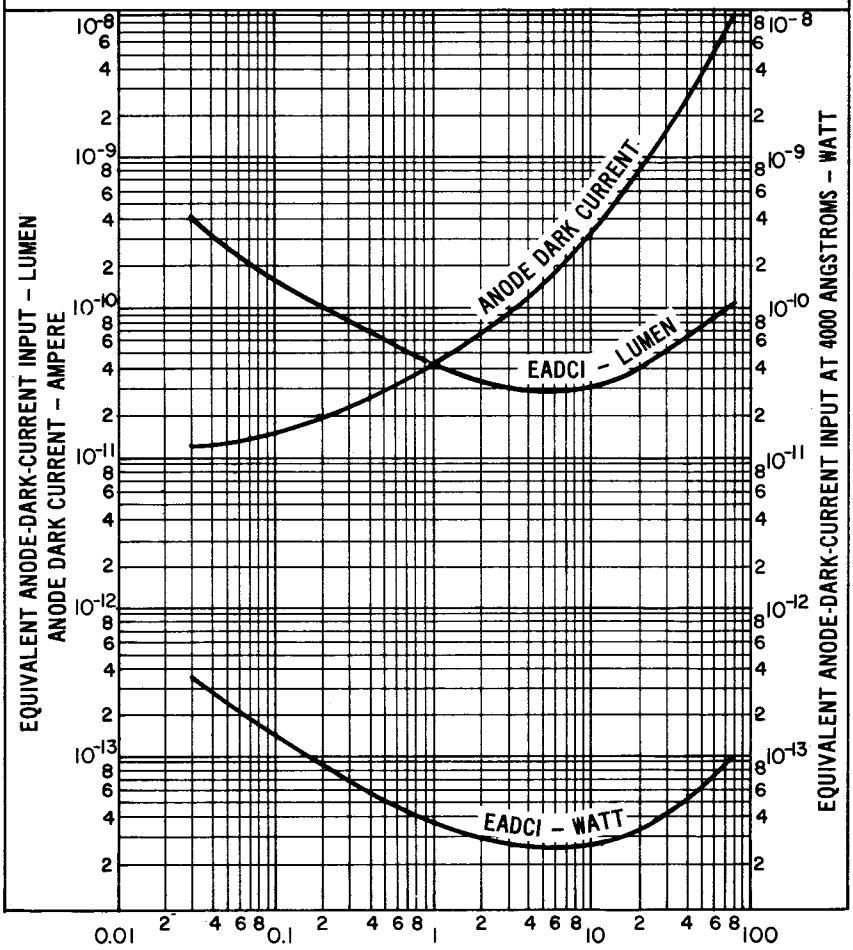
92LM-1929

Typical Dark Current and EADIC Characteristics

LUMINOUS SENSITIVITY IS VARIED BY ADJUSTMENT OF THE SUPPLY VOLTAGE (E) ACROSS A VOLTAGE DIVIDER WHICH PROVIDES VOLTAGES AS FOLLOWS:

BETWEEN	8.25% OF E MULTIPLIED BY
CATHODE AND DYNODE No. 1	1.2
DYNODE No. 1 AND DYNODE No. 2	1.2
DYNODE No. 2 AND DYNODE No. 3	1.7
EACH SUCCEEDING DYNODE-STAGE	1.0
ANODE AND CATHODE	12.1

TUBE TEMPERATURE IS 22° C.



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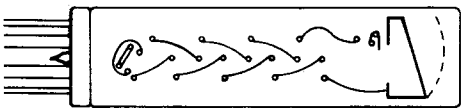
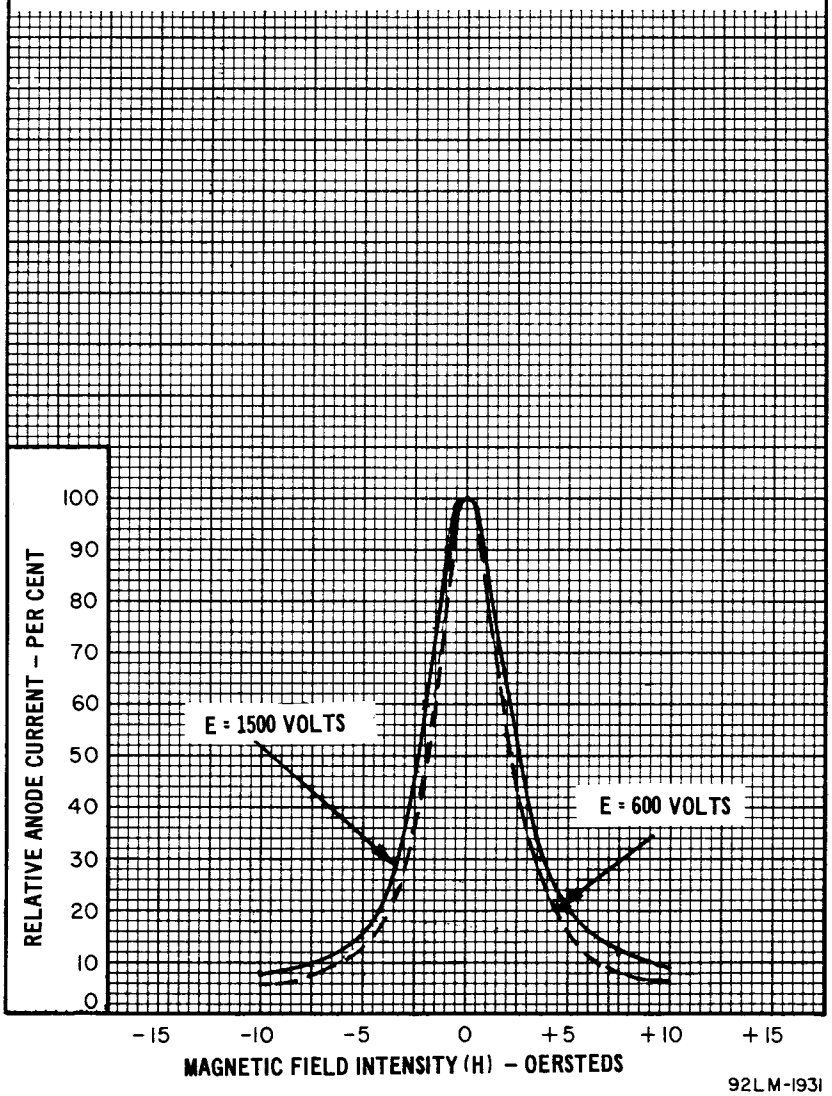
Typical Effect of Indicated Magnetic Field on Anode Current

SUPPLY VOLTAGE E IS ACROSS A VOLTAGE DIVIDER PROVIDING 1/6 OF E BETWEEN CATHODE AND DYNODE-No. 1; 1/12 OF E FOR EACH SUCCEEDING DYNODE-STAGE; AND 1/12 OF E BETWEEN DYNODE-No. 10 AND ANODE.

PHOTOCATHODE IS FULLY ILLUMINATED.
TUBE IS ORIENTED IN MAGNETIC FIELD AS SHOWN BELOW:



POSITIVE VALUES OF MAGNETIC FIELD INTENSITY (H) ARE FOR LINES OF FLUX OUT OF THE PAPER.



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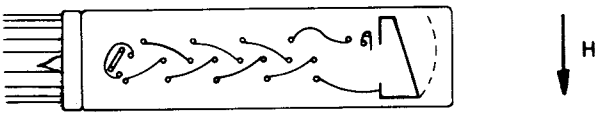
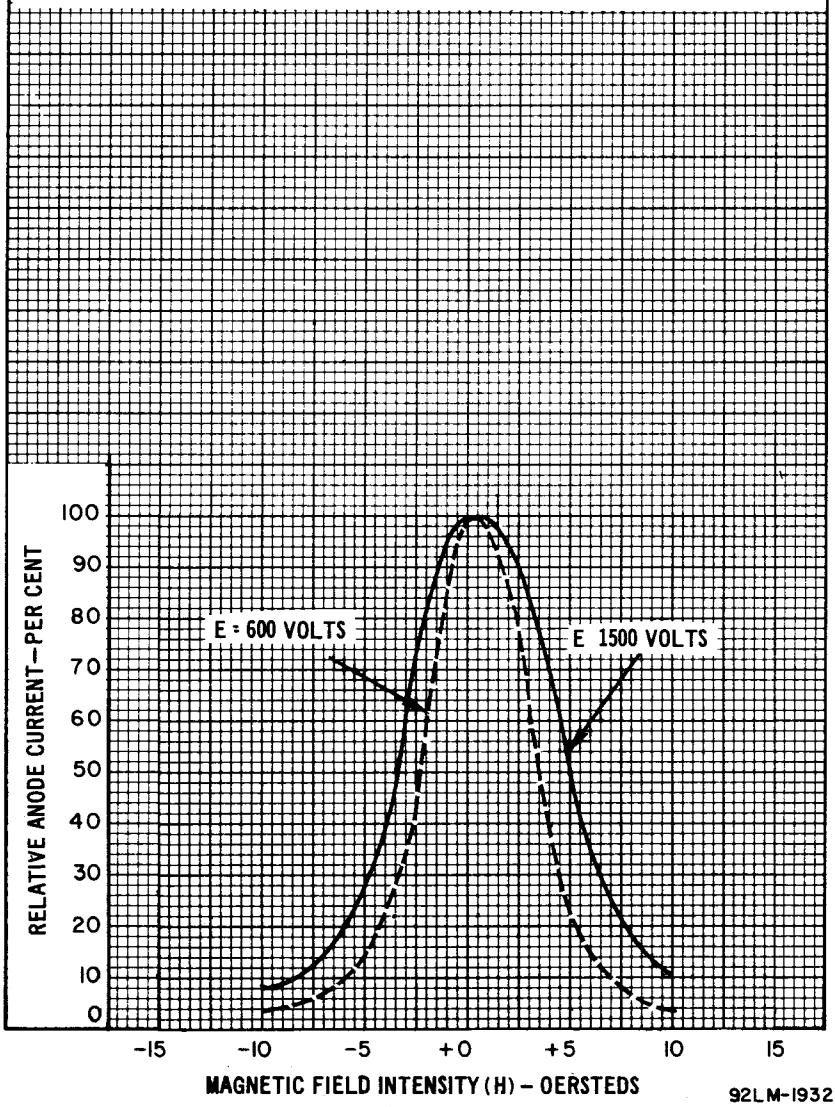
Typical Effect of Indicated Magnetic Field on Anode Current

SUPPLY VOLTAGE E IS ACROSS A VOLTAGE DIVIDER PROVIDING 1/6 OF E BETWEEN CATHODE AND DYNODE-No. 1; 1/12 OF E FOR EACH SUCCEEDING DYNODE-STAGE; AND 1/12 OF E BETWEEN DYNODE-No. 10 AND ANODE.

PHOTOCATHODE IS FULLY ILLUMINATED.
TUBE IS ORIENTED IN MAGNETIC FIELD AS SHOWN BELOW:



POSITIVE VALUES OF MAGNETIC FIELD INTENSITY (H) ARE FOR LINES OF FLUX IN INDICATED DIRECTION.



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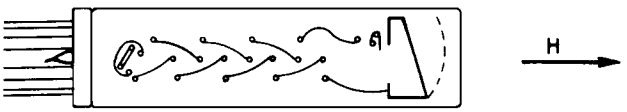
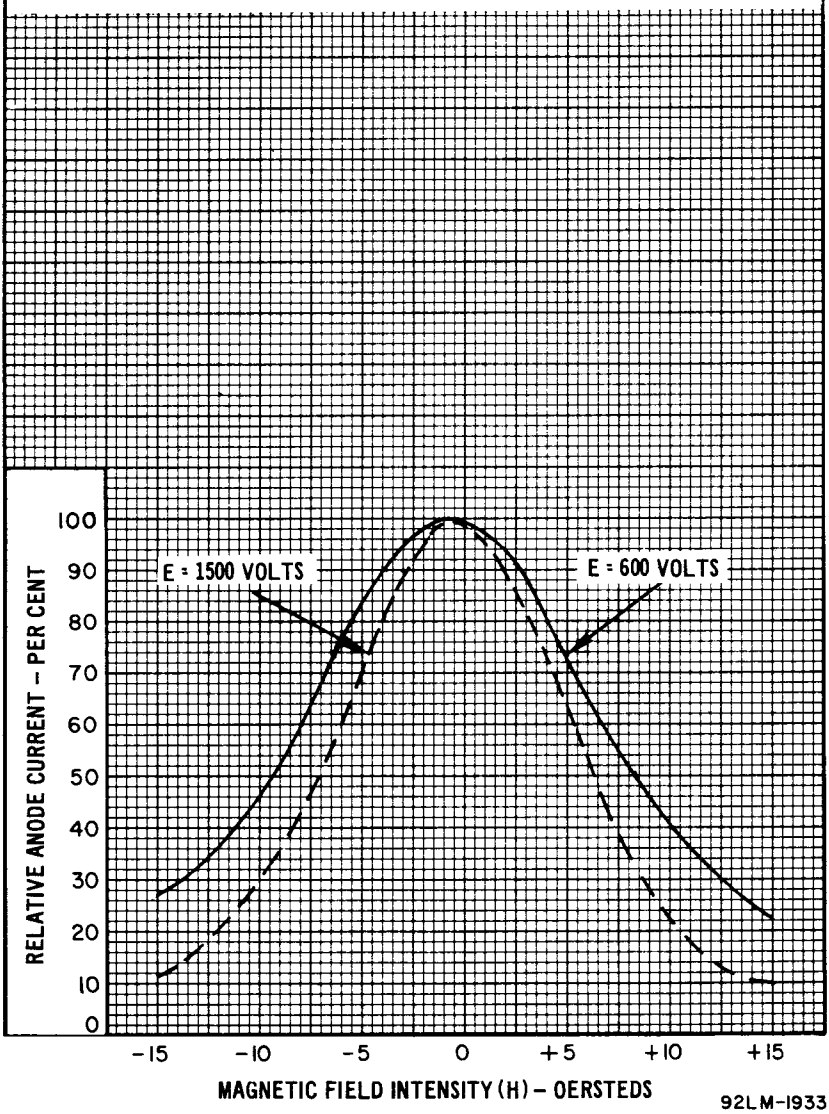
Typical Effect of Indicated Magnetic Field on Anode Current

SUPPLY VOLTAGE E IS ACROSS A VOLTAGE DIVIDER PROVIDING 1/6 OF E BETWEEN CATHODE AND DYNODE-No. 1; 1/12 OF E FOR EACH SUCCEEDING DYNODE-STAGE; AND 1/12 OF E BETWEEN DYNODE-No. 10 AND ANODE.

PHOTOCATHODE IS FULLY ILLUMINATED.
TUBE IS ORIENTED IN MAGNETIC FIELD AS SHOWN BELOW:



POSITIVE VALUES OF MAGNETIC FIELD INTENSITY (H) ARE FOR LINES OF FLUX IN INDICATED DIRECTION.



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