A STUDY OF THE INFLUENCE OF TEMPERATURE, CURRENT, AND MAGNETIC FIELD UPON THE INTENSITY AND LINE SHAPE OF THE 2537 A MERCURY SPECTRAL LINE FROM A GENERAL ELECTRIC 4-WATT, U-SHAPED, GERMICIDAL DISCHARGE TUBE

by

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INTRODUCTION

When a fast-moving electron collides with a slow-moving atom, the electron, if it possesses enough energy, may transfer some or all of this energy to the atom, elevating it to one of its excited states. A collision of this type has been called a "collision of the first kind". The reverse process also occurs, i.e., an excited atom may collide with a slow-moving electron and transfer its energy of excitation to the electron. This process, which is unaccompanied by radiation, has been called a "collision of the second kind".

Franck (2) extended the notions of "collisions of the first kind" and "collisions of the second kind" and the relation between the two (3), to include collisions between two atoms or molecules. Franck's extension supposes that when an excited atom or molecule collides with an unexcited atom or molecule, it is possible that the excited atom or molecule will give up its excitation energy to the unexcited atom or molecule. The unexcited atom or molecule will take up the energy in some combination of translational and internal energy.

When a chamber containing mercury vapor and the vapor of some other metal such as thallium is illuminated with the 2537 A resonance line of mercury, the radiation coming from the chamber may consist of some of the lines of the arc spectrum of thallium (1). Since thallium vapor can not absorb the 2537 A line, the only mechanism that could be responsible for the thallium lines in the spectrum coming from the chamber is collisions of the second kind between excited mercury atoms and unexcited thallium atoms. These collisions, in which the excited mercury atoms initially have a known amount of kinetic energy, result in the thallium atoms accepting excitation energy and kinetic energy from the mercury atoms and themselves becoming excited. The thallium atoms then may radiate away this energy as one of several of their characteristic lines. Franck has called this phenomena "sensitized fluorescence".

Thus to produce the phenomena of sensitized fluorescence, or for that matter, the excitation of resonance fluorescence and the phenomena connected with it (4), (5), the researcher must have, in addition to other apparatus, a source capable of performing the desired excitation.

To excite resonance fluorescence, and as a consequence sensitized fluorescence, in general, it is desirable to have a source that produces a relatively intense resonance line that shows no self-reversal (4), (5). The greater the intensity of the resonance line from the source, the greater will be the intensity of the radiation from the resonance chamber and the easier it will be to study the phenomena under observation. In most cases this intense line must not show self-reversal. This is obvious since, in self-reversal the center portion of the line is missing and this missing portion is entirely responsible for the excitation of resonance fluorescence.

Sensitized fluorescence may be studied in essentially two ways: (a) photographically and (b) electronically. A photographic study would consist of putting the light emitted from the resonance chamber into a spectrograph and allowing the emergent light to fall on a photographic plate. The low light level of the emitted light from the resonance chamber necessitates a long exposure time. During this exposure time, all influencing parameters must remain unaltered. This is a difficult if not an impossible condition to fulfill. Instead of a photographic plate one may use a photomultiplier tube, amplifying circuit, and an electronic voltmeter to eliminate the long exposure time. In doing so sensitivity is sacrificed. Small intensity differences are much less observable with this electronic method.

In either case, if the intensity of the resonance line of the source lamp is increased, small intensity changes due to, say, small changes in foreign gas pressures or resonance chamber temperatures would be easier to detect.

The above discussion is an example of but one of many uses which may require intensity knowledge of mercury lamps.

The research reported in this thesis concerned a study of the influence of temperature, current, and magnetic field upon the intensity and line shape of the 2537 A mercury line from a General Electric, 4-watt, U-shaped, germicidal discharge lamp. This specific lamp will be used in the further study of the phenomena connected with sensitized fluorescence.

PROCEDURE

Regulation of the Lamp

In order that the lamp could be run at its highest intensity output and with no line self-reversal, the lamp was properly current regulated and provisions were made to measure all influencing parameters.

Current through the lamp, voltage drop across the lamp, and temperature of the tube wall (the temperature of the tube wall influences the vapor pressure of the mercury inside the lamp) were controlled and varied. Methods of studying the line shape and intensity were provided for a complete study of the 2537 A radiation from the lamp.

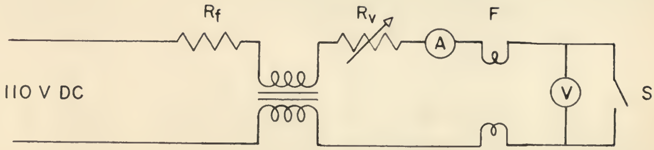
Power was supplied to the circuit, whose diagram is shown on Plate I, from a dc generator. For protection of the generator a fixed resistance, R_f, was placed in the circuit. When S is closed current flows through the filaments F of the discharge tube causing the filaments to heat and give off electrons thermionically. When S was opened the current ceases, but a large inductive voltage appears across the filaments of the tube. This along with the thermionic emission start the discharge. A variable resistance, R_r, was added to the circuit to control and provide adjustment for the current through the tube, which was measured by an ammeter A. The voltage drop across the tube was measured by the voltmeter V.

To control the wall temperature of the tube, a coolant

Explanation of Plate I

Circuit diagram of electrical equipment.

Plate I



jacket was constructed, a diagram of which is shown on Plate II. Cooling was supplied by a pump which pumps water or oil through a copper coil suspended in a large volume temperature bath. This bath could be held at temperatures ranging from below 0°C to above 100°C. This allowed for control and adjustment of tube temperature.

The tube temperature was measured by attaching one junction of a iron-constantan thermocouple to the tube wall of the lamp. The junction of the thermocouple was positioned at a point on the lamp that, determined by measurement, was the coolest. A potentiometer measured the thermocouple potential. With standard thermocouple temperature tables the tube temperature was then found.

The coolant jacket and lamp were clamped in a fixed position in front of the entrance slit of a Bausch and Lomb 500 mm monochrometer. The wavelength adjustment allows the 2537 A mercury line to be selected. This line was allowed to fall on a 1P28 RCA photomultiplier tube. The output from this tube amplified and measured by a Photovolt photometer. The meter reading of the Photovolt is taken as proportional to the intensity of the 2537 A line.

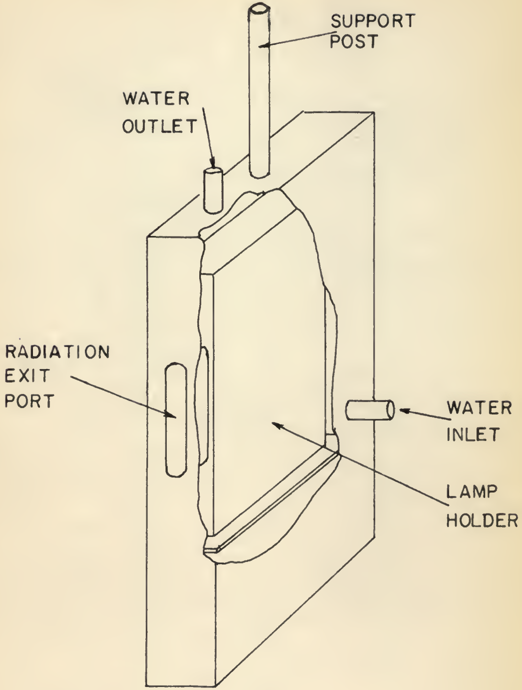
Photographic as well as electronic means were used to study the 2537 A line shape. Spectrograms of the discharge were taken with a Bausch and Lomb medium quartz spectrometer. Densitometer recordings were taken from these spectrograms.

The exit slit opening of the monochrometer was varied so as to change the portion of the line under observation.

Explanation of Plate II

Sketch of coolant jacket.

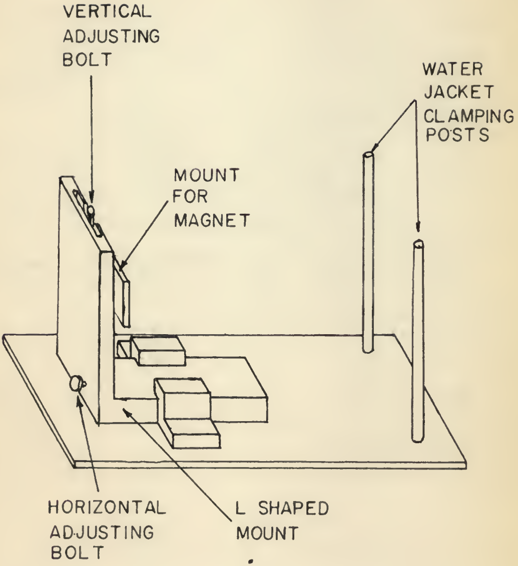
Plate II


SUPPORT
POST
WATER
OUTLET
RADIATION
EXIT
PORT
WATER
INLET
LAMP
HOLDER

Explanation of Plate III

Sketch of magnet and coolant jacket holder.

Plate III


VERTICAL ADJUSTING BOLT
WATER JACKET CLAMPING POSTS
MOUNT FOR MAGNET
HORIZONTAL ADJUSTING BOLT
L SHAPED MOUNT

In this way be varying the exit slit opening, self-reversal should be detectable, electronically.

In the study of the effect of a magnetic field on the lamp's characteristic curves of intensity, I, versus temperature, T, and current, i, also voltage, V, versus current and temperature, only the fact that there was a magnetic field of constant strength and position, with respect to the lamp, was considered. There was no intention of studying the effects of a magnetic field of varied strength and position.

A 2500 oersted, permanent magnet, with a 3 centimeter gap between pole faces, was held in an adjustable mount as illustrated on Plate III. The magnet was connected to a plate which was attached to a vertical adjusting bolt. All of this is held by an L shaped mount. The mount was also adjustable horizontally. The lamp and coolant jacket were clamped in place at one end of the plate. The gap of the magnet fitted over the coolant jacket. The magnet's position was so adjusted that the 2537 A mercury line intenstiy was a maximum for an arbitrary current and temperature. If the magnet needed to be removed it could be returned to its origional position by running the lamp at the current and temperature of the origional position and by adjusting its position so as to give the same maximum light intensity, as resulted from the origional setting.

The direction of the magnetic field and tube current was such that the effect of the magnetic field was, in part, to deflect the discharge beam, in the lamp, to the wall of the lamp near the exit opening of the water jacket. Thus there was less mercury vapor between the discharge beam and the tube wall. This would, as one consequence of the magnetic field, reduce the self-reversal of the 2537 A mercury line that was present.

Measurements

The measurements made were:

(1) The intensity of the 2537 A line was measured for a given current and temperature as a function of the exit slit opening of the monochrometer to determine the range of values of the exit slit opening to use in the study of the line shape of the 2537 A line. The results of the measurements are given on Plate III.

(2) The intensity of the 2537 A line measured with and without a magnetic field at currents of 0.050, 0.100, 0.150, 0.200, and 0.250 amperes, at various temperatures in the range 10°C to 105°C for each current, and at monochrometer exit slit openings of 0.050, 0.100, 0.150, 0.200, 0.250, 0.300, 0.350 and 0.400 millimeters for each current and temperature. The results of the measurements are given on Plate IV through Plate XV.

(3) Starting with new unused lamps, regulating their current and temperature, the change of intensity

of the 2537 A line as a function of time was observed. The results of the measurements are given on Plate XVI and Plate XVII.

EXPERIMENTAL DATA

The experimental data consists of sets of points giving

(1) 2537 A intensity as a function of monochrometer exit slit opening

(2) 2537 A intensity as a function of tube temperature

(3) 2537 A intensity as a function of tube current

(4) tube voltage as a function of tube temperature

(5) tube voltage as a function of tube current

There are several curves of each type. These curves are characterized by being with or without an applied magnetic field and having

(1) tube current and tube temperature as parameters

(2) tube current and the monochrometer exit slit opening as parameters

(3) tube temperature and the monochrometer exit slit opening as parameters

(4) tube current as a parameter

(5) tube temperature as a parameter

respectively. To make comparisons between the curves with and without an applied magnetic field the curves being compared must have all parameters the same. This is not the case with the data taken except when the parameter happens to be the monochrometer exit slit opening and /or tube current.

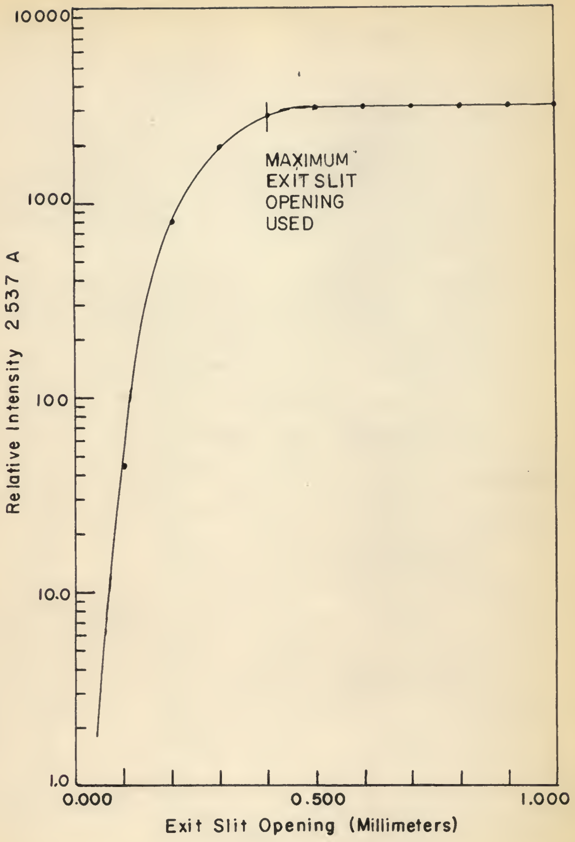
Therefore sets of curves have been derived so that the parameters take on regularly spaced values.

The curves with the monochrometer exit slit opening and/or the tube current as parameter and the derived curves are presented. The methods used in evaluating the derived sets of curves and treating the experimental data are presented in the appendix.

Explanation of Plate IV

Determination of maximum exit slit opening to be used.

Plate IV



10000
1000
100
10.0
1.0
Relative Intensity 2537 A
MAXIMUM EXIT SLIT OPENING USED
0.000
0.500
1.000
Exit Slit Opening (Millimeters)

Explanation of Plate V

Fig. 1. Intensity versus exit slit opening at a tube current of 0.050 amperes without a deflecting magnetic field and at various tube temperatures.

•-•-•	T = 20°C	□-□-□	T = 60°C
o-o-o	T = 30°C	x-x-x	T = 70°C
Δ-Δ-Δ	T = 40°C	⌓-⌓-⌓	T = 80°C
∇-∇-∇	T = 50°C	▿-▿-▿	T = 90°C
⊥-⊥-⊥	T = 100°C		

Fig. 2. Intensity versus exit slit opening at a tube current of 0.050 amperes with a deflecting magnetic field and at various tube temperatures.

•-•-•	T = 20°C	□-□-□	T = 60°C
o-o-o	T = 30°C	x-x-x	T = 70°C
Δ-Δ-Δ	T = 40°C	⌓-⌓-⌓	T = 80°C
∇-∇-∇	T = 50°C	▿-▿-▿	T = 90°C
⊥-⊥-⊥	T = 100°C		

Plate V

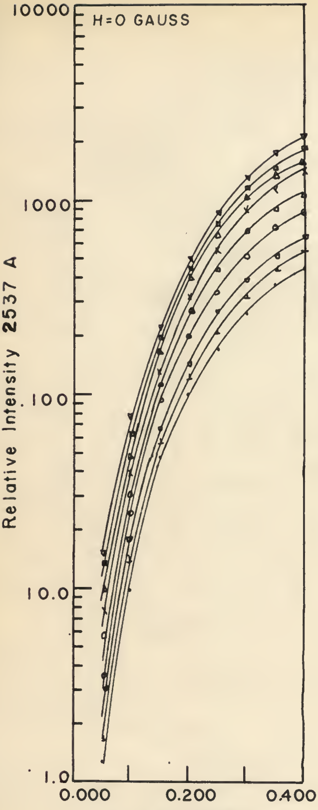


Fig. 1

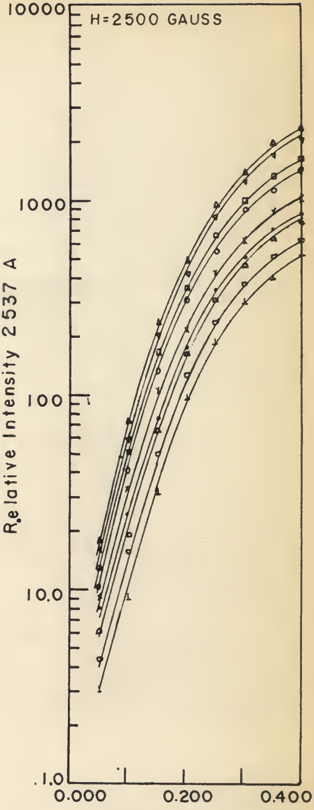


Fig. 2

Explanation of Plate VI

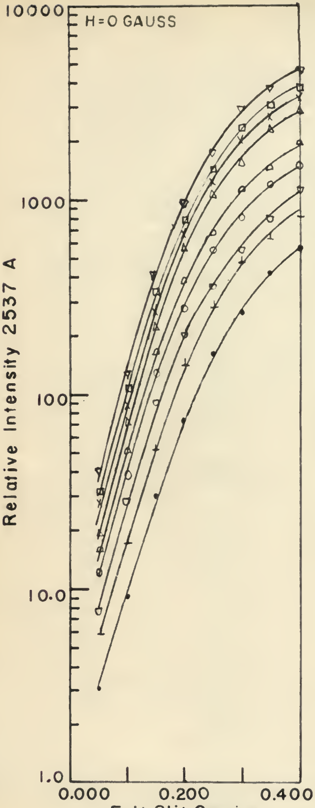
Fig. 1. Intensity versus exit slit opening at a tube current of 0.150 amperes without a deflecting magnetic field and at various tube temperatures.

•-•-•	T = 20°C	□-□-□	T = 60°C
o-o-o	T = 30°C	x-x-x	T = 70°C
△-△-△	T = 40°C	⌂-⌂-⌂	T = 80°C
▽-▽-▽	T = 50°C	ʊ-ʊ-ʊ	T = 90°C
⊥-⊥-⊥	T = 100°C		

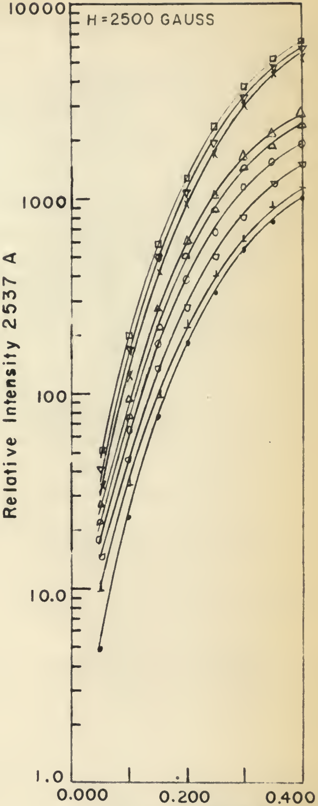
Fig. 2. Intensity versus exit slit opening at a tube current of 0.150 amperes with a deflecting magnetic field and at various tube temperatures.

•-•-•	T = 20°C	□-□-□	T = 60°C
o-o-o	T = 30°C	x-x-x	T = 70°C
△-△-△	T = 40°C	⌂-⌂-⌂	T = 80°C
▽-▽-▽	T = 50°C	ʊ-ʊ-ʊ	T = 90°C
⊥-⊥-⊥	T = 100°C		

Plate VI



Exit Slit Opening
(Millimeters)
Fig. 1



Exit Slit Opening
(Millimeters)
Fig. 2

Explanation of Plate VII

Fig. 1. Intensity versus exit slit opening at a tube current of 0.250 amperes without a deflecting magnetic field and at various tube temperatures.

•-•-•	T = 20°C	□-□-□	T = 60°C
o-o-o	T = 30°C	x-x-x	T = 70°C
△-△-△	T = 40°C	⌓-⌓-⌓	T = 80°C
▽-▽-▽	T = 50°C	⌓-⌓-⌓	T = 90°C
⊥-⊥-⊥	T = 100°C		

Fig. 2. Intensity versus exit slit opening at a tube current of 0.250 amperes with a deflecting magnetic field and at various tube temperatures.

•-•-•	T = 20°C	□-□-□	T = 60°C
o-o-o	T = 30°C	x-x-x	T = 70°C
△-△-△	T = 40°C	⌓-⌓-⌓	T = 80°C
▽-▽-▽	T = 50°C	⌓-⌓-⌓	T = 90°C
⊥-⊥-⊥	T = 100°C		

Plate VII

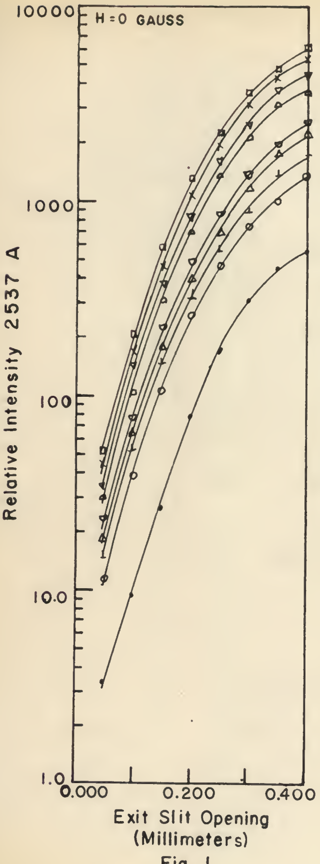


Fig. 1

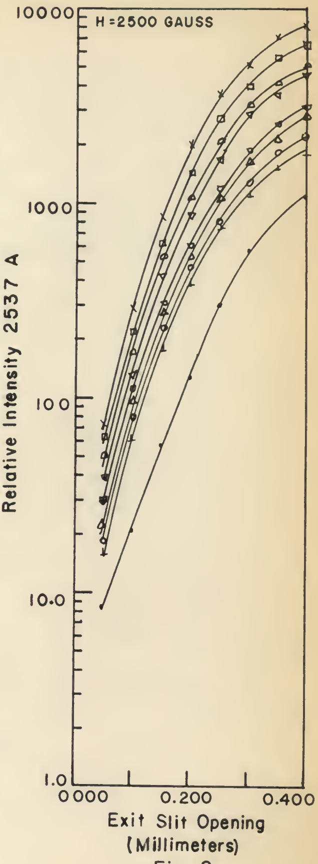


Fig. 2

Explanation of Plate VIII

Fig. 1. Intensity versus tube temperature at a tube current of 0.050 amperes without a deflecting magnetic field and at various exit slit openings.

•-•-•	s = 0.050 mm	□-□-□	s = 0.250 mm
o-o-o	s = 0.100 mm	x-x-x	s = 0.300 mm
Δ-Δ-Δ	s = 0.150 mm	⊥-⊥-⊥	s = 0.350 mm
∇-∇-∇	s = 0.200 mm	T-T-T	s = 0.400 mm

Fig. 2. Intensity versus tube temperature at a tube current of 0.050 amperes with a deflecting magnetic field and at various exit slit openings.

•-•-•	s = 0.050 mm	□-□-□	s = 0.250 mm
o-o-o	s = 0.100 mm	x-x-x	s = 0.300 mm
Δ-Δ-Δ	s = 0.150 mm	⊥-⊥-⊥	s = 0.350 mm
∇-∇-∇	s = 0.200 mm	T-T-T	s = 0.400 mm

Plate VIII

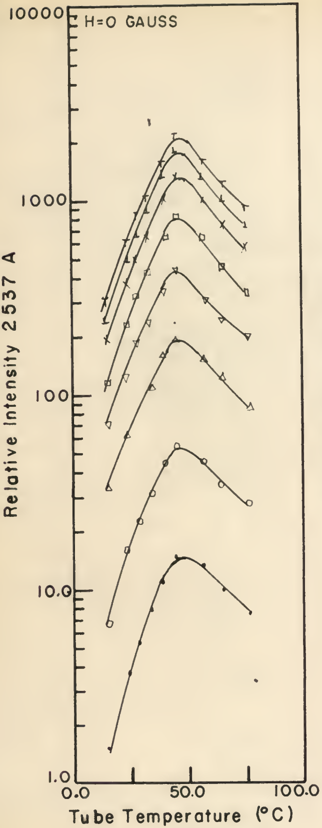


Fig. 1

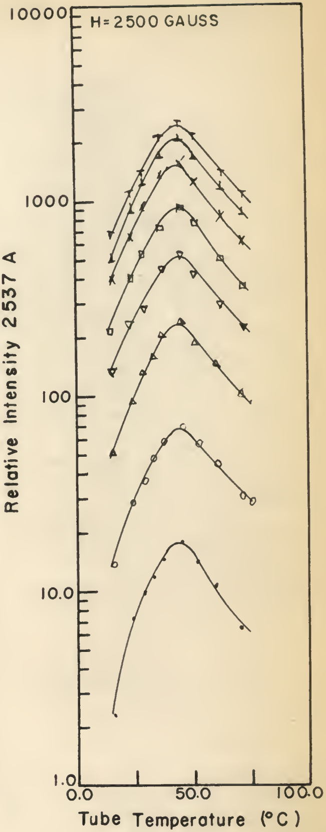


Fig. 2

Explanation of Plate IX

Fig. 1. Intensity versus tube temperature at a tube current of 0.150 amperes without a deflecting magnetic field and at various exit slit openings.

•-•-•	s = 0.050 mm	□-□-□	s = 0.250 mm
o-o-o	s = 0.100 mm	x-x-x	s = 0.300 mm
Δ-Δ-Δ	s = 0.150 mm	⊥-⊥-⊥	s = 0.350 mm
∇-∇-∇	s = 0.200 mm	T-T-T	s = 0.400 mm

Fig. 2. Intensity versus tube temperature at a tube current of 0.150 amperes with a deflecting magnetic field and at various exit slit openings.

•-•-•	s = 0.050 mm	□-□-□	s = 0.250 mm
o-o-o	s = 0.100 mm	x-x-x	s = 0.300 mm
Δ-Δ-Δ	s = 0.150 mm	⊥-⊥-⊥	s = 0.350 mm
∇-∇-∇	s = 0.200 mm	T-T-T	s = 0.400 mm

Plate IX

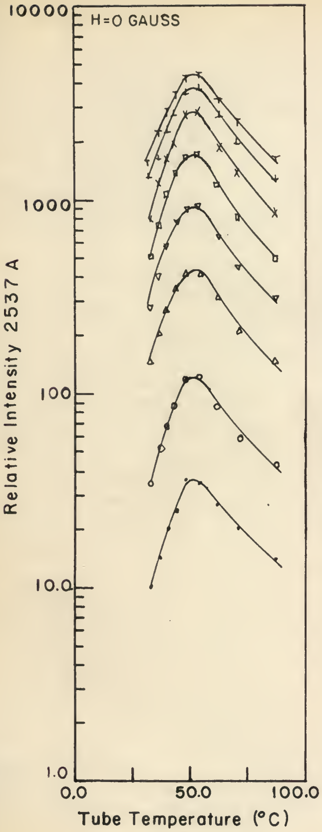


Fig. 1

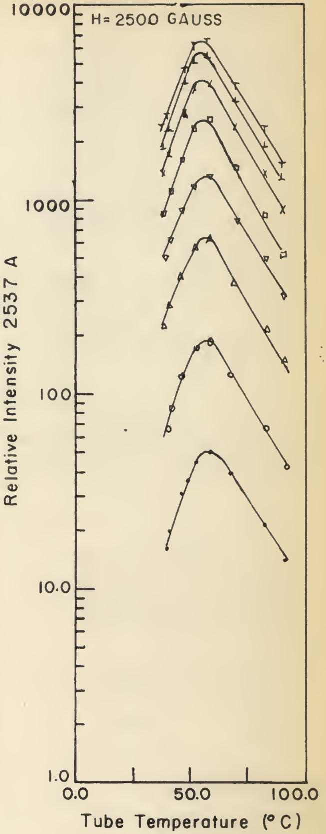


Fig. 2

Explanation of Plate X

Fig. 1. Intensity versus tube temperature at a tube current of 0.250 amperes without a deflecting magnetic field and at various exit slit openings.

•-•-•	s = 0.050 mm	□-□-□	s = 0.250 mm
o-o-o	s = 0.100 mm	x-x-x	s = 0.300 mm
Δ-Δ-Δ	s = 0.150 mm	⊥-⊥-⊥	s = 0.350 mm
∇-∇-∇	s = 0.200 mm	T-T-T	s = 0.400 mm

Fig. 2. Intensity versus tube temperature at a tube current of 0.250 amperes with a deflecting magnetic field and at various exit slit openings.

•-•-•	s = 0.050 mm	□-□-□	s = 0.250 mm
o-o-o	s = 0.100 mm	x-x-x	s = 0.300 mm
Δ-Δ-Δ	s = 0.150 mm	⊥-⊥-⊥	s = 0.350 mm
∇-∇-∇	s = 0.200 mm	T-T-T	s = 0.400 mm

Plate X

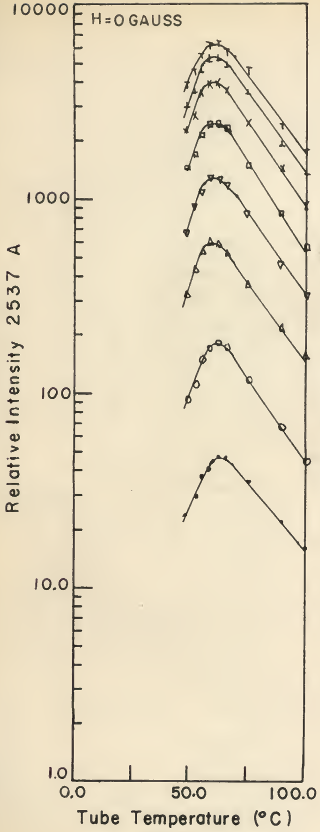


Fig. 1

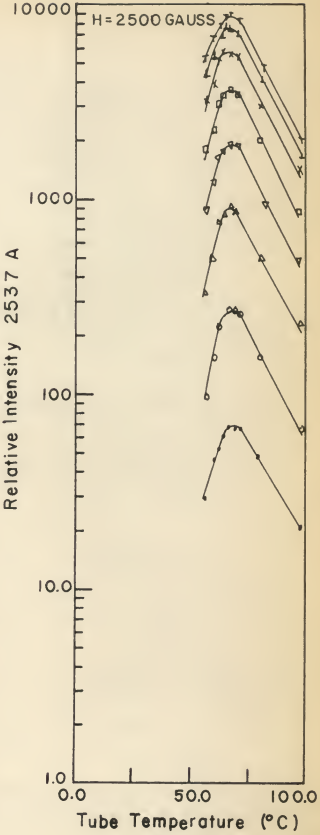


Fig. 2

Explanation of Plate XI

Fig. 1. Intensity versus tube current at an exit slit opening of 0.050 mm without a deflecting magnetic field and at various tube temperatures.

•-•-•	T = 20°C	□-□-□	T = 60°C
o-o-o	T = 30°C	x-x-x	T = 70°C
▲-▲-▲	T = 40°C	⊥-⊥-⊥	T = 80°C
▽-▽-▽	T = 50°C	⊤-⊤-⊤	T = 90°C
+-+-+	T = 100°C		

Fig. 2. Intensity versus tube current at an exit slit opening of 0.050 mm with a deflecting magnetic field and at various tube temperatures.

•-•-•	T = 20°C	□-□-□	T = 60°C
o-o-o	T = 30°C	x-x-x	T = 70°C
▲-▲-▲	T = 40°C	⊥-⊥-⊥	T = 80°C
▽-▽-▽	T = 50°C	⊤-⊤-⊤	T = 90°C
+-+-+	T = 100°C		

Plate XI

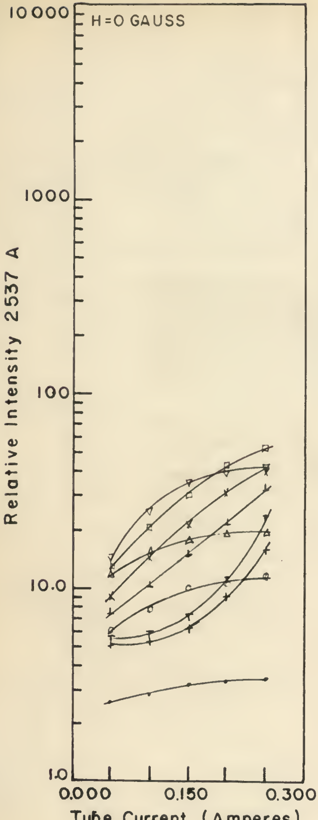


Fig. 1

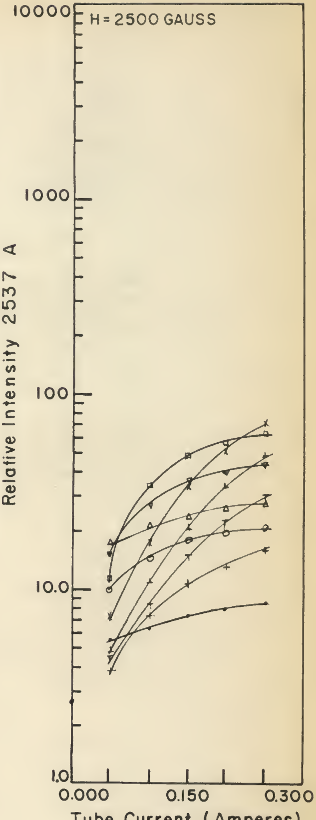


Fig. 2

Explanation of Plate XII

Fig. 1. Intensity versus tube current at an exit slit opening of 0.250 mm without a deflecting magnetic field and at various tube temperatures.

•-•-•	T = 20°C	□-□-□	T = 60°C
○-○-○	T = 30°C	x-x-x	T = 70°C
Δ-Δ-Δ	T = 40°C	⊥-⊥-⊥	T = 80°C
∇-∇-∇	T = 50°C	T-T-T	T = 90°C

+-+-+ T = 100°C

Fig. 2. Intensity versus tube current at an exit slit opening of 0.250 mm with a deflecting magnetic field and at various tube temperatures.

•-•-•	T = 20°C	□-□-□	T = 60°C
○-○-○	T = 30°C	x-x-x	T = 70°C
Δ-Δ-Δ	T = 40°C	⊥-⊥-⊥	T = 80°C
∇-∇-∇	T = 50°C	T-T-T	T = 90°C

+-+-+ T = 100°C

Plate XII

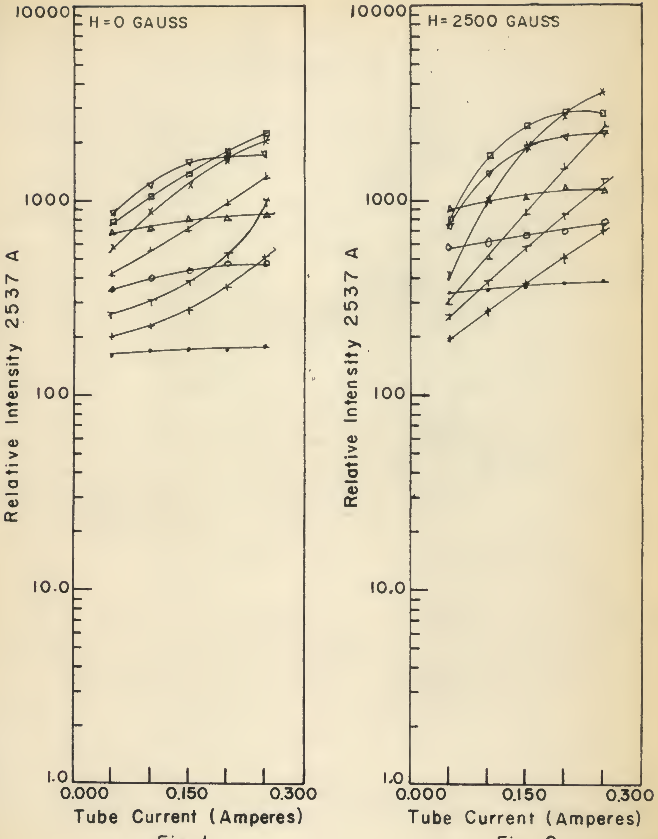


Fig. 1

Fig. 2

Explanation of Plate XIII

Fig. 1. Intensity versus tube current at an exit slit opening of 0.400 mm without a deflecting magnetic field and at various tube temperatures.

•-•-•	T = 20°C	□-□-□	T = 60°C
o-o-o	T = 30°C	x-x-x	T = 70°C
Δ-Δ-Δ	T = 40°C	⊥-⊥-⊥	T = 80°C
∇-∇-∇	T = 50°C	T-T-T	T = 90°C
+-+-+	T = 100°C		

Fig. 2. Intensity versus tube current at an exit slit opening of 0.400 mm with a deflecting magnetic field and at various tube temperatures.

•-•-•	T = 20°C	□-□-□	T = 60°C
o-o-o	T = 30°C	x-x-x	T = 70°C
Δ-Δ-Δ	T = 40°C	⊥-⊥-⊥	T = 80°C
∇-∇-∇	T = 50°C	T-T-T	T = 90°C
+-+-+	T = 100°C		

Plate XIII

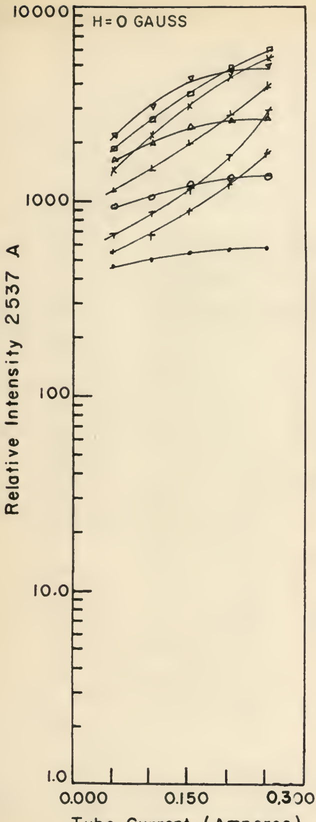


Fig. 1

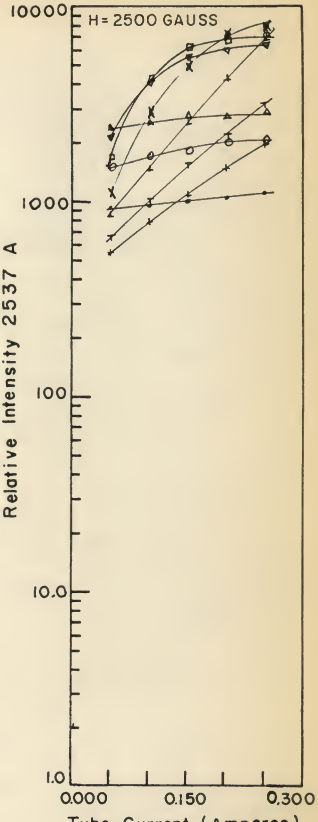


Fig. 2

Explanation of Plate XIV

Fig. 1. Tube voltage versus tube temperature at various tube currents without a deflecting magnetic field.

•-•-• i = 0.050 amperes
o-o-o i = 0.100 amperes
△-△-△ i = 0.150 amperes
▽-▽-▽ i = 0.200 amperes
□-□-□ i = 0.250 amperes

Fig. 2. Tube voltage versus tube temperature at various tube currents with a deflecting magnetic field.

•-•-• i = 0.050 amperes
o-o-o i = 0.100 amperes
△-△-△ i = 0.150 amperes
▽-▽-▽ i = 0.200 amperes
□-□-□ i = 0.250 amperes

Plate XIV

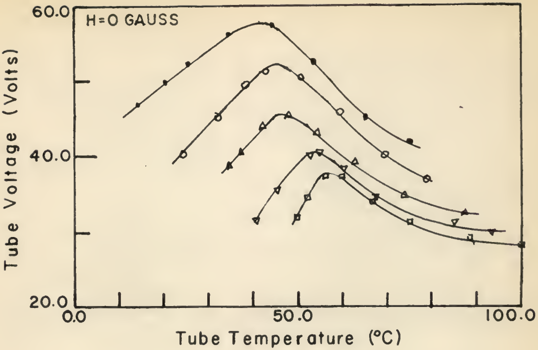


Fig. 1

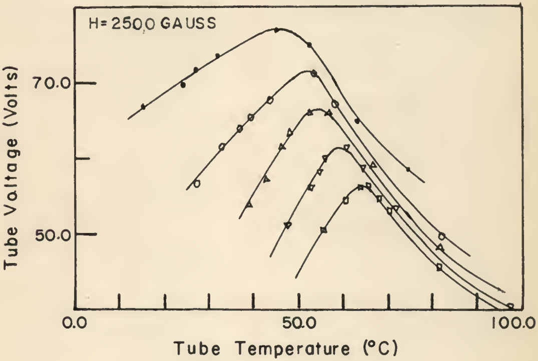


Fig. 2

Explanation of Plate XV

Fig. 1. Tube voltage versus tube current without a deflecting magnetic field and at various tube temperatures.

•-•-•	T = 20°C	□-□-□	T = 60°C
o-o-o	T = 30°C	x-x-x	T = 70°C
Δ-Δ-Δ	T = 40°C	⊥-⊥-⊥	T = 80°C
∇-∇-∇	T = 50°C	T-T-T	T = 90°C
+-+-+	T = 100°C		

Fig. 2. Tube voltage versus tube current with a deflecting magnetic field and at various tube temperatures.

•-•-•	T = 20°C	□-□-□	T = 60°C
o-o-o	T = 30°C	x-x-x	T = 70°C
Δ-Δ-Δ	T = 40°C	⊥-⊥-⊥	T = 80°C
∇-∇-∇	T = 50°C	T-T-T	T = 90°C
+-+-+	T = 100°C		

Plate XV

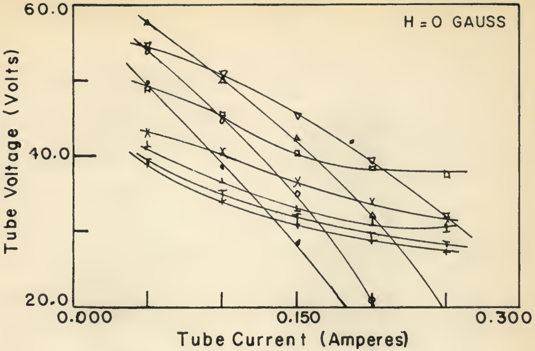


Fig. 1

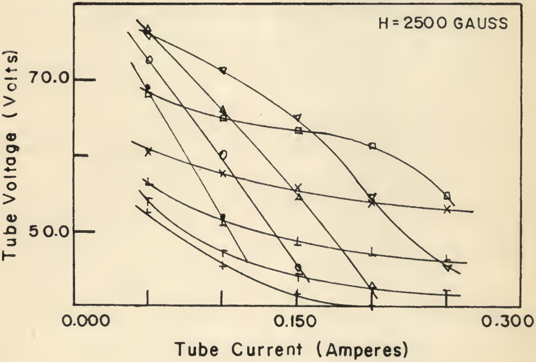


Fig. 2

Explanation of Plate XVI

Fig. 1. Intensity versus time at a tube current of 0.050 amperes, a tube temperature of 28.3°C, and at an average tube voltage of 53.0 volts without a deflecting magnetic field.

Fig. 2. Intensity versus time at a tube current of 0.250 amperes, a tube temperature of 93.0°C, and at an average tube voltage of 28.2 volts without a deflecting magnetic field.

Plate XVI

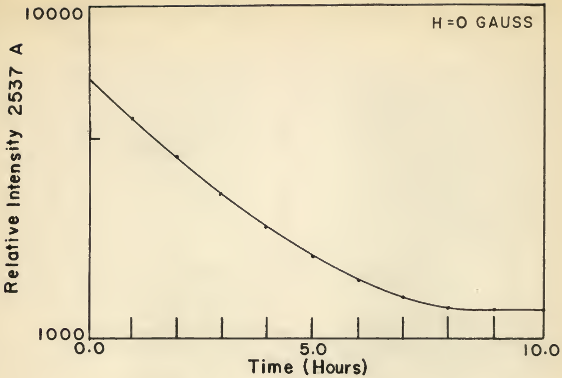


Fig. 1

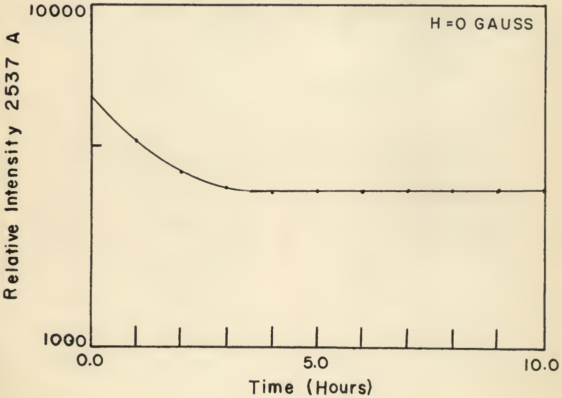


Fig. 2

Explanation of Plate XVII

Fig. 1. Intensity versus time at a tube current of 0.050 amperes, a tube temperature of 35.0°C, and at an average tube voltage of 69.9 volts with a deflecting magnetic field.

Fig. 2. Intensity versus time at a tube current of 0.250 amperes, a tube temperature of 70.0°C, and at an average tube voltage of 51.5 volts with a deflecting magnetic field.

Plate XVII

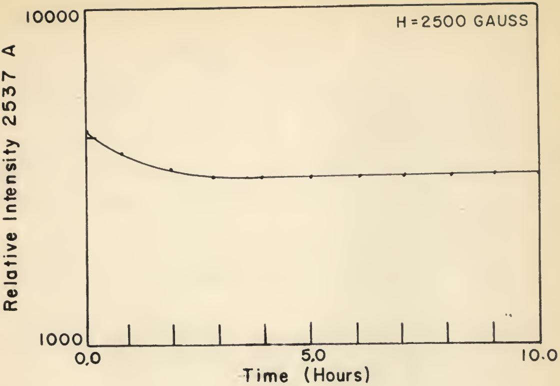


Fig. 1

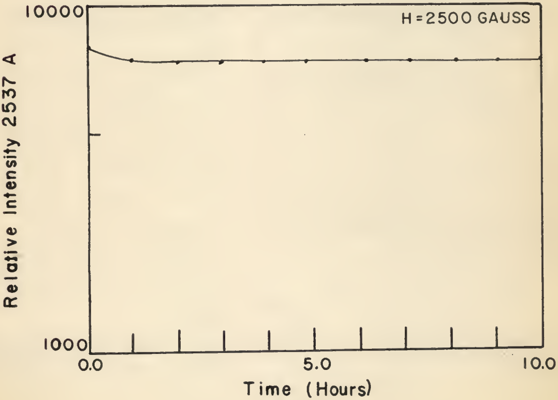


Fig. 2

Explanation of Plate XVIII

Fig. 1. Densitometer recordings of the 2537 A mercury line from spectrograms of the discharge operated at i = 0.050 amperes, T = 44.4°C, and V = 63.0 volts without a deflecting magnetic field.

Fig. 2. Densitometer recordings of the 2537 A mercury line from spectrograms of the discharge operated at i = 0.100 amperes, T = 58.0°C, and V = 53.0 volts without a deflecting magnetic field.

Fig. 3. Densitometer recordings of the 2537 A mercury line from spectrograms of the discharge operated at i = 0.150 amperes, T = 69.6°C, and V = 46.0 volts without a deflecting magnetic field.

Fig. 4. Densitometer recordings of the 2537 A mercury line from spectrograms of the discharge operated at i = 0.200 amperes, T = 80.6°C, and V = 39.5 volts without a deflecting magnetic field.

Fig. 5. Densitometer recordings of the 2537 A mercury line from spectrograms of the discharge operated at i = 0.250 amperes, T = 90.0°C, and V = 37.0 volts without a deflecting magnetic field.

Plate XVIII

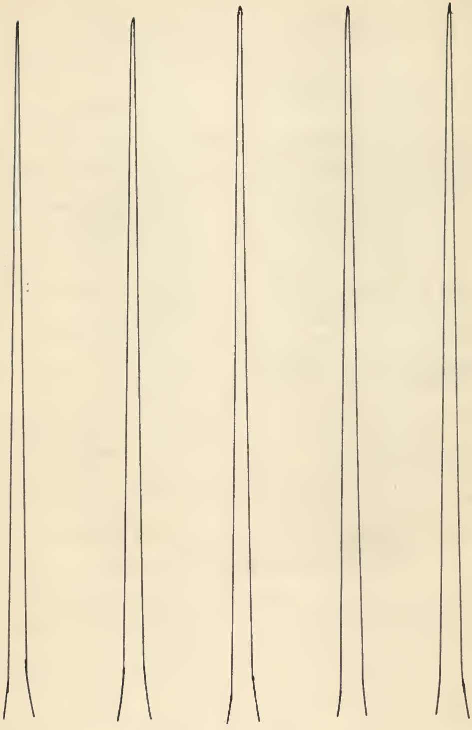


Fig. 1 Fig. 2 Fig. 3 Fig. 4 Fig. 5

Explanation of Plate XIX

Fig. 1. Densitometer recordings of the 2537 A mercury line from spectrograms of the discharge operated at i = 0.050 amperes, T = 44.4°C, and V = 77.0 volts with a deflecting magnetic field.

Fig. 2. Densitometer recordings of the 2537 A mercury line from spectrograms of the discharge operated at i = 0.100 amperes, T = 64.0°C, and V = 72.0 volts with a deflecting magnetic field.

Fig. 3. Densitometer recordings of the 2537 A mercury line from spectrograms of the discharge operated at i = 0.150 amperes, T = 77.0°C, and V = 69.0 volts with a deflecting magnetic field.

Fig. 4. Densitometer recordings of the 2537 A mercury line from spectrograms of the discharge operated at i = 0.200 amperes, T = 91.4°C, and V = 66.0 volts with a deflecting magnetic field.

Fig. 5. Densitometer recordings of the 2537 A mercury line from spectrograms of the discharge operated at i = 0.250 amperes, T = 99.0°C, and V = 60.0 volts with a deflecting magnetic field.

Plate XIX

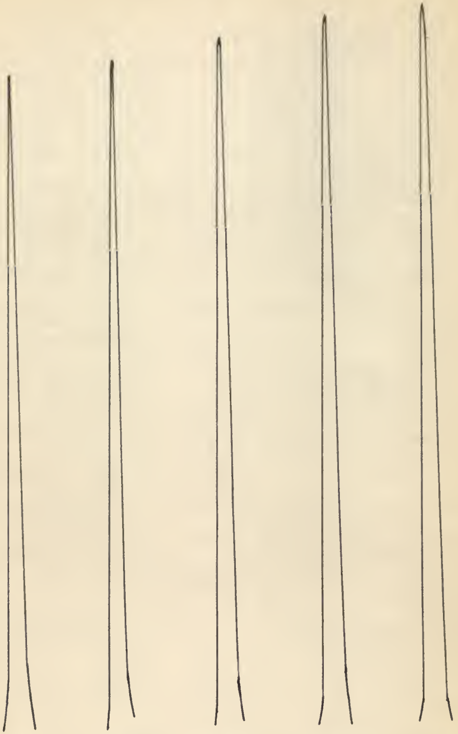


Fig. 1 Fig. 2 Fig. 3 Fig. 4 Fig. 5

EXPLANATION OF FEATURES OF THE EXPERIMENTAL DATA

The features of the experimental data to be treated below are mainly discussed without reference to an applied magnetic field. The magnetic field, applied transverse to the discharge bends the paths of the positive ions and thus the positive column, toward the wall of the discharge. The paths of the electrons in the discharge are bent into circles that drift along the tube due to the applied electric field. This bending of the paths of the positive ions toward the discharge wall and the electron paths into circles effectively increases the resistance of the discharge beam since more applied voltage is required to maintain the discharge, due to depletion of positive ions and effectively more electron collisions.

While all experiments were carried out with and without an applied magnetic field, the discussion will be mainly concerned with other phenomena than the effect of the magnetic field since besides the increased voltage drop across the tube the effects of the magnetic field are secondary.

Intensity of the 2537 A Mercury Spectral Line as a Function of Monochrometer Exit Slit Opening

The quantity previously refered to as intensity is not a true intensity but an integrated intensity. The exit slit opening of the monochrometer intercepts a certain wavelength interval of the spectrum produced by the grating in the monochrometer. The quantity measured is proportional to the area under the intensity versus wavelength curve intercepted by the exit slit.

To account for the observed variation of integrated intensity with monochrometer exit slit opening the integral of the intensity of the 2537 A mercury spectral line, as a function of wavelength, has been considered. The assumption was made that the discharge consisted of a central beam of electrons, excited unexcited, and ionized atoms surrounded by a layer of unexcited atoms. This layer is capable of absorbing the resonance radiation from the central beam. In addition a Maxwellian distribution of emitting and absorbing atoms was assumed, along with Doppler line broadning. It was also assumed that to a first approximation the magnetic field had no influence on the velocity distribution of emitting or absorbing atoms. Then

$$I(\lambda) = C\left\{\left(\frac{\mu}{2\pi R T_e}\right)^{3/2} e^{\frac{-\mu c^2}{2RT_e}\left(1-\frac{\lambda_0}{\lambda}\right)^2} - a\left(\frac{\mu}{2\pi R T_a}\right)^{3/2} e^{-\frac{\mu c^2}{2RT_a}\left(1-\frac{\lambda_0}{\lambda}\right)^2}\right\}$$

where C is an arbitrary constant, μ the atomic weight of the emitting and absorbing gas, R the molar gas constant, T_e and T_a the emitting and absorbing kinetic temperatures, λ the variable wavelength, λ_0 the fixed wavelength equal to 2537 A, and (a) a constant giving the fraction of the centrally emitted radiation that is absorbed by the unexcited atoms in the layer of unexcited atoms surrounding the discharge beam.

The integral of this expression, when a = 0 or $T_e = T_a$, is known to be of the same form as the experimental results presented on Plate V to Plate VII. When $a \neq 0$ or $T_e \neq T_a$ or both there will be changes in the curve. There might be changes in the smooth slope or faster or slower rises, initially or finally.

Because of the very close resemblance of the experimental curves to the curve obtained with $a = 0$ or $T_e = T_a$ one must conclude that either a is close to zero or T_e is close to T_a or both.

With no applied magnetic field the existence of the layer of unexcited atoms around the discharge beam prohibits a from being zero. Because of the action of the magnetic field on the discharge beam the beam is deflected against one wall or the discharge tube thus decreasing or eliminating the layer of neutral atoms, but because of incomplete ionization in the discharge beam one still must conclude that a is different from zero. Thus the two kinetic temperatures are approximately equal.

Intensity of the 2537 A Mercury Spectral Line as a Function of Tube Temperature

When the temperature of the discharge tube is increased, the number of mercury molecules increases. Since the 2537 A intensity is proportional to the number of mercury atoms in the resonance state, it is therefore proportional to the total number of mercury molecules.

As the temperature increases the self-absorption must also increase. But as is observed on Plate XIV an increase in tube temperature, beyond a temperature at which the curves reach a maximum, causes a decrease in tube voltage. Since the collision cross sections drops off radically with decreasing tube voltage the population of the 2537 A resonance level must decrease beyond this optimum temperature. Thus there are two competing processes that give rise to the 2537 A mercury intensity versus temperature curves.

Intensity of the 2537 A Mercury Spectral Line as a Function of Tube Current

The intensity of the 2537 A mercury line at constant tube temperature is proportional to the number of mercury atoms in the 2537 A resonance state. The number in this state is the sum of a probability function times each of two terms minus the sum of a probability function times each of two terms. The four terms are;

(a) the number of mercury atoms in states other than the 2537 A resonance state that are elevated up to or lowered into the 2537 A resonance state by collisions

(b) the number of mercury atoms in states other than the 2537 A resonance state that are lowered into the 2537 A resonance state by emission of radiation

(c) the number of mercury atoms taken out of the 2537 A resonance state by collisions

(d) the number of mercury atoms in the 2537 A state that go to the ground state by emission of radiation

respectively.

A similar expression holds for all states of the mercury and argon atoms.

The tube current is made up of electron current, current carried by argon ions, and current carried by mercury ions. As the total current increases, for constant tube temperature, a redistribution of the number of atoms in the various states occurs. Although the exact variation of intensity with current would be difficult to explain the apparent saturation effect can be explained with the fact that there are a limited number of atoms available to maintain the discharge. As the current increases the number of neutral atoms decreases. This number is distributed in the excited and ionized states of the mercury atom. Since there is a greater probability for an atom in an excited state high above the 2537 A resonance state to go to the 2537 A resonance state than to the ground state, the 2537 A intensity increases as current increases. Also since there is a limited number of atoms the intensity versus current curves should have a saturation appearance.

Tube Voltage as a Function of Tube Temperature

The tube voltage versus tube temperature curves at constant tube current are a result of two competing ionization processes. When the tube temperature is increased, starting from a low value, the mean free path of the argon atoms and ions decreases thus decreasing the tube current by decreasing the tube current by decreasing the drift velocity of the ions. Thus the voltage must increase to maintain constant current. Soon a point is reached where mercury ions contribute greatly to the current. Because of their lower ionization potential a greater number of mercury ions can be produced with argon. Since the current is the product of the number of carriers and their velocities, as the temperature increases to higher values the voltage decreases again as mercury ions become the predominant current carriers.

Tube Voltage as a Function of Tube Current

The current-voltage characteristics of an arc discharge has been discussed in many places. That the current-voltage characteristics should depend upon the tube geometry, and electrode material is well known. The temperature variation of these curves follows from a consideration of the two gases present in the tube. At low temperatures argon is the main ionic current carrier while at relatively high temperatures mercury ions are the predominant current carriers. It is obvious that the current-voltage characteristics in these two extremes should be different. In between these two extremes there should be a continuous variation.

The change in current-voltage characteristics when a magnetic field is applied transverse to the discharge, as mentioned proviously is an effective increase in resistance of the discharge. Thus for the same current and temperature the voltage is increased by this effective resistance.

Ageing of a Discharge Tube

Although little work has been done on determining the effect of age on the 2537 A production by the discharge tube, experimentally one notes that several hours are needed before a discharge tube puts out a constant 2537 A intensity. At first sight it appears that the tube current and the presence of a magnetic field effect the ageing of the discharge tube. Tube current undoubtedly does, but differences in discharge tubes from one tube to another very likely mask any such effects.

Conclusions

A practical method has been given to greatly increase the 2537 A intensity emitted by a mercury discharge. This method includes finding a tube temperature that gives a maximum intensity, increasing the tube current, within limits of tube endurance, and application of a transverse magnetic field that increases the power input into the tube by increasing the effective resistance of the tube.

The conclusion that is drawn from the study of the line shape is that self-reversal is not apparent and certainly no hinderance to the use of the lamp.

No study was made of the effect of the strength of the magnetic field and no study was made of the life-time of discharge tubes when run with higher than normal currents.

Although the practical problem has been approached the problem of the physical processes involved have been only sketchily touched.

ACKNOWLEDGMENTS

Assistance in the preparation of this thesis was obtained from Dr. R. H. McFarland and from the Kansas State University IBM computing center and Dr. S. T. Parker, Mr. Tom Hamilton, and Miss Susan O'Bryan of the computing center. Without the help of the computing center the numerical treatment of the data would have been a difficult problem. The author wishes to thank Dr. A. B. Cardwell and Dr. R. A. Anderson for their assistance in starting the research project, the Diamond Ordnance Fuze Laboratory of Washington, D. C. for their financial support and the author's wife for typing the thesis.

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APPENDIX

TREATMENT OF EXPERIMENTAL DATA

Purpose and General Methods

The purpose of the particular type of treatment of experimental data was two-fold;

(1) To obtain least-square curves of the data which enabled an easier plotting of the curves.

(2) To obtain sets of curves from the origional experimental data that could not be obtained by a straight-forward plotting of the origional data.

The least-square analysis and the determination of the derived sets of curves can be broken down into two major parts:

(1) Determination of the lowest order curves that fit the origional experimental data within certain limits at each experimental point.

(2) The determination, from these curves, of the derived sets of curves.

The first of these major parts can be separated again into two parts:

(1) Estimating initially

(a) the possible error in the 2537 A intensity due to errors in the exit slit opening, s, tube temperature, T, and tube current, i, and

(b) the possible error in tube voltage due to errors in tube temperature, T, and tube current, i.

(2) Using an iteration process to determine, by least

squares, the lowest order curves that fit the experimental data within the initial estimates of error.

Initial Estimate of Error

The initial estimate of error consisted of;

(1) Determining, for all sets of experimental points, the coefficients of the curves that pass exactly through each of the experimental points.

(2) Using the equations of the curves determine the value of the dependent variable at the limits of error in the independent variable, and use this data as the initial estimate of error.

Iteration Procedure

The iteration procedure consisted of;

(1) Determining, from the initial estimate of error, the maximum range of uncertainty in

  (a) the 2537 A intensity at each experimental point due to uncertainties in, s, T, i, and the Photovolt readings,

  (b) tube voltage at each experimental point due to uncertainties in T, and i.

(2) Evaluating, by least squares, the coefficients of

$$\log_{10} I = a_o + a_1 s + \ldots + a_j s^j$$
$$\log_{10} I = b_o + b_1 T + \ldots + b_k T^k$$

$$\log_{10} I = c_o + c_1 i + \ldots + c_m i^m$$

$$V = d_o + d_1 T + \ldots + d_n T^n$$

$$V = f_o + f_1 i + \ldots + f_p i^p$$

where j, k, m, n, and p are the smallest intergers that will allow the least squares curves to pass through the experimental points within the limits of error given by the initial estimate.

(3) Using these lowest order curves to make a new estimate of error at each experimontal point and repeat the complete procedure until the coefficients of the equations for the lowest order curves differ on successive iterations by a certain preassigned amount.

Determination of the Derived Sets of Curves

Using the last lowest order curves obtained from the iteration procedure, the derived sets of curves were obtained by;

(1) Evaluating V and $\log_{10}$ I at T = 20°C, 30°C, ..., 100°C, for all values of the parameter i.

(2) Use this data to determine, by the above iteration procedure, the lowest order curves of $\log_{10}$ I versus i, T and s as parameters, $\log_{10}$ I versus s, T and i as parameters, and V versus i, T as a parameter.

From the sets of curves obtained the ones presented in the experimental data are obtained.

A STUDY OF THE INFLUENCE OF TEMPERATURE, CURRENT,
AND MAGNETIC FIELD UPON THE INTENSITY AND LINE SHAPE
OF THE 2537 A MERCURY SPECTRAL LINE FROM A GENERAL ELECTRIC
4-WATT, U-SHAPED, GERMICIDAL DISCHARGE TUBE

by

JAMES ELMER SWAIN

B. S., KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE, 1958

ABSTRACT OF A THESIS

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requirements for the degree

MASTER OF SCIENCE

Department of Physics

KANSAS STATE UNIVERSITY
OF AGRICULTURE AND APPLIED SCIENCE

1960

The 2537 A intensity from a mercury discharge can be used in many studies involving mercury atoms. A mercury discharge was investigated to see what influence current, temperature, and the prescence of a magnetic field had upon the 2537 A emission from the discharge and upon the 2537 A line shape. With this knowledge the 2537 A intensity from the discharge could be maximized.

To carry out this study the temperature of the lamp was varied by varying the rate of coolant flow through a coolant jacket around the lamp. The current was varied by use of a rheostat. The intensity was measured by the use of a 500 mm Bausch and Lomb monochrometer and a Photovolt photometer. The line shape was studied by observing the variation of the intensity with exit slit opening and by taking densitometer recordings of the 2537 A line from spectrograms of the discharge. The magnetic field was applied transverse to the discharge by placing the coolant jacket and discharge tube between the pole faces of the magnet.

The intensity versus temperture curves, with current as a parameter, showed maximums at temperatures that increase with the current parameter. The intensity versus current curves, with temperature as a parameter, showed no maximums but did show a saturation effect at high currents. Voltage versus temperature curves, obtained in the process of the study, with current as a parameter, showed maximums at temperatures that increase with the current parameter. Voltage versus current curves, also obtained in the process of the study, with temperature as a parameter, showed that the discharge was operated from the arc side of the abnormal glow-arc transition region to the pure arc region of the normal voltage-current characteristic curve of a discharge.

The effect of the magnetic field was to approximately double the tube voltage and to increase the intensity by a factor of approximately five, for all currents and temperatures.

The 2537 A line study showed, both by exit slit opening variation and densitometer recordings, that there was no self-reversal of the center portion of the line that could be detected, and that the emitting and absorbing mercury atoms approximated a Maxwellian distribution.

Therefore the maximum 2537 A intensity could be obtained from the discharge by operating the lamp at a certain current, as high as possible without seriously shortening the life-time of the lamp, and at a definite temperature for the chosen current and with a transverse magnetic field.