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CONSTRUCTION AND OPERATION OF
ELECTRODELESS LAMPS FOR
SPECTROSCOPIC PURPOSES

Thesis for the Degree of M. S.
MICHIGAN STATE COLLEGE
James Sylvester Grimes
1953



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presented by

James Sylvester Grimes

has been accepted towards fulfillment
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CONSTRUCTION AND OPERATION OF ELECTRODELESS LAMPS

FOR

SPECTROSCOPIC PURPOSES

By

James Sylvester Grimes

A THESIS

Submitted to the School of Graduate Studies of Michigan

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James S. Grimes

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I Introduction

The purpose of this thesis was to construct some electrodeless lamps, design and construct an oscillator to operate the lamps, and determine something about the operating characteristics of the lamps.

Electrodeless lamps are not new ^{1,2} but since 1946 there has been a large amount of work done with them at the National Bureau of Standards at Washington D.C. by W.F. Meggers and others ^{3,4,6}. The early lamps contained only gases and were well suited for studying complex spectra. Some of the recent work has been in the use of very high frequency excitation and metals or metallic vapors in the lamps to obtain the spectra of the metals ³⁻⁷. In 1950 the National Bureau of Standards announced that the N.B.S. - Meggers Mercury 198 Spectroscopic Lamps were available for qualified government, scientific, and industrial laboratories. Mercury 198 is used in these lamps because of its easily excited intense radiations in the visible portion of the spectrum — particularly the green line (5461) and the yellow doublet; it is a heavy atom, and therefore gives small doppler broadening; it is a single isotope, hence no isotopic structure; it is an even mass isotope, hence there is no fine structure; it is the easiest isotope of mercury to produce in a pure form ⁴.

Electrodeless lamps for the study of spectra have several advantages over the arc method. Among them are no contamination by the electrodes; low pressure, reducing pressure

broadening of lines; the equivalency of a low current arc ⁵; smallness of sample required, a sample too small to be seen may be used; time that the sample emits radiation; and the sharpness of the lines. The electrodeless lamp has advantages over the lamps with electrodes in the lamp in that no glass-to-metal seals are required and no contamination by the electrodes. C.H. Corliss, W.R. Bozman, and F.C. Westfall have published some good pictures showing the comparison of the spectra produced by the electrodeless lamp and the arc-light ⁶. The fine lines produced make this kind of lamp desirable as a source for use as a spectroscopic and interferometer standard, and for comparison purposes.

In this project lamps were made containing CuCl_2 , NiCl_2 , FeCl_3 , Cd , CdI_2 , CdCl_2 , Hg , HgCl_2 , A , and He , and were operated by using a 378 megacycle - 15 watt (approx.) oscillator.

II Operating Unit

Power Supply

The power supply used to furnish power for the oscillator was a conventional power supply using two 836 half-wave rectifier tubes and a two section choke-input filter. For continuous operation it is rated at 1750 volts and 200 milliamperes. The power out put is controlled by means of a V-5 variac. The circuit is as shown in fig. 1. The ripple in the out put is very small—too small to be measured conveniently on an oscilloscope.

The power supply is built in the bottom section of the metal cabinet, below the oscillator, as shown in fig. 9.

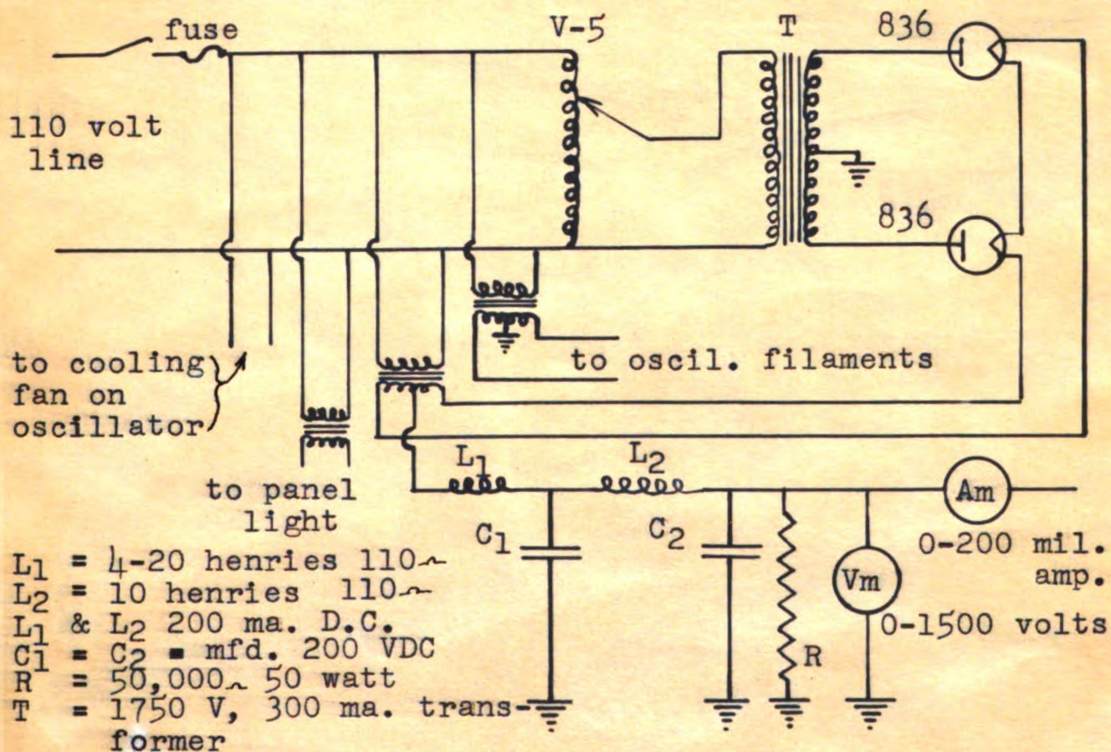


fig. 1

Oscillator Design and Construction

To operate the electrodeless lamps a power oscillator was required. The term power oscillator indicates that the tube carries plate current only in short pulses and that the grid bias is relatively large. Under these conditions the tube operates essentially as a class C amplifier, and the efficiency of the power conversion is relatively high ⁹.

To obtain the maximum possible power output from a triode that is being used as a class C amplifier, it is necessary to have a relatively low plate impedance and to use large plate currents. In general the frequency stability of an oscillator is improved by increasing the plate load impedance to relatively high values. Thus to achieve a high power output frequency stability is sacrificed to some extent, but frequency stability was not considered too important; a high power output was desirable.

The oscillator, was designed to use two R.C.A. 8012A transmitting tubes in a push-pull circuit using parallel plate-type lines. The resonant circuit consists of two parallel plates with a tube at each end. The resonant frequency of such a circuit may be changed by changing the length or width of the lines. Making the lines narrower or longer lowers the frequency.

The 8012A tube characteristics are as follows;

Mount	vertical only
type	R.F. power amplifier and oscillator

filament	6.3 volts A.C. or D.C. 1.92 amp.
interelectrode capacitance	
grid - plate	2.5 $\mu\mu f$
grid - cathode or filament	2.7 $\mu\mu f$
plate - cathode	0.4 $\mu\mu f$
max. ratings (absolute values)	<u>C.C.S.</u> *
D.C. plate voltage	1000volts
D.C. grid voltage	-200 volts
D.C. plate current	80 ma.
D.C. grid current	20 ma.
plate input	50 watts
plate dissipation	40 watts

May be operated with maximum ratings up to 500 M.C.

35 % efficient at 600 M.C.

The oscillator circuit is shown in fig. 2a and b, the equivalent circuit is shown in fig. 3, and the oscillator in fig. 4.

The operation of the oscillator may be explained by noting that the oscillator circuit may be divided in half, each becoming a complete single tube oscillator.

Referring to the top half of fig. 3, and considering only the radio frequency (R.F.) current, component number one represents the impedance due to cathode lead inductance,

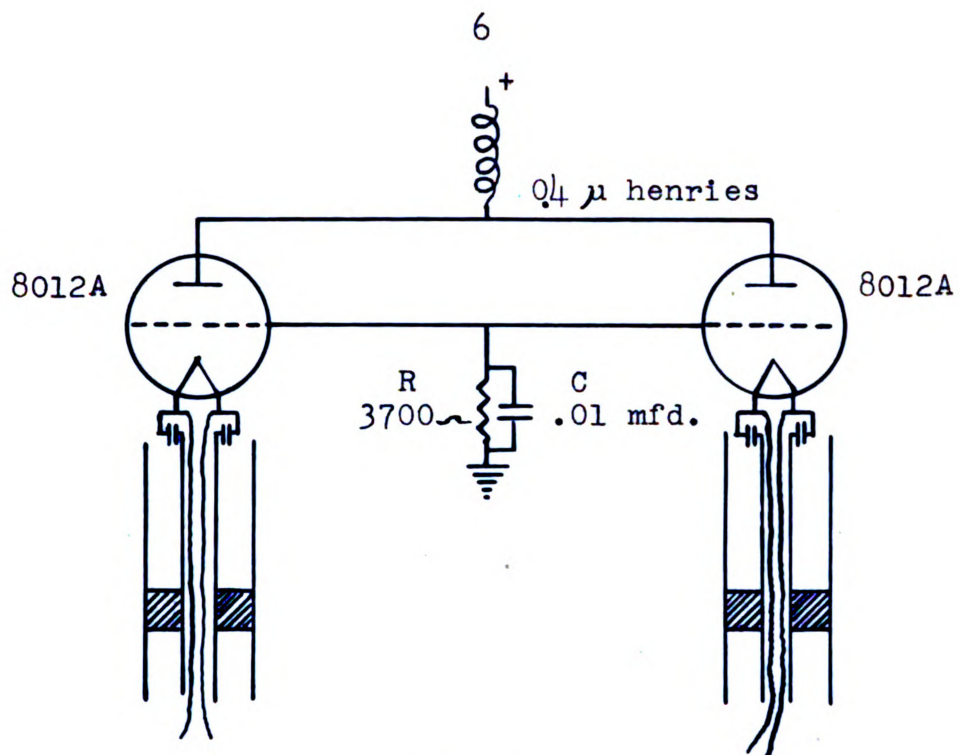


fig. 2a

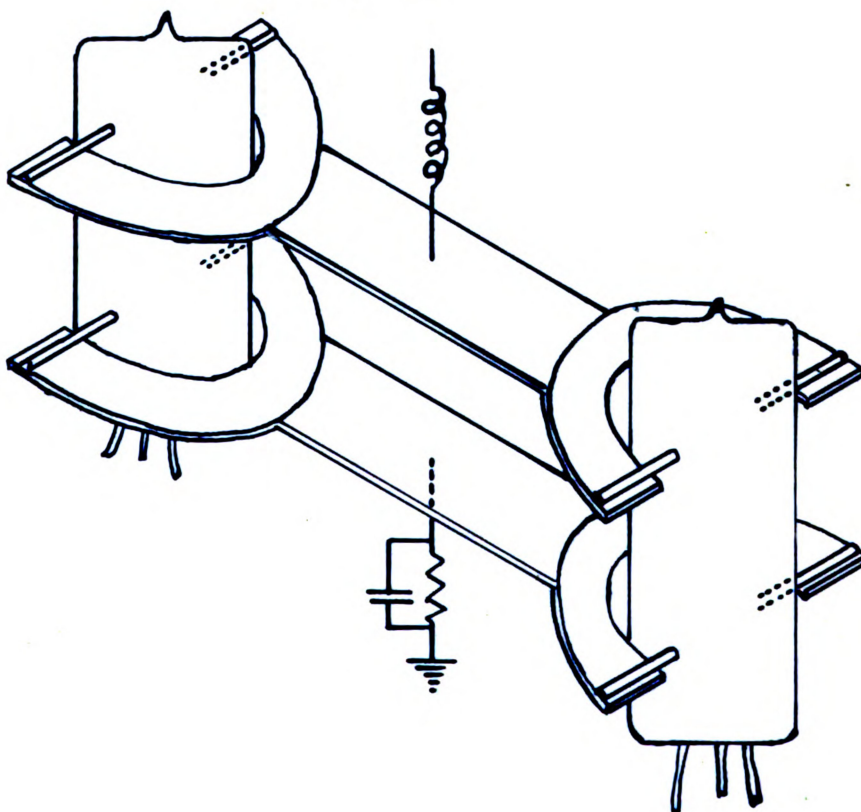


fig. 2b

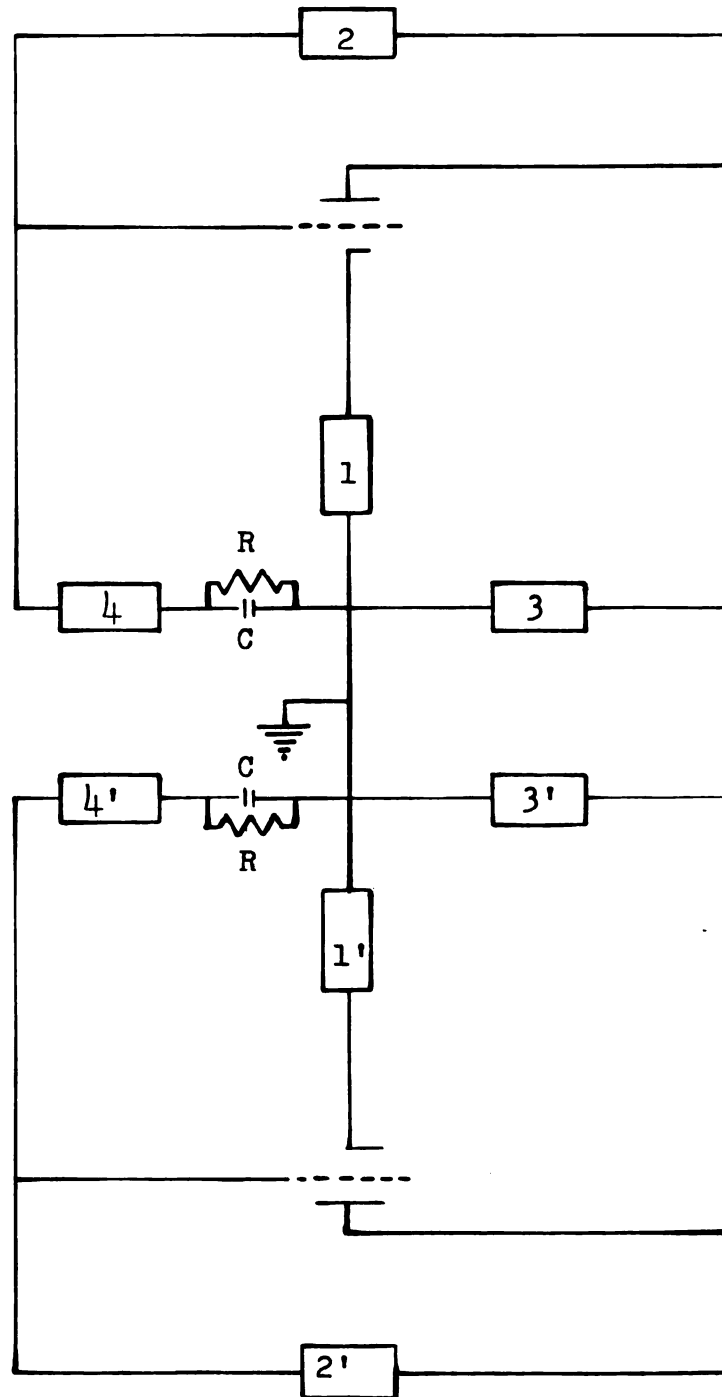


fig. 3

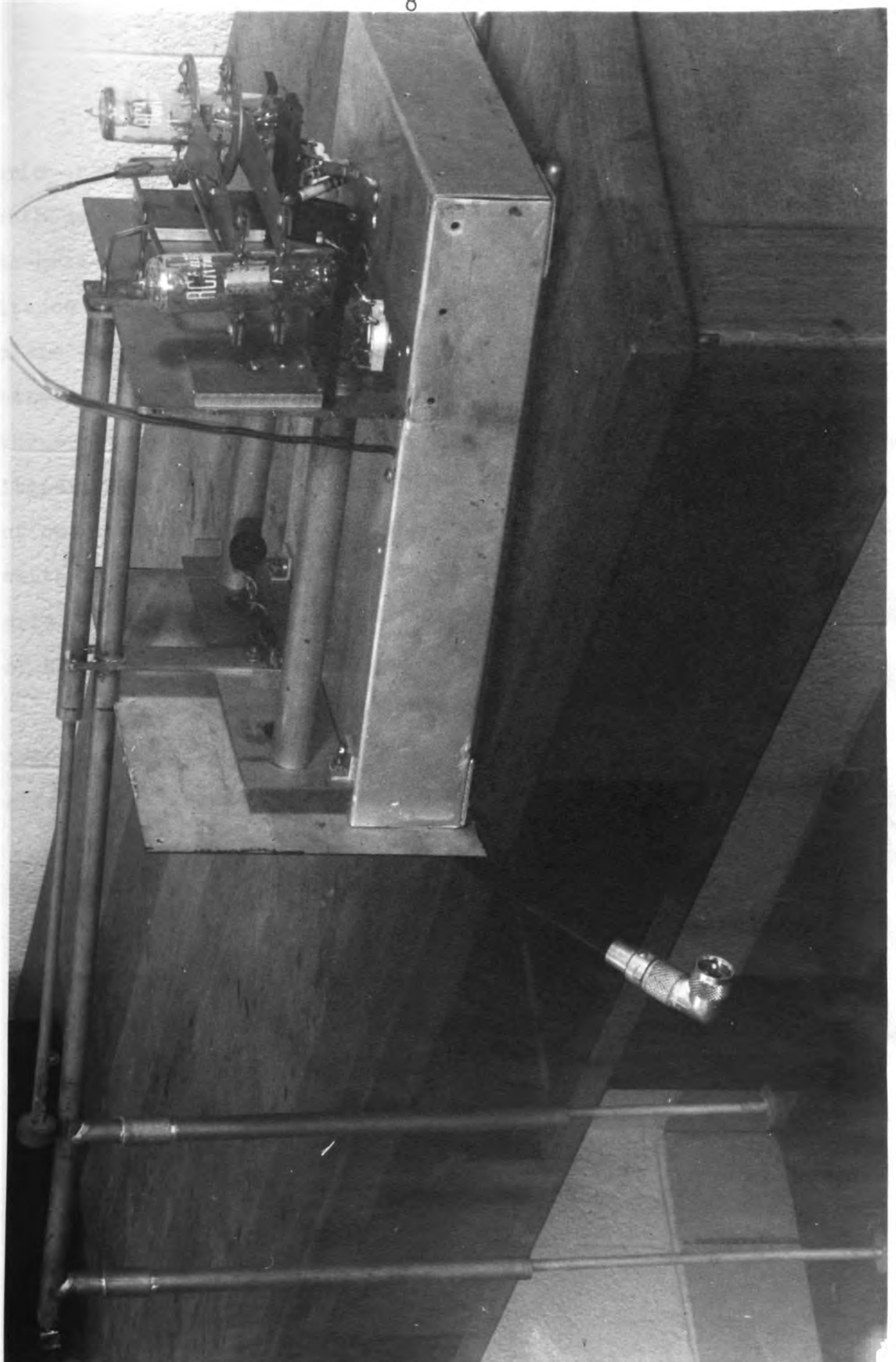


fig. 4

grid-cathode capacitance, plate-cathode capacitance, and the cathode tuners. Component number two represents the plate-to-grid impedance. This is composed of the plate-grid capacitance of the tube, one-half of the capacitance between the plate and grid lines, and one-half of the mutual inductance between the plate and grid lines (plates). Component number three represents the impedance due to plate-cathode capacitance, the plate lead inductance, and the self-inductance of one-half of the plate line. Component number four represents the impedance due to grid-cathode capacitance, the grid lead inductance, and the self-inductance of one-half of the grid line.

The grid-cathode capacitance affects the impedance in components one and four. The plate-cathode capacitance affects the impedance in components one and three.

The R.F. current on the grid line is grounded through the grid capacitor C to ground. The plate line has an electrical length of one-half wave length, and the center is a nodal point making it effectively at ground potential as far as the R.F. current is concerned but not at ground potential with respect to D.C. current. Though there are two resistors R and two capacitors C shown in fig. 3 the actual circuit has only the one R. and one C. This comes about by the fact that these components need not be considered when considering the R.F. circuit but were put in fig. 3 to show

where they are located in reference to the other components, and to indicate how the grid potential is obtained. The current flows through each half of the circuit alternately.

The value of resistance R was determined experimentally with 1,000 volts on the plate. Larger values of R cause the plate current to decrease thus causing a decrease in the power output. While smaller values of R cause an increase in the plate current resulting in overheating of the plates.

The capacitor C was found experimentally but not with the accuracy that R was determined. Mica capacitors worked the best here and they were not available in the suitable sizes for experimentally finding the best value nor was the performance affected so much with a change of this capacitance.

The plate choke consist of two Ohmite R.F. chokes, each with 0.2μ henries of inductance in the range 320 to 520 megacycles. Two of these chokes worked much better than one and perhaps three would work better than two, but two was all that was available, and chokes with more inductance for frequencies in this range were not available.

The plates connecting the tubes, the plate and grid lines, were made about 2.8 cm wide, about .8 mm thick, and long enough to separate the tube centers about 16.5 cm. The ends of the plates were attached to the center of a semicir-

cular yoke whose ends are attached to the plate or grid terminals on either side of the tube. The plate and grid plates were made identical; not to any particular size, but only of a size so that the frequency of the oscillator will not be too high as the higher the frequency the lower the efficiency of the tube.

Tunable coaxial cathode lines are used with this oscillator. Thus they can be adjusted to give maximum results. The filament leads are run through the inner conductor of the coaxial lines and the outer conductor is slotted part way to allow the shorting plungers to be adjusted by short tab handles that protrude through the outer conductor. The capacitors shown in fig. 2a at the end of the inner conductors are small padding condensers. Though these were set at about $30 \mu\mu f$, the size is not critical.

The operation of the oscillator may be checked by holding a neon bulb on or near the plate line; the ends of the plate line being the most sensitive. With the cathode lines properly adjusted and no coupling out device used, this oscillator will very brilliantly light up an ordinary 10 watt incandescent light; lighting it more brilliantly than when used in a socket on a 110 volt line. It will light up a 25 watt incandescent lamp, but not as bright as when used in the regular manner.

The frequency of the oscillator was measured by means

of lecher wires fig.5. The loop at the end of the lecher wires is supported between the tubes and above the plate line so that the lecher wires are coupled inductively to the oscillator. The wave length is then found by sliding the neon bulb indicator, see fig. 5, along the wires. The neon bulb will glow brightest at the points where the amplitude of the standing wave of R.F. voltage is the greatest and the glow will be weakest where the amplitude is normally zero. Due to reflections in the lecher wire system, the amplitude may not be actually zero any where along the wire. It was found that the wavelength was most easily measured by using the points of minimum voltage amplitude on the standing wave; the distance from one minimum to the next being one half wavelength. The average of eight readings was 39.55 cm. Thus the wavelength of 79 cm. or the frequency of 377.9 megacycles per second.

The power was coupled out by means of a tuned loop made of 1/8 in. brass rod. The tuning control being a shorting plunger between two coaxial conductors, the center one being a continuation of the pick-up loop. The outer conductor, a 1/2 inch brass tube, being grounded to the brass plate that holds the tube supports, the ends of the cathode tuners, and the end of the coaxial transmission line. The power was brought out of the unit by means of a coaxial transmission line; the center conductor being a continuation of the coupling out loop and the outer conductor a 1/2 inch brass tube.

The transmission line extends about 40 cm out of the unit. The end of the transmission line is equipped with a double stub load-to-line matching device. These matching stubs are located as near the load as is convenient and $1/8$ of a wavelength (10 cm) apart. The stubs are constructed in the same manner as the loop tuner and about 25 cm long (they need to be at least a quarter of a wavelength long). The very end of the coaxial transmission line is equipped with two small flat copper plates, one soldered to each conductor so as to be parallel. The load, electrodeless lamp, is supported by or between these two copper plates on the coaxial transmission line. The degree of coupling between the oscillator and the pick-up loop is regulated by adjusting the distance between the loop and the plate line. This distance is adjusted by loosening the screw that is through the clamp supporting the end of the coaxial transmission line. The entire coupling out device may be removed by loosening the screw below the loop-end of the transmission line and removing the screw that is in the lower end of the transmission line support at the front end of the oscillator unit.

To remove the oscillator from the metal cabinet remove the top section of the front panel, the two top screws in the center section of the front panel, loosen the lower end of power cable and pull on the top power cable connection to pull oscillator out about three inches, then disconnect the

filament leads connector, and remove the oscillator from the cabinet.

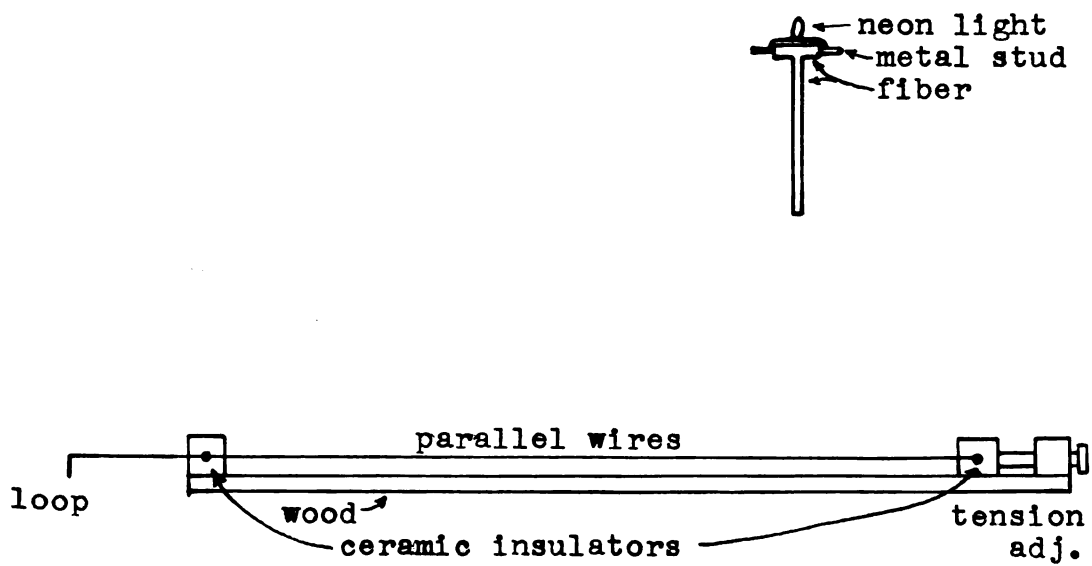


fig. 5

Oscillator Tuning

In tuning the oscillator it is very important to always keep a close watch on the plates in the tubes and the plate voltage below 1,050 volts.

The tuning procedure is as follows:

1. Turn the oscillator on, making sure that the variac control on the power supply is turned all the way down.
2. Turn the power up (the variac control) until the plate current (the milliammeter on the power supply) reads about 40 milliamperes or the oscillator goes into operation; indicated by a sudden decrease in the plate current reading as the voltage is increased on the plates. If the oscillator goes into operation, turn the power up to about 500 volts and allow the unit to warm up for about five minutes.
3. Adjust the cathode tuners individually for minimum plate current.
4. Increase the plate voltage to about 900 volts providing the plate current does not exceed 50 ma. or the tube plates overheat.
5. Place an electrodeless lamp in-between the small copper plates at the end of the coaxial transmission line. If the lamp does not light of its own accord, use a Tesla coil to start the lamp. If the lamp will not light, check position of the pick-up loop. It should (normally) be within one-fourth inch of the plate line. Once the lamp is

lit, adjust the plate voltage (if necessary) until the lamp emits light from only a portion (about half or less) of the lamp. Then adjust the shorting plunger that tunes the pick-up loop so that the lamp emits a maximum of light.

6. If the lamp is fully lit, decrease the plate voltage until only about half of the lamp emits light, and adjust the load-to-line matching stub nearest the oscillator for a maximum of light.
7. Repeat step 6 for the other load-to-line matching stub.
8. The position of the pick-up loop should now be adjusted so that with 1,000 volts on the plates, the plate current is about 45 ma. or as high as it may be allowed to be without overheating the tube plates. Adjust the pick-up loop by loosening the screw in the brass plate below the end of the coaxial line and move the end of the coaxial line either up or down.

When the oscillator is moved, the tuning may be thrown off some. Usually the only part that needs retuning then is the load-to-line matching stubs.

III Electrodeless Lamps

Production of Lamps

In this project lamps were made containing CuCl_2 , NiCl_2 , FeCl_3 , Cd, CdI_2 , CdCl_2 , Hg, HgCl_2 , A, and He. The lamps were made of pyrex glass tubing in lengths of 12 to 17 cm. and inside diameters of 5 and 6.5 mm.

The lamp blanks were cut from new glass tubing and one end of each blank was sealed shut and blown out into a bulb; the bulb being made to facilitate end-on viewing. The lamp blanks were cleaned by, 1. filling the blanks with a hot saturated solution of sodium hydroxide and placing them in a beaker of the hot solution for about a half-hour, 2. repeating step 1, after rinsing well with tap water; only this time using a hot chromic acid cleaning solution¹⁰, 3. flush with concentrated nitric acid and let stand filled with nitric acid until ready for use.

The vacuum system shown in fig. 6 was used to make the lamps. Valve A was to shut the vacuum system off from the pump. Valve B was used to keep chlorine gas out of the mercury manometer after making FeCl_3 or NiCl_2 in the lamp blank. Valve C was used to keep the chlorine in the lamp blank section when making FeCl_3 or NiCl_2 . Valve D was to admit the inert gas (A or He) or the Cl_2 . Valve E was a high pressure-to-vacuum cut-off valve designed and made in the machine shop of the physics department. A rubber hose connected the vacuum system and the tank of inert gas; therefore it was necessary

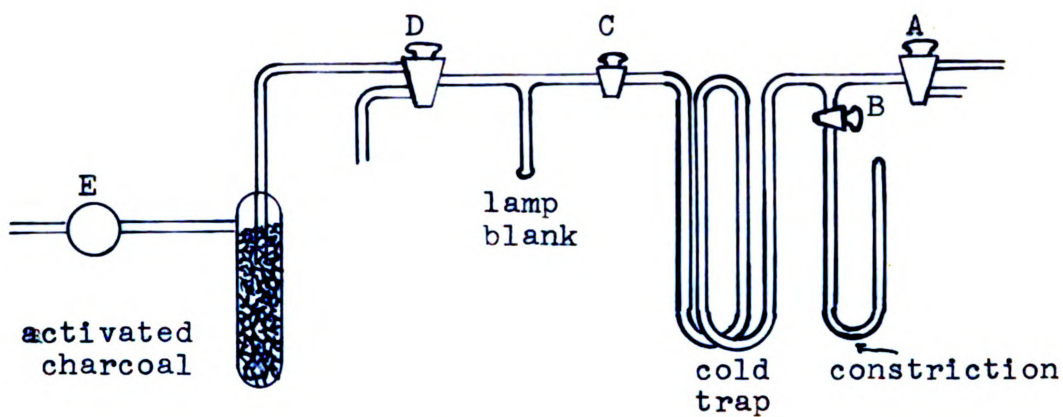
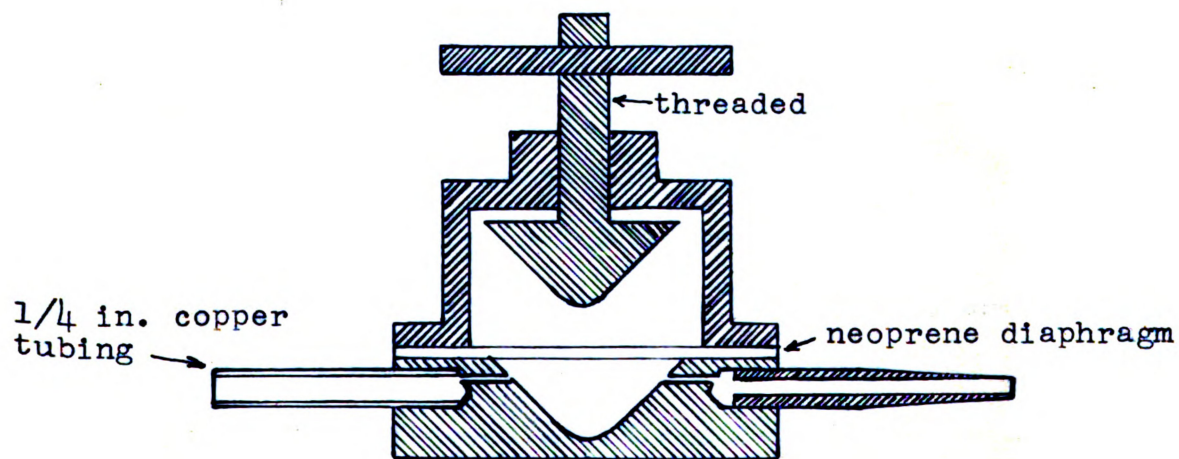


fig. 6a



fig. 6b



section drawing of valve E

fig. 6c

to keep some gage pressure in the rubber hose to insure that any leak would be outward and the gas would not get contaminated. The cold trap and the activated charcoal container were immersed in thermoses of dry ice and acetone. When making FeCl_3 or NiCl_2 in the lamp blank, a calcium chloride dryer was connected to valve D and the chlorine gas from the generator (HCl and MnO_2) was passed through the dryer and into the system. A Cenco Hyvac vacuum pump was used to produce the vacuum. While this pump would produce a lower pressure than could be accurately read on the mercury manometer, it would not produce as good a vacuum as is desirable.

The lamps were made in the following manner. The lamp blank was removed from the nitric acid and rinsed several times with tap water then rinsed well with distilled water. The blank was dried with a gas-oxygen torch flame, and the compound that was to be in the finished lamp was placed in the blank (except for FeCl_3). The blank was then sealed onto the vacuum system. The system was then evacuated and out-gassed with a torch, from valve D to valve C, to drive off the absorbed gases. When out-gassing the system, the lower part of the lamp blank was wrapped with wet asbestos paper to keep the compound cool. After about fifteen minutes of out-gassing, the system was flushed two or three times with the inert gas and then was allowed to cool down and the wet asbestos paper moved up the blank so that the lower part of

the blank could be out-gassed. When out-gassing the lower part of the blank, the compound was evaporated and recondensed under the asbestos paper.

When making lamps that are to contain rather easily vaporized substance such as mercury, it may be necessary to use dry ice and acetone to keep it cool while out-gassing the system.

After the out-gassing, the system was pumped down to the lowest pressure obtainable and held there for about twenty minutes to assure evacuation of all the gases possible. Valve A was then closed and the inert gas was admitted to the system at a pressure of about one-half atmosphere, and allowed to stand for about five to ten minutes before being pumped out. After several flushings (sometimes as many as twenty) of the system with the inert gas, the gas pressure was pumped down to the desired pressure and the lamp blank carefully sealed off.

All of the CuCl_2 and most of the NiCl_2 lamps were made by using a hydrated form of CuCl_2 and $\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$, and driving the water off during the out-gassing. The FeCl_3 and one NiCl_2 lamps were made by putting the pure element in the lamp blank and forming the chloride in the system.

When making the compound in the system (FeCl_3 or NiCl_2), the chlorine was admitted to the system after the first out-gassing step (see above); taking care to close valves B and

C first. The element (Fe or Ni₂) was then heated in the presence of chlorine to form FeCl₃ or NiCl₂. There will be some Fe or Ni that will not have united with the chlorine to form FeCl₃ or NiCl₂, it being left in the elemental state or other chloride forms. By changing the system slightly as shown in fig. 6b and not heating excessively, one can condense into the lamp blank what appears to be pure FeCl₃ or NiCl₂.

Several lamps were made by changing the above procedure slightly as follows. After the out-gassing was complete, the oscillator was positioned so that the lamp blank was in position to be lighted by the oscillator. When the lamp is operated, the color of the light changes noticable with time. After the color has apparently stopped changing, the lamp was evacuated completely of the gas and refilled. This procedure was repeated until no color change was noticed and then the lamp blank was carefully sealed off.

Operating Characteristics of the Lamps

The electrodeless lamps will operate at frequencies of 10 megacycles and above. They have been operated at frequencies as high as 3,000 megacycles by use of a magnetron. The mercury electrodeless lamps when operated at frequencies below 100 megacycles exhibited clean-up, and consequently the loss of the mercury spectrum, in a relatively short time. When operated above 100 megacycles, the clean-up is extremely slow. The clean-up is accompanied by black bands appearing in the lamp near the edge of the high frequency terminals ⁴. In the work presented here, what appears to be clean-up has been observed in electrodeless lamps containing cadmium and cadmium compounds even though the frequency was well above 100 megacycles (375 M.C.). The mercury electrodeless lamp that has cleaned-up can be rejuvenated by heating the black bands in a flame until they glow a dull red ⁴. The intensity and efficiency of the electrodeless lamps increases as the operation frequency is increased. Jacobsen and Harrison report an increase of intensity in a mercury 198 lamp of 16 fold in changing the frequency from 150 to 3,000 megacycles per sec. ⁷.

This project was mainly concerned with the affect of the nature of the compound and the inert-gas pressure in the electrodeless lamp. Lamps were made containing CuCl_2 , NiCl_2 , FeCl_3 , Cd, CdI_2 , CdCl_2 , Hg, HgCl_2 , A and He; and at "sealing-off-pressures" from one mm to seventeen mm.

By "sealing-off-pressure" is meant the pressure reading on the mercury manometer when valve C is closed just prior to sealing off the lamp blank. This pressure cannot be read as accurately as may be desired when the pressure is low; and the pressure in the lamp may be changed by the sealing off process. In sealing off the lamp there may be gases driven off or out of the glass that may or could not have been driven off during the out-gassing process; due to the limit of the temperature that the glass may safely be brought to for out-gassing.

The mercury lamp (Hg and A at 3 mm of pressure) worked the best of all the lamps made; its spectrum, without cooling, being a good clean mercury spectrum without a noticable argon spectrum. The A, He, and HgCl_2 lamps worked well giving a clear spectrum of sharp lines, the CuCl_2 , CdCl_2 , NiCl_2 , and the FeCl_3 lamps gave only the spectrum of the argon. The spectrum of the Cd lamps contained the cadmium 5086 lines (rather weak) and a considerable number of lines of the argon spectrum.

The CdI_2 lamp at room temperature gave a clear spectrum of iodine and some argon but no cadmium. When one end of the lamp was immersed in a mixture of dry ice and acetone a clear spectrum of argon only was observed; as the lamp began to warm up the argon spectrum began to fade out, and iodine lines and molecular bands began to appear; the bands in the region 5100 to 6500 angstroms.

The cadmium lamps after a few minutes of operation began to turn black in the region around the electrodes and the cadmium 5086 line disappeared. By heating the blackened portion of the lamp, the black substance was vaporized and deposited at other parts of the lamp. Then when the lamp was excited again the cadmium 5086 line reappeared. One of the cadmium lamps after operating for about two hours had turned black over a considerable area, and when heated the substance in the lamp turned a yellowish brown but no cadmium lines reappeared. All the lamps that contained any cadmium blackened after a few minutes of operation.

It has been observed that the intensity of the mercury lamp changes considerably and quite suddenly at times. This is believed to be due to frequency changes of the oscillator; a small change of frequency will produce a considerable change in power out-put at these frequencies.

It is believed that if the oscillator had had a considerably higher power out-put, the FeCl_3 , NiCl_2 and CuCl_2 lamps would have produced the spectrum of the metals. Also the other lamps would probably have worked better.

IV Radiation from Electrodeless Lamps and

High Resolution Spectroscopy

A. High Resolution Spectroscopy

General Theory

In order to investigate the radiation from the electrodeless lamps and compare it with that from other sources it was necessary to use high resolution equipment.

High resolution optical instruments utilize high orders of interference to produce interference fringes. Some of the instruments used for high resolution spectroscopy that employ the interference principle are:

1. Fabry - Perot interferometer
2. Lummer - Gehrcke plate
3. Reflection and transmission echelons

When a suitable source is provided, an optical instrument of moderate resolution may show a line as a single broad line whereas an instrument of high resolving power may show the same radiation as a group of lines. The high resolution instrument will show the group as a pattern of interference fringes; each individual line producing a pattern of narrow interference fringes, and the patterns superimposed on one another.

If the light source does not produce very nearly monochromatic light, it is necessary to use some other instrument

or device along with the high resolution instrument to separate out the narrow range of wave lengths that you wish to observe. Other devices that may be used in conjunction with the high resolution instrument are spectrographs, spectrometers, monochromators, filters, etc.

For this work the Fabry - Perot interferometer was used in conjunction with a constant deviation spectrometer.

Fabry - Perot Interferometer

The Fabry - Perot interferometer consists essentially of two optical plane surfaces that are silvered on their adjacent faces and separated by a homogeneous medium, usually air. To observe the interference fringes, light from a broad source of monochromatic light is allowed to traverse the interferometer plates. A ray of light from a point P_1 , on the source is incident on the silvering of the first plate E_1 , at an angle θ (see fig. 7) and produces a series of parallel rays from the second plate in the same direction as the original ray. By placing a convergent lens in the path of these parallel rays, they may be brought to a focus at a point P_2 . The condition for reinforcement of the rays at P_2 is

$$2 d n \cos \theta = m \lambda \quad (1)$$

where: n = index of refraction of medium between the plates

d = separation of the silvered surfaces

λ = wave length

m = order number (integral)

The conditions for reinforcement is met by all points on a circle through P_2 whose center lies on an axis of lens L_2 , and observer; and in the plane parallel to the plates containing point P_2 .

Since $\cos \theta$ is at its maximum when θ is 0° , the central fringe has the highest order number and the order number of the other fringes each decrease by one as they are counted

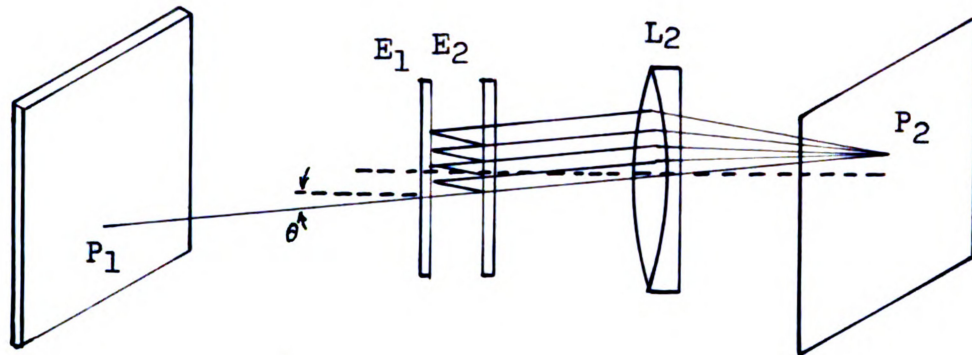


fig. 7

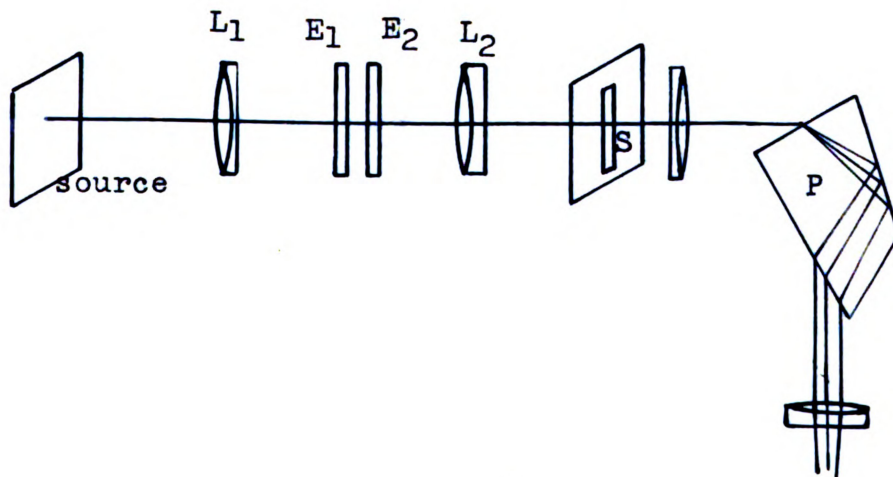


fig. 8

outward from the central fringe. The medium between the plates was air, hence n may be set equal to one.

The resolving power, R. P., of the instrument is by definition $\frac{\lambda}{d\lambda}$; where $d\lambda$ is the difference in wave length of two lines that can just be resolved and λ is the wave length at which the resolving power is being considered. From equation (1), the resolving power becomes

$$\frac{\lambda}{d\lambda} = \frac{1}{\frac{dm}{m} + \tan \theta d\theta} \quad \begin{array}{l} \text{(neglecting the sign in} \\ \text{the right hand member)} \end{array}$$

Near the center of the fringe pattern the angle θ approaches 0, and at the center

$$\text{R.P.} = \frac{\lambda}{d\lambda} = \frac{m}{dm}$$

Assuming that two overlapping fringes of equal intensity will be just resolved when the ratio of minimum to maximum intensity in the combined intensity distribution is $0.8106 (8/\pi^2)$, — the Rayleigh criterion—then the resolving power becomes

$$\text{R.P.} = \frac{\lambda}{d\lambda} = 2.98 \frac{r^{\frac{1}{2}}}{(1-r)} m ,$$

a function of the interference order m and surface reflection coefficient r . This resolving power may be increased simply by increasing the plate separation, i.e. increasing m , and by increasing the reflection power of the surface ¹³.

Another characteristic of the instrument of importance is the spectral range. It is commonly stated in wave numbers (reciprocal of the wave length) rather than in angstroms.

The spectral range is the difference of wave numbers between two lines such that the m^{th} order interference fringe of one line is superimposed on the $m+1$ order interference fringe of the other line. Thus at the center of the fringe pattern, from the equation (1), $\frac{1}{\lambda} = \nu$

$$\nu_1 2d = m$$

$$\nu_2 2d = m+1$$

$$\nu_2 - \nu_1 = \frac{1}{2d}$$

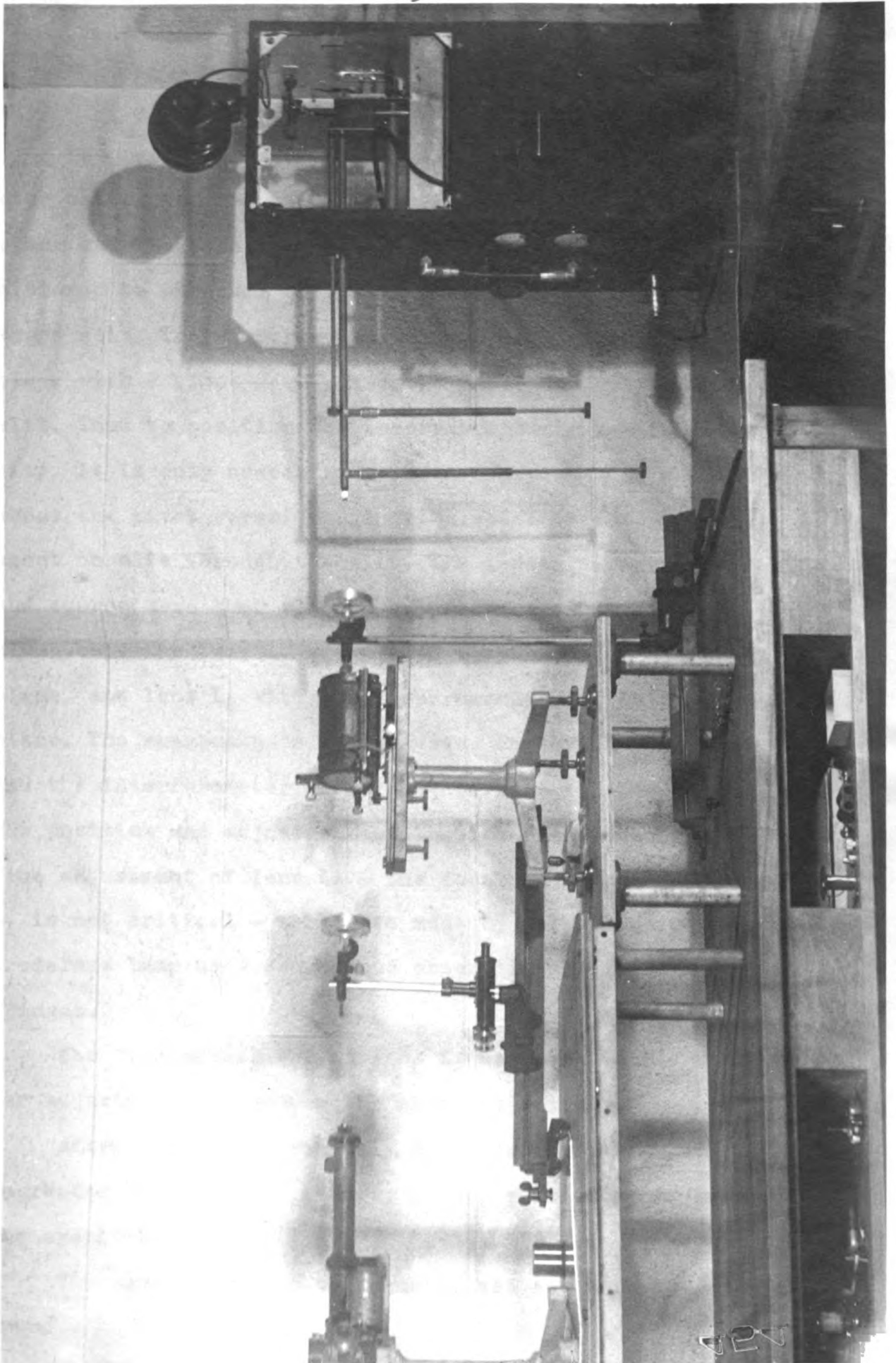
$$\text{spectral range, } \Delta \nu (\text{cm}^{-1}) = \nu_2 - \nu_1 = \frac{1}{2d(\text{cm})}$$

B. Experimental

Optical System

The optical system used to examine the spectra of the lamps is shown schematically in fig. 8 and pictorially in fig. 9. The lamp source is placed at the focal point of lens L_1 . Lens L_2 , as is shown in fig. 7, is necessary in order to observe the interference fringes. The parts of Fig. 8 to the right of lens L_2 are all contained in the constant deviation spectroscope. The slit S, adjustable, is located at the focal point of lens L_2 . The slit cuts out of vision all but a narrow band of the interference pattern. This pattern will contain, superimposed on one another, an interference pattern for each wave length of light. The prism P will disperse the various wave lengths. Thus the observed pattern is a series of images of the slit, each image containing an interference pattern produced by one wave length. If there are wave lengths that are nearly equal the interference pattern in the slit image will show the line structure i.e. different interference patterns superimposed on one another.

Wave lengths may be measured by this constant deviation spectroscope by a pointer located just in front of the eyepiece and using a calibrated mechanism to rotate the prism. Thus the wave length may be determined by setting the line on the pointer and reading the wave length on the prism rotating mechanism.



Procedure

The optical system was aligned by placing the oscillator unit, then the two optical benches parallel to each other and level as shown in fig. 9. The lenses were then positioned to the same height as the center of the spectroscopy slit. The spectroscopy was set on a flat aluminum plate with a pivot screw directly under the spectroscopy slit. Thus to position the spectroscopy for maximum intensity, it is only necessary to move the plate (it rotating about the pivot screw) causing the spectroscopy, to rotate about an axis through the slit. The lenses, spectroscopy, and source were then aligned by use of a straight edge and plumb-bob. The lens L_1 was placed with the lamp in its focal plane, and lens L_2 with the spectroscopy slit in its focal plane. The spectroscopy was adjusted for maximum intensity and the interferometer was placed between the two lenses. The position and adjustment of the interferometer and the fine adjustment of lens L_2 — the focal adjustment of lens L_1 is not critical — were then made by using a mercury electrodeless lamp as a source and observing the interference fringes.

The fine adjustment of lens L_2 was made with the micrometer adjustment to produce the sharpest fringes.

After adjustment visually, the fringe patterns were photographed by placing a camera, properly focused, adjacent to the eyepiece.

The camera, an f/8 box camera, was set with the camera

lens within $1/4$ to $3/8$ of an inch of the eyepiece lens of the spectroscope, and focused on the pointer in the spectroscope.

The pictures were all taken on Kodak Safety film, Super Panchro-Press, Type B size $2\ 1/2 \times 3\ 1/4$ inches, and developed for $3\ 1/2$ minutes in Kodak D-19 developer.

Results

The pictures on the following pages show some of the fringes produced with the electrodeless lamps and a common mercury arc light as sources; using the optical system described above. The interferometer plate separation was 15 mm giving a spectral range $\Delta\lambda$ of 0.33 cm^{-1} . At $\lambda = 5461\text{\AA}$ the spectral range in angstroms is $d\lambda = 0.098\text{\AA}$.

The mercury arc used was a Cooper-Hewitt Lab-arc quartz lamp operating on 110 volts, 60 cycle current without an external resistance; thus it operates as a low pressure arc when first lit and as a high pressure (perhaps a pressure of one atmosphere) arc when it warms up.

The fringes show that the Lab-arc produces a very narrow line and strong radiation of $5461\text{\AA}$ when cold (when first lit) and as the lamp warms up the $5461\text{\AA}$ line becomes very broad so that the interference fringes over-lap, as shown, to such an extent that the fringes are difficult to distinguish.

The hyperfine structure of the natural mercury $5461\text{\AA}$ line shows up very well in the photographs of the spectrum of the cold mercury-arc lamp but in a very short time the lines broaden out to a great extent; therefore the mercury arc lamp would not produce a fine line spectrum long enough to make adjustments on the system or for observation.

The hyperfine structure in the spectrum of the electrodeless lamp containing natural mercury does not appear clearly

in the photographs but is easily seen visually. The hyper-fine structure from this electrodeless lamp was much clearer than that from the cold mercury arc lamp when they were observed visually, even though the electrodeless lamp had been in operation for an hour or more. Some of the things that caused this lack of detail in the exposures are the long exposure times required, temperature changes that may take place during the exposure, and the vibrations in the building and equipment.

The photograph of the fringes produced by NBS Meggers mercury 198 electrodeless lamp shows very narrow and sharp fringes which would probably have been even more narrow and sharp if effects due to temperature changes and vibrations had been eliminated. Some rather rough measurements made on the photograph give a line width of about 0.007 angstrom.

Lamps were made with "sealing-off-pressures" from one mm to seventeen mm but the only ones that operated satisfactorily had "sealing-off-pressure" of 3 mm or less. See table below.

Lamp No.	"Kind"	"Sealing-off-pressure"		
18	A	2.5 to 3.0	(mm of Hg)	
27	Hg	3	"	" "
34	He	3	"	" "
NBS Meggers Hg	Hg ¹⁹⁸	3	"	" "
29	CdI ₂	3	"	" "
30	HgCl ₂	2.5-3.0	"	" "
39	Cd	1-1.5	"	" "



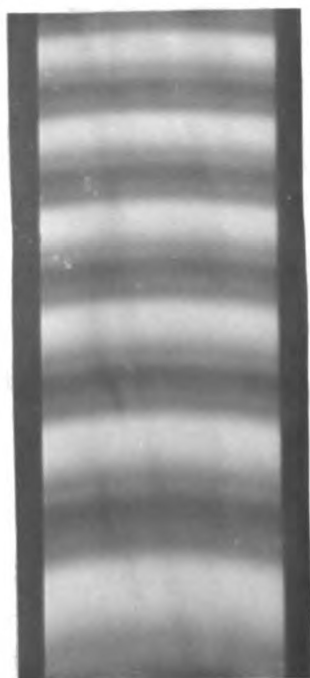
30 min. exposure
He 5015.9A
Electrodeless
Lamp No. 34



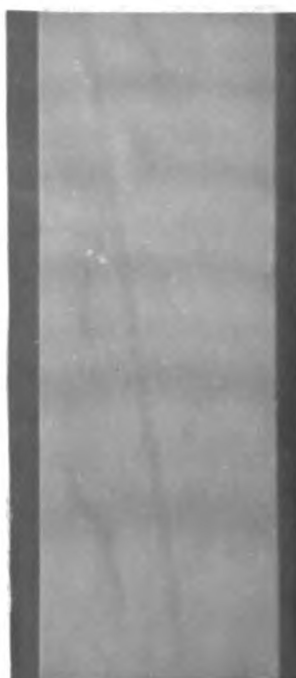
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He 4921.9A
Electrodeless
Lamp No. 34



14 hr. exposure
A region of 4200A
Electrodeless
Lamp No. 18



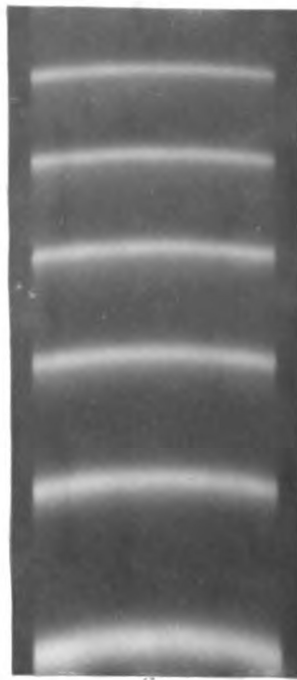
30 sec. exposure
Hg 5461A(natural)
Arc cold



10 sec. exposure
Hg 5461A(natural)
Arc after 20 min.
of operation



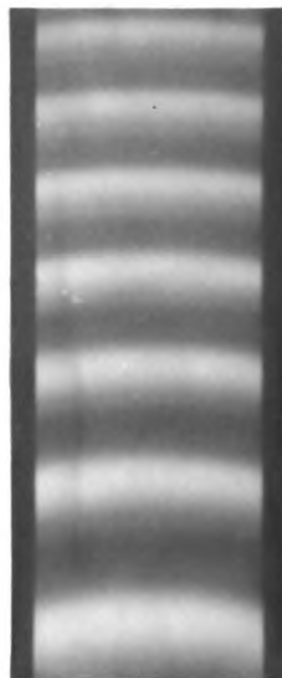
16 min. exposure
 Hg^{198} 5770, 5790A
 NBS Meggers Hg^{198}
 Electrodeless



3 min. exposure
 Hg^{198} 5461A
 NBS Meggers Hg^{198}
 Electrodeless



8 min. exposure
 Hg 5770, 5790A (natural)
 Electrodeless
 Lamp No. 27



2 min. exposure
 Hg 5461A (natural)
 Electrodeless
 Lamp No. 27

Conclusions

Several electrodeless lamps were made containing a variety of substances and a high frequency oscillator was designed and built to operate the lamps. While many of the lamps did not produce the desired spectrum, it is believed that much of the trouble was due to insufficient power to operate the lamps properly. The lamps when working properly are quite intense and produce a narrow line spectrum, over long periods.

From the results obtained with the lamps produced in this project it is believed that the best "sealing-off-pressure" is of the order of 3 mm of Hg or less. This is the lower limit of the recently published work ^{4,6}.

What appears to have been clean-up has been observed when exciting the cadmium lamps at a frequency of 378 megacycles. It has been reported that in the mercury lamps that clean-up is very slow or non-existent if operated above 100 megacycles.

The comparison of the spectrum of electrodeless lamps with that of other sources is made best visually unless their intensities are nearly the same; then the actual results are not interfered with by difference in exposure times.

A refinement of the work with these lamps would be the inclusion of an accurately controllable temperature bath. The photographs of the argon and helium lines would probably have shown narrower fringes if the lamps had been cooled.

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