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AN INVESTIGATION OF THE OUTPUT OF A GAS LASER WITH VARIATION OF PARAMETERS

John Davis Hunsuck, B.E.E.

Capt. USAF

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Preface

When I started work on the construction of the helium-neon gas laser, the work appeared to be straight forward and relatively simple. I figured that the greatest amount of time would be spent obtaining the coated Fabrey-Perot reflectors. It turned out that the reflectors were available long before the complete unit could be assembled. The vacuum system gave me many headaches. Leaks and cracks which formed during bake-out, and the epoxy used to seal the system caused a lot of concern. At times I was not sure that it would ever be completed. Success, although it came late in the time allowed, was very welcome.

Many thanks to Dr. Wm. C. Eppers, Dr. G. Medicus, Mr. W. Jehn, Mr. F. Ruf, and Mr. Mason Friar of the Gaseous Electronics Section of the Electronics Technology Laboratory for all the time and help they so selflessly gave to assist me in this project. Thanks also to my wife who typed the rough draft and put up with my grouchiness while I was struggling with the several phases of the thesis.

John D. Hunsuck

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Abstract

Need for construction of laser is discussed. Design criteria of laser are established. Accuracy of adjustments is established. Requirement of temperature compensation of laser is discussed. The final design of the gas laser is described. Theory of operation of the helium-neon gas laser is outlined. Derivation of field distribution in the laser interferometer is given. Mode patterns of the output are discussed. Stability of the laser is given. Further studies possible with the laser are outlined and discussed.

AN INVESTIGATION OF THE OUTPUT OF A GAS LASER WITH VARIATION OF PARAMETERS

I. Introduction

The recent development of the gas laser which emits a continuous and highly coherent wave has opened a great number of avenues for the use of the laser in studies which require monochromatic light sources and in communications where the crowding of the lower frequencies has forced investigations into the infrared and visible spectrum for sources of usable amounts of coherent power in the micron wave lengths. The problem of modulating, amplifying, and demodulating these sources became apparent. The parameters of the laser which may be varied to produce an intelligence modulated output must be investigated with an aim to find the most efficient method of accomplishing this transmission of information on the beam produced by the laser. The major amount of work in this investigation is the construction of a flexible laboratory version of the helium-neon gas laser whose parameters can readily be varied in a controlled manner and the effect of such variation measured in the output.

Fine adjustment of every parameter of the laser is necessary in order that the effect of small changes of each parameter can be measured with high accuracy. Temperature stability of the laser operation is very important to maintain operation within one set of adjustments over a long period of time. Control of thermal expansion of metal parts so that their total effect is less than one-half micron change in effective length of the laser tube and less than one second of arc in angular displacement of the ends of the laser tube is necessary for accurate determination of effects of mechanical adjustments of the laser dimensions (Ref 3:1521). Due to the lack of exact published data on the design of the He-Ne gas laser, it was decided that maximum exactness within the capabilities of the Institute shops would be utilized in the design of mechanical parts of the gas laser. Dr. Francis Turner of Bausch and Lomb was contacted, and he agreed to coat the flat reflectors used at the ends of the laser tube. Mr. Daniel George of General Telephone Laboratories coated two concave mirrors for use in the laser.

More difficulty than was anticipated was encountered in the construction of the laser due to the high vacuum necessary to insure a very clear discharge of the He-Ne plasma. The required cleanliness of the inside of the laser tube and filling manifold led to the development of highly refined methods of brazing of the copper, kovar, glass, and stainless steel parts which make up the gas filled system. Using the best methods available, it took more than one month just to assemble the sensitive gas system.

Since so much time was spent in the fabrication of the laser, there was not enough time available to make all the measurements which would be required to complete the sets of specific output changes with the several sets of adjustments which should be examined more thoroughly. Most of this thesis will, therefore, be concerned with the fabrication and necessary construction specifications of the gas laser.

II. Gas Laser Design

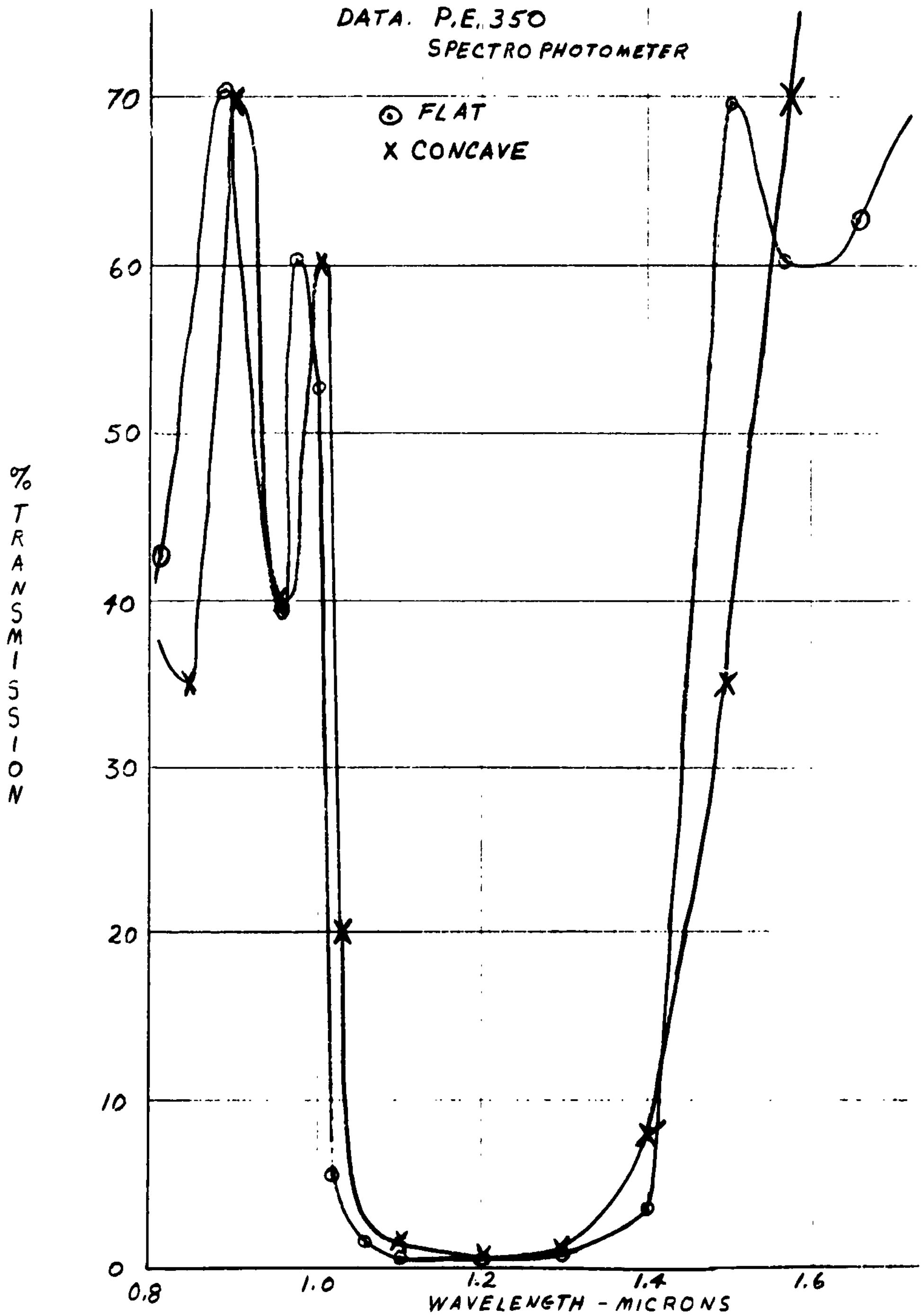
The required mechanical accuracy of the design of the gas laser to give the necessary flexibility of adjustment and measurement of the adjustments of the several parameters of the gas laser will be discussed first. For the measured variations in output to be meaningful, the accurate measurement of the parameter being changed is necessary.

The general dimensions of the gas laser are well-known, but precise limits on the length of the discharge tube versus the diameter of the tube and effect of the change in dimensions with temperature are not published. As a starting point, it was decided that a tube of about one meter length and one cm inside diameter should be large enough to give measurable amounts of power output, and its dimensions would give no great problems in alignment and support. Tubes up to two meters in length and six mm inside diameter have been built, but it was decided that supporting such a tube and maintaining it optically straight would impose problems which would detract from the goals of this laser design (Ref 2:107).

It is necessary to attach highly reflective surfaces at the ends of the discharge tube to set up a standing wave of the operating frequency along the tube. In effect, the mirrors must act as the ends of a cylindrical resonant cavity. Silvered mirrors do not reflect efficiently enough for good operation, being just over 90% reflective at the infrared frequency at which the He-Ne gas laser operates. A multiple layer dielectric coating on an optically flat glass blank is used to achieve 98% reflection and about 1% transmission. Alternating layers of zinc sulfide and magnesium fluoride are evaporated onto the surface of the glass, each layer being $1/4\,\lambda$ thick at the desired operating frequency until about 1% transmission of the operating frequency is achieved. This usually results in 11 to 14 layers. The flat reflectors used in this laser have 13 layers, and the concave mirrors have 11 layers. The curves of the transmission of different wavelengths through the operating frequency region for the flat and concave mirrors are shown in Fig. 1 on the following page.

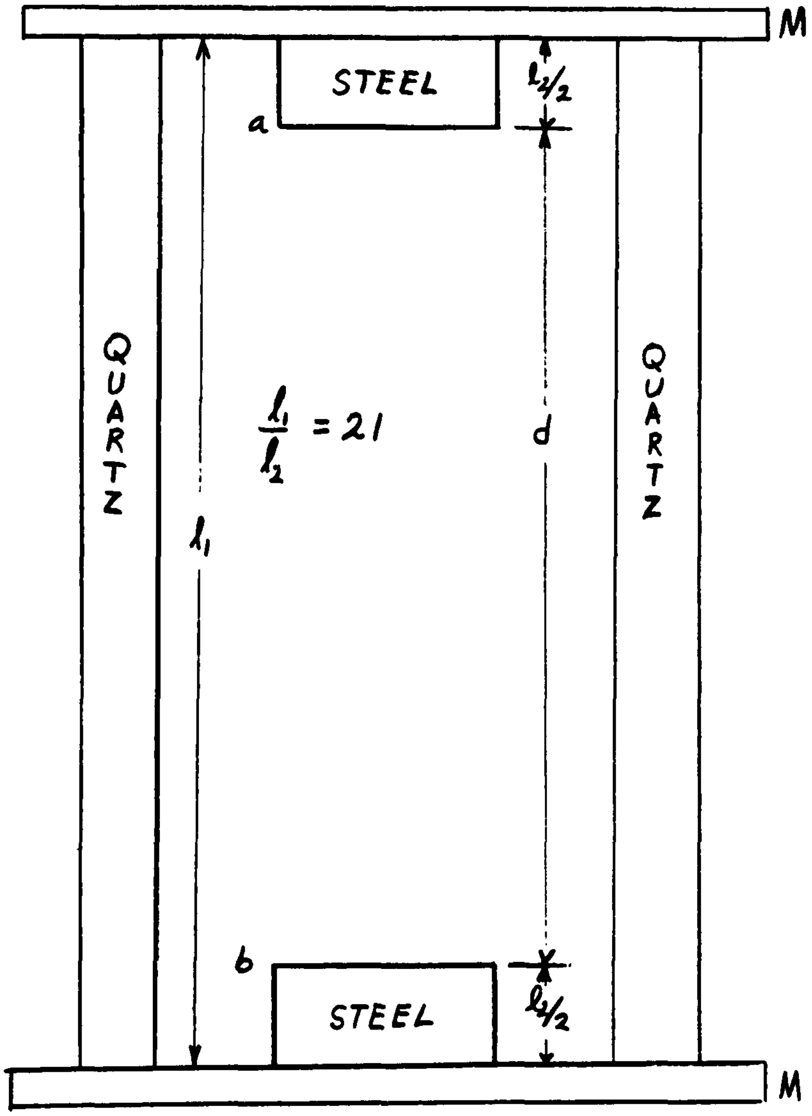
To maintain the effective length between the mirrors of the laser constant, a system of quartz and steel tubes is utilized. The thermal expansion coefficient of quartz is 0.50×10^{-6}, and the thermal expansion coefficient of steel is 10.5×10^{-6}. Therefore, to get the same linear change in lengths of steel and quartz tubes for the same change in temperature of the tubes, a ratio of length of quartz to steel of 21:1 is necessary. If the quartz and steel tubes are arranged as shown in Fig. 2 (page 6), the distance, d, remains a constant over a range of temperature from $0^{\circ} - 100^{\circ}$C.(Ref 8:2275). If the plates, M, are allowed to slide on a smooth surface and the reflectors are effectively mounted at b, the distance between the reflectors will not change with temperature variations in the above range.

A method of aligning the mirrors so that their reflective surfaces are parallel to each other and perpendicular to the axis of the gas discharge tube is necessary. A two degree of freedom gimbal mount has been devised to permit very fine adjustment of these parameters. The design drawings of these gimbals are shown in Figs. 3 and 4 on page 7 and in Fig. 5 on page 8.



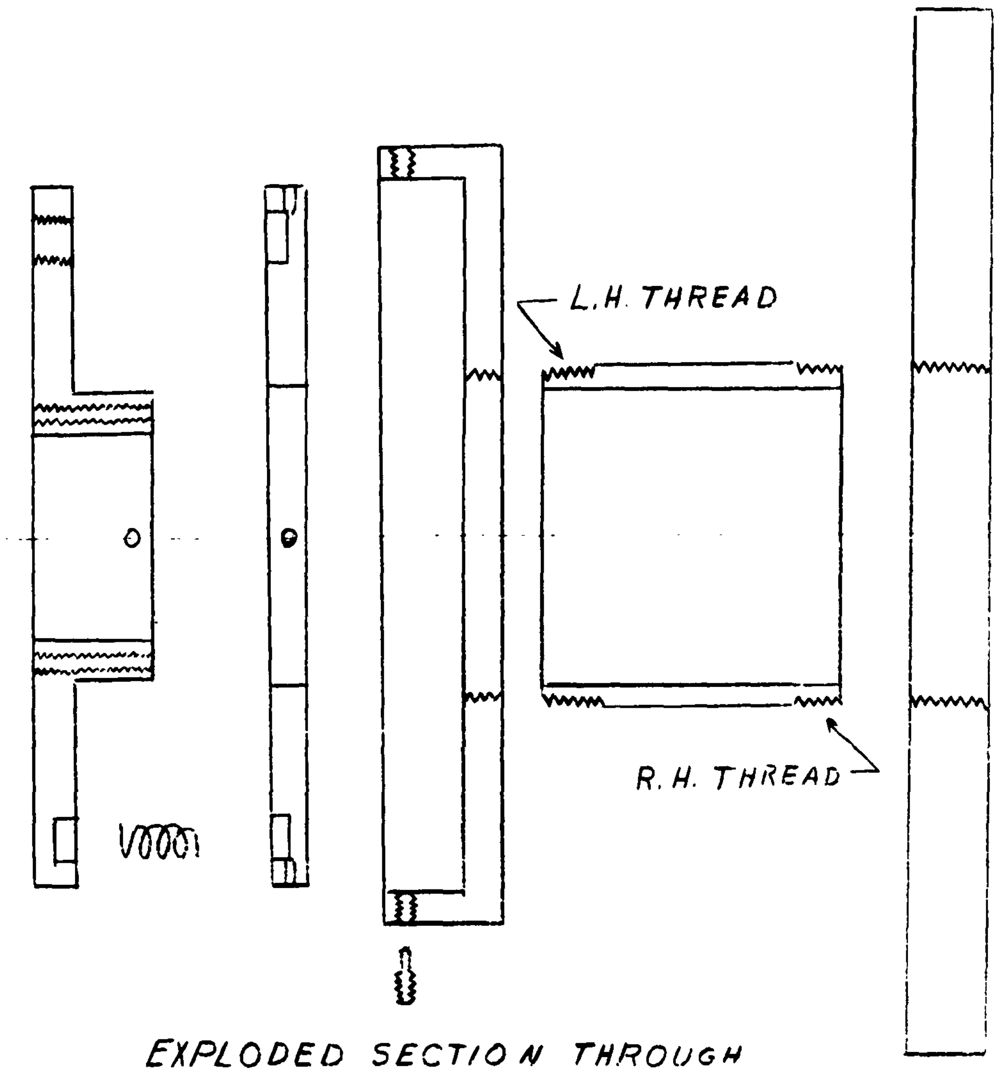
TRANSMISSION CURVES -REFLECTORS

FIGURE 1

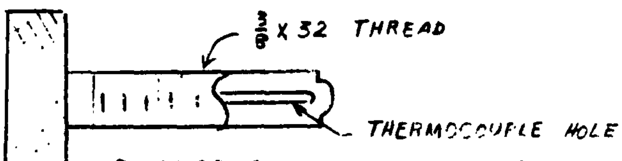


TEMPERATURE COMPENSATION ARRANGEMENT

FIGURE 2

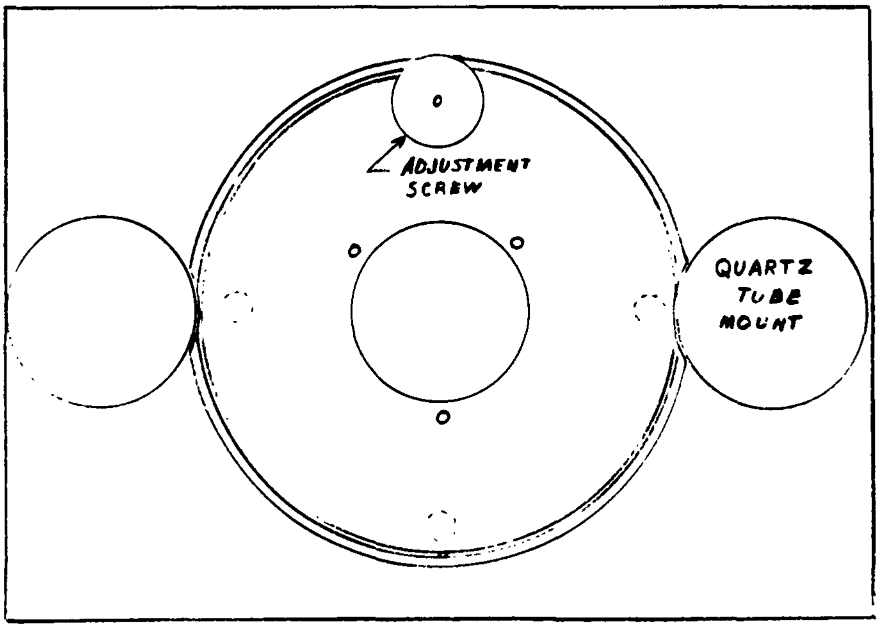


EXPLODED SECTION THROUGH
VERTICAL AXIS
GIMBAL END MOUNT
FIGURE 3



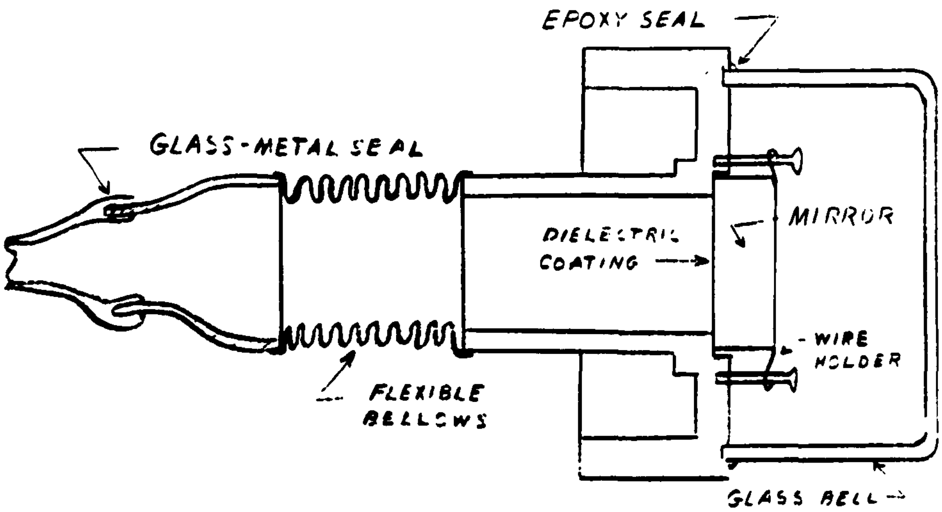
COARSE ADJUSTMENT SCREW

FIGURE 4



MIRROR GIMBAL MOUNT, END VIEW

FIGURE 5

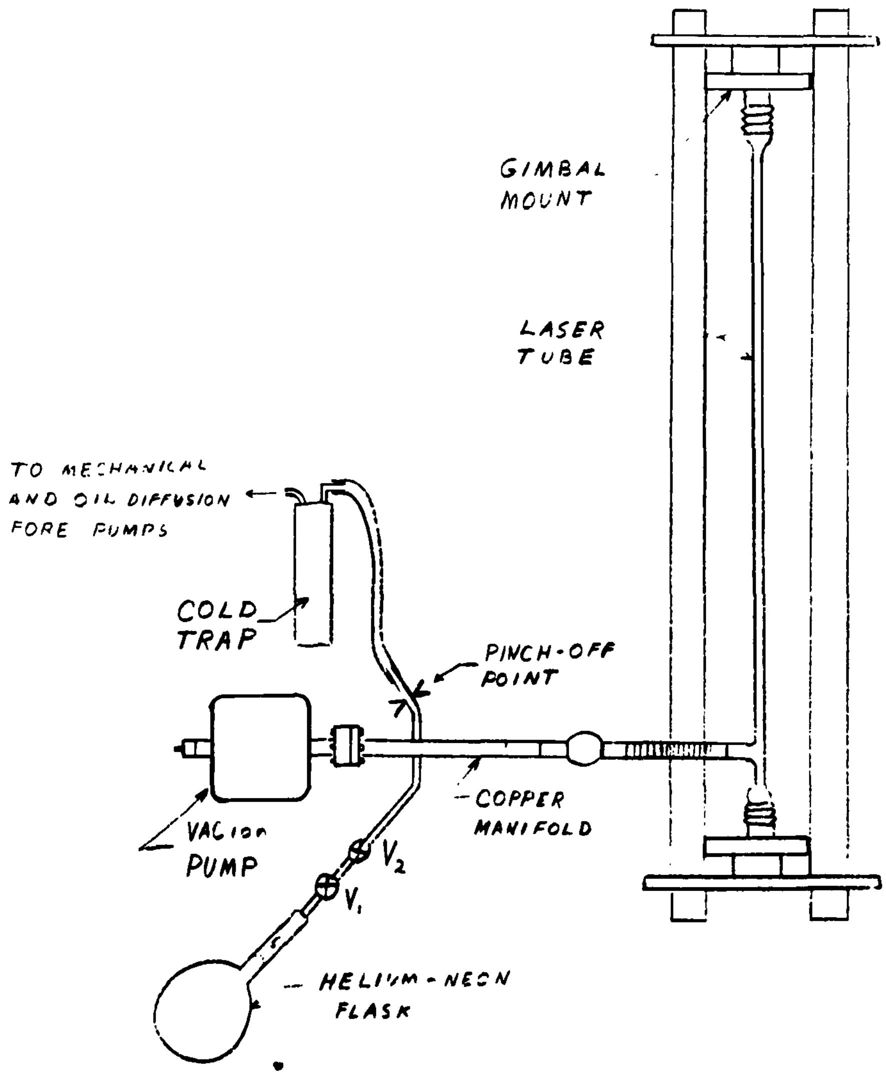


MIRROR HOLDER AND END BELL

FIGURE 6

The mirrors used in this laser are mounted within the gas system, requiring that the mirror mounts be gas tight. The design drawing of the mounts and bell covers for the mirrors is shown in Fig. 6 on page 8; a metal bellows allows attachment of the mirror mount to the glass discharge tube and freedom of movement of the mount within the gimbals. The mirror mount is so designed that the reflecting surface of the mirrors is in the plane of the axes of the gimbals. This allows adjustment of alignment of each axis without cross-coupling to the other axis. The threads of the adjusting screws have a pitch of 1/32 of an inch which will move the mirror through 43 minutes of arc for each full turn of the screw. For finer adjustment of the mirrors, heater collars can be slipped over the screws to give approximately one second of arc movement for each 10°C. temperature rise. The precise angular movement of the mirrors by this method has not been verified due to lack of instruments to measure such small deflections. As is shown in Fig. 4 (page 7), a hole has been drilled into each gimbal adjustment screw to allow a thermocouple to be installed for measuring the temperature of the screw under the heater collar so that a correlation can be made between temperature of the screw and deflection of the mirror. A heater and thermocouple can also be wrapped around the temperature compensating tubes to adjust the distance between the mirrors.

A large part of the problem of building the gas laser was devising a system to pump a hard vacuum within the tube and allow a measured amount of He-Ne mixture into the tube at the proper pressure. It was decided that a mechanical vacuum fore pump and oil diffusion pump would be used to pump down to about 10^{-4} mm Hg; these pumps would then be removed from the system by pinching off a copper exhaust tube with a hydraulic pinch-off tool which cold welds the copper tube in a vacuum tight seal. A VACion pump which is sealed into the manifold (as shown in Fig. 7 on page 11) would then take over and complete the pumping down to about 10^{-7} mm Hg. The high vacuum valve, V_2, would then be closed and the break off seal on the He-Ne bottle would be opened. The bottle holds a 10 to 1 helium-neon mixture at 1 atmosphere (760 mm Hg). The volume between the high vacuum valves has been measured at 1 cubic centimeter and the volume of the rest of the vacuum system is 830 cubic centimeters. This ratio gives a final pressure within the laser tube of 0.915 mm Hg when the first valve is closed and the second valve opened allowing the gas to expand into the system. The VACion pump remains in the system to allow a clean-up of impurities, if necessary, after filling with gas. The VACion pump will pump the noble gases very slowly and can be used in a cataphoresis experiment which will be discussed in a later section. It was thought at first that a vacuum of better than 10^{-8} mm Hg could be accomplished, but the epoxy glue used to seal the end bells onto the mirror mounts evidently out-gasses at about the pump rate of the VACion pump at 10^{-7} mm Hg. It was decided that the laser should be filled at this pressure, and, if necessary, the tube could be cleaned further by the selective pumping of the VACion at the total pressure of the He-Ne mixture. Although the spectrum as viewed by a portable spectroscope showed lines which were not contained in a pure He-Ne discharge, the laser action did not seem to be impaired appreciably by the impurities. The impurities are present at the ratio of one part in ten million, and running the VACion while the



LASER AND MANIFOLD

FIGURE 7

discharge in the laser tube is taking place appears to decrease the intensity of the spectral lines present due to the impurities. These impurities may be coming from the glass tube itself which is made of kovar 7052 glass since the flux used in the manufacture of the glass contains chlorine. These impurities may also be coming from the epoxy. A spectral analysis by the materials lab should reveal the exact types of impurities present. A kovar 650 glass tube which is manufactured without the use of a chlorine flux is available and should be used if the laser is rebuilt at a later date.

In the final configuration, a combination of concave and flat mirrors is used. The concave mirror has a radius of curvature of 36 inches, and the flat mirror is placed just inside this radius. This arrangement allows easy adjustment for laser action and selection of mode of oscillation (Ref 7:743). The laser has operated in a single mode for about twelve hours. The laser design thus satisfies the requirement for stable operation under changing thermal conditions, and the mechanical integrity of the supporting structure appears satisfactory.

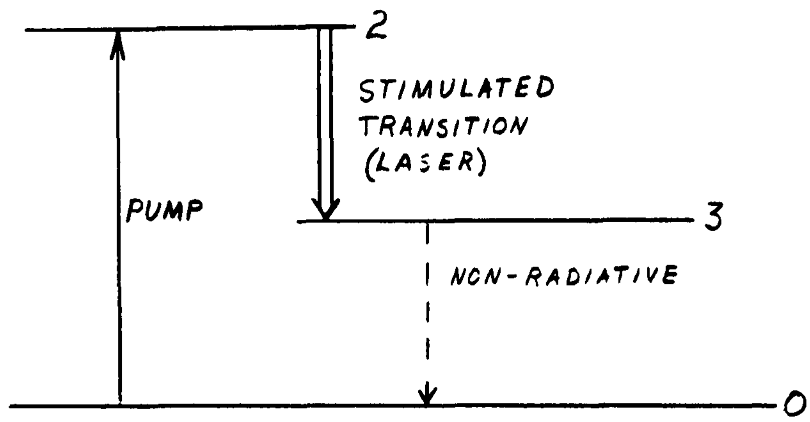
III. Theory of Operation

It has been shown that transitions between energy states within the atomic structure occur in discrete quanta of energy. The masers and lasers utilize this phenomenon in their operation by choosing, in various manners, which energy transitions are to be used. These energy states are quantized and are represented by the equation

$$E = h\nu \tag{1}$$

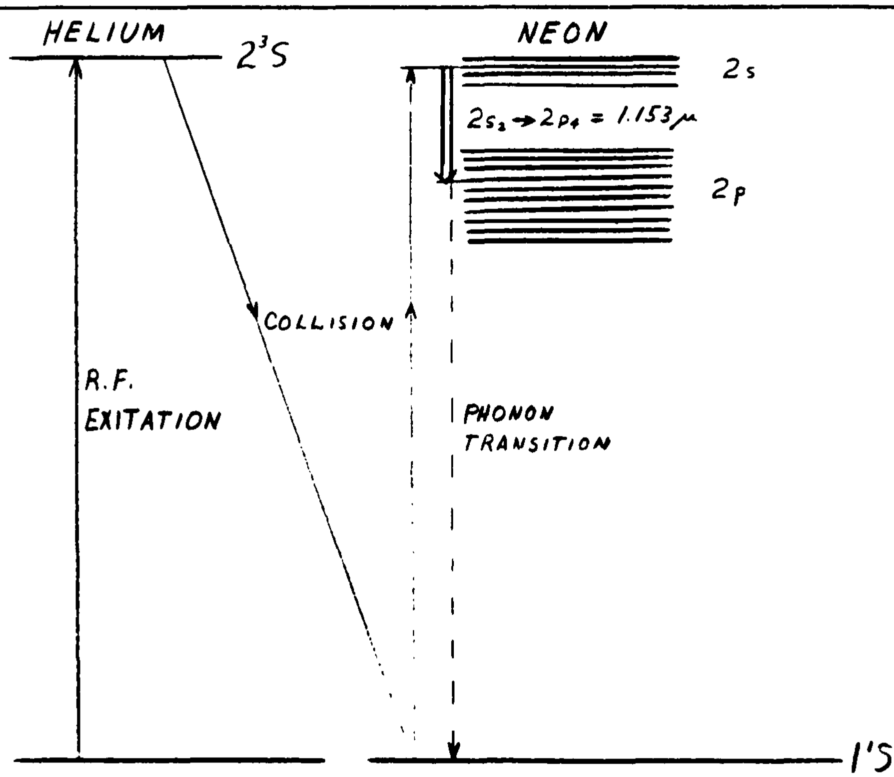
where E is the difference in energy between two states of the atom, h is Planck's constant, and ν is the frequency of radiation or absorption associated with the transition. By adding energy to the atom in the form of electromagnetic radiation of a frequency corresponding to the difference between two allowed energy states, the atom absorbs a quanta of energy from the wave and moves to a higher energy state. The atom is unstable in this higher energy state and will return after a time, τ, corresponding to a probability function of the atom structure, giving off a quanta of energy in the form of electromagnetic radiation or in phonon form wherein the molecular material rises in temperature. This first type of transition is used in the laser.

If an electromagnetic wave passes through an atomic structure whose energy state is excited to a level corresponding to an energy difference above a lower state to which a transition can be made and this energy difference coincides with the frequency of the electromagnetic wave as in Eq (1), the atoms will be stimulated to fall to the lower state and give their quanta of energy to the electromagnetic wave. This action causes the wave to grow in magnitude as it passes through the medium and may be considered as amplification of the incident wave. The process of getting the atom of the medium into the excited state from which the amplifying transitions can be made is called "pumping". This pumping of the atom into the excited state creates a condition known as "population inversion". To keep the pumping energy from interfering with the incoming or generated signal, the pump frequency is usually higher than the signal frequency. This separation of the pump energy from the signal energy is accomplished by pumping the atoms to a high state over several energy levels at once and using only a portion of this pump energy in the downward transition for amplification. This can be done in several ways, but a simple explanation is given by referring to Fig. 8 on page 15. The pump energy causes the transition from energy level 0 to 2. Stimulated emission amplification takes place during the transition from 2 to 3. The transition from 3 back to 0 is actually a loss in the total system and is usually a phonon transition which raises the temperature of the medium. The laser must depend upon the ability of the atom being used to remain in state 2 long enough to wait for the signal wave to come along and vacate level 3 fast enough to allow the transition from 2 to 3 to take place. The time that the atoms will spend in each energy level is a probability function of the atomic structure and limits the selection of materials available for laser action.



LASER TRANSITION MODEL

FIGURE 8



HELIUM-NEON LASER ENERGY TRANSITIONS

FIGURE 9

As mentioned before, any method which can be devised to create the population inversion between the desired levels within the atomic structure can generate laser action in the medium. The helium-neon laser built for this study used a different method than that explained above, but the result is effectively the same. A model of the energy levels of the helium and neon is shown in Fig. 9 on page 15. The helium atoms are excited to the 2^3S level by an R.F. discharge. This energy level is 19.81 ev above the zero or ground state of helium. The helium atom will maintain this state for about 1 millisecond, during which time it is accelerated by the electric field of the R.F. discharge in the gas. The helium atoms collide with neon atoms, with a slight energy loss (heat) causing the neon to jump from its ground state to the 2s levels that the neon may occupy according to the amount of energy gained from the helium collision. The neon atoms will tend to remain in any of the 2s states for a time of about 1 millisecond at which time it will spontaneously fall to any of the next ten 2p states with a probability of the transition to each of the states varying from 0 to 7/9 as computed by Koster and Statz. These probabilities are shown in Table I along with the wavelength of the emission and energy difference in electron volts (Ref 5:2055). Table I appears on the following page.

Between the four 2s levels and ten 2p levels there are 32 possible transitions. One of the more probable transitions is from the $2s_2$ to the $2p_4$ corresponding to a quanta of photon energy of 1.15259 micron wavelength or 11,525.9 Å. The neon atom is very unstable in the 2p levels and will return to the ground state after about 10^{-6} second which opens

Table I

Neon Transition Table

Transition		λ(microns)	Relative Probability	Energy (ev) Difference	Observed Laser Action
$2s_2$	$2p_{10}$	0.88677	0		
3	10	0.89910	0		
4	10	0.94893	1/18	1.309	
5	10	0.96681	5/18	1.285	
2	9	1.01239	0		
3	9	1.02850	0		
2	8	1.02982	0		
3	8	1.04648	0		
2	7	1.06236	0		
3	7	1.08010	0		
2	6	1.08475	0		
4	9	1.09422	0		
3	6	1.10325	0		
4	8	1.11461	1/2	1.113	
5	9	1.11806	7/9	1.109	1.118
5	8	1.13936	1/18	1.088	
2	5	1.14123	1/9	1.087	
2	4	1.15259	5/9	1.077	1.153
4	7	1.15282	5/18	1.076	
2	3	1.16047	0		
3	5	1.16173	2/9	1.068	1.160
3	4	1.17351	0		
2	2	1.17700	2/9	1.053	
4	6	1.17923	1/18	1.052	
5	7	1.17931	1/18	1.051	
3	3	1.18168	0		
3	2	1.19882	1/9	1.032	1.199
5	6	1.20696	1/2	1.027	1.207
4	5	1.24628	0		
4	4	1.25984	0		
4	3	1.26927	1/9	.979	
5	5	1.27730	0		
4	2	1.28907	0		
5	4	1.29156	0		
5	3	1.30146	0		
5	2	1.32229	0		
2	1	1.52349	1/9	0.81	
3	1	1.56025	0		
4	1	1.71666	0		
5	1	1.77608	0		

up the 2p state for another transition to take place from the 2s level. The helium again collides with the neon, raising it to the 2s level again and the process repeats itself. If a signal of 11,525.9 Å wavelength impinges upon an atom of neon in the $2s_2$ level and the $2p_4$ level is empty, the transition will be "stimulated" to take place increasing the magnitude of the incident wave. The incident wave may be an external signal or a wave from another atom making a spontaneous transition. In the helium-neon laser built for this study, the laser is pumped with enough energy to invert the population to the point that oscillation occurs if the cavity containing the gas is "tuned" in some manner to reflect the electromagnetic energy of the spontaneous emissions repeatedly through the excited gas. This cavity is tuned by the placement of frequency selective reflectors at the ends of the tube containing the gas. These reflectors are known as Fabrey-Perot interferometer mirrors. Their reflection is maximized at a single band of frequencies by the method discussed in Section II of this thesis.

If the reflectors are placed an odd number of half-wavelengths apart, the fields will be in phase after each reflection and a standing wave at the selected frequency will result. If this condition is achieved, a steady state will be reached with the magnitude of the standing wave remaining constant and the helium-neon collisions and transitions taking place at a steady rate at a single frequency of stimulated emission. Since the Fabrey-Perot reflectors are not perfect, about 1% of the energy is transmitted through the mirrors and out of the cavity. This beam is of a single frequency, highly directive and coherent in both time and space if the reflectors remain stationary.

The possible modes that can occur within the interferometer are necessarily transverse electromagnetic or TEM_{mnq} since there are no boundaries along the tube. The development of the solutions for the fields within the tube between the reflectors is as follows (Ref 7:460-461).

If the dimensions of the interferometer using confocal spherical mirrors or flat mirrors are such that the distance between the mirrors is much greater than the diameter of the mirrors, the solution for the distribution of the fields can be obtained by an iterative process. Assuming that a plane wave originates between the reflectors and impinges normally on the surface of the mirror, the iterative equation for computing the steady state field distribution can be written:

$$E_{q+1}(r_2, \varphi_2) = \frac{j}{2\lambda} \int_0^a \int_0^{2\pi} E_q(r_1, \varphi_1) \frac{e^{-jkR}}{R} (1 + \frac{b}{R}) r_1 \, d\varphi_1 \, dr_1 \qquad (2)$$

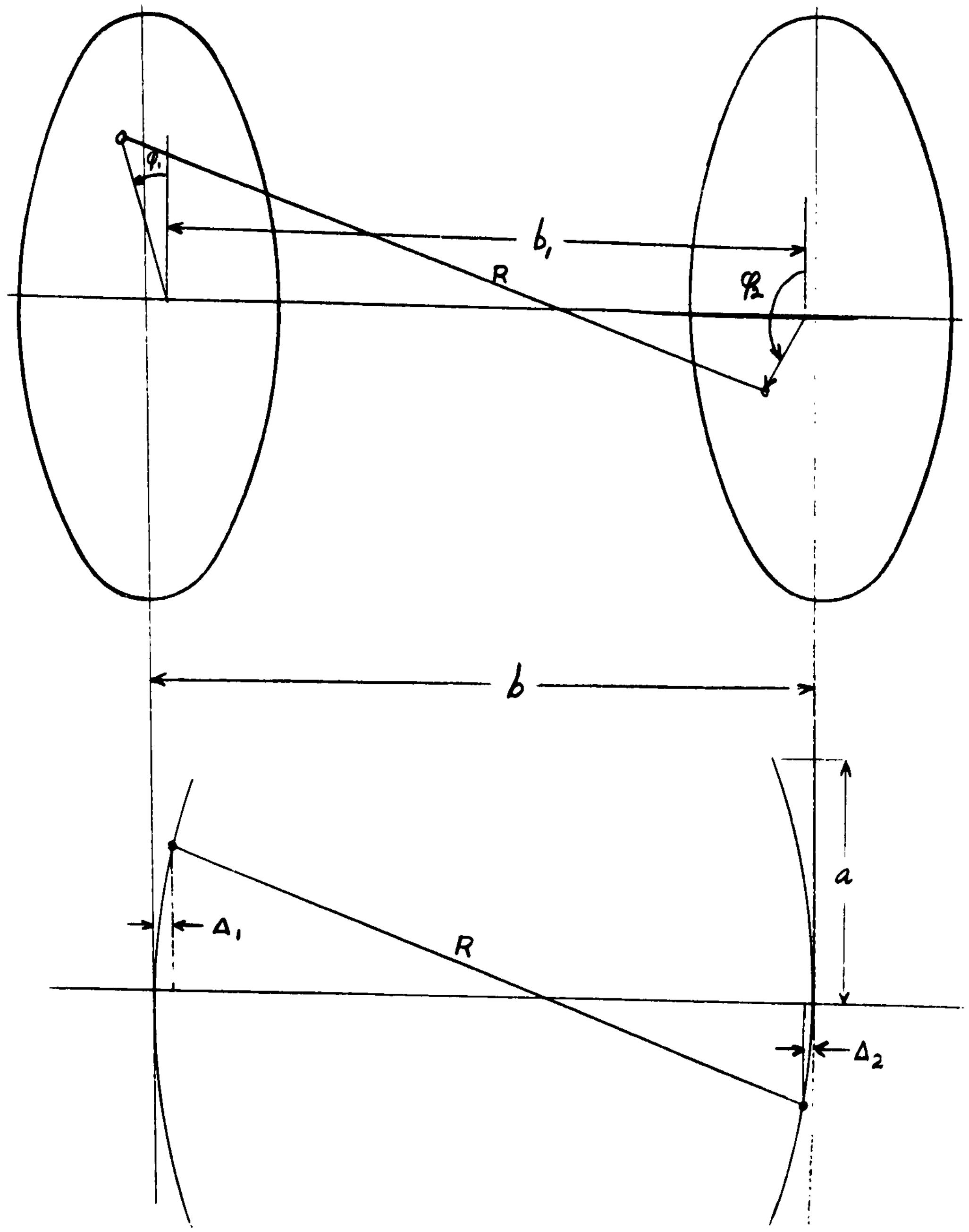
Referring to Fig. 10 on page 20 for the dimensions, where

$$R = \sqrt{b^2 + r_1^2 + r_2^2 - 2 r_1 r_2 \cos(\varphi_1 - \varphi_2)}$$

and if $a^2/b\lambda \leqslant (b/a)^2$ Eq (2) reduces to

$$E_{q+1}(r_2, \varphi_2) =$$

$$\frac{je^{-jkb}}{\lambda b} \int_0^a \int_0^{2\pi} E_q(r_1, \varphi_1) e^{-jk\,(r_1^2 + r_2^2)/2b - (r_1 r_2/b)(\cos\varphi_1 - \varphi_2)} r_1 \, d\varphi_1 \, dr_1 \qquad (3)$$



GEOMETRY OF THE CONFOCAL SPHERICAL RESONATOR

FIGURE 10

since

$$e^{jn(\pi/2 - \varphi_2)} J_n \left(\frac{k\, r_1\, r_2}{b}\right) = \frac{1}{2\pi} \int_0^{2\pi} e^{jk(r_1\, r_2/b)\, \cos(\varphi_1 - \varphi_2) - jn\, \varphi_1}\, d\varphi_1 \qquad (4)$$

and integrating Eq (3) with respect to φ_1 it is seen that

$$E(r, \varphi) = R_n(r)\, e^{-jn\varphi} \qquad n = \text{integer}$$

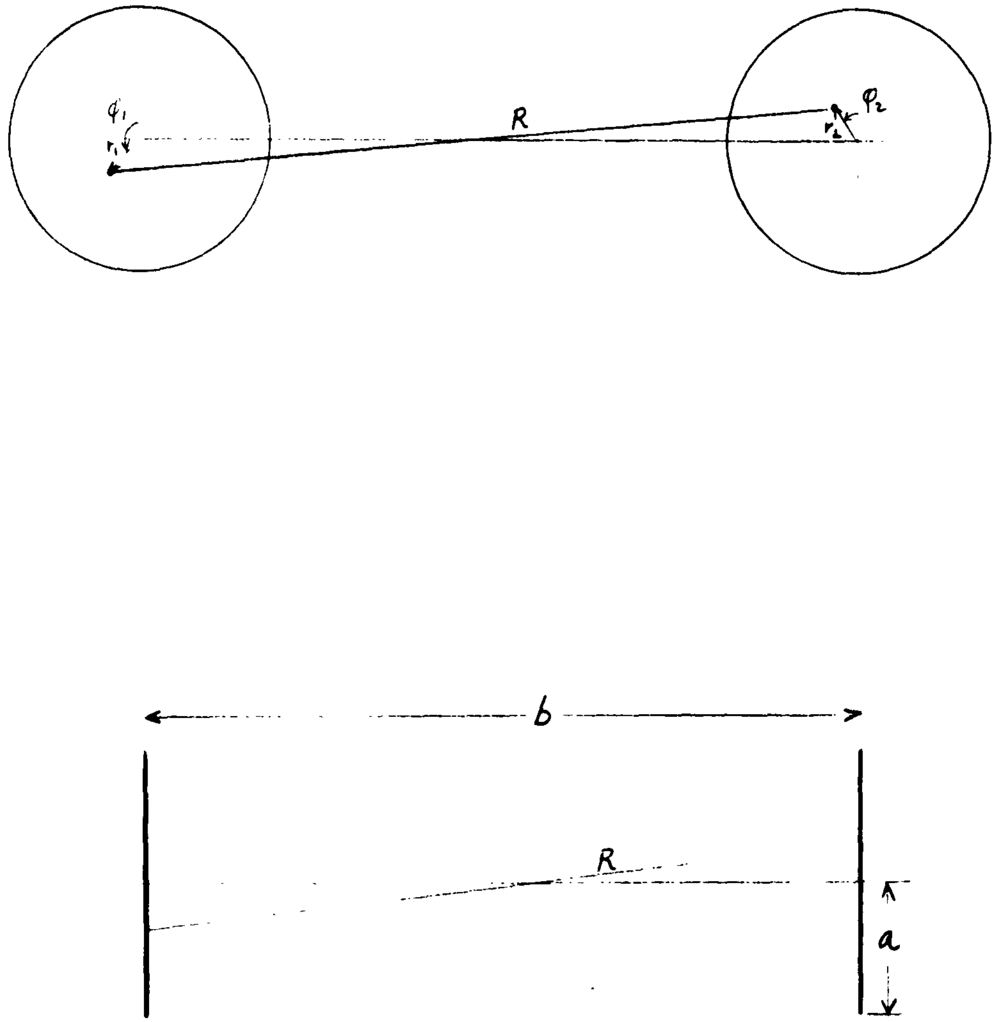
satisfies Eq (3). The function $R_n(r)$ satisfies the reduced integral equation:

$$R_n(r^2) \sqrt{r_2} = \gamma_n \int_0^a K_n(r_2\, r_1)\, R_n\, (r_1) \sqrt{r_1\, dr_1} \qquad (5)$$

when

$$K_n(r_2\, r_1) = \frac{j^{n+1}\, k}{b}\; J_n\left(k\, \frac{r_1\, r_2}{b}\right) \sqrt{r_1}\; r_2\; e^{-jk\, \frac{r_1^2\, r_2^2}{2b}} \qquad (6)$$

with $J_n(r)$ a Bessel function of the first kind of the n^{th} order. These solutions satisfy the conditions for either the flat reflectors shown in Fig. 11 on page 22 or the confocal spherical reflectors shown in Fig. 10 on page 20; therefore the identical mode pattern should be observed with either arrangement or a combination of a spherical and flat mirror. These mode patterns are observable and have been photographed. Some examples of these photographs will be identified in the next section of this thesis.



GEOMETRY OF FLAT MIRROR RESONATOR

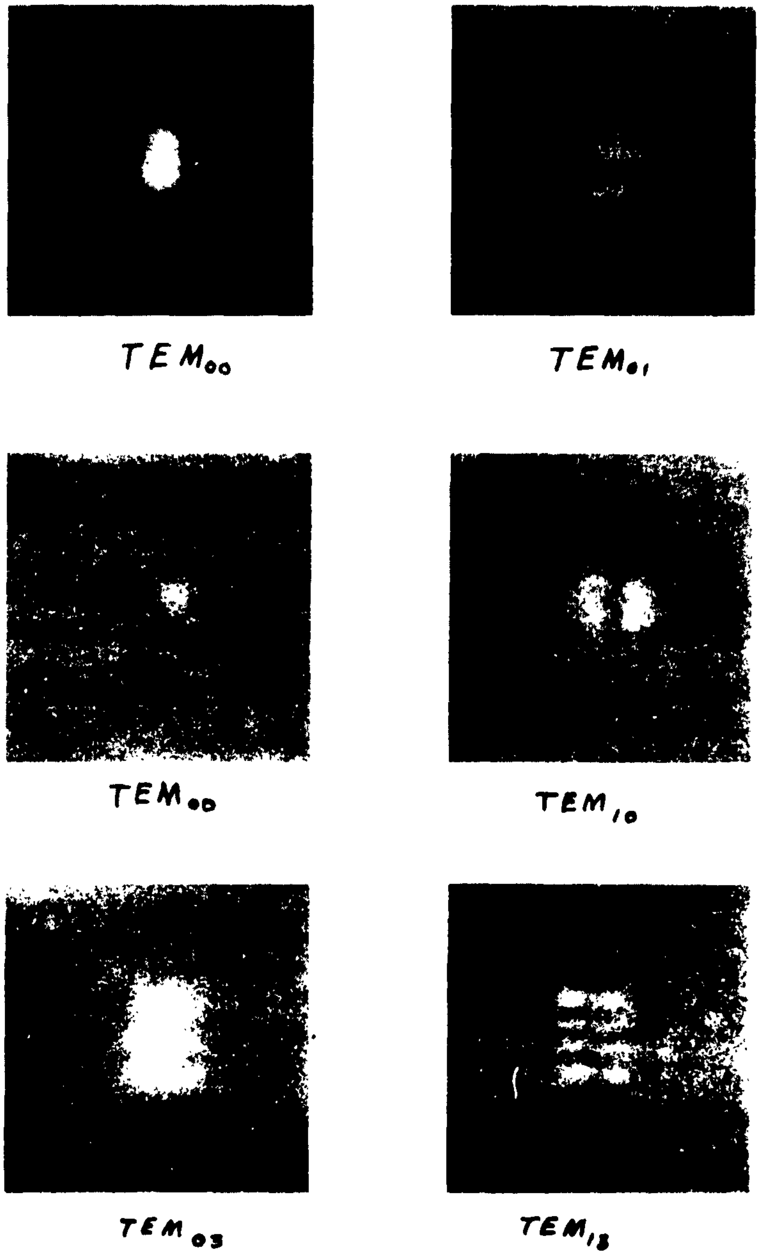
FIGURE 11

IV. Instrumentation and Measurements

Due to lack of time to make detailed measurements of the laser output, data gathered from the laser in operation consist of a set of photographs of the laser mode patterns as observed through the infrared image converter, threshold data for laser operation of this tube, and time stability of single mode operation.

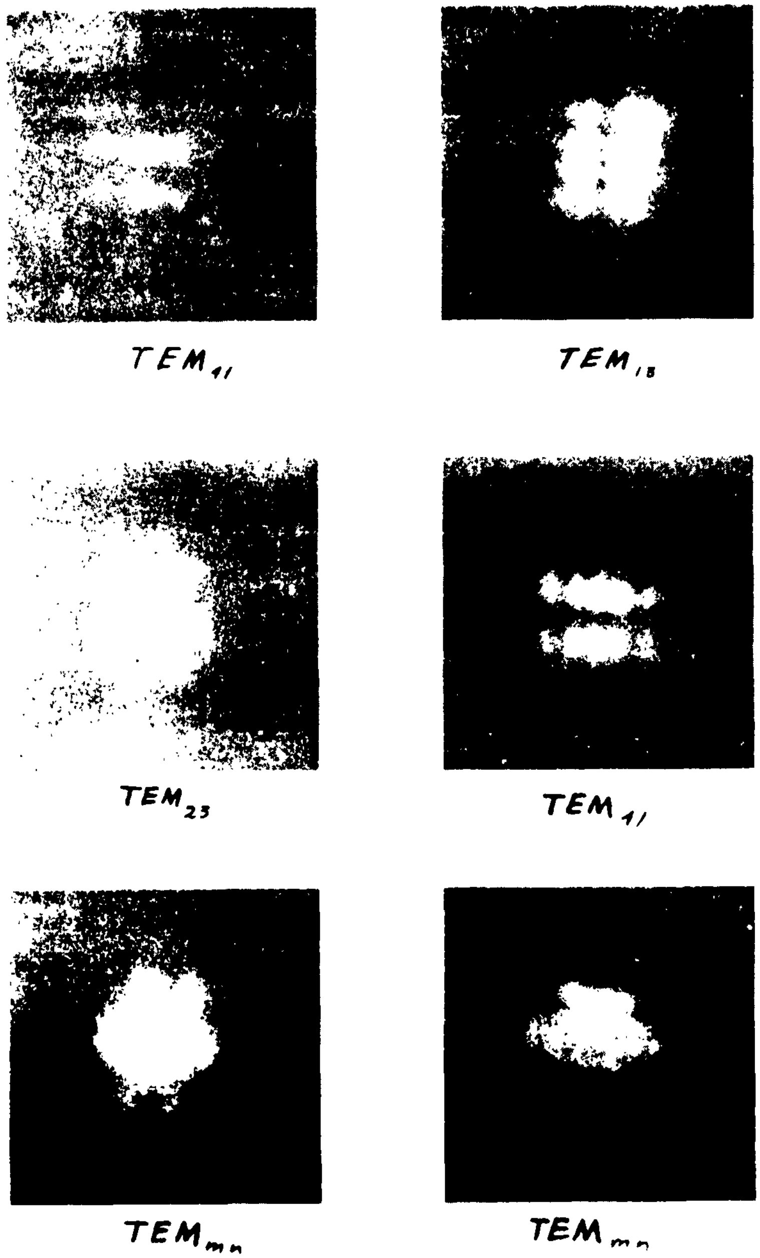
The mode patterns, which are readily obtainable by adjusting the coarse gimbal controls on the spherical mirror, are easily reproducible and may be identified in the TEM_{mnq} notation by counting the dark symmetric bands occurring in the pattern. These bands correspond to modes in the radial and angular directions of the field pattern. One pattern which was observed, but did not reproduce on the photograph, was a TEM_{14} where the 1 refers to a Bessel function of the first kind-first order, resembled a toroid with 4 radial black bands. For some reason, this pattern was not observed again. The zero order pattern, which is a circular spot, is an exception and is readily obtainable. The photographs, Fig. 12 on page 24 and Fig. 13 on page 25, are some of the specific modes which are readily obtainable. The more complicated modes are not identified due to their complexity and inability of the camera to show their fine detail. These complicated patterns are actually overlaid combinations of many modes.

The threshold power input, measured at the output of the R.F. oscillator, is 22 watts for a visible mode pattern on the [illegible]. It is believed that this figure should be much lower. The [illegible]



LASER OUTPUT MODES

FIGURE 12



LASER OUTPUT MODES

FIGURE 13

impurities of about 1 part in 10 million which has raised the threshold for laser action. Also the infrared converter as a sensing device for laser operation has one great drawback; its best sensitivity is centered on a spectrum of infrared whose half power points fall at 7000 Å and 9000 Å. It can be seen from this statement that its sensitivity at 11,530 Å is very poor. The curves available on the converter tube are not plotted past 10,000 Å, and so it can only be guessed that the conversion sensitivity is less than 5% of the 8000 Å center design sensitivity . A calibrated bolometer was to be used to measure the power output of the laser, but the vacuum tube millivoltmeter to be used with the bolometer is out of commission and cannot be repaired in the laboratory. It must be returned to a calibration facility for overhaul and thus is not available for the power measurements. A vacuum calorimeter which will measure the output is on base but due to the time restriction was not available in time for use in compiling data for this thesis.

To check on the time stability of the laser in operation in a single mode, it was run for twelve hours and checked periodically to see if the same mode was present. At the end of twelve hours the same mode was observed. The laser was then shut down and remained off for ten hours. When it was turned on again, the same mode was observed which had run for twelve hours the previous day. This observation attests to the time and temperature stability of the laser in operation. A time limit on single mode operation has not been achieved yet, but it is believed that the temperature compensating arrangement of the laser should secure single mode operation for an indefinite time period.

V. Conclusions

The laboratory model of the helium-neon gas laser designed and fabricated for this thesis has achieved and surpassed its intended stability and flexibility for use in studies toward improving laser modulating techniques and may easily be used in monochromatic light source experiments. Although time would not permit the tabulation of all of the effects of changes of the laser parameters, it has been demonstrated why this laser will be useful as a tool in future investigations. It is suggested that further studies of the laser output be made to tabulate the variations of the output of the laser with changes in radio frequency excitation, mirror displacement, and the effects of electric and magnetic fields in the vicinity of the plasma tube.

The laser tube should be rebuilt using kovar 650 halide free glass to eliminate impurities in the gas discharge and the use of matching windows in the ends of the laser tube to allow use of external reflectors should be considered. A set of Fabrey-Perot reflectors for the 6328 Å wavelength should be acquired to operate the laser at this visible wavelength to eliminate the necessity of the infrared converters and the problems associated with power measurements in the infrared region of the spectrum (Ref 4:207).

The new tube constructed for the laser should have a heater and cathode placed in an appendage near one end and an anode at the other end so that the plasma may be excited with a direct current source since a direct current source is more efficient than a radio frequency power generator.

Studies should also be made on the effect of changes of the helium to neon ratio for most efficient operation. The cataphoresis experiment mentioned earlier could be used to vary the ratio of helium to neon without opening the system. An appendage to the manifold containing a pair of oppositely charged electrodes would attract the heavier neon ions to the cathode more readily than the helium ions and would slowly change the helium-neon ratio within the laser tube. The rate of attraction of the neon from the mixture can be calculated for a fixed potential between the electrodes at a known pressure (Ref 6:1369-1371). The possibility of directly exciting the pure neon is of interest and may be achieved using the direct current excitation method. It is regrettable that a more complete study of this laser was not accomplished, but the tool is now available for many future studies.

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