LIGHT INTENSITY MODULATION IN HYDROGEN AND DEUTERIUM DISCHARGE TUBES

by

DONALD EUGENE JONES

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INTRODUCTION

The behavior of the light output of a gaseous discharge tube with an alternating current superimposed upon a direct current discharge has not been widely studied. This is particularly true of the frequency range above one megacycle. Tucker (1) has performed experiments using square and sine wave modulation with a mercury discharge tube to frequencies of 500 kilocycles. He found that the percentage light modulation decreases with increasing frequency above 3 kilocycles.

In a direct current discharge with a sine wave current superimposed on it, the resulting light modulation is an intensity variation of the steady state light output. An idealized waveform representing light intensity is a simple sine wave displaced above a given reference line. A diagram of this waveform is shown in Plate I, Fig. 1. From oscilloscope traces one may read the distances which represent the values of light maximum, light minimum, and light zero. Using these values and the sine variation approximation, a value of the percentage light modulation as defined by the author, is given by the equation,

$$\%\ \text{light modulation} = \frac{100\ (\text{light maximum} - \text{light minimum})}{2\ (\text{light average} - \text{light zero})}$$

One purpose of this experiment was to determine the variation in light modulation with frequency of modulation and wavelength of light as parameters. From these variations the maximum modulation of light as well as the maximum frequency

EXPLANATION OF PLATE I

Fig. 1 is an idealized waveform representing light output.

Fig. 2 represents idalized waveforms of light output and voltage showing a time lapse before light output results from a voltage increase.

PLATE I

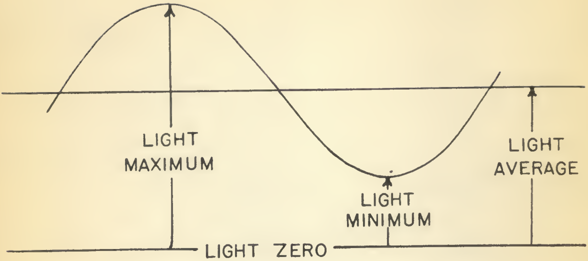


FIG. 1

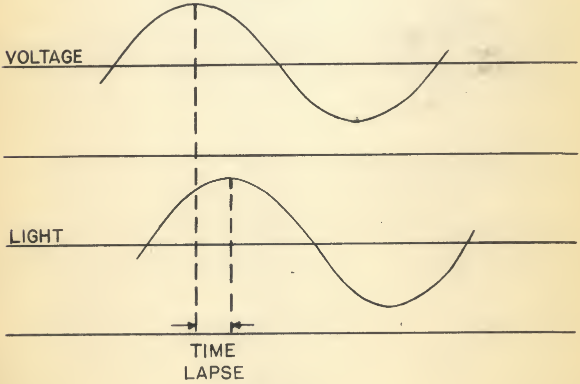


FIG. 2

at which modulation is possible can be determined. A second objective was the determination of the physical processes involved in the light output being studied.

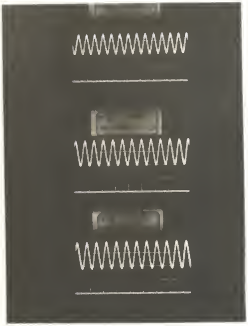
The percentage light modulation should decrease as higher frequencies are applied. In a direct current discharge an equilibrium condition is reached in which the population of excited energy states due to exciting collisions is balanced by the depopulation of the states by dissociation and the emission of radiation. When a high frequency electric field is applied, electrons are given velocities in a direction antiparallel to that of the field. Consider the first quarter cycle of a sine wave variation applied to a direct current discharge. The population of molecules in high energy levels increases because more energy is available from the electrons. This increased population results in an increased light output. If the voltage were brought to the peak value and held there, a new light level would be established. This increased light output would be the result of a greater population of the high energy levels due to a greater amount of energy being introduced through the electrons.

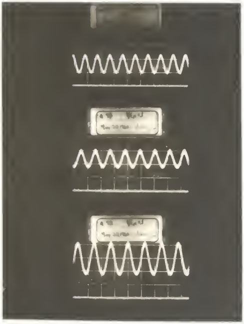
In the second quarter cycle less energy is given to the electrons with correspondingly less energy transferred to the molecules. This gives a lower population of high energy levels with a subsequent decrease in intensity. In the third quarter cycle the energy input is further lowered and in the fourth quarter cycle the energy input begins to increase.

EXPLANATION OF PLATE II

Photographs are of the actual light output as seen on the oscilloscope. These waveforms were used for the hydrogen graph of Plate IX. Frequencies in numerical order are: 7.925, 9.00, 10.61, 13.35, 14.10, 15.98, 17.62, 19.12, 21.15, 31.96 megacycles per second.

PLATE II





Idealized waveforms are shown in Plate I, Fig. 2. Actual waveforms are shown in the photographs of Plate II.

Note that there is a time lapse between collision of an energetic electron with a molecule and the emission of radiation. Because of this time lapse, the equilibrium conditions are less nearly approached, during a given part of the cycle, as the voltage changes become more rapid; i.e., as the frequency increases. Adding to this time lapse is the accelerating time of the electrons. Thus, as the frequency increases, the light modulation decreases, approaching zero. Because the life times of the various excited states, acceleration times for various energies of electrons, and the electron energy distribution affect the amount of light modulation, the light modulation may vary with the wavelength of the emitted radiation.

Specifically, the purpose of this thesis is to discuss the modulation of light in the range of frequencies from seven to thirty-two megacycles per second. In addition, related experiments attempting to clarify more completely the operating conditions are discussed.

APPARATUS

The data were taken using a cylindrical discharge tube with an envelope 1. 5 cm in diameter and with electrodes separated 1. 5 cm. A molybdenum disc 1 cm in diameter formed the anode. The directly heated cathode was made of nonactivated thoriated tungsten ribbon in U-shaped geometry. An oxide coating was applied to the ribbon to obtain efficient electron emission.

The central portion of the envelope of the discharge tube was made of fused quartz for its desired ultraviolet light transmission.

Near one end of the discharge tube a connection was made to a vacuum system which was capable of evacuating the tube to a pressure of 10^{-6} mm of Hg.

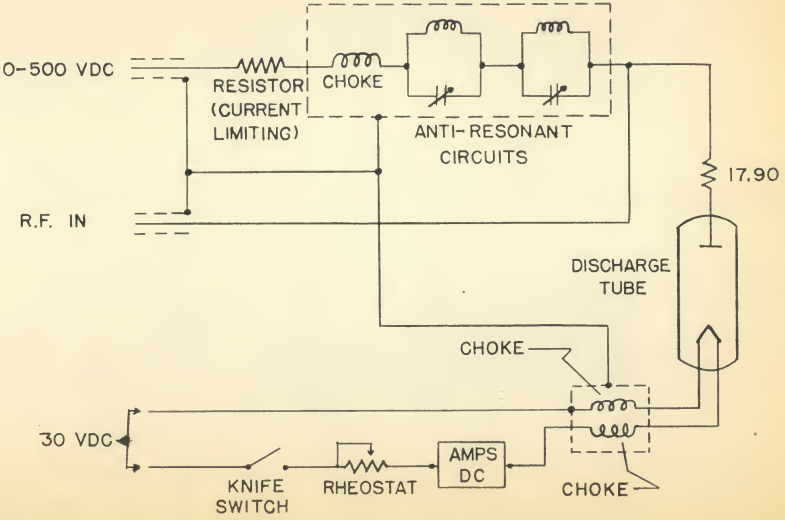
A schematic diagram of the discharge tube circuit is shown in Plate III. A Heathkit model PS-3 direct current, 0-500 volt, regulated power supply was used for the continuous discharge current. For the radio frequency current source, a Heathkit DX-20 amateur transmitter was used. Several arrangements were tried to prevent overloading of the transmitter due to the connection to the low impedance of the direct current power supply. The final result was a pair of anti-resonant circuits in series with a large choke. This combination was placed on the direct current side of the radio frequency-direct current junction. The choke was used to limit the radio frequency current drawn by the direct current power supply during tuning of the anti-resonant circuits. The filament was heated with a direct current supplied from storage batteries through two radio frequency chokes.

Light signals were detected using an RCA IP28 photomultiplier tube supplied with 1000 volts direct current.

EXPLANATION OF PLATE III

Schematic of discharge tube circuit.

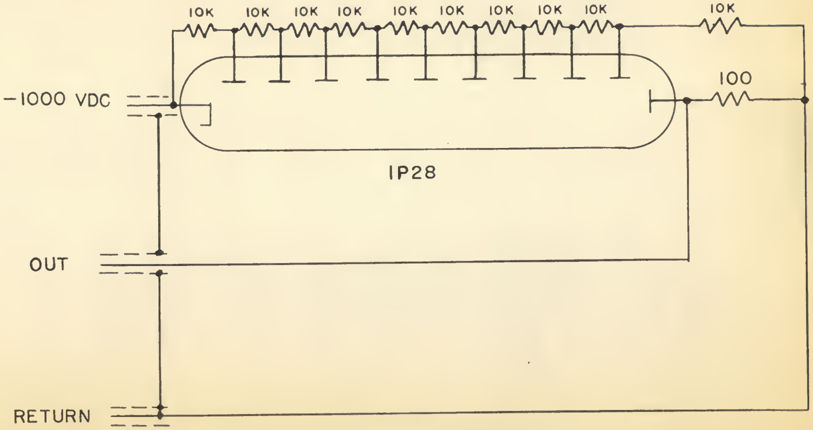
PLATE III


0-500 VDC
RESISTOR (CURRENT LIMITING)
CHOKE
ANTI-RESONANT CIRCUITS
17.90
R.F. IN
DISCHARGE TUBE
CHOKE
30 VDC
KNIFE SWITCH
RHEOSTAT
AMPS DC
CHOKE

EXPLANATION OF PLATE IV

Schematic of photomultiplier circuit.

PLATE IV


10K
10K
10K
10K
10K
10K
10K
10K
10K
10K
100
-1000 VDC
IP28
OUT
RETURN

Voltage division for the various dynodes was carried out with a series of similar resistors (10,000 ohm 2 watt.) The signal to the oscilloscope was developed across a 100 ohm resistor placed in the anode circuit. See Plate IV.

The light from the discharge tube was admitted to the detector by two methods. The first method was by the use of a filter for ultraviolet light (2). The ultraviolet light behavior was the main concern in this study, hence the majority of the data were taken using this method. The second method for admitting the light to the detector was the use of a Bauch and Lomb quartz ultraviolet monochrometer. Specifically, this latter device was used for the measurement of light modulation for various wavelengths. All remaining data were taken using the ultraviolet filter. The voltage drop across the 100 ohm resistor which measured the light output was applied to a Tektronix type 545 oscilloscope. The oscilloscope was directly coupled to the light detector so measurements could be made on both the steady state light output and the radio frequency modulation of the light output. Photographs were taken with a Dumont type 302 Polaroid-land oscilloscope camera.

A modified discharge tube was also used for experimentation. This tube was very similar to the ribbon filament tube except in cathode construction. The modified cathode was a coil of oxide coated tungsten similar to those in a 40T12 fluorescent lamp. There were two purposes for using this tube. The primary purpose was to allow light measurements throughout the monochrometer range. The ribbon filament tube had developed a metallic coating during an attempt to activate the thoriated tungsten. This coating greatly reduced the intensity of the longer wavelengths of light.

The second purpose of the coiled filament tube was to allow the use of smaller filament currents. It was hoped this would give more stable emission of electrons thus improving the data.

A photograph of the apparatus is shown in Plate V.

PROCEDURE

The vacuum system, including the discharge tube, was pumped and outgased to a pressure of 10^{-6} mm. The high vacuum side was then separated from the pumps and the desired gas (hydrogen or deuterium) was introduced to bring the system up to the working pressure. During operation of the discharge, the direct current and radio frequency currents were measured with an oscilloscope (Tektronix 515) by determining the corresponding voltage drops across a 17.90 ohm resistor placed in series with the discharge tube.

After the filament was heated, the direct current voltage was applied to start the discharge. Then the transmitter was tuned to give a suitable radio frequency current. The filament current required and suitable values of direct current and radio frequency currents were determined experimentally. In early measurements of percentage modulation versus filament current, it was found that there was a critical range of filament currents for which modulation could occur. This is shown in Plate VI. For the ribbon filament tube, the currents required were over 10 amperes. With such a large current, small changes of filament current which could cause large modulation changes, were barely discernable on the meter available for filament current readings.

Radio frequency current values to be used were chosen by determining the maximum value of radio frequency current which could be maintained for all desired frequencies.

The direct current used was chosen to be the lowest value which still allowed good light modulation.

The procedures used were directed toward determining the relationships which exist between the resulting light modulation and various parameters which might affect or be affected by the modulation. Specifically, measurements made were:

1. The modulation of light under given conditions as the frequency of the radio frequency current was varied.
2. The modulation as the wavelength of light observed was varied.
3. The light modulation as the filament current was varied.
4. The light modulation as the direct current was varied.
5. The light modulation as the radio frequency current was varied.

EXPLANATION OF PLATE V

Photograph of equipment as used in this experiment. Shown are:

(1) Discharge tube.

(2) Vacuum system.

(3) Light detector.

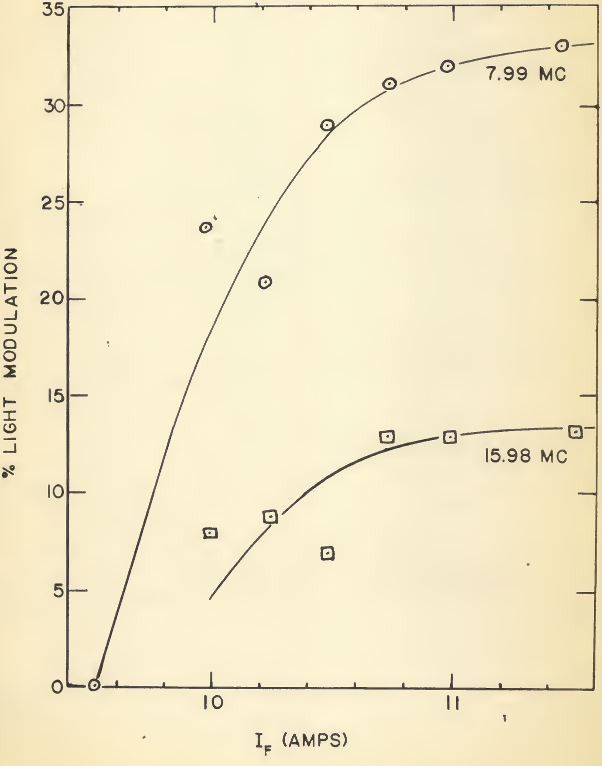
(4) Portions of circuitry.

PLATE V

EXPLANATION OF PLATE VI

Percent ultraviolet light modulation plotted as
a function of the filament current.
Hydrogen discharge. Pressure 1.9 mm. Hg.

PLATE VI


% LIGHT MODULATION
35
30
25
20
15
10
5
0
10
11
I$_F$ (AMPS)
7.99 MC
15.98 MC

6. The characteristics of the discharge through the operating range.

In each case above, the parameters not being investigated were held as nearly constant as possible with the available equipment.

In order that the photographs contain a zero light level indication, each waveform was exposed twice. The first exposure was made of the light waveform; the second exposure was made with the light opening closed. This method of recording the oscilloscope traces also makes possible the measurement of extraneous noise.

The distances representing light maximum, light minimum, and light zero were measured directly from the pictures using a traveling microscope.

RESULTS

The results are given in the form of graphs:

Plate VI shows the variation of the light modulation with filament current as the controlling parameter at two frequencies.

Plate VII shows the variation of the light modulation with the radio frequency current at a frequency of 14.1 megacycles per second.

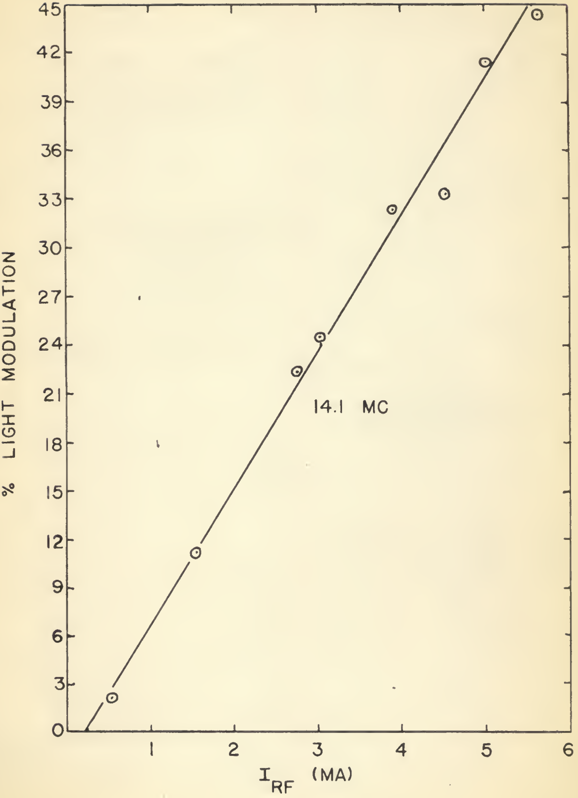
Plate VIII shows the effect of changes in the amount of direct current upon light modulation.

Plates IX and X show the light modulation as the

EXPLANATION OF PLATE VII

Percent ultraviolet light modulation plotted as a function of the radio frequency current. Hydrogen discharge. Pressure 1.9 mm. Hg.

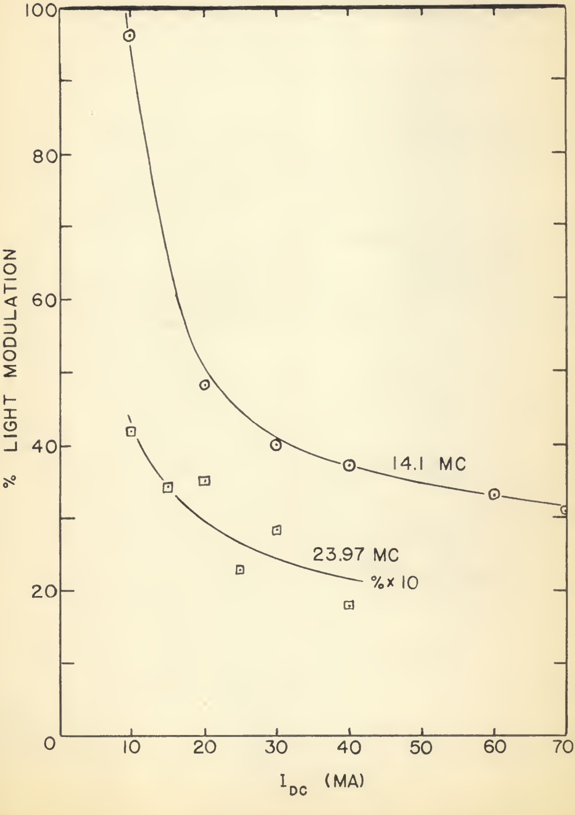
PLATE VII


% LIGHT MODULATION
0
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45
1
2
3
4
5
6
I_{RF} (MA)
14.1 MC

EXPLANATION OF PLATE VIII

Percent ultraviolet light modulation plotted as
a function of the direct current.
Hydrogen discharge. Pressure 1.9 mm. Hg.

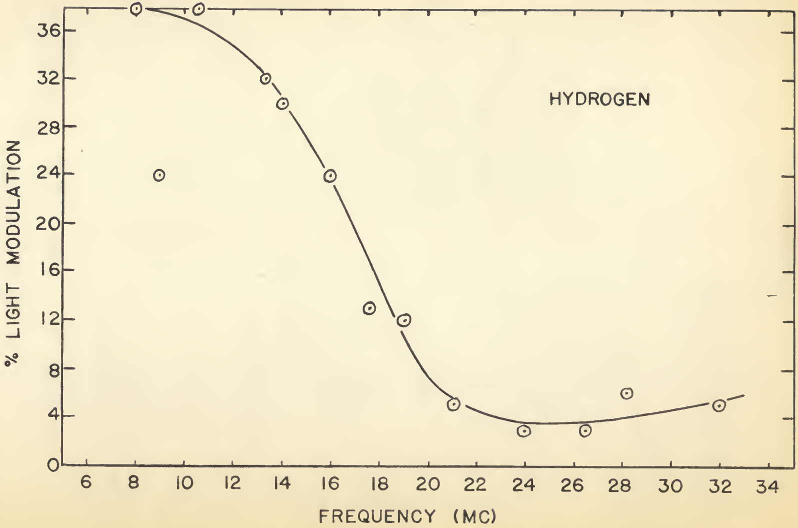
PLATE VIII


100
80
60
40
20
0
10
20
30
40
50
60
70
% LIGHT MODULATION
I_{DC} (MA)
14.1 MC
23.97 MC
%x 10

EXPLANATION OF PLATE IX

Percent light modulation plotted as
a function of the frequency of the modulating current.
Hydrogen discharge. Pressure 1.2 mm. Hg.

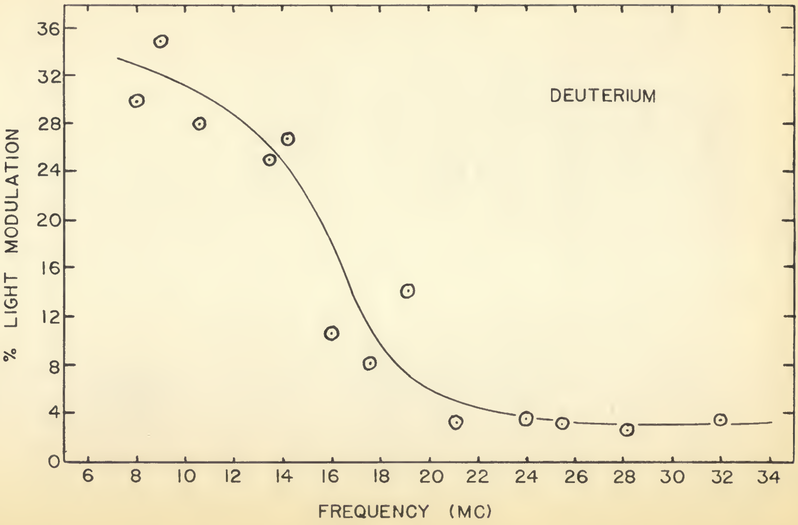
PLATE IX


HYDROGEN
% LIGHT MODULATION
0
4
8
12
16
20
24
28
32
36
FREQUENCY (MC)
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34

EXPLANATION OF PLATE X

Percent light modulation plotted as
a function of the frequency of the modulating current.
Deuterium discharge. Pressure 1.5 mm. Hg.

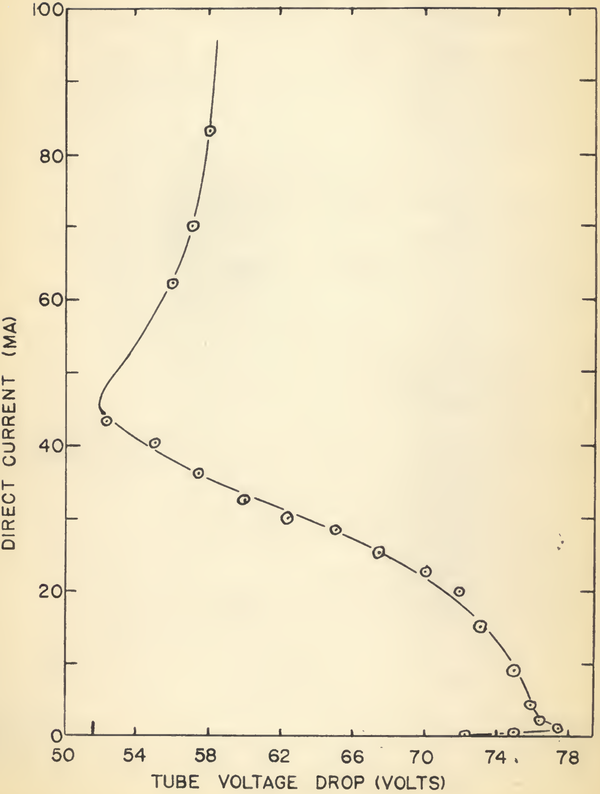
PLATE X


DEUTERIUM
% LIGHT MODULATION
36
32
28
24
20
16
12
8
4
0
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
FREQUENCY (MC)

EXPLANATION OF PLATE XI

Direct current characteristic curve
for the hydrogen discharge tube with
a filament current of 0.7 amperes.

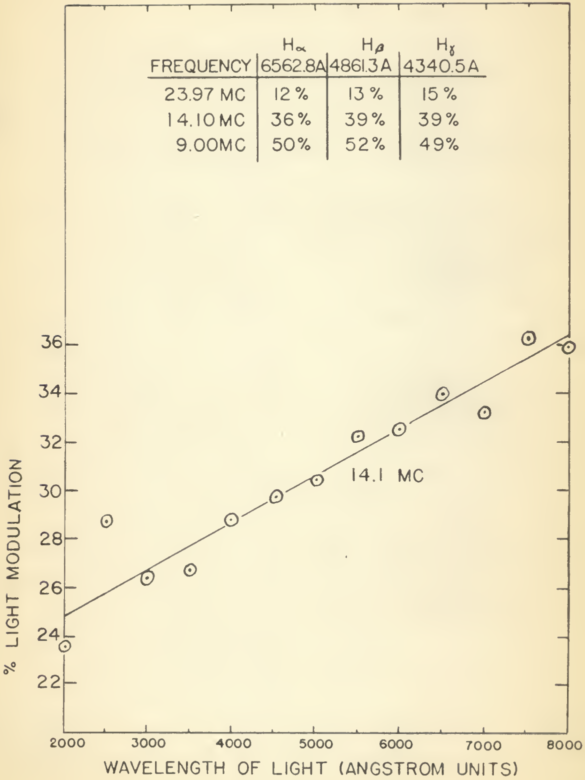
PLATE XI


100
80
60
40
20
0
DIRECT CURRENT (MA)
50
54
58
62
66
70
74
78
TUBE VOLTAGE DROP (VOLTS)

EXPLANATION OF PLATE XII

Percent light modulation plotted as a function of the wavelength of the emitted light. The table gives values for the hydrogen lines, H_α, H_β, and H_γ.

PLATE XII



	H$_\alpha$	H$_\beta$	H$_\gamma$
FREQUENCY	6562.8A	4861.3A	4340.5A
23.97 MC	12 %	13 %	15 %
14.10 MC	36 %	39 %	39 %
9.00 MC	50 %	52 %	49 %

frequency of modulating current is varied. Plate IX represents the modulation for a hydrogen discharge; Plate X represents the modulation for a deuterium discharge.

Plate XI shows the characteristic curve of the hydrogen discharge.

Plate XII shows the modulation as the wavelength of the observed light is varied.

DISCUSSION AND CONCLUSION

The light modulation depended markedly upon the character of the discharge. Small variations in operating conditions of the discharge caused the light modulation to change appreciably. Fluctuations in operating conditions resulted in a lack of complete reproducibility of the data. Attempts to repeat the experiments gave the same general shape very well with the exception that some points would vary from the smooth curve. An example is seen in Plate IX at 17.62 megacycles. The point at 9.000 megacycles was an exception in that this point gave consistently low readings with hydrogen. This was attributed to a resonance in the circuitry, particularly that used for the current measurement. Supporting evidence was given by the necessity of greatly reducing the output power of the transmitter to obtain the desired current at this frequency.

The results indicate a drop in the light modulation with frequency increases as was expected. Noting Plates IX and X we see this drop occurs between 12 and 21 megacycles. This is a reasonable result. In consulting the literature concerning the lifetimes of excited states in hydrogen and deuterium, one finds good agreement on values of the order of 10^{-8} sec. Herzberg (3) states that the mean lifetimes for allowed transitions is of the order of 10^{-8} sec. James and Coolidge (4) have calculated the mean lifetimes for several quantum states. For hydrogen their values range from 1.19×10^{-8} sec for a vibrational quantum number of $v = 4$. With a frequency of ten megacycles one complete oscillation takes place in 10^{-7} sec. At this frequency then, the lifetimes are one tenth the total time of one period. When the lifetimes become nearly the time of a cycle, the modulation should decrease. This is because the changes in the populations of excited states occur faster than depopulation changes can occur. Since the changes in population are periodic, the net result would be an equilibrium condition in which the total increase in population during a cycle is equal to the total decrease per cycle. As higher frequencies are applied, the depopulation rate should become more nearly constant.

From these data a maximum frequency of modulation could not be estimated. This was due to the asymptotic approach to zero modulation. The data indicate the modulation may level off to some small value.

The data of Plate XII show the modulation to have some dependence upon the wavelength of emitted radiation. The lower percentage modulation values for shorter wavelengths indicate longer transition times for the higher energies associated with shorter wavelengths.

At all positions in the spectrum, including the three main hydrogen lines, the monochrometer slits needed to be opened very wide to obtain sufficient amounts of light for measurements. This reduced the resolving power making the exact wavelength values meaningless.

This work suggests further investigations along related lines. Improvements in the apparatus are the main requirements. Such improvments are: (1) Current regulated power supplies for the filament, direct and radio frequency currents, (2) Greater frequency and power ranges for the radio frequency source, (3) More sensitive light detecting device for operation under circumstances less susceptible to pick up of stray signals.

The investigation at higher frequencies is of special interest as it would determine whether the maximum frequency exists. A maximum frequency near the frequencies used would be strong evidence for lifetimes limiting the modulation.

ACKNOWLEDGMENTS

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1960

The purpose of this thesis is to describe the intensity variation of the light output from hydrogen and deuterium discharges when an alternating current at high frequency is superimposed upon the direct current. This variation was given as a percentage light modulation which is studied as a function of the frequency of the modulating current and of the wavelength of the observed light.

The light output was detected by a photomultiplier and observed on an oscilloscope. Light was admitted to the detector through an ultraviolet filter and a quartz ultraviolet monochrometer. An amateur radio transmitter operating from 7 to 32 megacycles per second served as the alternating current source.

The percentage light modulation was found to decrease with increasing frequency as was expected. A very large drop in the light modulation occured between 12 and 21 megacycles per second. Above 21 megacycles the modulation appeared to approach a small constant value up to the maximum frequency observed. Thus, a maximum frequency at which modulation is possible could not be estimated. The large drop in percentage modulation indicates the lifetimes of the excited states, which are of the order 10^{-8} sec, are probably the limiting factors for high frequency modulation.

The percentage modulation of light was found to have some dependence upon the wavelength of the emitted light. The range of observation was 2000 to 8000 angstrom units.

The modulation at the wavelengths of the three main hydrogen lines, H_α, H_β, and H_γ, were similar. At these wavelengths the monochrometer slits were opened very wide, as was necessary for all wavelength measurements, greatly reducing the resolving power. This included much light from the continuum in the line spectrum measurements and was necessary to obtain measurable light intensities. These data indicate the transition times for the shorter wavelengths may be greater than those for the longer wavelengths.

The data for hydrogen and deuterium were almost identical in all respects.