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# The Wavelength Shifting of Cerenkov Radiation

Philip A. Deutchman

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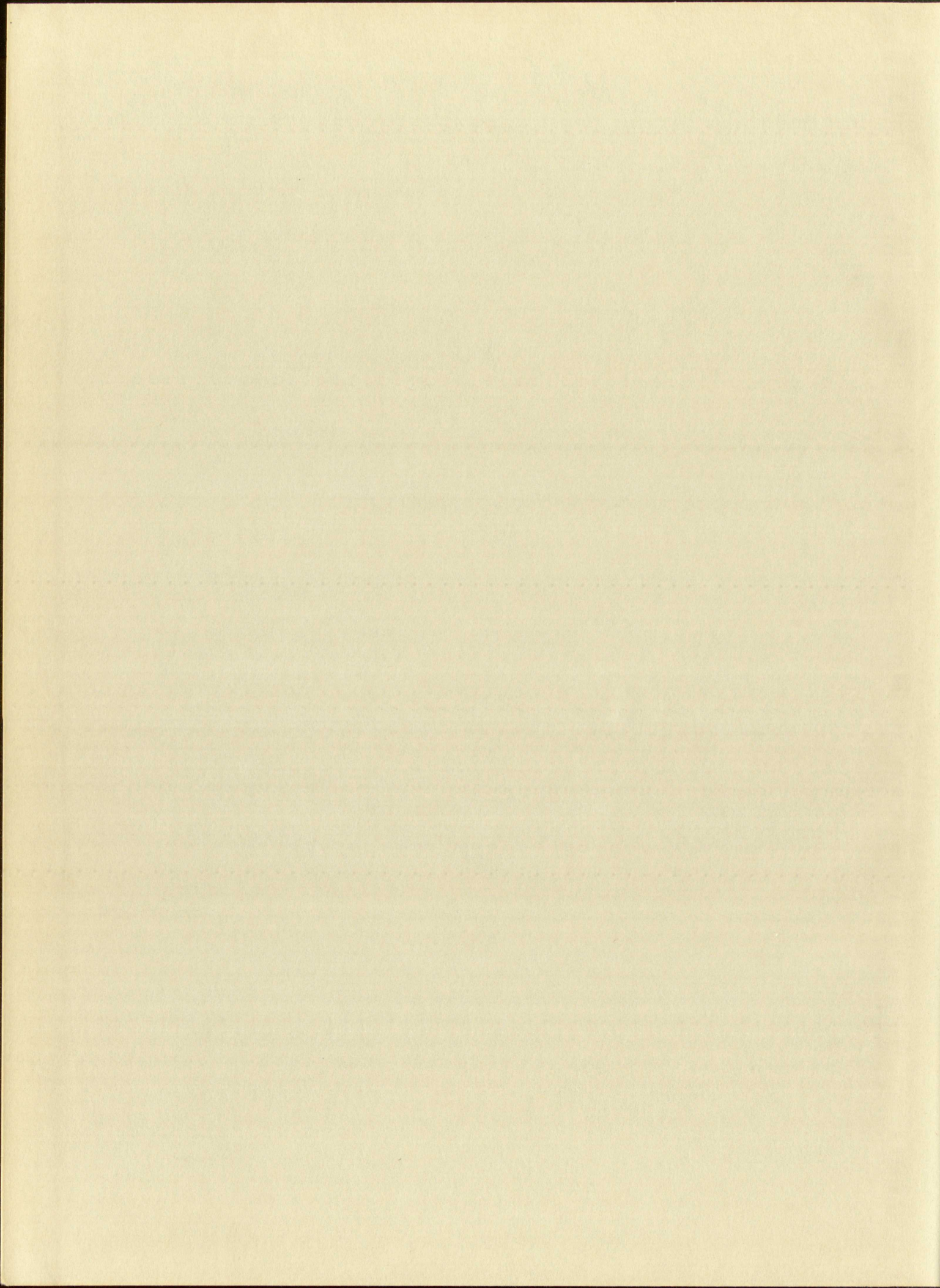
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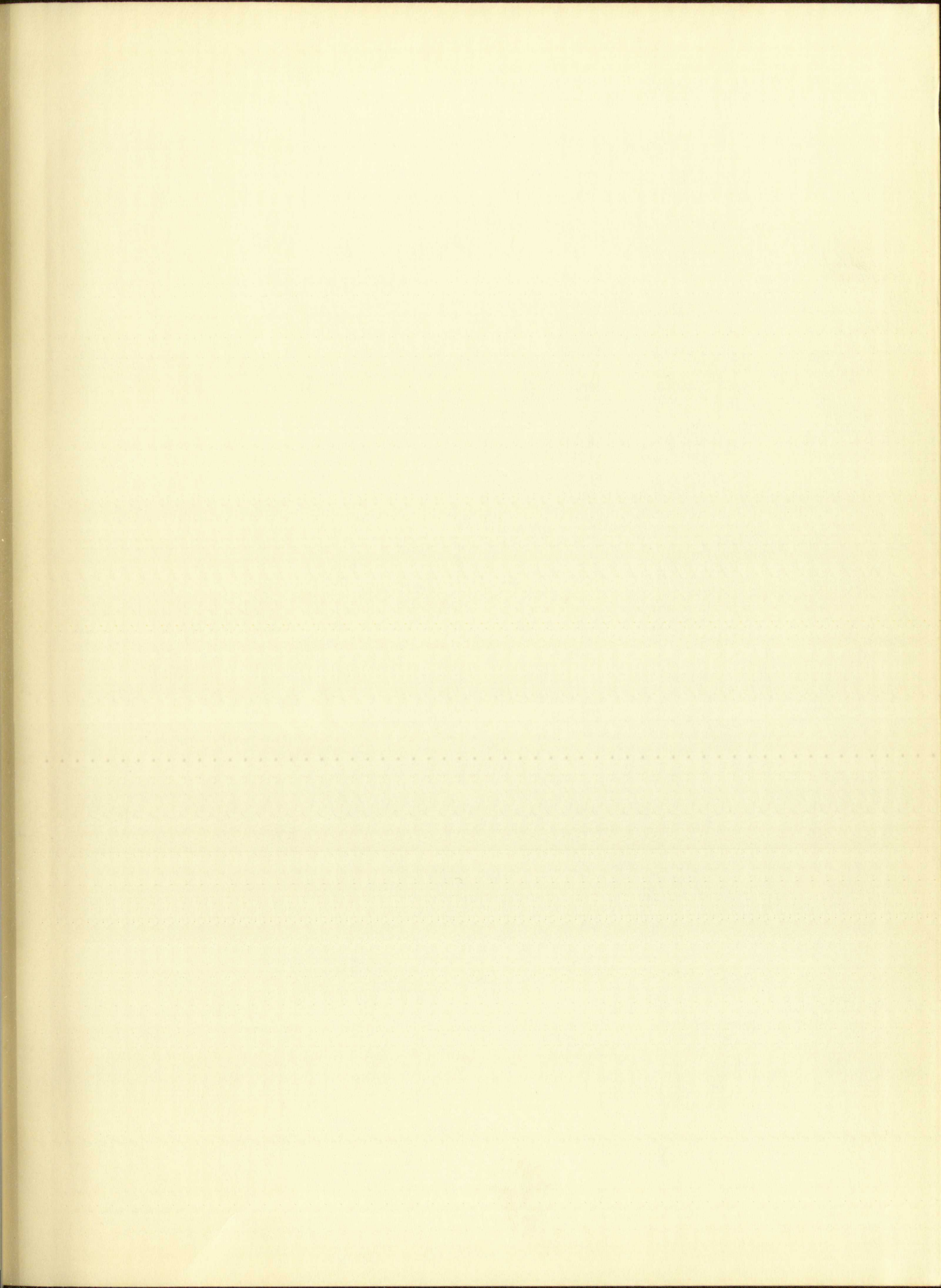


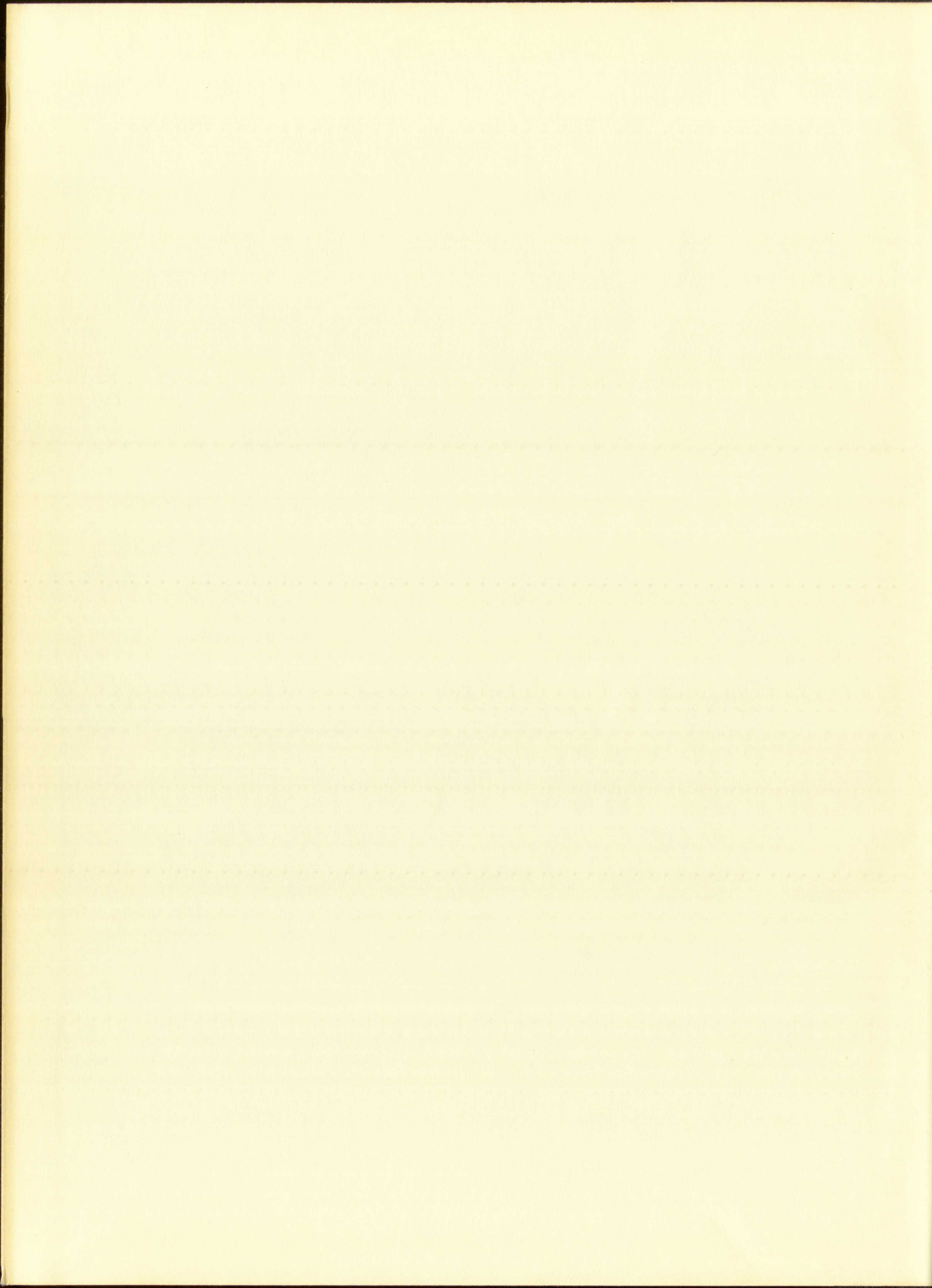




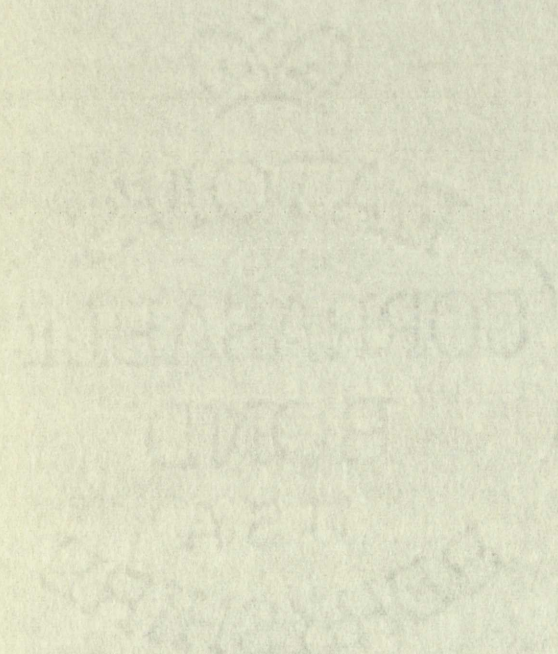














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THE WAVELENGTH SHIFTING OF CERENKOV RADIATION

By

Philip A. Deutchman

A Thesis

Submitted in Partial Fulfillment of the  
Requirements for the Degree of  
Master of Science in Physics

The University of New Mexico

1961



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Chicago, Illinois  
1941



This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of the University of New Mexico in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

E. Wasteller  
Dean

May 30, 1961  
Date

**THE WAVELENGTH SHIFTING OF CERENKOV RADIATION**

**By**

**Philip A. Deutchman**

Thesis committee

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Howard Bryant

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20% COTTON CONTENT

This thesis, in its present form, has been approved by the University of New Mexico, and is hereby recommended for the degree of

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EXPLANATION  
OF SYMBOLS



#### ACKNOWLEDGEMENTS

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# MILLERS FALL

I sincerely appreciate your letter and the  
for giving me such a good idea of the  
helpful suggestions, and for the  
Hodges for her efforts and assistance in this matter.



## CHAPTER I

### A. INTRODUCTION

Since the discovery of radiation, which was the birth of Modern Physics, many areas of investigation have exploded forth in an attempt to explain the phenomenon in all its aspects. We are still at the beginning.

The main interest in this paper is to study the effect of the fluorescent wavelength shifter "POPOP" with respect to Cerenkov radiation and to determine how the efficiency of a Cerenkov counter is affected.

"POPOP" or diphenylhexatriene has been used in many scintillation counters as a booster of the light pulses so it would be natural to see if a similar result could be obtained for Cerenkov radiation.

Most photomultiplier tubes used in scintillation and Cerenkov counters are sensitive only to a certain range of wavelengths. Their maximum sensitivity is approximately  $4000 \text{ \AA}$  to  $5000 \text{ \AA}$  so the tube is fairly insensitive to the violet and ultraviolet regions where most of the Cerenkov radiation exists. A fluorescent material is used to shift the wavelengths of the light toward the more sensitive areas of the photomultiplier in order to increase the pulse heights produced in the tube.



## CHAPTER I

### A. INTRODUCTION

Since the discovery of radioactivity, which was the first of a new era in physics, many areas of investigation have been opened up. It is now possible to explain the phenomena in all the sciences. We are still at the beginning.

The main interest in this work is to study the effect of the fluorescent wavelength shift on "POP" with respect to the energy of the ion and to determine how the wavelength of the fluorescent ion is affected.

"POP" or diphenylpicrylhydrazyl has been used as a radical in many experiments as a detector of the light pulse. It is found that it is not as sensitive as a detector of the light pulse. It is found that it is not as sensitive as a detector of the light pulse.

Most photomultiplier tubes used in the laboratory are sensitive only to a certain range of wavelengths. Their maximum sensitivity is approximately 4000 Å to 5000 Å. The tube is fairly insensitive to the red and infrared regions where most of the Compton radiation occurs. A fluorescent material is used to shift the wavelength of the light toward the more sensitive areas of the photomultiplier in order to increase the signal produced in the tube.



I employed several types of Cerenkov counters using the poor man's source of high energy radiation, cosmic rays. This radiation was measured by a geiger counter and the counting rate will be plotted as a function of discriminator level, then for any change in the wavelength of the light "seen" by the phototube, a corresponding change in the counting rate should occur. The discriminator setting segregates out those pulses that are unable to trigger the circuit to produce a count so the higher the setting the smaller the counting rate becomes. Measurements will be made by selecting a particular counting rate and then noting the change in discriminator setting, if any, after the introduction of POPOP.

The first type of Cerenkov counter employed was a liquid counter that used  $\text{CCl}_4$  both as the dielectric medium and as a solvent for the POPOP. The second kind will again be a liquid counter but Ethyl alcohol will replace the  $\text{CCl}_4$ . The last counter used will be a solid Cerenkov type using "Lucite" as the radiator. The first and last counters have been utilized by others but there has been no mention in the present literature of a liquid Cerenkov counter using Ethyl alcohol. Whether POPOP can or cannot be dissolved in alcohol will also be decided in this paper.

In liquid counters the wavelength shifter is mixed into the radiating material and even though there is an increase of pulse height one severe disadvantage is introduced. Cerenkov radiation is directional, i.e., for a given velocity there is a particular angle with respect to the path of the particle at which the radiation is emitted, so that a Cerenkov counter has a directional response, but after mixing the wavelength shifter into the radiator, this directionality







is partially destroyed since the POPOP molecules can radiate in all directions.

An attempt will be made to eliminate this drawback with the solid counter. The POPOP will be inserted between the radiator and the phototube in the form of a thin film in order to preserve directionality. This last experimental situation will be studied and evaluated as to its feasibility.

#### B. PREVIOUS WORK

Jones, Kratz, and Rouvina,<sup>1</sup> at General Electric Research Lab, Schenectady, New York, used POPOP to increase Cerenkov pulse heights and to improve the resolution of their total absorption Cerenkov counter.

A small counter was first tested with just pure  $\text{CCl}_4$  as the radiator and then the system was tested with  $\text{CCl}_4$  saturated with POPOP. It is claimed by the authors that the addition of POPOP increased the mean pulse height by a factor of two. There is some question as to whether  $\text{CCl}_4$  saturated with this shifter scintillates. To see if they could detect scintillations, a thin window glass cell was filled with the saturated solution and this was exposed to a beam of 6 MEV protons. There were no measurable scintillations observed.

In the preparation of large plastic scintillators, Clark, Scherb, and Smith,<sup>2</sup> from M.I.T., use a composition of polystyrene, p-terphenyl, and POPOP.

A measurement of the relative merit of different samples was carried out where, for a fixed amount of polystyrene and p-terphenyl,



# EXPERIMENTAL RESULTS

is partially developed since the...  
directions.  
An average will be given...  
counter. The X-ray...  
photographs in the form of a...  
Allyl. This last experiment...  
as to its feasibility.

## 2. EXPERIMENTAL

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and to improve the...  
counter.

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radiation and then the...  
POPOL. It is...  
increased the mean...  
question as to whether...  
To see if they could...  
was filled with the...  
of 6 MeV protons. There...  
In the preparation of...  
and allyl, from 2.1...  
and POPOL.

A measurement of...  
carried out where...  
the...  
the...



the concentration of POPOP was varied. Measurements were then taken for different fixed amounts of the former two materials where the POPOP was again varied.

Their figure of merit was determined as follows: The samples were irradiated with gamma-rays from a  $\text{Co}^{60}$  source and the distribution in height of the scintillation pulses was measured. The discriminator bias level, which gave a reading of sixty-four counts/second with the source at a standard position from the sample, was then defined as the relative merit. It was also assumed by this group that since all the samples were nearly identical in mass and composition, the energy distribution and total rate of the Compton electrons produced by the  $\text{Co}^{60}$  gamma rays were approximately the same. Therefore, this figure of merit was a measure of the relative number of photoelectrons in the phototube which were produced by a certain fixed amount of excitation energy. They show the results of at least four different samples where the relative merit is a function of the concentration of POPOP and in each case an increase in concentration shows an increase in the relative merit up to the saturation point.

It is of some interest to see how much of a change can be brought about with different concentrations of POPOP and a new technique of accomplishing the wave shifting was tried using the solid counter.





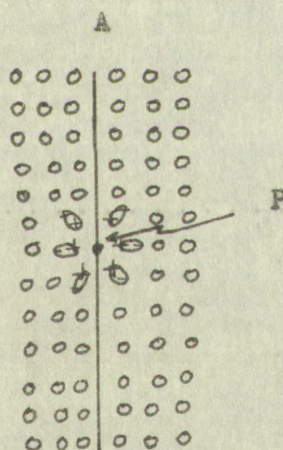


## CHAPTER II

### A. QUALITATIVE DESCRIPTION OF CERENKOV RADIATION<sup>3</sup>

Suppose we have an electron traversing a transparent medium. There are essentially two cases to consider. One is when the electron is moving slowly and the other case is when the electron approaches the speed of light.

Consider Figure I. The circles are supposed to represent the individual atoms, in say, a piece of glass. Let P be the point where the electron resides at an instant. Let AB be the track of the moving electron.



B  
FIG.1

The atoms that are removed from point P are undisturbed and are roughly spherical, but those near the electron will be polarized because of the electric field they experience from the electron. When the electron has moved on, the polarized atoms will act like elementary

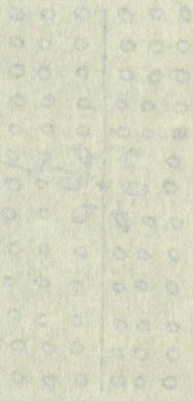


# 2010-10-11

## CHAPTER 1

### A. QUALITATIVE ASPECTS OF ELECTRICITY

Suppose we have an electric circuit consisting of a wire connected to a battery. There are essentially two kinds of motion. The first is the motion of the electrons, which is moving slowly and in the opposite direction to the direction of the current. The second is the motion of the positive ions, which is moving very slowly in the direction of the current. The speed of light is the speed of the electromagnetic wave. Consider Figure 1. The circuit is connected to a battery. Individual atoms, in the wire, are shown. The electrons are shown moving to the right, where the electron current is in the direction of the current. The moving electron.



The atoms that are connected to the battery are shown. The atoms are roughly spherical, but their nuclei are much smaller. The electric field of the electric field that exists between the battery and the electron has moved on. The potential energy will be different.



dipoles and radiate electromagnetic energy. Since there is symmetry about the azimuthal angle and along the axis there will be no resulting field at large distances from point P and no radiation.

Suppose now that the speed of the electron is comparable to that of light in the medium. Since the electric field of the charged particle has a finite propagation time  $\tau_e$ , the atoms directly in front of the electron do not experience this field immediately because the electron is traveling faster than the velocity of the electric field it produces. This results in an asymmetry where the atoms in front of the electron are not yet polarized until the electron passes them. Figure 2 shows how the geometry has changed. There is still symmetry along the azimuthal angle, but it no longer exists along the axis. As a result, there is a resultant dipole field along the axis so that essentially there will be a brief electromagnetic pulse emanating from each elemental distance along the track.

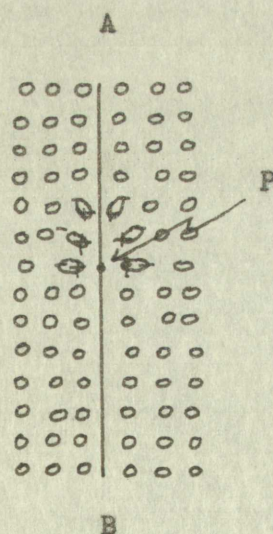
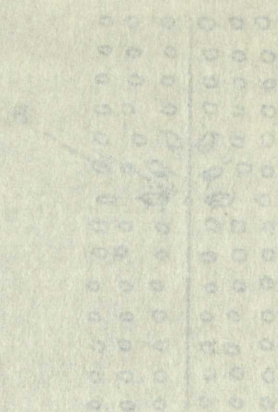


FIG.2



dipoles and radiate electromagnetic energy. In the  
 about the electron in its orbit. The field is  
 ing field at large distances from the electron.  
 Suppose now that the electron is moving with  
 of light in the medium. If the electron is moving  
 particle has a finite velocity. The field is  
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 electron passes them. Figure 2 shows the field of the  
 There is still symmetry about the electron's path. The  
 exists along the axis. As a result, the field is  
 field along the axis is not zero. The field is  
 electromagnetic pulse moving with the electron.  
 the track.





Now the laws of optics intervene for if these radiated pulses interfere destructively, then at large distances the resultant field intensity is still zero. The condition for a resultant field is when the velocity of the particle is greater than the phase velocity of the light in the medium.

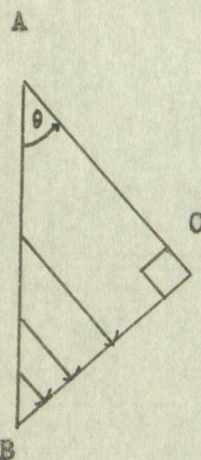


FIG. 3

Fig. 3 shows that the Huygen wavelets interfere constructively to produce a resultant field BC at an angle  $\theta$  from the axis.

Let  $\Delta T$  be the time it takes for the particles to travel from A to B. This is also the same time for the light to travel from A to C. Let the velocity of the particle be  $\beta c$  where  $\beta$  is the usual definition of the ratios of the velocity of the particle to that of light in vacuo. Suppose that  $n$  is the index of refraction of the glass so that the phase velocity of the light is  $\frac{c}{n}$  in this medium. The distance that the particle travels in the time  $\Delta T$  is  $AB = \beta c \Delta T$  and the light will travel a distance,  $AC = \frac{c}{n} \Delta T$ . The



How the laws of optics are altered by the presence of a moving medium is a question which has been the subject of much discussion. The question is not only of theoretical interest, but also of practical importance, as it is the basis of the theory of the aberration of light. The velocity of the particle is denoted by  $v$ , and the velocity of light in the medium by  $c$ . The angle between the direction of motion and the direction of the light is denoted by  $\theta$ .



FIG. 3

Fig. 3 shows that the light wave has a component velocity  $v \sin \theta$  in the direction of the hypotenuse AB. This produces a resultant angle  $\phi$  at vertex B. Let  $\Delta t$  be the time taken for the particle to travel from A to B. This is also the time for the light to travel from A to B. Let the velocity of the particle be  $v$ , and the velocity of light in the medium be  $c$ . The distance that the particle travels in time  $\Delta t$  is  $v \Delta t$ , and the light will travel a distance  $c \Delta t$ . The usual definition of the velocity of the particle is  $v$ , and the usual definition of the velocity of light in the medium is  $c$ . Suppose that  $\theta$  is the angle of incidence of the light in the medium. The distance that the particle travels in time  $\Delta t$  is  $v \Delta t$ , and the light will travel a distance  $c \Delta t$ . The angle between the direction of motion and the direction of the light is denoted by  $\theta$ .



famous "Cerenkov relation" can then be obtained.

$$\cos \theta = \frac{1}{\beta n} \quad (1)$$

The threshold velocity is obtained when  $\cos \theta = 1$ . Therefore,  $\beta_{\min} = \frac{1}{n}$ . No radiation takes place below this velocity and the direction of the radiation lies along the track of the particle.

There is also a maximum angle of emission of the resulting radiation which occurs when  $\beta \rightarrow 1$ , then  $\cos \theta_{\max} = \frac{1}{n}$ .

Both Fig. 1 and Fig. 2 are two-dimensional drawings but in three dimensions there is symmetry about the track of the particle so that actually a cone of light is emitted along the trajectory of the particle and  $\theta$  is one-half of the apex angle of this cone.

Two other precautions that must be observed before coherence can be obtained are that the length AB of the track must be large compared to the wavelength of the radiation so that the diffraction phenomenon will not become dominant and that the velocity of the particle must be constant over a number of atomic spacings.

The fundamental equation for the output of radiation per unit length of radiator is:

$$\frac{dW}{dl} = \frac{e^2}{c^2} \int \left(1 - \frac{1}{\beta^2 n^2}\right) \omega d\omega ; \quad (2)$$



# WHITE LIGHT

James "Caretaker" and John "Caretaker"

$$\cos \theta = \frac{1}{n}$$

The threshold velocity of the electron is  $v = \frac{1}{2}c$ . The direction of the radiation is along the direction of the electron's motion. There is also a maximum angle of emission of the radiation. Both Fig. 1 and Fig. 2 are two-dimensional diagrams. Three dimensions there is present about the axis of the particle so that actually a cone of light is emitted along the direction of the particle and  $\theta$  is measured at the edge of the cone. Two other phenomena that must be considered are the Doppler effect and the aberration of light. The Doppler effect can be obtained by the use of the relativistic Doppler formula compared to the wavelength of the radiation from a stationary phenomenon will not be the same as the wavelength of the radiation from a moving phenomenon. The fundamental equation for the velocity of the particle must be constant over a range of angles. The fundamental equation for the velocity of the particle is:

$$\frac{dw}{dt} = \frac{1}{2} \left( 1 - \frac{v^2}{c^2} \right)^{-\frac{1}{2}}$$

# WHITE LIGHT



where  $e$  is the charge of an electron,  $c$  is the velocity of light,  $\omega$  is the angular velocity of the radiation,  $n$  the index of refraction of the radiator and  $\beta c$  is the velocity of the particle in the medium.

This equation was derived by Franck and Tamm<sup>3</sup>, assuming the following:

1. The medium was considered as a continuum so the dielectric constant is then the only parameter used to describe the medium.
2. The dispersion is ignored, at least in the first approximation.
3. Radiation reaction is neglected.
4. The conductivity is assumed zero and the magnetic permeability  $\mu = 1$ . Then the medium is a perfect isotropic dielectric and there is no absorption of radiation.
5. The electron is considered to move with a constant velocity so the slowing down due to ionization and multiple Coulomb scattering is ignored.
6. The medium is unbounded.

As equation (1) appears, there has been no frequency cut-off imposed, but there is one important factor that limits the frequency spectrum.

If dispersion is considered, then  $n$  is a function of  $\omega$ ,  $n(\omega)$  and in order for the "Cerenkov relation" to hold, we must have  $\frac{1}{\beta n(\omega)} \leq 1$  so that  $n(\omega) \geq \frac{1}{\beta}$ . In the x-ray region  $n(\omega) < 1$ , so the radiation does not occur, but in most transparent substances  $n(\omega) > 1$  for the near ultraviolet, visible, far infrared, and radio wave regions. Once again  $n(\omega) < 1$  in the far ultraviolet so the radiation is again forbidden.

Usually one would rather have the radiation intensity expressed



# RESEARCH REPORT

## ON THE THEORY OF

### ELECTROMAGNETIC RADIATION

where  $e$  is the charge of an electron,  $\mathbf{r}$  is the position vector of the electron,  $\mathbf{v}$  is the velocity of the electron, and  $\mathbf{a}$  is the acceleration of the electron. The radiation field is given by the retarded potentials, and the radiation reaction force is given by the Abraham-Lorentz-Dirac equation.

Following:

1. The radiation reaction force is given by the Abraham-Lorentz-Dirac equation, which is a third-order differential equation for the position vector  $\mathbf{r}$ .
2. The radiation reaction force is proportional to the third derivative of the position vector  $\mathbf{r}$ .
3. Radiation reaction is important in the theory of the motion of charged particles, particularly in the theory of the motion of electrons in atoms and molecules.
4. The radiation reaction force is important in the theory of the motion of charged particles, particularly in the theory of the motion of electrons in atoms and molecules.
5. The radiation reaction force is important in the theory of the motion of charged particles, particularly in the theory of the motion of electrons in atoms and molecules.
6. The radiation reaction force is important in the theory of the motion of charged particles, particularly in the theory of the motion of electrons in atoms and molecules.

As equation (1) is a third-order differential equation, it is not well-posed. There are two ways to deal with this problem. One way is to assume that the radiation reaction force is zero, which is the case in the theory of the motion of charged particles in atoms and molecules. The other way is to assume that the radiation reaction force is given by the Abraham-Lorentz-Dirac equation, which is the case in the theory of the motion of charged particles in atoms and molecules.

If dispersion is neglected, then  $\mathbf{r}$  is a function of  $t$  only, and in order for the radiation reaction force to be non-zero,  $\mathbf{r}$  must be a function of  $t$  only. This is the case in the theory of the motion of charged particles in atoms and molecules. The radiation reaction force is given by the Abraham-Lorentz-Dirac equation, which is a third-order differential equation for the position vector  $\mathbf{r}$ . The radiation reaction force is proportional to the third derivative of the position vector  $\mathbf{r}$ . Radiation reaction is important in the theory of the motion of charged particles, particularly in the theory of the motion of electrons in atoms and molecules. The radiation reaction force is important in the theory of the motion of charged particles, particularly in the theory of the motion of electrons in atoms and molecules. The radiation reaction force is important in the theory of the motion of charged particles, particularly in the theory of the motion of electrons in atoms and molecules.

Usually one would expect that the radiation reaction force is given by the Abraham-Lorentz-Dirac equation, which is the case in the theory of the motion of charged particles in atoms and molecules.



as the number of photons emitted by an electron. Consider equation (1) again.

$$\frac{dW}{d\ell} = \frac{e^2}{c^2} \int_{\omega_1}^{\omega_2} \left(1 - \frac{1}{\beta^2 n^2}\right) \omega d\omega.$$

The  $\omega_1$  and  $\omega_2$  are associated with the different wave lengths  $\lambda_1$  and  $\lambda_2$ . Assume that  $n$  is now the average index of the refraction of the radiator.

$$\therefore \frac{dW}{d\ell} = \frac{e^2}{c^2} \left(1 - \frac{1}{\beta^2 n^2}\right) \int_{\omega_1}^{\omega_2} \omega d\omega. \quad (3)$$

Now the energy of the light may be expressed as a function of the number of photons  $N$  by the following:

$$W = N h\nu. \quad (4)$$

$$\frac{dN}{d\ell} = \frac{e^2}{hc^2} \left(1 - \frac{1}{\beta^2 n^2}\right) \int_{\omega_1}^{\omega_2} \frac{\omega}{\nu} d\omega. \quad (5)$$

$$\frac{dN}{d\ell} = \frac{e^2}{hc^2} \left(1 - \frac{1}{\beta^2 n^2}\right) \int_{\omega_1}^{\omega_2} d\omega. \quad (6)$$

$$\frac{dN}{d\ell} = \frac{e^2}{hc^2} \left(1 - \frac{1}{\beta^2 n^2}\right) (\omega_2 - \omega_1). \quad (7)$$



as the number of photons emitted by the radiator,  $N$ , is given by

(1) again,

$$N = \frac{W}{h\nu} = \frac{W}{h\nu} \left( \frac{1}{\epsilon} - 1 \right)$$

The  $\omega_1$  and  $\omega_2$  are associated with the different wave lengths  $\lambda_1$  and  $\lambda_2$

Assume that  $\lambda_1$  is not the average value of the radiation of the

radiator,

$$N = \frac{W}{h\nu} \left( \frac{1}{\epsilon} - 1 \right) \quad \therefore \quad \frac{W}{h\nu} = \frac{N}{\epsilon - 1}$$

Now the energy of the light can be expressed as a function of

the number of photons  $N$  in the following:

$$(1) \quad W = h\nu N$$

$$(2) \quad \frac{W}{h\nu} = \frac{N}{\epsilon - 1}$$

$$(3) \quad \frac{W}{h\nu} = \frac{N}{\epsilon - 1}$$

$$(4) \quad \frac{W}{h\nu} = \frac{N}{\epsilon - 1}$$

COLLISION CONTROL

RESEARCH



$$\omega_1 = \frac{2\pi c}{\lambda_1}, \quad \omega_2 = \frac{2\pi c}{\lambda_2}. \quad (8)$$

$$\therefore \frac{dN}{d\lambda} = 2\pi\alpha \left(1 - \frac{1}{\beta^2 n^2}\right) \left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right). \quad (9)$$

$$\alpha = \frac{e^2}{\hbar c} \quad (10)$$

$$\alpha \sim \frac{1}{137}.$$

where  $\alpha$  is the fine structure constant.

Therefore, the total number of photons for a given length  $l$  of the radiator and between two wavelengths  $\lambda_1$  and  $\lambda_2$  is given by:

$$N = 2\pi\alpha l \left(1 - \frac{1}{\beta^2 n^2}\right) \left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right) \quad (11)$$

From this equation we can see the main feature of the Cerenkov radiation spectral distribution. The number of photons per unit path length is inversely proportional to the wavelength.

$$\frac{dN}{d\lambda} \sim \frac{1}{\lambda}. \quad (12)$$



# MILLER FALLS E-Z-ERASE

## INSTRUCTIONS

$$(1) \quad \frac{dN}{dx} = \frac{N}{\lambda} \left( 1 - e^{-\alpha x} \right)$$

$$(2) \quad \alpha = \frac{2\pi}{\lambda}$$

$$\alpha = \frac{2\pi}{\lambda}$$

where  $\alpha$  is the absorption coefficient.

Therefore, the total number of atoms per unit length of the radiator and reflector is given by

$$N = \frac{1}{\lambda} \left( 1 - e^{-\alpha x} \right)$$

From this equation we can see that as the wavelength of radiation spectral distribution, the number of atoms per unit path length is inversely proportional to the wavelength.

$$\frac{dN}{dx} = \frac{N}{\lambda}$$



From this the number of photons per unit length per unit wave-length interval is:

$$\frac{d^2 N}{d\ell d\lambda} \sim \frac{1}{\lambda^2} \quad (13)$$

so that the energy per unit length per unit wave length interval is then:

$$\frac{d^2 W}{d\ell d\lambda} \sim \frac{1}{\lambda^3} \quad (14)$$

In terms of the emitted frequencies, the energy per unit path length per unit frequency interval is:

$$\frac{d^2 W}{d\ell d\nu} \sim \nu \quad (15)$$

It should be remembered that no frequency cut-off has been imposed in deriving the energy relations, but if the dispersion characteristics of the radiator are considered, a cut-off will be introduced. The dispersion may be such that the index of refraction decreases sharply over a short range of frequencies so that the energy radiated in this region will decrease rapidly. This can be seen considering equation (3) again.



From this we may write the energy per unit length as:

length interval is:

$$\frac{d^2W}{d\lambda^2} = \frac{1}{\lambda^2}$$

so that the energy per unit length is still constant, but now it is

then:

$$\frac{d^2W}{d\lambda^2} = \frac{1}{\lambda^2}$$

In terms of the energy per unit length, the energy per unit length

length per unit length interval is:

$$\frac{d^2W}{d\lambda^2} = \frac{1}{\lambda^2}$$

It should be remembered that in the energy per unit length form

imposed in deriving the energy relations, we assumed the radiation

characteristics of the radiation are characterized by a constant

be introduced. The characteristic of the radiation is characterized by a constant

tion decreases sharply over a small range of frequencies, and the

energy radiated in this region will decrease rapidly, and can be

seen considering equation (1) above.



$$\frac{dW}{d\ell} = \frac{e^2}{c^2} \left(1 - \frac{1}{\beta^2 n^2}\right) \int_{\omega_1}^{\omega_2} \omega d\omega.$$

The smaller  $n$  becomes for different materials the larger the negative term grows and  $dW/d\ell$  decreases.

Suppose the maximum emission of Cerenkov radiation for the radiator occurs approximately at  $\lambda = 3000 \text{ \AA}$  so that  $\nu = 10^{15} \frac{c}{\text{sec}}$ . If this material becomes strongly dispersive below  $3000 \text{ \AA}$ , then an energy distribution would probably look like Fig. 4.

Also, anomalous dispersion might be critical, especially in the higher frequencies, so a substance should be investigated for these effects.

The final criterion is, of course, the sensitivity of the phototube. The sensitivity of most tubes falls off toward the higher frequencies, so it is quite possible that these dispersion effects might not be observed.

## B. FLUORESCENCE

"Fluorescence is due to the prompt, spontaneous transition of a molecule from an excited state to a lower energy level".<sup>4</sup> This should be contrasted to phosphorescence where the light emission lasts for a considerable length of time. The lifetime of fluorescent absorption and emission of energy is  $\tau \approx 10^{-7} \text{ sec}$ .



$$\left( \frac{1}{\sqrt{1-\beta^2}} - 1 \right) \frac{e_0}{c^2} = \frac{Wb}{\lambda b}$$

The smaller it becomes the difference between the two negative terms grows and  $\lambda b$  increases.

Suppose the maximum radiation of frequency  $\nu$  of the radiator occurs approximately at  $\lambda = 2\pi c / \nu$ . Then as this material becomes strongly dispersive below  $1000 \text{ cm}^{-1}$ , the energy distribution would probably look like fig. 1.

Also, anomalies appear in the region of optical frequencies, higher frequencies, so a spectrum would be very irregular in effect.

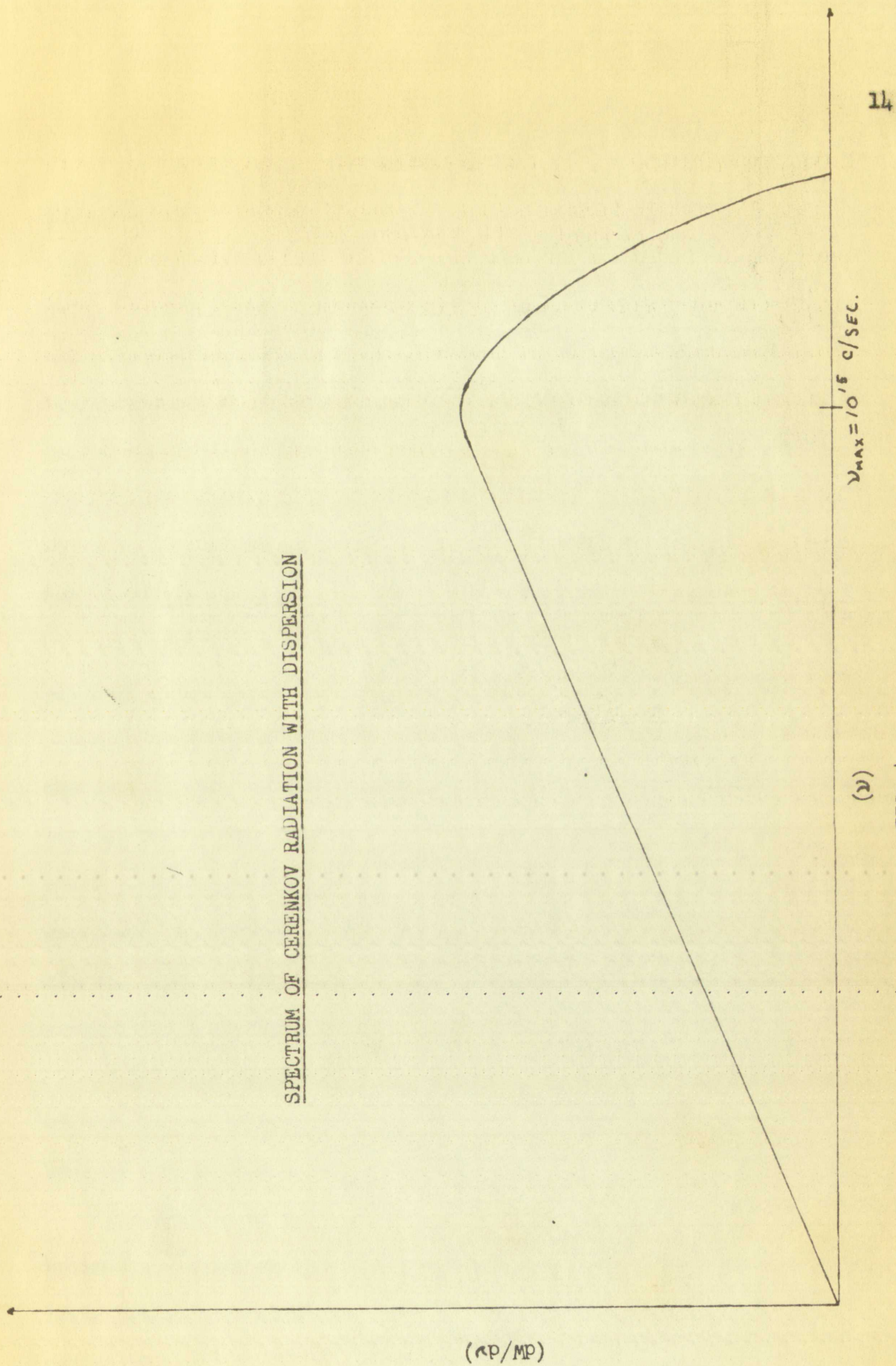
The final criterion is, of course, the sensitivity of the tubes. The sensitivity of such tubes falls off rapidly at higher frequencies, so it is quite possible that these frequencies might not be observed.

## REFERENCES

- "Fluorescence in the infrared," *Journal of Chemical Physics*, 1934, 2, 1.
- Molecules from an excited state to a lower state, *ibid.*, 1934, 2, 1.
- should be contrasted to the absorption spectrum of  $\text{H}_2$  which is
- lasts for a considerable length of time. The life-time of the
- cent absorption and emission in energy is  $10^{-10}$  sec.

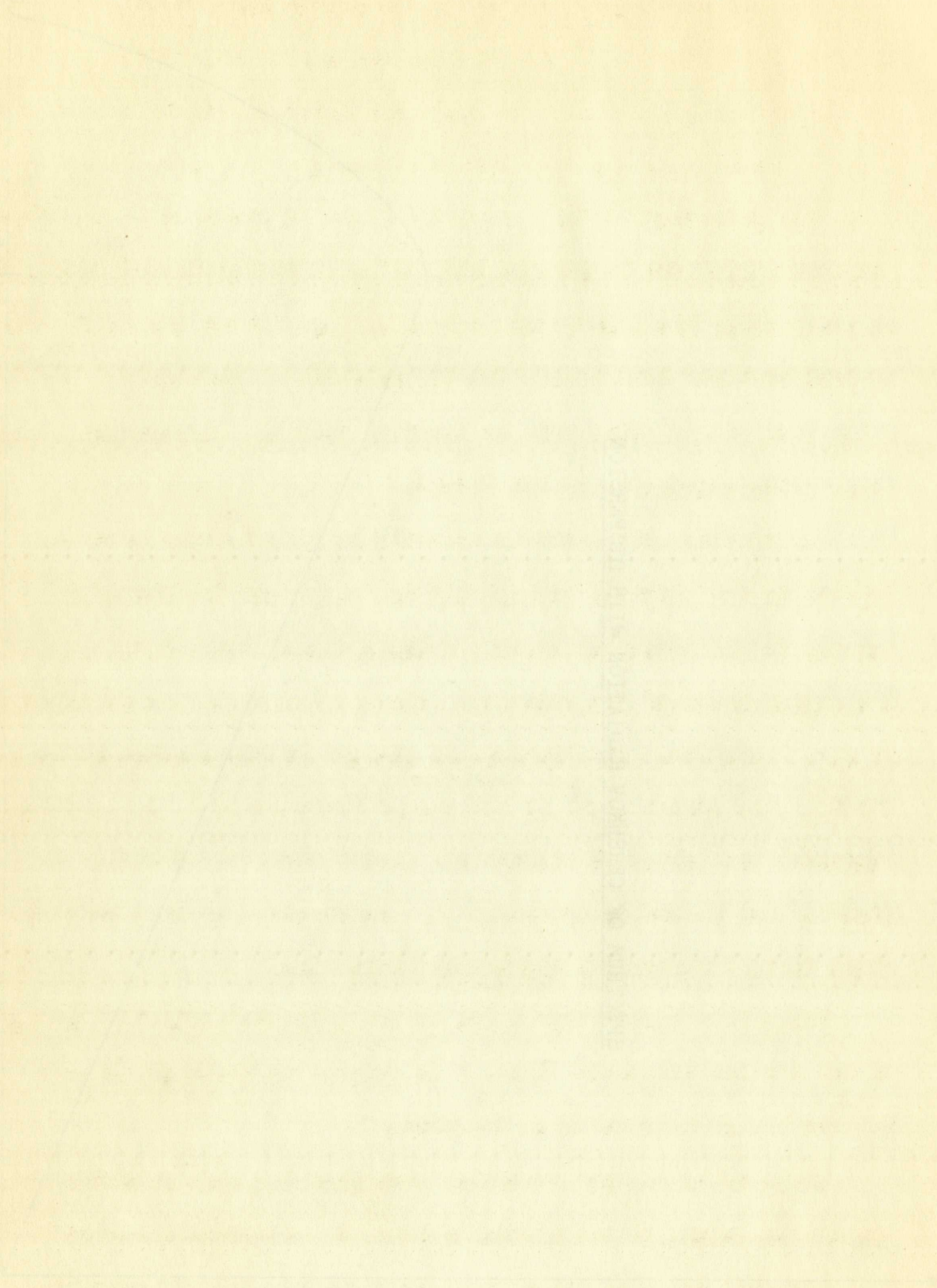


SPECTRUM OF CERENKOV RADIATION WITH DISPERSION



( $\nu$ )  
FIG. 4.





(2000)



Consider a fluorescent atom in its ground state subject to some incident radiation  $E=h\nu$ , and suppose the energy is absorbed. The atom then exists in an excited state and quickly returns to its ground state by reemitting the same amount of energy  $E=h\nu$ ; so in this case, the wavelength of the reemitted light is the same as the absorbed radiation. It must be pointed out that only certain quanta can even be absorbed by the fluorescent molecule, i.e., there are only certain absorption bands associated with the molecule so that only a particular kind of radiation must be incident upon the fluorescent atoms before fluorescence manifests itself.

Now consider the diatomic molecule in Fig. 5<sup>5</sup>. The abscissa represents the distance between the two atoms and the ordinate represents the potential energy of the system. Curve 1 represents the energy state of the unexcited molecule and AB is the distance between the atoms. The "zero-point energy" is represented by CD which is the ground state of the atom. The numbers 1, 2, 3, etc., represent the number of vibrational quanta that the molecule can absorb. Let a quantum of energy  $E=h\nu$  be absorbed by this molecule where Curve 2 represents the excited molecule.

Point F is higher than B due to the increased potential energy of the excited molecule. Also, F is further to the right than B because the AB bond has been weakened.

The results of wave mechanics show that the most probable transition occurs at the middle of line CD, but transitions of lower probability also exist to produce a band width of reemitted radiation.



Consider a fluorescent atom in the ground state before it is

excited by incident radiation  $E_{\nu}$ , and suppose the energy is absorbed.

When then exists in an excited state, and possibly emits light

state by reemitting the same amount of energy  $E_{\nu}$  as it absorbed.

Since the wavelength of the reemitted light is the same as the wavelength

radiation. It must be emitted with the same frequency as it was absorbed.

be absorbed by the fluorescent molecule, i.e., the energy is absorbed

absorption bands associated with the molecule as a whole, and not

either kind of radiation must be emitted with the same frequency as

before fluorescence molecule itself.

Now consider the distance between the two states,  $E_2 - E_1$ , the energy

represents the distance between the two states and the energy

represents the potential energy of the system. When a molecule

the energy state of the excited molecule and the ground state

between the states. The "zero-point" energy is represented by  $E_0$

which is the ground state of the system. The energy  $E_0$  is

represent the number of vibrational quanta that the molecule can

absorb. Let a quantum of energy  $h\nu$  be absorbed by the molecule

where Curve 2 represents the excited state and Curve 1 the ground

Point P is higher than B due to the increased potential energy

of the excited molecule. Also, P is higher than B due to the

because the AB bond has been weakened.

The results of wave mechanics show that the wave function

transition occurs at the middle of the AB bond, and the transition

lower probability. It also shows that the probability of reemission

radiation.



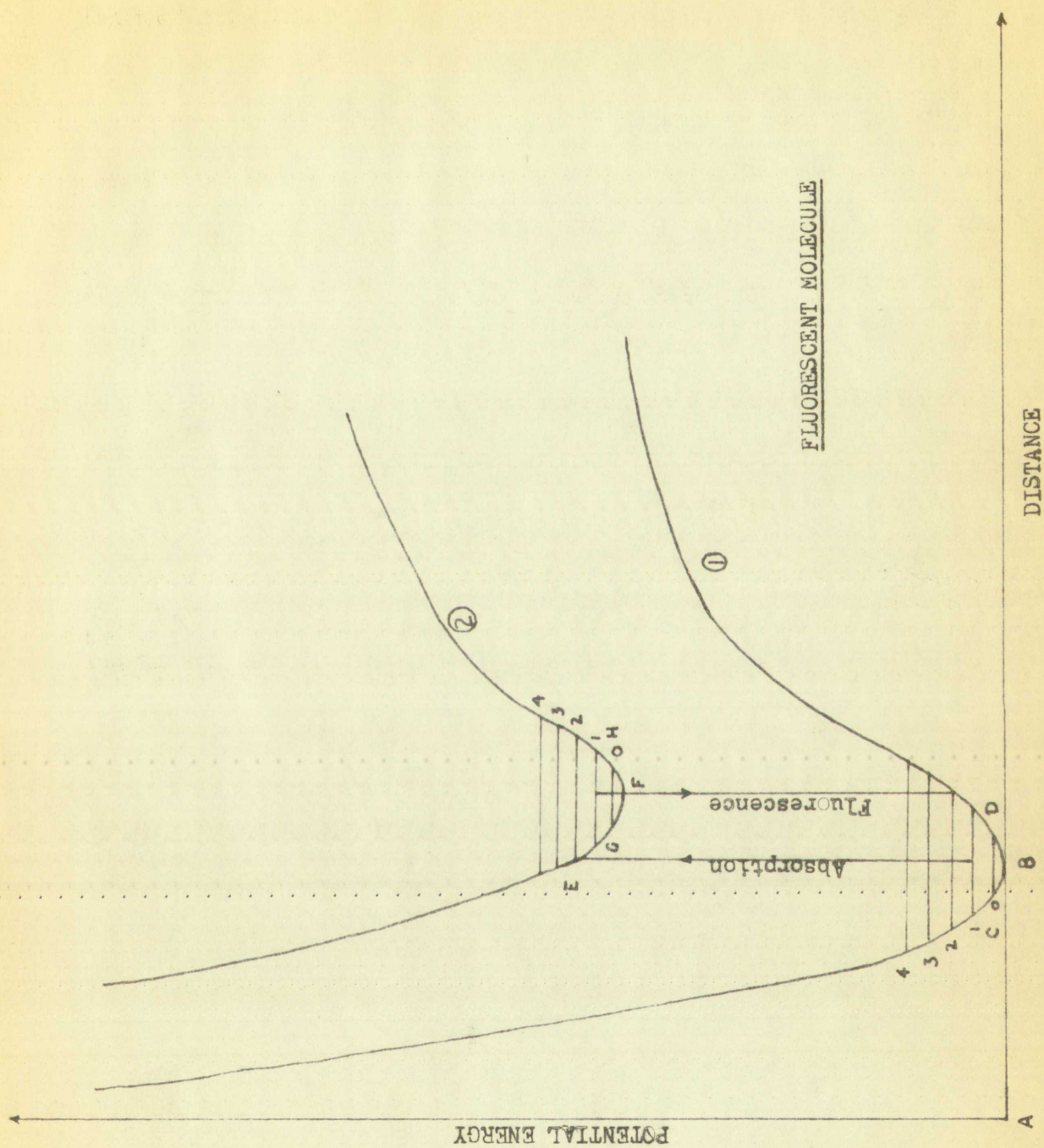


FIG. 5.







Ordinarily, if the molecule is undisturbed, a reemission process can occur directly from E to CD, but in a liquid this is not the case. After absorption the molecule will suffer collisions with its neighbors and some of its absorbed energy is taken away by the other molecules in the form of vibrational excitation. This heat degrading process "quenches" some of the radiation and the excited molecule is lowered to its "zero-point energy" GH. Then, if the molecule is not disturbed further, a reemission of its remaining energy  $E' = h\nu'$  can occur and the molecule returns to point J. Since the wavelength of the absorption line is greater than that of the emission line,  $\nu > \nu'$ , or  $\lambda' > \lambda$ , which means that the light has been shifted toward the longer wavelengths. This law was discovered empirically by Stokes<sup>6</sup> and, hence, red fluorescence is excited by orange light, yellow by green, green by blue, and violet by ultraviolet. Small departures from Stokes law do exist, but only at high temperatures where it might be possible for surrounding molecules to transfer heat energy to the fluorescent molecule and cause a shorter wavelength to be emitted, but the present measurements were made at room temperature so Stokes law was held valid. POPOP is sensitive to near ultraviolet and violet radiation, so the reemitted light is shifted toward the violet and blue wavelengths. Actually, most of the reemission occurs approximately at  $4000 \text{ \AA}$ .

The quenching exhibited by fluorescent compounds is an important fact to mention.<sup>7</sup> The absorbed light is not reemitted, but is degraded into heat by a variety of processes. There are essentially three separate quenching mechanisms that compete with the reemission of light.<sup>8</sup>



Ordinarily, if the molecule is excited, it will return to the ground state by emitting light. This process can occur directly from the excited state, or it can occur via a series of intermediate states. After absorption the molecule will return to the ground state by emitting light. Some of the absorbed energy is lost as heat, and some of it is lost as fluorescence. The process of fluorescence is a process "quenched" some of the radiation and the molecule is transferred to its "zero-point energy" state. If the molecule is excited further, a transition to the ground state is also possible, and the molecule returns to point 1. Since the wavelength of the absorption line is greater than that of the emission line,  $\lambda' > \lambda$ , which means that the light has been shifted toward the longer wavelengths. This law has been observed experimentally in many cases, and, hence, the fluorescence is shifted to longer wavelengths. Green, green by blue, and violet by ultraviolet. The Stokes law does exist, and only in some cases. It might be possible for a molecule to emit light at a shorter wavelength than the fluorescent molecule, and emit a shorter wavelength than the Stokes law was first stated. But if the molecule emits light at a shorter wavelength, so the transition is to a higher energy state, violet and blue wavelengths. Similarly, most of the absorption occurs approximately at 4000 Å.

The quenching exhibited by fluorescent molecules is a very fast process. The absorbed light is not returned, but is emitted into heat by a variety of processes. There are many different ways of quenching fluorescent molecules, and the results are all different.



The first is an internal quenching of the excitation energy due to the solvent molecule in the solvent itself. This competes with the transfer of the excitation energy to the fluorescent molecule.

The second type of quenching is an internal quenching which is independent of the concentration of the fluorescent molecules.

The third effect is concentration quenching where the fluorescent molecule suffers collisions with other fluorescent molecules.

Kallman and Furst<sup>8</sup> state that Diphenyl solutions have the disadvantage that only a small amount can be used because of the relatively strong self-quenching or concentration quenching.

Kallman and Furst<sup>9</sup> studied the intensities of the fluorescent light for many different compounds, and in general, each of their curves show a maximum followed by a decrease due to increasing concentrations. See Fig. 6. Unfortunately a curve of the relative intensity as a function of the concentration of POPOP was not given.

Since POPOP is strongly self-quenching, the maximum must immediately occur followed by a sharp decline of relative intensity.

The curve probably looks something like Fig. 7.







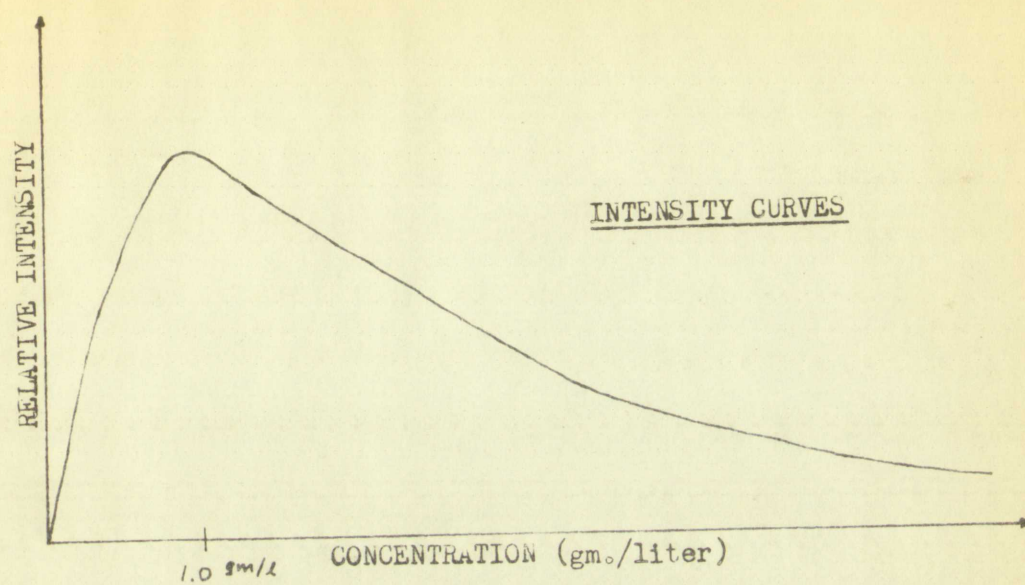


FIG. 6.

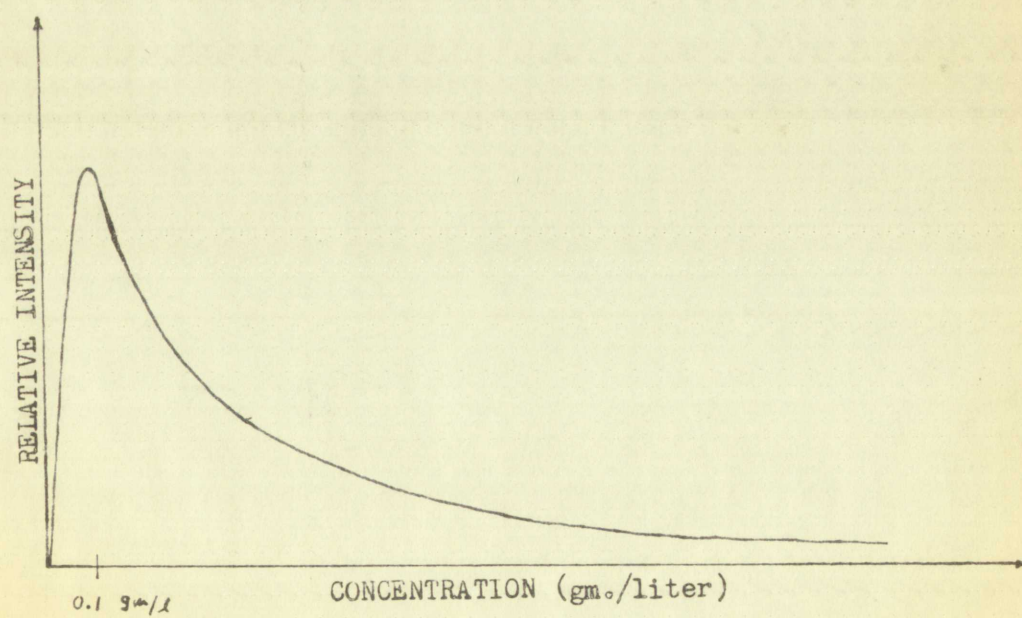


FIG. 7.







### CHAPTER III

#### THE EXPERIMENTAL ARRANGEMENT

##### A. LIQUID CERENKOV COUNTER

A liquid Cerenkov counter was built in order to study the affects of the POPOP in solution. The essential features of the liquid counter are as follows: First, a 250 ml beaker was filled with 150 ml of the solvent and then optically sealed with a silicon fluid to a phototube. Black muslin cloth covered the whole apparatus to insure light-tightness. The beaker was wrapped with aluminum foil and the top was also capped with foil. This was done to increase the light collection efficiency because of the random direction of the reemitted light. Fig. 8 shows the arrangement. Aluminum strips were taped to the beaker and tube to prevent sliding of the beaker. The lights were turned off and a "Photon-emitter", i.e., flashlight, was shown upon all areas searching for light leaks. If nothing was noticed on the oscilloscope, separate runs were taken with the lights on and off to determine that the count was not being affected by any possible light leaks.

It was learned that the "Scotch Brand" black electrical tape caused light emission when it is pulled off a surface because of static electricity. The tape naturally pulls away on its own accord, so care must be taken to prevent the phototube from seeing this emitted light. The aluminum strips were taped to the beaker and not to the phototube, because there was a possibility for this "static light" to be refracted into the beaker and reflected back toward the tube.



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light collection efficiency because of the random direction of the

scattered light. Fig. 8 shows the arrangement. Aluminum strips were

taped to the beaker and tube to prevent sliding of the beaker. The

lights were turned off and a "Photon-sensor", i.e., flashlight, was

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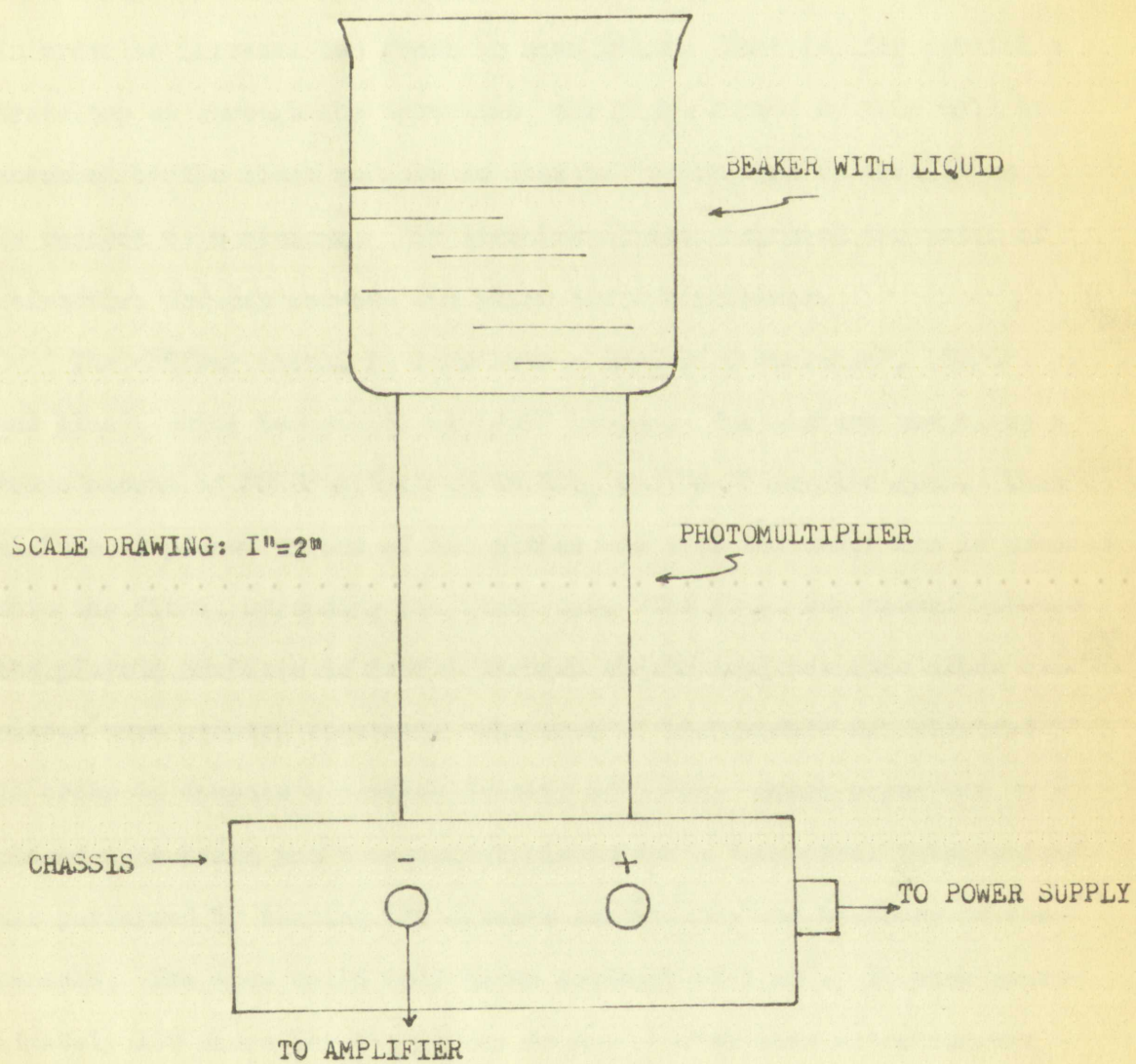
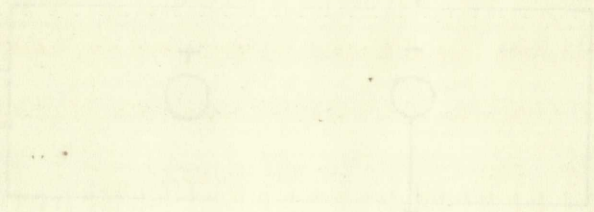
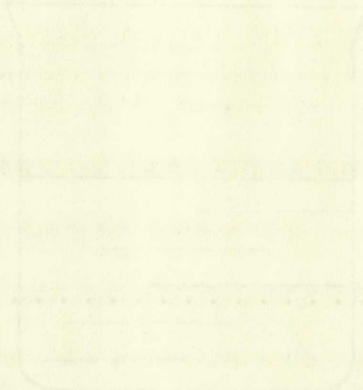
LIQUID COUNTER ARRANGEMENT

FIG. 8.



MECHANICAL PARTS





### B. SOLID CERENKOV COUNTER

The solid used in this counter was a 4" long lucite (polymethyl methacrylate) cylinder with a diameter of  $2\frac{1}{4}$ ". The set-up is pictured in Fig. 9.

The radiator was polished smooth and the top surface was painted with a black plastic paint mixed with dissolved lucite. This was done in order to increase the front to back ratio. That is, for particles traveling up through the apparatus, the light formed by them will be absorbed by the black surface so that the reflection of this light is reduced to a minimum. The dissolved lucite improved the match of refractive indices between the paint and the cylinder.

The shifter itself is made into a "PP and G sandwich", (POPOP and glue), using two plates of  $1/32$ " lucite. The mixture comprises a known amount of POPOP dissolved in  $\text{CCl}_4$  and "B-7" acrylic glue. This mixture is poured on one of the plates and then the other one is pressed onto the first, spreading the fluid out. The fluid was poured between the plastic surfaces so that a pancake shaped area resulted after the plates were pressed together. The area of the pancake was measured in order to compute a surface density of POPOP. Graph paper was placed underneath the transparent plates and a "numerical integration" was performed by summing the squares enclosed by the boundary of the pancake. The area could read to an accuracy of  $1 \text{ mm}^2$ . It took approximately 100 hours for the plates to dry. After this a section was chosen which was bubble-free so that a  $2\frac{1}{4}$ " diameter disk could be cut out. It was noticed that an inhomogeneity around the edges of the disks resulted which was due to the separation of the plates letting







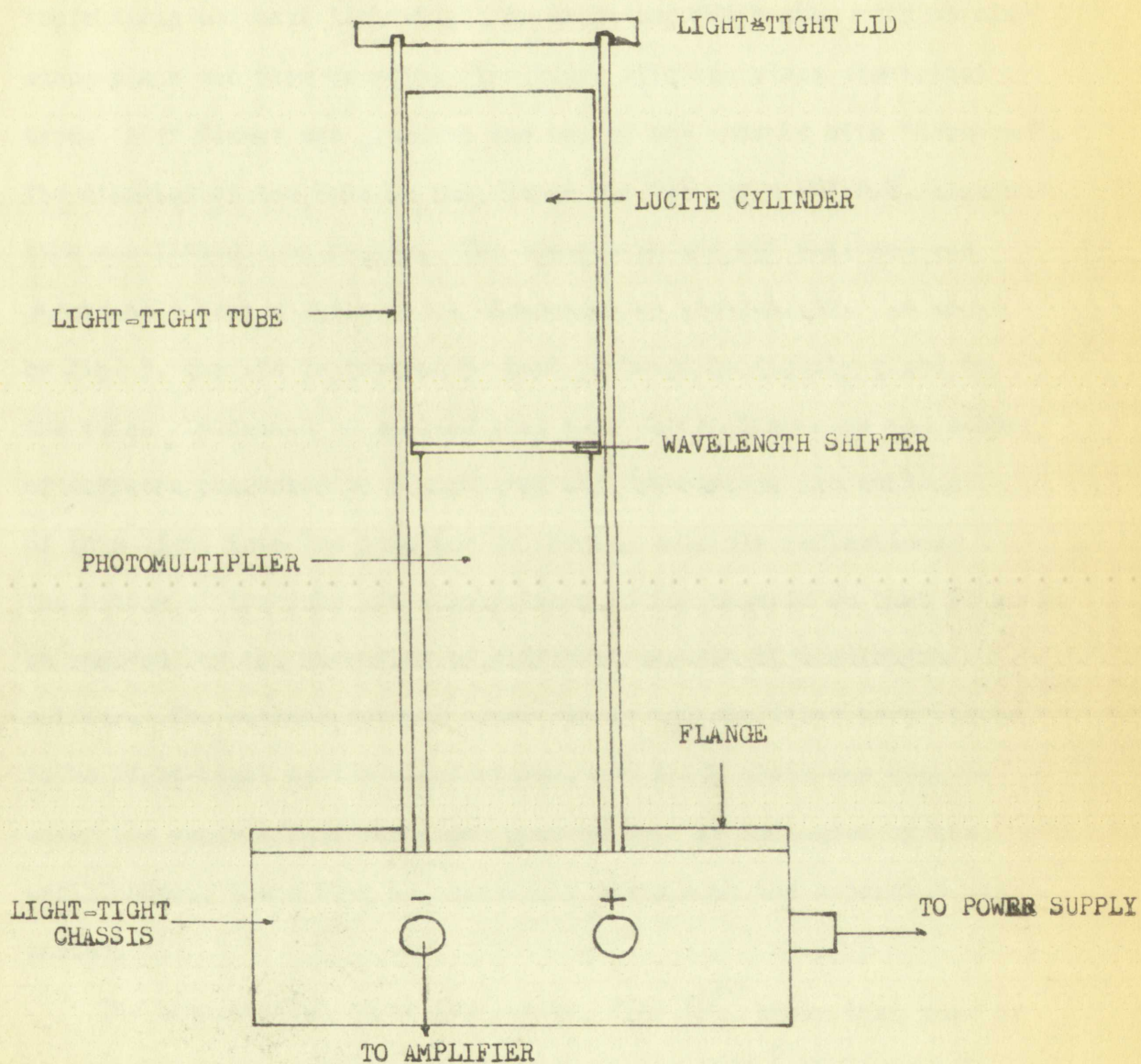
CROSS SECTIONAL VIEW OF SOLID COUNTER

FIG. 9.







air in, but since the plates were larger than the phototube, the edging effects could be ignored. Finally, the plates were optically sealed between the phototube and the lucite radiator.

The problem of light leaks and the requirement of facility of changing wave length shifters was reconciled in the following way. The chassis was made light-tight by enclosing the bottom with an aluminum plate and then covering five sides with the black electrical tape. A  $\frac{1}{4}$ " flange was glued to the top of the chassis with "Eccobond". The diameter of the hole in the flange was  $2\frac{1}{2}$ " and a  $2\frac{1}{2}$ " O.D. aluminum tube was fitted down snugly. The outer tube was  $9\frac{1}{2}$ " tall and was permanently capped again using "Eccobond" as the sealant. As shown by Fig. 9, the lid is grooved so that it could be tightly glued to the tube. It should be noticed that this design increases the number of surfaces presented to a light ray and discourages the entrance of this light into the interior by forcing multiple reflections. The bottom of the tube was simply taped to the chassis so that it could be removed for the insertion of different amounts of wavelength shifter. The outlets for the power supply and amplifier were stated to be light-tight by the manufacturer, but black cloth was used to cover the whole affair for added protection. As indicated by the oscilloscope, there were no measurable leaks when the apparatus was tested.

The transmission curve for lucite, Fig. 10<sup>10</sup>, shows that some of the ultraviolet radiation is absorbed, but at  $3400\text{ \AA}$ <sup>0</sup> the material lets 80% of the light through, so most of the ultraviolet light is transmitted. The optical properties of lucite are given in Fig. 11<sup>11</sup>.







TRANSMISSION CHARACTERISTICS OF LUCITE

(% TRANSMISSION THROUGH 1/8" SHEET)

25

5500

5000

4500

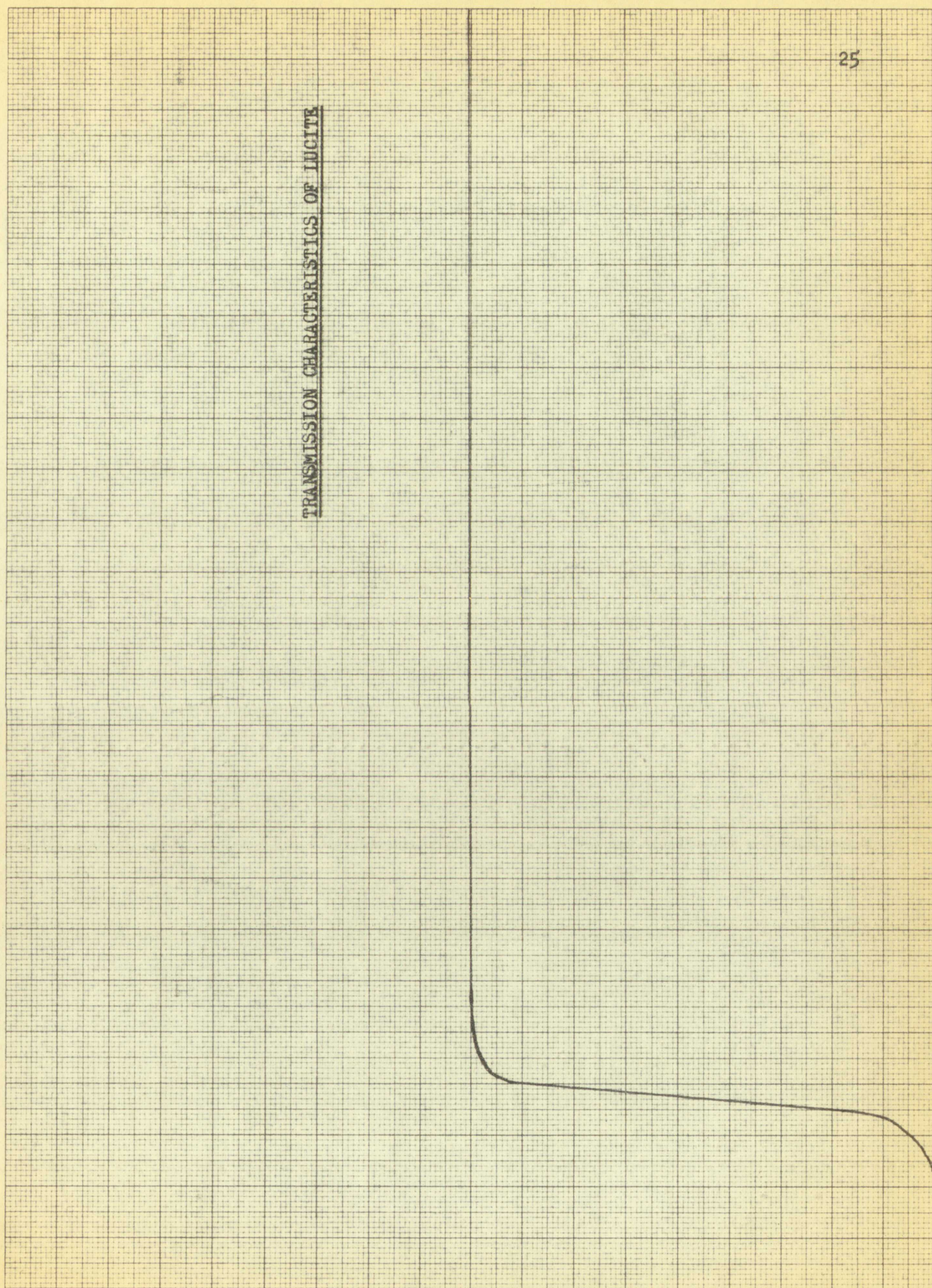
4000

3500

3000

( $\lambda$ )

FIG. 10.









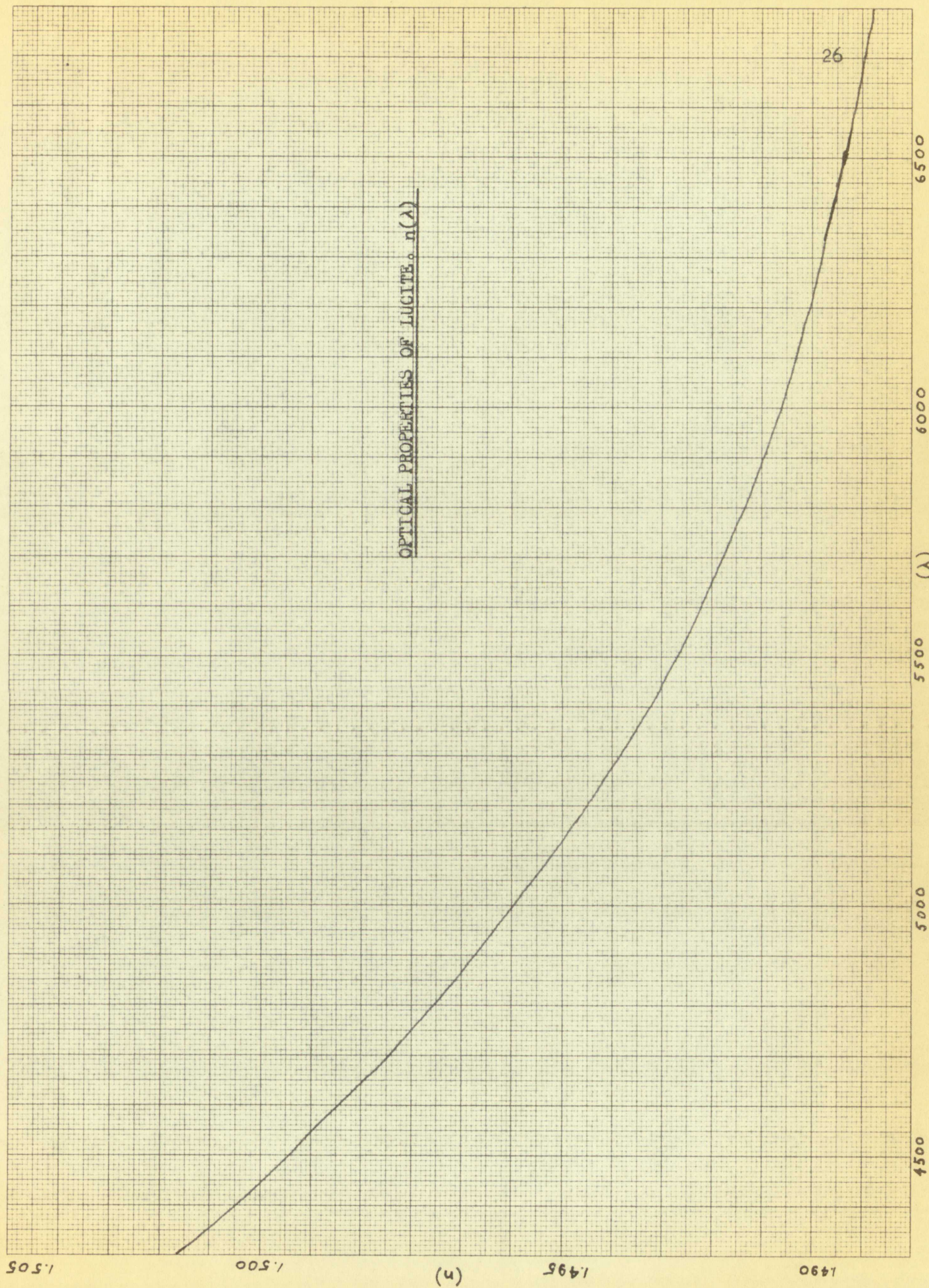


FIG. 11.







The refractive index of this material is fairly constant past 3400 Å<sup>o</sup> with low dispersion and good transmission characteristics.

Since the electronics apparatus used was comparatively simple, block diagrams will be unnecessary. A "John Fluke" power supply ran directly to the photomultiplier and the negative pulses were chosen from the phototube circuit. These pulses were amplified and sent to the "Beckman/Berkeley" pulse counter. The oscilloscope was used as a check to see if the pulses behaved correctly.

### C. THE PHOTOMULTIPLIER

The phototube used is a 9514S E.M.I. Cs-Sb cathode type and its characteristics are given in Table I. The spectral response curve<sup>12</sup> is given in Fig. 12. It can be seen that the tube is relatively insensitive to violet and red light. This 13-stage phototube has a relatively small dark current which makes it convenient to work with.

The dark current is the residual current which flows in the tube when the tube is immersed in total darkness. If the photomultiplier is exposed to light, energy can be absorbed and trapped by the photocathode surface and then reemitted at a later time. Usually several hours would be necessary for the tube to settle down, but in the experiment it was never exposed to direct light. When any changes had to be made, the lights were turned off and a flashlight capped with a red filter provided sufficient light for the experimenter without disturbing the tube.

Aluminum foil was wrapped around the phototube and pinned to the cathode. This was done to provide a shield for the electrode structure.



The refractive index of this material is about 1.5 and it is transparent with low dispersion and good transparency. Since the electronic apparatus used in this experiment is of the block diagram type, it is necessary to have a means of connecting directly to the photomultiplier tube. This is accomplished by connecting from the photomultiplier tube to the "Beckman/Geckley" pulse generator. The output of the pulse generator is connected to the input of the oscilloscope. It is necessary to check to see if the pulse generator is working.

#### 2. THE PHOTOEFFECT

The phototube used is a 9313 A-1, 10-20 microampere tube. The characteristics are given in Table I. The spectral response curve is given in Fig. 12. It can be seen that the tube is relatively insensitive to violet and red light. The spectral response curve is relatively small dark current. The spectral response curve is given in Table I. The dark current is the current which flows in the tube when the tube is immersed in total darkness. In the photomultiplier tube, energy can be absorbed and converted to electrons. Cathode surface and then converted to a current. The spectral response curve would be necessary for the tube to be used in this experiment. It was never exposed to direct light. When the experiment was made, the light was turned off and a 1000-volt potential was applied. The light provided sufficient light for the experiment without disturbing the tube.

Aluminum foil was wrapped around the phototube and placed in the cathode. This was done to prevent light from the phototube from reaching the cathode.



CHARACTERISTICS  
OF THE E.M.I. PHOTOMULTIPLIER

Tube Type	9514S
No. of Stages	13
Cathode Diameter (mm.)	44
Max. Envelope Diameter (mm.)	51
Cathode Type	Cs-Sb(S)
Window Glass	Pyrex or Soda
Minimum Photosensitivity ( $\mu\text{A/L}$ )	20
Average Photosensitivity ( $\mu\text{A/L}$ )	25
Minimum Overall Sensitivity at 160V/Stage or less ( $\text{A/L}$ )	2,000
Maximum Dark Current at Minimum Overall Sensitivity ( $\mu\text{A}$ )	1.0

TABLE I.



1. Name of the person or organization 2. Address 3. City 4. State 5. Zip 6. Country	
7. Name of the person or organization 8. Address 9. City 10. State 11. Zip 12. Country	
13. Name of the person or organization 14. Address 15. City 16. State 17. Zip 18. Country	
19. Name of the person or organization 20. Address 21. City 22. State 23. Zip 24. Country	
25. Name of the person or organization 26. Address 27. City 28. State 29. Zip 30. Country	
31. Name of the person or organization 32. Address 33. City 34. State 35. Zip 36. Country	
37. Name of the person or organization 38. Address 39. City 40. State 41. Zip 42. Country	
43. Name of the person or organization 44. Address 45. City 46. State 47. Zip 48. Country	
49. Name of the person or organization 50. Address 51. City 52. State 53. Zip 54. Country	
55. Name of the person or organization 56. Address 57. City 58. State 59. Zip 60. Country	
61. Name of the person or organization 62. Address 63. City 64. State 65. Zip 66. Country	
67. Name of the person or organization 68. Address 69. City 70. State 71. Zip 72. Country	
73. Name of the person or organization 74. Address 75. City 76. State 77. Zip 78. Country	
79. Name of the person or organization 80. Address 81. City 82. State 83. Zip 84. Country	
85. Name of the person or organization 86. Address 87. City 88. State 89. Zip 90. Country	
91. Name of the person or organization 92. Address 93. City 94. State 95. Zip 96. Country	
97. Name of the person or organization 98. Address 99. City 100. State 101. Zip 102. Country	
103. Name of the person or organization 104. Address 105. City 106. State 107. Zip 108. Country	
109. Name of the person or organization 110. Address 111. City 112. State 113. Zip 114. Country	
115. Name of the person or organization 116. Address 117. City 118. State 119. Zip 120. Country	



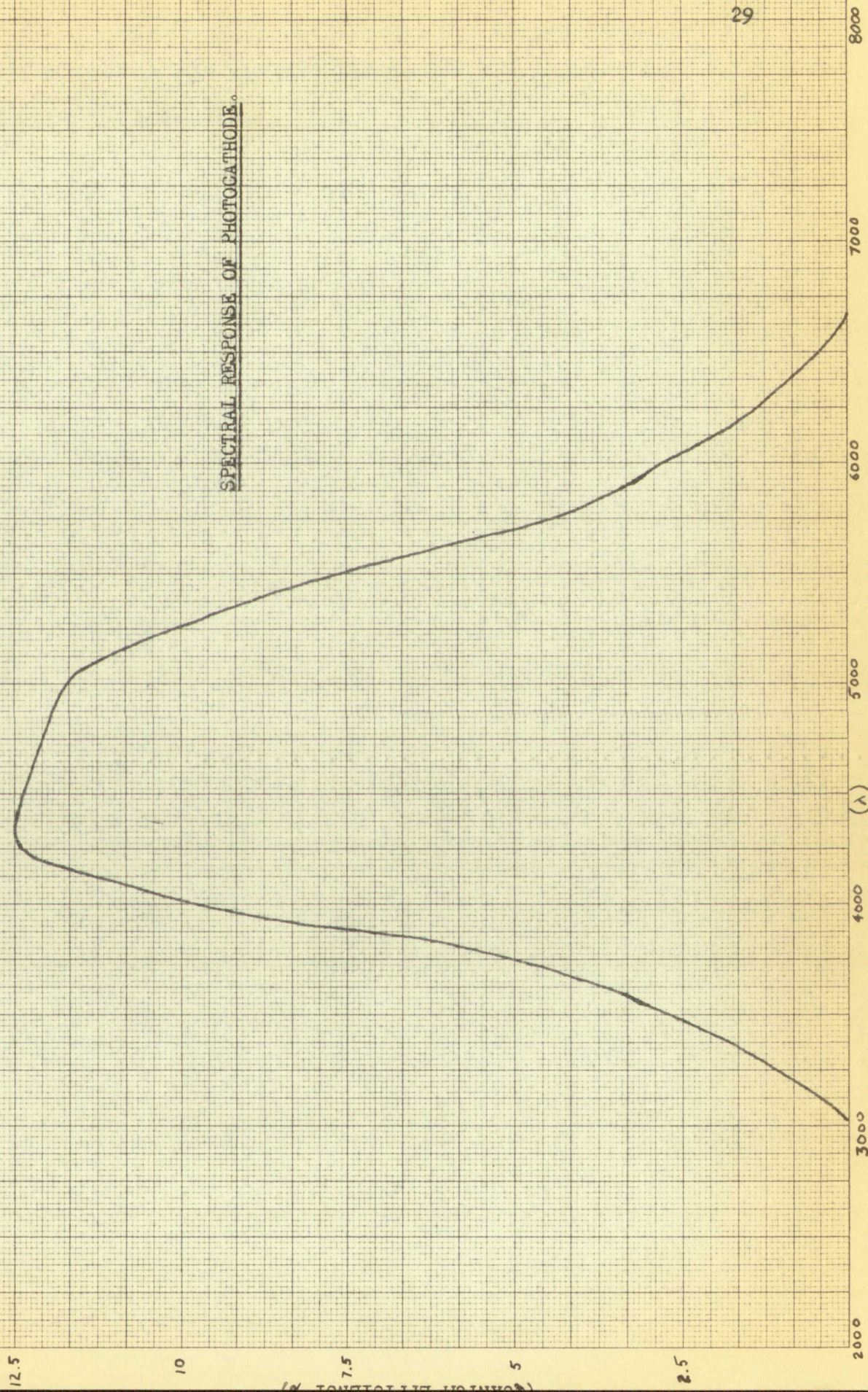
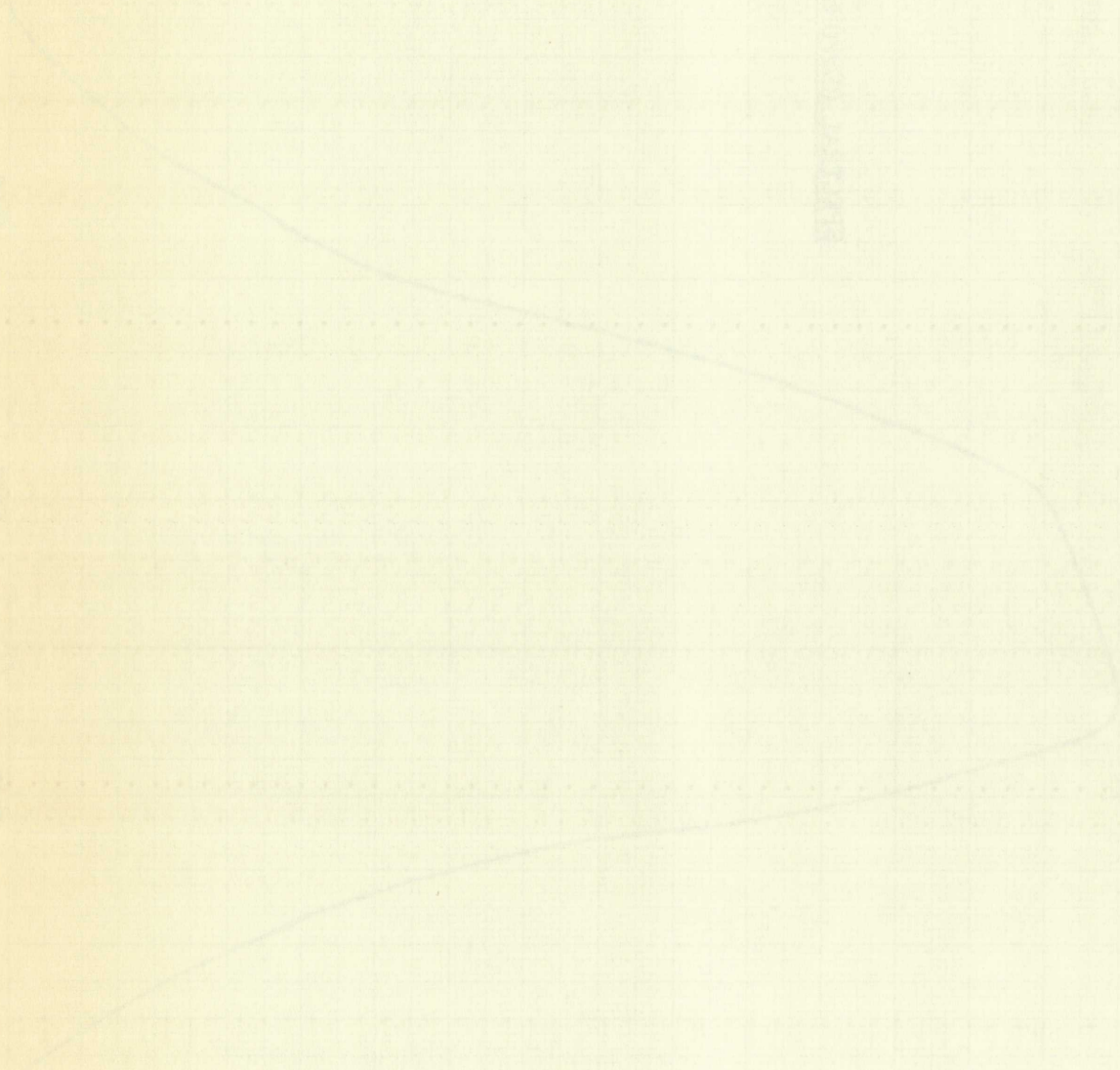
SPECTRAL RESPONSE OF PHOTOCATHODE.

FIG. 12.



1871





The black electrical tape was used to hold the foil in place and was also used for insulation.



THE BLACK ELECTRICAL TAPE WAS USED TO INSULATE THE  
WAS ALSO USED FOR INSULATION.



## CHAPTER IV

### DATA AND RESULTS

#### A. PROCEDURE

Several runs were taken with the solid counter to see what type of curves result and to check on reliability. Table II, Fig. 13 and Fig. 14 show the results of two consecutive days and, as can be seen, the agreement is very satisfactory. The high counting rate at low discriminator levels is due to dark current noise in the tube, but it dies out very quickly with increasing discriminator level. At counting rates of 90/min. and lower, the noise is negligible, so these counting rates are due essentially to Cerenkov light. It should be noticed that in order to obtain reasonable statistics, the counting rate was measured over a comparatively long length of time for a single point! One should be able to see that as much as 3 to 4 hours could be spent plotting the whole curve, so for the sake of the time involved a small range was chosen from 60 counts/min. to 80 counts/min.

#### B. INTRODUCTION OF THE POPOP

Using  $\text{CCl}_4$  as the radiator, a counting rate comparison was made with and without POPOP. For the concentration used a small increase of the counting rate is observed, so it seemed that the experimental arrangement was measuring the reemitted light and previous results were verified. See Table III.

It was discovered that Ethyl alcohol can dissolve POPOP and the Cerenkov radiation was measurably shifted for the concentration used.



## CHAPTER IV

### DATA AND RESULTS

#### A. PROCEDURE

Several runs were taken with the solid counter for two types of curves result and to check on reliability. Table II, Fig. 13 and Fig. 14 show the results of two consecutive days and, as can be seen, the agreement is very satisfactory. The high counting rate at low discriminator levels is due to dark current noise in the tube, but it dies out very quickly with increasing discriminator level. At counting rates of 90/min. and lower, the noise is negligible, so these counting rates are due essentially to Geranov light. It should be noticed that in order to obtain reasonable statistics, the counting rate was measured over a comparatively long length of time for a single point. One should be able to see that as much as 3 to 4 hours could be spent plotting the whole curve, so for the sake of the time involved a small range was chosen from 60 counts/min. to 80 counts/min.

#### B. INTRODUCTION OF THE POPP

Using CCl<sub>4</sub> as the radiator, a counting rate comparison was made with and without POPP. For the concentration used a small increase of the counting rate is observed, so it seemed that the experimental arrangement was measuring the reemitted light and previous results were verified. See Table III.

It was discovered that Ethyl alcohol can dissolve POPP and the Geranov radiation was measurably shifted for the concentration used.



DATA FOR BIAS CURVES

Disc.	Counts/Minute $N \pm \sqrt{N}$	Counts/Minute $N \pm \sqrt{N}$
20	1229/5 = 246 $\pm$ 7	1253/5 = 251 $\pm$ 7
30	1094/10 = 109 $\pm$ 3	1336/12 = 111 $\pm$ 3
40	1090/12 = 91 $\pm$ 3	1378/15 = 92 $\pm$ 2
50	829/11 = 16 $\pm$ 3	1454/19 = 76 $\pm$ 2
60	826/13 = 64 $\pm$ 2	1231/19 = 65 $\pm$ 2
70	516/12 = 43 $\pm$ 2	1091/23 = 47 $\pm$ 1
80	317/11 = 29 $\pm$ 2	859/28 = 31 $\pm$ 1

TABLE II.

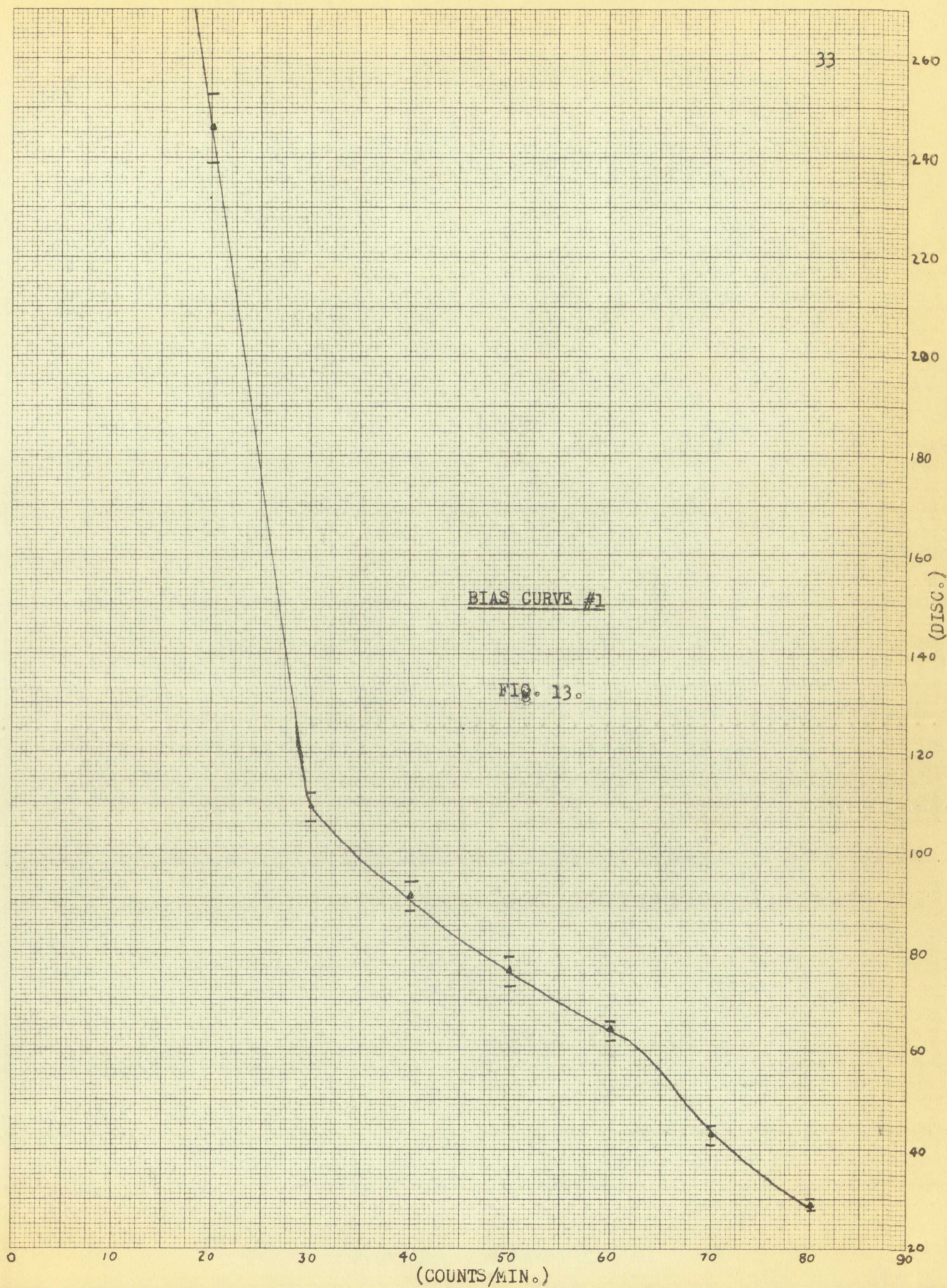


11. 11. 11

80	31.0.11 = 31.0.11	31.0.11 = 31.0.11	31.0.11 = 31.0.11
10	21.0.11 = 21.0.11	21.0.11 = 21.0.11	21.0.11 = 21.0.11
2	11.0.11 = 11.0.11	11.0.11 = 11.0.11	11.0.11 = 11.0.11
2	11.0.11 = 11.0.11	11.0.11 = 11.0.11	11.0.11 = 11.0.11
10	21.0.11 = 21.0.11	21.0.11 = 21.0.11	21.0.11 = 21.0.11
30	31.0.11 = 31.0.11	31.0.11 = 31.0.11	31.0.11 = 31.0.11
11. 11. 11	11. 11. 11	11. 11. 11	11. 11. 11

11. 11. 11







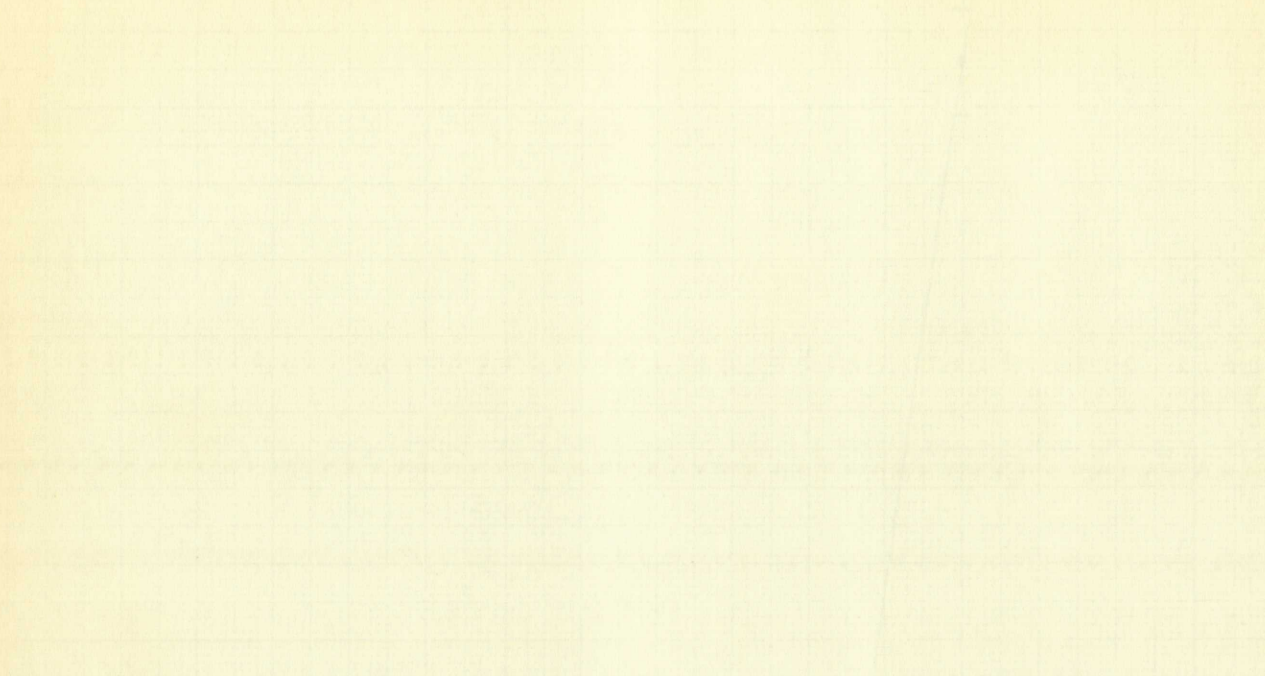
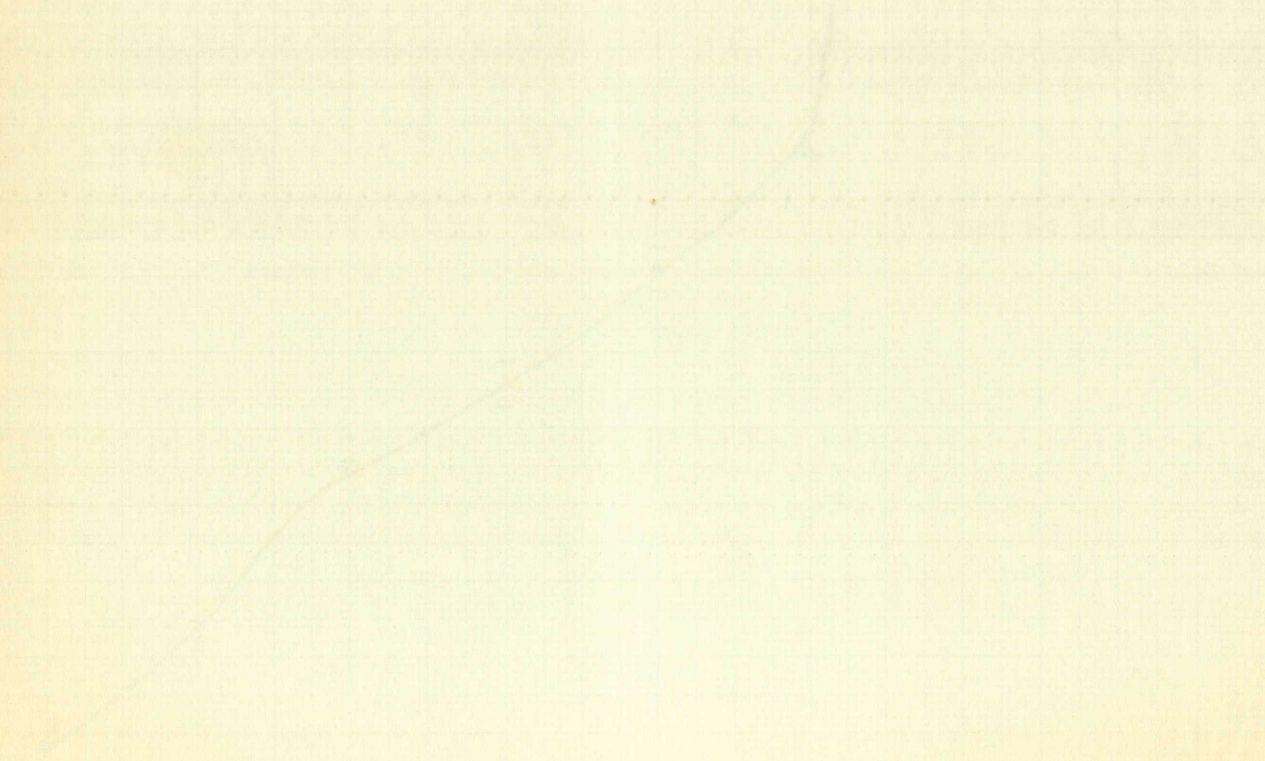


FIG. 1. MAP OF THE

FIG. 2. MAP OF THE

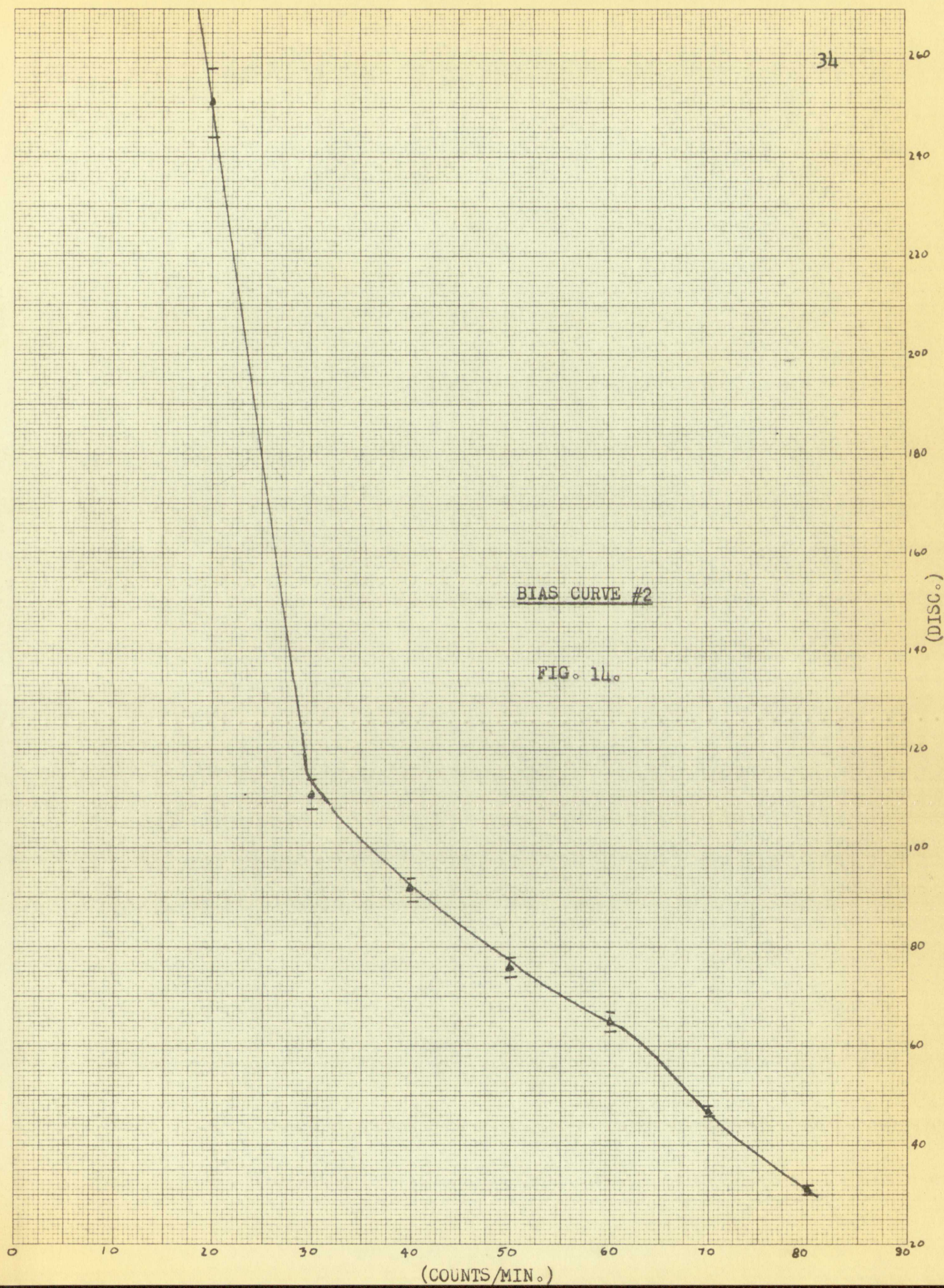




34

BIAS CURVE #2

FIG. 11.









BEAKER WITH  $\text{CCl}_4$   
Gain=3, V=1900 Volts

WITHOUT POPOP		WITH .013 mgm. OF POPOP	
Disc.	Counts/Min. $N \pm \sqrt{N}$	Disc.	Counts/Min. $N \pm \sqrt{N}$
50	1109/16 = $69 \pm 2$	50	1522/20 = $75 \pm 2$
60	1162/19 = $61 \pm 2$	60	1046/16 = $66 \pm 2$

TABLE III.



Diac <sup>+</sup>	Concentration $A + L_1$	Diac <sup>+</sup>	Concentration $A + L_2$	Diac <sup>+</sup>	Concentration $A + L_3$
00	$1900 \setminus 10 = 00 = 0$	00	$1000 \setminus 10 = 00 = 0$		
20	$1700 \setminus 10 = 00 = 0$	20	$1200 \setminus 10 = 10 = 0$		

$GM \setminus 10 = 1000 \setminus 10 = 00 = 0$   
 $GM \setminus 10 = 1000 \setminus 10 = 00 = 0$



See Table IV and Fig. 15. This experiment shows that Ethyl alcohol could be used as a liquid Cerenkov counter and wavelength shifting can be accomplished.

Then a plate filled with a known concentration of POPOP was placed between the phototube and the beaker of alcohol, which was devoid of the wavelength shifter. It was discovered that a decrease in counting rate occurred compared to a plate without POPOP. This is shown in Table V. The plate with POPOP is #3 and the plate without is #0.

#### C. RESULTS OF THE SOLID COUNTER

This counter was tested under three situations. The first situation employed Plate #0 which was filled only with a mixture of  $\text{CCl}_4$  and acrylic glue. The ratio of the  $\text{CCl}_4$  to the glue was always kept at 2:1 for all of the plates. Then, at least the background mixture was always constant and only the POPOP concentrations were varied. This ratio was chosen because the fluid was neither too viscous or too thin for the purposes of measuring its volume and insured adequate gluing.

Plate #1 represents the maximum amount of POPOP concentration and Plate #2 represents the minimum concentration. Both were tested in order to determine a maximum and a minimum counting rate. The amounts of POPOP used, surface density, and concentrations of all these plates are given in Table VI.

Both plates showed a decrease in counting rate compared to Plate #0. The data is given in Table VII. As far as the statistical errors of this experiment are concerned, there isn't any difference between



See Table IV and Fig. 11. This experiment was carried out at 40°C.

could be used as a liquid counter and the following results

can be accomplished.

Then a glass filled with a known concentration of  $^{40}\text{K}$  was

placed between the phototube and the source of radiation, which was

divided of the wavelength spectrum. The results are shown in Table V.

In counting rate counted compared to a glass which was 100%  $^{40}\text{K}$  was

is shown in Table V. The glass which was 100%  $^{40}\text{K}$  was 100% efficient

is 40.

#### 4. Results with $^{40}\text{K}$ and $^{40}\text{Ca}$

This counter was tested under three conditions. The first was

tion employed plate 40 which was filled with a mixture of 100%

and acrylic glass. The ratio of the  $^{40}\text{K}$  to the  $^{40}\text{Ca}$  was 100% and

at 2:1 for all of the plates. Then, at least the counter was

was always constant and only the  $^{40}\text{K}$  concentration was varied.

This ratio was chosen because the  $^{40}\text{K}$  was always 100% efficient

too thin for the purpose of measuring the volume and the  $^{40}\text{K}$  was

giving.

Plate 41 represents the maximum amount of  $^{40}\text{K}$  concentration and

Plate 42 represents the minimum concentration. The results are

order to determine a standard and a minimum counting rate. The results

of  $^{40}\text{K}$  used, surface quality, and concentration of all these factors

are given in Table VI.

Both plates showed a standard counting rate recorded in Table

40. The data is given in Table VII. The data is the average of

of this experiment are compared with the results of the other

EXPERIMENTAL RESULTS



BEAKER WITH ALCOHOL

WITHOUT POPOP		WITH .021 mgm. POPOP	
Disc.	Counts/Min. $N \pm \sqrt{N}$	Disc.	Counts/Min. $N \pm \sqrt{N}$
50	1627/23 = $71 \pm 2$	65	1031/15 = $69 \pm 2$
60	995/18 = $55 \pm 2$	80	1033/18 = $57 \pm 2$

TABLE IV.



TABLE 14

1960-1961		1961-1962		1962-1963	
Area	Value	Area	Value	Area	Value
1	100	1	100	1	100
2	100	2	100	2	100
3	100	3	100	3	100
4	100	4	100	4	100
5	100	5	100	5	100
6	100	6	100	6	100
7	100	7	100	7	100
8	100	8	100	8	100
9	100	9	100	9	100
10	100	10	100	10	100
11	100	11	100	11	100
12	100	12	100	12	100
13	100	13	100	13	100
14	100	14	100	14	100
15	100	15	100	15	100
16	100	16	100	16	100
17	100	17	100	17	100
18	100	18	100	18	100
19	100	19	100	19	100
20	100	20	100	20	100
21	100	21	100	21	100
22	100	22	100	22	100
23	100	23	100	23	100
24	100	24	100	24	100
25	100	25	100	25	100
26	100	26	100	26	100
27	100	27	100	27	100
28	100	28	100	28	100
29	100	29	100	29	100
30	100	30	100	30	100
31	100	31	100	31	100
32	100	32	100	32	100
33	100	33	100	33	100
34	100	34	100	34	100
35	100	35	100	35	100
36	100	36	100	36	100
37	100	37	100	37	100
38	100	38	100	38	100
39	100	39	100	39	100
40	100	40	100	40	100
41	100	41	100	41	100
42	100	42	100	42	100
43	100	43	100	43	100
44	100	44	100	44	100
45	100	45	100	45	100
46	100	46	100	46	100
47	100	47	100	47	100
48	100	48	100	48	100
49	100	49	100	49	100
50	100	50	100	50	100
51	100	51	100	51	100
52	100	52	100	52	100
53	100	53	100	53	100
54	100	54	100	54	100
55	100	55	100	55	100
56	100	56	100	56	100
57	100	57	100	57	100
58	100	58	100	58	100
59	100	59	100	59	100
60	100	60	100	60	100
61	100	61	100	61	100
62	100	62	100	62	100
63	100	63	100	63	100
64	100	64	100	64	100
65	100	65	100	65	100
66	100	66	100	66	100
67	100	67	100	67	100
68	100	68	100	68	100
69	100	69	100	69	100
70	100	70	100	70	100
71	100	71	100	71	100
72	100	72	100	72	100
73	100	73	100	73	100
74	100	74	100	74	100
75	100	75	100	75	100
76	100	76	100	76	100
77	100	77	100	77	100
78	100	78	100	78	100
79	100	79	100	79	100
80	100	80	100	80	100
81	100	81	100	81	100
82	100	82	100	82	100
83	100	83	100	83	100
84	100	84	100	84	100
85	100	85	100	85	100
86	100	86	100	86	100
87	100	87	100	87	100
88	100	88	100	88	100
89	100	89	100	89	100
90	100	90	100	90	100
91	100	91	100	91	100
92	100	92	100	92	100
93	100	93	100	93	100
94	100	94	100	94	100
95	100	95	100	95	100
96	100	96	100	96	100
97	100	97	100	97	100
98	100	98	100	98	100
99	100	99	100	99	100
100	100	100	100	100	100

TABLE 15



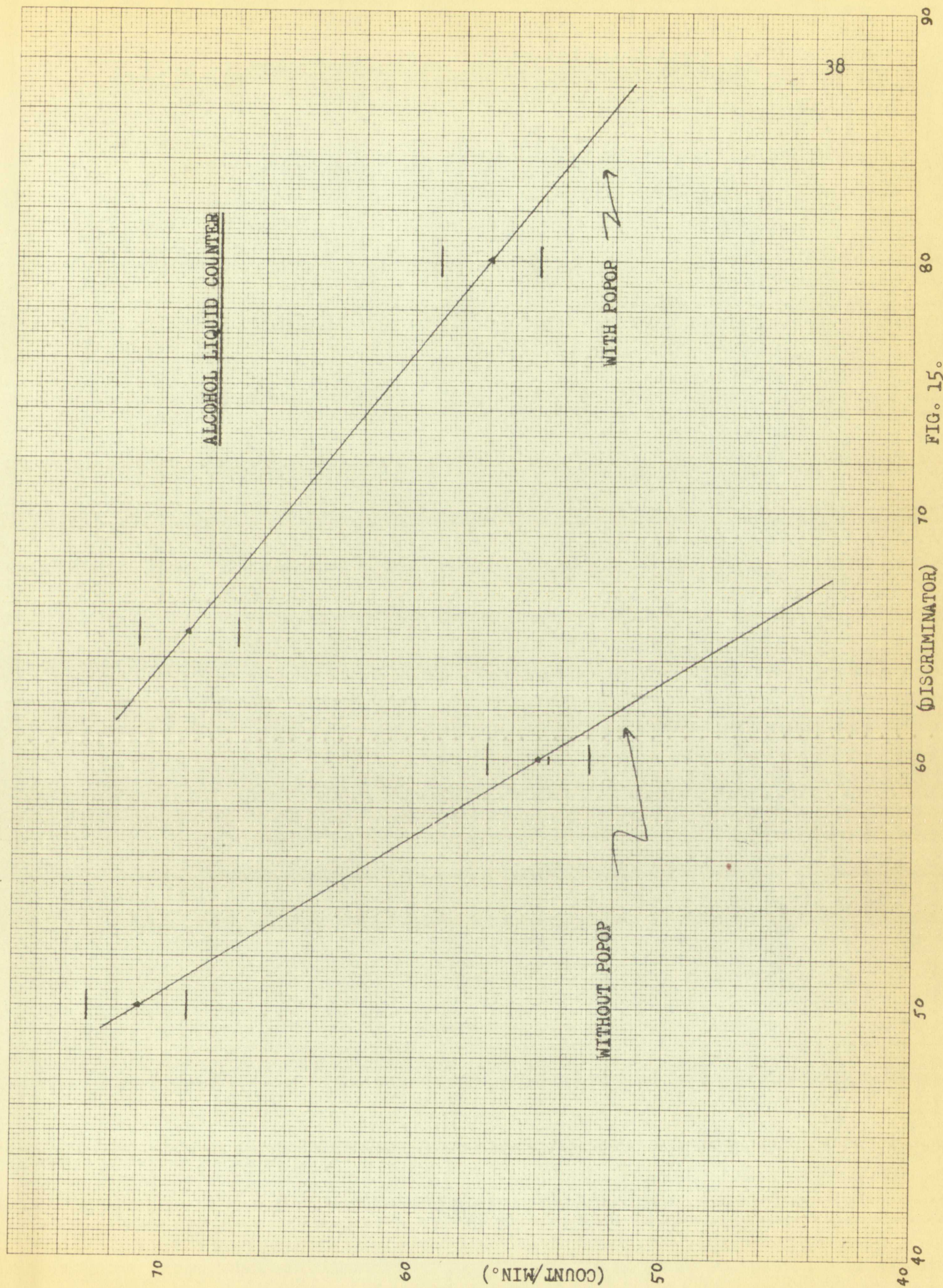


FIG. 15.







LUCITE PLATES

WITHOUT POPOP #0		WITH POPOP #3	
Disc.	Counts/Min. $N \pm \sqrt{N}$	Disc.	Counts/Min. $N \pm \sqrt{N}$
50	1308/17 = $77 \pm 2$	50	1238/19 = $65 \pm 2$
60	1154/19 = $61 \pm 2$	60	1069/19 = $57 \pm 2$

TABLE V.



DATE: 10/10/00

DATE	TIME	LOCATION	WIND DIRECTION	WIND SPEED	WIND GUST
10/10/00	08:00	1000 ft	100	10	15
10/10/00	09:00	1000 ft	100	10	15

WIND DIRECTION

WIND SPEED

WIND GUST

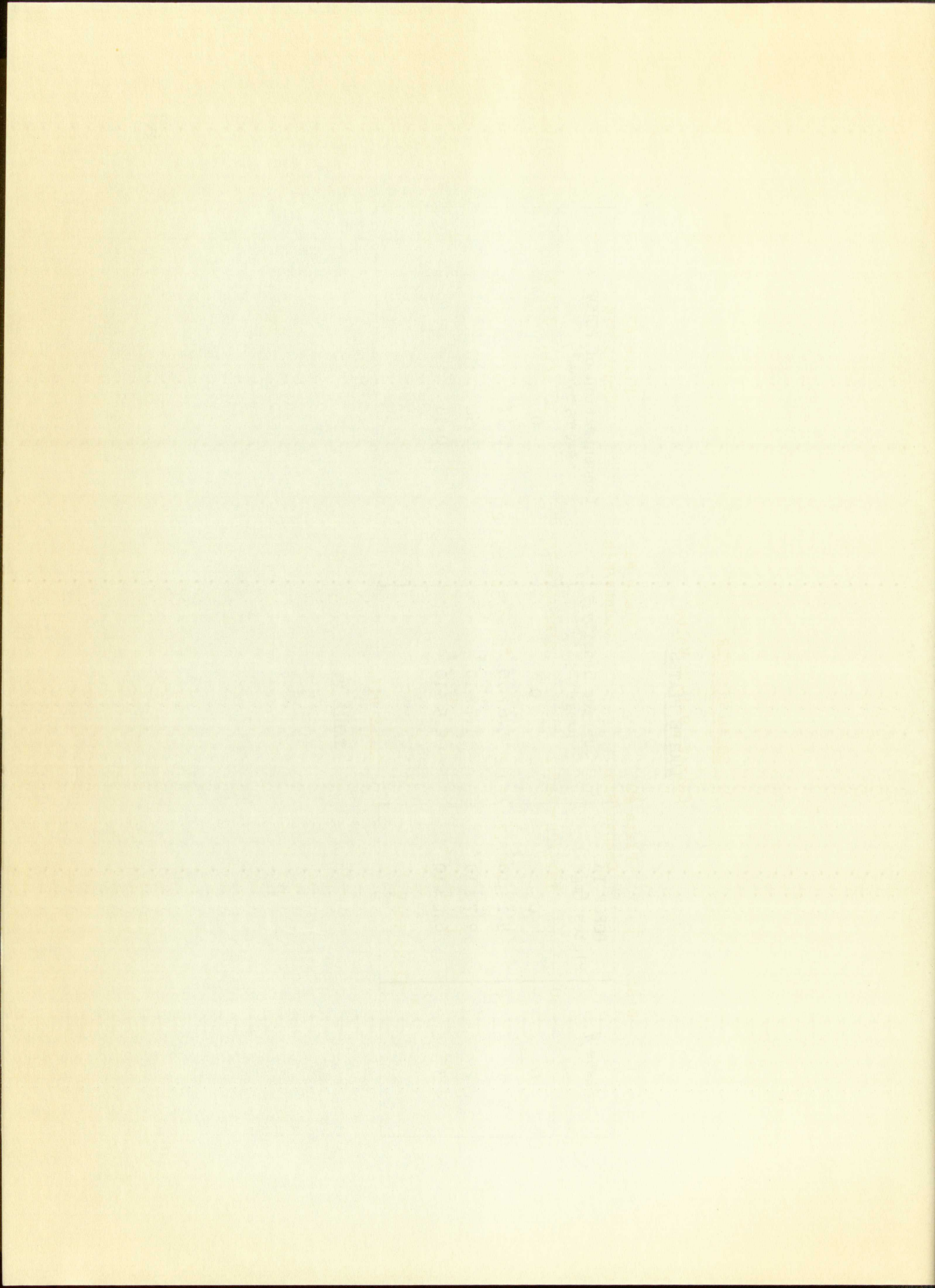


LUCITE PLATES

Plate #	POPOP In Plates (mgm.)	Surface Density $\sigma$ (mgm/cm <sup>2</sup> )	Concentration of PPOPOP $\rho$ (mgm/cm <sup>3</sup> )
0	0	0	0
1	$4.1 \times 10^{-2}$	$1.6 \times 10^{-3}$	0.17
2	$9.7 \times 10^{-2}$	$3.7 \times 10^{-3}$	0.54
3	$6.4 \times 10^{-2}$	$2.5 \times 10^{-3}$	0.38

TABLE VI.







# SOLID COUNTER

Gain=2, V=1900 Volts

Disc.	Plate #0 Counts/Min.	Plate #1 Counts/Min.	Plate #2 Counts/Min.
50	1915/24 = $80 \pm 2$	1066/14 = $76 \pm 2$	1055/14 = $75 \pm 2$
60	1036/17 = $61 \pm 2$	* 2477/38 = $65 \pm 2$	1760/32 = $55 \pm 2$

\* Light Leak.

TABLE VII.



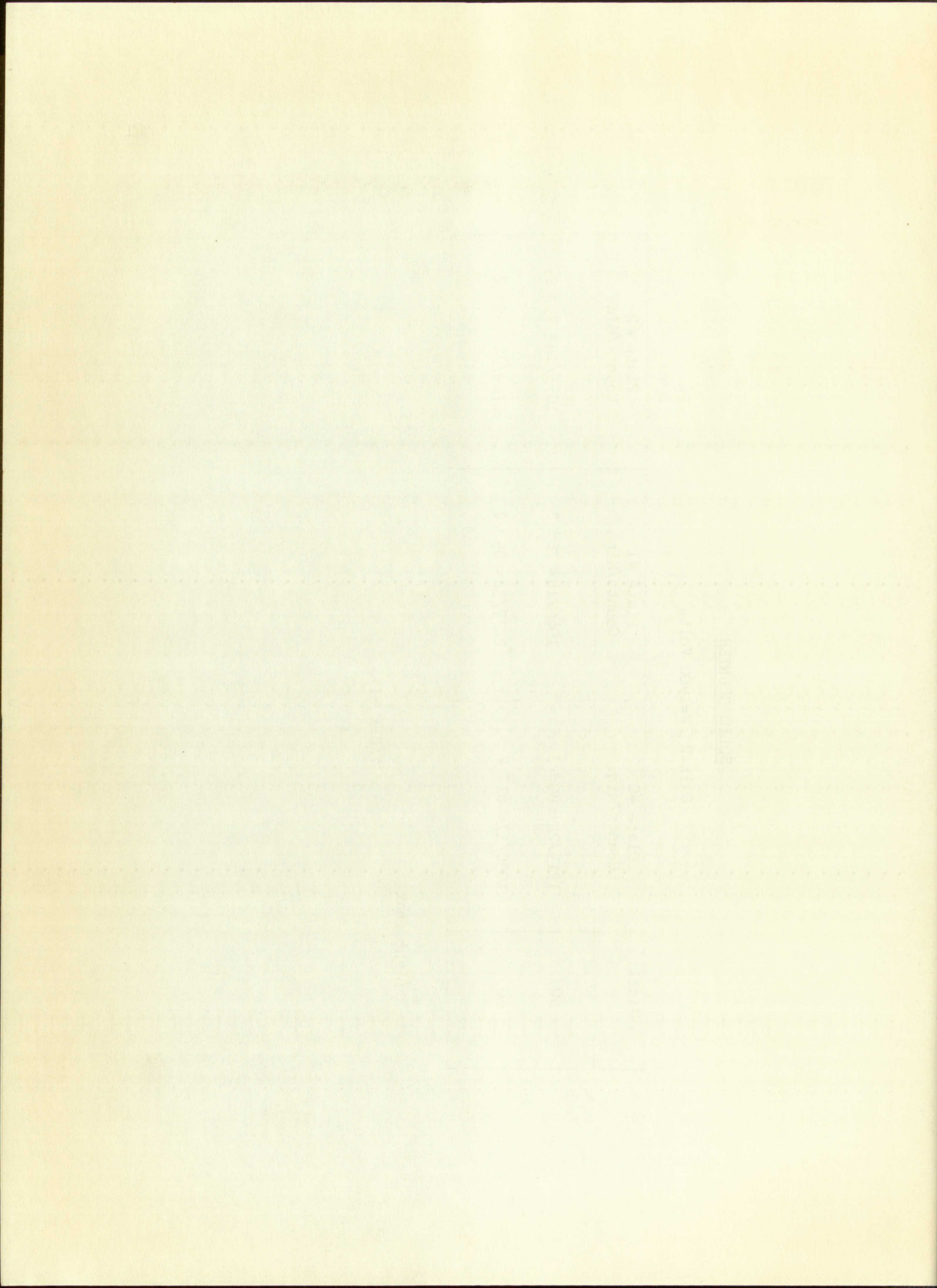




Plate #1 and Plate #2 show that a range of concentrations can not be determined.



Plate VI and Plate VII show the same scene from different angles.

detached.

EXERASE  
COTTON CEMENT



## CHAPTER V

### DISCUSSION OF RESULTS

#### A. THE SHIFTER RATIO

If the spectral response  $S(\lambda)$  of a photomultiplier is known and the Cerenkov spectrum  $C(\lambda)$  is known, then an energy response  $R$  can be determined for the Cerenkov counter by:

$$R \sim \int C(\lambda) S(\lambda) d\lambda. \quad (15)$$

This expression is associated to the energy response of the phototube without the fluorescent compound in the system. After adding the wavelength shifter, the Cerenkov radiation is changed as far as the phototube is concerned, so that a new energy response,  $R'$ , can be considered:

$$R' \sim \int C'(\lambda) S(\lambda) d\lambda. \quad (17)$$

$C'(\lambda)$  is the new Cerenkov spectrum as seen by the phototube.

Define a "shifter ratio"  $\delta$  for the areas of the two curves above.

$$\delta = \frac{R'}{R} \quad (18)$$



# CHAPTER V DISCUSSION OF RESULTS

## 1. THE SPECTRAL RESPONSE

If the spectral response  $S(\lambda)$  of a phototube is known and the characteristic spectrum  $C(\lambda)$  is known, then an energy response  $R$  can be determined for the phototube system and

$$R = \int C(\lambda) S(\lambda) d\lambda$$

This expression is associated with the energy response of the phototube without the fluorescent component in the system. When using the energy length filter, the characteristic spectrum is changed and the energy tube is concerned, so that a new energy response,  $R'$ , can be determined,

$$R' = \int C'(\lambda) S(\lambda) d\lambda \quad (1)$$

$C'(\lambda)$  is the new characteristic spectrum and  $S(\lambda)$  is the spectral response.

Define a "shift factor"  $\delta$  in the following manner:

above.

$$\delta = \frac{R'}{R}$$

(1)



Then for a change in the counting rate, either  $\delta > 1$  or  $\delta < 1$ . So if all things are held constant,  $\delta$  is a rough measure of the different counting rates due to the addition of the POPOP.

It should be pointed out that this ratio can only be applied to one particular counting rate because the shifted bias curve will not, in general, be parallel to the unshifted curve. The reason for this is that the pulses of the shifted light are small ones, so they would be discriminated out at higher discriminator settings. This means that the difference between the lower counting rates of the two curves will become smaller.

So in order to determine a shifter ratio, a particular counting rate will be chosen and the maximum ratio between the discriminator settings will be used to express  $\delta_{max}$ . The values of  $\delta_{max}$  for the different experimental arrangements are given in Table VIII.

#### B. THE LIQUID COUNTERS

The value of  $\delta_{max}$  for the  $\text{CCl}_4$  liquid counter with the POPOP is not too large because of the small amount of fluorescent material added. There apparently is not too much internal quenching of the solvent on the POPOP because an increase was observed. The absorption in the  $\text{CCl}_4$  was minute and was probably reduced even more due to the relatively small absorption length presented to the reemitted radiation. There is always the possibility that the reemitted light may be absorbed again and again by the solvent and non-radiating transfer of energy can take place, but this process was probably negligible.







SHIFTER RATIOS

TYPE OF COUNTER USED	$\delta_{max}$
$\text{CCl}_4$ LIQUID COUNTER	1.09
ALCOHOL LIQUID COUNTER	1.33
LUCITE PLATE #1	0.95
LUCITE PLATE #2	0.90

TABLE VIII



DATE	DESCRIPTION	AMOUNT	CHECK NO.	BANK	INITIALS
10/10/1910	PAID TO ORDER	100.00	100	WELLS FARGO	J. H. B.
10/15/1910	PAID TO ORDER	50.00	101	WELLS FARGO	J. H. B.
10/20/1910	PAID TO ORDER	25.00	102	WELLS FARGO	J. H. B.
10/25/1910	PAID TO ORDER	75.00	103	WELLS FARGO	J. H. B.
10/30/1910	PAID TO ORDER	125.00	104	WELLS FARGO	J. H. B.
11/05/1910	PAID TO ORDER	175.00	105	WELLS FARGO	J. H. B.
11/10/1910	PAID TO ORDER	225.00	106	WELLS FARGO	J. H. B.
11/15/1910	PAID TO ORDER	275.00	107	WELLS FARGO	J. H. B.
11/20/1910	PAID TO ORDER	325.00	108	WELLS FARGO	J. H. B.
11/25/1910	PAID TO ORDER	375.00	109	WELLS FARGO	J. H. B.
11/30/1910	PAID TO ORDER	425.00	110	WELLS FARGO	J. H. B.
12/05/1910	PAID TO ORDER	475.00	111	WELLS FARGO	J. H. B.
12/10/1910	PAID TO ORDER	525.00	112	WELLS FARGO	J. H. B.
12/15/1910	PAID TO ORDER	575.00	113	WELLS FARGO	J. H. B.
12/20/1910	PAID TO ORDER	625.00	114	WELLS FARGO	J. H. B.
12/25/1910	PAID TO ORDER	675.00	115	WELLS FARGO	J. H. B.
12/30/1910	PAID TO ORDER	725.00	116	WELLS FARGO	J. H. B.
1/05/1911	PAID TO ORDER	775.00	117	WELLS FARGO	J. H. B.
1/10/1911	PAID TO ORDER	825.00	118	WELLS FARGO	J. H. B.
1/15/1911	PAID TO ORDER	875.00	119	WELLS FARGO	J. H. B.
1/20/1911	PAID TO ORDER	925.00	120	WELLS FARGO	J. H. B.
1/25/1911	PAID TO ORDER	975.00	121	WELLS FARGO	J. H. B.
1/30/1911	PAID TO ORDER	1025.00	122	WELLS FARGO	J. H. B.
2/05/1911	PAID TO ORDER	1075.00	123	WELLS FARGO	J. H. B.
2/10/1911	PAID TO ORDER	1125.00	124	WELLS FARGO	J. H. B.
2/15/1911	PAID TO ORDER	1175.00	125	WELLS FARGO	J. H. B.
2/20/1911	PAID TO ORDER	1225.00	126	WELLS FARGO	J. H. B.
2/25/1911	PAID TO ORDER	1275.00	127	WELLS FARGO	J. H. B.
2/30/1911	PAID TO ORDER	1325.00	128	WELLS FARGO	J. H. B.
3/05/1911	PAID TO ORDER	1375.00	129	WELLS FARGO	J. H. B.
3/10/1911	PAID TO ORDER	1425.00	130	WELLS FARGO	J. H. B.
3/15/1911	PAID TO ORDER	1475.00	131	WELLS FARGO	J. H. B.
3/20/1911	PAID TO ORDER	1525.00	132	WELLS FARGO	J. H. B.
3/25/1911	PAID TO ORDER	1575.00	133	WELLS FARGO	J. H. B.
3/30/1911	PAID TO ORDER	1625.00	134	WELLS FARGO	J. H. B.
4/05/1911	PAID TO ORDER	1675.00	135	WELLS FARGO	J. H. B.
4/10/1911	PAID TO ORDER	1725.00	136	WELLS FARGO	J. H. B.
4/15/1911	PAID TO ORDER	1775.00	137	WELLS FARGO	J. H. B.
4/20/1911	PAID TO ORDER	1825.00	138	WELLS FARGO	J. H. B.
4/25/1911	PAID TO ORDER	1875.00	139	WELLS FARGO	J. H. B.
4/30/1911	PAID TO ORDER	1925.00	140	WELLS FARGO	J. H. B.
5/05/1911	PAID TO ORDER	1975.00	141	WELLS FARGO	J. H. B.
5/10/1911	PAID TO ORDER	2025.00	142	WELLS FARGO	J. H. B.
5/15/1911	PAID TO ORDER	2075.00	143	WELLS FARGO	J. H. B.
5/20/1911	PAID TO ORDER	2125.00	144	WELLS FARGO	J. H. B.
5/25/1911	PAID TO ORDER	2175.00	145	WELLS FARGO	J. H. B.
5/30/1911	PAID TO ORDER	2225.00	146	WELLS FARGO	J. H. B.
6/05/1911	PAID TO ORDER	2275.00	147	WELLS FARGO	J. H. B.
6/10/1911	PAID TO ORDER	2325.00	148	WELLS FARGO	J. H. B.
6/15/1911	PAID TO ORDER	2375.00	149	WELLS FARGO	J. H. B.
6/20/1911	PAID TO ORDER	2425.00	150	WELLS FARGO	J. H. B.
6/25/1911	PAID TO ORDER	2475.00	151	WELLS FARGO	J. H. B.
6/30/1911	PAID TO ORDER	2525.00	152	WELLS FARGO	J. H. B.
7/05/1911	PAID TO ORDER	2575.00	153	WELLS FARGO	J. H. B.
7/10/1911	PAID TO ORDER	2625.00	154	WELLS FARGO	J. H. B.
7/15/1911	PAID TO ORDER	2675.00	155	WELLS FARGO	J. H. B.
7/20/1911	PAID TO ORDER	2725.00	156	WELLS FARGO	J. H. B.
7/25/1911	PAID TO ORDER	2775.00	157	WELLS FARGO	J. H. B.
7/30/1911	PAID TO ORDER	2825.00	158	WELLS FARGO	J. H. B.
8/05/1911	PAID TO ORDER	2875.00	159	WELLS FARGO	J. H. B.
8/10/1911	PAID TO ORDER	2925.00	160	WELLS FARGO	J. H. B.
8/15/1911	PAID TO ORDER	2975.00	161	WELLS FARGO	J. H. B.
8/20/1911	PAID TO ORDER	3025.00	162	WELLS FARGO	J. H. B.
8/25/1911	PAID TO ORDER	3075.00	163	WELLS FARGO	J. H. B.
8/30/1911	PAID TO ORDER	3125.00	164	WELLS FARGO	J. H. B.
9/05/1911	PAID TO ORDER	3175.00	165	WELLS FARGO	J. H. B.
9/10/1911	PAID TO ORDER	3225.00	166	WELLS FARGO	J. H. B.
9/15/1911	PAID TO ORDER	3275.00	167	WELLS FARGO	J. H. B.
9/20/1911	PAID TO ORDER	3325.00	168	WELLS FARGO	J. H. B.
9/25/1911	PAID TO ORDER	3375.00	169	WELLS FARGO	J. H. B.
9/30/1911	PAID TO ORDER	3425.00	170	WELLS FARGO	J. H. B.
10/05/1911	PAID TO ORDER	3475.00	171	WELLS FARGO	J. H. B.
10/10/1911	PAID TO ORDER	3525.00	172	WELLS FARGO	J. H. B.
10/15/1911	PAID TO ORDER	3575.00	173	WELLS FARGO	J. H. B.
10/20/1911	PAID TO ORDER	3625.00	174	WELLS FARGO	J. H. B.
10/25/1911	PAID TO ORDER	3675.00	175	WELLS FARGO	J. H. B.
10/30/1911	PAID TO ORDER	3725.00	176	WELLS FARGO	J. H. B.
11/05/1911	PAID TO ORDER	3775.00	177	WELLS FARGO	J. H. B.
11/10/1911	PAID TO ORDER	3825.00	178	WELLS FARGO	J. H. B.
11/15/1911	PAID TO ORDER	3875.00	179	WELLS FARGO	J. H. B.
11/20/1911	PAID TO ORDER	3925.00	180	WELLS FARGO	J. H. B.
11/25/1911	PAID TO ORDER	3975.00	181	WELLS FARGO	J. H. B.
11/30/1911	PAID TO ORDER	4025.00	182	WELLS FARGO	J. H. B.
12/05/1911	PAID TO ORDER	4075.00	183	WELLS FARGO	J. H. B.
12/10/1911	PAID TO ORDER	4125.00	184	WELLS FARGO	J. H. B.
12/15/1911	PAID TO ORDER	4175.00	185	WELLS FARGO	J. H. B.
12/20/1911	PAID TO ORDER	4225.00	186	WELLS FARGO	J. H. B.
12/25/1911	PAID TO ORDER	4275.00	187	WELLS FARGO	J. H. B.
12/30/1911	PAID TO ORDER	4325.00	188	WELLS FARGO	J. H. B.
1/05/1912	PAID TO ORDER	4375.00	189	WELLS FARGO	J. H. B.
1/10/1912	PAID TO ORDER	4425.00	190	WELLS FARGO	J. H. B.
1/15/1912	PAID TO ORDER	4475.00	191	WELLS FARGO	J. H. B.
1/20/1912	PAID TO ORDER	4525.00	192	WELLS FARGO	J. H. B.
1/25/1912	PAID TO ORDER	4575.00	193	WELLS FARGO	J. H. B.
1/30/1912	PAID TO ORDER	4625.00	194	WELLS FARGO	J. H. B.
2/05/1912	PAID TO ORDER	4675.00	195	WELLS FARGO	J. H. B.
2/10/1912	PAID TO ORDER	4725.00	196	WELLS FARGO	J. H. B.
2/15/1912	PAID TO ORDER	4775.00	197	WELLS FARGO	J. H. B.
2/20/1912	PAID TO ORDER	4825.00	198	WELLS FARGO	J. H. B.
2/25/1912	PAID TO ORDER	4875.00	199	WELLS FARGO	J. H. B.
2/30/1912	PAID TO ORDER	4925.00	200	WELLS FARGO	J. H. B.



The Ethyl alcohol was successful as a Cerenkov radiator so other experimenters can use this material in future Cerenkov counters if desired. Then, after it was discovered that the POPOP could be dissolved in alcohol, a result similar to that of the  $\text{CCl}_4$  solution was obtained. A somewhat larger amount of the POPOP was put in compared to the  $\text{CCl}_4$  radiator and a greater increase was encountered.

A test was undertaken to prove that the shifting was definitely taking place, using the  $\text{CCl}_4$  radiator without the aluminum jacket. Since the Cerenkov light is directional, most of this radiation will be collected by the phototube, but the losses of the emitted radiation due to the fluorescent material should be greater, since the direction of this light is randomly oriented. Table IX and Fig. 16 verify this assumption. The concentration of POPOP used was a correct amount so that quenching did not become dominant.

### C. THE WAVELENGTH SHIFTER PLATES

The plates that were tried showed a decrease, or  $\delta_{\text{max}} < 1$  after insertion. First, this shows that the Cerenkov light was being shifted, but the question is, what happened to this light?

Since the lucite radiator was not covered with aluminum there exists a possibility that some light was lost out of the radiator after reemission. There could also be a loss if some of the reemitted light was reflected back toward the black surface of the lucite cylinder to be absorbed.

The main reason for this loss of light is probably the fact that we are dealing with a solid state. As compared to a liquid solution,



The first alcohol was found in the stomach of the victim.

Experimenters and the victim were both found to be

drunk. Then, after the victim had been found to be

drunk in alcohol, a search was made of the victim's

clothing. A search of the victim's pockets

to the U.S. Treasury and a search of the victim's

A foot was found in the victim's pocket.

taking place, during which the victim was found to be

drunk. The victim was found to be drunk in the

be collected by the victim's pocket.

due to the fact that the victim was found to be

of this light is somewhat unusual. The victim was

assumption. The victim was found to be drunk in the

that drinking the victim was found to be

The victim was found to be drunk in the

The victim was found to be drunk in the

insertion. The victim was found to be drunk in the

but the question is, what is the victim's

Since the victim was found to be drunk in the

exists a possibility that the victim was found to be

after insertion. The victim was found to be drunk in the

light was reflected back to the victim's pocket.

to be absorbed.

The main reason for this is that the victim was

we are dealing with a victim who was found to be



WITHOUT ALUMINUM JACKET

WITHOUT POPOP		WITH POPOP ( $\rho = 0.01 \frac{\text{mg}}{\text{cm}^2}$ )	
Disc.	Counts/Min. $N \pm \sqrt{N}$	Disc.	Counts/Min. $N \pm \sqrt{N}$
50	1151/20 = $58 \pm 2$	40	1021/18 = $57 \pm 2$
40	1071/14 = $76 \pm 2$	32	1328/17 = $78 \pm 2$

TABLE IX.



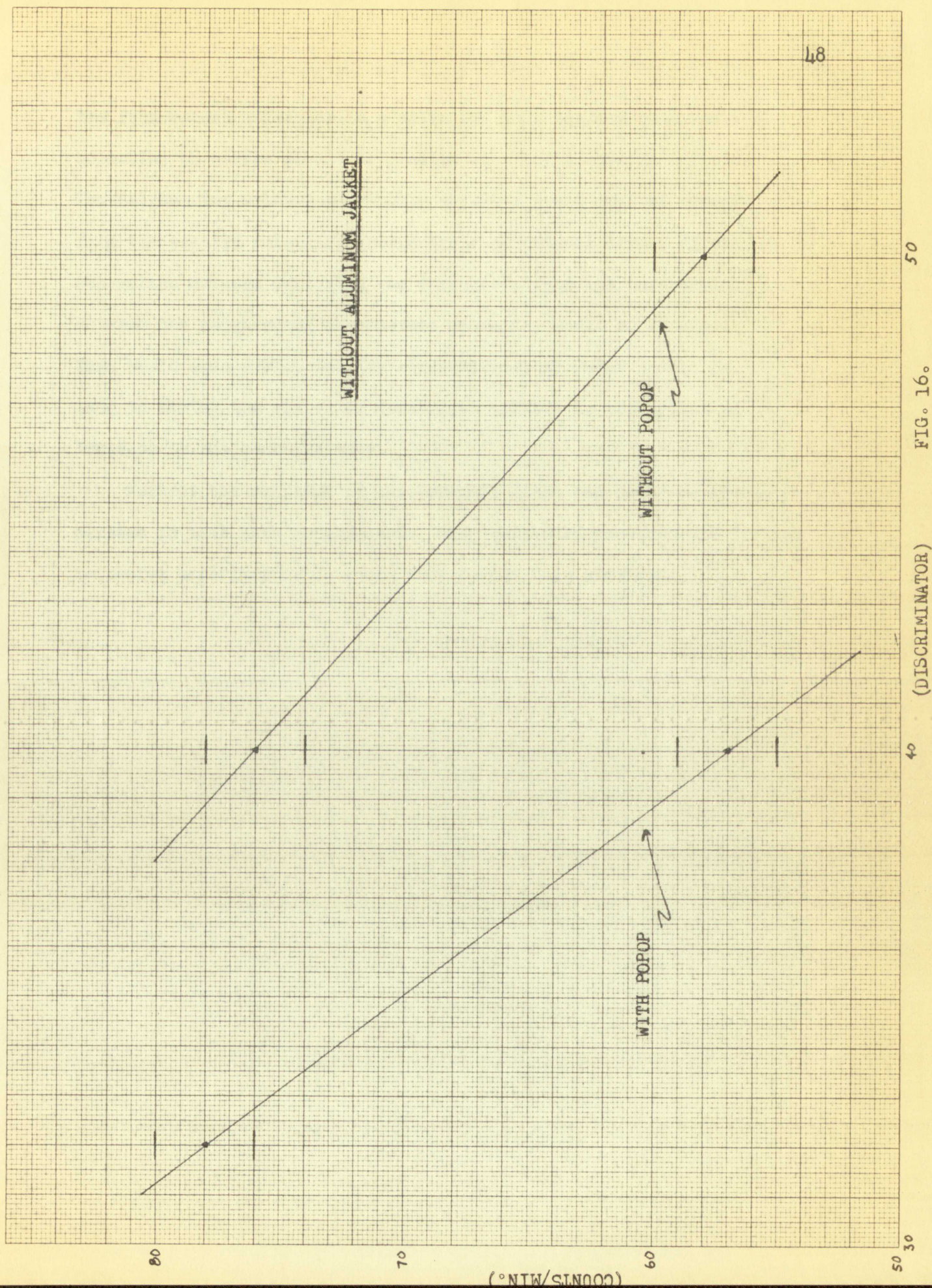
STATE IV

10	$Y \wedge X \wedge Z = 10 + 5$	35	$Y \wedge X \wedge Z = 10 + 5$	10	$Y \wedge X \wedge Z = 10 + 5$
20	$Y \wedge X \wedge Z = 20 + 5$	40	$Y \wedge X \wedge Z = 20 + 5$	20	$Y \wedge X \wedge Z = 20 + 5$
30	$Y \wedge X \wedge Z = 30 + 5$	45	$Y \wedge X \wedge Z = 30 + 5$	30	$Y \wedge X \wedge Z = 30 + 5$
40	$Y \wedge X \wedge Z = 40 + 5$	50	$Y \wedge X \wedge Z = 40 + 5$	40	$Y \wedge X \wedge Z = 40 + 5$
50	$Y \wedge X \wedge Z = 50 + 5$	55	$Y \wedge X \wedge Z = 50 + 5$	50	$Y \wedge X \wedge Z = 50 + 5$
60	$Y \wedge X \wedge Z = 60 + 5$	60	$Y \wedge X \wedge Z = 60 + 5$	60	$Y \wedge X \wedge Z = 60 + 5$
70	$Y \wedge X \wedge Z = 70 + 5$	65	$Y \wedge X \wedge Z = 70 + 5$	70	$Y \wedge X \wedge Z = 70 + 5$
80	$Y \wedge X \wedge Z = 80 + 5$	70	$Y \wedge X \wedge Z = 80 + 5$	80	$Y \wedge X \wedge Z = 80 + 5$
90	$Y \wedge X \wedge Z = 90 + 5$	75	$Y \wedge X \wedge Z = 90 + 5$	90	$Y \wedge X \wedge Z = 90 + 5$
100	$Y \wedge X \wedge Z = 100 + 5$	80	$Y \wedge X \wedge Z = 100 + 5$	100	$Y \wedge X \wedge Z = 100 + 5$

STATE V

10	$Y \wedge X \wedge Z = 10 + 5$	35	$Y \wedge X \wedge Z = 10 + 5$	10	$Y \wedge X \wedge Z = 10 + 5$
20	$Y \wedge X \wedge Z = 20 + 5$	40	$Y \wedge X \wedge Z = 20 + 5$	20	$Y \wedge X \wedge Z = 20 + 5$
30	$Y \wedge X \wedge Z = 30 + 5$	45	$Y \wedge X \wedge Z = 30 + 5$	30	$Y \wedge X \wedge Z = 30 + 5$
40	$Y \wedge X \wedge Z = 40 + 5$	50	$Y \wedge X \wedge Z = 40 + 5$	40	$Y \wedge X \wedge Z = 40 + 5$
50	$Y \wedge X \wedge Z = 50 + 5$	55	$Y \wedge X \wedge Z = 50 + 5$	50	$Y \wedge X \wedge Z = 50 + 5$
60	$Y \wedge X \wedge Z = 60 + 5$	60	$Y \wedge X \wedge Z = 60 + 5$	60	$Y \wedge X \wedge Z = 60 + 5$
70	$Y \wedge X \wedge Z = 70 + 5$	65	$Y \wedge X \wedge Z = 70 + 5$	70	$Y \wedge X \wedge Z = 70 + 5$
80	$Y \wedge X \wedge Z = 80 + 5$	70	$Y \wedge X \wedge Z = 80 + 5$	80	$Y \wedge X \wedge Z = 80 + 5$
90	$Y \wedge X \wedge Z = 90 + 5$	75	$Y \wedge X \wedge Z = 90 + 5$	90	$Y \wedge X \wedge Z = 90 + 5$
100	$Y \wedge X \wedge Z = 100 + 5$	80	$Y \wedge X \wedge Z = 100 + 5$	100	$Y \wedge X \wedge Z = 100 + 5$







1. The first part of the paper is devoted to a general discussion of the problem.

2. The second part is devoted to a detailed analysis of the case of a single

particle. The third part is devoted to a detailed analysis of the case of a

system of particles. The fourth part is devoted to a detailed analysis of the

case of a system of particles. The fifth part is devoted to a detailed analysis

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detailed analysis of the case of a system of particles. The twenty-third

part is devoted to a detailed analysis of the case of a system of particles.



the fluorescent molecules in a solid are in a tighter bond and the quenching processes should be greater in a solid than in a fluid. The neighboring molecules probably absorb a great deal of energy from the excited molecule through their structural bond. If the separation between molecules was increased, then the interaction between the neighboring fluorescent molecules would be lessened. This would mean a much smaller concentration of POPOP should be used in making the plates of wavelength shifter to accomplish an increase in the counting rate.

Perhaps the shifting of the Cerenkov light can never be accomplished in this last arrangement. Only continued research and further intensive experimentation could ever decide this question.



the fluorescent substance, which is a

pressure process, is a solid, and

The nitrogenous matter is a solid, and

from the solid, which is a solid, and

separation between the solid, and

between the solid, and the solid, and

This solid is a solid, and the solid, and

used in making the solid, and the solid, and

increase in the solid, and the solid, and

perhaps the solid, and the solid, and

placed in the solid, and the solid, and

intensive experiments on the solid, and the solid, and



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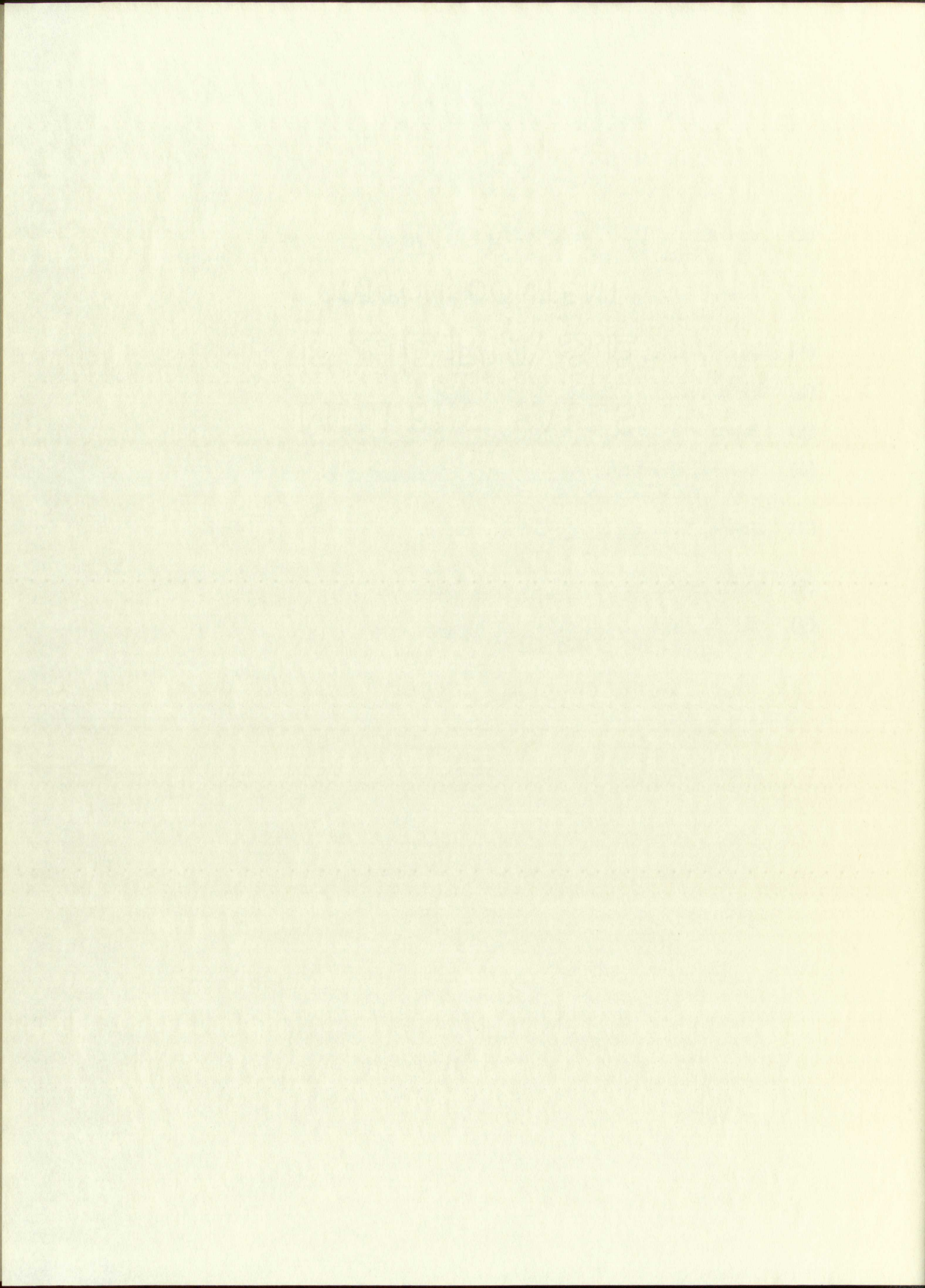


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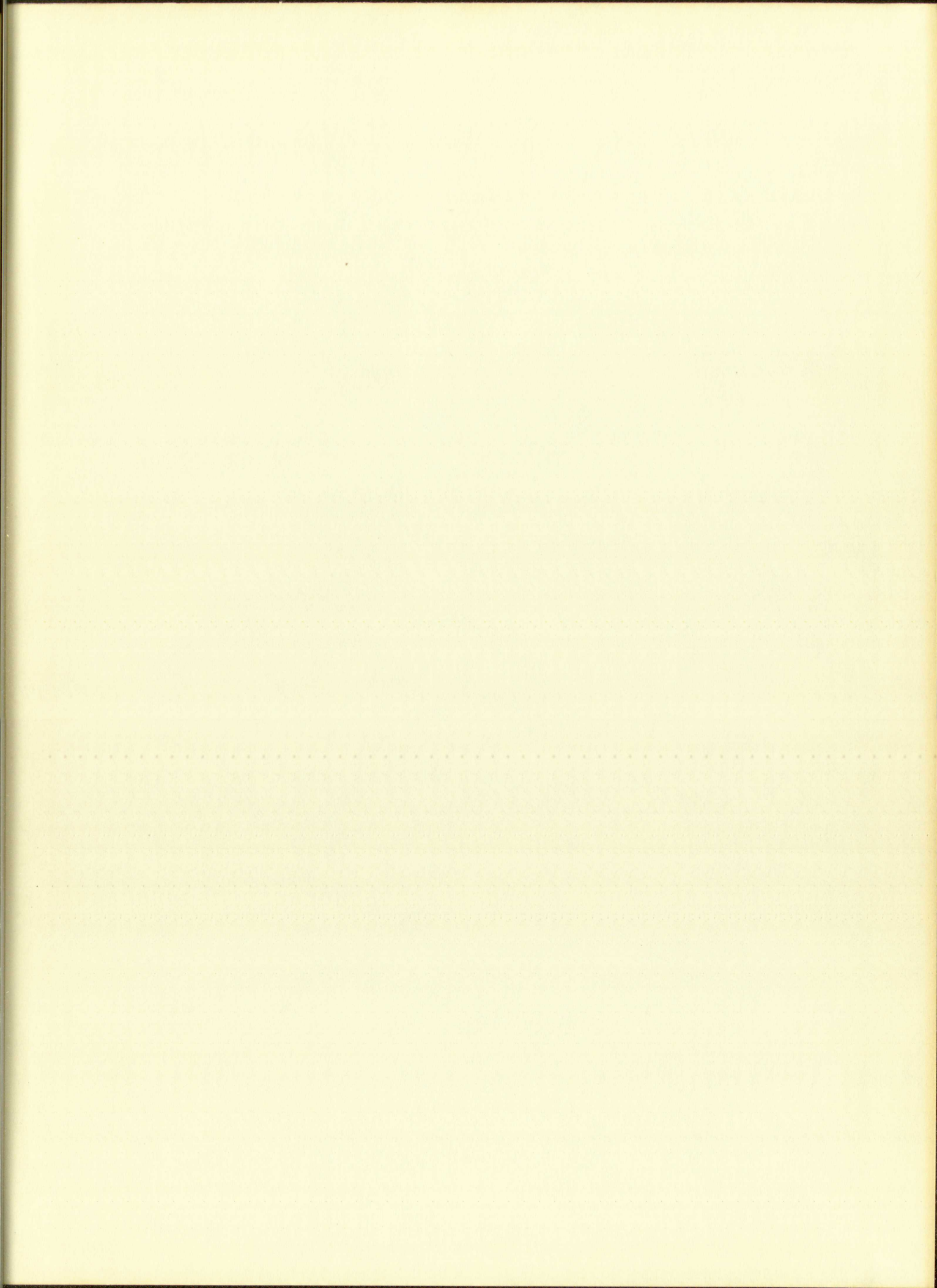
CHAPTER I

CHAPTER II

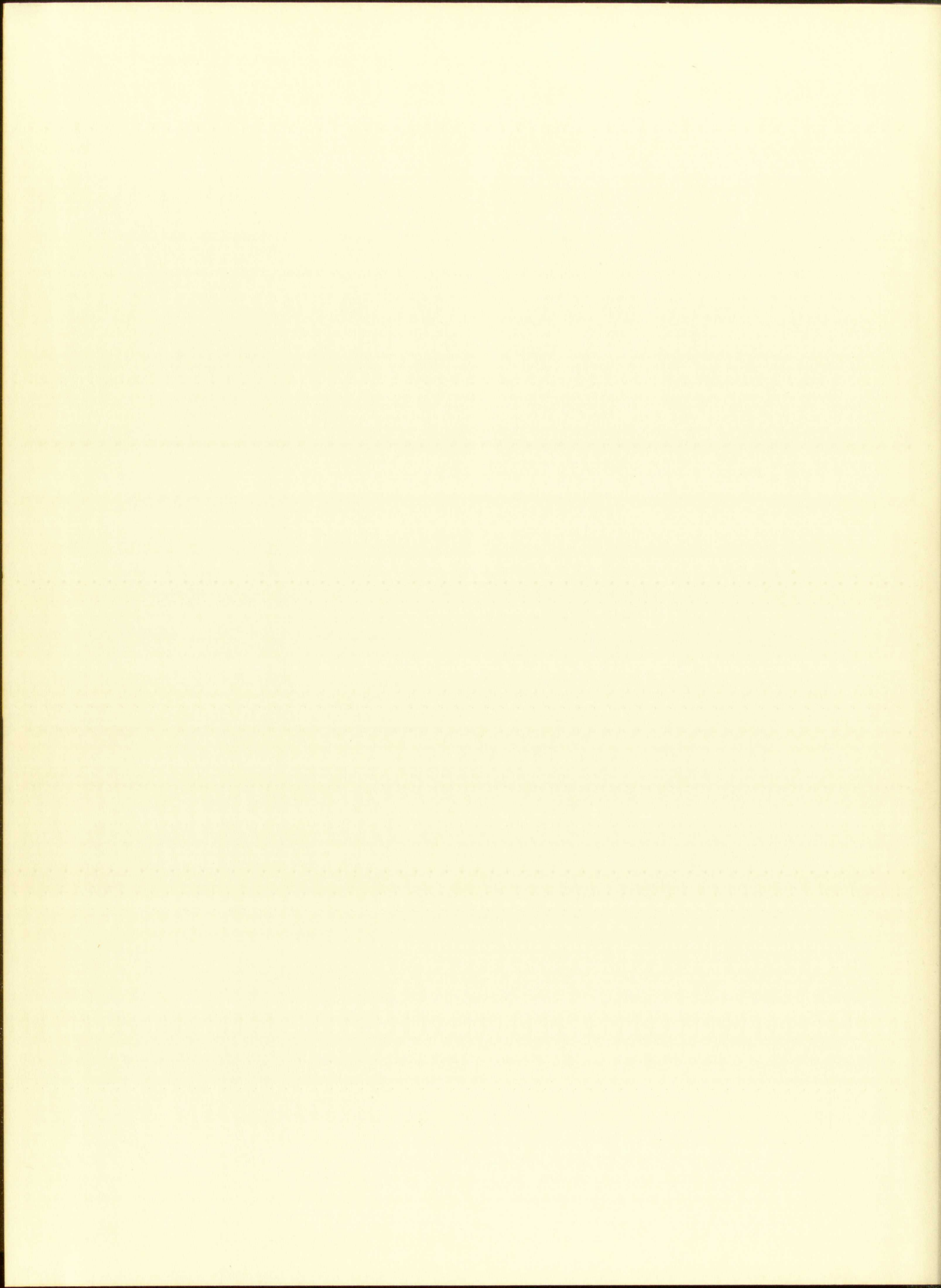




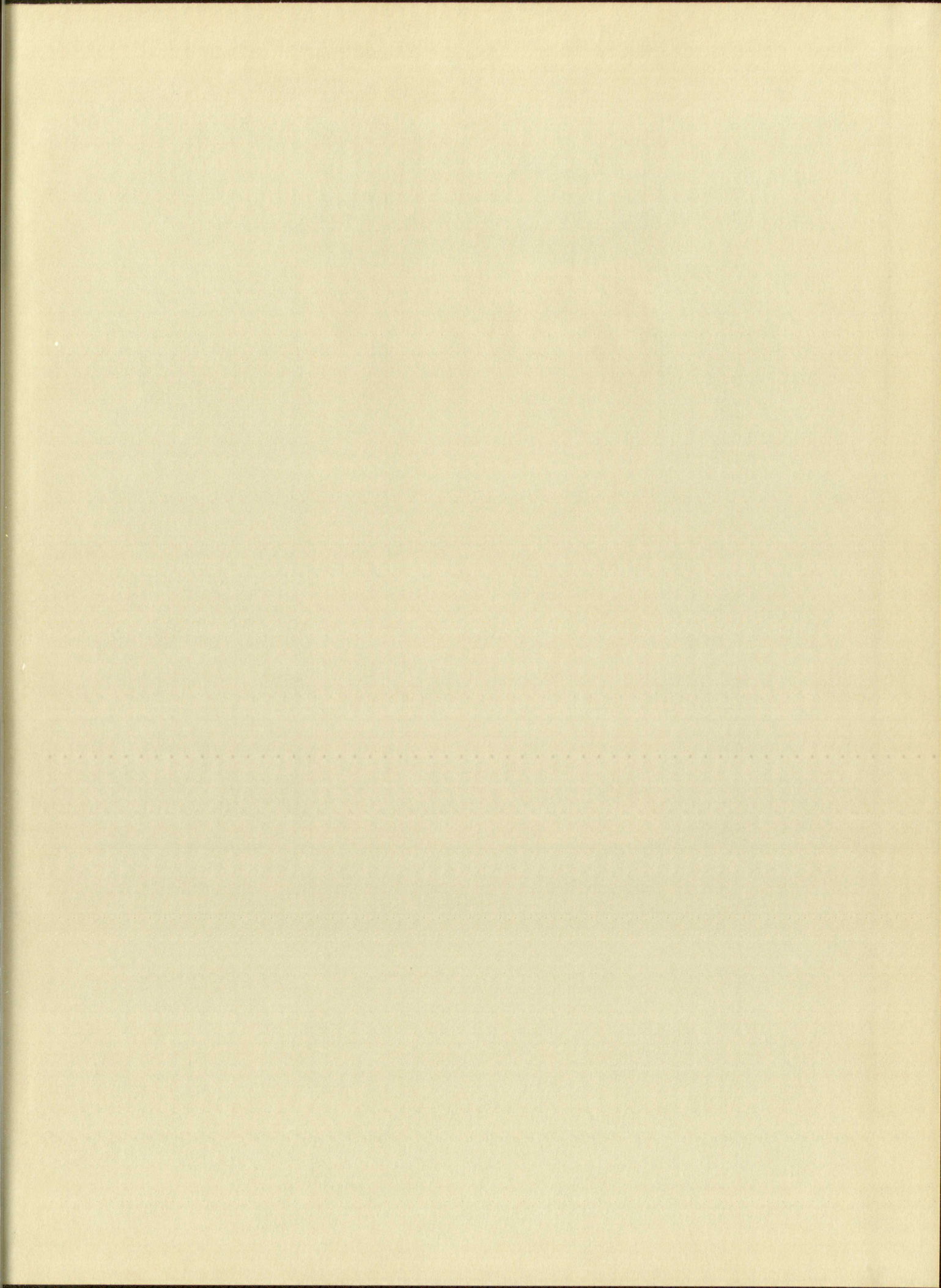














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