

BEHAVIOR OF COLORED IONS IN ELECTRIC AND  
MAGNETIC FIELDS

by

HAROLD FREDERICK WAHL

A THESIS

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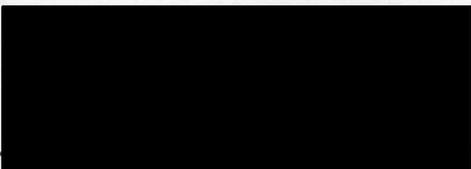
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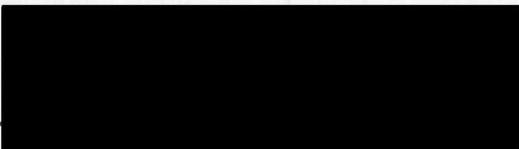
MASTER OF ARTS

June 1936

APPROVED:

  
\_\_\_\_\_  
Professor of Physics and Head of Department  
In Charge of Major

  
\_\_\_\_\_  
Chairman of School Graduate Committee

  
\_\_\_\_\_  
Chairman of College Graduate Council

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SUCCESS BOND

BEHAVIOR OF COLORED IONS IN ELECTRIC AND  
MAGNETIC FIELDS

I

INTRODUCTION

This investigation was prompted by several observations, the chief one being that there is frequently great difficulty in getting certain colors to spread evenly over a paper surface. Almost every user of inks and water colors has experienced such trouble at one time or another. Repeated filtering does not help the situation materially.

The solution of this and similar problems, it was felt, would entail a study of colored substances in polarized light, in static fields, and in magnetic fields. Apparatus was constructed for the polarized light study, but had to be abandoned when it was discovered that the polarizing plates were defective. Consequently this report deals only with the behavior of colored ions in electric and magnetic fields. However, it is hoped that this paper will be the first of a series on peculiar color phenomena.

The literature contains many studies of the motions of ions, colored and otherwise, in electric fields. The literature does not reveal mention of studies of colored ions in magnetic fields. Further, the famous Liesegang phenomenon of rhythmic banding does not appear to have been studied in either an electric or a magnetic field.

Physical changes of various kinds have been followed in many substances by noting their successive color changes. For example, the color changes due to changing the temperature of an originally colorless potassium bromide crystal containing a trace of calcium were described by Pohl in the September 1935 issue of *Physikalische Zeitschrift*.

Edward O. Holmes of the Chemical Laboratory of Boston University discovered accidentally that Schiff's reagent (Schiff's reagent is a colorless dilute solution of magenta rendered colorless by bubbling sulphur dioxide through it) contained in a clear quartz flask developed a color when exposed to ultraviolet light, and that the color disappeared slowly when removed from the exposure. (Pub. Jour. Amer. Chem. Soc., Feb. 1922)

Wood in his book "Physical Optics", mentions the fact that when powdered glass is immersed in carbon bisulphide and benzene is added, the transmitted light is first red, then yellow, green, and blue. Increasing the temperature changes the color of the transmitted light toward the blue. Another fascinating array of color changes lies in the substances known as gems. Radium emanation changes colorless topaz to yellow or orange and heating makes it colorless again. These are only a few of a long list of color changes that could be mentioned. The study of color change is

thus seen to be one of the fascinating avenues of approach to the determination of the constitution of matter.

## II

### APPARATUS

Electric fields were applied between immersed platinum electrodes in the usual manner.

The magnetic field was produced by a large magnet fashioned from an old Edison bi-polar machine by constructing suitable pole pieces and pole piece holders. These were made from Swedish iron (a lathe tool ground as for turning copper was found to give a smooth surface). One pair of pole pieces was provided with a three-eighths inch hole. (Wandering of the drill was prevented by rotating the drill in the tail stock through  $90^{\circ}$  for every quarter inch of progress made.) The general dimensions of the pole pieces are: one set of solid pole pieces 4 inches long,  $2\frac{3}{4}$  inches in diameter turned down at 45 degrees to faces 1 inch in diameter; one set as above but turned down at 45 degrees to  $\frac{1}{2}$  inch diameter; and one set like the first mentioned but bored with a  $\frac{3}{8}$  inch hole lengthwise.

The relation between field strength and current for different shaped pole pieces and different

# CALIBRATION CURVES FOR ELECTRO-MAGNET

## BORED POLE PIECES

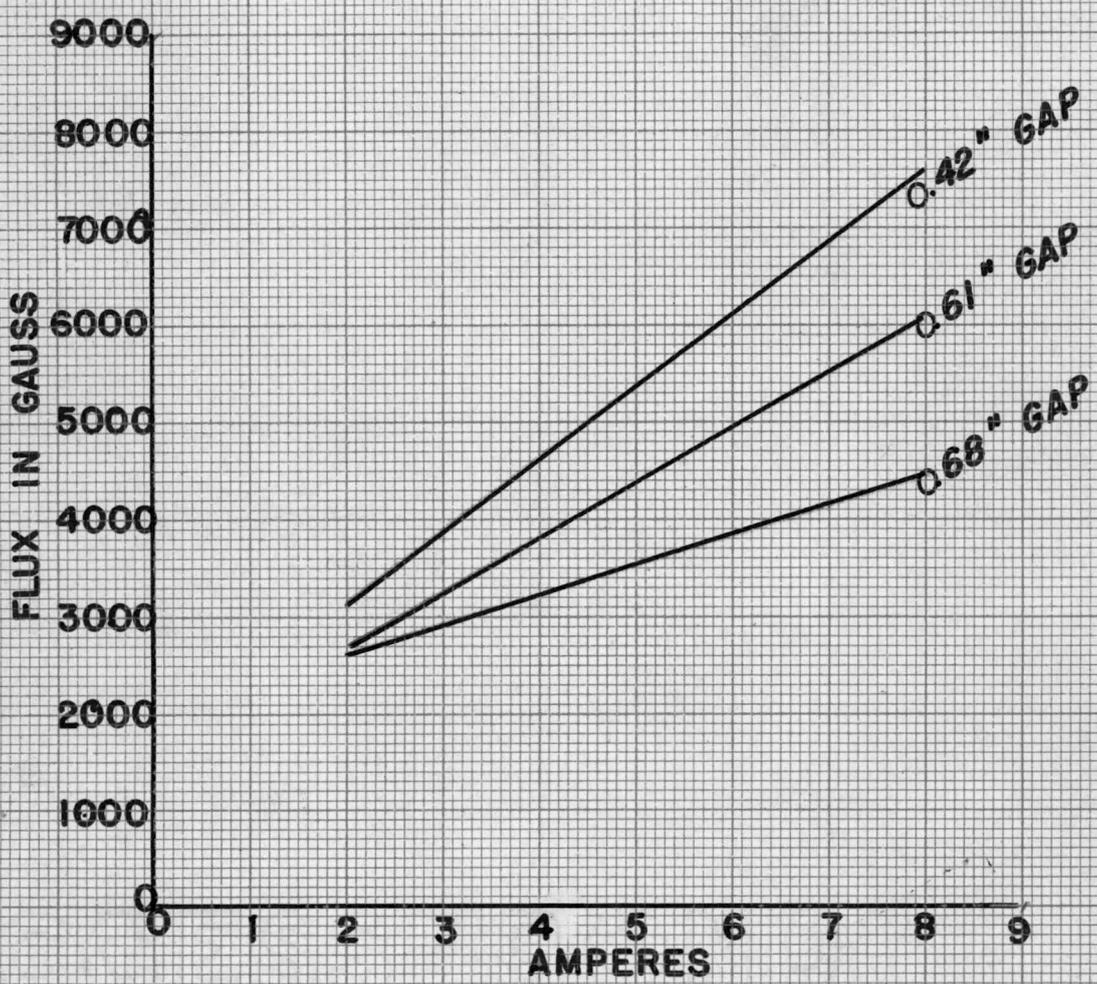


FIG. 1

# CALIBRATION CURVES FOR ELECTRO-MAGNET

SOLID POLE PIECES

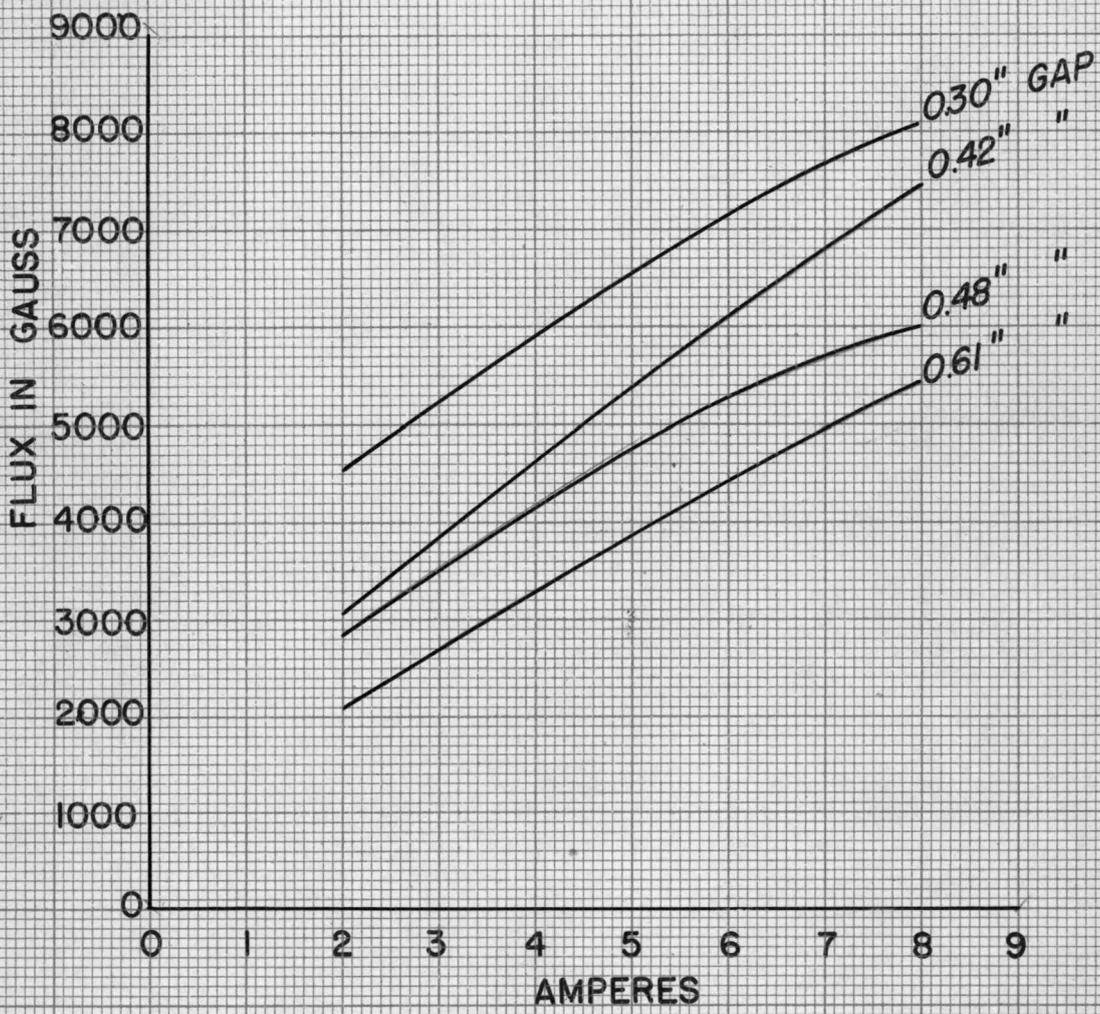


FIG. 2

### CALIBRATION CURVES FOR ELECTRO-MAGNET

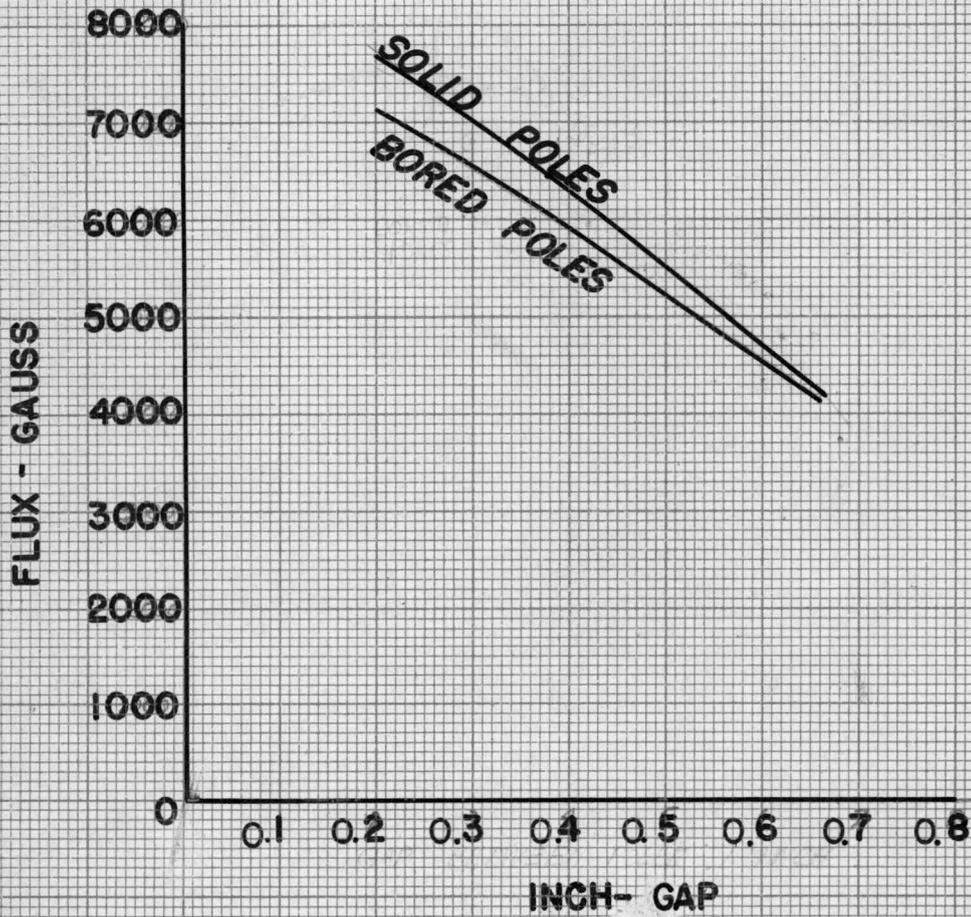


FIG. 3

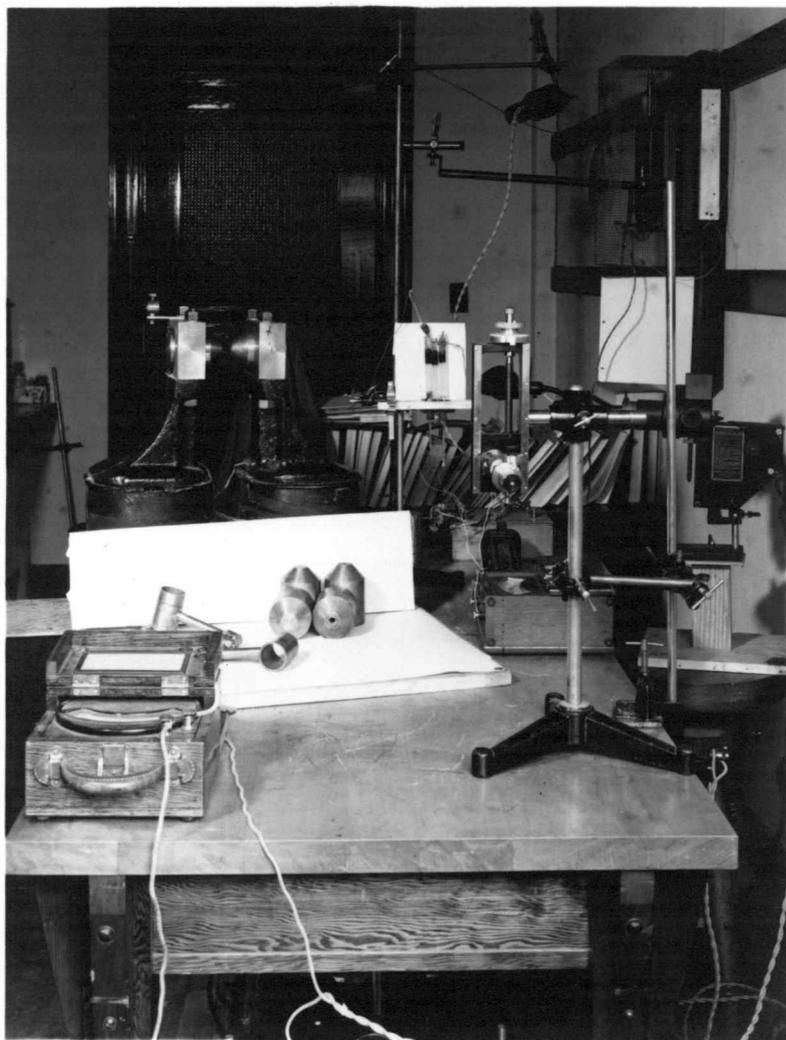


FIG. 4

gaps is given by curves on the following three pages (Fig. 1, 2, 3). The flux was measured with a Grassot fluxmeter giving values directly in gauss.

A view of the magnet and some of the auxiliary equipment is shown in the photograph which is Fig. 4.

The apparatus not shown in the photograph included two spectrometers, an ultramicroscope, and an electrolytic cell. All measuring instruments were standard laboratory instruments of good quality.

### III

#### A STUDY OF CERTAIN DYES

The color of an organic dye cannot be predicted from the mere knowledge of the carbon, hydrogen, and oxygen content. Color absorption depends on molecular structure and molecular grouping. The color of organic dyes disappears upon reduction. The resulting leuco-base regains its color upon oxidation.

There have appeared in the literature many statements concerning the color of a dye. Some ascribe color to vibrations of electrons in the molecules of the dye but fail to state which electrons vibrate and how and why they vibrate. The idea of the production of the complementary color on the basis of resonance is very much discredited.

Steubing, a pupil of Mie known for his work on the optical properties of colloidal solutions, made a contribution in this field. While working with gold sols, Steubing measured the intensity of the scattered light and found that only a small amount of the intensity is lost by scattering, the greater part being absorbed on the surfaces of the metallic gold particles. The work bears out the fact that the production of color by resonance is not possible. Mie found that the scattered light from the finest subdivisions of gold shows a very distinct maximum in the greenish yellow rather than in the blue violet. The finest subdivisions of gold are blue violet.

Some of the work of Mie and Steubing was repeated in this investigation. Two spectrometers were mounted so that the transmitted and the scattered components could be viewed at the same time. At proper adjustment of the instruments, the two components of the sodium line were of the same intensity. It was in this study on gold sols that the polarizing plates were discovered to be defective and that optical analyses, therefore, were out of the question at this time.

A few dyes were available which transmitted one color and reflected another. These were studied in an electric field; the results are summarized in Fig. 5. None of these dyes are mixtures but were dissolved from

AN  
ELECTROLYTIC  
COLOR ANALYSIS CHART

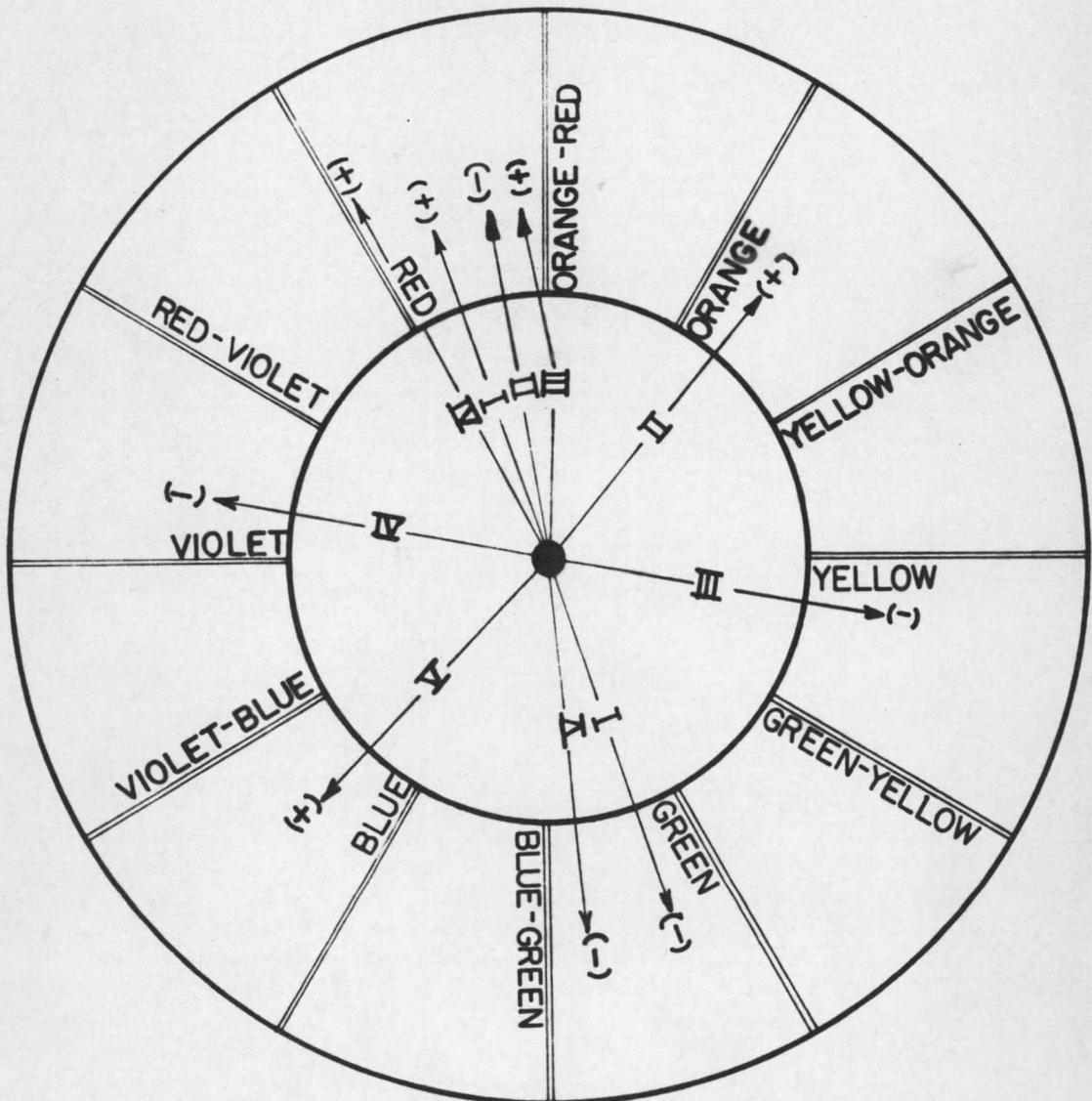


FIG. 5

crystals as sold commercially and then electrolyzed.

Consider the dye, Victoria Green, whose chart identification is I. This is a commercial crystalline aniline dye which transmits red and reflects the complement green. Upon electrolysis it is separated into two components (labeled I). Their respective polarities are shown in the chart.

The two components of the dye "aniline red Merck" are red and orange labeled II on the chart. If the electrolysis is not performed with very small potentials, the orange component has a cloudy appearance. The behavior of the supporting medium after electrolysis has removed all the color ions is characteristic of the behavior of a leuco-base. The leuco-base of an originally basic dye will develop a trace of the original color upon the addition of a dilute acid.

The yellow  $\rho$ -Nitrosodimethylaniline is shown to contain red. These components are labeled III on the chart.

The violet dye given under IV reflects violet and transmits red. The respective polarities of these two components are given.

The commercial brilliant blue is shown to contain green. This is shown in number V. Electrolysis shows that Meythl blue is a blue with only one component which is blue, while brilliant blue is composed of blue and green.

One of the best photoelectric color analyzing machines costs at present several hundred dollars. This machine is manufactured by the General Electric Company. It prints automatically a card containing the analysis of the colors to be found in the substance under test. This analysis is practical, exact, and very valuable for precision color analysis.

The electrolytic process is slower, but probably offers at least one advantage besides giving a rough determination of the color components of a mixture, the cost is negligible.

Consider in general any one of the 4,000,000 commercial dyes that might be used in dyeing cotton. Mordants are usually used to make the dyeing of cotton possible. The study of mordants is in itself almost a lifetime work but the following suggestion is given for what it may be worth. The absorption of dyes by mordants, such as hydrous alumina and stannic oxide is selective. Alumina precipitated from an aluminum acetate solution is known to absorb acid green and croceine orange but not emerald green or chrysoidine. It is highly probable in view of this electrolytic study that the components of the dye, if it is a mixture, are not taken up equally well by mordants and that this accounts for many of the known instances of the dyed fabric being of a different shade than the dye solution. This is one

problem of technical importance that has been suggested by this study of the movements of colored ions.

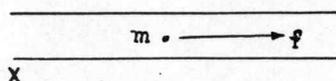
#### IV

### THE MOVEMENTS OF COLORED IONS IN ELECTRIC FIELDS

The statement that dyes, water colors, and colored solutions in general can be separated by means of electrolysis invokes a general theory.

An electrical potential of about 2 volts applied lengthwise to a volume of the solution approximately 1 sq. cm. by 10 cm. is usually sufficient in the case of aqueous solutions of dyes to cause a current of about 1 milliamperere to flow.

Consider a very simple case with ionic motion only in the X direction



The potential difference causes an accelerating force on the color ions and the resulting current follows Ohm's law for low potentials. Extremely high potentials cause ionizing and polarizing effects that are troublesome.

We may say that this particle of mass  $m$  moving in the X direction experiences a force  $f$ . As we

have chosen small velocities, the retarding force is proportional to the velocity  $u$ , and we have

$$m \frac{du}{dt} = f - ku$$

where  $k$  is the retarding force of the supporting medium per unit change of velocity.

This differential equation is readily solved by separating the variables:

$$u = f/m \left( 1 - e^{-Kt/m} \right)$$

Now from Stokes law where  $a$  is the radius of the particle and  $\eta$  is the coefficient of viscosity of the medium,  $k$  the retarding force is equal to

$$K = 6\pi a\eta$$

If, for practical purposes, the shape of the colored ion is regarded as spherical

$$K/m = \frac{6\pi a\eta}{\frac{4}{3}\pi a^3\rho}$$

where  $\rho$  is the density of an ion. Since  $K/m$  is going to be very large, something of the order of  $10^{17}$ , the value of  $(1 - e^{-Kt/m})$  rapidly approaches 1. Then the velocity of separation of the colors is proportional to some function of  $f/m$ , and the rate of loss of color is also proportional to  $f/m$ .

Light absorption can be readily measured.

The transmitted light passing through a layer of thick-

ness,<sup>d</sup> we have for the resulting intensity  $I$  in terms of the impinging intensity  $I_0$ , an expression such as

$$I = I_0 e^{-cd}$$

Since the velocity of color loss from the dye solution is proportional to  $f/m$ , it would be of value to know what relation existed between  $f/m$  and the above equation for transmitted light through an electrolyzed solution. The  $c$  of the equation will of course depend on the concentration which according to Beer's law, is

$$c = c_1 \sigma$$

where  $\sigma$  is the concentration and  $c_1$  is the light absorption constant for unit concentration.

Apparatus is being planned for the continuous measurement of scattered and transmitted radiation from colloidal solutions as those solutions are being carefully electrolyzed. This technique, it is hoped, will shed some light on the color changes of many sols. There is some debate about the dependence of the color of the sol upon the size of the colloidal gold particles. Supposedly, the color ranges from red to blue for the corresponding small to large sizes of the gold particles.

Almost everyone is aware that there is very little chance for a dye or pigment to be entirely of one color. It is interesting and perhaps useful to know that the constituents can be readily and easily

detected by electrolysis and that mixtures containing more than one solution of color can be separated into their components as a step preliminary to analysis. If the color is a pure color, there will be motion of color during electrolysis in only one direction. The rate of loss of color has been shown to be a function of the impressed potential and time.

## V

### THE BEHAVIOR OF WATER COLORS IN MAGNETIC FIELDS

The experimental arrangement to determine whether or not water colors migrate in magnetic fields is shown in Fig. 6. The set-up for this study was very simple. A test tube containing a water color mixture was placed in the magnetic field between the pole pieces whose faces are  $\frac{1}{2}$  inch in diameter.

The colors which migrated to the strong part of the field as illustrated by the dots between the pole pieces of Fig. 6 are listed in Fig. 7. These colors are, from the artist's point of view, basic or primary colors. Their chemical as well as their artistic merits make them "friendly". That is to say, they mix pleasingly in all proportions due to their color values and their chemical nature. They are so chosen that the complementary colors strongly tend to produce grey when properly mixed.

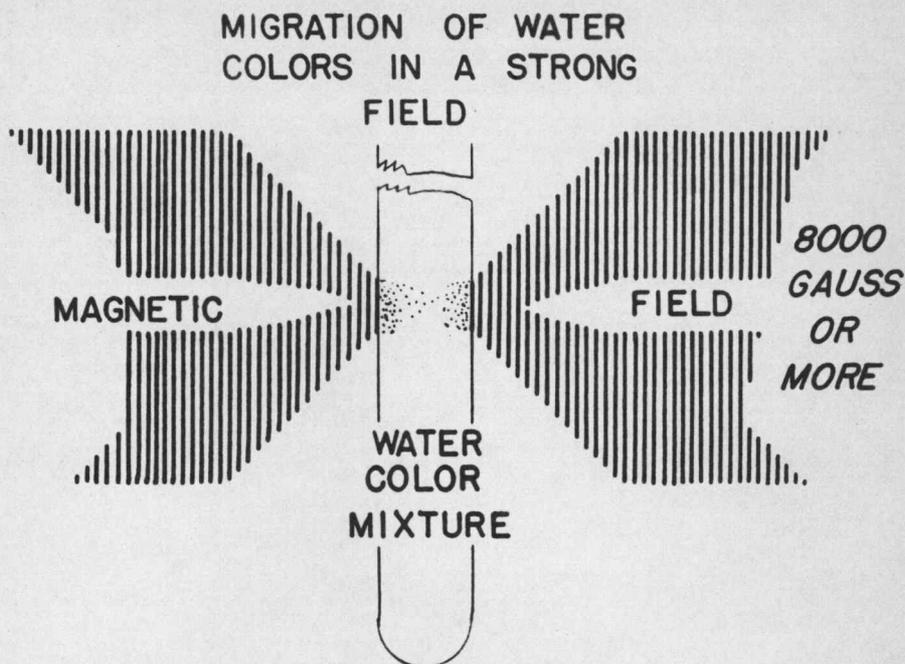


FIG. 6

FIG. 7

COLOR COMBINATION

COLOR WHICH  
MIGRATED  
TO  
STRONG PART  
OF  
FIELD

RED - GREEN

GREEN

BLUE - CHROME ORANGE

BLUE

BLUE - GREEN

GREEN

YELLOW - VERMIL ION

VERMIL ION

BLUE - VERMIL ION

BLUE

YELLOW - BLUE = GREENBLUE

WINSOR NEWTON WATER COLORS,  
LONDON, ENGLAND

It is unfortunate that the chemical analysis of the water colors used was not available for then some idea of their magnetic susceptibilities might have been ascertained. It is unlikely that the migration of colloidal particles in magnetic fields will be so simply explained as by attributing the accelerating force on the particles to their magnetic properties. This point will be more strongly emphasized in the next chapter. It is more to the point to consider now the general chemical nature of water colors which is well established. The vermilion are usually varieties of sulphide of mercury, and should contain no excess of sulphur, if pure. Due to their sulphur content they are best avoided with mixtures of lead and copper pigments. The ultramarines also contain sulphur and are to be avoided with mixtures of lead and copper pigments. The genuine ultramarine, which is not the artificial ultramarine variously known in the trade as permanent blue, new blue and French blue, is obtained from lapis lazuli. Lapis lazuli is a mineral substance of historical importance and is valued for its deep blue color. The main constituent of lapis lazuli is lazulite which has a chemical formula  $\text{Na}_4(\text{NaS}_3\text{Al})\text{Al}_2(\text{SiO}_4)_3$ . Prussian blue has a base of ferric ferrocyanide. The sulphide of cadmium is the base of most yellows; for some, however, lead chromate is used as the base. This brief synopsis, which is far from complete,

only emphasizes the fact that the migration of colored ions in magnetic fields appears to be a very complex phenomenon due to the fact that the magnetic susceptibilities are practically negligible. A mere discovery of the variables which are likely to affect any future studies along this line will be of value.

Notice in the data Fig. 7 the colors which migrated into the strong part of the field. Those colloidal particles which were out of the influence of the field settled in time to the bottom of the tube. This usually took days, as the water color particles are very small and as a rule show a very large Brownian movement. The classic substance studied in Brownian movements is gum gamboge which is a semi-soluble gum resin of a rich transparent yellow color. It is not used as a water color due to its bleaching action in sunlight and due to the fact that it decomposes in mixtures of metallic pigments.

The water color artist need no longer be perplexed over the handling of certain colors, particularly the blues. The customary practice is, as has been stated, to "wash" the paper with water. If this wash be made slightly acid, any basic color applied later will tend to precipitate in very fine grains. This statement cannot be verified by photomicrographs since the structure of the paper is revealed in such bold

relief as to make the color grains obscure. The colloidal chemist would explain this occurrence on the basis of ionic adsorption and the fact that particular electrolytes precipitate certain sols. If an acid wash is used, however, more color must be added to obtain the same color value as would be obtained from a water wash.

## VI

### THE BEHAVIOR OF OTHER SUBSTANCES IN MAGNETIC FIELDS

The result of the study of the movements of ions in magnetic fields led to new problems and to some new facts. The original observation that a magnetic field affects ionic movements of water colors led to the discovery of similar movements in organic and inorganic non-magnetic substances. Many of these observations were publicly demonstrated during the present school year at meetings of the physics seminar and at a meeting of the Oregon section of the American Association of Physics Teachers.

The effect of the magnetic field on ionic movements appears as an accelerating force which is best described by considering the following experimental discussion. It was not fully appreciated at first that these observations and demonstrations

require meticulous care, cleanliness, and purity of substances.

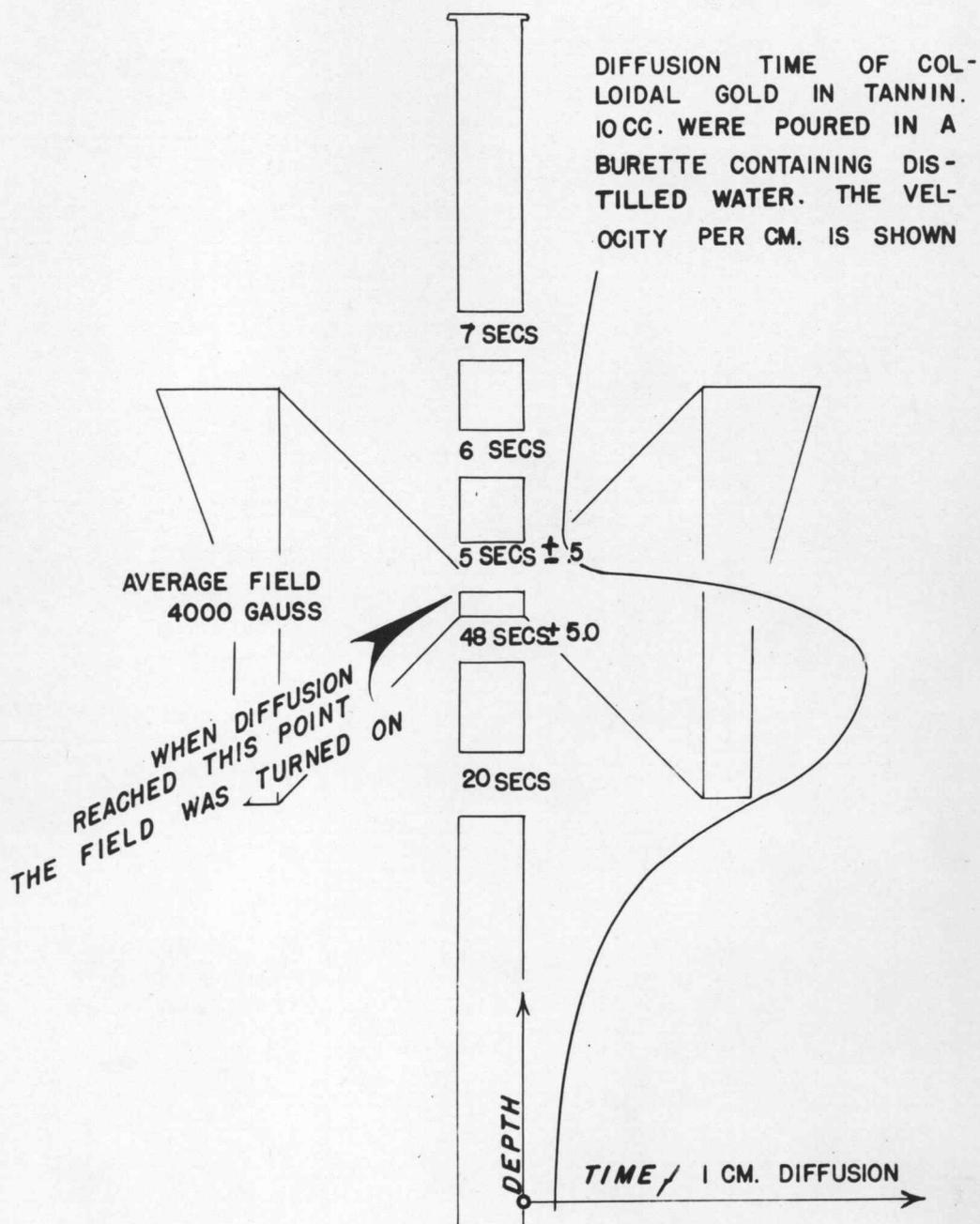
The question of the quantitative study of the effect of a magnetic field on ionic movements presented itself. It seemed that the logical method of an approach required a thorough study of only one substance and that this substance be non-magnetic, free from magnetic impurities, and give reproducible results. It seemed that a study of the diffusion of a solution into some other liquid might be important. One could then observe whether or not the diffusion boundary was accelerated one way or another in the magnetic field.

After careful consideration it appeared that a gold sol prepared from gold chloride in tannic acid might be the ideal substance to study. Two cc. of the commercial 1 per cent gold chloride solution is diluted with 100 cc. of distilled water. 0.5 gr. C. P. tannin is dissolved in 100 cc. of water. If both solutions are heated and about 1 part of tannin is added to 3 parts of gold, a clear red gold sol results. These sols are stable and can be kept for some time; however, tannin solutions are susceptible to mould.

The experimental arrangement is shown graphically on the next page (Fig. 8). A burette is mounted

# DIFFUSION THROUGH A STRONG MAGNETIC FIELD

## FIG. 8



vertically between the pole pieces of the electromagnet. The 20 centimeter mark on the burette was placed in the same horizontal plane at the center of the pole pieces. The burette was filled with distilled water to the 40 centimeter mark. When enough time had elapsed to allow all motion of the water to cease and for temperature equilibrium to be attained, 10 cc of the gold sol was poured into the burette. The boundary surface is sharp. The downward speed of this surface was measured; it is represented graphically for a particular gold solution in Fig. 8.

The results were hard to repeat regularly.

This is probably due to several causes:

- (1) The colloidal particles in any preparation vary in size.
- (2) The medium through which the solution is diffusing is undoubtedly experiencing abnormal ionic behavior, especially in the strong part of the field. The maximum force of the field is exerted only on those particles that are moving at right angles to the magnetic lines of flux.
- (3) Slight local temperature changes in the liquid exist. A temperature gradient may also exist in the liquid. The particles affected by the magnetic field are similar in dimensions to those that exhibit Brownian movements.

- (4) It is possible from the theoretical point of view that Brownian movements play a considerable part in causing the abnormal behavior in a strong magnetic field. The purity and concentration as well as the stability of colloids are always questionable.
- (5) Uncontrollable boundary conditions affect the electrical conditions of a solution.
- (6) Too small a burette produces unnecessary friction, whereas too large a one makes it difficult to provide a concentrated field.
- (7) The strength of the field varied somewhat due to the increased resistance of the coils as the magnet grew warm.

The shapes of the particles and the tendency of some colloids, such as certain water colors, to flock together in the region of the most intense magnetic flux cannot help but affect the ordinary diffusion rate after passing through the magnetic field. However, to definitely establish this point, that the rate of diffusion of the ions becomes abnormal in a magnetic field, it was deemed desirable to reduce the number of variables. Consequently diffusion experiments were conducted in a gel instead of a liquid. Convection currents, temperature effects and the like were thereby either eliminated or materially reduced. Since the famous Liesegang phen-

omenon of rhythmic banding provides sharp lines of demarcation, it was adopted for the present purpose. Any abnormal behavior of the Liesegang diffusion due to a magnetic field will decide the point at issue. The phenomena can be photographed thus providing a permanent record. Further, since the formation of rhythmic bands has not yet been fully explained, it was hoped that possibly some light might be shed on this point.

## VII

### THE LIESEGANG PHENOMENON IN MAGNETIC FIELDS

Liesegang rings form in a gelatin gel containing a small amount of potassium chromate when concentrated silver nitrate solution is allowed to diffuse into the gel, the reaction being



Fine red silver chromate precipitates in rhythmic bands, fine and close at the top, gradually getting farther apart.

Gortner in his "Outlines of Biochemistry" p. 251, makes the following statement:

"There have been many theories and many attempts to successfully account for rhythmic banding. It has been suggested that the silver ions diffusing into a chromate which remains in a supersaturated

condition due to the protective action of the gelatin. As the concentration of the silver increases, the silver chromate micelles are coagulated and crystallize out of the gel forming an impermeable layer. This silver chromate band would absorb silver ions, retarding the diffusion of such ions through the gel, but would not absorb nitrate ions which pass through possibly in the form of nitric acid. As the silver chromate gel ages, it would break down, become coarser in structure, allow the silver ions to pass through and a new point of saturation be reached, causing the formation of new bands."

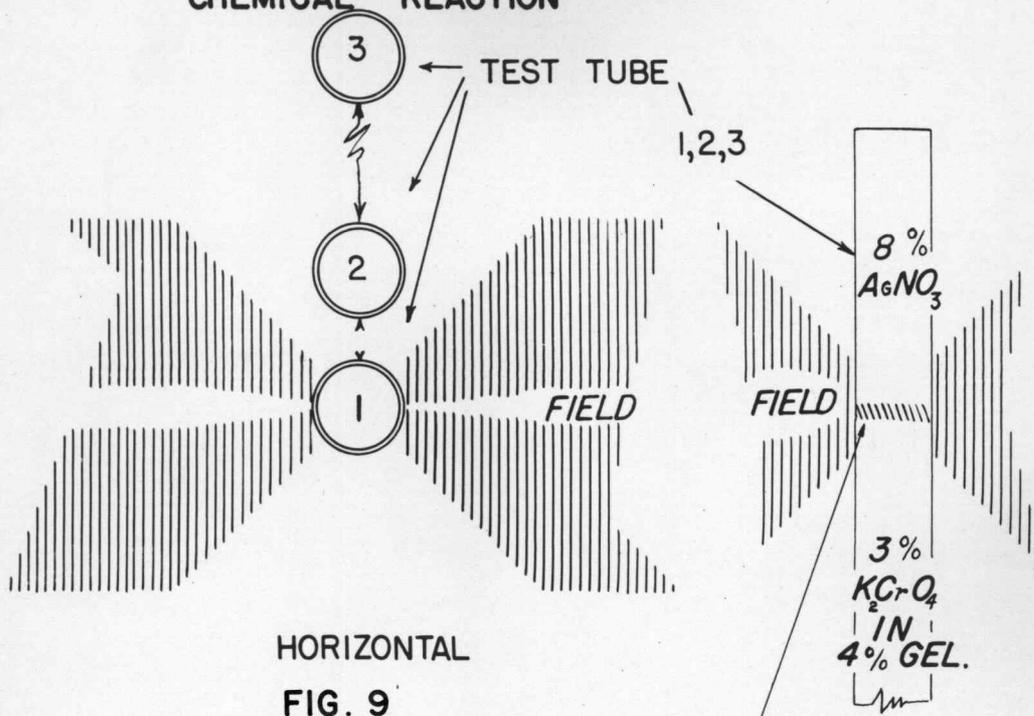
The potassium chromate used for this experiment was obtained from potassium dichromate and potassium hydroxide as follows



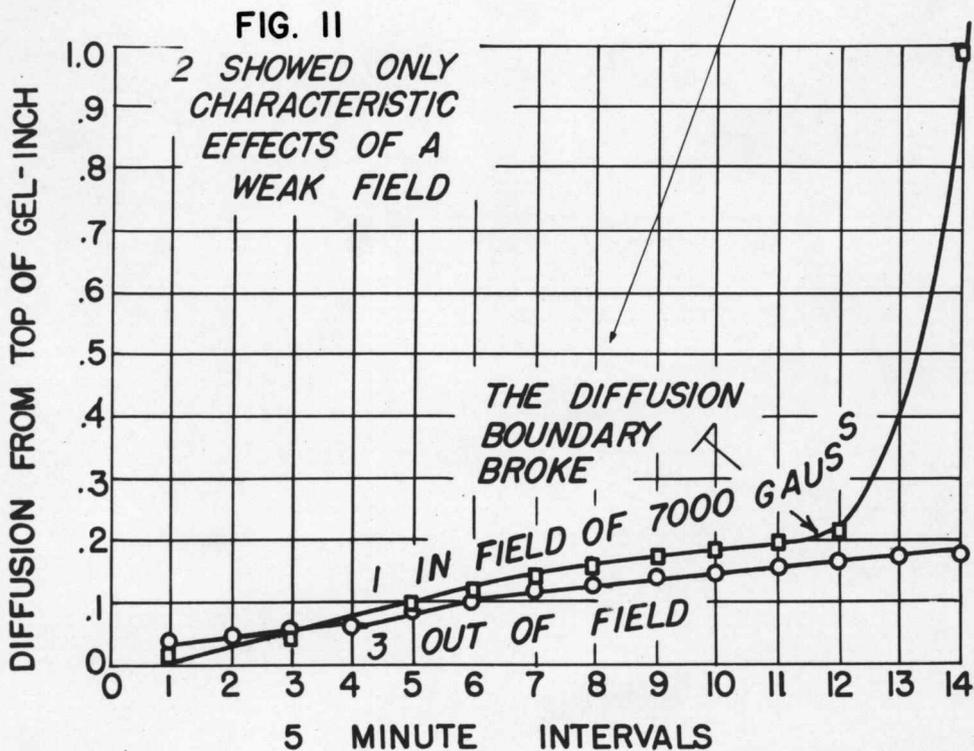
The gelatin gel was made by adding 4 grams of gelatin to a (0.1 to 0.35%) potassium chromate solution. The diffusing silver nitrate was an 8% solution.

New pyrex glass tubing was sterilized in hot running water and was then cut into the desired lengths. This insured practically identical conditions for the control and the test specimens. New cork stoppers were used exclusively. The potassium chromate solution was warmed just to the boiling point before the gelatin was added. The gel was poured into the pyrex tubes and chilled in running water at 13°C. When the gel had thoroughly set, the tubes were removed from the water bath and placed as indicated in Fig. 9 and 10 with the

EFFECT OF MAGNETIC FIELD ON A CHEMICAL REACTION



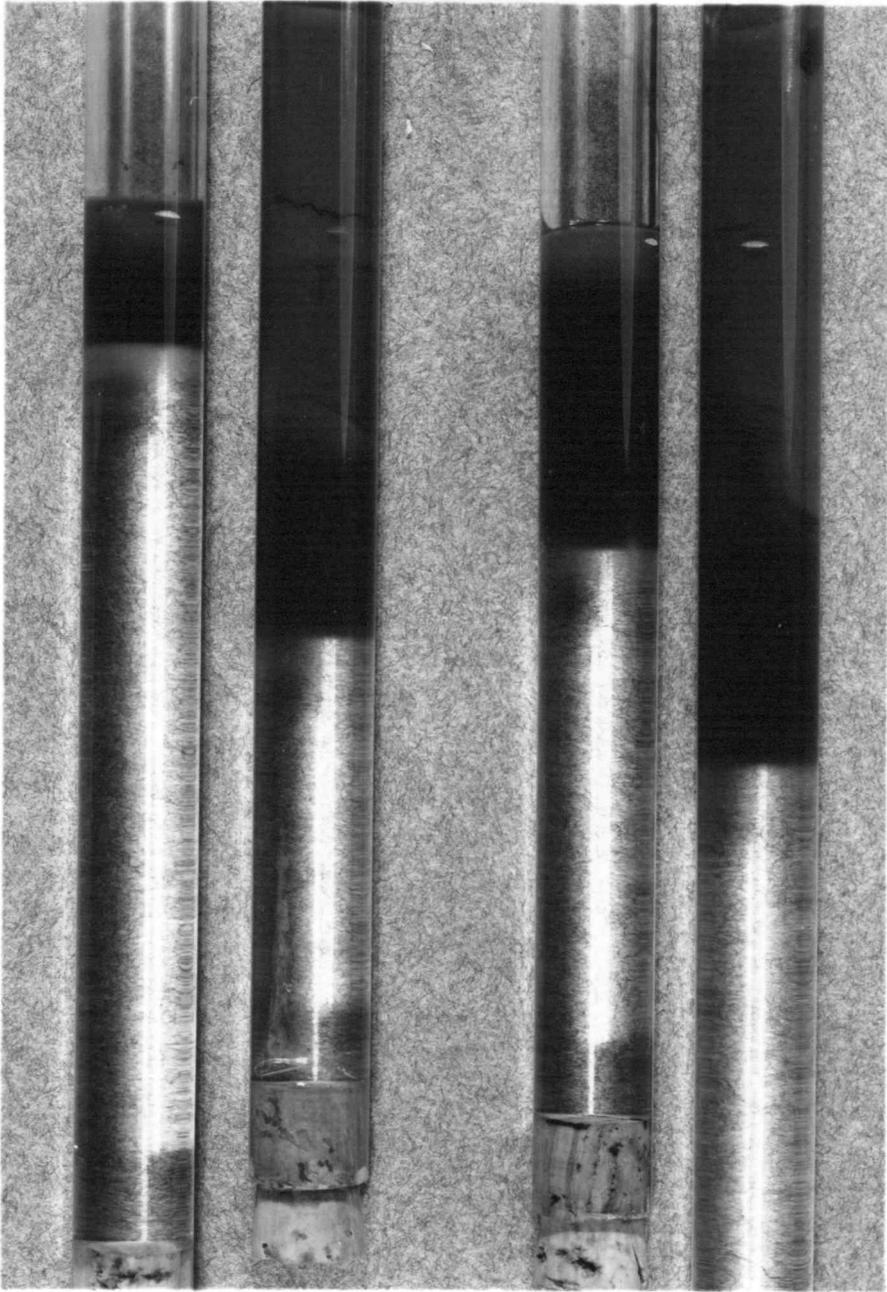
ROOM TEMP.  
25 C.



junction between the gel and the silver nitrate at the center of the magnetic field. The control of course was not placed in the magnetic field.

The first visible effect of the magnetic field on the Liesegang reaction is the red coloring of the silver nitrate; this is probably due to the fact that the potassium chromate is being forced upward. Some time later the diffusion boundary breaks as indicated in the graph (Fig. 11).

Photographs of two samples run in the magnetic field, Numbers 2 and 4, may be compared with their corresponding controls - Numbers 1 and 3. (Fig. 12). Diffusion had continued for a longer time in sample 3 than in 1 due to a delay in taking the photographs. During the process of diffusion, the boundaries are not as smooth and regular as indicated in Fig. 12. The process takes place in some such fashion as indicated in Fig. 13. This photograph was taken shortly after the end of the experiment. Sample 1 was the sample run in the field, and sample 2 was a control which was immediately adjacent to 1 during the experiment. The running of the control so close to the field in this case was to equalize the temperature as much as possible and to indicate in the photograph that the difference in behavior was caused by the magnetic field and not a possible difference in temperature conditions.



1

2

3

4

FIG. 12



1 2  
FIG. 13

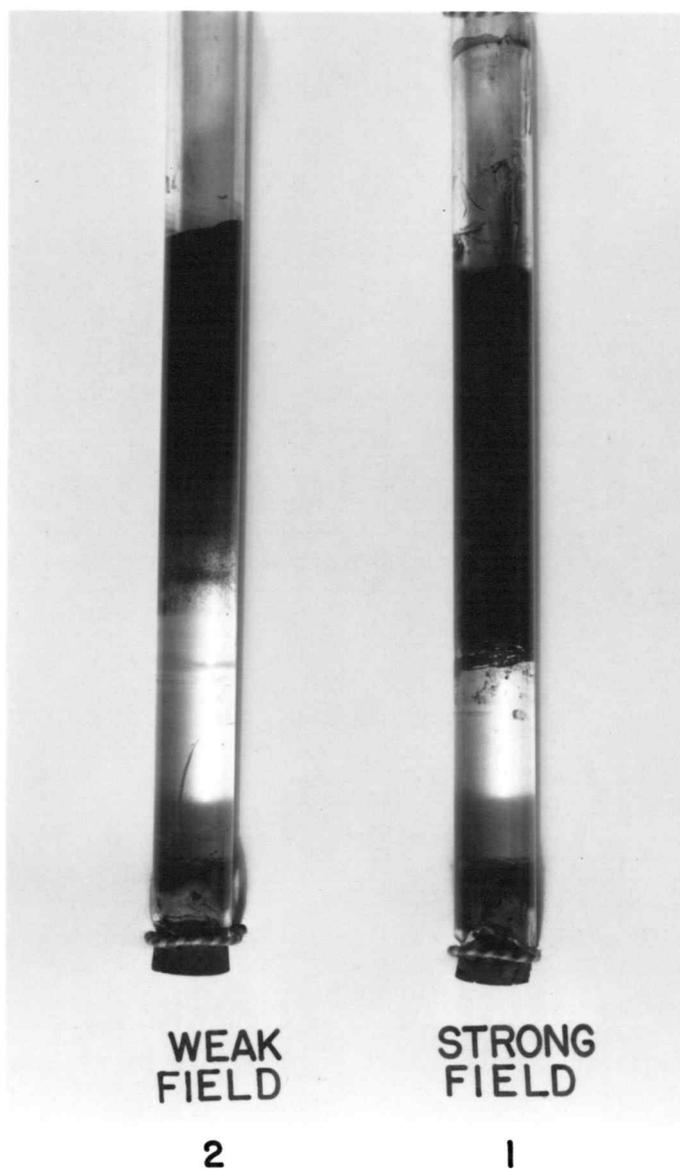


FIG. 14

The appearance of the samples shown in Fig. 13 is shown in Fig. 14 after the two samples had been allowed to diffuse freely under the action of gravity for seven days. The control sample was labeled, "Weak Field", and the test sample "Strong Field". The sample whose appearance was so rugged as a result of diffusing in the strong field has shown very little vertical extension of the lower limit of the diffusion boundary. The only change seems to be that the rugged appearance has become more smooth and continuous. The diffusion of the control over this same period of time has extended from the narrow band shown in sample 2 in Fig. 13 almost to the lower limit of sample 1 in Fig. 14. There are many bands in this sample, some of which are invisible in the photograph.

It seemed quite evident that by placing the control adjacent to the sample in the strong magnetic field that the change in temperature due to the electromagnet was not the cause of the abnormal diffusion rate. The effect of the magnetic field seems to be the only plausible explanation. Furthermore, the samples in the field are characteristically different in appearance. The actual difference between room temperature and the temperature of the air between the pole pieces after the magnet current of 6 amperes had been on for an hour or more was  $2^{\circ}$  C.

The temperature at which a gelling solution solidifies or melts depends upon the rate of temperature change, the slower a gel is warmed, the lower the temperature at which it melts. The slower a gel is cooled, the higher the temperature at which it solidifies in order to get comparable results. For the study of the thermal properties of a gel a satisfactory cooling rate must be determined. The rate assumed in the following study was a 40 degree change for 14 minutes. It is definitely known that there is no definite temperature at which a gel freezes. A 4% potassium chromate gel freezes at about 30°C. In searching the literature, mention was found of cooling curves of gels for different concentrations but not for different ingredients. It was thought that possibly the cooling curve of a potassium chromate gel might be slightly different than one containing silver chromate. Such a study would indicate the plausibility of investigating the Liesegang phenomenon in a magnetic field from the thermal point of view on the basis that the apparent increased ionic movement due to the field increases the temperature appreciably.

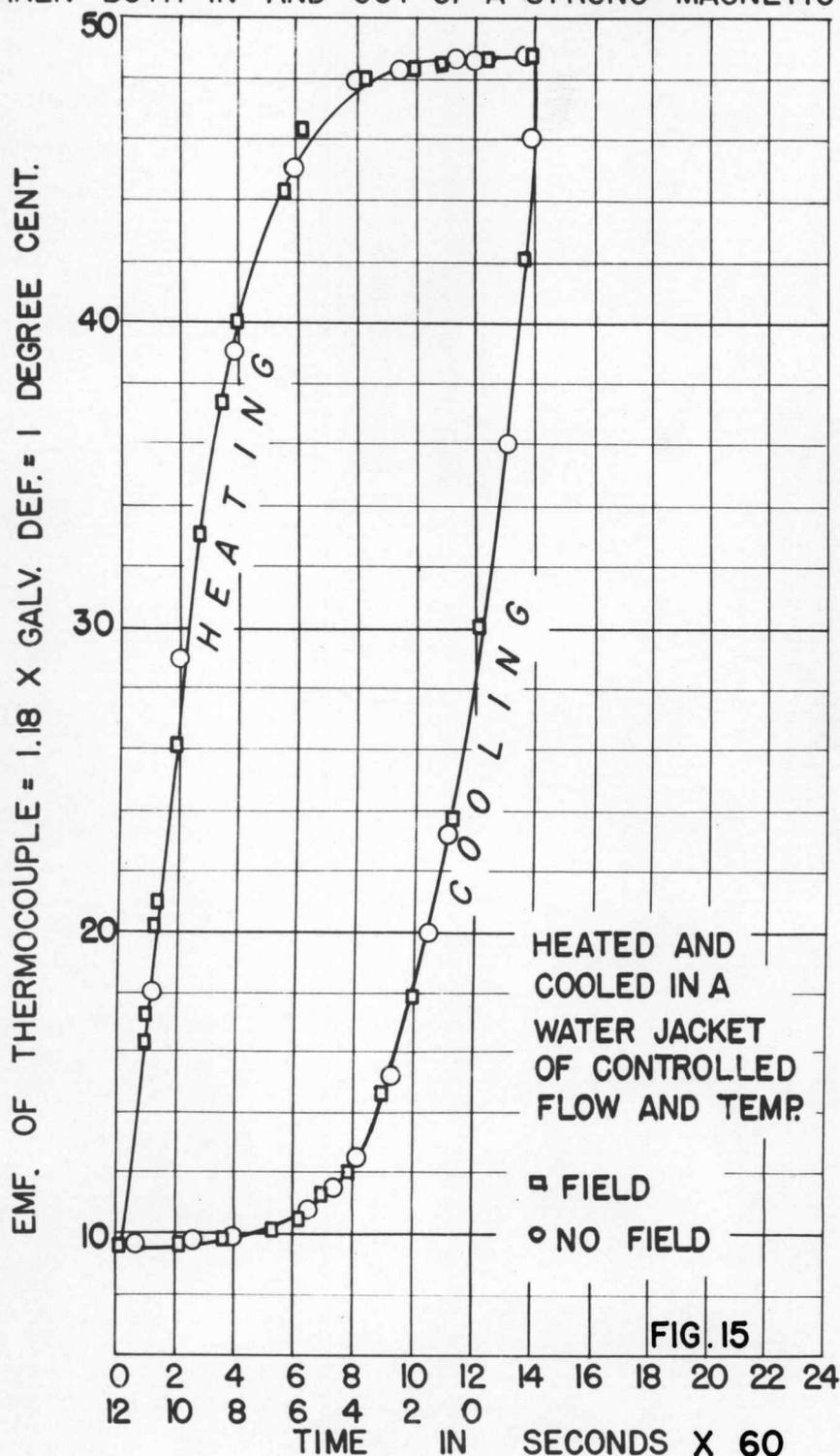
A thin brass jacket was made for two test tubes so that they could be surrounded by a steady stream of water. The speed of the stream could be regulated up to a maximum of 3000 cc. per min. The

jacket was mounted between the pole pieces of the magnet and two test tubes of the gel were introduced. The effective strength of the field was reduced to such a small value by the one-inch gap required by the water jacket that the Liesegang reaction could not be performed at a controlled temperature. However, it was possible to take the cooling curves of the gels containing potassium chromate and silver chromate. The curves shown on Fig. 15 show that the heat of the magnet does not affect the cooling system. These curves were obtained in the following manner:

Warm water was first introduced into the jacket and after the temperature had become constant it was replaced by cold water. The cold water cooled the system and after 14 minutes the gel had reached the temperature of the cold water in the cooling system.

This temperature was measured with a spot welded #36 Chromel C and Copel wire thermocouple sealed in the thinnest possible lead glass tube. The thermocouple was calibrated against a standard with the cold junction immersed in melting ice. This calibration of the thermocouple yielded a straight line between the temperature ranges required and gave as a constant, the value of 1.18 times the galvanometer reading in millimeters for one degree centigrade. A thermometer could have been used had one been available with the lower

2 SETS OF SUPERIMPOSED DATA OF ROUGH DETERMINATIONS TAKEN ON 3%  $K_2Cr_2O_7$  GELS. ALSO 2 SETS OF THE  $K_2Cr_2O_7$  GEL WHEN  $AgNO_3$  WAS ADDED. THESE COOLING CURVES WERE TAKEN BOTH IN AND OUT OF A STRONG MAGNETIC FIELD



scale readings sufficiently high on the glass to be readable. When the gel had cooled the process was repeated for the warm water and after 14 minutes the gel arrived at the temperature of the warm water in the cooling system. Thus a cycle of warming and cooling was completed which could be repeated a number of times. The average of these readings was used to plot the curves in Fig.15.

The results are exactly what one might expect from an experiment in which only tenths of a degree could be measured. There is no detectable difference between the cooling curve of the silver chromate gel and the potassium chromate gel. The 2 degree rise above room temperature between the pole pieces of the magnet did not affect the cooling system or the curves. If the apparent increased diffusion rate of the Liesegang phenomenon in the magnetic field is to be investigated thermally, more refined temperature measurements must be made.

Weighing all the evidence that has been accumulated, the statement seems to be justified that a strong magnetic field causes this particular Liesegang phenomenon to progress with abnormal rapidity.

## VIII

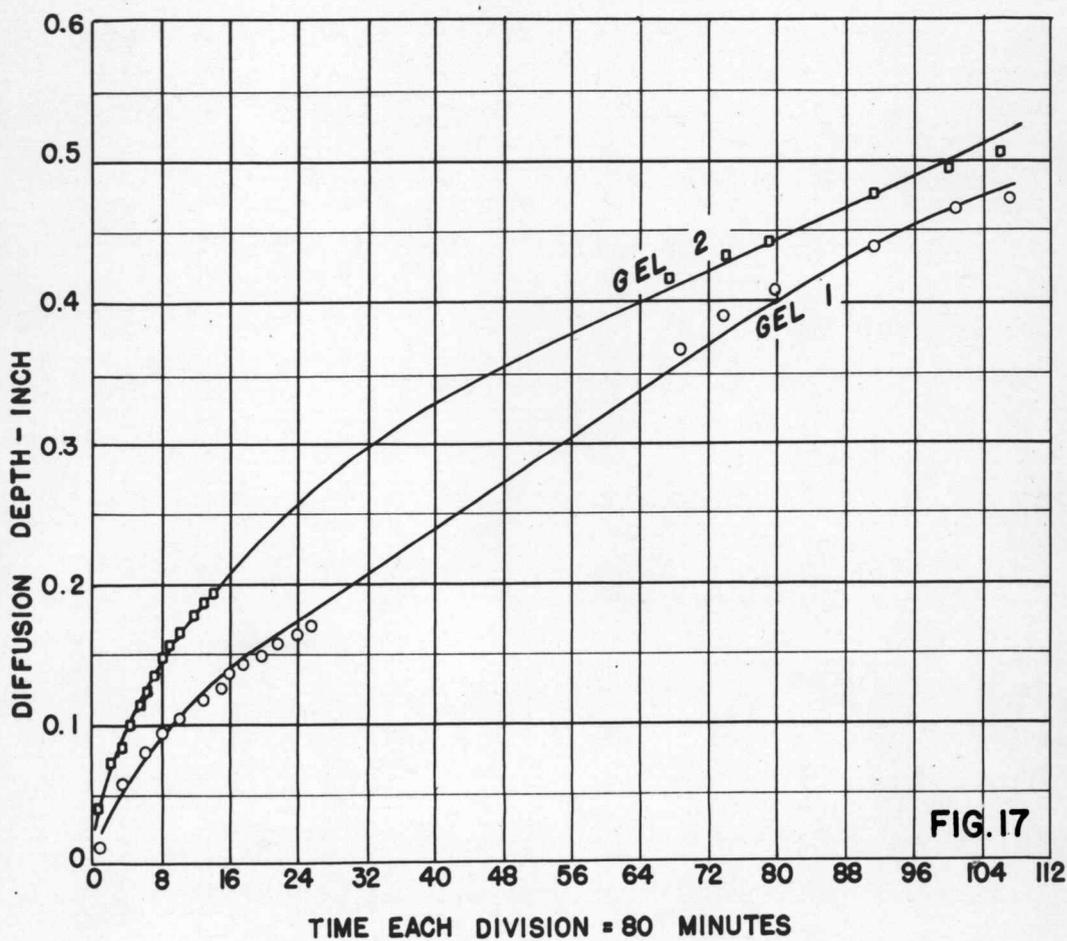
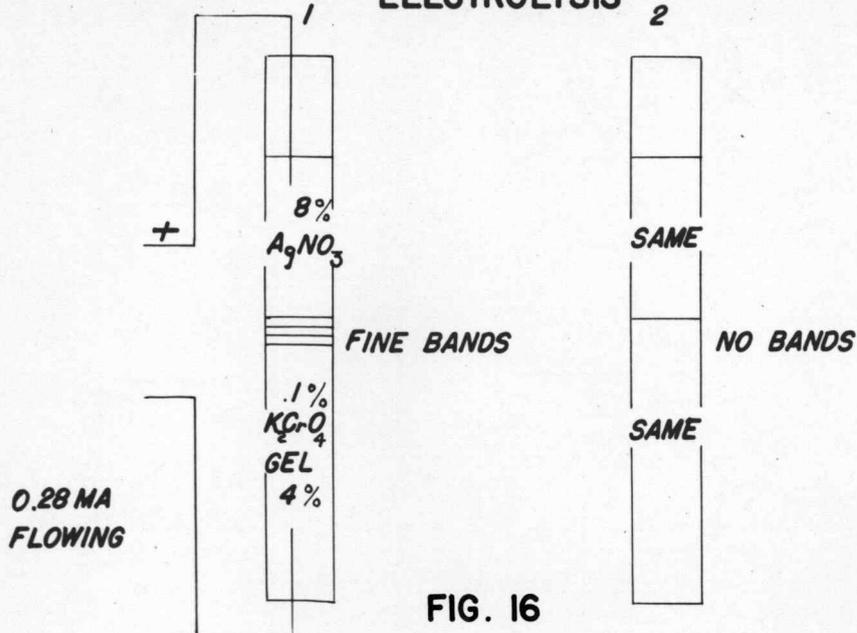
## THE LIESEGANG PHENOMENON IN ELECTRIC FIELDS

There remains but one phase of the study of ionic movements to make this paper symmetrical and that is the study of a gel reaction in an electric field. The method involves diffusion measurements of the Liesegang phenomenon in electric fields.

The preparation of the ingredients for the gels was exactly the same as for the experiments in the magnetic field. One electrode was placed in the gel before the gel had set in order to insure good contact. Platinum electrodes were used in all cases. When the gel had set by chilling in a water bath at 13° C., the tubes were removed and held in the vertical position by clamps. The arrangement can be seen in Fig.4. The long focus traveling microscope used for measuring the rate of diffusion is shown in the right foreground. The field of the microscope was large enough to permit the three specimen tubes to be viewed together.

The first data obtained on the Liesegang phenomenon in the electric field are shown graphically in Fig.17. The position and polarity of the electrodes is shown in Fig.16. Only a fraction of a milliampere was allowed to flow through the gel during the progress of the diffusion.

### RYTHMIC BANDING BY ELECTROLYSIS



### LIESEGANG RINGS BY ELECTROLYSIS

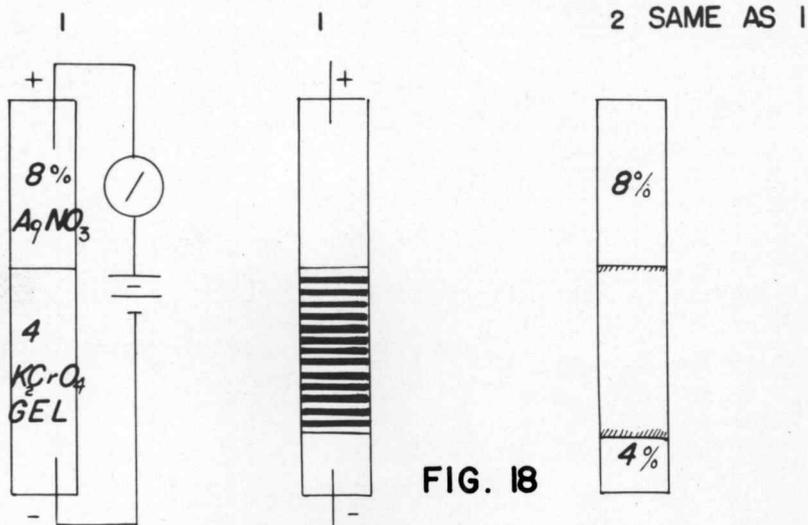


FIG. 18

DATA

GEL 1	TIME-HOURS	GEL 1	DIFFUSION DEPTH-INCH	GEL 2	APPEARANCE
0.21 MILLIAMPS	1	0.19	ORDINARY	0.25	ORDINARY
	2	0.25	3 FINE BANDS	0.31	NO BANDS
	3	0.31	5 " "	0.38	" "
	4-1/4	0.34	8 " "	0.44	" "
	5	0.38	12 " "	0.50	" "
	6	0.44	14 " "	0.55	" "
	12	0.63	" "	0.75	" "
0.05 "	14	0.75	" "	0.81	" "

FIG. 19

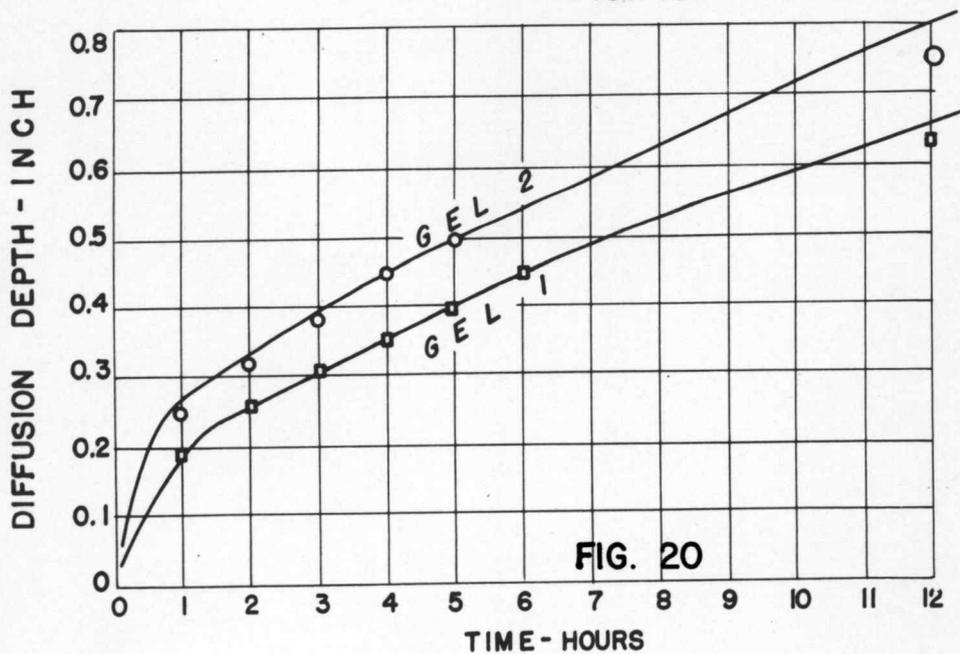


FIG. 20

The appearance of the two samples is interesting. Tube 1 of Fig. 16 which was in the electric field, showed many fine bands that could not be photographed due to troublesome shadows and reflections. Banding had not become apparent in the control in the corresponding region of the gel, however, they did appear later but in much different fashion.

The experiment was repeated many times with the same results. A sample of this repetition is shown in Fig. 18, 19 and 20. The experimental set-up is shown in Fig. 18 and the accompanying data in Fig. 19 show many interesting facts. There were no bands in the control or at least they could not be seen until later. The test sample, however, showed very fine banding during this period, the depth of diffusion being slightly less than in the control. This may be seen in Fig. 20. Referring again to data of Fig. 19, notice that an apparent increase in resistance is indicated by the decrease in current through the gel. This is a very important point in connection with the further investigation of the Liesegang phenomenon. The appearance of bands accompanied with the decrease in resistance makes one think of a space charge condition. This point is worthy of the most exacting experimental scrutiny for in its investigation lies apparently a wealth of data. Notice that the slope of the curves of

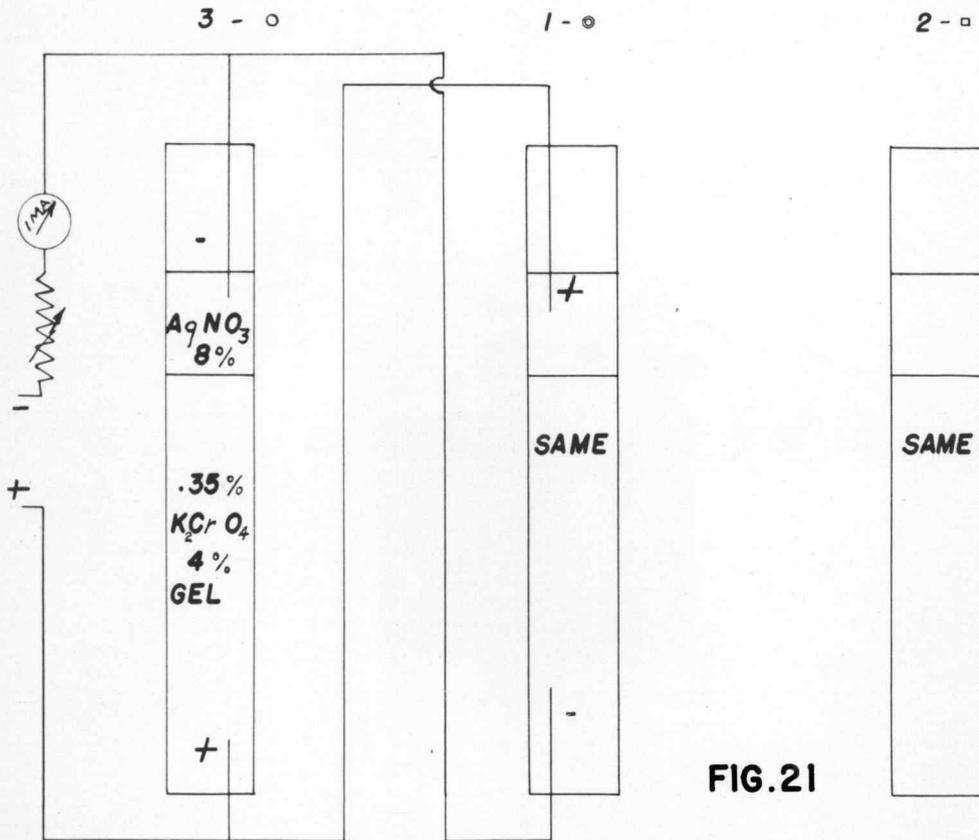


FIG.21

EFFECT OF ELECTROLYSIS ON DIFFUSION

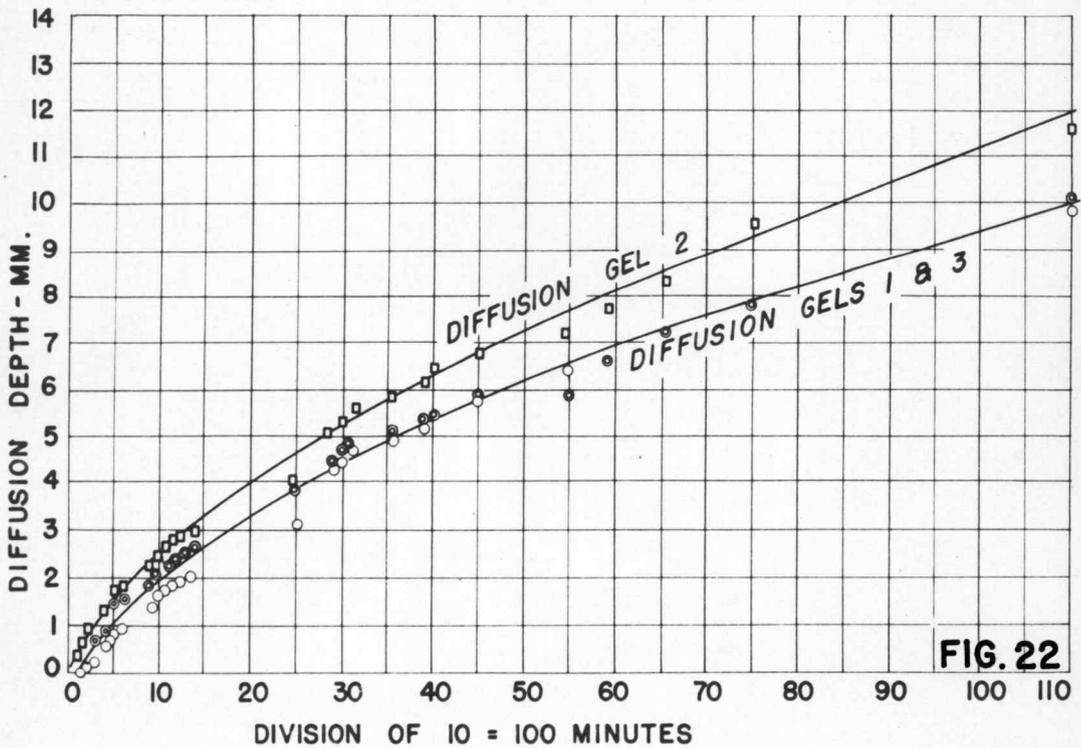
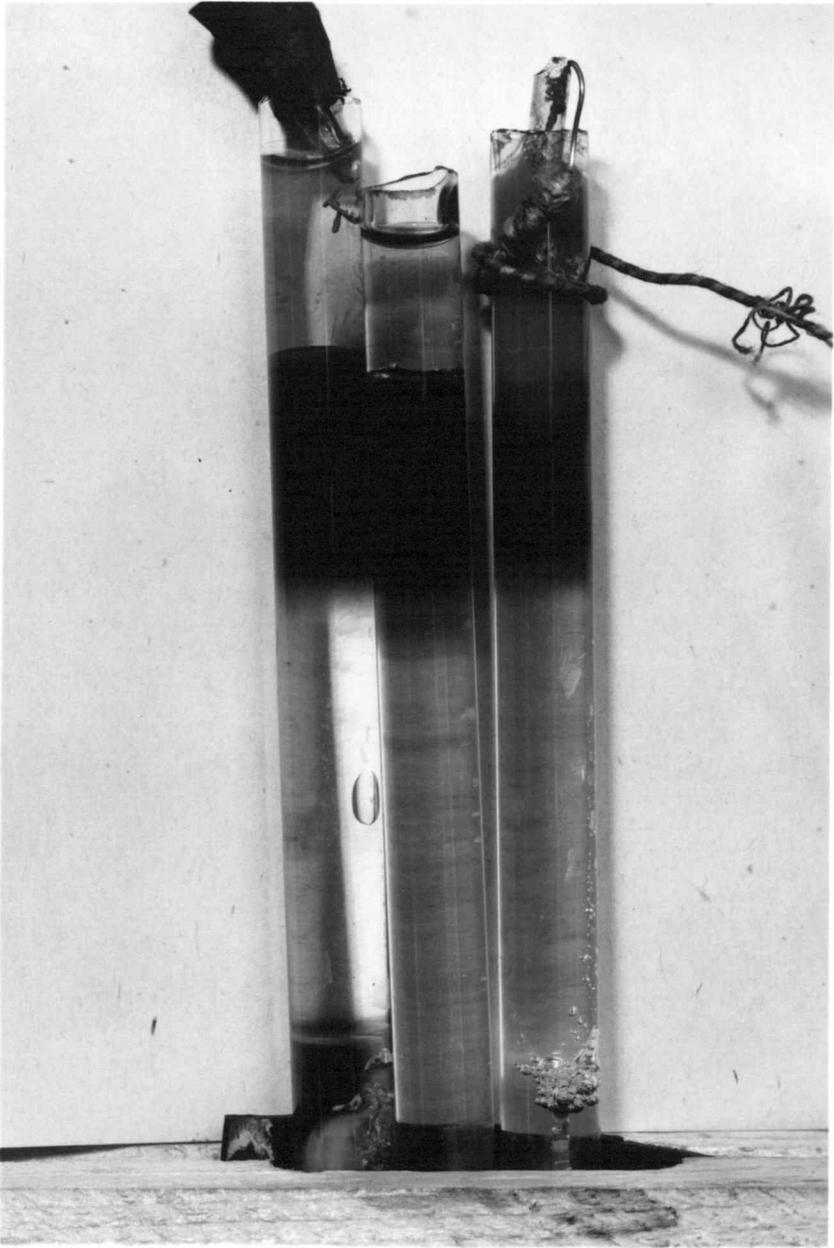


FIG. 22



1 2 3

FIG.23

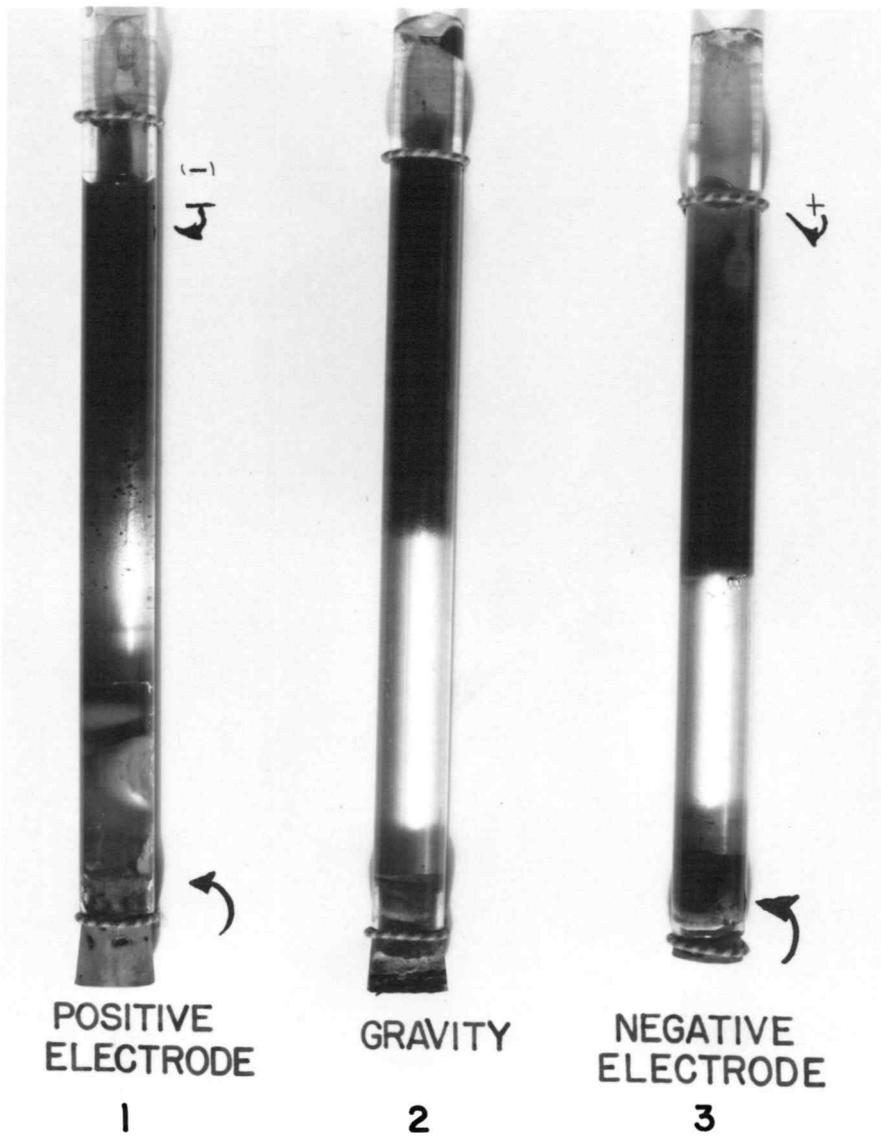


FIG. 24

Fig. 20 are practically the same excepting for the first few minutes when the ionic movement in the test sample is becoming equalized in the two directions.

The experimental set-up shown in Fig. 21 is another instance of measuring the rate of motion of the diffusion boundary of the Liesegang phenomenon, but in this case the electric field is applied in opposite directions in the two samples. The current in both samples was 1 milliampere. This is somewhat too large, being accompanied by a slight evolution of gas; one bubble is shown in gel 1, Fig. 23. The amount of current necessary for the best results for making such a study appears to be about 0.1 milliampere between parallel, symmetrical platinum electrodes. The data plotted in Fig. 22 indicate that the direction of the current is immaterial in this particular study and that the diffusion in the field is slightly slower than in the control.

Notice the appearance of the gels of Fig. 21 in the photograph of Fig. 23. Number 1 displays a distinct band at the positive electrode. This band is green interspaced with yellow. The appearance of the gels after they had been allowed to diffuse freely under the action of gravity is shown in Fig. 24. Their true appearance cannot be truly appreciated due to the shadows and reflections.

## IX

## CONCLUSIONS

The variety of applications of the studies of colored ion movements in magnetic and electric fields has led to some new and valuable information. We have an experimental procedure which will adapt itself naturally and simply to the studies of many colloidal problems. These problems have been shown to be of theoretical as well as practical importance. A resume of the conclusions drawn from this study follows.

- (1) Organic dyes and other color mixtures can be analyzed for their color components by electrolysis. The results are more or less rough due to the reducing action of the process. It is practical in spite of this.
- (2) Those dyes which reflect one color and transmit another, usually the complement, have been shown to be mixtures of the two respective color components.
- (3) The colored ions of many colloidal solutions experience a definite accelerating force in a magnetic field. Some colored solutions may be analyzed in a magnetic field.
- (4) Water colors can be prevented from settling in a mottled appearance if they are basic in

nature by using a preliminary wash of acid rather than pure water.

- (5) The diffusion rate of a gold colloid may be retarded or accelerated in crossing a magnetic field. At the present stage of the study there seems to be a definite correlation between the displacement of the particles due to the Brownian movement and the effect of the field on these colloidal particles but the experimental technique for a real study of this relationship has not yet been perfected. The preparation of a gold sol from an electric arc possibly will improve the technique.
- (6) The diffusion rate of the Liesegang phenomenon of silver nitrate into potassium chromate becomes abnormal in a magnetic field.
- (7) The diffusion rate of the Liesegang phenomenon is only slightly retarded in an electric field.
- (8) An electric field affects the position, number, and in some cases the color of the rhythmic bands, as compared to the control.
- (9) The symmetry of the bands is not affected by the non-uniformity of the field due to the electrodes being not quite parallel.
- (10) The apparent increase in resistance of a gel

as the bands are forming indicates strongly that the ultimate explanation of rhythmic banding will be electrical

## X

### ACKNOWLEDGMENTS

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## XI

### INTERVIEWS AND SEARCH OF LITERATURE

The names of the artists and industrial plants interviewed are withheld because of personal requests.

The periodical indexes were searched for titles of such studies as are here described but none were found.

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