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INVESTIGATION OF THE CHEMICAL EFFECTS OF ULTRASONIC WAVES

Final Report
Covering the Period June 14, 1951 to June 14, 1953

by

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Final Report Contract Nonr-331(00)

Summary

One paper has already been published and circulated under this contract, namely "The Chemical Effects of Ultrasonics" by Virginia Griffing (J. Chem. Phys., 20, 939-42 (1952)). A second technical report has been circulated, i.e. "Luminescence Produced as a Result of Intense Ultrasonic Waves" by Virginia Griffing and D. Sette. This is to be modified somewhat and published in the Journal of Chemical Physics. In addition a short paper on "The Effect of Ultrasonics on the Explosive Sensitivity of Ammonium Permanganate" by Virginia Griffing and Andrej Macek is to be published in the Transactions of the Faraday Society. Copies of these papers will be submitted with this report and reprints circulated to the distribution list when they are available.

In addition to the above papers this report includes a paper "The Role of Dissolved Gases in Chemical Reactions Produced by Ultrasonics" by Mary Evelyn Fitzgerald and Virginia Griffing. These two preliminary reports on cavitation are included in this report. More work needs to be done before definite conclusions can be reached. They are "On the Origin of Cavitation in Liquids", by F.E. Fox, V. Griffing and Daniel Sette, and "Threshold of Cavitation in Water Saturated with Pure Gases and Gaseous Mixtures", by Virginia Griffing and Daniel Sette.

Two other studies were started under this contract and are now nearing completion under NG-ONR-255, Task Order 3. These studies are

1. The influence of various physical variables on the production of H_2O_2 in water with various dissolved gases and gas mixtures.
2. The depolymerization of polystyrene in various organic solvents by means of ultrasonics.

With the help of the contract our experimental facilities were improved so that cavitation experiments can be undertaken over a frequency range of $1/2$ to 2 mc/sec at intensities up to 8 watts/cm².

Summary of the More Important Results of this Study

1. Chemical reactions attributed to ultrasonics can be classified according to three mechanisms. 1) Reactions due to cavitation never occur without the formation of bubbles. All of these reactions take place in the gas phase, are primarily thermal and are due to the heat developed during adiabatic compression. Thus, only reactants with an appreciable vapor pressure are affected. 2) Many reactions in the liquid phase are of secondary origin due to reactions with dissolved products of the primary reaction in the gas phase. Luminescence is also a secondary effect. 3) Some reactions are due to the uniform temperature elevation caused by absorption of acoustic energy of very high intensity in a short path length.

2. Luminescence, when it does occur, is always present with cavitation and starts at the same energy level as cavitation. Various water solutions show luminescences in the same relative amounts as the yield of the chemical reaction caused by intense sound waves. From this it is concluded that, at least in these cases, the phenomena is

chemiluminescence. An apparent frequency dependence of the luminescence was observed; however, it was shown that the threshold of cavitation was the frequency dependent phenomena.

3. The most important result of this study was the demonstration of the importance of measuring the intensity for the threshold of cavitation as well as the intensity at which the experiments are conducted under the specific experimental conditions before any conclusions are reached about the effects of various physical variables.

The Role of Dissolved Gases in Chemical Reactions
Produced by Ultrasonics*

by

Mary Evelyn Fitzgerald** and Virginia Griffing

Abstract

A study has been made of the effects of ultrasonics on the decomposition of carbon tetrachloride dissolved in water. The yield of free chlorine and the change in pH of the solutions are reported as a function of voltage and incident intensity. The measurements are made on a series of solutions saturated with different gases. A definite correlation is found between the yield of free chlorine and the ratios of specific heat of the dissolved gases. Thus it is concluded that the primary reactions are thermal decompositions in the gas phase due to the adiabatic compression of the gas bubbles in the intense sound beam.

* Supported by Office of Naval Research. Part of this material is taken from a Ph.D. thesis, Catholic University of America.

** Now at Mount St. Vincent's College, Halifax, Nova Scotia.

Introduction

It has been recognized for a long time by most investigators that the presence of dissolved gases is necessary before chemical reactions can be induced by ultrasonics. On the assumption that a dissolved gas forms minute bubbles in the sound field, an explanation of these phenomena has been suggested by one of us.¹ It has been suggested that the primary reactions take place inside the bubbles, are primarily thermal, and are brought about by the heat developed during the adiabatic compression of the gas bubbles. Thus no reactant is directly affected by the sound field unless it has sufficient vapor pressure so that it is found inside the gas bubbles in sufficient concentrations for reaction to take place there. The following experiments were undertaken to determine the effects of various gases on the rate of decomposition of a carbon tetrachloride-water solution.

Experimental Procedure

The experiments were carried out with a 2 mc quartz crystal mounted in a lucite holder in one end of a glass tank. The tank was filled with water to transmit the high intensity sound waves from the source to the reaction vessel which was immersed in the water. The water served as a constant temperature bath to maintain approximately constant temperature inside the reaction vessel. The crystal was driven by an oscillator from a radio transmitter and the intensity was kept constant over a given run by keeping the voltage across the crystal constant. The voltage was

¹ V. Griffing, J. Chem. Phys., 18, 997 (1950); J. Chem. Phys., 20, 929 (1952).

monitored with a vacuum tube voltmeter with a range of 0 to 1500 volts rms. The absolute intensity was determined by observing the radiation pressure² on a rubber disc suspended in the tank in the usual way. The reactions were carried out in tubes one inch inside diameter, 6 inches long, closed at one end and supported in a horizontal position in the tank. The open end of the tube was closed with a cellophane film which was non-reactant, impermeable to product and reactants, and permitted 99% of the sound energy to pass into the reaction vessel. The measured intensities are the intensities of the sound beam entering the reaction vessel. The reaction vessel was closed at the far end so that all the sound energy would be reflected back into the reaction vessel. Originally it was planned to keep a constant intensity by measuring the sound intensity transmitted through a similar thin film at the far end of the reaction vessel and thus, by absorbing this energy, to measure the effects of a progressive wave of a known intensity. However, as soon as cavitation begins, many small bubbles are produced in the sound field and the sound energy is scattered by the bubbles. It was found that the most reproducible results were thus achieved by this set-up in which all the sound energy is scattered back into the reaction vessel. Although this method of determining the relative dependence on intensity was adequate,³ it is not entirely satisfactory for determination of chemical effects as a function of the absolute intensity of the sound beam.

² F.E. Fox and V. Griffing, J. Acoust. Soc. Am., 21, 352 (1949).

³ When the relative intensity is measured in this way, it is possible to obtain reproducible results with different crystals, mounts and tanks.

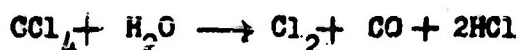
The presence of cavitation was assured by observing the cavitation bubbles in a Tyndall beam which was passed through the solution in each experiment. Any experiment during which cavitation ceased was discarded.

Many observers have reported the production of free chlorine when water saturated with carbon tetrachloride is irradiated with ultrasonics; we made the assumption that we could follow the evolution of free chlorine by titration as a measure of the rate of our reaction for purposes of determining the comparative role of various gases dissolved in the solution. The acidity of the resulting solutions was also measured with a pH meter. Double distilled water was degassed by boiling for fifteen minutes in a specially designed flask. The flask was equipped with stopcocks which could be used to close off the water until it was cooled to room temperature; then one of the pure gases was introduced into the flask through a two-way stopcock. A few milliliters of carbon tetrachloride were introduced into the solution through a second opening. The flask was then shaken vigorously for several minutes and allowed to stand for 15 to 24 hours (the saturated solution of CCl_4 in water at 20°C contains 5.8×10^{-3} moles/liter). The reaction tubes were equipped with two side arms with stopcocks. These tubes were flushed out and completely filled with distilled water which was then driven out with the gas being used in the given experiment. The tubes were then filled with the solution from the flask, care being taken that no excess CCl_4 was carried over. Compressed gas was used to force the solution from the flask to the reaction vessel. The voltage was set to correspond to a given intensity and the runs were clocked with a stop watch. Fifty milliliters of the sample were pipetted

into an Erlenmeyer flask containing 50 ml of 0.1 normal potassium iodide and 2 ml of starch solution. After ten minutes titration was made with 0.001 normal sodium thiosulphate. The pH of the original and of the irradiated solution was checked. A series of runs were made with solutions saturated with helium, neon, argon, nitrogen, oxygen, carbon monoxide, sulfur hexafluoride and freon.

Experimental Results

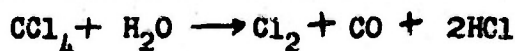
The results are given in the accompanying graphs. In all cases the titration curve gives the milliequivalents of free chlorine formed. The pH curves give the milliequivalents of hydrogen ion formed. We have also plotted a combined curve on the assumption that the end products might be represented by the following tentative stoichiometric equation:



The validity of this scheme is doubtful inasmuch as the hydrolysis of CCl_4 in sealed tubes at 250°C as reported by Goldschmidt⁴ goes according to the equation:



Furthermore, although Weissler⁵ in the ultrasonic study of this reaction has proposed the following mechanism:



⁴ Goldschmidt, Ber., 14, 928 (1881).

he reports⁵ that "the scheme fails to agree with the fact that infrared and mass spectrometric analyses show that CO_2 is produced rather than CO ". However, we are not primarily interested at the moment in the detailed chemical mechanisms of the reactions occurring, but rather in the comparison of the results as a function of the physical variables of the dissolved gas in order to understand why ultrasonics induces chemical reactions. Thus the interpretation of the curves in terms of mechanism of the chemical reaction is not necessary at present.⁶

In Figure 1 and Figure 2 the results of experiments on the water-argon- CCl_4 mixture is presented. In Figure 1 the yield as function of time is plotted. The deviation of these curves from linearity is probably due to the complications introduced by secondary chemical reactions and the degassing of the solutions. Much longer runs lead to considerable complications, but the rate does fall to a steady state value indicating some kind of equilibrium. In Figure 2 the yield as function of voltage is given. These points represent an average of several runs of five minutes each for each voltage. In Figure 3, Figure 4 and Figure 5, the yield of free chlorine, hydrogen ion concentration and the combined yields are plotted as a function of time (the intensity is constant) for solution saturated with various gases. The yield of free chlorine seems to give the most consistent results. In Figure 6, Figure 7 and Figure 8, the yield as function of intensity is given for a number of gases.

⁵ Weissler, A., NRL report, S-3483 (1949).

⁶ We are now studying the reaction $\text{H}_2\text{O} \rightarrow \text{H}_2\text{O}_2$ as function of all the physical variables. Here the secondary reactions do not complicate the chemistry so much.

In addition to these results a set of careful experiments were undertaken to determine whether H_2O_2 could be produced by ultrasonics in water that was oxygen free. Water was carefully degassed by vacuum distillation and then heated while pumping out for several hours. Then spectroscopically pure helium was admitted and these samples were irradiated with ultrasonics. Hydrogen peroxide was formed. Thus it would seem that oxygen need not be present in order to produce H_2O_2 from water by means of ultrasonics; however, it was not possible to rule out completely the presence of minute traces of O_2 . In addition, experiments were made with fluoro-substituted alkyl chlorides. The following summary indicates the results obtained in ten minute runs at a constant intensity.

	<u>Free Chlorine</u> (meq.)	<u>pH Change</u>
a. Freon 12 + degassed water	0	-
b. Freon 12 + water + air	0.027×10^{-3}	-
c. Freon 12 + degassed water + CCl_4	0.031×10^{-3}	-
d. Freon 21 + degassed water	0	5.6 → 5.0
e. Freon 21 + degassed water + CCl_4	0	6.6 → 4.1
f. Genetron + degassed water	0	6.6 → 4.7
g. Genetron + degassed water + CCl_4	0	6.8 → 4.7

The results of the runs with Freon 114 are shown on the graphs with the other gases. In general, these gases were not useful in studying the reaction selected since they reacted with the otherwise degassed water under the influence of the ultrasonic beam.

Discussion of Results

The yield of free chlorine is seen in Figure 6 to be greater for those solutions which were saturated with gases having a high ratio of specific heats (γ) and to decrease for the remaining gases in the same order as γ decreases. This suggests that the chemical reaction is due to the high temperatures produced by the adiabatic compression of the gas bubbles in the sound field; however, solutions saturated with gases having the same γ (e.g. argon, neon, helium) do not give the same yield. This variation can be explained on the basis of the difference in thermal conductivity and rate of diffusion of the gases from the bubbles into the liquid.

Since the yield decreases as the thermal conductivity of the gases increase, one can conclude that this reaction takes place in the gas phase. The fact that solutions saturated with helium do not give much greater yield than solutions saturated with nitrogen can be explained by the high rate of diffusion of helium out of the gas bubbles. This is supported by the fact that it is more difficult to maintain bubbling in solutions saturated with helium.

From the thermal properties, one would have expected that the experiments with nitrogen and carbon monoxide would give the same results. A considerable difference was observed and this must be due either to a

chemical complication or to the fact that carbon monoxide is about one and one-half times as soluble as nitrogen. These experiments were done with saturated solutions of the gases. Further experiments determining the dependence of the rate of reaction on the concentration of dissolved gases are being made in order to clarify the dependence on solubility of the gas.

The yield of free chlorine increased with increasing intensity and followed a linear law within the experimental error. The dependence of the yield on the nature of the dissolved gas maintained the same relative order over the entire intensity range.

The complexity of the reaction (i.e. the hydrolysis of carbon tetrachloride), the subsequent secondary reactions, the production of hydrogen peroxide particularly when oxygen was present, and the difficulty of being sure that no trace of dissolved oxygen was left in the water, makes it difficult to obtain any more quantitative results from these experiments; in particular these factors are probably responsible for the erratic behavior shown in observed pH changes. The actual production of bubbles by the sound field seems to depend on a number of factors that are difficult to control. Since the results are entirely dependent upon the formation and persistence of bubbles, the detailed explanation of mechanism will only be possible after the fundamentals of cavitation itself are clarified.⁷

Conclusions

These experiments demonstrate that part of the reactions produced by ultrasonics are correlated with the ratio of specific heat of

⁷ Measurements determining the intensity threshold of cavitation as a function of gas content have been carried out in this laboratory by V. Griffing and D. Sette and will be published elsewhere.

the dissolved gas; they support the previous conclusion¹ that these reactions are thermal decompositions at high temperatures produced by the adiabatic compression of the gas bubbles. In a previous paper¹ it has been shown that there is no appreciable heating in the liquid phase surrounding these gas bubbles inasmuch as the inversion of sucrose in acid solution does not increase in rate under the influence of ultrasonics.

Many reactions in the liquid phase have been reported simply as due to ultrasonics which now appear to be secondary reactions. For example, oxidizing agents such as H_2O_2 or OH radicals which have been formed in the gas bubbles may dissolve in the liquid and cause further reaction. Examples of these are the decomposition of KI and the oxidation of Na_2SO_3 to Na_2SO_4 . The change in pH of the solution brought about by reactions in the gas bubbles is responsible for other reactions that have been attributed directly to cavitation. An example of this is the slight increase in the rate of inversion of sucrose in neutral solutions. Luminescence observed in some solutions is also a secondary effect of the cavitation process⁸ and is probably chemiluminescence for water solutions.

Some reactions are due to the temperature elevation caused by the absorption of acoustic energy of very high intensity in a short path length. An example of such a reaction is the denaturization of proteins.⁹ In these experiments ox eyes were irradiated with ultrasonics until cataracts were produced. That this was due to absorption heating was conclusively

⁸ V. Griffing and D. Sette, "Luminescence Produced as a Result of Intense Ultrasonic Waves", ONR Report No. 2 to be published.

⁹ Lavine, Langenstrauss, Boyer, Fox, Griffing, and Thaler, Archives of Ophthalmology, 1952.

demonstrated by placing a thermocouple in the center of the lens of the eye and recording the temperature. That the temperature reached was sufficient to produce opacities was shown by heating eyes to the same temperature in a constant temperature bath. The opacities were more quickly produced at higher frequencies, which is to be expected, since the absorption varies as the square of the frequency. This suggests that frequency dependence would enable one to distinguish between reactions due to cavitation and those due to absorption heating. It is not possible at present to conclude definitely the mechanism of the depolymerization of polymers by ultrasonics but a study is now in progress in this laboratory in an attempt to elucidate this matter.

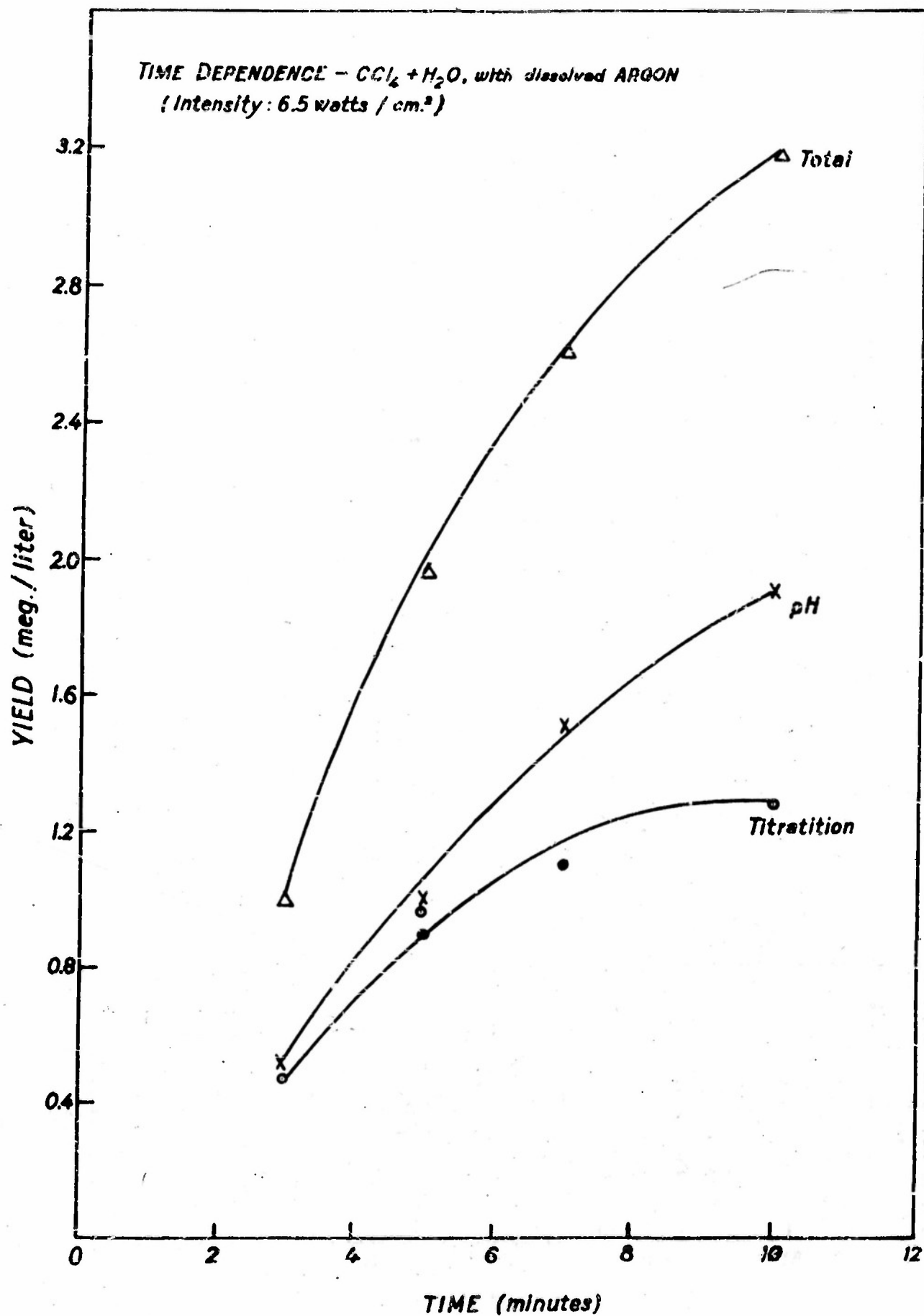


Figure 1

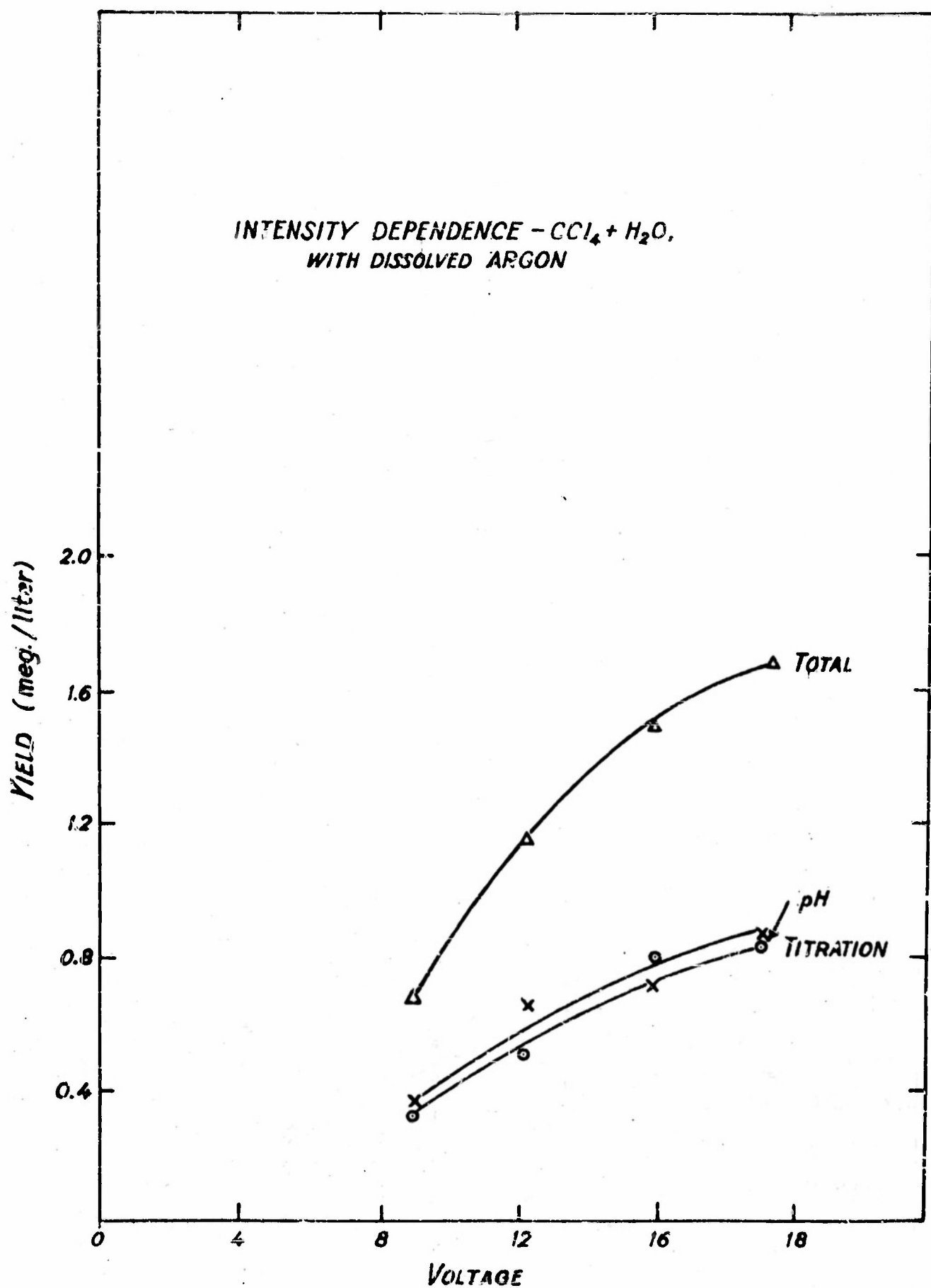


Figure 2

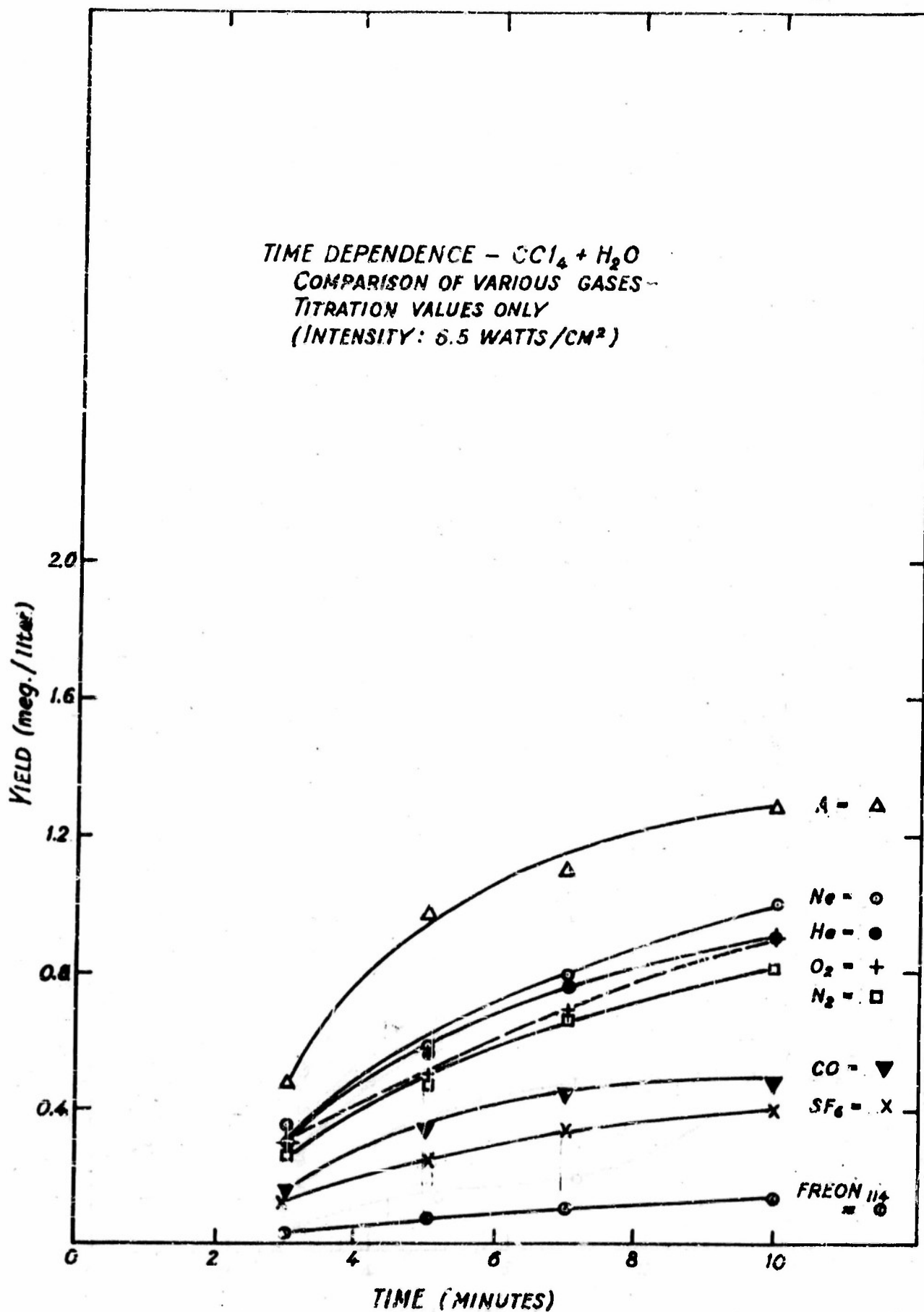


Figure 3

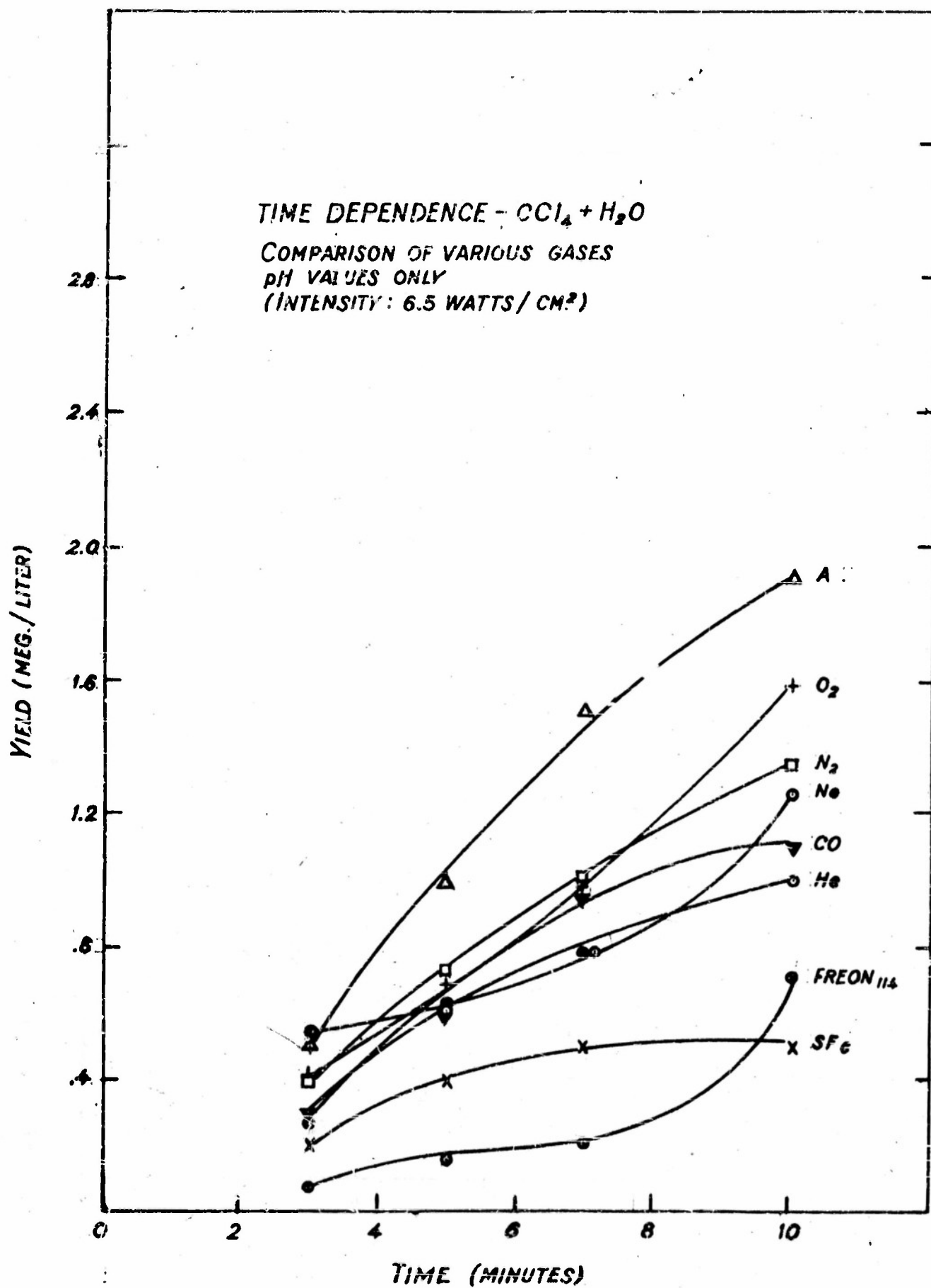


Figure 4

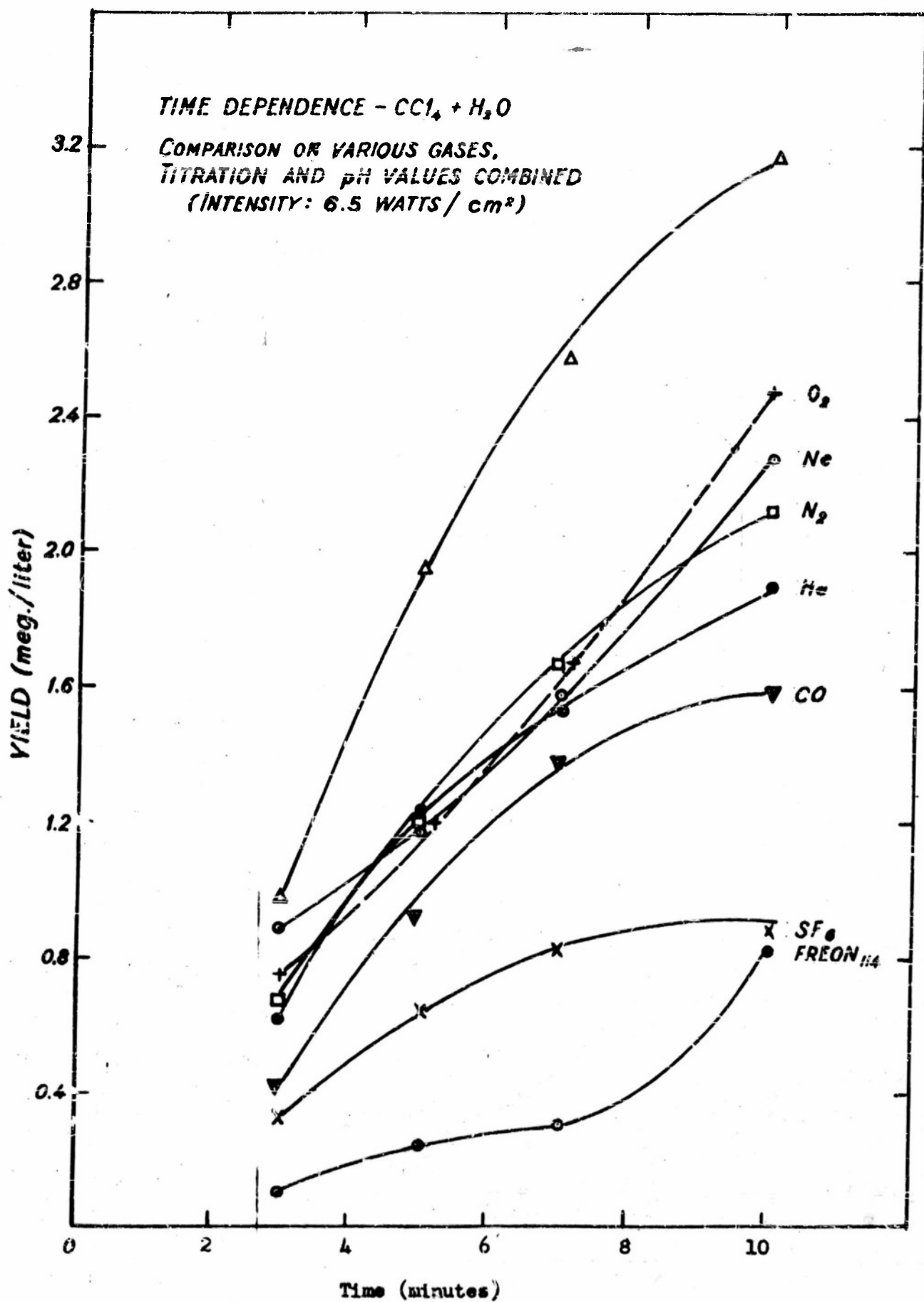


Fig. 5

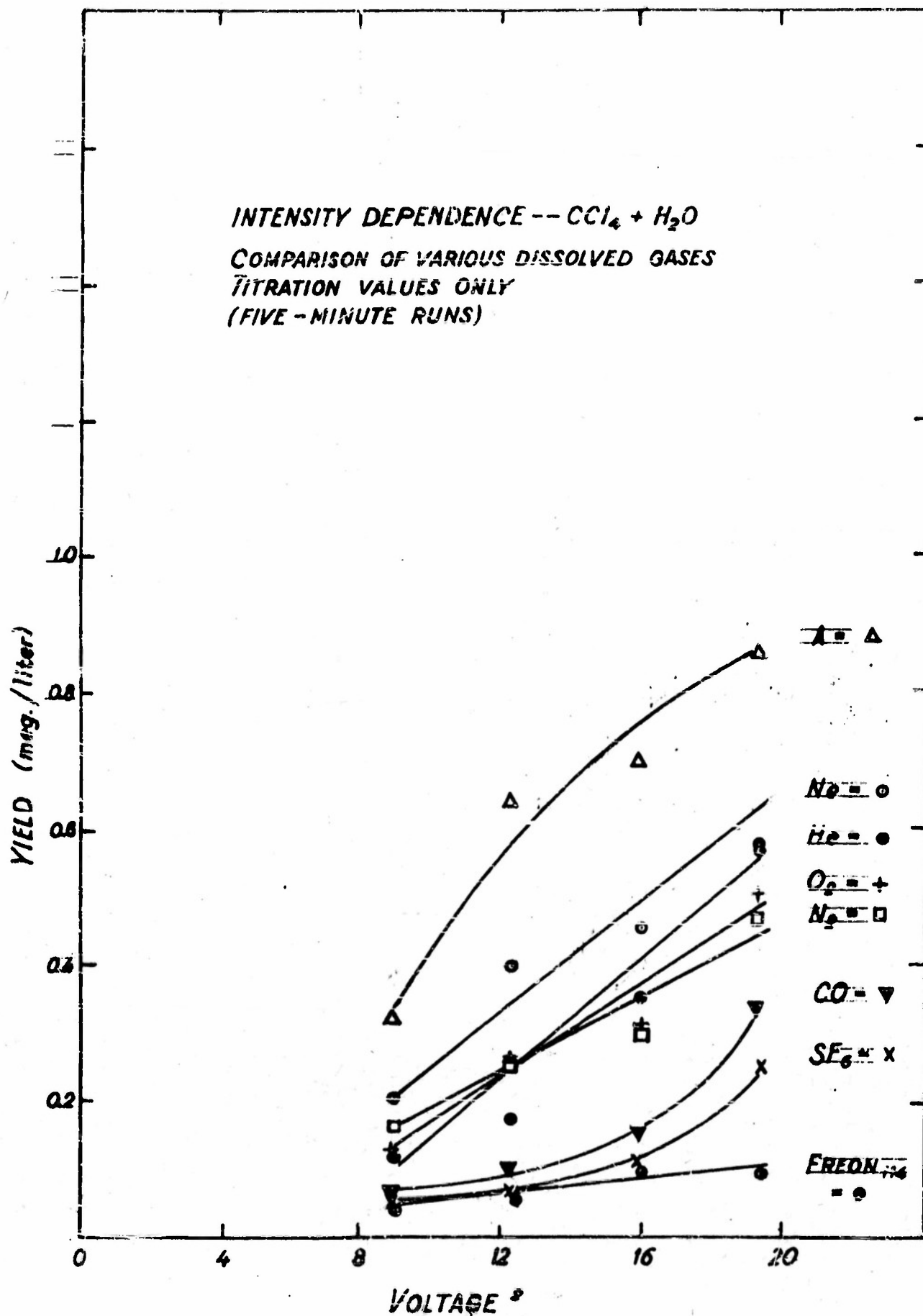


Figure 6

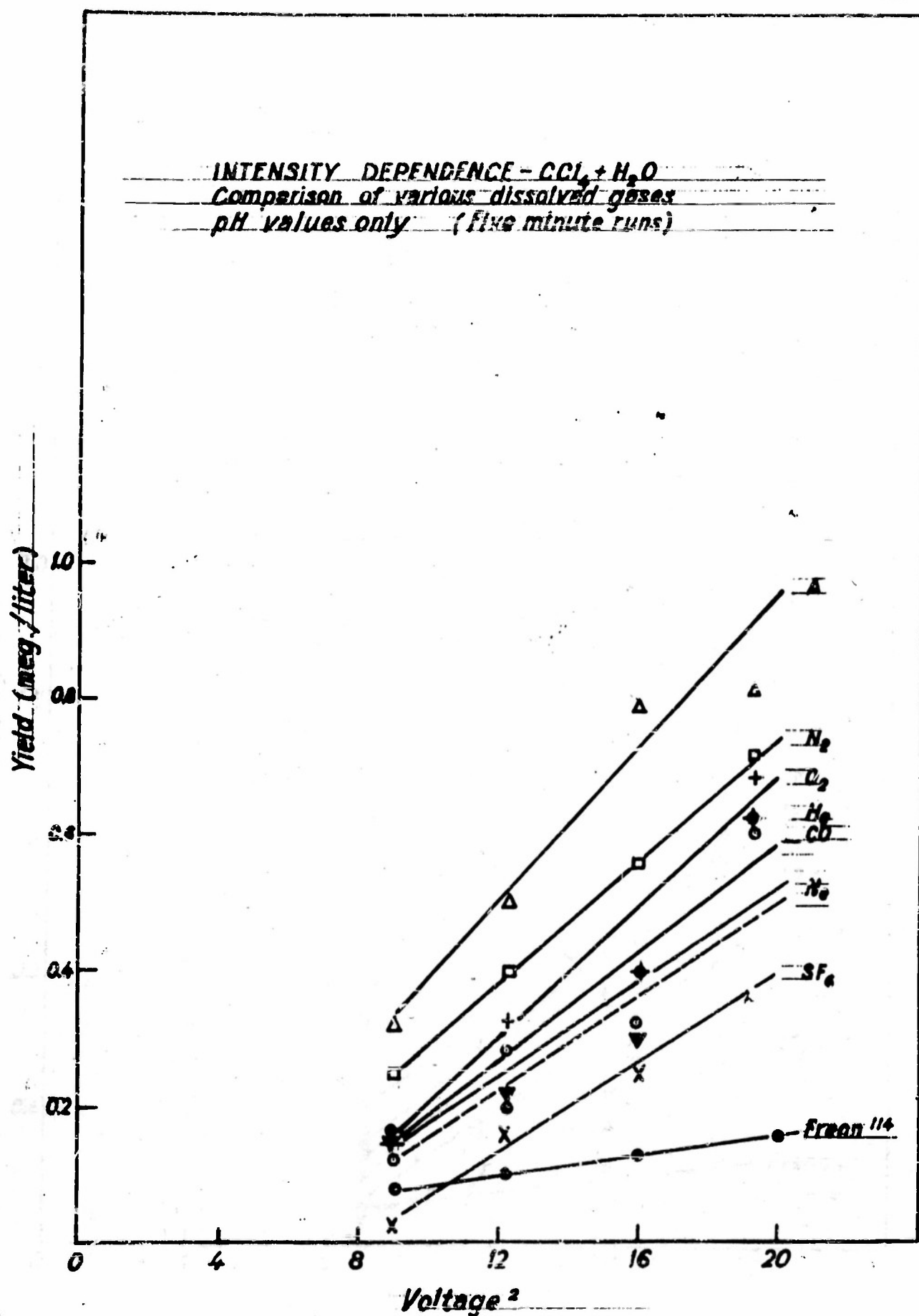


Figure 7

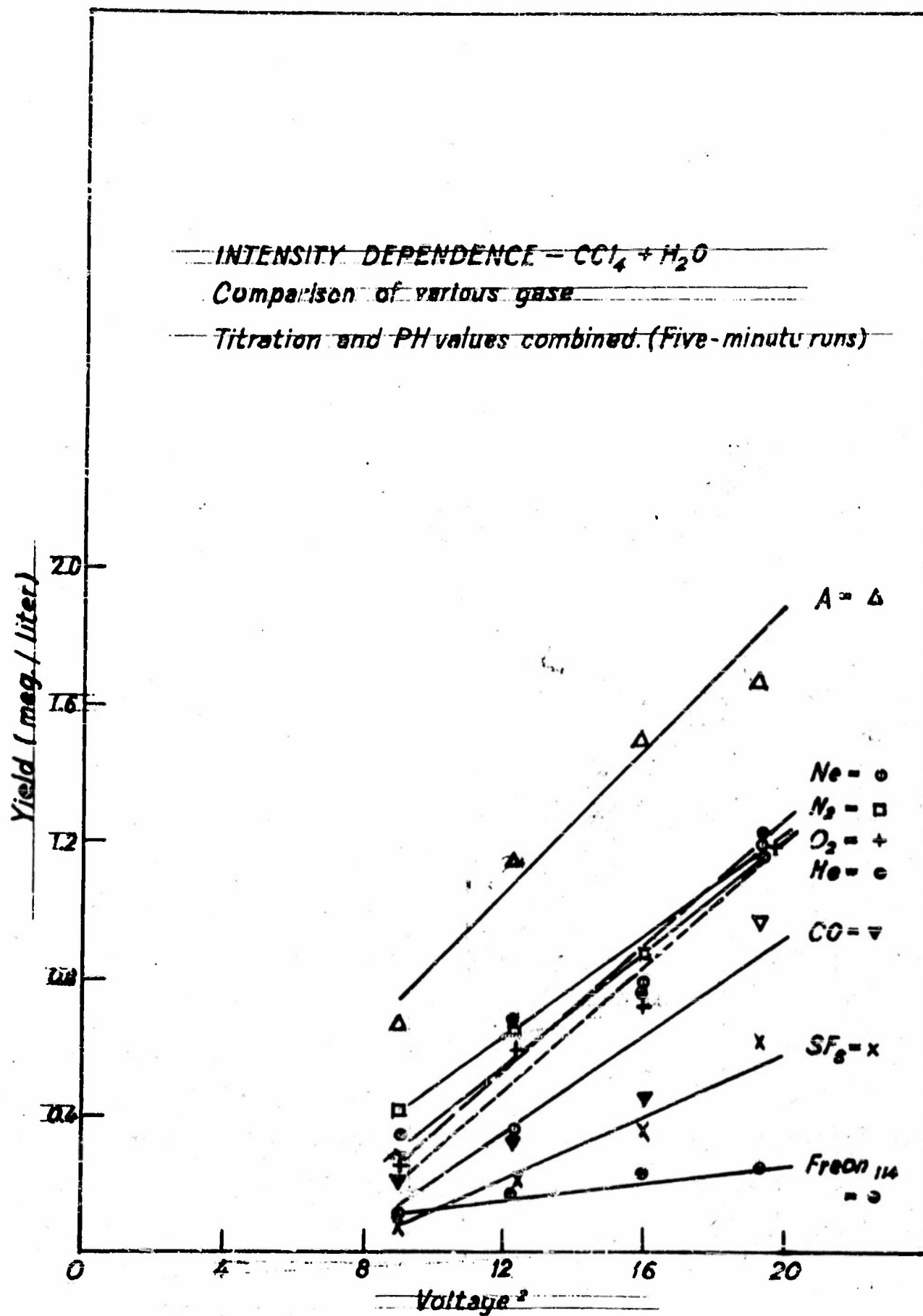


Figure 8

Threshold of Cavitation in Water
Saturated with Pure Gases and Gaseous Mixtures

by

Virginia Griffing and Daniel Sette

Experimental Procedure

The experimental setup for the determination of the cavitation threshold in water having various gases dissolved in it is indicated in Figure 1. The sound source is located at one end of a tank filled with water ($25 \times 25 \times 35 \text{ cm}^3$). Two opposite walls of the tank are glass plates to allow a light beam to pass in a direction normal to the sound beam. Light from a 100 watt projector bulb is concentrated by an optical system in the region of the sound field to be investigated. With such an arrangement very small cavities can be seen at the onset of cavitation.

A cell containing the liquid to be studied is put inside the tank near to the sound source in such a position as to allow sound radiation to enter freely. The walls of this cell are made of glass except for the one near the input of the sound beam. This wall is a thin sheet (.04mm thickness) of cellophane whose sound transparency is 99 percent. Two tubes with stopcocks are used for filling the cell. The procedure used for this operation is as follows. The cell is first filled with water which has been doubly distilled. Next the water is pushed out using the same compressed gas which is dissolved in the liquid to be investigated. Finally the liquid solution is forced into the cell by external pressure of the same gas from the container in which it was prepared.

The preparation of the mixtures was made following the method described by Fitzgerald . Doubly-distilled water is boiled for 30 minutes in a glass bulb to free most of the dissolved gases. At the end of such period the bulb is isolated from the atmosphere by closing a stopcock and it is then cooled down to room temperature. The gas to be dissolved is now introduced into the bulb and the system is left at nearly atmospheric pressure for about 15 hours in order to attain equilibrium before starting the measurements. The transducer used was a barium titanate plate resonating at 1.1 mc/sec. To determine the sound intensity in the field a calibration was made using a radiation pressure method. In this way it was possible to determine the proportionality constant between the sound intensity and the square of the voltage applied to the barium titanate plate. During this calibration the cell was removed so that the sound propagation took place exclusively in the water contained in the tank. The characteristics of the cell are such that while the sound energy losses at the entrance of the cell can be neglected, the reflections from the curved glass surface at the other end contribute somewhat to the shape of the sound field inside the cell. Since we were interested mainly in comparing results obtained under the same experimental conditions and because the observation for the onset of cavitation was always made in the region of the cell near the sound entrance wall where the influence of the reflected waves is small, we have taken as cavitation threshold the intensity of sound waves measured in water at the same distance from the source as the region of the cell where cavitation was observed and for the same voltage at the electromechanical transducer. The procedure

used for determining cavitation threshold was as follows: the voltage was applied to the transducer for intervals of 15 seconds, allowing 30 seconds rest in between. Each time the voltage was increased a few per cent above the preceding. As soon as small bubbles started to form the voltage was turned off and three minutes of rest allowed before starting another run on the same specimen.

The precaution of not letting cavitation go for an appreciable time proved to be important in order to obtain better agreement with the results for different runs on the same specimen and on other specimens. This fact is clearly shown by Table I. It refers to four specimens of distilled water saturated with a mixture N_2 - O_2 having 75 percent N_2 . The measurements on the first specimen were made allowing cavitation to proceed for about 1 minute at the end of each run. The measurements on the other specimens were made without letting the cavitation continue. The reason of this behavior is seen in the fact that the threshold of cavitation depends, in addition to other factors, on the amount of gas dissolved in the liquid and this quantity obviously changes as cavitation draws gas out of the liquid. This effect is more easily detectable when the quantity of liquid irradiated is small as it was in our case (about 80 cc).

The temperature at which the measurements were performed was $21 \pm 0.5^\circ C$.

Results

Table II gives the values of cavitation threshold found in a series of solutions of pure gases in distilled water. The gases considered are oxygen, nitrogen, argon, carbon monoxide and sulphur hexafluoride.

The Table III gives the results obtained in distilled water saturated with different mixtures of N_2-O_2 and $A-O_2$.

Both pure gases and gaseous mixtures were obtained from the Matheson Co.

Table I

Effect of Degassing the Liquid on the Cavitation Threshold
Distilled Water Saturated with a Mixture 75% N_2 -25% O_2

<u>Specimen</u>	<u>Run</u>	<u>Voltage at the Source for Cavitation Onset</u>
1	1	50
	2	54
	3	56
	4	58
	5	60
	6	59
	7	60
2	1	50
	2	50
	3	52
	4	50
	5	51
	6	52
	7	54
3	1	51
	2	52
	3	52
	4	52
4	1	51
	2	51
	3	52
	4	51

Table II

Bidistilled Water Saturated with Various Gases

Gas	Cav. Thres. (W/cm ²)
SF ₆	1.40
A	1.16
O ₂	.96
CO	.78
N ₂	.65

Table III

Bidistilled Water Saturated with Gaseous Mixtures

A) O₂-N₂

N ₂ %	Cav. Thres. (W/cm ²)
0	.96
5	.88
15	.86
25	.89
50	.75
75	.61
100	.65

B) O₂-Ar

Ar%	Cav. Thres. (W/cm ²)
0	.96
25	.96
50	.78
75	.57
85	.71
95	1.03
100	1.16

Experiments are under way in the physics department which will determine the threshold of cavitation in various organic liquids. Only preliminary experiments are now completed, however, the threshold seems to be somewhat higher than in water.

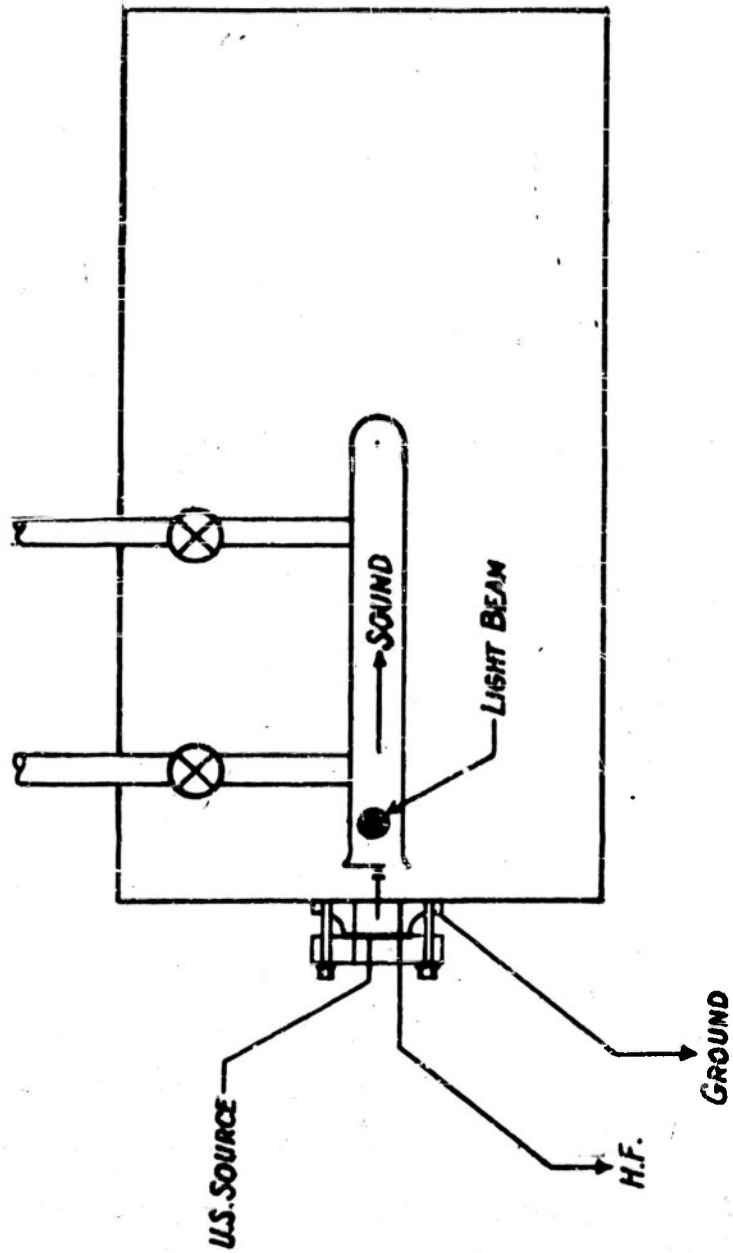


Figure 1

On the Origin of Cavitation in Liquids

by

F.E. Fox, Virginia Griffing and Daniel Sette

As is well known cavitation by intense ultrasonic waves in a liquid in which gases are dissolved starts at values of acoustic pressure well below the pressure needed for tearing apart the liquid. At present it is assumed that this effect is due to the presence of small solid or gaseous nuclei around which the gaseous bubbles can grow during acoustic irradiation.

A difficulty arises for assuming the existence of gaseous nuclei due to the fact that if the sizes of the nuclei are very small, as must be the case, it is not clear how they can remain in equilibrium under surface tension and external and internal pressures. To avoid this difficulty it has been suggested that a skin of organic greasy materials envelopes the gas nuclei. Some experiments, which are here reported, seem to show that this skin hypothesis is not satisfactory.

The first experiment shows that cavitation occurs in carbon tetrachloride and benzene always at sound pressures far from those needed for tearing apart the liquids. These two liquids are usually considered efficient solvents for organic materials such as those which are supposed to constitute the skins.

A second experiment has been performed in order to see if cavitation can occur in a liquid which has gases dissolved in it but is free of solid nuclei and of possible skins for gaseous nuclei.

The figure shows the glass apparatus used. It is formed by three glass bulbs. The bulb A contains spectroscopic Argon produced by the Linde Co. It is sealed inside the tubing connecting it to the rest of the apparatus. The fragile glass sealing can be easily broken by a metallic ball of magnetic material which is normally located in the seat B and can be moved by using a magnet outside of the apparatus. The one liter glass bulb C is a reservoir of water; the bulb D is the cell where ultrasonic waves are propagated in the liquid to be tested. Part of the glass walls of bulb D has been reduced to a very small thickness ($\sim 0.3\text{mm}$) in order to decrease the losses of sound energy entering the cell. The sound source was a quartz crystal having a resonance frequency of 670 kc/sec. Water was used as an intermediary medium between the quartz crystal and the bulb D.

Doubly-distilled water was introduced into the bulb C through the pipe E. By reducing the pressure in the apparatus to the water vapor pressure at room temperature the water was boiled for 30 minutes to free it of dissolved gases. Then the tubing E was sealed under vacuum.

If under these conditions some water is allowed to go from bulb C to bulb D and ultrasonic waves are sent into the latter no cavitation can be detected with a sound intensity of about 3 watt/cm² notwithstanding the fact that a light beam sent through the bulb D shows that some small solid particles are suspended in the liquid.

Following this test all the water was transferred into bulb C and low velocity distillation of water into bulb D and in the various tubings was effected by maintaining a small temperature difference between C and the rest of the apparatus. This operation, repeated many times,

succeeded in removing all the solid particles from the bulb D and the tubing connection which could act as nuclei in the cavitation process. At the end of the repeated distillation there remained in bulb D a water sample in which no suspended particles could be seen by scattered light while the bluish color characteristic of molecular scattering was observed by passing a light beam through the liquid.

In bulb D then we had a sample of water free of solid nuclei and without an appreciable amount of dissolved gases. The aim of the research was to see if adding a very clean gas to the water was sufficient to produce cavitation by a sound field. For this reason the seal of the Argon container was broken with the metallic ball. At the time the seal was covered with about 2 cm of distilled water in the glass tubing connecting bulb B to the rest of the apparatus.

After breaking the seal no cavitation was observed for about 25 minutes using a sound intensity of about 3 watt/cm^2 . During this period some small solid particles suspended in the water were observed. It is believed that they were small glass fragments which were produced when the Argon sealing was broken. It could be that some of them were not stopped by the water distilled on top of the sealing because of the violence of the efflux of the gas from bulb B. After 25 minutes cavitation appeared in very vigorous way.

The presence of some solid glass dust particles in the liquid before the cavitation started does not allow us to draw a positive conclusion on the experiment, but the vigor with which the cavitation was suddenly established cannot be explained by the presence of few solid particles. If this were the case the experiment would have to be interpreted

in the sense that cavitation can appear also if there are no preexistent nuclei. Then it would be necessary to consider a different process for the beginning of formation of bubbles in a liquid under sound radiation.

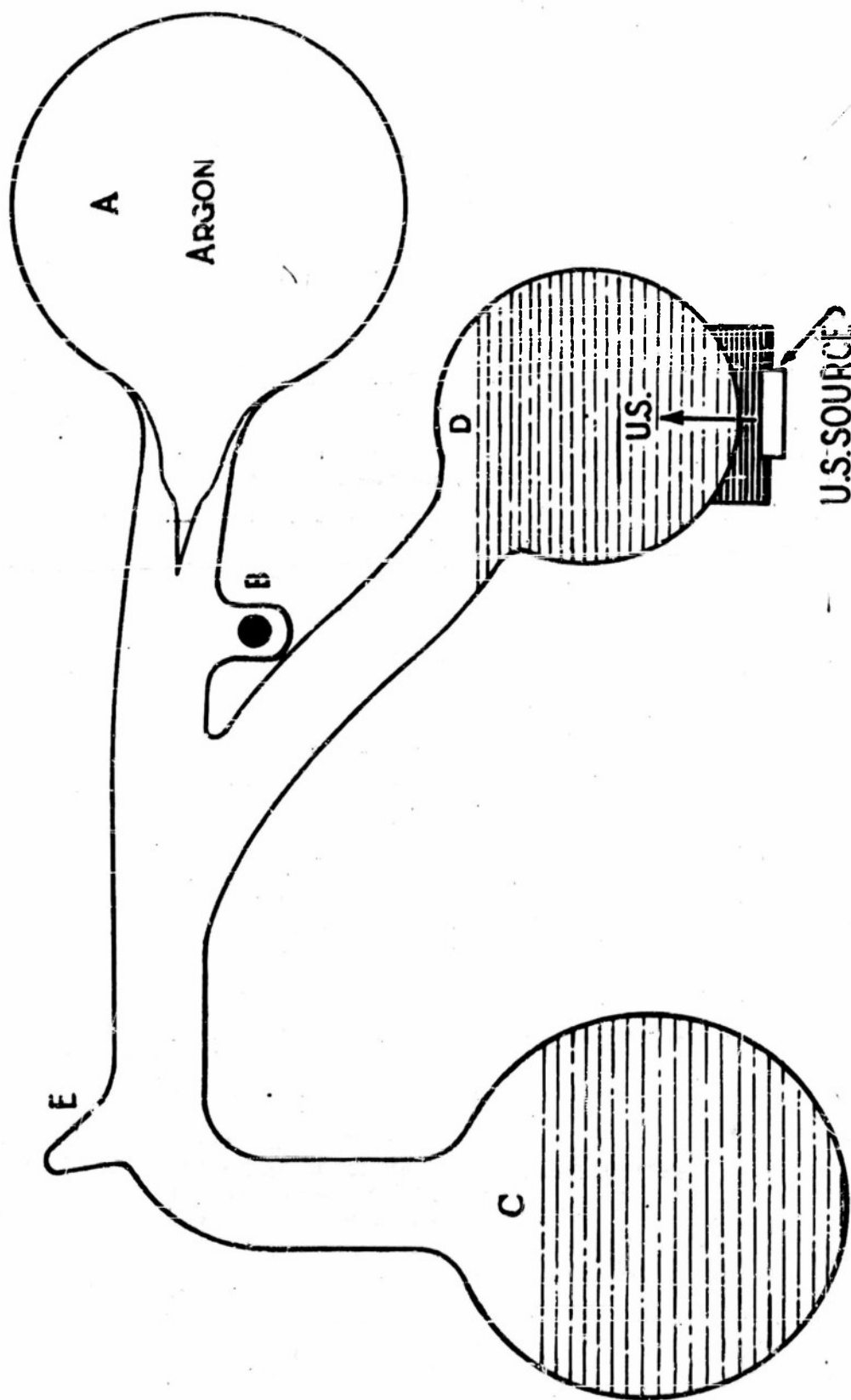


Figure 1

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