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on
Fire-Extinguishing Agents
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Purdue University
July, 1950

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Final Report

on

FIRE EXTINGUISHING AGENTS

for the period

September 1, 1947 to June 30, 1950

covering research conducted by

Purdue Research Foundation and Department of Chemistry

Purdue University

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Final Summary Report

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on

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Purdue Research Foundation and Department of Chemistry
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FIRE EXTINGUISHING AGENTS

Abstract

Negotiations between the Army Engineers Research and Development Laboratories resulted in Contract No. W44-009 eng - 507 for conducting studies, research and investigations leading to the development of a fire extinguishing agent with fire fighting characteristics equal to or superior to methyl bromide. Although fluorine containing compounds were of a great deal of interest to this project, the investigation was not limited to a study of the applicability these compounds as fire extinguishing agents.

A literature search revealed that no systematic study had been made of compounds to be used as fire extinguishing agents. In general, a proposed compound was tested by putting out fires under specified conditions. Such a test method was obviously not suited for rating research samples of a few grams of material.

A laboratory screening test of compounds for their fire inhibiting properties was set up by determining the limits of flammability of mixtures of fuel, (n-heptane) air, and the proposed extinguishing agent. The peak in the curve obtained by plotting data concerning the flammability of mixtures was considered as a measure of the flame extinction properties of the test compound. This hypothesis was later shown to be valid by tests conducted at Fort Belvoir. Dibromodifluoromethane heads the list of the thirty-one compounds found to be more effective than methyl bromide on the basis of this test. When the comparisons were made on a weight basis instead of a volume basis only eight compounds were found to be more effective than methyl bromide.

It was found that in a given homologous series of compounds, the effectiveness in fire extinction properties increases with an increase in molecular weight. No apparent relationship could be found between the fire extinction properties and molecular weight of compounds chosen at random.

As part of a program of determining the effectiveness of elemental composition of a compound in decreasing the flammability of mixtures of air and *n*-heptane, several non-carbon compounds were studied. Halides of silicon, sulfur, and boron have flame inhibition properties which are greater than those for the corresponding carbon halides. The properties of these non-carbon halides rule them out as suitable fire extinguishing agents. Subsequent research should include a study of methods leading to the preparation of organic polyhalides containing sulfur, silicon and boron as an additional element.

The effect of a halogen substituent upon the fire extinction properties of carbon compounds was studied in some detail. The order of increasing effectiveness is $F < Cl < Br < I$. There are, however, some anomalies to this generalization which cannot be satisfactorily explained. For example, the alkyl iodides are more effective flame inhibiting agents than the corresponding alkyl bromides, but the perfluoroalkyl iodides may or may not be as effective as the corresponding perfluoroalkyl bromides.

The replacement of a bromine atom for a fluorine atom in carbon tetrafluoride greatly increases the effectiveness of the resulting compound, bromotrifluoromethane, in decreasing the flammability of mixtures containing air and *n*-heptane. Subsequent replacements of bromine for fluorine results in the formation of compounds which are more effective as fire extinguishing agents, however, this increase in effectiveness is not a linear relationship.

Unsaturated compounds were found, in general, to be ineffective in decreasing the flammability of mixtures of air and *n*-heptane. Tetrafluoroethylene was found to burn in air. 2,2-Difluorovinyl bromide was found to be as effective as methyl bromide. The (perfluoroalkyl)benzenes, such as benzotrifluoride were found to be flammable in air.

The effect of temperature upon the coordinates of the peak in the flammability curves was determined at -78°C ., $+26^{\circ}\text{C}$., and $+145^{\circ}\text{C}$.. The order of effectiveness, based upon the volume per cent of the halogen compound in the mixture, is the same at the three temperatures. The flammable areas obtained at -78°C . were found to be quite irregular. It was also found that as the temperature increases, the peak in the flammability curve also increases.

The standard fuel used for rating the various fire retarding agents with respect to one another was *n*-heptane. When the standard fuel, *n*-heptane, was replaced by a different fuel a qualitative parallel relationship exists between the fire retarding agents. Other fuels investigated included diethyl ether, pentane, benzene acetone, ethyl acetate, and methanol.

The possibility of using a mixture of compounds as a fire extinguishing agent was also investigated. Several binary mixtures of

halogen compounds were used as fire retarding agents on mixtures of n-pentane and air. This preliminary study indicated that in certain instances the use of a mixture of halogen-containing compounds is advantageous. The actual effectiveness appeared to be characteristic of the particular mixture used. Hence no generalizations could be made regarding choice of constituents in the mixture.

As a continuation of a study of the effect of variables on the flammable limits of mixtures containing air, n-heptane, and a halogen compound, the flammable areas at subatmospheric pressures of 200, 300, 400, and 500 mm. Hg were determined. For mixtures containing methyl bromide as the flame inhibiting agent, not only is the flammability peak lowered with a decrease or increase in pressure from 400 mm. Hg but in general the flammable area lies within the area found at 400 Hg pressure. When trifluoromethyl bromide was used as the flame inhibiting agent the peak in the flammability curve was essentially the same at 300, 400, and 500 mm. Hg pressure and lower at 200 mm. Hg pressure. In the case of dichlorodifluoromethane, the peaks are equivalent at 300 and 400 mm. Hg pressure and lower at 200 and 500 mm. Hg pressure. These examples are too few to warrant drawing any conclusions concerning the effect of pressure on the flammable areas.

An accelerated stability test of various halogen compounds to iron, copper, aluminum, brass and magnesium was performed. Tests were conducted at reflux temperatures at 200°F. (93.3°C.) and at 392°F. (200°C.) under anhydrous and aqueous conditions. Small strips of the test metal were noted for corrosion and loss in weight. Data show that halogen compounds are less stable toward aluminum than to either brass, copper, iron or magnesium. There appears to be no significant difference between the stability of these compounds to brass and to copper. The compounds are most stable to iron. The fluorocarbons are the most stable and the monohaloalkanes the least stable.

Restivity measurements show that for practical purposes fluorocarbons are non-conductors of electricity and hence would be suitable for use in combating electrical fires.

A knowledge of the behavior of halogen compounds under conditions favoring decomposition is of interest in the interpretation of data relating to the toxicological properties and corrosive action. Accordingly, several halogen-containing compounds were introduced into a flame resulting from the combustion of propane in air and the products of decomposition studied. A special burner was designed so that the materials introduced and products formed could be quantitatively measured. The halogen compound was injected to the flame in either of two ways. The halogen compound was first premixed with the propane stream before burning or the air stream before burning. Considerable soot was formed except when carbon tetrafluoride and sulfur hexafluoride were used. Then only trace amounts were noted. The amount of soot obtained was always a little less than the amount of carbon present in the halogen compound introduced. This suggests that soot formation arises

ethane are about equivalent in effectiveness.

Unsaturated compounds were found, in general, to be ineffective in decreasing the flammability of mixtures of air and *n*-heptane. However, 2,2-difluorovinyl bromide ($\text{CF}_2 = \text{CHBr}$) was found to be unexpectedly effective. The peak in the flammability curve was 9.7%.

Tetrafluoroethylene was found to be flammable in air. The lower limit of flammability lies between 16.0 and 16.3% and the upper limit between 43.0 and 44.0%. These limits are for the upward propagation of flames. The flames resulting from combustion of mixtures whose compositions were in the region of the lower limit were pale blue in color and no smoke was present. The flames resulting by burning mixtures of tetrafluoroethylene and air having a composition in the region of the upper limit of flammability were red and much soot was formed.

Mixtures of *n*-heptane, air and nitrogen trifluoride were found to be explosive when ignited. The violence of the combustion reaction was increased as the percentage of nitrogen trifluoride was increased to 70% where further testing was stopped. These results were unexpected since nitrogen trifluoride is a stable compound and relatively inert. As a result of these tests it was concluded that nitrogen trifluoride was of no further interest as a fire extinguishing material.

The (perfluoroalkyl)benzenes, benzotrifluoride, bis(trifluoromethyl)benzenes and 1-(pentafluoroethyl)-4-(trifluoromethyl)benzenes, were eliminated from further consideration when they were found to be flammable. The ring halogenated derivatives of these compounds were not studied because of their low vapor pressure.

Weight Effectiveness vs. Molar Effectiveness. The method used for the determination of the flame extinction properties of halogen-containing compounds is based upon the volume percentage of the agent in a mixture of vapors. While this procedure provides a convenient means for evaluating the compounds and correlating the results, the weight effectiveness becomes significant from an economic viewpoint since these materials are usually sold on the weight basis. It is also important to consider the weight of material required for fire protection. In general, this point is more significant in cases where aircraft is concerned than in other cases.

A comparison is made in Table II between the weight effectiveness of a halogen compound as a fire extinguishing agent and the volume effectiveness of these same compounds. The following equation was used in calculating the weight of halogen compound equivalent to the volume percentage of the halogen compound at the peak in the flammability curve. Grams of Extinguisher = $\frac{100 \text{ liters}}{22.4 \text{ liters}}$ x Mol. Wt. of Extinguisher x Vol.% Extinguisher at Peak. The calculations are based on 100 liters of gaseous mixture at 0°C. and one atmosphere of pressure. It will be noticed that some compounds which have a low flammability peak are found to be less effective on a weight basis than others with a high flammability peak and vice versa. It is interesting to note that on the volume basis, thirty-one of the compounds tested are better than methyl bromide; whereas, on a weight basis, only eight compounds are more effective than methyl bromide.

Table II

SUMMARY OF COMPOUNDS EVALUATED AS FIRE EXTINGUISHING AGENTS
(Room Temperature)

<u>Compound</u>		<u>Peak in Flammability Curve, %</u>	<u>Extinguisher, g.*</u>	<u>Order of Effective- ness</u>	
<u>Formula</u>	<u>Name</u>			<u>Vol. Wt. basis</u>	<u>Wt. basis</u>
CBr_2F_2	Dibromodifluoromethane	4.2	39.37	1	6
CBr_3F	Tribromofluoromethane	4.3	51.96	2	17
$\text{CF}_3\text{CHBrCH}_3$	2-Bromo-1,1,1-trifluoro- propane	4.9	38.71	3	4
$\text{CBrF}_2\text{CBrF}_2$	1,2-Dibromotetrafluoro- ethane	4.9	56.87	4	22
$\text{CF}_2\text{ICF}_2\text{I}$	Tetrafluoro-1,2-diiodo- ethane	5.0	79.01	5	37
CH_2Br_2	Dibromomethane	5.2	40.39	6	7
$\text{CF}_3\text{CF}_2\text{I}$	Pentafluoriodoethane	5.3	58.19	7	26
$\text{CF}_3\text{CH}_2\text{CH}_2\text{Br}$	3-Bromo-1,1,1-trifluoro- propane	5.4	42.67	8	11
$\text{CH}_3\text{CH}_2\text{I}$	Ethyl iodide	5.6	39.00	9	5
$\text{CF}_3\text{CF}_2\text{Br}$	Bromopentafluoroethane	6.1	54.16	10	18
CH_3I	Methyl iodide	6.1	38.67	11	3
CBrF_3	Bromotrifluoromethane	6.1	40.57	12	8
$\text{CH}_3\text{CH}_2\text{Br}$	Ethyl bromide	6.2	30.15	13	1
$\text{CH}_2\text{BrCF}_2\text{CH}_3$	1-Bromo-2,2-difluoro- propane	6.3	44.69	14	13
$\text{CClF}_2\text{CHBrCH}_3$	2-Bromo-1-chloro-1,1- difluoropropane	6.4	55.28	15	20
CHBr_2F	Dibromofluoromethane	6.4	54.85	16	19

* These values were obtained by calculations assuming 100 liters of gaseous mixture at 0°C. and one atmosphere of pressure.

Table II (Continued)

Compound		Peak in Flammability Curve, %	Extinguisher, g.*	Order of Effective- ness	
Formula	Name			Vol. basis	Wt. basis
$\text{CBrF}_2\text{CH}_2\text{Br}$	1,2-Dibromotetrafluoroethane	6.8	68.0	17	30
$\text{CF}_3\text{CH}_2\text{Br}$	2-Bromo-1,1,1-trifluoroethane	6.8	49.66	18	16
C_7F_{16}	Perfluoroheptane	7.5	129.91	26	49
$\text{C}_6\text{F}_{11}\text{C}_2\text{F}_5$	Perfluoro(ethylcyclohexane)	6.8	121.42	19	46
$1,3\text{-C}_6\text{F}_{10}(\text{CF}_3)_2$	Perfluoro(1,3-dimethylcyclohexane)	6.8	121.42	26	47
$1,4\text{-C}_6\text{F}_{10}(\text{CF}_3)_2$	Perfluoro(1,4-dimethylcyclohexane)	6.8	121.42	21	48
CF_3I	Trifluoriodomethane	6.8	59.5	22	27
$\text{CH}_2\text{BrCH}_2\text{Cl}$	1-Bromo-2-chloroethane	7.2	45.69	23	14
$\text{CClF}_2\text{CH}_2\text{Br}$	2-Bromo-1-chloro-1,1-difluoroethane	7.2	57.69	24	24
$\text{C}_6\text{F}_{11}\text{CF}_3$	Perfluoro(methylcyclohexane)	7.5	117.18	25	45
CH_2BrCl	Bromochloromethane	7.6	43.93	27	12
CHBrF_2	Bromodifluoromethane	8.4	49.12	28	15
$\text{CClF}_2\text{CCl}_2\text{F}$	1,1,2-trichlorotrifluoroethane	9.0	75.3	29	36
CBrClF_2	Bromochlorodifluoromethane	9.3	68.71	30	31
HBr	Hydrogen bromide	9.3	33.62	31	2
CH_3Br	Methyl bromide	9.7	41.13	32	9
$\text{CF}_2=\text{CHBr}$	2,2-Difluorovinyl bromide	9.7	61.92	33	28
$n\text{-C}_4\text{F}_{10}$	Perfluoro n-butane	9.8	104.12	34	44

* These values were obtained by calculations assuming 100 liters of gaseous mixture at 0°C. and one atmosphere of pressure.

Table II (Continued)

Compound		Peak in Flammability Curve, %	Extinguisher, g.*	Order of Effectiveness Vol. Wt.	
Formula	Name			basis	basis
SiCl ₄	Silicon tetrachloride	9.9	75.1	35	35
CBrF ₂ CBrClF	1,2-Dibromo-2-Chloro-1, 1,2-trifluoroethane	10.8	133.5	36	50
CClF ₂ CClF ₂	1,2-dichlorotetrafluoro- ethane	10.8	82.4	37	40
CCl ₄	Carbon tetrachloride	11.5	79.0	38	38
CF ₃ CHClCH ₃	2-chloro-1,1,1-tri- fluoropropane	12.0	70.99	39	33
CF ₃ CH ₂ CH ₂ Cl	3-chloro-1,1,1-tri- fluoropropane	12.2	72.16	40	34
CClF ₃	Chlorotrifluoromethane	12.3	57.38	41	23
CF ₃ CF ₃	Hexafluoroethane	13.4	82.55	42	41
CCl ₂ F ₂	Dichlorodifluoromethane	14.9	80.4	43	39
CHCl ₃	Chloroform	17.5	93.3	44	42
CHF ₃	Trifluoromethane	17.8	55.6	45	21
CHClF ₂	Chlorodifluoromethane	17.9	69.12	46	32
C ₄ F ₈	Octafluorocyclobutane	18.1	161.61	47	53
SF ₆	Sulfur hexafluoride	20.5	133.6	48	51
BF ₃	Boron Trifluoride	20.5	62.05	49	29
PCl ₃	Phosphorous trichloride	22.5	138	50	52
HCl	Hydrogen Chloride	25.5	41.55	51	10
CF ₄	Carbon tetrafluoride	26	102.1	52	43
CO ₂	Carbon dioxide	29.5	57.94	53	25

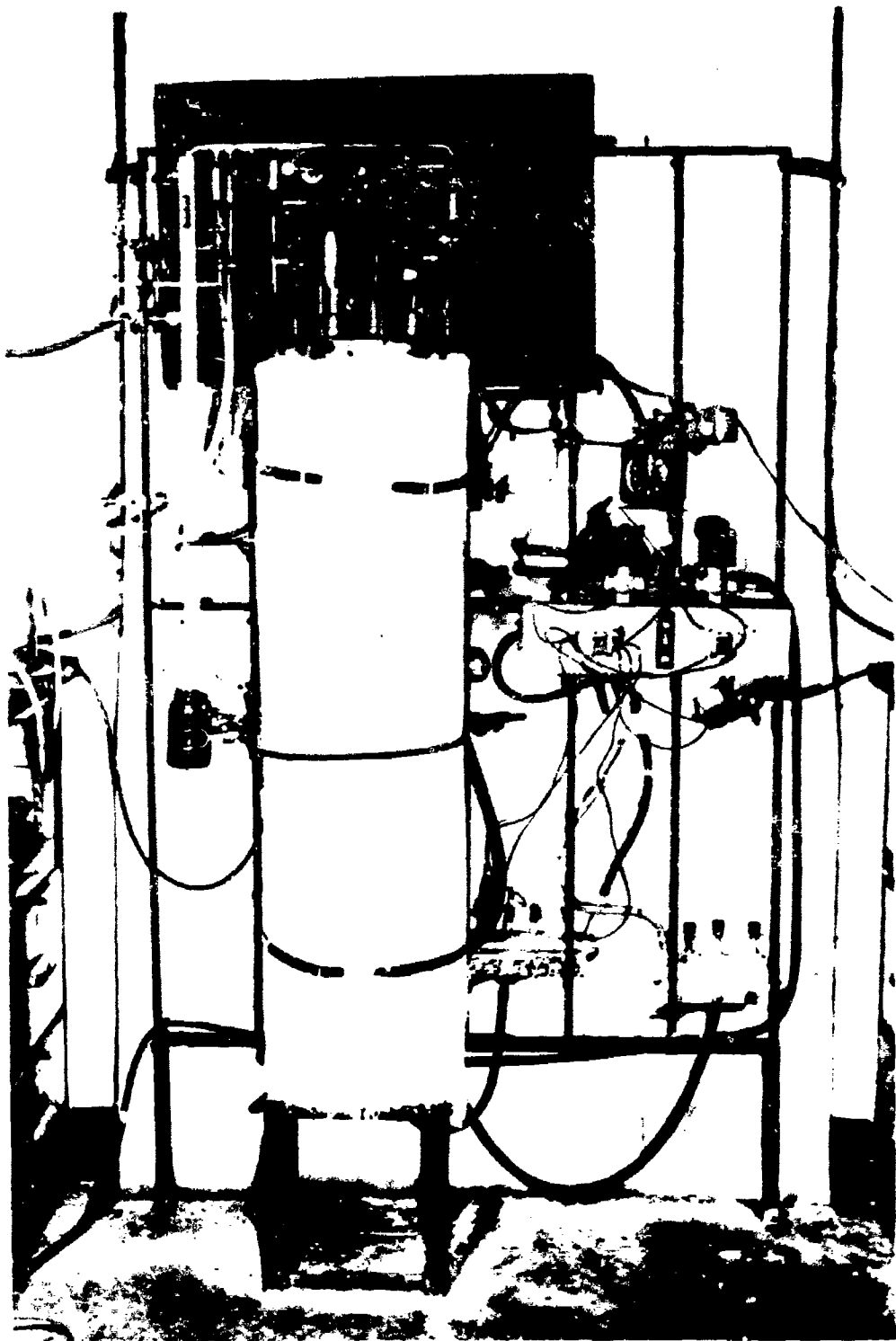
* These values were obtained by calculations assuming 100 liters of gaseous mixture at 0°C. and one atmosphere of pressure.

Effect of Temperature. The effect of temperature upon the coordinates of the peak in the flammability curves and the flammable areas was determined. Since it was desired that one of the temperatures be at least as low as -50°C . it was necessary to choose materials for this study which have a vapor pressure at -50°C . sufficiently high to obtain mixtures having the desired concentrations, as the test procedure is based upon the measurement of the flammability of a mixture of vapors. Methane was investigated first as the flammable material, but it was observed that the flame was not always luminous. Isobutane was found to be satisfactory in all respects as the flammable material. Methyl bromide, bromotrifluoromethane and chlorotrifluoromethane, sulfur hexafluoride and carbon tetrafluoride were chosen for use as the flame inhibitors.

The apparatus used was similar to the one previously described except that the combustion tubes were immersed in a constant temperature bath as shown by photograph in Plate I and by diagram in Figure 4. The Pyrex combustion tube (A) was 51 mm. inside diameter and 120 cm. long. The rubber stopper (B), held on by atmospheric pressure, sealed the upper end of A. The lower end of A was connected by means of 8 mm. Pyrex tubing (C) to the gas mixing system. The upper end of A was connected to the gas mixing system by means of E. The gas mixing system consisted of the mercury piston (G) and the one-way check valves (F). Thus, when the mercury rose and fell in G, the gas mixture in A was circulated and thoroughly blended into a homogeneous mixture. Relay (J) and solenoids (I_1 and I_2) controlled the pump action in G by regulating the flow of compressed air into the mercury reservoir (H). Tube A was connected to the manifold (L) through stopcocks (D and N_5). Manometer (M) was used to measure the pressure in A. A vacuum pump and sources for dry air, fuel, and halogen compound were connected to L through stopcocks (N_1 , N_2 , N_3 , and N_4 respectively). The electrodes (O) used for ignition, were made of number 29 gauge platinum wire and were connected to the high voltage terminals of a Model-T Ford induction coil (not shown). The constant temperature bath was constructed of one-sixteenth inch sheet copper and was lagged with 1.5 inches of magnesia (not shown). For elevated temperatures the bath was filled with oil which was heated by 250-watt nichrome wire immersion heaters (not shown). For low temperatures, the bath was filled with trichloroethylene and cooled with dry ice.

The apparatus was operated as follows: Tube A was evacuated by the vacuum pump by closing and opening appropriate stopcocks. Fuel, extinguisher, and dry air were introduced in order of increasing vapor pressure. The composition was calculated from the partial pressure of each component as noted on the manometer (M). Clamp (Q) was opened and the pump (G) was allowed to operate until thorough mixing had occurred. The mixing time was determined by several preliminary runs. After mixing, the mixture was fired and a positive result was recorded if the flame traveled the whole length of the tube A. Before the next run the system was flushed with air by opening stopcock K.

Coordinates for the peak in the flammability curves for mixtures of the halogen compounds with air and isobutane at -78°C ., $+26^{\circ}\text{C}$. (room temperature) and $+145^{\circ}\text{C}$. are summarized in Table III. The flammable areas at -78° , $+26^{\circ}$ and $+145^{\circ}\text{C}$. are shown in Figures 5-18 inclusive. The order of effectiveness, based upon the amount of halogen compound in the mixture, is the same at -78°C . as at $+26^{\circ}\text{C}$. The order is as follows.



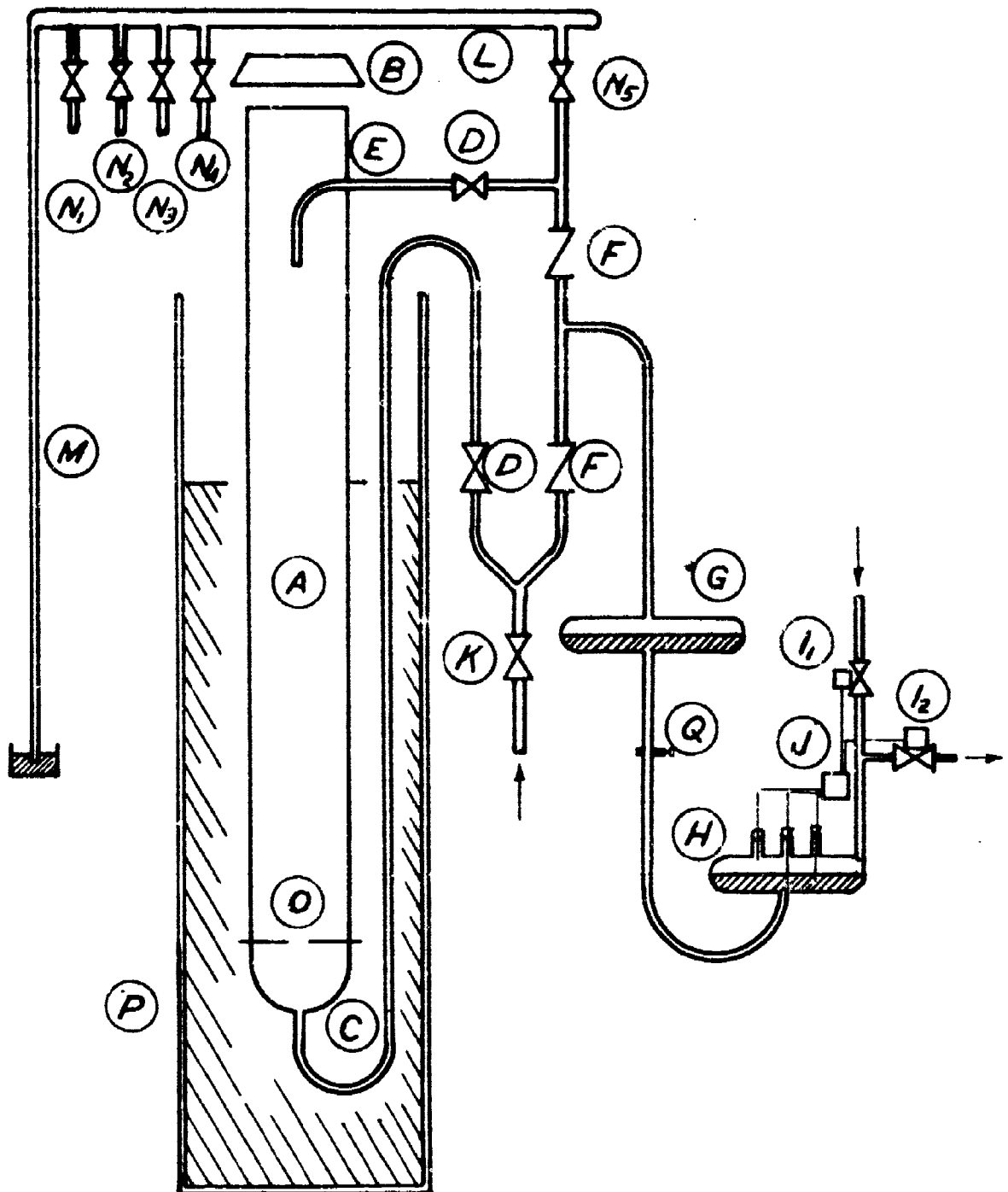


FIG. APPARATUS FOR THE DETERMINATION OF FLAMMABILITY LIMITS AT VARIOUS TEMPERATURES

Figure 4

Table III

EFFECT OF TEMPERATURE ON THE PEAK IN
THE FLAMMABILITY CURVES

Temperature, °C.	-78		+26		+145	
	Peak in flammability curve		Peak in flammability curve		Peak in flammability curve	
Halogen Compound	Halogen Compd. %	C ₄ H ₁₀ %	Halogen Compd. %	C ₄ H ₁₀ %	Halogen Compd. %	C ₄ H ₁₀ %
CBrF ₃	3.25	4.5	4.7	4.6	7.3	4.0
CH ₃ Br	3.75	3.5	6.75	4.0	8.3	4.0
CClF ₃	8.25	3.5	10.75	4.25	12.8	4.0
SF ₆	12.75	5.0	15.75	5.0	17	5.5
CF ₄	18.25	5.0	23.75	4.0	14	3.5

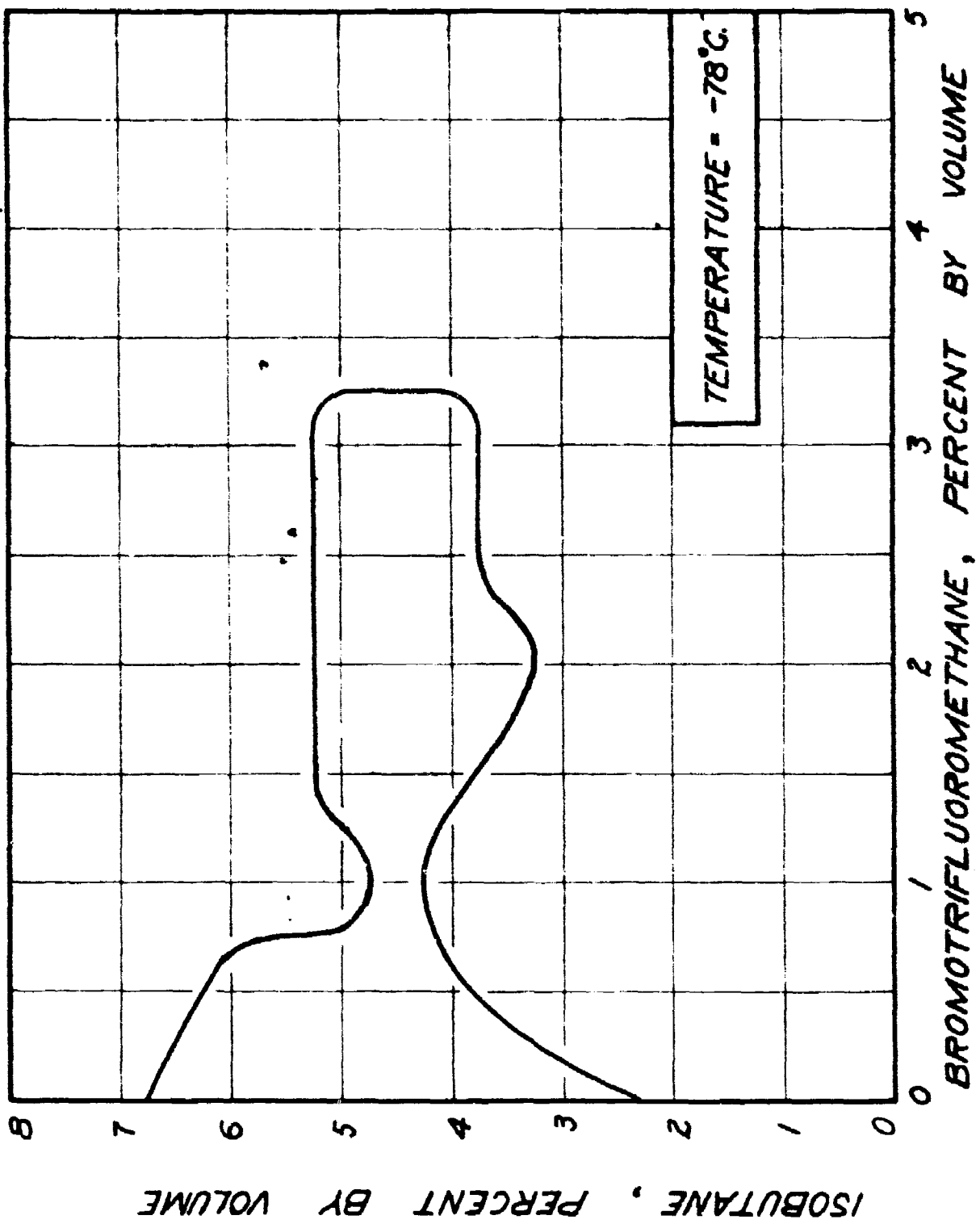


Figure 5 Effect of Temperature on Peak in the Flammability Curves

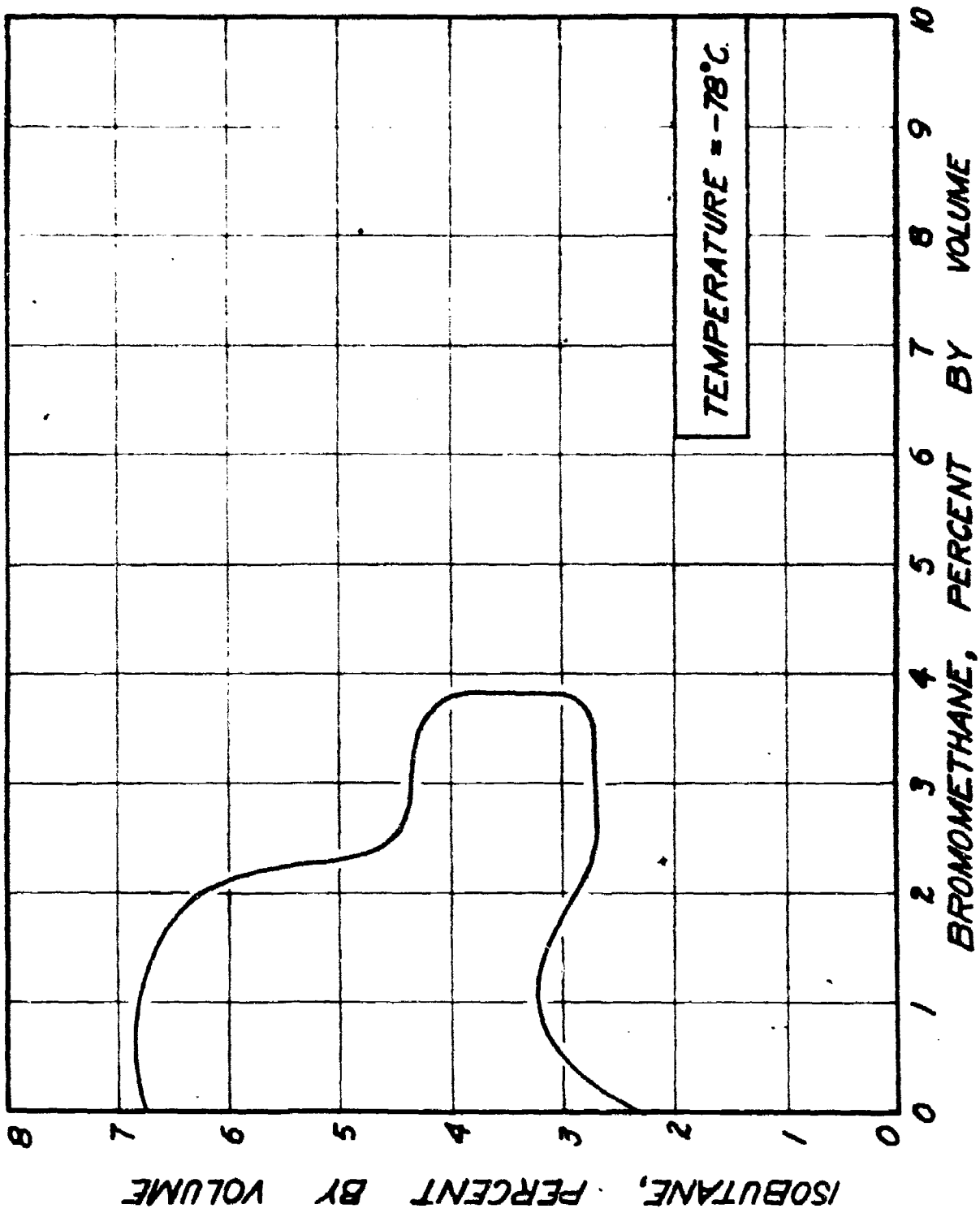


Figure 6 Effect of Temperature on Peak in the Flammability Curves

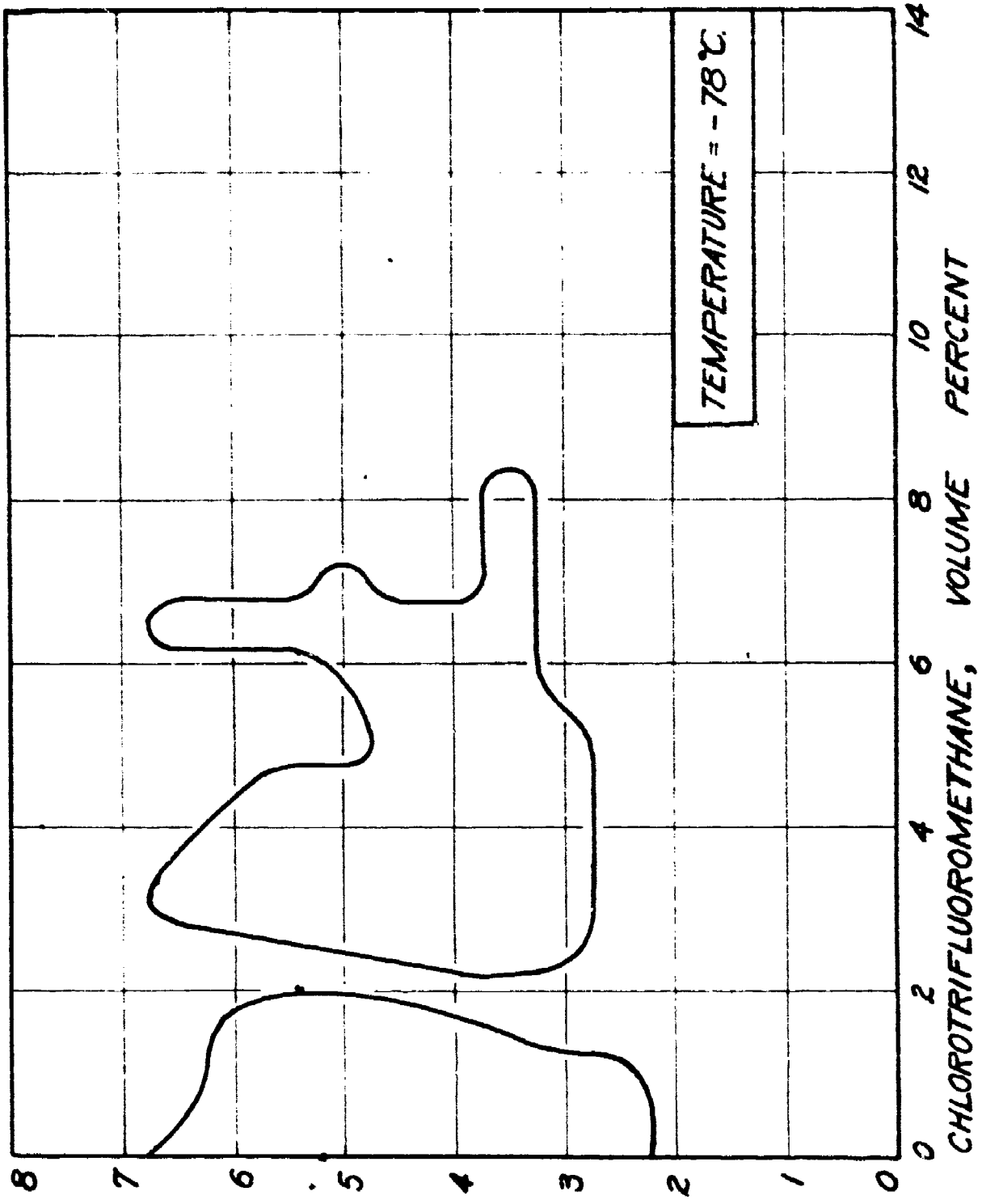


Figure 7 Effect of Temperature on Peak in the Flammability Curves

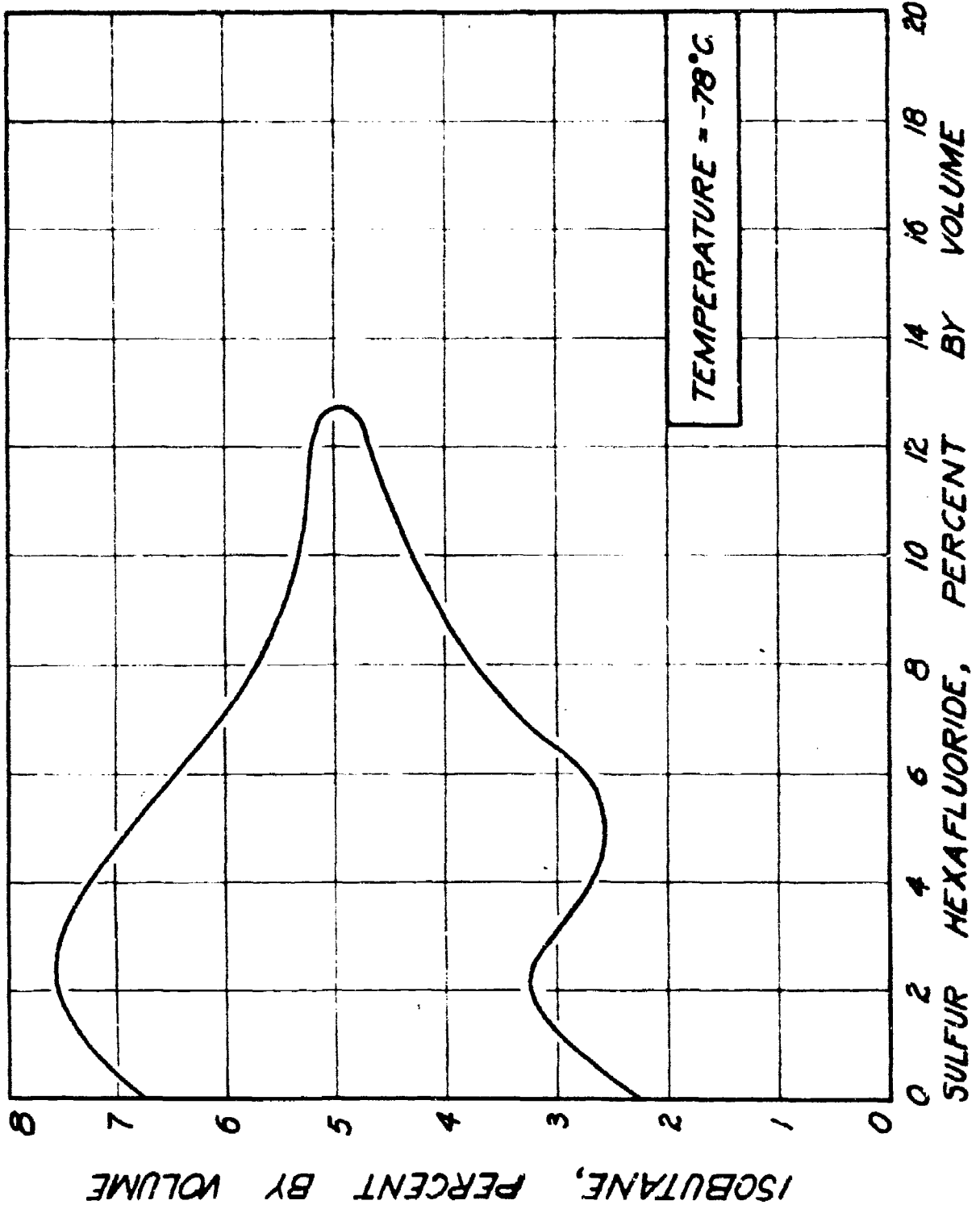


Figure 8 Effect of Temperature on Peak in the Flammability Curves

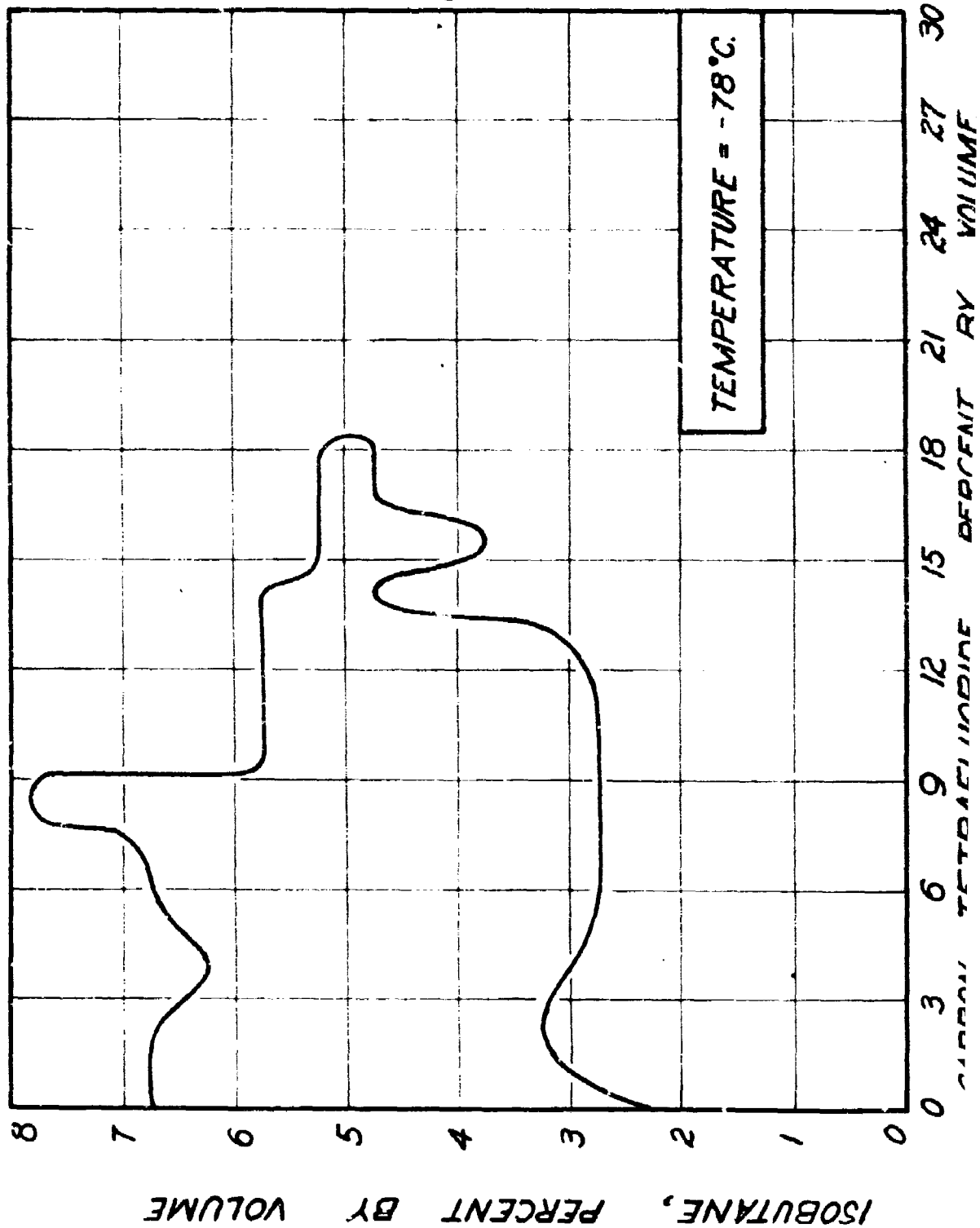


Figure 9 Effect of Temperature on Peak in the Flammability Curves

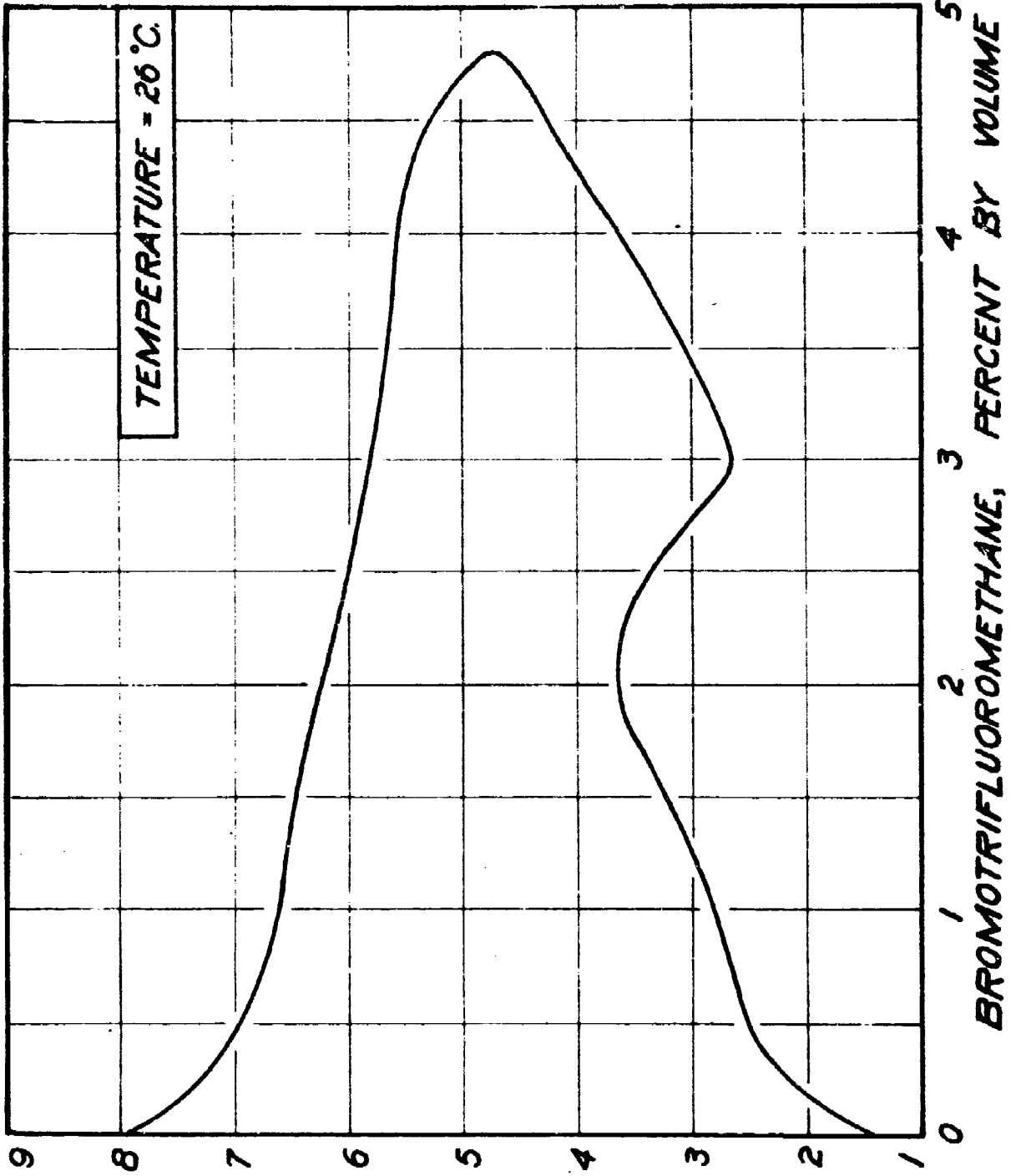
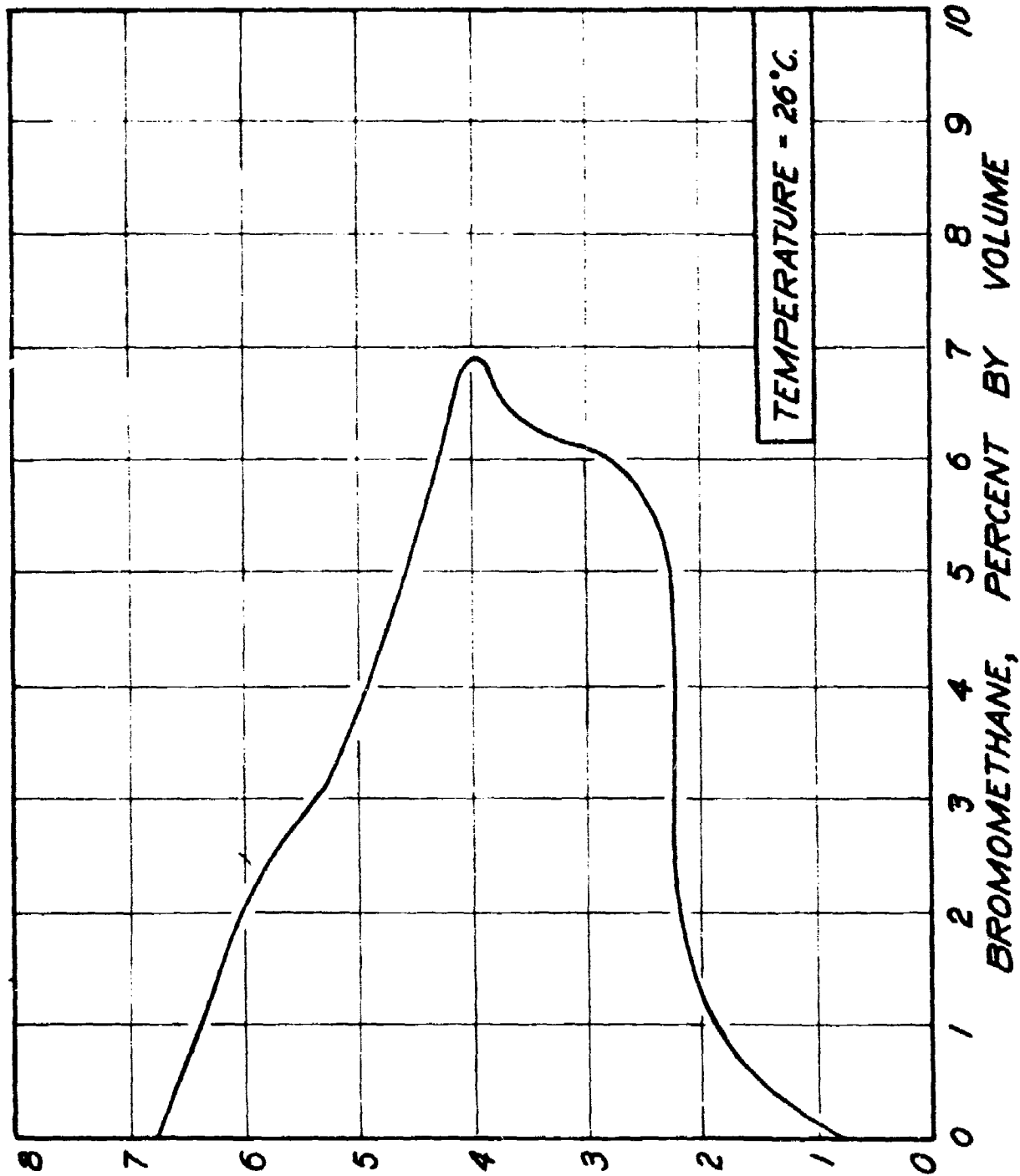


Figure 10 Effect of Temperature on Peak in the Flammability Curves



ISOBUTANE, PERCENT BY VOLUME

Figure 11 Effect of Temperature on Peak in the Flammability Curves

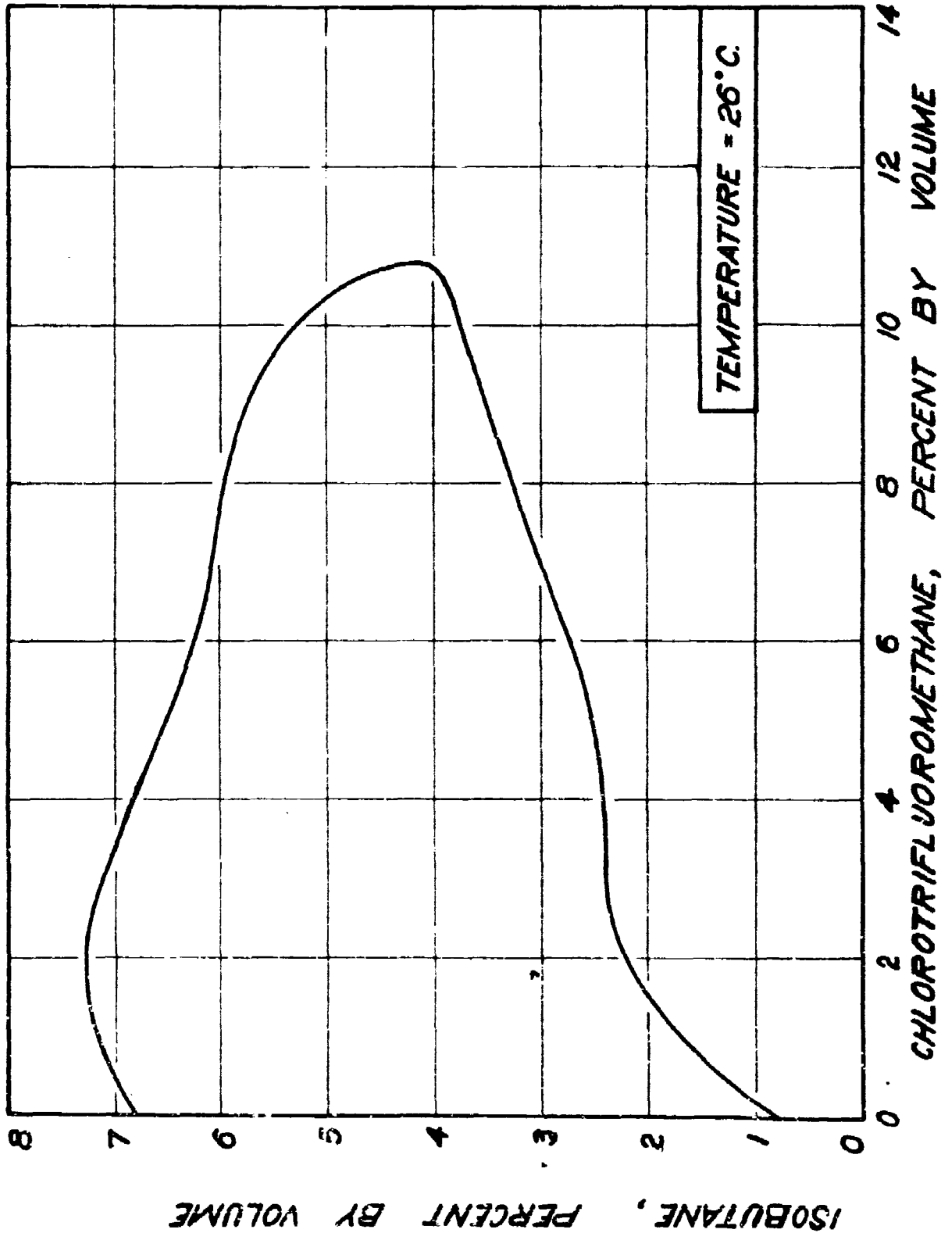
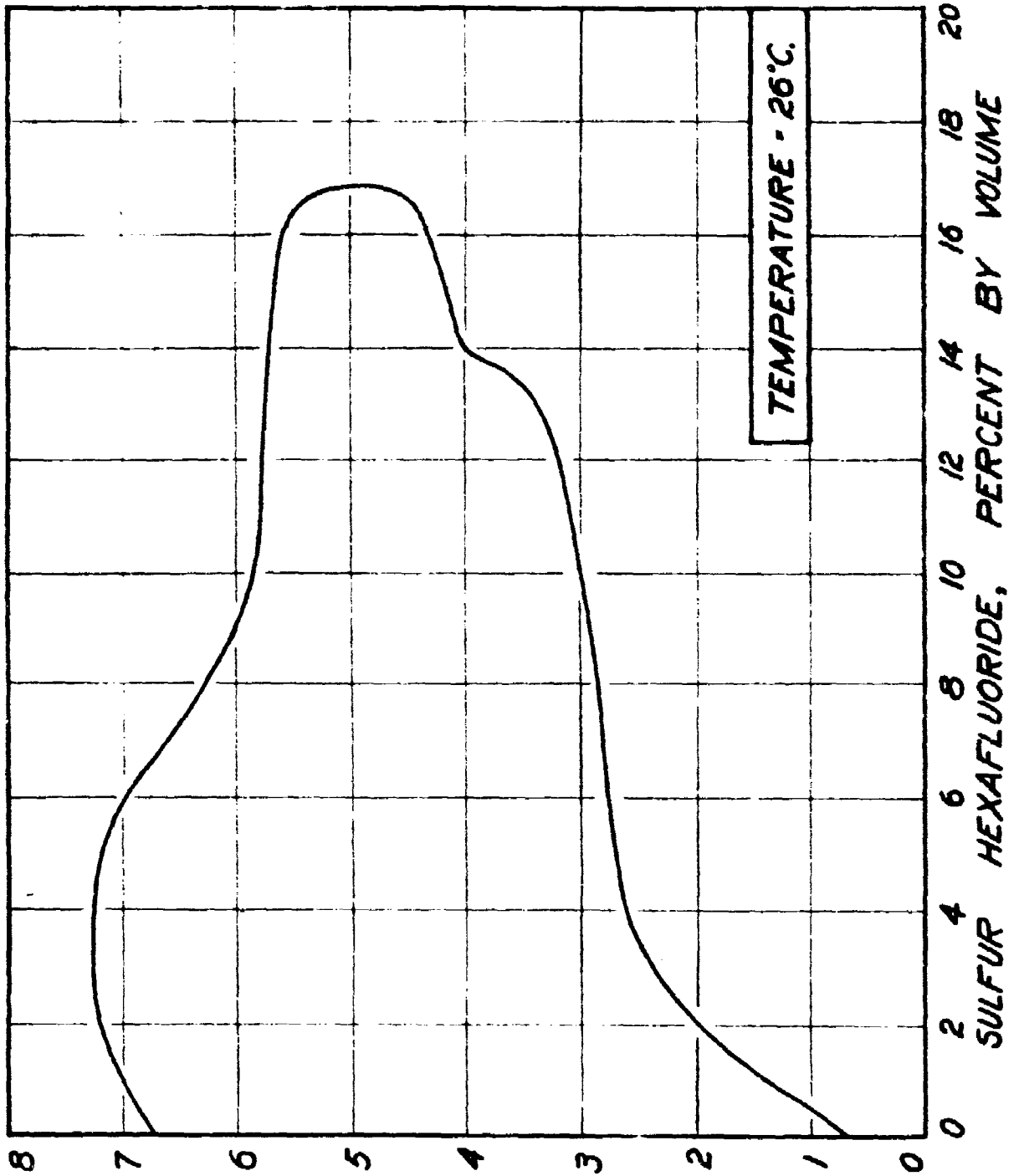


Figure 12 Effect of Temperature on Peak in the Flammability Curves



ISOBUTANE, PERCENT BY VOLUME

Figure 13 Effect of Temperature on Peak in the Flammability Curves

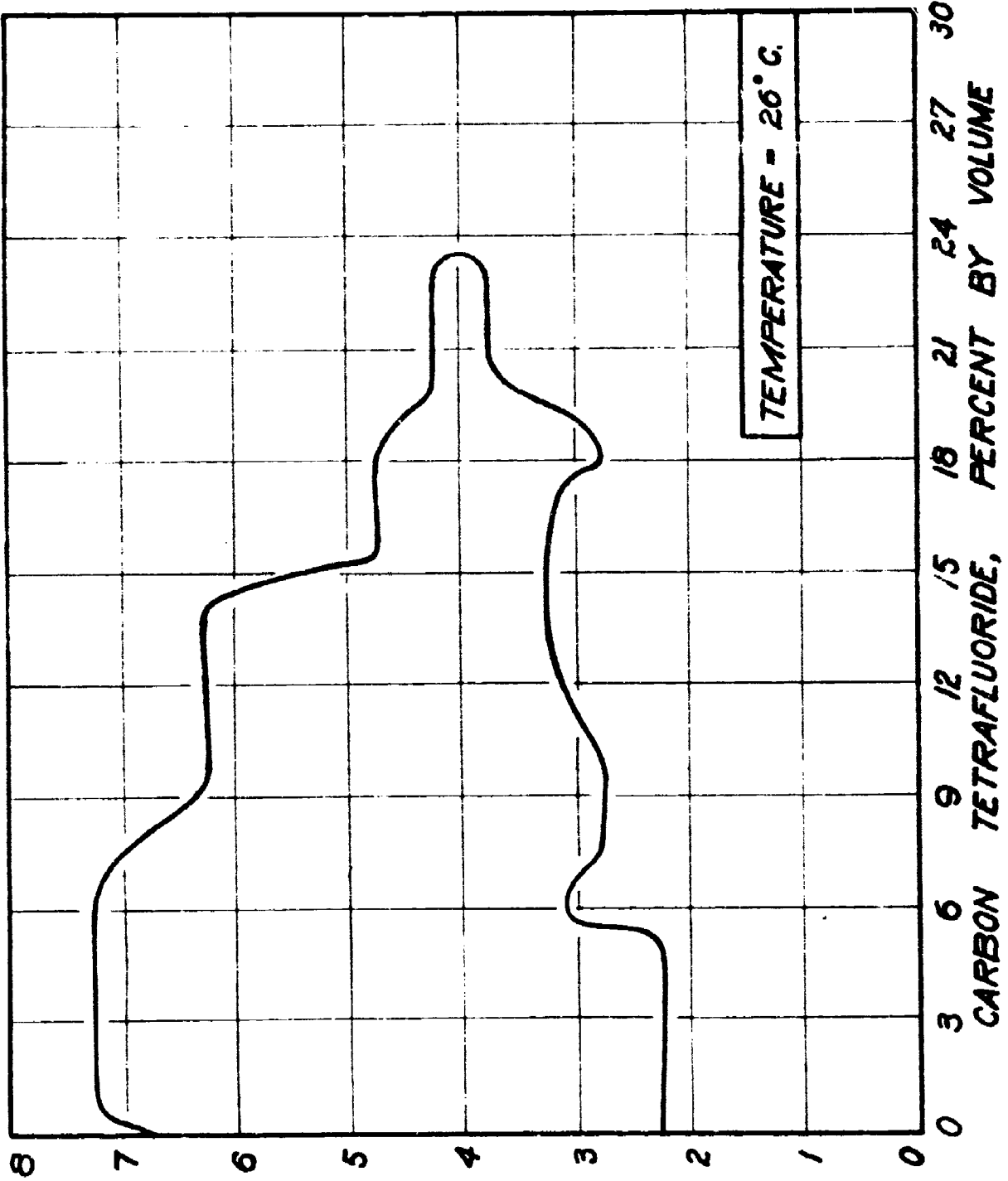


Figure 14 Effect of Temperature on Peak in the Flammability Curves

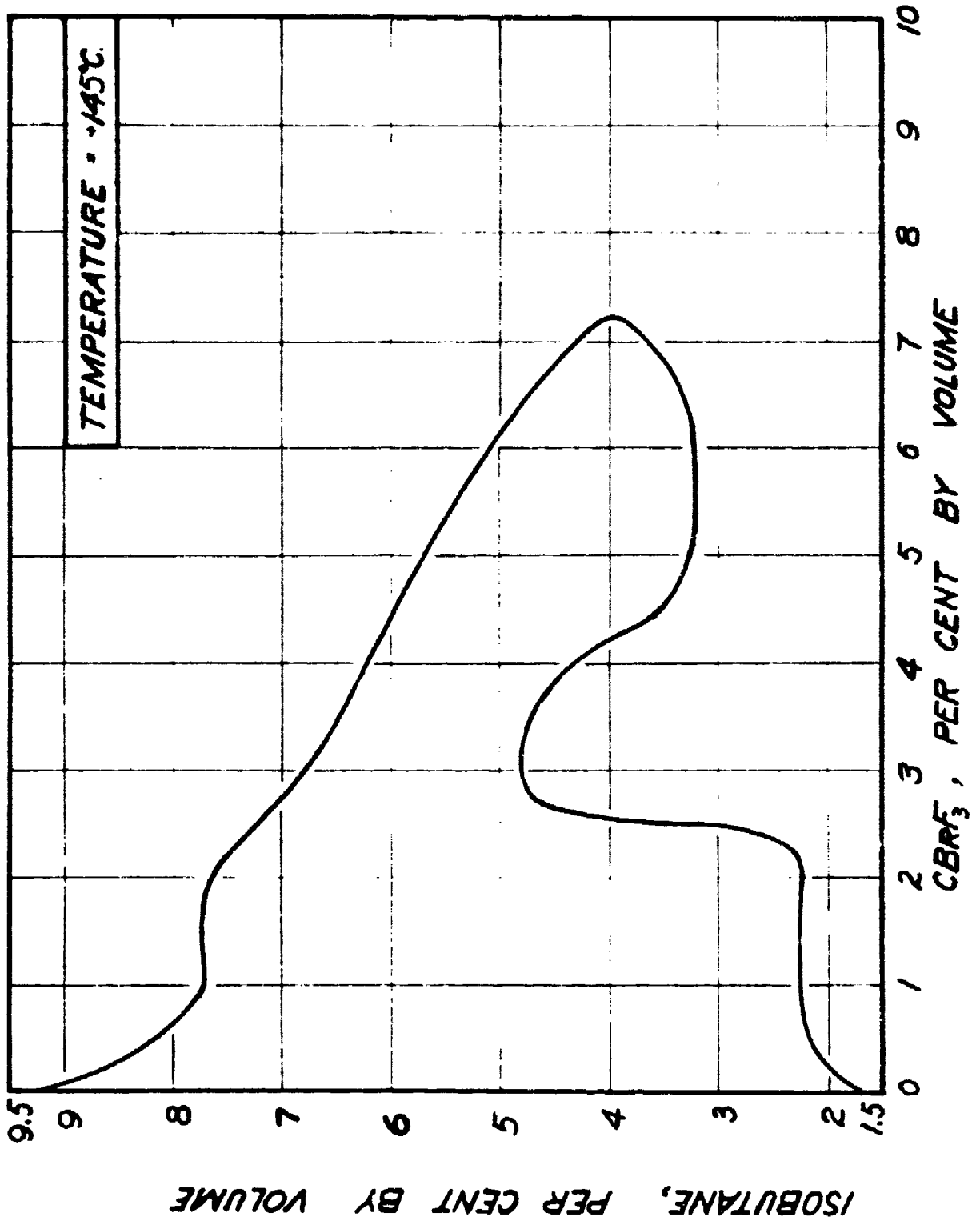


Figure 15 Effect of Temperature on Peak in the Flammability Curves

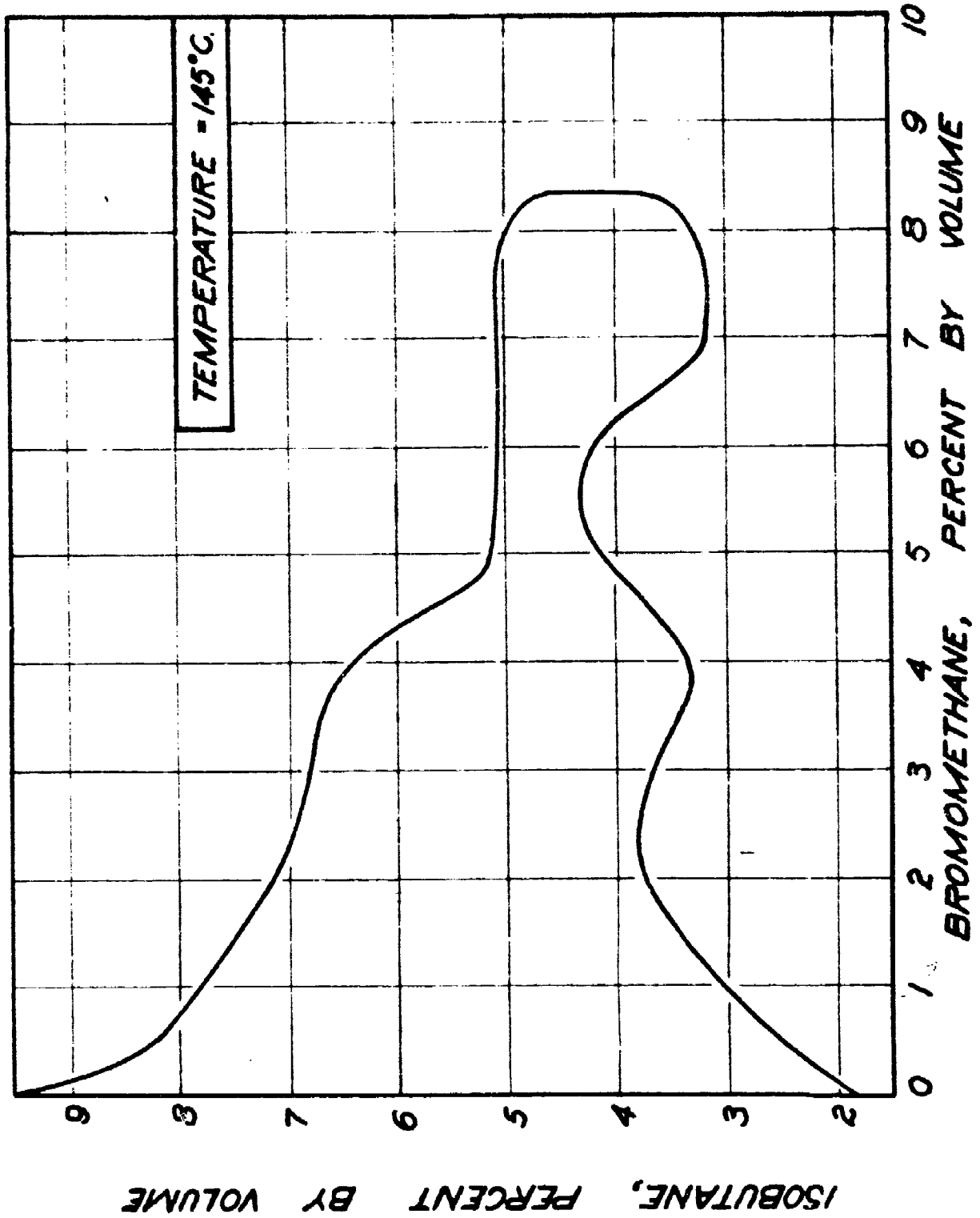


Figure 16 Effect of Temperature on Peak of the Flammability Curves

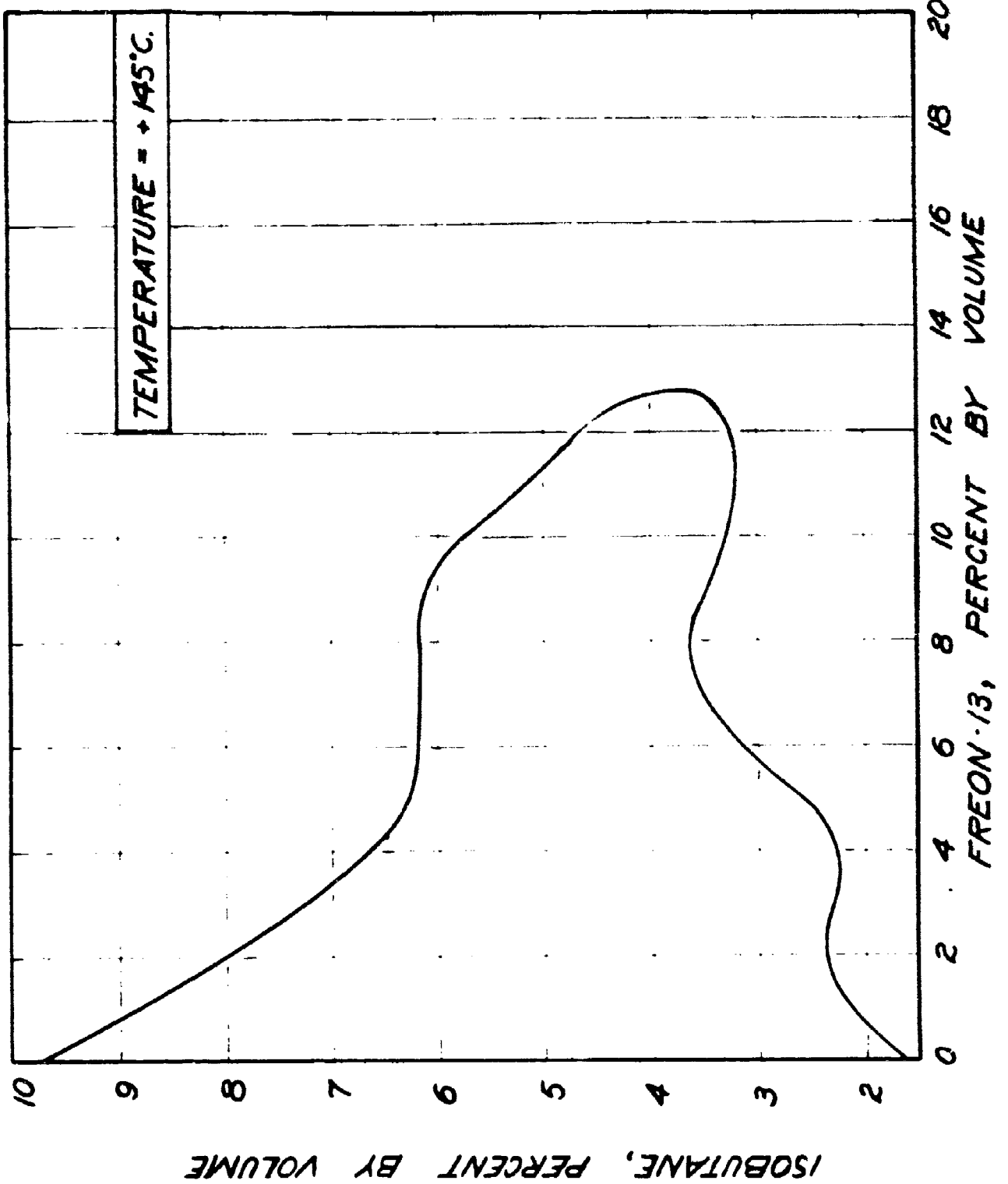
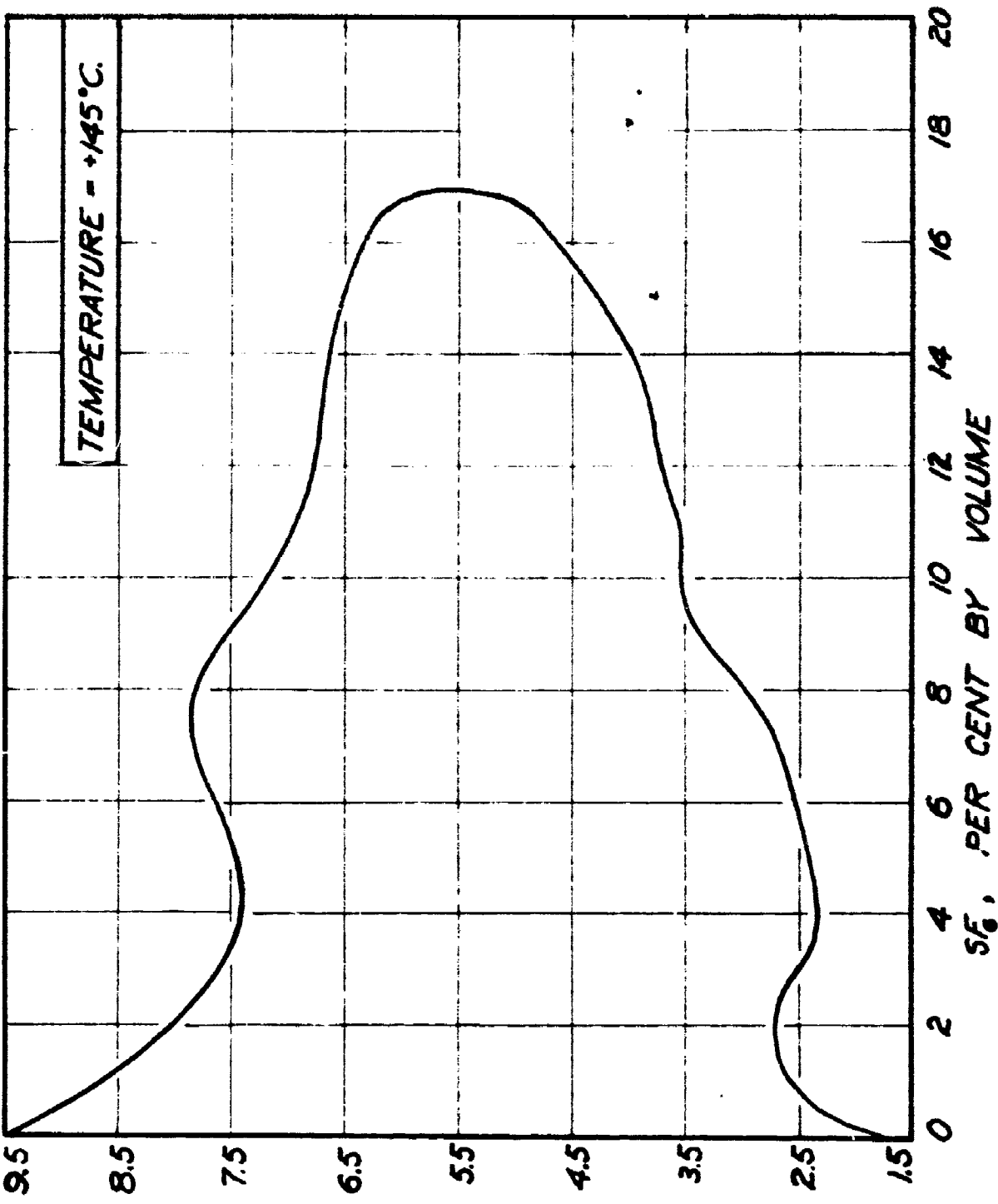


Figure 17 Effect of Temperature on Peak of the Flammability Curves



ISOBUTANE, PER CENT BY VOLUME

Figure 18 Effect of Temperature on Peak in the Flammability Curves

1. bromotrifluoromethane
2. methyl bromide
3. chlorotrifluoromethane
4. sulfur hexafluoride
5. carbon tetrafluoride

At 145°C. the order of decreasing effectiveness is bromotrifluoromethane, methyl bromide, chlorotrifluoromethane and carbon tetrafluoride.

As shown in Figures 5-9, the curves defining the flammable areas at -78°C. are quite irregular. The flammable area for mixtures of air, chlorotrifluoromethane and isobutane is unique since it is divided into two regions. None of the mixtures containing 2% chlorotrifluoromethane burned. There is a constriction in the flammable area for mixtures of bromotrifluoromethane, isobutane and air at 1% bromotrifluoromethane. There is a slight indentation in the curve showing the flammable area for mixtures of carbon tetrafluoride, isobutane and air. There is no evidence of such phenomena in the curves showing the flammable areas with the other halogen compounds. Likewise there is no evidence of such a constriction in any of the flammable areas determined at room temperature using heptane as the flammable material. Since a zone of non-combustion was found to exist with isobutane and chlorotrifluoromethane at low temperatures, the region above the peak in the flammability curve for mixtures of air, chlorotrifluoromethane and isobutane at +26°C. was explored to determine whether a second flammable area could be found. No area of combustion was found even with concentrations of 40% chlorotrifluoromethane. With one exception, the data in Table III support the hypothesis that the percentage of halogen compound in the mixture of air, flammable material and halogen compound at the peak in the inflammability curve increases as the temperature increases. Carbon tetrafluoride appears to be more effective in reducing the flammability of mixtures of air and isobutane at 145°C. than at 26°C. or at -78°C.

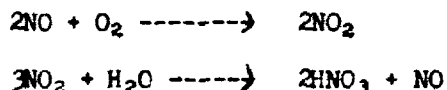
Effect of Flammable Materials. This research project was undertaken to find a superior fire extinguishing agent for use in combating fires resulting from flammable liquids and/or electricity. Early in the research program, it was demonstrated that, in general, the types of materials being investigated for possible fire extinguishing agents were nonconductors of electricity¹⁰. Since heptane vapors were used in the evaluation studies, it seemed wise to undertake a project to determine whether or not a parallel relationship exists between the abilities of halogen containing compounds to reduce the flammability of mixtures of air and heptane and mixtures of air with other flammable materials. Pentane, benzene, ethanol, diethyl ether, acetone and ethyl acetate were chosen as the combustibles after a consideration of availability and volatility as well as flammability. Methylene dibromide, ethyl bromide, methyl bromide, sulfur hexafluoride, carbon tetrafluoride, and bromotrifluoromethane were chosen as the flame inhibitors. These materials were chosen because of their availability and, on the basis of previous tests, because a wide range of effectiveness is represented by these materials. Data are summarized in Table IV which show the peak in the flammability curve for the various combustibles mixed with air and with the selected halogen containing compound.

It can be concluded from the data in Table IV that a qualitative parallel relationship exists between the abilities of halogen containing compounds to reduce the flammability of mixtures of air and heptane and mixtures of air with other flammable materials. Those points which appear to be more or less effective than expected have been checked and found to be accurate within experimental error.

Effect of Binary Mixtures of Halogen Compounds. Developments have emphasized the need for a fire extinguishing agent applicable for use at temperatures ranging upward from -54°C . (-65°F .). A single material which could be used over the entire temperature range would be desirable. One requirement of such a material is that it have a vapor pressure sufficiently high at the low temperature to propel itself from the container to the fire. The vapor pressure of chlorotrifluoromethane (b.p. -78°C) is too low at -54°C . to carry the extinguishing agent any appreciable distance from its container²². Therefore, it seems probable that a substance should have a boiling point of -100°C . or lower if it is to be a self-propelling fire extinguishing agent at -54°C . Chemicals selected from a group of about ten thousand organic and inorganic materials having a normal boiling point below -100°C . are listed in Table V. An examination of this list shows that those known materials which may be of interest as a fire extinguishing agent are limited to a small group comprising of helium, neon, nitrogen, argon, krypton, nitric oxide, carbon tetrafluoride, nitrogen trifluoride and xenon.

Carbon tetrafluoride has been shown to be more effective with respect to fire extinction properties than nitrogen. It is believed that there is no great difference in effectiveness between nitrogen, helium, neon, argon, krypton, and xenon. The choice would depend upon performance tests, availability and economics.

Nitric oxide has favorable physical properties but its chemical properties are unfavorable. One reaction may be summarized as follows:



The first reaction may be advantageous since oxygen is being consumed, but the second reaction would be disadvantageous because of the corrosive nature of nitric acid produced by the reaction of nitrogen dioxide with water.

In view of the relatively few compounds available with boiling points below -100°C ., it seems evident that a higher boiling substance(s) will have to be used along with a propellant. Such a material should have a freezing point below -54°C . and should be relatively non-viscous at -54°C . If the fluid is a mixture of substances, the freezing point of one or more of the components may be somewhat higher than -54°C .

Table IV
EFFECT OF FLAMMABLE MATERIALS

Flammable Materials	Halogen Compound						
	CH ₂ Br ₂	CBrF ₃	C ₂ H ₅ Br	CH ₃ Br	SF ₆	CF ₄	
C ₇ H ₁₆	5.2	6.1	6.2	7.7	20.5	26	
C ₅ H ₁₂	6.8	6.3	6.3	8.4	19.8	20.4	
C ₆ H ₆	7.3	4.3	8.2	8.4	18.3	23.6	
C ₂ H ₅ OH	5.7	3.7	5.2	6.2	10.6	19.8	
(C ₂ H ₅) ₂ O	7.7	6.3	7.3	7.2	21.8	22.4	
CH ₃ COCH ₃	5.7	5.3	5.3	7.3	16.4	18.7	
CH ₃ CO ₂ C ₂ H ₅	4.3	4.6	6.3	6.8	17.5	21.4	

Table V

CHEMICALS BOILING BELOW -100°C . AT NORMAL PRESSURES

<u>Name</u>	<u>Formula</u>	<u>B.P.,$^{\circ}\text{C}$.</u>	<u>M.P.,$^{\circ}\text{C}$.</u>	<u>Mol.Wt.</u>	<u>Remarks</u>
Helium	He	-268.9	< -272	4	
Hydrogen	H ₂	-252.7	-259.1	2	Flammable
Neon	Ne	-245.9	-248.7	20	
Nitrogen	N ₂	-195.8	-209.9	28	
Carbon Monoxide	CO	-192	-207	28	Flammable, highly toxic
Fluorine	F ₂	-187	-223	38	Extremely reactive
Argon	A	-185.7	-189.2	40	
Oxygen	O ₂	-183	-218.4	32	Supports combustion
Fluorine Oxide	F ₂ O	-167	-----	54	Believed highly toxic
Methane	CH ₄	-161.4	-182	16	Flammable
Krypton	Kr	-151.8	-169	84	
Nitric Oxide	NO	-151	-161	30	
Carbon Tetrafluoride	CF ₄	-128	-184	88	
Silane	SiH ₄	-112	-185	32	Ingnites spontaneously
Ozone	O ₃	-112	-251	48	Favors combustion
Nitrogen Trifluoride	NF ₃	-110	-210	71	
Xenon	Xe	-109	-140	131	
Ethylene	C ₂ H ₄	-103.9	-169	28	Flammable
Boron Trifluoride	BF ₃	-101	-127	68	Hydrolyzes readily

The possible need for using a mixture of compounds for a fire extinguishing agent was mentioned in the preceding paragraphs. Accordingly, research was initiated to determine the effectiveness of binary mixtures of halogen containing compounds in decreasing the flammability of mixtures containing *n*-heptane, air and halogen compounds. Data obtained in this preliminary study are summarized in Table VI. These data indicate that in certain instances the use of a mixture of halogen-containing compounds is advantageous.

In subsequent studies pentane was used as the flammable material to avoid certain irregularities in the data believed to result from the condensation of the heptane from the mixture. The concentration of combustible material was maintained constant in this study. Pentane concentrations of 2.5, 4 and 6% were used with each mixture of halogen compound. The data are plotted in Figures 19-36 inclusive. The straight line in each plot represents the curve expected if the relationship between the flame inhibition activities of the two extinguishing agents were arithmetical. Mixtures of ethyl bromide and methyl iodide follow this line at a pentane concentration of 4% (Fig. 26). At a pentane concentration of 2.5% (Fig. 25) the curve lies below the line for mixtures of ethyl bromide and methyl iodide containing 65-100% ethyl bromide, indicating that the mixture in this region is more effective than calculated. The curve lies above the line for mixtures containing from 35-100% methyl iodide (0-65% ethyl bromide), indicating that in regions the mixture is less effective than calculated from the consideration of the effectiveness of the two components. At a pentane concentration of 6% (Fig. 27), the entire curve lies below the straight line. At pentane concentrations of 2.5%, 4% and 6% (Figs. 28, 29 and 30), the curves for mixtures of ethyl bromide and methylene chloride lie below the straight line, indicating a synergistic effect in all pentane concentrations of this binary mixture of halogen compounds. This is the only mixture investigated which shows enhancement of effectiveness in all concentrations of the hydrocarbon. A summary of the effect of the mixtures is given in Table VII.

The evaluation of mixtures of carbon tetrachloride and trichloroethylene was performed, in response to a request from representatives of ERDL. This request was made since a mixture comprising 70% carbon tetrachloride and 30% trichloroethylene has been recommended for use as a fire extinguishing fluid. In general on the basis of tests with pentane, it can be stated that a mixture comprising 70% carbon tetrachloride and 30% trichloroethylene are not the most effective that can be obtained by mixing the two compounds. In choosing the composition of such a mixture consideration must be given to economic factors and freezing point characteristics as well as effectiveness. Should the 70-30 composition represent the optimum from the cost consideration and the freezing point characteristics, then a sacrifice in effectiveness may be justified.

Table VI

EFFECT OF BINARY MIXTURES OF HALOGEN COMPOUNDS IN
DECREASING THE FLAMMABILITY OF MIXTURES CONTAINING
AIR AND n-HEPTANE

(% CH₂Br₂ = % Compound A)

<u>Compound A</u>	<u>CH₂Br₂,%</u>	<u>Compound A,%</u>	<u>Peak in Flammability Curves</u>	
			<u>Mixture, %</u>	
			<u>Obs.</u>	<u>Calc.*</u>
CBr ₃ F	5.2	4.3	5.3	4.8
C ₆ F ₁₁ C ₂ F ₅	5.2	6.8	5.4	6.0
CH ₃ CH ₂ Br	5.2	6.2	5.7	5.7
CCl ₄	5.2	11.5	7.2	8.4
CHCl ₃	5.2	17.5	9.3	11.4

* Calculated Value = $\frac{\% \text{CH}_2\text{Br}_2 + \% \text{Compound A}}{2}$

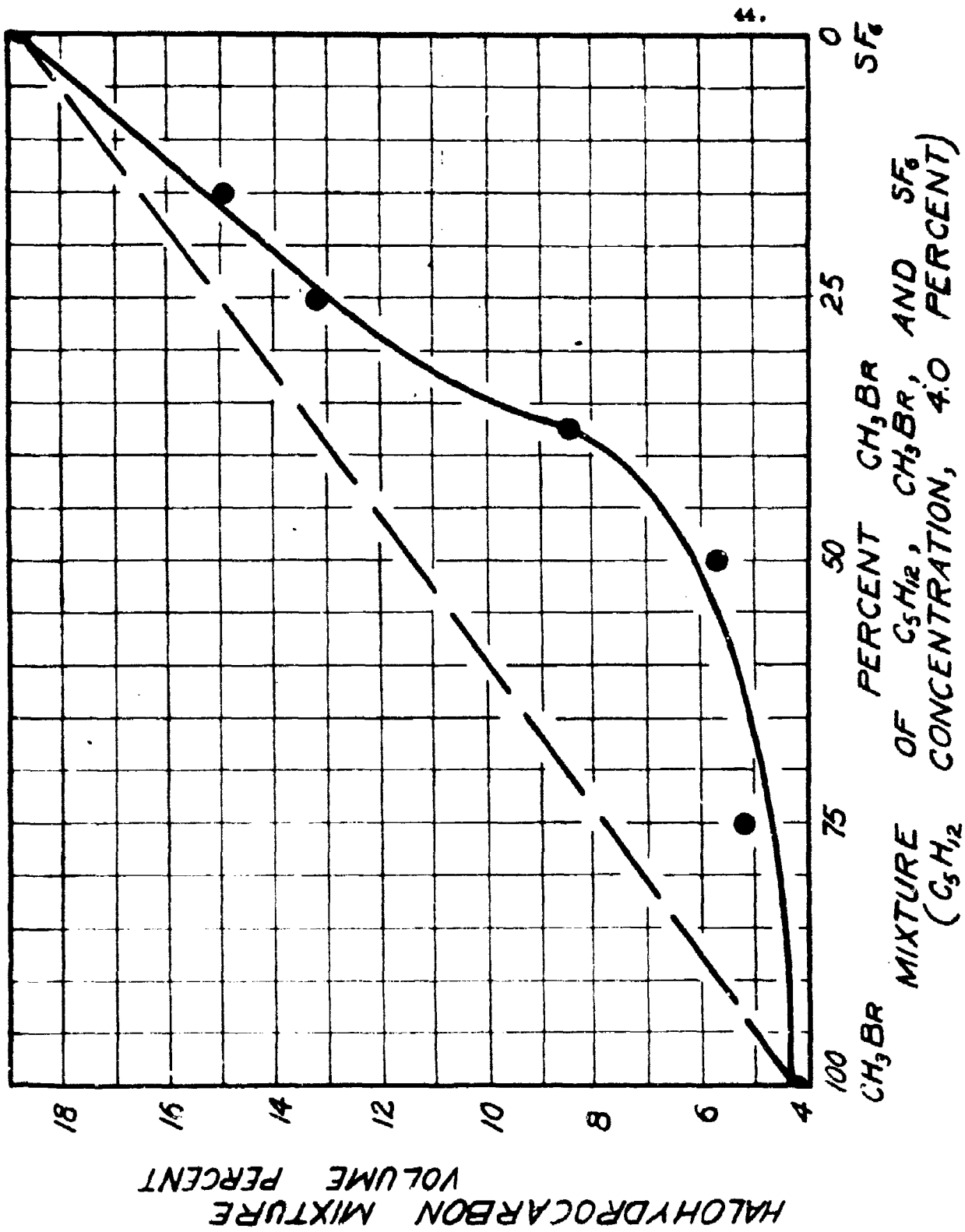


Figure 19 Effect of Binary Mixtures in Decreasing the Flammability of Air and Pentane

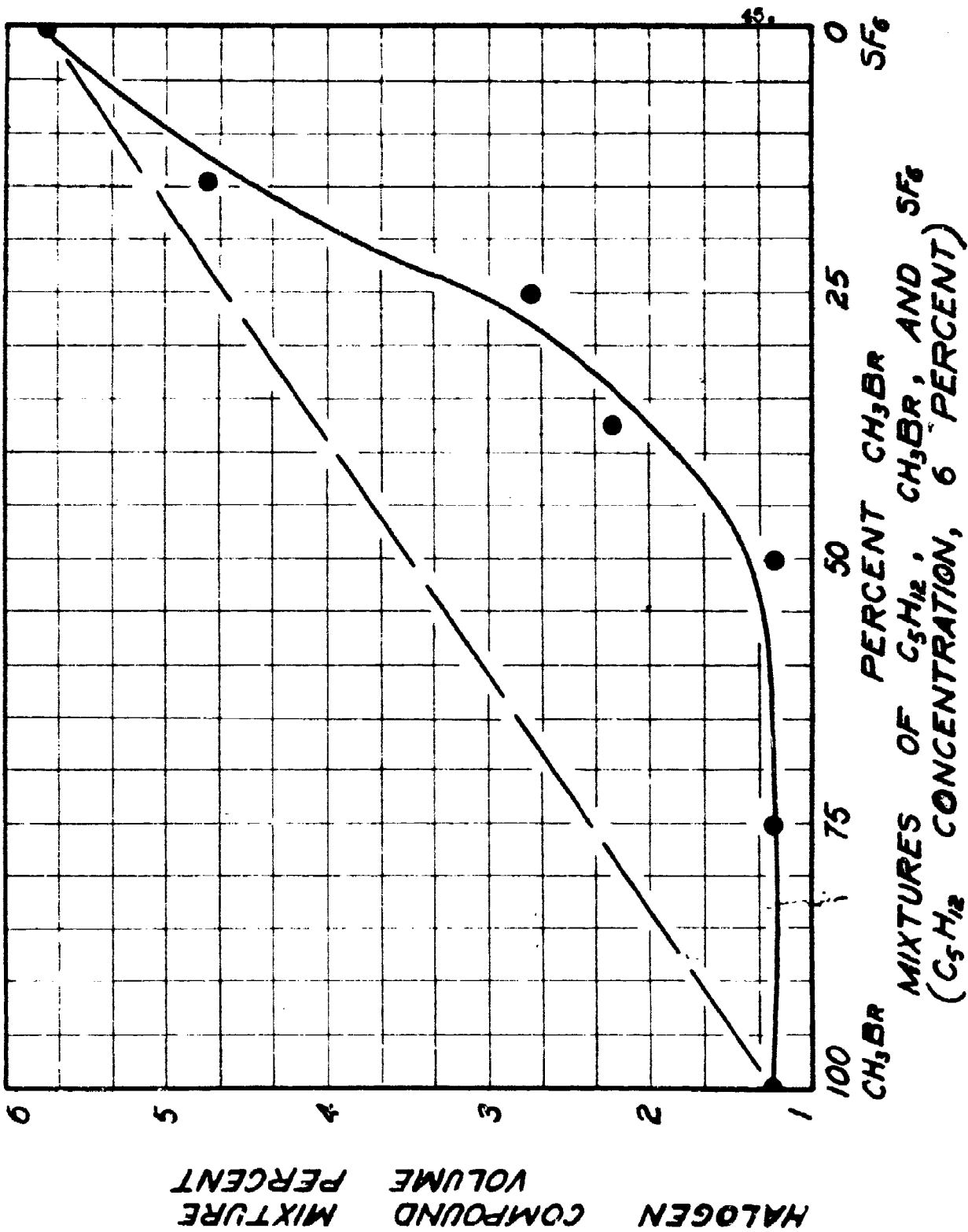
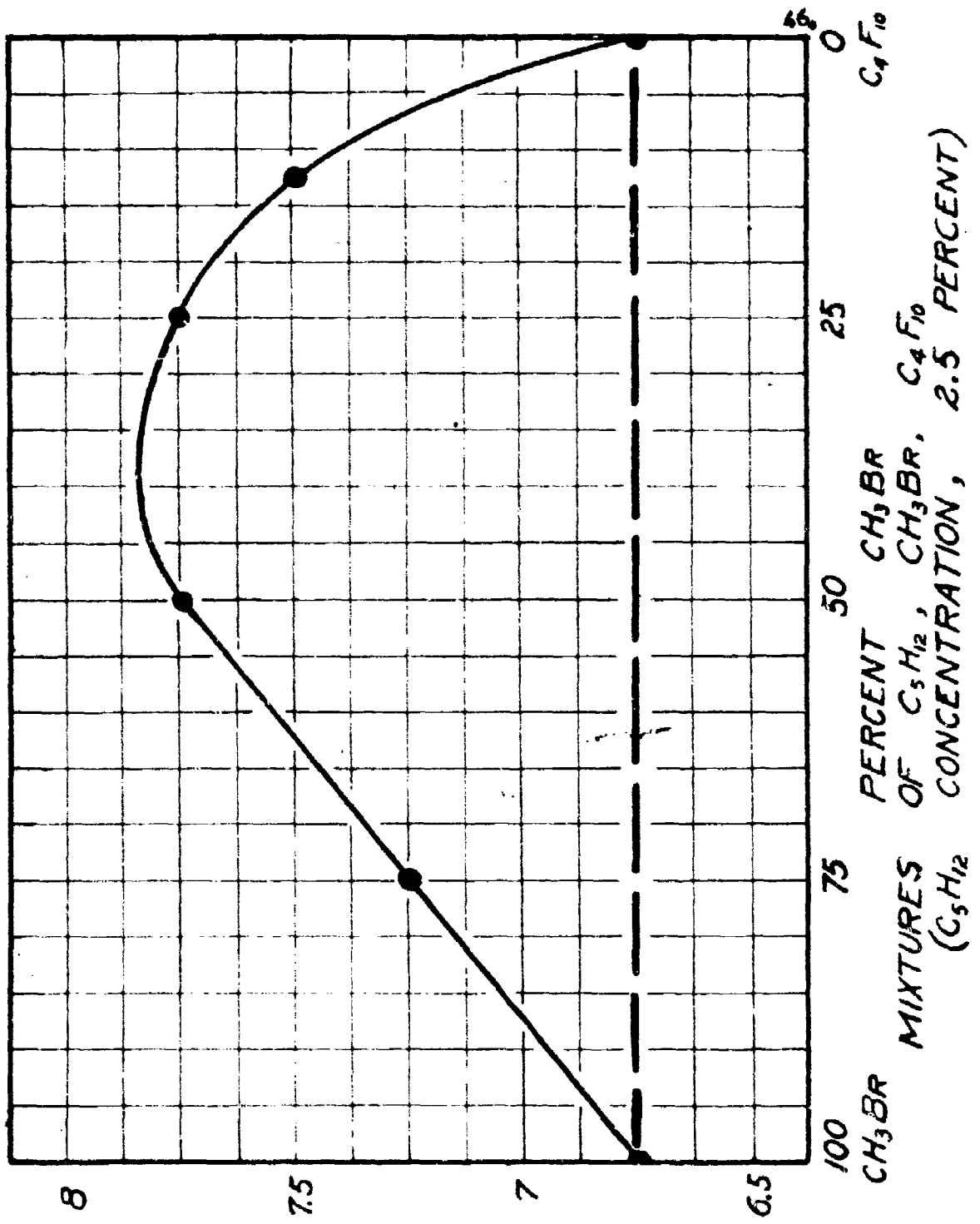


Figure 20 Effect of Binary Mixtures in Decreasing the Flammability of Air and Pentane



HALOHYDROCARBON MIXTURE VOLUME PER CENT

Figure 21 Effect of Binary Mixtures in Decreasing the Flexibility of Air and Pentane

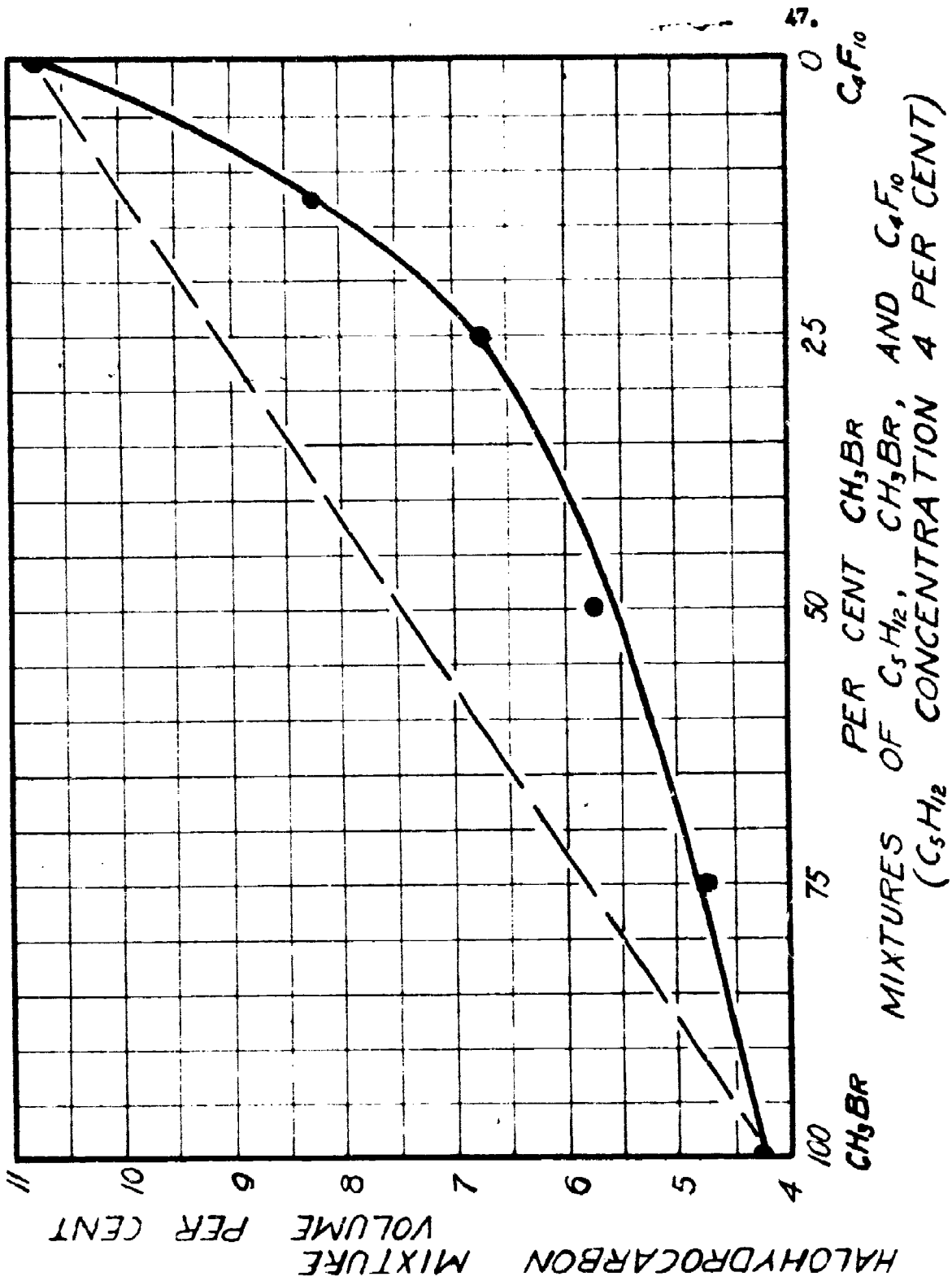


Figure 22 Effect of Binary Mixtures in Decreasing the Flammability of Air and Pentane

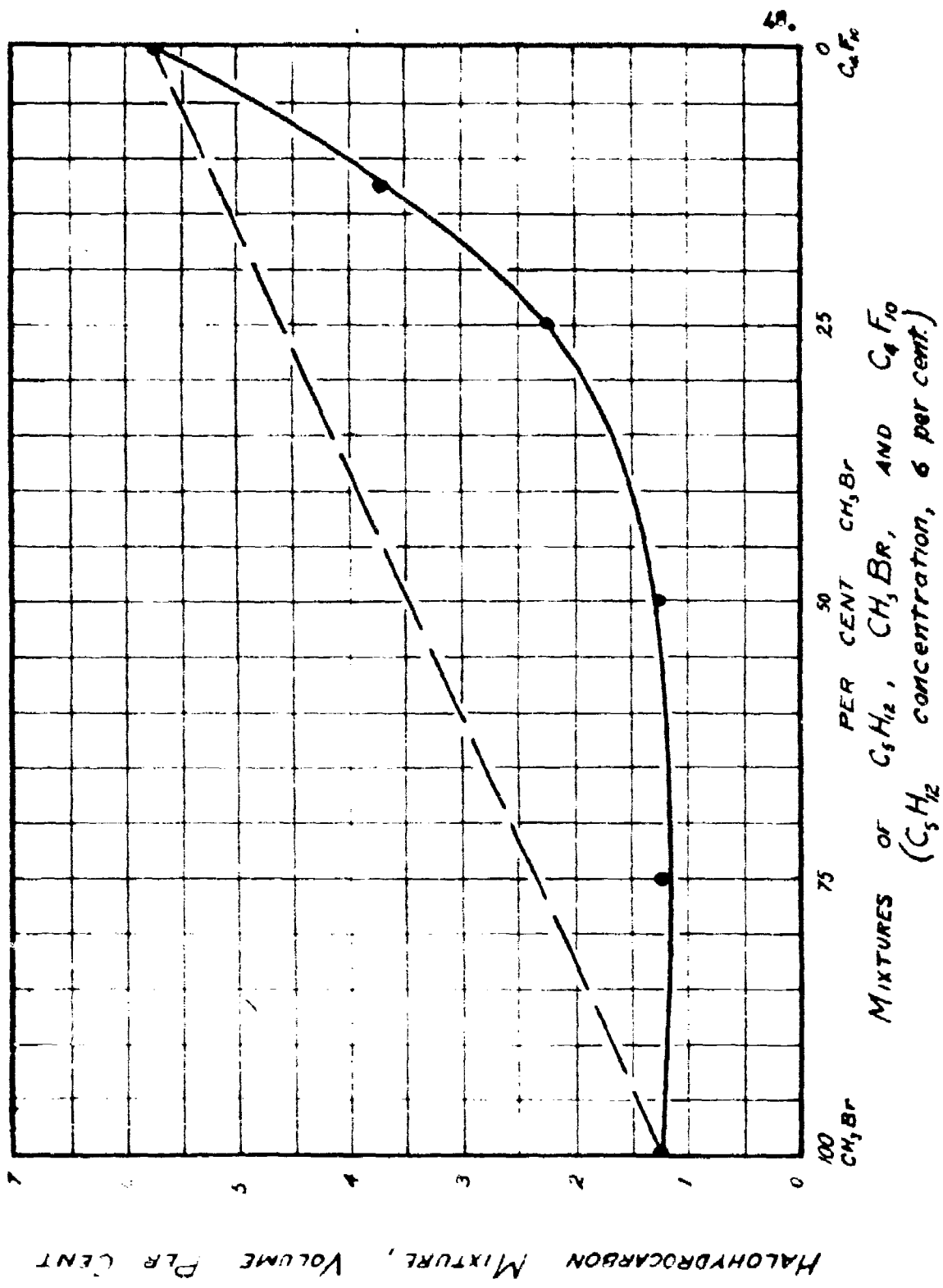
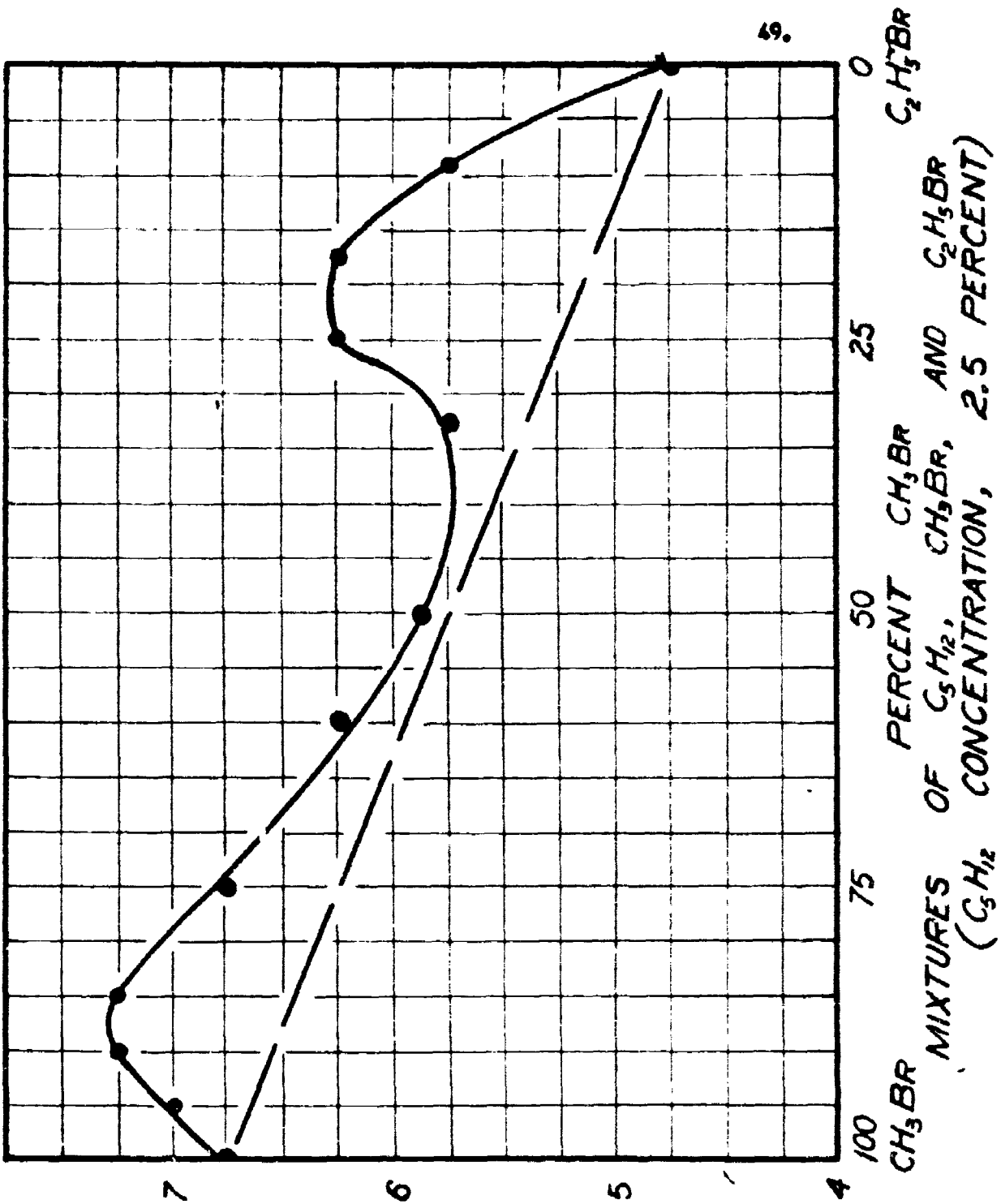


Figure 23 Effect of Binary Mixtures in Decreasing the Flammability of Air and Pentane



HALOHYDROCARBON MIXTURE
 VOLUME PERCENT
 Figure 24 Effect of Binary Mixtures in Decreasing
 the Flameability of Air and Pentane

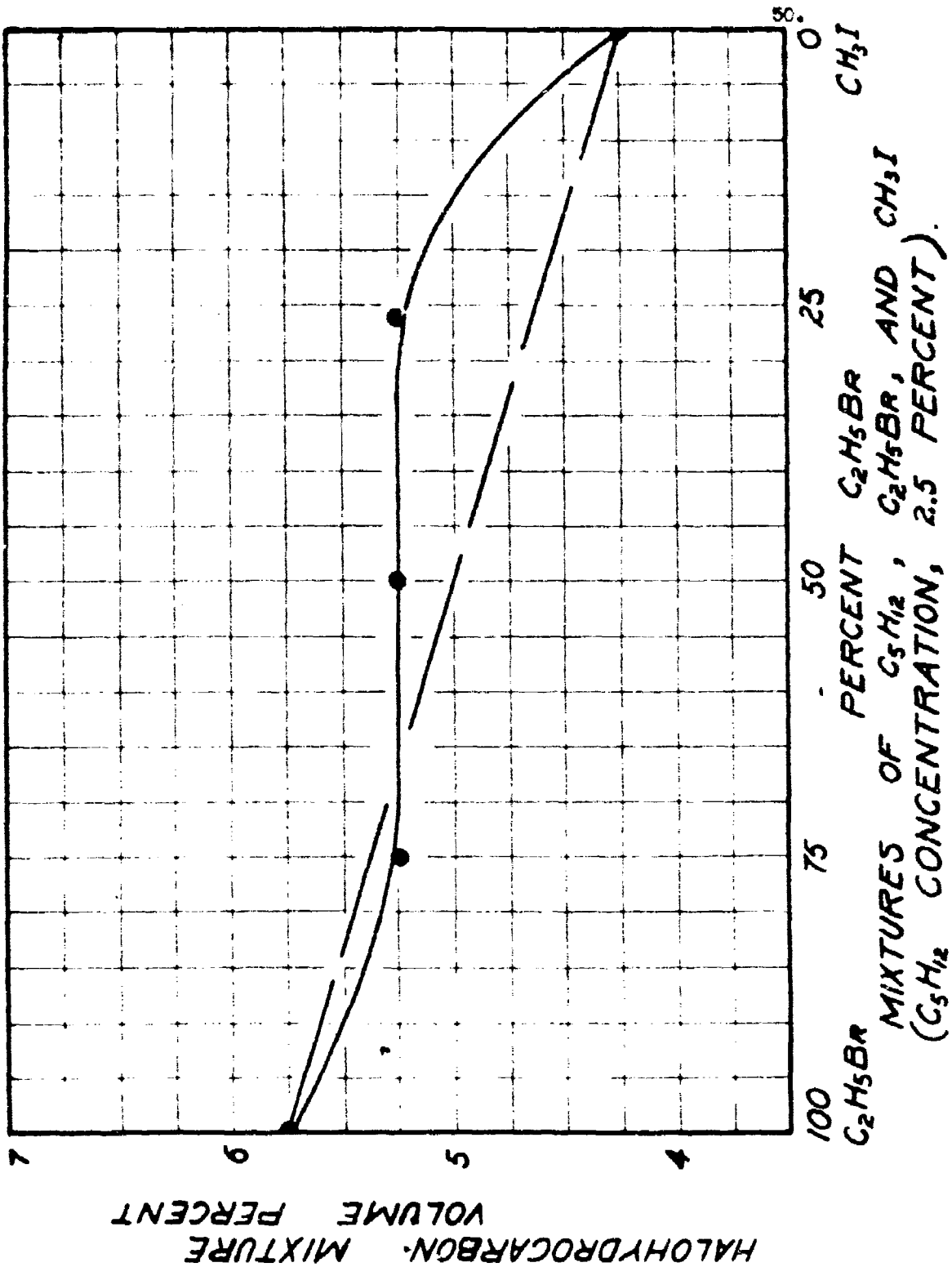
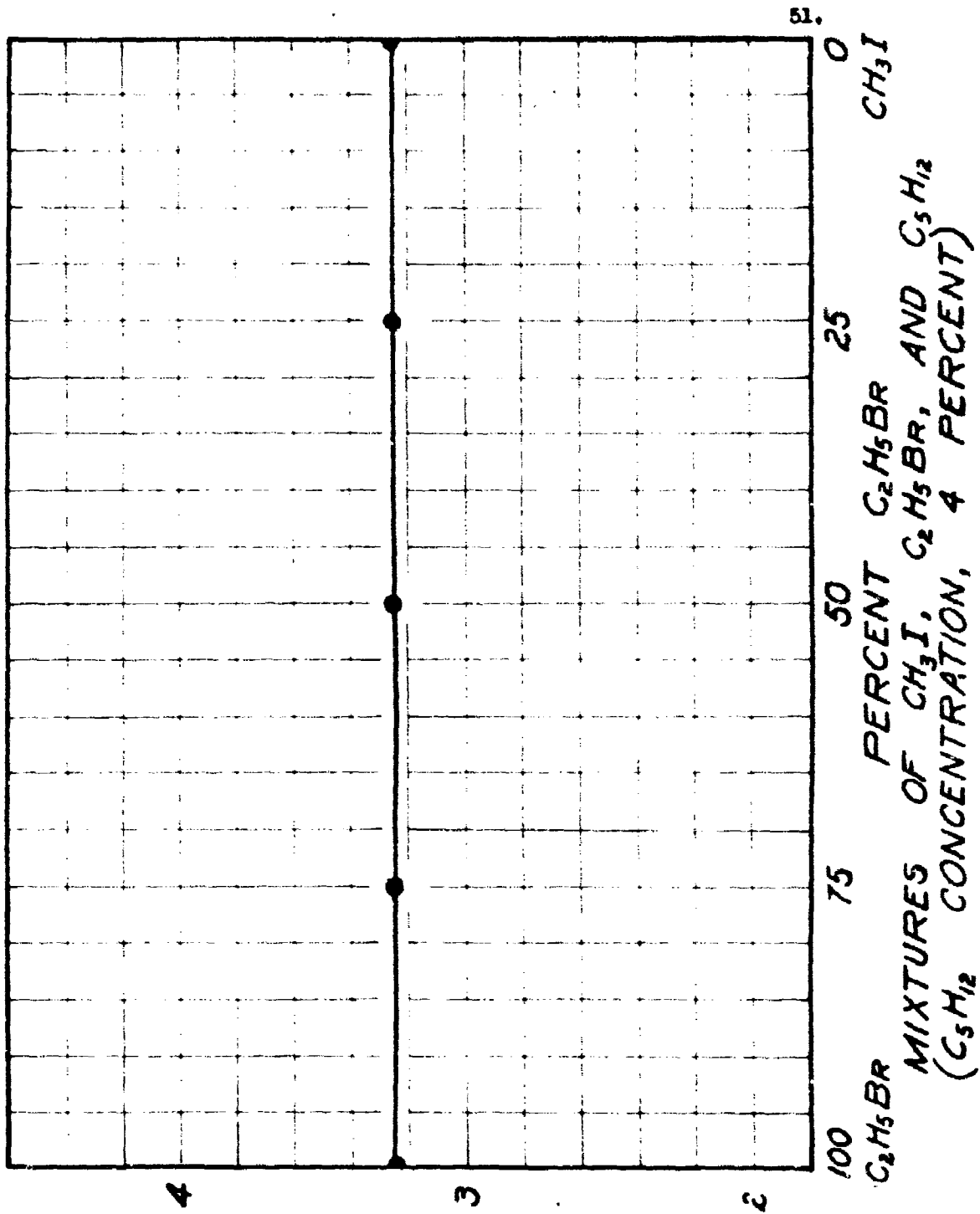


Figure 25 Effect of Binary Mixtures in Decreasing the Flammability of Air and Pentane

HALOHYDROCARBON MIXTURE
 VOLUME PERCENT

Figure 26 Effect of Binary Mixtures in Decreasing
 the Flammability of Air and Pentane



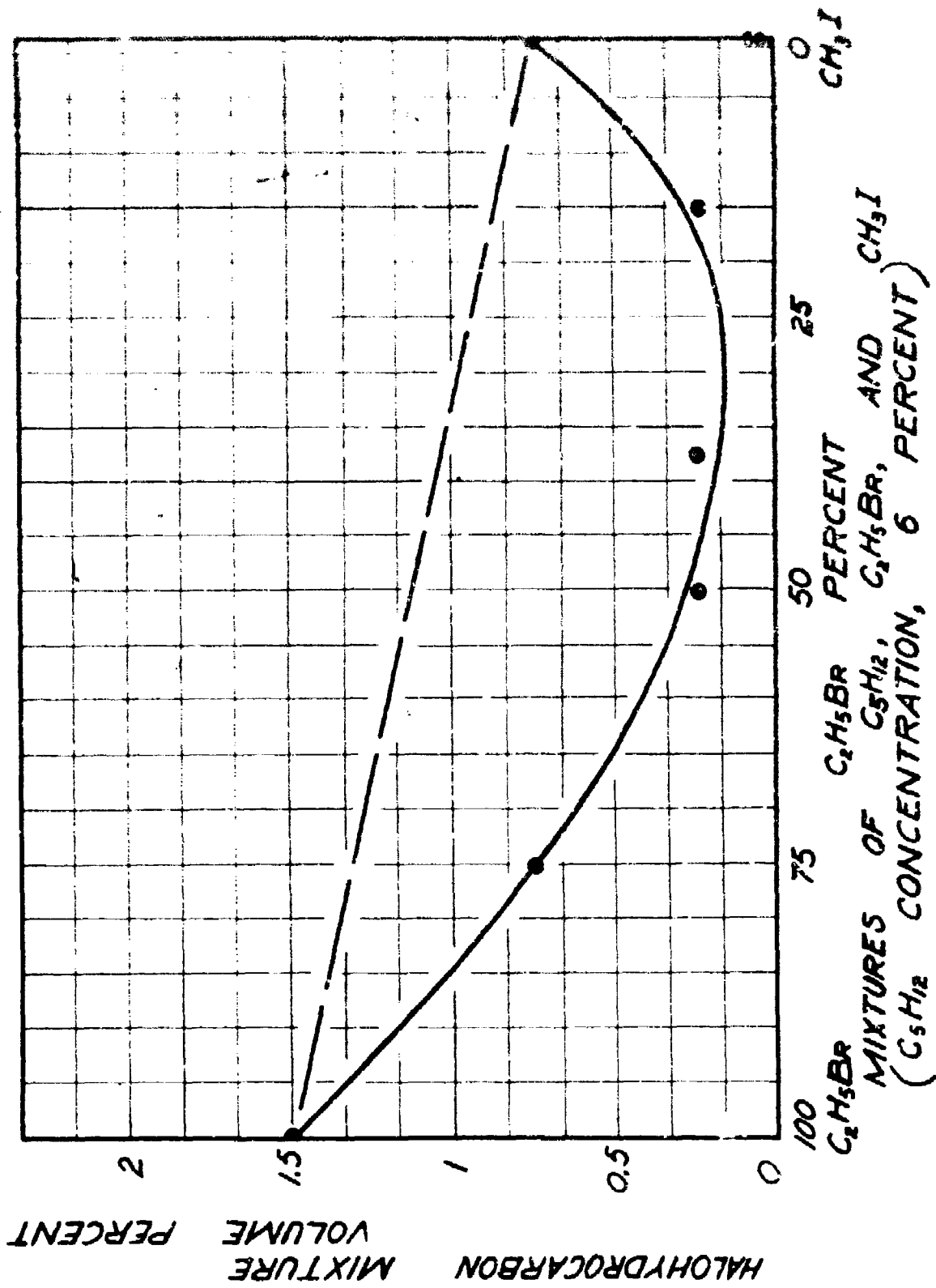


Figure 27 Effect of Binary Mixtures in Decreasing the Flammability of Air and Pentane

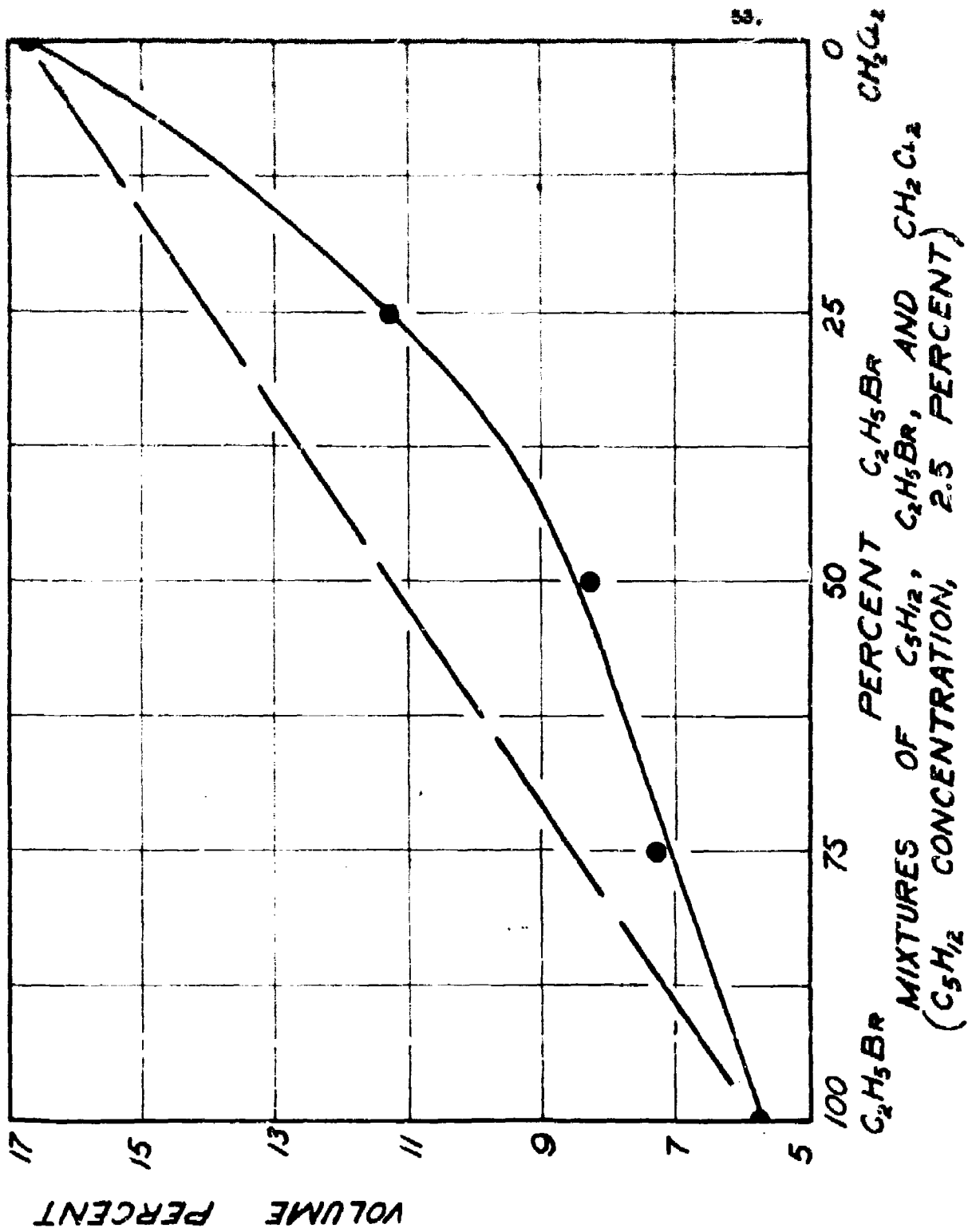


Figure 28 Effect of Binary Mixtures in Decreasing the Flammability of Air and Pentane

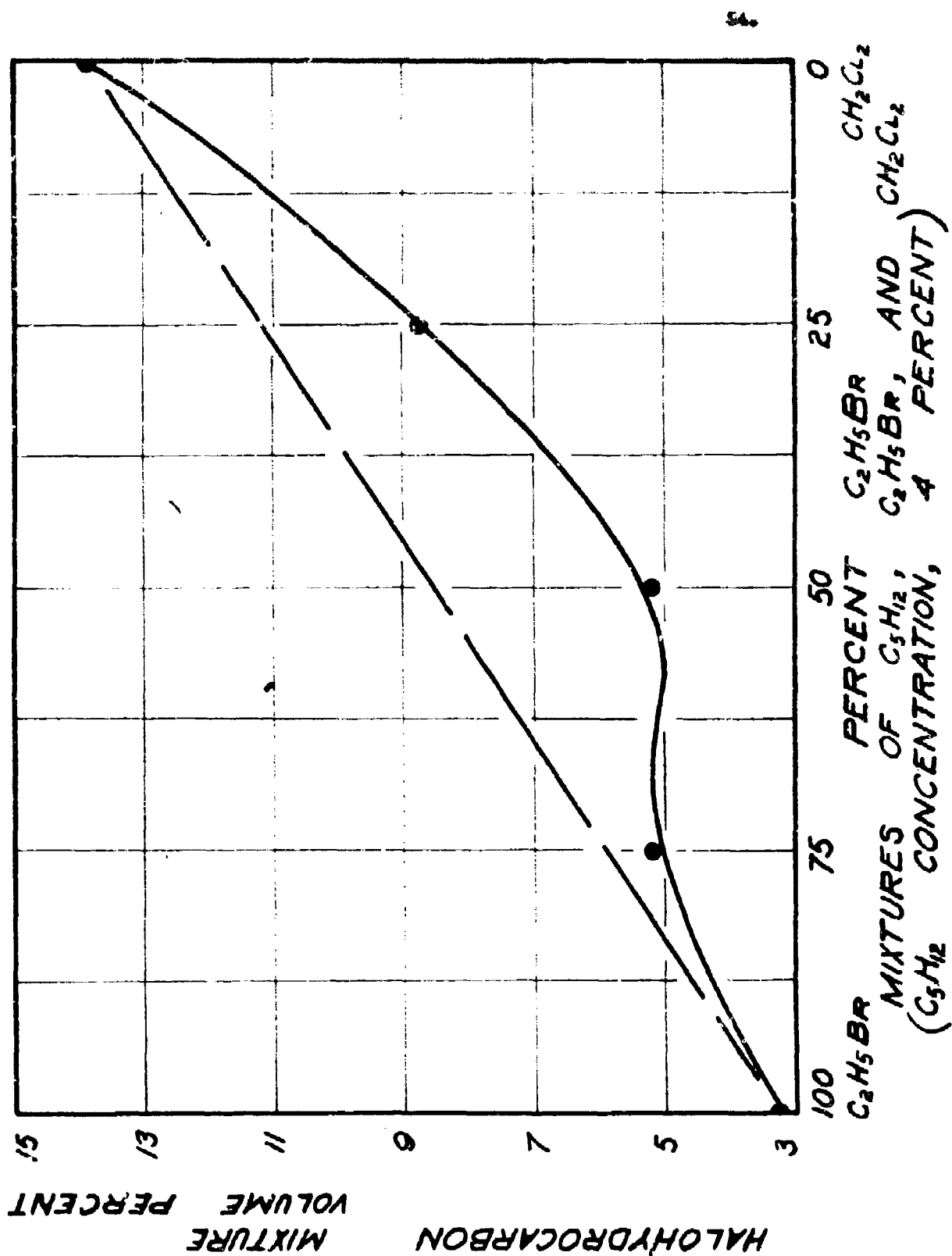


Figure 29 Effect of Binary Mixtures in Decreasing the Flammability of Air and Pentane

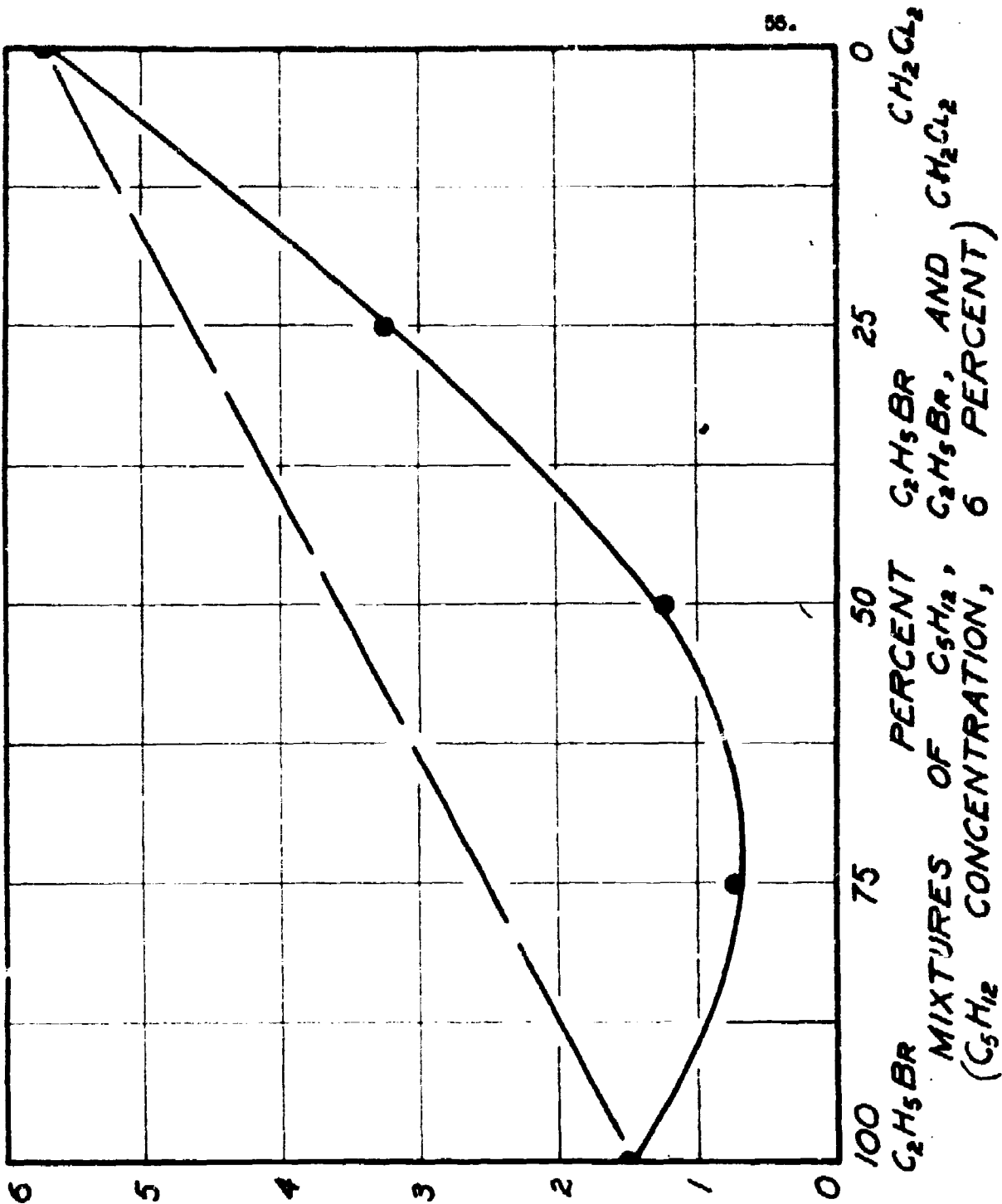


Figure 30 Effect of Binary Mixtures in Decreasing the Flammability of Air and Pentane

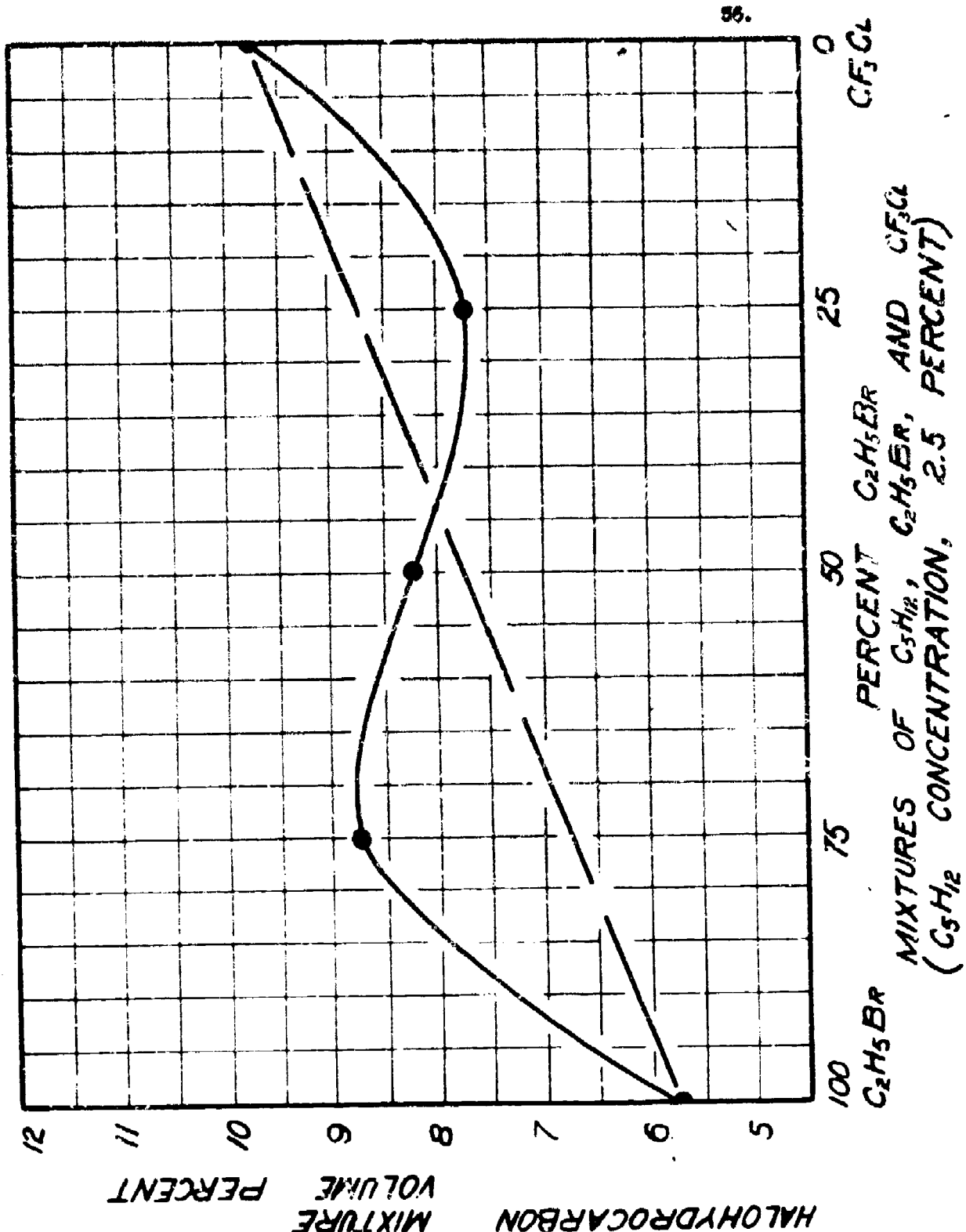


Figure 61 Effect of Binary Mixtures in Decreasing the Flammability of Air and Pentane

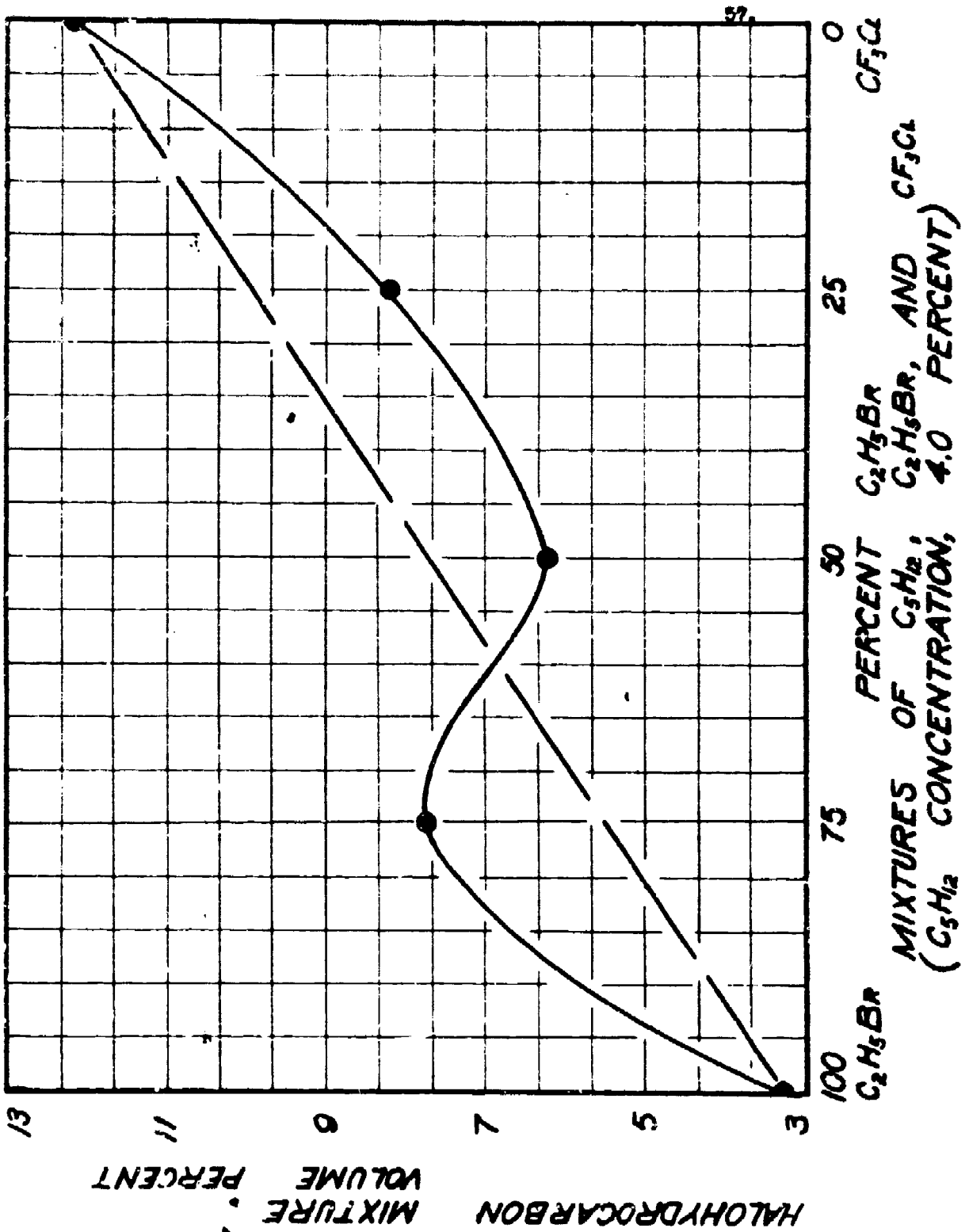


Figure 32 Effect of Binary Mixtures in Decreasing the Flammability of Air and Pentane

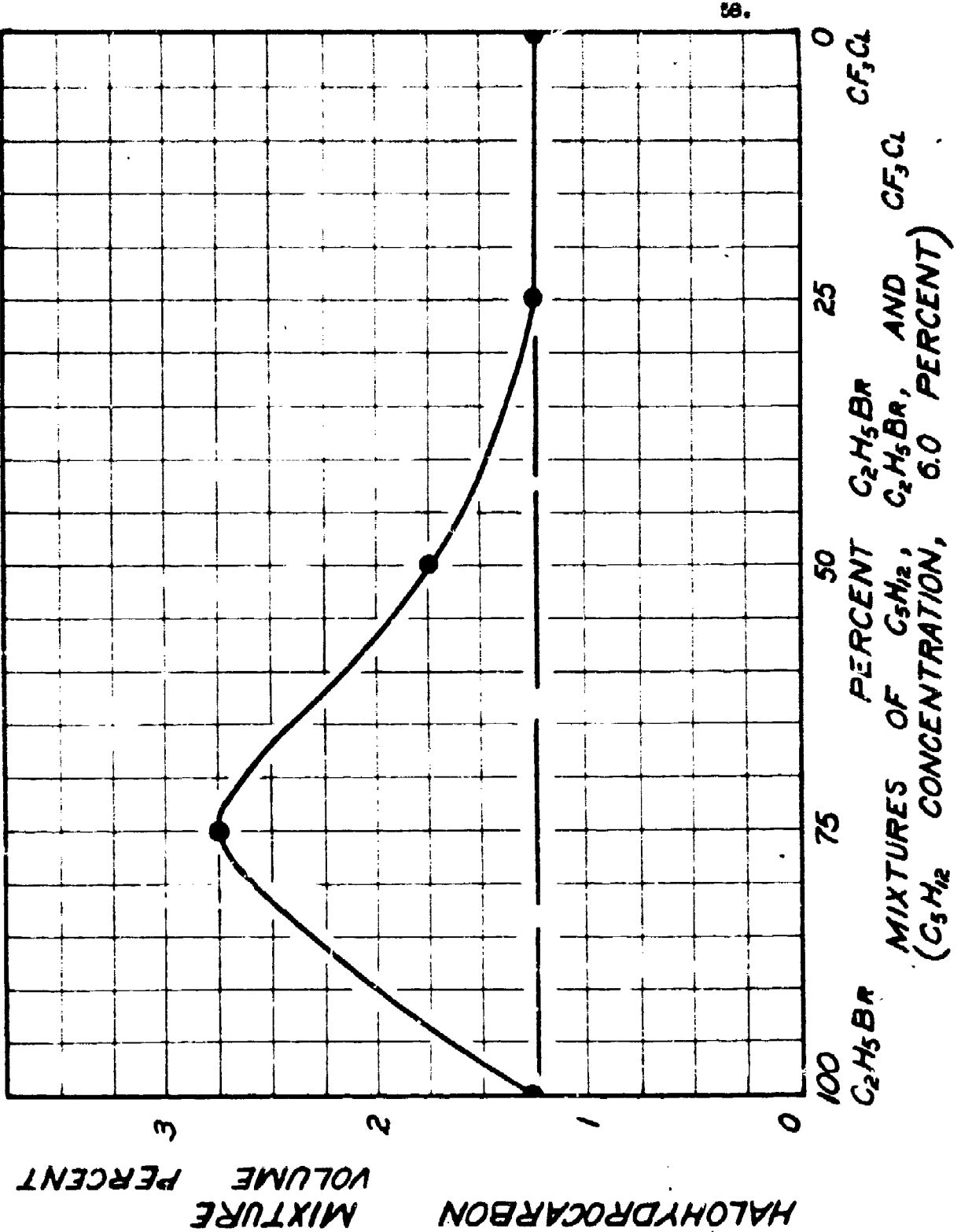


Figure 33 Effect of Binary Mixtures in Decreasing the Flammability of Air and Pentane

MIXTURE VOLUME PERCENT

100 C_2H_5BR 75 50 25 0
 PERCENT MIXTURES OF C_2H_5BR , AND CF_3Cl
 (C_5H_{12} CONCENTRATION, 6.0 PERCENT)

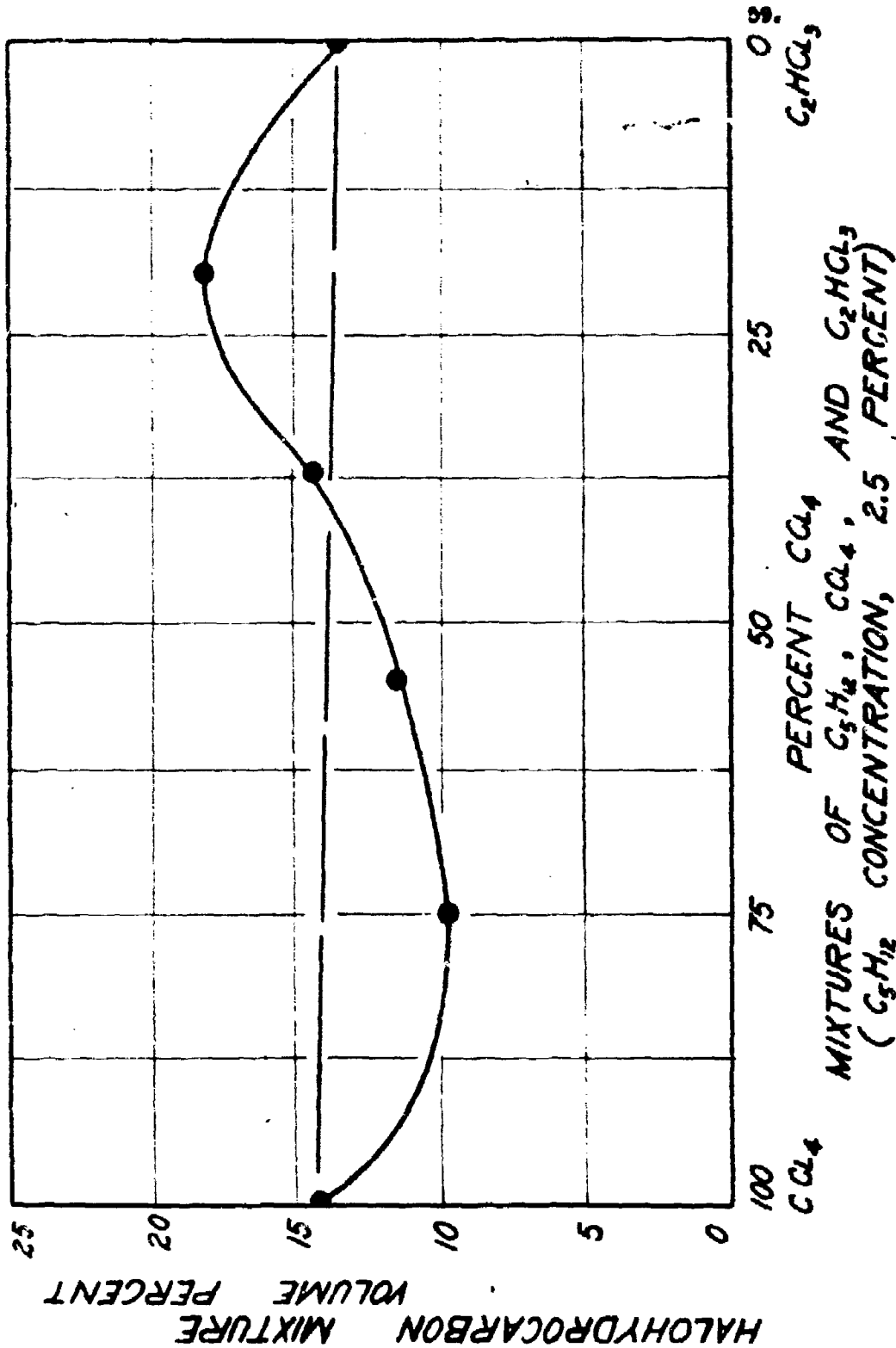
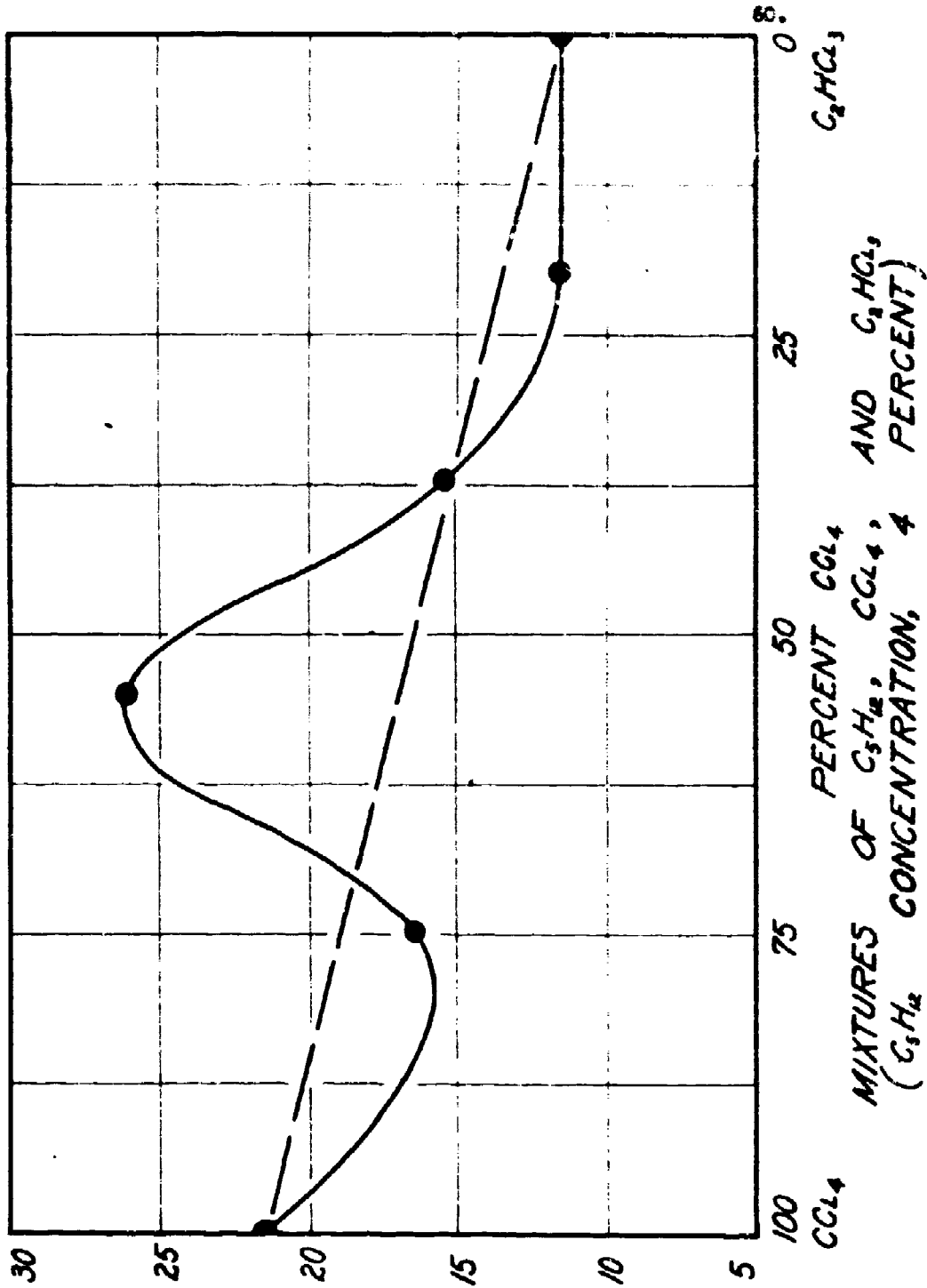
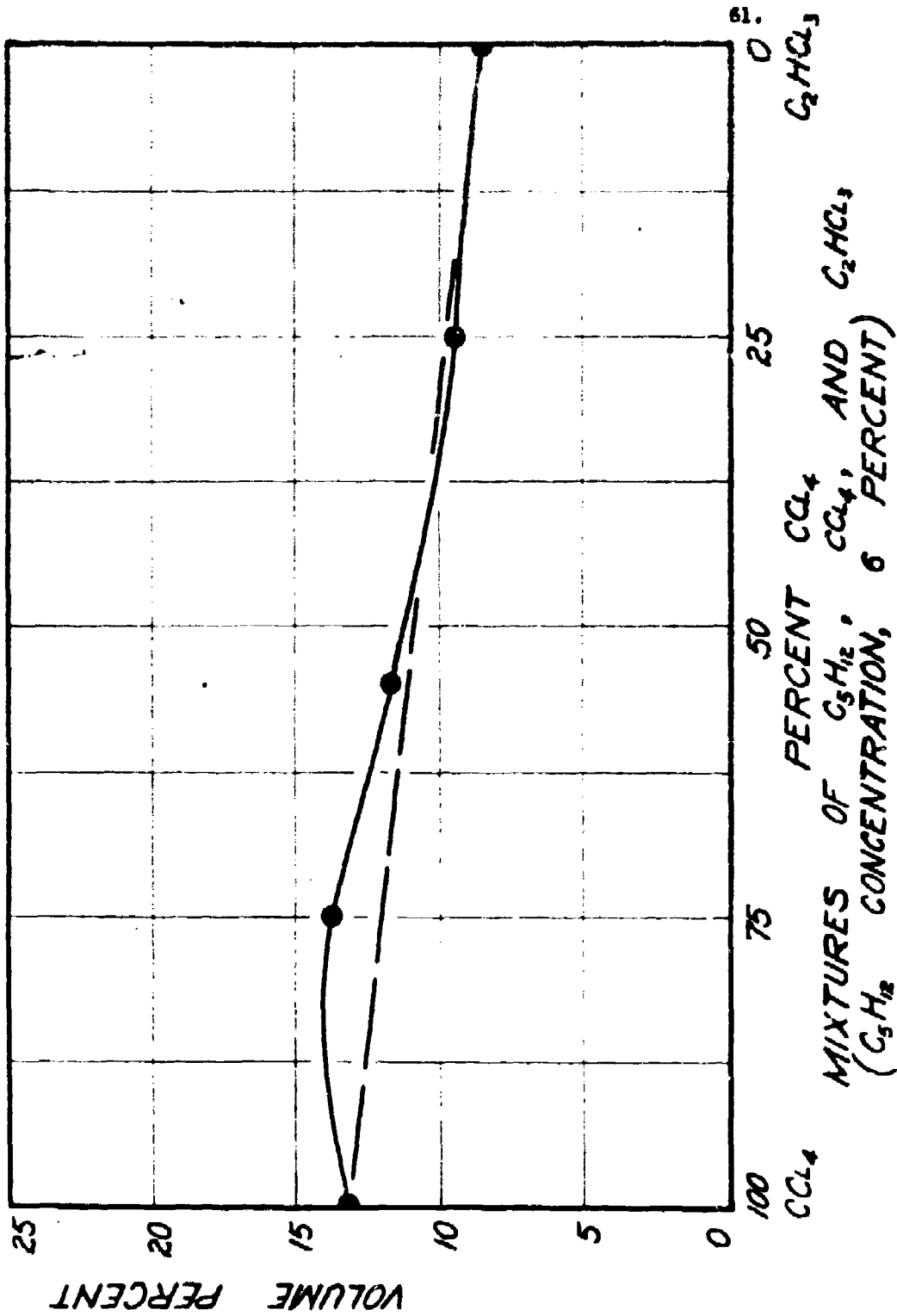


Figure 34 Effect of Binary Mixtures in Decreasing
 the Flammability of Air and Pentane



HALOHYDROCARBON MIXTURE
VOLUME PERCENT

Figure 36 Effect of Binary Mixtures in Decreasing the Flammability of Air and Pentene



Effect 36 Effect of Binary Mixtures in Decreasing the Flammability of Air and Pentane

Table VII

BINARY MIXTURES OF HALOGEN COMPOUNDS

<u>Mixture</u>	<u>Pentane, %</u>	<u>Effect</u>
CH ₃ Br-SF ₆	2.5	Synergistic over 40 to 100% SF ₆ ; less effective over other concentrations
	4.0	Synergistic over entire range
	6.0	Synergistic over entire range
CH ₃ Br-C ₄ F ₁₀	2.5	Less effective than calculated over entire range
	4.0	Synergistic over entire range
	6.0	Synergistic over entire range
CH ₃ Br-C ₂ H ₅ Br	2.5	Less effective than calculated
CH ₃ I-C ₂ H ₅ Br	2.5	Synergistic for C ₂ H ₅ Br concentrations of 65-100%; less effective than calculated at other concentrations
	4.0	Follows curve calculated
	6.0	Synergistic over entire range
CH ₂ Cl ₂ -C ₂ H ₅ Br	2.5	Synergistic over entire range
	4.0	Synergistic over entire range
	6.0	Synergistic over entire range
CClF ₃ -C ₂ H ₅ Br	2.5	Synergistic at CClF ₃ concentrations of 55-100%; less effective at other concentrations
	4.0	Synergistic at CClF ₃ concentrations of 40 to 100%; less effective at other concentrations
	6.0	Follows calculated curve 75 to 100%; less effective at other concentrations
CCl ₄ -CCl ₂ -CClH	2.5	Synergistic for CCl ₄ concentrations of 30-100%; less effective at other concentrations.

Table VII (Continued)

<u>Mixture</u>	<u>Pentane, %</u>	<u>Effect</u>
	4	Synergistic for CCl_4 concentrations of 70 to 100%, less effective than calculated at CCl_4 concentration of 28-70% and synergistic at concentration of 0 to 24% CCl_4 .
	6	Less effective at concentrations of CCl_4 from 45-100%; More or as effective for CCl_4 concentrations of 0-45%.

Effect of Pressure. As a continuation of a study of the effect of variables on the flammable limits of mixtures containing air, *n*-heptane and a halogen compound, the flammable areas at subatmospheric pressures and at room temperature were determined for these mixtures wherein methyl bromide, trifluoromethyl bromide, and dichlorodifluoromethane were used as the halogen compounds. The areas obtained at pressures of 200, 300, 400 and 500 mm. Hg. pressure are shown in Figures 37-48, inclusive. Data showing peaks in the flammable areas are summarized in Table VIII. For mixtures containing methyl bromide as the flame inhibiting agent it can be seen that not only is the flammability peak lowered with a decrease or increase in pressure from 400 mm. Hg., but that in general the flammable area lies within the area found at 400 mm. Hg pressure. But when trifluoromethyl bromide was used as the flame inhibiting agent the peak in the flammability curve was essentially the same at 300, 400 and 500 mm. Hg pressure and lower at 200 mm. Hg pressure. In the case of dichlorodifluoromethane, the peaks are equivalent at 300 and 400 mm. Hg pressure and lower at 200 and 500 mm. Hg pressure.

These examples are too few to warrant drawing any conclusions concerning the effect of pressure on the flammable areas.

Stability Tests

Specifications of the desired fire extinguishing fluid require a compound stable under any climatic condition for long periods of time. An accelerated test is desirable in a program in which a number of conditions was used in predicting the behavior of the compounds when stored. Iron, copper, aluminum, brass and magnesium were chosen for use in these studies because they are commonly encountered in materials of construction.

Stability at Reflux Temperature. Tests were conducted to show the stability of halogen compounds being investigated to iron filings, aluminum powder and copper powder. The experiments were conducted as follows: A 10 ml. sample of halogen compound was refluxed with the finely divided metal for 100 hours. The liquid was then tested for unsaturation with a solution of potassium permanganate in a acetone and the aqueous extract for halide ions using the zirconyl-alizarin "Red S" test for fluoride ion and aqueous silver nitrate for bromide and chloride ions. The test was followed with another in which 10 ml. of distilled water was added to the mixtures of organic compound and metal and the resulting mixture refluxed for 100 hours. Tests for halide ions and unsaturation were carried out as described previously. The results of these tests are summarized in Table IX. The data show that in general the compounds are quite stable to both iron and copper under the conditions of the test. Decomposition was observed with wet bromochloromethane, (not shown in Table IX) 1-bromo-2-chloroethane and carbon tetrachloride in contact with both iron filings and copper powder.

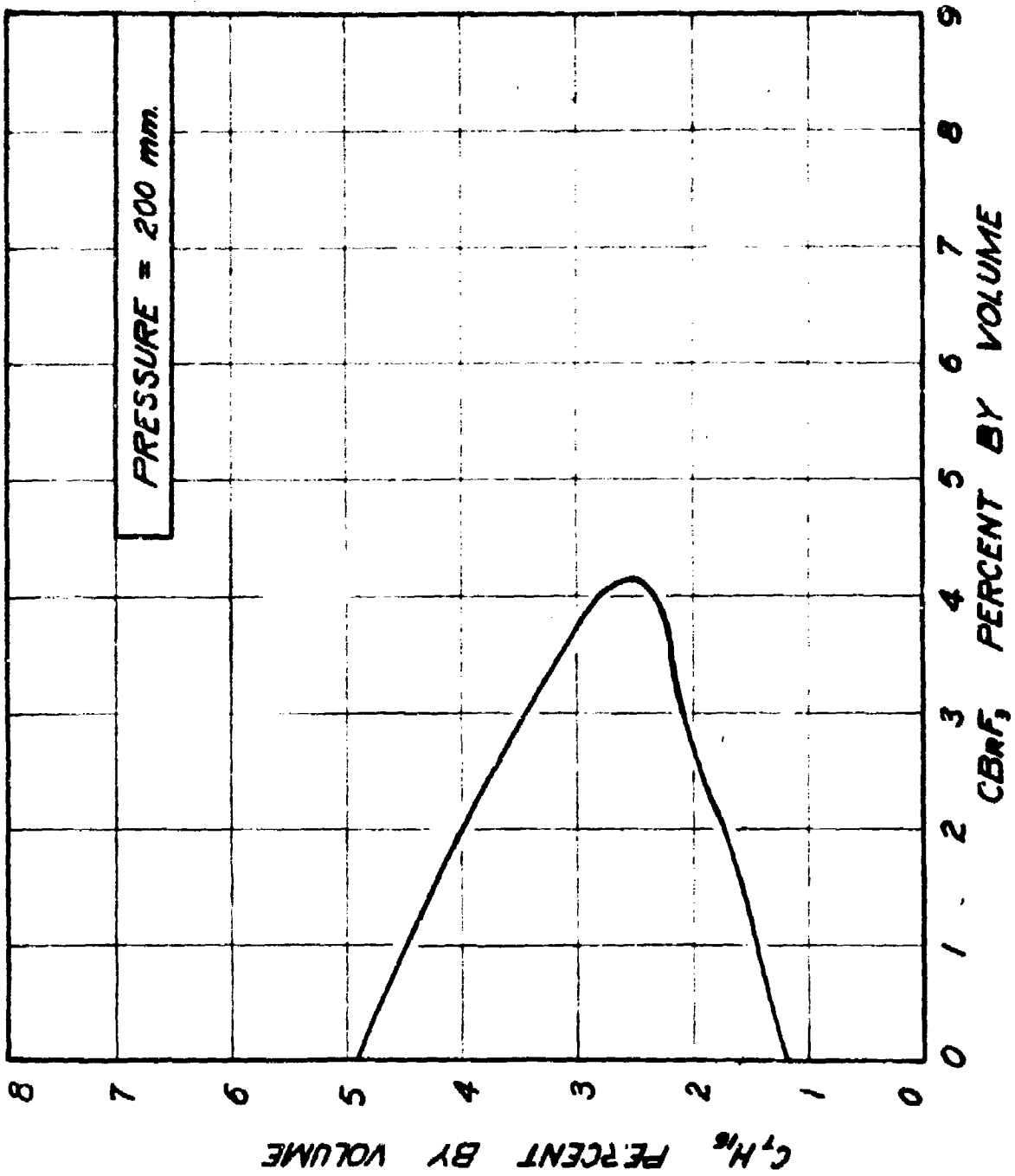


Figure 37 Effect of Pressure on Peak in the Flammability Curves

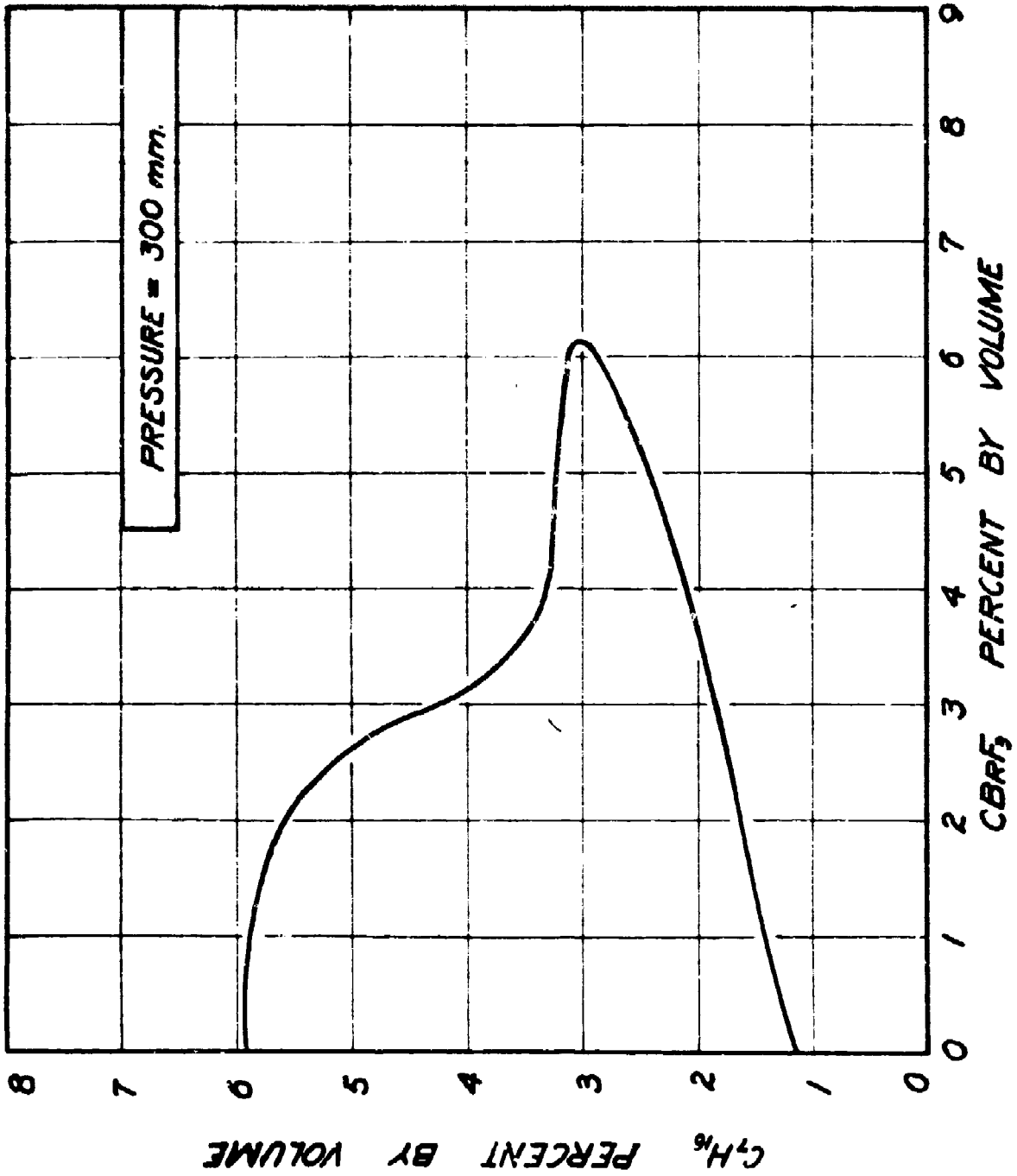


Figure 38 Effect of Pressure on the Peak in the Flammability Curves

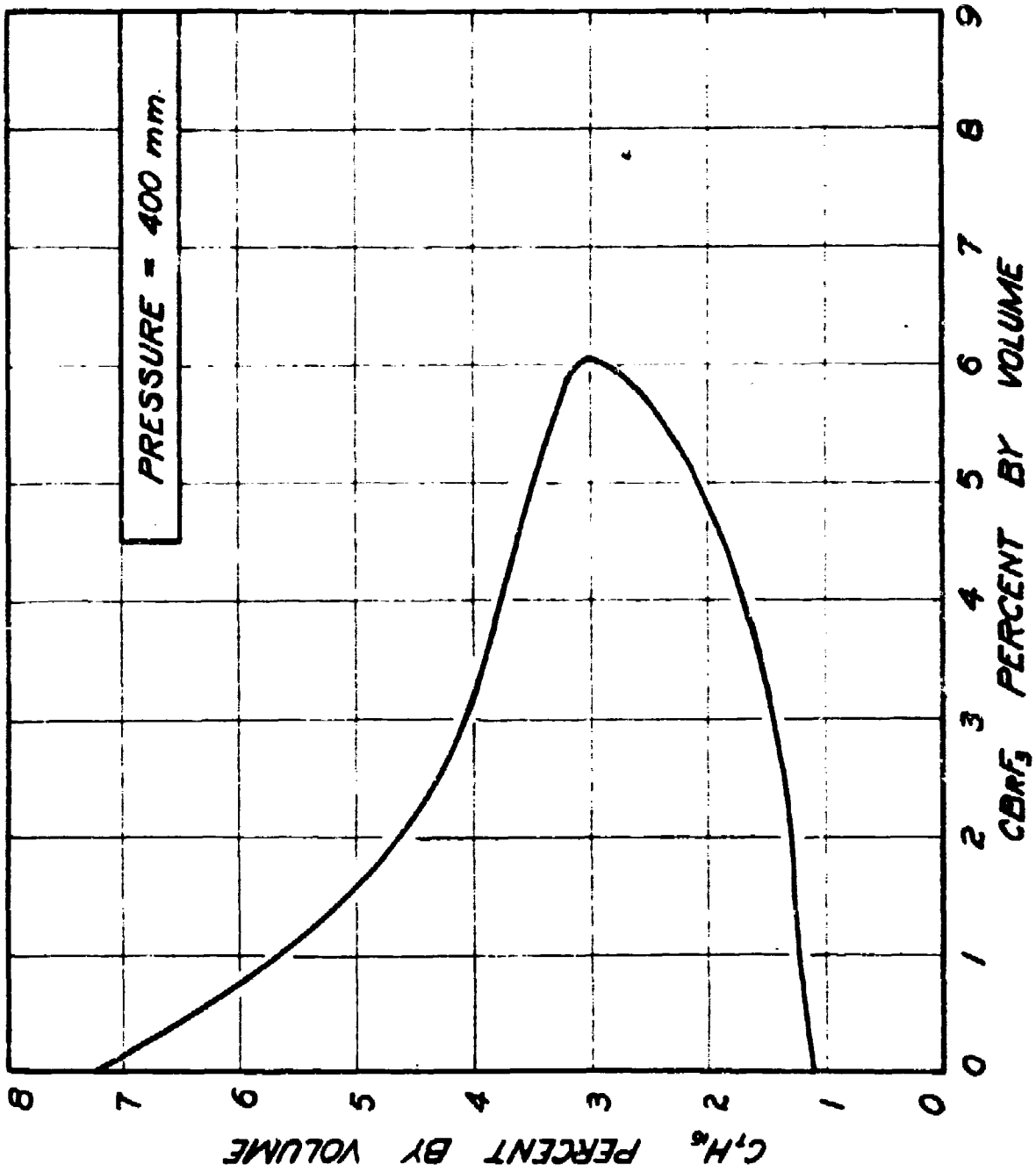


Figure 39 Effect of Pressure on Peak in the Flammability Curves

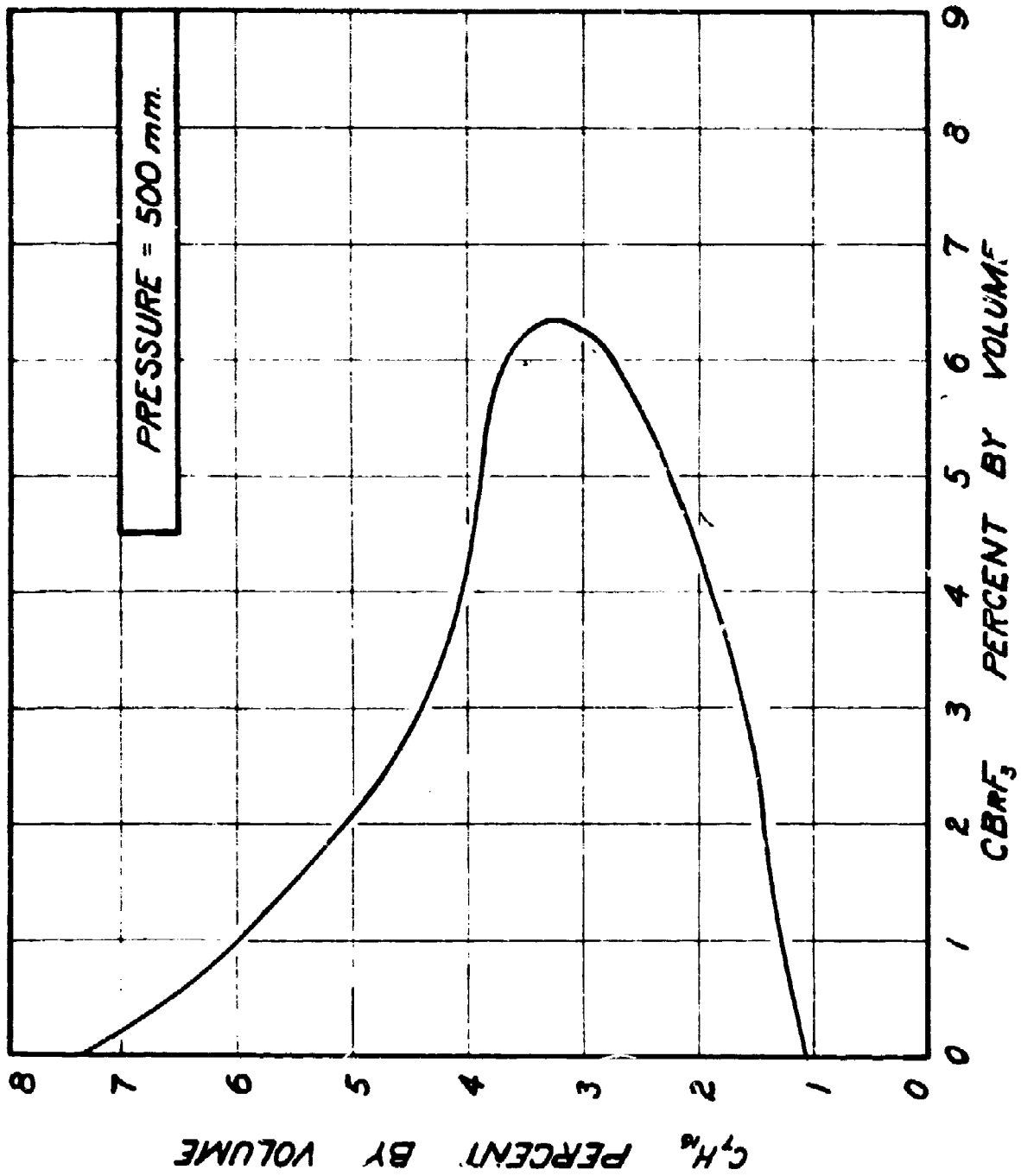


Figure 40 Effect of Pressure on Peak in the Flammability Curves

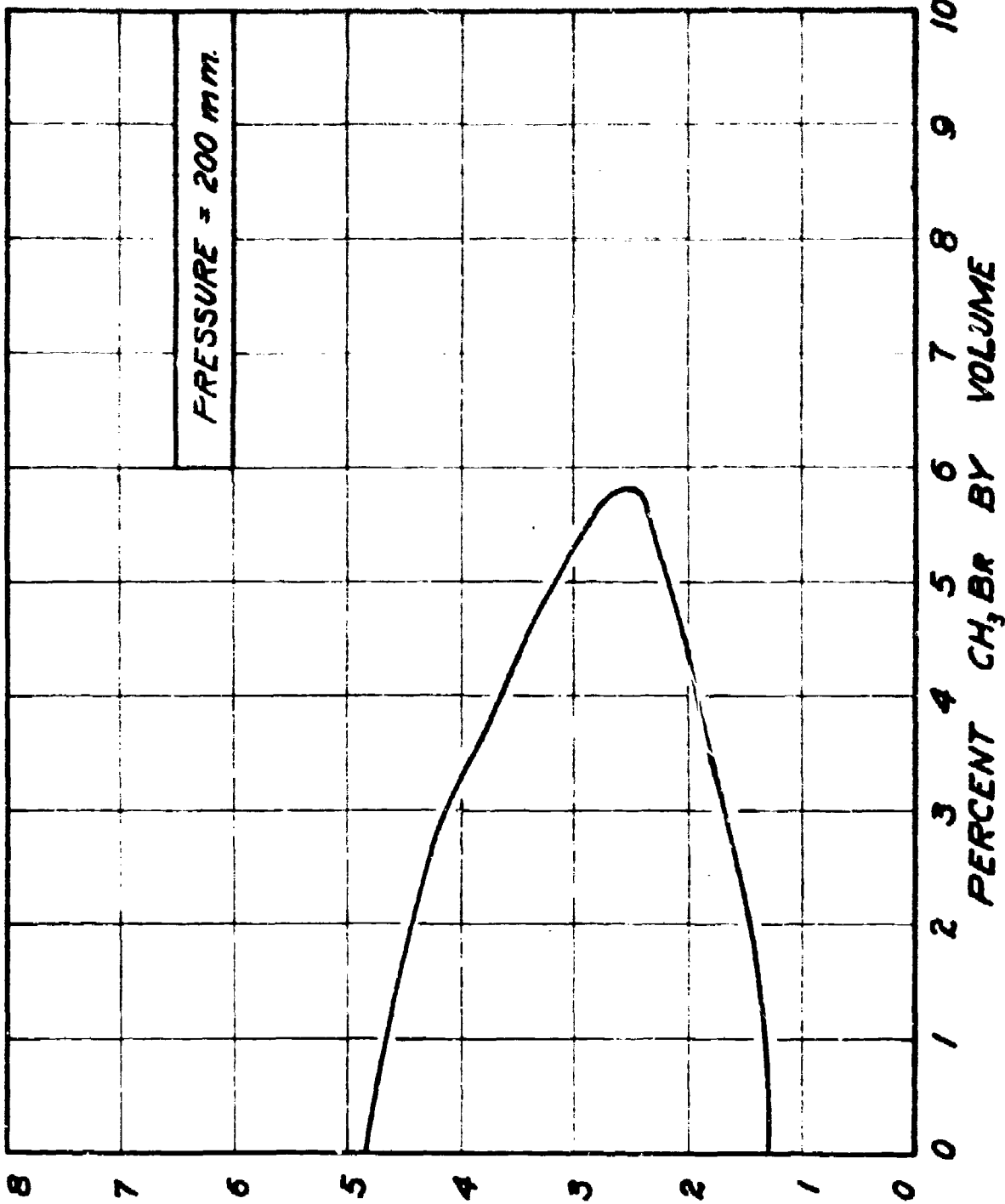


Figure 41 Effect of Pressure on Peak in the Flammability Curves

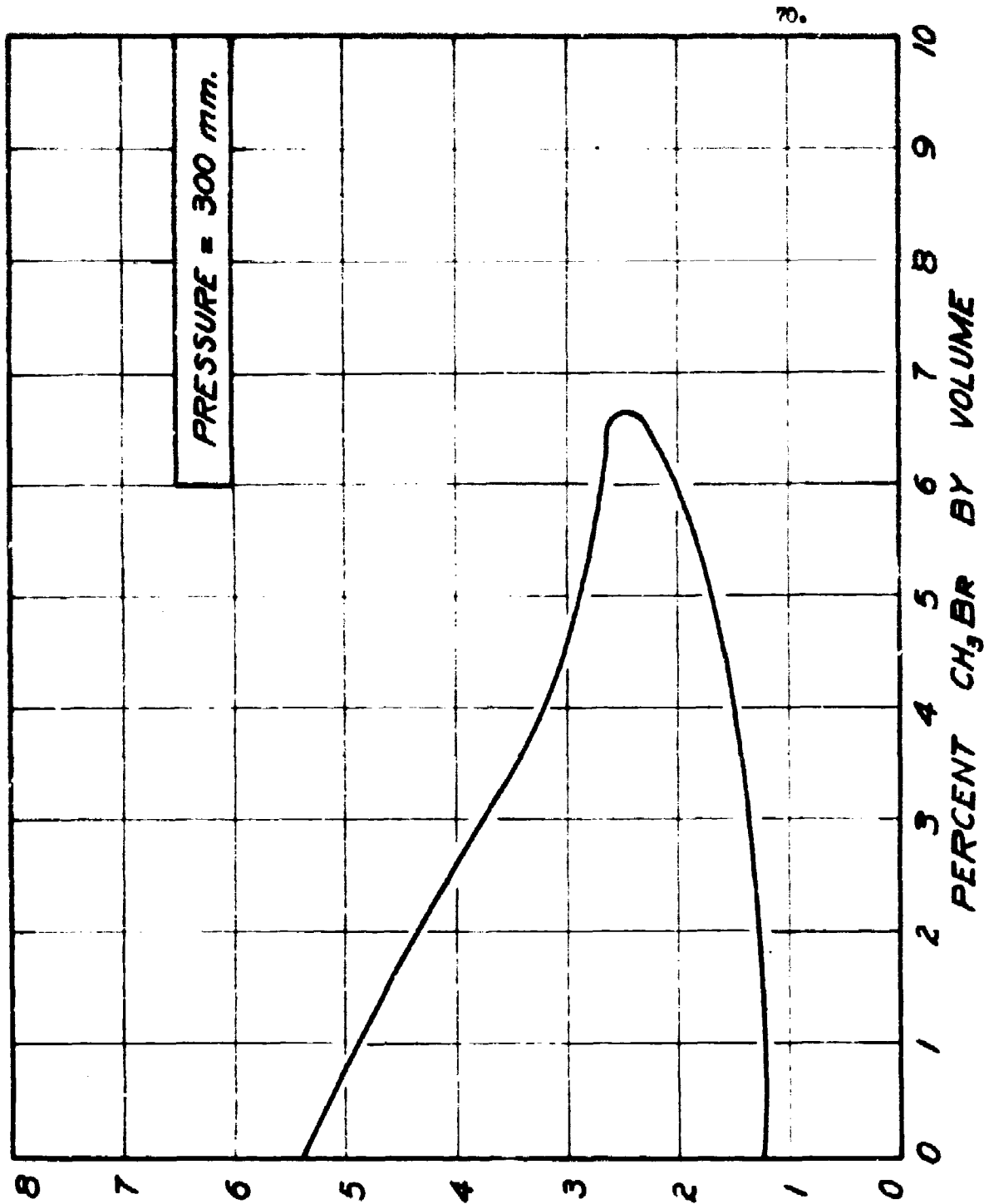


Figure 42 Effect of Pressure on Peak in the Flammability Curves

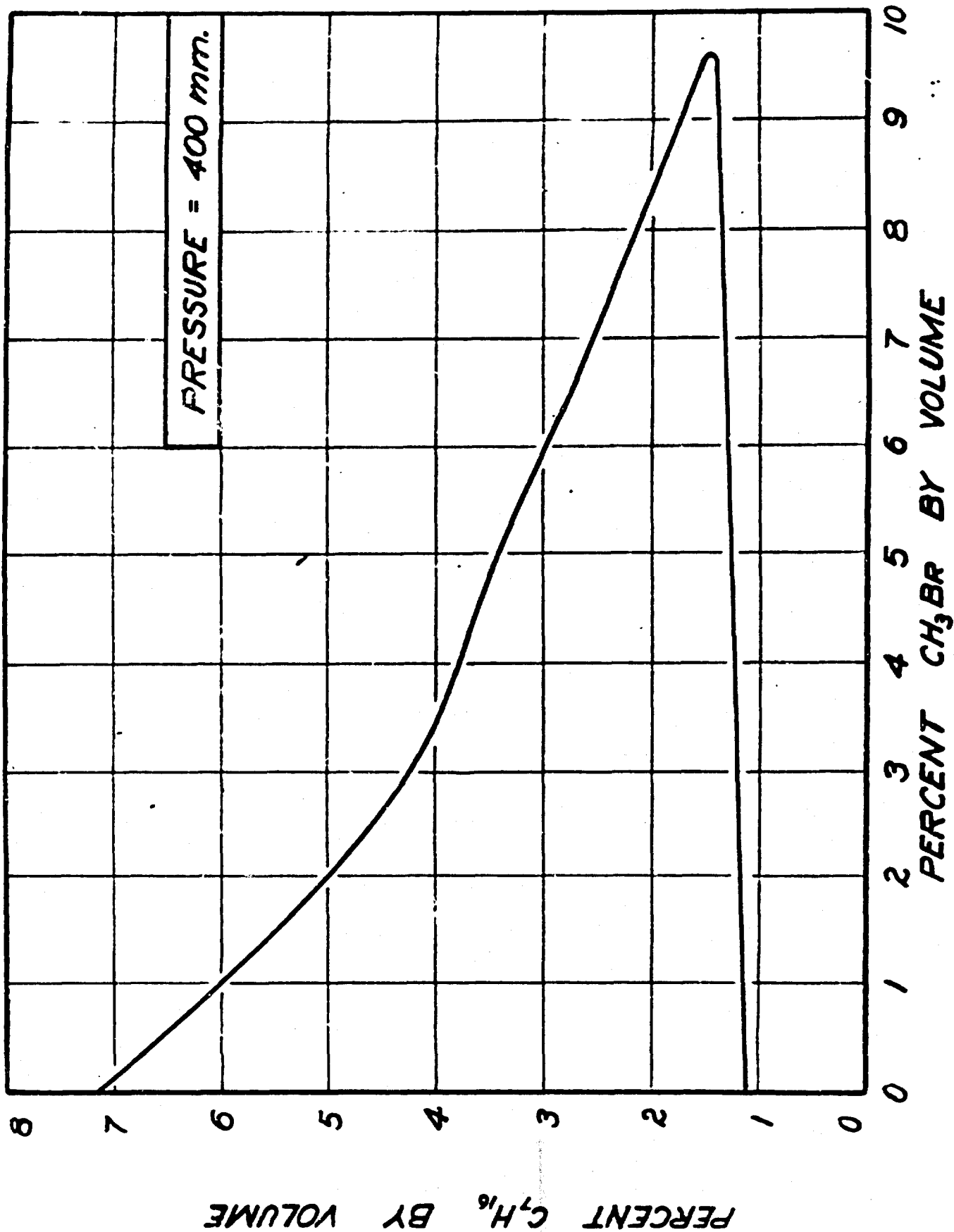


Figure 43 Effect of Pressure on Peak in the Flammability Curves

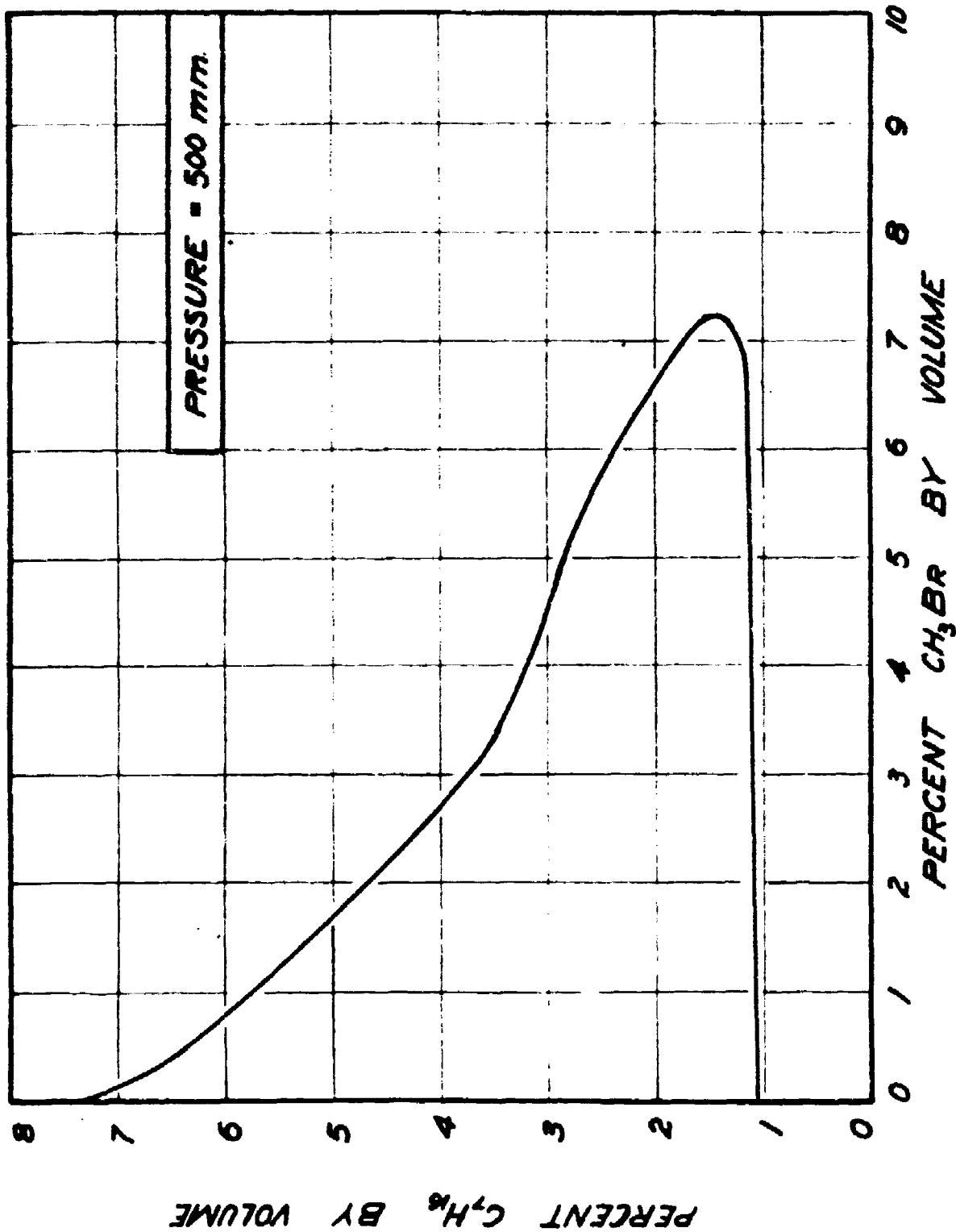


Figure 44 Effect of Pressure on Peak in the Flammability Curves

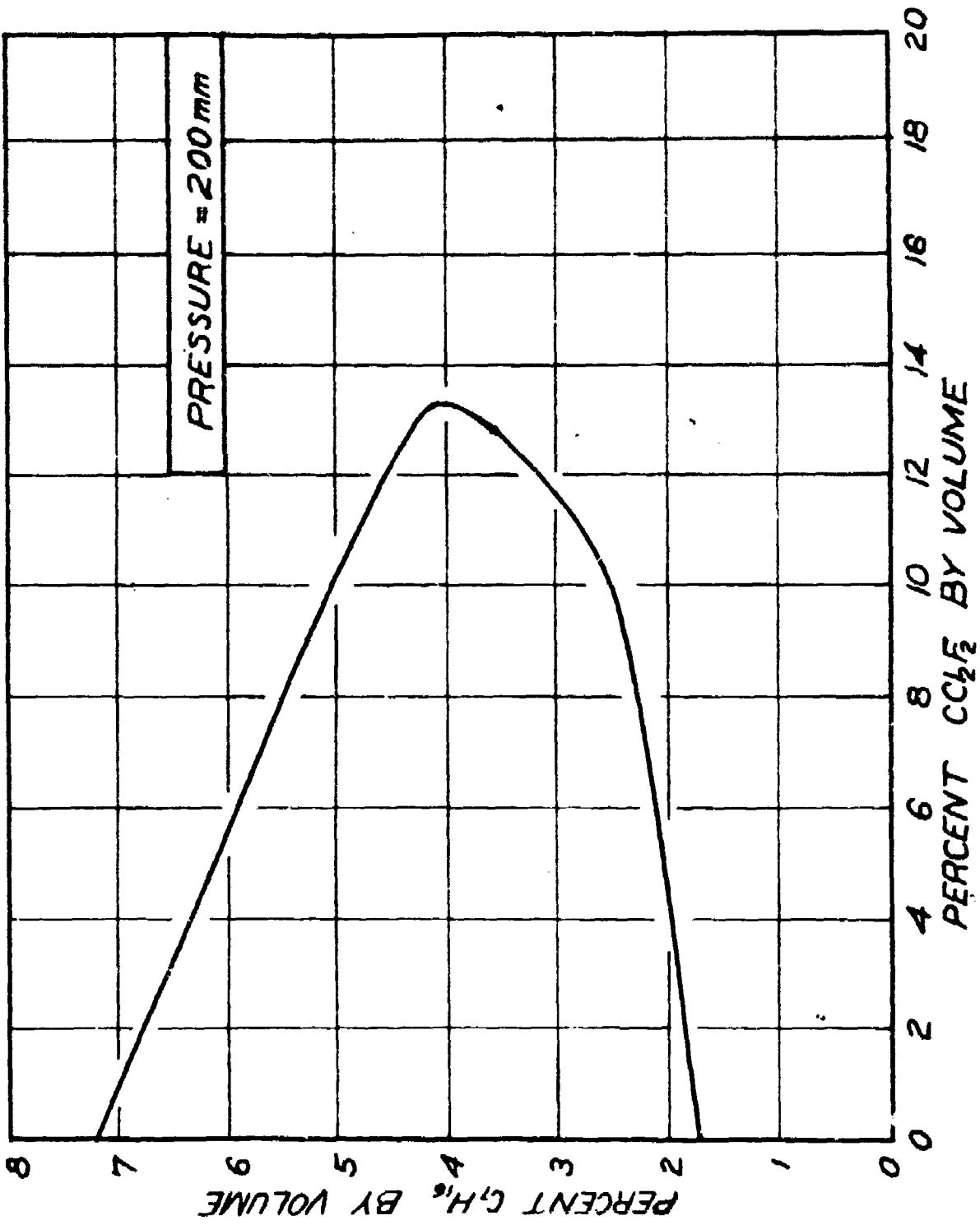


Figure 45 Effect of Pressure on Peak in the Flammability Curves

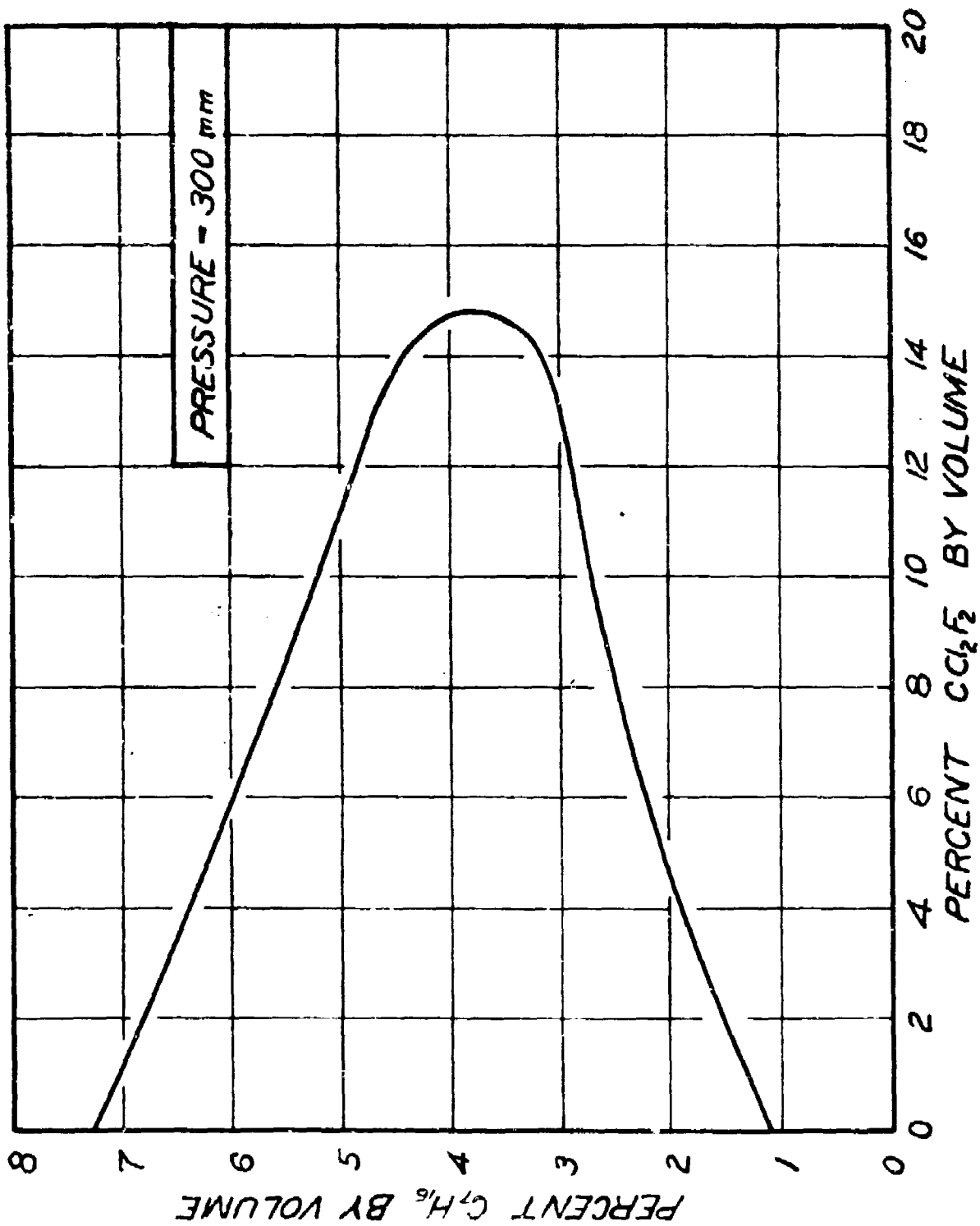
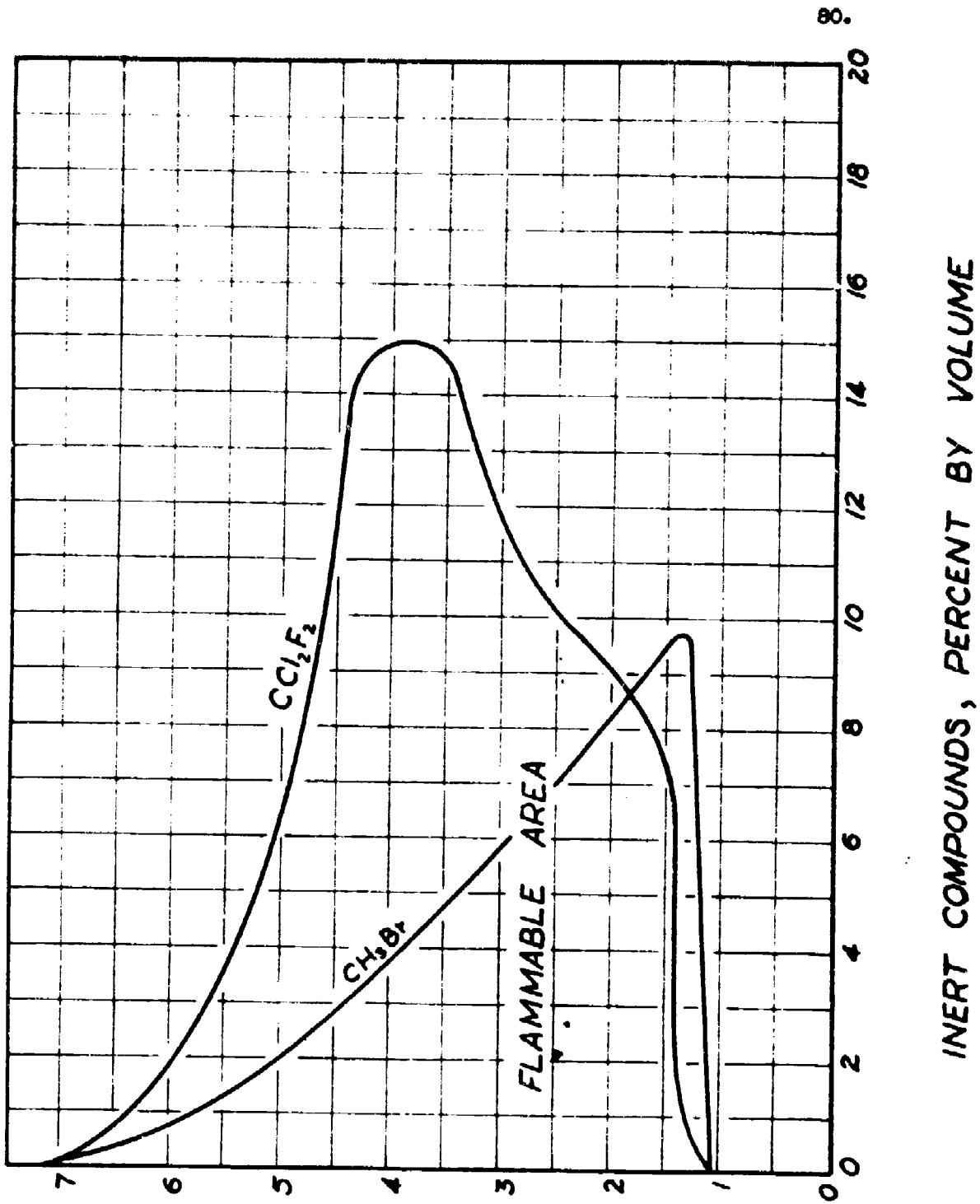


Figure 46 Effect of Pressure on Peak in the Flammability Curves



n-HEPTANE VAPOR, PERCENT BY VOLUME

Figure 47 Effect of Pressure on Peak in the Flammability Curves

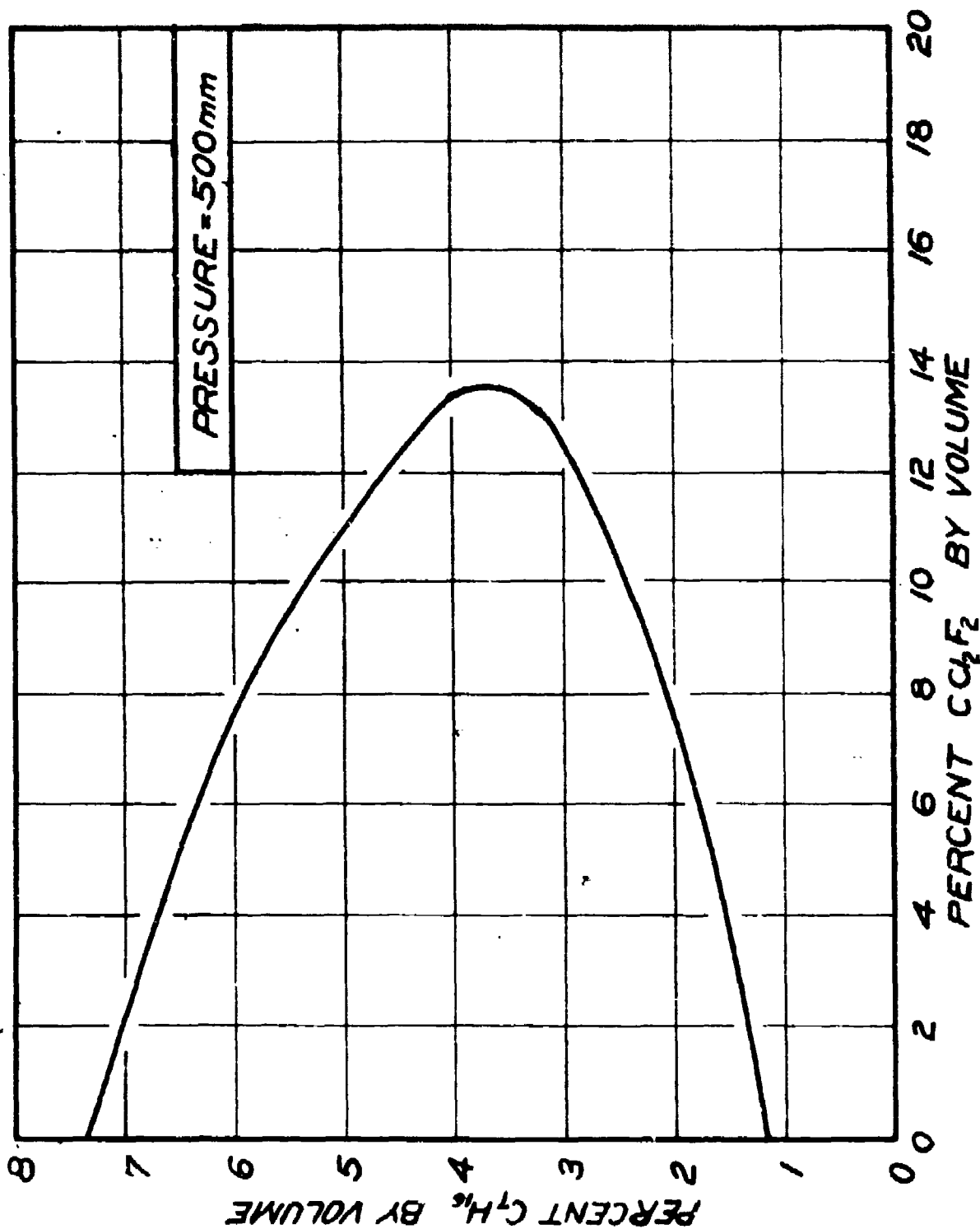


Figure 48 Effect of Pressure on Peak in the Flammability Curves

Table VIII

THE EFFECT OF PRESSURE ON THE PEAK IN THE FLAMMABILITY CURVE

<u>Compound</u>	<u>Pressure, mm. Hg</u>	<u>Peak in Flammability Curve, % Halogen Compound</u>
CH ₃ Br	200	5.8
	300	6.6
	400	9.7
	500	7.2
CBrF ₃	200	4.3
	300	6.1
	400	6.1
	500	6.3
CCl ₂ F ₂	200	13.4
	300	14.8
	400	14.9
	500	13.4

Table IX

CORROSIVE ACTION OF HALOGEN COMPOUNDS AT REFLUX TEMPERATURE
(TIME, 100 HOURS)

Compound	Anhydrous		Hydrous	
	Unsatn.	Halide Ions	Unsatn.	Halide Ions
Perfluoroheptane				
Copper Powder	-	-	-	-
Aluminum Powder	-	-	-	-
Iron Filings	-	-	-	-
Perfluoroethylcyclohexane				
Copper Powder	-	-	-	-
Aluminum Powder	-	-	-	-
Iron Filings	-	-	-	-
Perfluoro-1,4-dimethylcyclohexane				
Copper Powder	-	-	-	-
Aluminum Powder	-	-	-	-
Iron Filings	-	-	-	-
Perfluoromethylcyclohexane				
Copper Powder	-	-	-	-
Aluminum Powder	-	-	-	-
Iron Filings	-	-	-	-
Perfluoronaphthalene				
Copper Powder	-	-	-	-
Aluminum Powder	-	-	-	-
Iron Filings	-	-	-	-
Perfluoroindane				
Copper Powder	-	-	-	-
Aluminum Powder	-	-	-	-
Iron Filings	-	-	-	-
Carbon Tetrachloride				
Copper Powder	-	-	-	+
Aluminum Powder	-	-	-	+
Iron Filings	-	-	-	+
Dichloromethane				
Copper Powder	-	-	-	-
Aluminum Powder	-	-	-	-
Iron Filings	-	-	-	-
1-Bromo-2-chloroethane				
Copper Powder	-	-	+	+
Aluminum Powder	-	-	+	+
Iron Filings	-	-	+	+

+ Indicates positive tests; - indicates negative tests.

Another series of tests were conducted in which carbon tetrachloride (with and without an inhibitor) and bromochloromethane were treated in the following manner: A mixture comprising 15 ml. of the test compound and 15 ml. of distilled water was refluxed for 100 hours in the presence of polished and weighed strips of copper, aluminum and iron. The results of these experiments are summarized in Table X. These data indicate that carbon tetrachloride is more corrosive to copper and iron than bromochloromethane. In all three cases the aluminum strip was consumed.

Stability at Elevated Temperatures. A series of experiments were conducted in which the test compounds were heated in contact with strips of metal at 392°F. (200°C.). Only the materials boiling above about 50°C. were used in this study and these compounds were chosen to show the effects, if any, of structural relationships on instability.

The procedure used in this study was as follows: Polished and weighed strips of the metal and 20 ml. of the halogen compound were sealed in ampoules (Carius tubes). The tubes were inserted in iron pipes which, in turn, were placed in an oven heated at 392°F. After 30 days, the tubes were allowed to cool to room temperature and then opened. The physical appearance of each strip was noted. After removing coatings from the strips which had corroded, the strips were reweighed and changes in weight compared with the original value were recorded. This study was initiated to show the stability of halogen compounds to aluminum, copper and iron, common materials of construction. After this study was initiated it was requested that brass strips be substituted for copper strips. Data are summarized in Table XI.

Compounds showing marked instability to the metals at 392°F. were heated in contact with the same metals at 200°F. In addition, experiments were conducted in which the halogen containing compounds were heated in contact with magnesium ribbon at 200°F. Data from these experiments are summarized in Table XII. Experiments with magnesium deviated from the experiments with the other metals in one respect, namely, after two weeks at 200°F. the ampoule was removed from the oven, cooled to room temperature, and the contents examined visually. Those ampoules in which there was little or no attack on the magnesium were returned to the oven for a second period of heating.

The compounds have been divided into four groups, according to the weight change in the metal. Group A contains those compounds in which the weight change was less than 0.01 g. Group B contains those compounds in which the weight change was between 0.01 and 0.1 g. Group C contains those compounds in which the weight change was greater than 0.1 g. and less than complete consumption of the metal. Group D contains those compounds in which the metal was completely consumed. The stability of halogen-containing compounds toward metals according to these classifications are summarized in Table XIII. Data show that

Table X

CORROSIVE ACTION AT REFLUX TEMPERATURE, UNDER AQUEOUS CONDITIONS
(TIME = 100 HOURS)

<u>Compound</u>	<u>Weight of Metals, g.</u>		<u>Change in Weight</u>	
	<u>Original</u>	<u>Final</u>	<u>g.</u>	<u>%</u>
Carbon Tetrachloride				
Copper	1.8449	1.7271	-0.1178	7
Aluminum	1.2891	0.0000	-1.2891	100
Iron	3.4522	2.4549	-0.9973	29
Carbon Tetrachloride (with inhibitor)				
Copper	1.8289	1.7306	-0.0983	5
Aluminum	1.2921	0.0000	-1.2921	100
Iron	3.2768	2.1348	-1.1420	32
Bromochloromethane				
Copper	1.7705	1.7652	-0.0053	nil
Aluminum	1.3454	0.0000	-1.3454	100
Iron	3.4169	2.8851	-0.5308	16

Table XI

STABILITY AT 392°F. (200°C.) FOR 30 DAYS

Compound	Weight of Metals, g.		Change in Weight		Appearance
	Original	Final	g.	%	
Carbon Tetrachloride (with inhibitor)					
Copper	1.8297	0.0000	-1.8297	-100	Completely corroded
Aluminum	1.1894	0.0000	-1.1894	-100	Completely corroded
Iron	3.0947	0.0000	-3.0947	-100	Completely corroded
Carbon Tetrachloride (without inhibitor)					
Copper	1.7005	0.0000	-1.7005	-100	Completely corroded
Aluminum	1.4000	1.3567	-0.0433	-3	Gray coating
Iron	2.8319	2.7562	-0.0757	-3	Black coating
Dichloromethane					
Copper	1.7005	0.0000	-1.7005	-100	black, completely corroded
Aluminum	1.4190	1.3393	-0.0797	-6	black coating
Iron	3.1027	3.0785	-0.0242	-8	black coating
Bromochloromethane					
Copper	1.8078	0.0000	-1.8078	-100	Completely corroded
Aluminum	1.1758	0.6501	-0.5257	-45	Corroded
Iron	2.7196	2.7351	+0.0156	+1	Red coating
Dibromomethane					
Copper	1.7856	0.0000	-1.7856	-100	Completely corroded
Aluminum	1.1824	0.7041	-0.4783	-40	Corroded
Iron	3.2240	3.1121	-0.1119	-34	Red coating
1,1,2-Trichlorotri- fluoroethane					
Copper	1.8443	0.9085	-0.9358	-51	Gray coating
Aluminum	1.1920	1.1920	0.0000	0	Slight discoloration
Iron	3.0530	3.0530	0.0000	0	Slight discoloration
1-Bromo-2-chloroethane					
Copper	1.7457	0.7730	-0.9727	-60	Black coating
Aluminum	1.4380	1.3188	-0.1192	-8	Black coating
Iron	3.2271	3.1982	-0.0289	-1	Black coating
1,2-Dibromotetrafluoro- ethane					
Copper	1.7443	1.5442	-0.2001	-11	Gray coating
Aluminum	1.4465	0.0000	-1.4465	0	Gray, completely corroded
Iron	2.9080	2.9043	-0.0037	nil	Black coating

Table XI (Continued)

STABILITY AT 392°F. (200°C.) FOR 30 DAYS

Compound	Weight of metals, g.		Change in Weight		Appearance
	Original	Final	g.	%	
3-Bromo-1,1,1-tri-fluoropropane					
Copper	1.7581	1.6965	-0.0616	-3	Gray coating
Aluminum	1.2280	1.2280	0.0000	0	No discoloration
Iron	3.1935	3.1841	-0.0094	nil	No discoloration
2-Bromo-1,1,1-tri-fluoropropane					
Copper	1.6717	1.5705	-0.1012	-6	Black coating
Aluminum	1.3970	0.0000	-1.3970	0	Completely corroded
Iron	3.2663	3.2510	-0.0153	nil	Black coating
Brass	3.5531	3.5198	-0.0333	-1	
Perfluoroheptane					
Copper	1.6055	1.6055	0.0000	0	No change
Aluminum	1.4428	1.4601	+0.0173	0	Slight tarnish
Iron	2.7258	2.7258	0.0000	0	No change
Brass	3.8199	3.8253	+0.0054	nil	
Perfluoroethyl cyclohexane)					
Copper	1.6861	1.6861	0.0000	0	No change
Aluminum	1.4149	1.4327	+0.0178	0	Slight tarnish
Iron	3.1050	3.1050	0.0000	0	No change
Brass	4.0718	4.0772	+0.0054	nil	
Perfluoro(1,3-dimethyl-cyclohexane)					
Copper	1.6838	1.6854	+0.0016	nil	Slight tarnish
Aluminum	1.3945	1.4041	+0.0096		Slight tarnish
Iron	2.8250	2.8256	+0.0006	nil	Slight tarnish
Brass	4.0095	4.0112	+0.0017	nil	
Perfluoro(1,4-dimethyl-cyclohexane)					
Copper	1.7371	1.7371	0.0000	0	No change
Aluminum	1.3883	1.4062	+0.0179		Slight tarnish
Iron	3.1313	3.1318	+0.0005	nil	No change
Brass	3.9070	3.9094	+0.0024	nil	
Perfluoro(methyl-cyclohexane)					
Copper	1.6209	1.6209	0.0000	0	No change
Aluminum	1.4803	1.5062	+0.0234		Slight tarnish
Iron	2.9908	2.9908	0.0000	0	No change
Brass	3.8367	3.8424	+0.0057	nil	

Table XI (Continued)

STABILITY AT 392°F. (200°C.) FOR 30 DAYS

Compound	Weight of Metals, g.		Change in Weight		Appearance
	Original	Final	g.	%	
Perfluoronaphthalene					
Copper	1.7350	1.7350	0.0000	0	No change
Aluminum	1.4029	0.0000	-1.4029	-100	Black, completely corroded
Iron	2.9379	2.9379	0.0000	0	No change
Perfluoroindane					
Copper	1.6678	1.6678	0.0000	0	No discoloration
Aluminum	1.4031	1.4175	+0.0144	+1	Black coating
Iron	3.8083	3.8083	0.0000	0	No discoloration
Methyl bromide					
Copper	1.8437	1.8698	+0.0261	+1	Slight discoloration
Aluminum	1.2145	1.2145	0.0000	0	No discoloration
Iron	2.8084	2.8130	+0.0046	nil	Slight discoloration
Trifluoromethane					
Copper	1.7830	1.7830	0.0000	0	No discoloration
Aluminum	1.2572	1.2572	0.0000	0	No discoloration
Iron	3.1043	3.1043	0.0000	0	No discoloration
Bromotrifluoromethane					
Copper	1.8290	1.8398	+0.0108	+1	Slight discoloration
Aluminum	1.2101	1.2110	+0.0009	nil	No discoloration
Iron	3.1116	3.1170	+0.0054	nil	Slight discoloration
Chlorotrifluoromethane					
Copper	1.8625	1.8625	0.0000	0	No discoloration
Aluminum	1.1830	1.1830	0.0000	0	No discoloration
Iron	2.9177	2.9177	0.0000	0	No discoloration

Table XII

CORROSIVE ACTION AT 200°F. (93°C.)

Compound	Time	Weight of Metals, g.		Change in Weight		Appearance
		Have Original	Final	g.	%	
Carbon Tetrachloride	30					
Copper		1.8331	1.7821	-0.0510	-3	Black coating
Aluminum		1.2198	0.6177	-0.6021	-49	Black coating
Iron		3.3224	3.2718	-0.0506	-2	Red coating
Brass		3.9153	3.9004	-0.0076	nil	
Carbon Tetrachloride (with inhibitor)	30					
Copper		1.8828	1.5780	-0.3048	-16	Black coating
Aluminum		1.1596	0.0000	-1.1596	-100	Completely corroded
Iron		3.3024	2.7677	-0.5347	-14	Red coating
1-Bromo-2-chloroethane	30					
Copper		1.7733	1.7485	-0.0248	-1	Black coating
Aluminum		1.2397	0.0000	-1.2397	-100	Completely corroded
Iron		3.2377	3.2255	-0.0122	nil	Black coating
Brass		3.9855	3.9779	-0.0076	nil	
Magnesium		0.9061	0.9177	+0.0116	1	Dull
2-Bromo-1,1,1-trifluoropropane	30					
Copper		1.8174	1.8174	0.0000	0	No discoloration
Aluminum		1.3880	1.3880	0.0000	0	No discoloration
Iron		3.6006	3.6006	0.0000	0	No discoloration
Brass		2.6455	2.6444	-0.0011	nil	
1,2-Dibromotetrafluoroethane	30					
Copper		1.8552	1.8552	0.0000	0	No discoloration
Aluminum		1.1781	1.1761	0.0000	0	No discoloration
Iron		3.4582	3.4582	0.0000	0	No discoloration
Brass		3.8064	3.8053	-0.0011	nil	
1,3-Dibromo-2,2-difluoropropane	32					
Copper						
Aluminum		1.1061	1.1063	+0.0002	nil	Bright
Iron		2.6956	2.6859	-0.0098	nil	Corroded
Brass		3.7418	3.7412	-0.0006	nil	Slightly dull
Magnesium		1.2002	1.2199	+0.0197	2	Dull, coated
1,2-Dibromotetrafluoroethane	14					
Copper						
Aluminum		1.3998	1.3843	-0.0155	1	Dull, pitted
Iron		2.9675	2.8798	-0.0877	3	Dull, pitted
Brass		3.7823	3.7513	-0.0310	1	
Magnesium		1.1434	1.2344	+0.0960	8	Dull, pitted

Table XII (Continued)

CORROSIVE ACTION AT 200°F. (93°C.)

<u>Compound</u>	<u>Time Days</u>	<u>Weight of Metals, g.</u>		<u>Change in Weight</u>		<u>Appearance</u>
		<u>Original</u>	<u>Final</u>	<u>g.</u>	<u>%</u>	
Ethyl Bromide	a	2.4042	2.3914	-0.0128	1	Badly corroded
Copper						
Aluminum		1.1212	0.9076	-0.2136		Badly eaten
Iron						
Brass		3.8040	3.7921	-0.0119		Corroded
Magnesium		1.1886	1.2760	+0.0874		Coated
Ethyl Iodide	a					
Copper		2.9471	2.9304	-0.0167		Corroded
Aluminum		0.7314	0.1138	-0.6176		Eaten away
Iron						
Brass		3.4665	3.4413	-0.0252		Corroded
Magnesium		1.2098	1.2628	+0.0530		Coated
Perfluoroheptane	27	0.8763	0.8803	+0.0040		Shiny
Perfluoro(methyl- cyclohexane)	27	0.8368	0.8420	+0.0052		Shiny
Perfluoro(ethyl- cyclohexane)	27	0.8763	0.8803	+0.0040		Shiny
Perfluoro(1,3-di- methylcyclohexane)	27	0.8408	0.8467	+0.0059		Shiny
Perfluoro(1,4-dimethyl- cyclohexane)	27	0.8530	0.8607	+0.0077		Dull
Perfluoronaphthalane	27	0.8883	0.8973	+0.0090		Dull
1,1,2-Trichlorotri- fluoroethane	14	0.9140	0.9348	+0.0208		Dull, pitted brittle

Table XIII

STABILITY OF HALOGEN-CONTAINING COMPOUNDS TO METALS
(Unless otherwise indicated, contact time = 30 days)

COMPOUND	ALUMINUM		BRASS		COPPER		IRON		MAGNESIUM	
	392°F	200°F	392°F	200°F	392°F	200°F	392°F	200°F	392°F	200°F
Halocarbons										
C ₇ F ₁₆	B	-	A	-	A	-	A	-	-	A ³
C ₆ F ₁₁ CF ₃	B	-	A	-	A	-	A	-	-	A ³
C ₆ F ₁₁ CF ₂ CF ₃	B	-	A	-	A	-	A	-	-	A ³
1,3-C ₆ F ₁₀ (CF ₃) ₂	B	-	A	-	A	-	A	-	-	A ³
1,4-C ₆ F ₁₀ (CF ₃) ₂	B	-	A	-	A	-	A	-	-	A ³
C ₁₀ F ₁₈	D	-	-	-	A	-	A	-	-	A ³
CCl ₂ FCCLF ₂	A	-	-	-	C	-	A	-	-	B ¹
CBrF ₂ CBrF ₂	D	A	-	A	C	A	A	A	-	-
CF ₂ ICF ₂ I	-	C ¹	-	B ¹	-	-	-	B ¹	-	-
CCl ₄	B	C	-	B	D	B	B	B	-	-
Halohydrocarbons										
CF ₃ CH ₂ CH ₂ Br	A	-	-	-	B	-	B	-	-	-
CF ₃ CHBrCH ₃	D	A	B	A	C	A	B	A	-	-
CH ₂ BrCF ₂ CH ₂ Br	-	A ⁴	-	A ⁴	-	-	-	B ⁴	-	B ⁴
CH ₂ BrCH ₂ Cl	C	D	-	A	C	B	C	B	-	B
CH ₂ BrCl	C	-	-	-	D	-	B	-	-	-
CH ₂ Br ₂	C	-	-	-	D	-	C	-	-	-
CH ₂ Cl ₂	B	-	-	-	D	-	B	-	-	-
CH ₃ CH ₂ Br	-	C ²	-	B ²	-	-	-	C ²	-	B ²
CH ₃ CH ₂ I	-	C ²	-	B ²	-	-	-	C ²	-	B ²

1 Contact time = 14 days

2 Contact time = 11 to 15 days

3 Contact time = 27 days

4 Contact time = 32 days

the compounds are less stable toward aluminum than to either brass, copper, iron or magnesium. There appears to be no significant difference between the stability of these compounds to brass and to copper. The compounds are most stable to iron.

As a class of compounds, the fluorocarbons are the most stable of the compounds investigated, and the monohaloalkanes the least stable. The haloalkanes containing halogen atoms on adjacent carbon atoms were less stable than the haloalkanes containing halogen atoms in the 1-3 position. This is illustrated by the fact that 2-bromo-1,1,1-trifluoropropane was less stable than 3-bromo-1,1,1-trifluoropropane. This type of instability is to be expected, since dehalogenation is one of the expected reactions between a metal and a haloalkane. This reaction occurs more readily when the halogen atoms are on adjacent carbon atoms than when there is a carbon atom between the two carbon atoms holding the halogen atoms.

The halogen compounds proved to be more stable to the metals at 200°F. than at 392°F. This was expected, since, in general, the rate of a reaction doubles each time the temperature is increased by 10°. Carbon tetrachloride containing an inhibitor, was more corrosive at 392°F than carbon tetrachloride containing no inhibitor. Perhaps the inhibitor decomposed under the conditions of the tests.

Of the liquid compounds other than fluorocarbons tested at 392°C., 3-bromo-1,1,1-trifluoropropane was the least corrosive while the carbon tetrachloride containing an inhibitor was the most corrosive.

Resistivity Measurements

A material useful in extinguishing electrical fires should be a non-conductor. Accordingly, apparatus was assembled for use in resistivity measurements. A Westinghouse Power Factor Cell (cell constant 396) and a General Radio Megohm Bridge, type 544-B, Serial No. 842, were available for use in making these measurements. Results of the determination are summarized in Table XIV. Resistivity measurements were limited to the fluorocarbons. The data obtained show that the fluorocarbons tested are, for practical purposes, non-conductors and hence would be suitable for use in combating electrical fires. It is believed that the other compounds shown to be of interest as fire-extinguishing agents are equally effective as insulators.

Attempts were made to determine the resistivity of bromotrifluoromethane following the same procedure used for the liquid fluorocarbons. Values ranging from 1×10^{10} to 1×10^{14} were obtained. When results were obtained which were variable the project was discontinued for lack of time. The data obtained indicate that bromotrifluoromethane is a non-conductor of electricity.

Table XIV
RESISTIVITY OF FLUOROCARBONS

<u>Compound</u>	<u>Resistivity, ohm cm.</u>
Perfluoro(methylcyclohexane)	4×10^{14}
Perfluoro(ethylcyclohexane)	1×10^{11}
Perfluoroindane	2×10^{14}
Perfluoro-n-heptane	2×10^{12}
Perfluoroaaphthalane	4×10^{13}

Products of Decomposition

The major part of the study of fire extinguishing agents at Purdue University was concerned with the determination of the flammable limits of mixtures of air, *n*-heptane and a halogen-containing compound. A plot of these data on coordinate paper showed graphically the flammable area for the three component mixtures. The peak in the curve defining this flammable area serves as a measure of the flame inhibition characteristics of the compound in question.

A knowledge of the behavior of compounds under conditions favoring decomposition is of interest in the interpretation of data relating to the toxicological properties and corrosive action. For compounds with favorable flame inhibition characteristics, this knowledge is also of interest in the advancement of the theoretical understanding of flame extinction. Decomposition in (a) a flame, (b) "hot zone" and (c) electric arc are of particular importance in a project relating to fire extinguishing agents. Therefore, in the final phases of this investigation, attention was directed to a study of the behavior of compounds chosen because of their flame inhibition characteristics under these conditions.

Flame Decomposition Studies. The apparatus that was used for the determinations of flammable limits was not suitable for a study of the products of combustion because the quantities of materials involved were insufficient for a total analysis. Therefore, a combustion apparatus was assembled as shown diagrammatically in Figure 41.

Compressed air was regulated by the needle valve 1 to maintain a constant flow as indicated by the calibrated flowmeter 4. Propane was released from the cylinder by means of the needle valve 2 to maintain the desired flow as shown by the calibrated flowmeter 5. The fire retarding agent was released by the needle valve from the cylinder 3 which was of 20 ml. capacity. Flowmeter 6 was used to maintain a constant gas flow from cylinder 3; however, the quantity of retarding agent used was determined by difference in weight of the cylinder before and after the experiment. The burner barrel 8 was the top of an ordinary laboratory Bunsen burner, 10.7 cm. tall, 1.0 cm. inside diameter, and wall thickness of 0.1 cm. The burner was held in place by the piece of quarter inch copper tube 7. The combustion zone was at the top of the burner. The mixture was ignited by means of the spark coil 14 and electrodes 7 and 13. The flame can be observed through the small mica window 9 and the mirror 10. The large Pyrex test tube 11, 10 cm. in diameter and 18 inches deep, made an air tight seal with the rubber stopper 12. The chimney 15 was made from a piece of stainless steel tube 14 cm. long and 6 cm. in diameter. The large goose-neck 16 was made of nickel tubing 4 cm. in diameter. The bonds in the nickel tubing and nickel-stainless steel connections were welded. The choice of the nickel tubing was arbitrary and based upon material readily available. To aid in dismantling the apparatus for cleaning, flanges 17 and 19 were provided with neoprene gaskets held in place by small bolts. The 2-liter, stainless steel beaker 18 containing

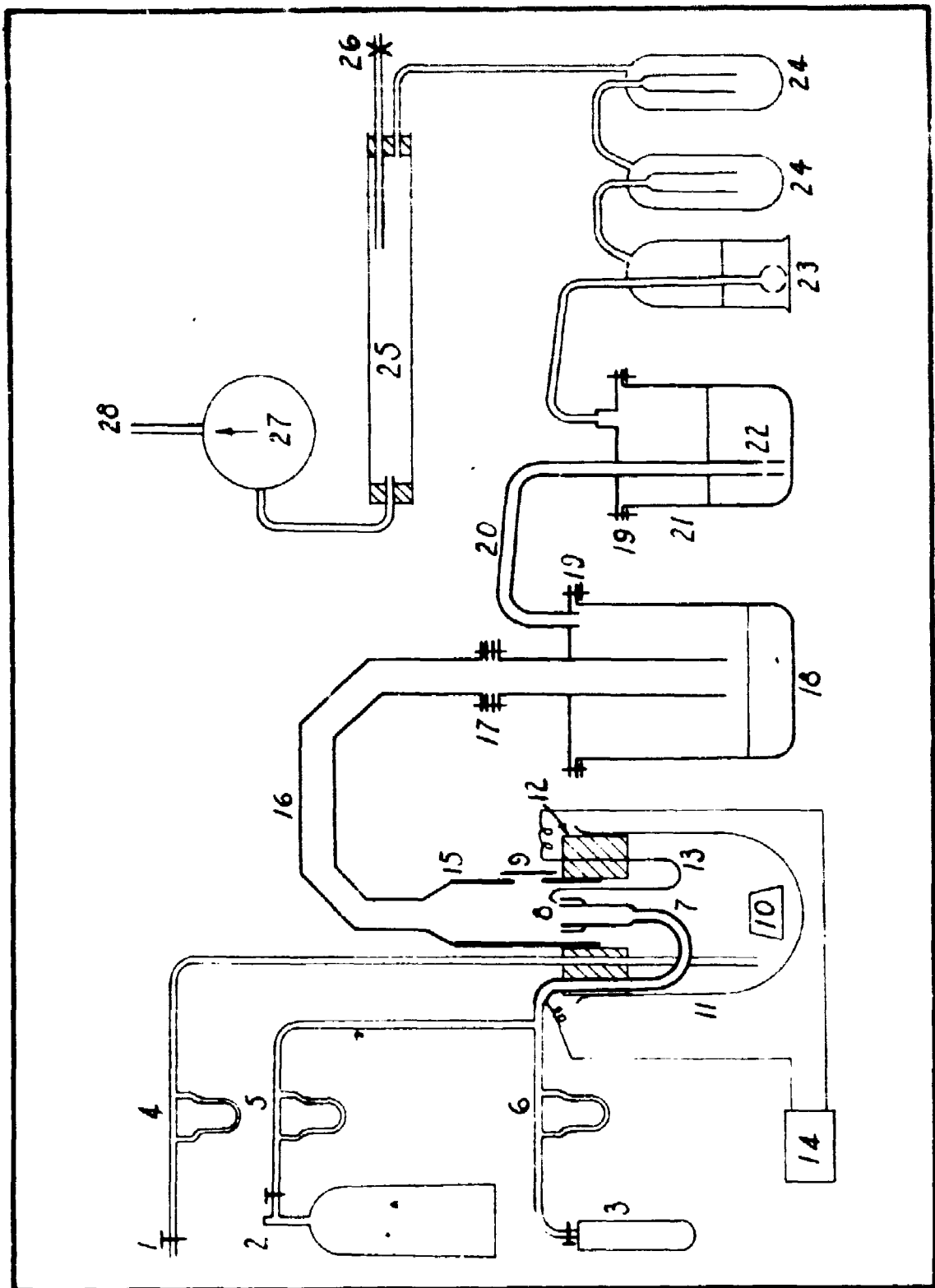


Figure 49

COMBUSTION APPARATUS

20 ml. of distilled water collected most of the soot and a large proportion of the combustion products soluble in water. The water level in 13 must not be higher than the lower edge of 16 in order to avoid large gas bubbles which would effect the flame at 8. The gas from 18 passed by means of the stainless steel tube 20, 8 mm. inside diameter, into the 1-liter, stainless steel beaker 21 containing 600 ml. of distilled water. The lower end of 20 at 22 had small holes drilled in the walls in order to disperse the gas bubbles into a fine stream for thorough contact with the water and also to maintain a constant gas pressure at 8. The gas stream leaving 21 was free of corrosive hydrogen fluoride, but a Pyrex glass scrubbing tower 23 was provided for taking out residual soluble products that may have gotten past 18 and 21. The cold finger traps 24 were chilled with Dry Ice-trichloroethylene mixture for removal of elemental halogen or other condensible products. Samples of gas were withdrawn at 26 for analysis on a Burrell gas analyser. The last traces of soot settled out in the tube 25, 100 by 5.2 cm. The gases then passed through the West Test meter 27 and was vented to the hood at 28.

The propane and air flows were adjusted so that the resulting flame was luminous but not smokey. The halogen compound was added (as a gas) to the propane stream or to the air stream through a T-tube so as to be premixed before burning.

In all runs the flow rates of propane and air were adjusted at 0.238 and 7.18 moles per hour respectively. After the mixture was burning steadily, the fire retarding agent was introduced slowly in increasing amounts until the flame tended to go out. The amount of the fire retarding agent was then decreased slightly and the combustion was allowed to burn for the desired time. At the completion of a run, the apparatus was dismantled and the soot in 15 and 16 was brushed loose for weighing. The contents of the scrubbers 18, 21, and 23 and of the cold fingers 24 were filtered by suction and thoroughly rinsed with distilled water. The soot was dried at 110°C. and weighed. The filtrate was diluted to 2000 ml. from which aliquots were taken for chemical analysis.

Analysis data for the combustion products of several halogen compounds are summarized in Table IV.

Analytical Procedures. - Aliquots of the scrubbing solutions were taken for analysis at the completion of each run. Chloride and/or bromide ion was determined gravimetrically by precipitation with silver nitrate¹⁹. Fluoride ion was determined gravimetrically by precipitation as calcium fluoride²⁹.

A Burrell De Luxe Build-Up Model J gas analyser was used for the analysis of the gaseous mixture coming from the water scrubbers⁵. Carbon dioxide was absorbed in 30 per cent aqueous potassium hydroxide. Illuminants or unsaturated organic compounds were absorbed in 30 per cent oleum. Oxygen was determined by absorption in alkaline sodium hydrosulfite. Hydrogen was determined by oxidation to water. Carbon monoxide was determined by oxidation to carbon dioxide followed by absorption of the carbon dioxide in a 30 per cent potassium hydroxide solution. Total paraffins or saturated hydrocarbons were analysed by catalytically oxidizing to water

and carbon dioxide. Nitrogen was determined by difference.

Samples of gas were collected for analysis with respect to organic constituents according to the procedure which follows:

A quantity of gas, 38 to 76 liters, was scrubbed with 30 per cent potassium hydroxide and then with aqueous sodium hydrosulfite to remove carbon dioxide and oxygen, respectively. Carbon dioxide was removed to facilitate later rectification, and oxygen was removed to avoid a possible explosion hazard. The gas was passed from the scrubbers through a trap cooled with liquid nitrogen which condensed all of the organic components along with some residual oxygen and a little nitrogen. This mixture was then rectified on the Podbielniak Hyd-Robot low temperature fractionating column. In all cases, there was a large forerun of non-condensable material consisting of oxygen and nitrogen. The quantities of the various components present were calculated from the resulting rectification curves.

The results of these rectifications may be summarized as follows:

Run No. 12. - It was found that approximately 4% of carbon tetrafluoride was destroyed when it was premixed with propane and then burned in air. This value was obtained by analysis of the fluoride ion present in the hydrolysis solution. The object of this experiment was to see how much of the carbon tetrafluoride could be recovered from the combustion products by rectification. Propane and carbon tetrafluoride were first premixed before burning in air. Flow rates of propane, carbon tetrafluoride, and air were 0.238, 0.244, and 7.18 moles per hour, respectively. After burning and stripping off the non-condensable material carbon tetrafluoride was present to the extent of 0.072 mole per 76 liters of gas. This corresponds to 63 per cent of the carbon tetrafluoride originally introduced.

Run Nos. 17 and 18. - Nineteen liters of gas collected from each run were combined for the rectification. A trace of ethane, b.p. range -87 to -88°C. was indicated. No trace of dibromodifluoromethane was found, thus indicating that it was completely decomposed.

Run No. 19 - For this experiment, 76 liters of gas were collected and three fractions were isolated. Methane, b.p. -166°C., was present to the extent of 0.0031 mole per 76 liters of gas and ethane, b.p. -86 to -87°C. was present to the extent of 0.0047 per 76 liters of gas. The third fraction, b.p. -136°C., is of unknown composition, and was present to the extent of 0.0015 mole per 76 liters of gas.

Run No. 20 - Only carbon tetrafluoride was present to the extent of 0.184 mole per 76 liters of gas. This corresponds to 56 per cent of the carbon tetrafluoride originally introduced.

Discussion of Results. - Table XV presents a summary of the results of analysis of the products of combustion. In all cases, considerable soot formation occurred except for carbon tetrafluoride and sulfur hexafluoride where only trace amounts were noted. The amount of

Table XV

SUMMARY OF ANALYSIS OF PRODUCTS OF COMBUSTION

Run Number	6	8	9	10	11	12	13	14	16	18	19	20
Air, Moles	7.18	7.18	7.78	6.82	8.26	4.19	5.15	4.55	5.03	5.63	4.19	14.8
Propane, moles	0.238	0.238	0.258	0.226	0.274	0.139	0.171	0.151	0.167	0.187	0.138	0.492
Halogen compound moles	0.0918	CH ₃ Br	CBrF ₃	CHClF ₂	CClF ₃	CF ₄	C ₂ F ₆	SF ₆	CBr ₂ F ₂	CBr ₂ F ₂	CH ₃ Br	CF ₄
Carbon, g. (calcd.)	1.10	1.10	1.02	2.10	1.439	2.673	6.766	22.75	1.548	0.630	1.590	17.167
Total halogen, g. (calcd.)	7.34	11.57	12.82	11.08	16.93	28.55	43	38	24.90	10.379	10.6	108.7
Combustion time, minutes	60	60	65	57	69	35	43	38	42	47	35	124
Combustion Products												
Analytical Data												
Scrubbing Solutions	None	0.8930	1.0631	0.3894	0.5199	Trace	0.7506	Trace	2.2551	0.7949	0.6613	0.1365
Soot, g.		84.30	76.80	91.80	91.35		91.48					
Carbon, %		0.99	1.45	0.52	0.83		0.86					
Hydrogen, %			4.615	5.994	5.817	0.6054	22.85	16.64	3.14	1.74		1.32
Fluoride ion, g.												
Chloride ion, g.												
Bromide ion, g.												
Total halide ion, g.		8.365	6.921						13.95	6.750	6.453	1.32
Gaseous Mixtures after		8.365	11.536	11.923	9.595	0.6054	22.85	16.64	17.09	8.49	6.453	
Water Scrubbers,												
% by volume	3.38	2.72	3.42	4.58	5.05	8.94	10.48	5.31	4.33	5.20	5.58	10.40
Carbon dioxide	0.12	0.20	0.39	0.51	0.00	0.04	0.05	0.00	0.49	0.36	0.51	0.10
Illuminants	14.51	15.51	14.83	14.29	13.64	5.90	6.26	9.48	11.36	0.84	4.98	2.40
Oxygen	0.00	0.04	0.13	0.19	0.16	0.31	1.08	2.19	1.99	1.70	1.12	0.70
Hydrogen	0.16	0.60	0.31	0.22	1.02	0.02	0.84	0.31	0.33	0.10	0.30	0.40
Carbon Monoxide	0.50	0.85	0.20	0.24	0.74	0.14	0.36	1.29	0.95	0.80	1.02	0.46
Total paraffins	81.33	80.08	80.72	79.97	79.39	84.65	80.93	81.47	80.55	85.00	86.49	85.54
Nitrogen												

a The propane and halogen compound were premixed before entering the combustion zone for burning.

b The air and halogen compound were premixed before entering the combustion zone for burning.

c Nitrogen was obtained by difference and may contain some inert fluorine compounds.

soot obtained was always a little less than the amount of carbon present in the halogen compound introduced. This suggests that soot formation arises from the halogen compound and not from the propane, a point which could be checked by burning a halogen compound containing labeled carbon. The analysis for total halide ion gives the degree to which the halogen compound is decomposed. Due to the hydrolytic action of the water scrubbers, only total halide ions were determined. Possible halogen compounds such as carbonyl halides or easily hydrolysed organic halides were not determined qualitatively or quantitatively since their structure would be destroyed by passing through water. From the results of Table XV it is apparent that all of the halogen compounds except carbon tetrafluoride tested are largely decomposed. The percentage decomposition of the halogen compound when premixed with the propane stream can be determined by dividing the calculated total halogen introduced into the total halide ion found by analysis of the combustion products. In Table XVI flammability peaks and per cent decomposition are tabulated for the halogen compounds tested when premixed with the propane stream. Halogen compounds having low values for the flammability peaks have high values of per cent decomposition with the exception of dibromodifluoromethane.

Halogen compounds containing bromine or chlorine in addition to fluorine were largely destroyed and since those compounds having strong fire retarding characteristics contain bromine and/or chlorine in addition to fluorine, it can be expected that they will be largely destroyed in a flame. Dibromodifluoromethane appears to be an exception to that observation since it has a flammability peak of 4.2 but is decomposed to the extent of 69 per cent (%) as determined by the quantity of halide ion formed.

In the case of sulfur hexafluoride, no total sulfur balance was obtained but free sulfur, sulfur dioxide, and hydrogen sulfide were identified. The concentration of hydrogen sulfide in the gas stream was of the order of 5×10^{-4} grams per liter.

There appears to be very little difference in the results obtained by introducing the halogen compound with either the air or the propane.

Examination of the results of the gas analysis in Table XV shows that the introduction of the halogen compound to the propane-air mixture is accompanied by a decrease in the completeness of combustion as evidenced by increases in the amounts of illuminants, hydrogen and carbon monoxide produced. Two exceptions are noted. Carbon tetrafluoride and octafluoropropane seem to enhance the degree of combustion as noted by the large increase of carbon dioxide produced.

Pyrolysis Studies - Three types of experiments were conducted in this category; namely, heating the halogen compound, in the presence of and in the absence of air, at 800°C. in an iron pipe heated to 800°C. and heating the halogen compound in a platinum tube at 800°C. in the absence of air. Details of these experiments are as follows:

100.

Table XVI

RELATION OF FLAMMABILITY PEAK TO PER CENT
DECOMPOSITION OF HALOGEN COMPOUNDS

<u>Halogen Compound</u>	<u>Flammability Peak</u>	<u>Decomposition, %</u>
CBr_2F_2	4.2	69
CBrF_3	6.1	100
CH_3Br	9.7	114
CClF_3	12.3	87
CHClF_2	17.9	93
C_3F_8	-	80
SF_6	20.5	73
CF_4	26	4

Pyrolysis Studies in the Presence of Air. An iron pipe, 20 inches long and five-eighths inch inside diameter, was loosely packed with about 10 grams of coarse steel wool. A 12-inch, electrically heated tube furnace was used for heating the iron pipe at $800^{\circ} \pm 10^{\circ}\text{C}$. The temperature was measured by a thermocouple placed near the center of the tube and on the outside between the tube wall and the heating elements. Air and the halogen compound were premixed before passing through the hot zone. In the case of liquid halogen compounds, boiling near room temperature and over, premixing was done by passing a measured amount of air through the compound in a test tube. The loss of weight of the test tube gave the amount of halogen compound used. Gaseous compounds were measured by means of calibrated flowmeters. The products from the hot tube were passed directly into a receiver cooled by liquid nitrogen. All of the organic components were condensed along with some air. At the completion of a run, the entire contents of the cold trap were rectified on a Podbielniak Hyd-Robot low temperature fractionating column.

Air and the halogen compound were protected from moisture but no special precautions were taken to dry the gases before pyrolysis. It was assumed that ordinary compressed air and commercial halogen compounds were sufficiently dry for all practical purposes.

The halogen compounds chosen for the pyrolysis studies contained no hydrogen in their structure. The reason for this choice was based upon the fact that there would be no hydrogen halide, especially hydrogen fluoride, formed as a result of the pyrolysis. Hence, the gaseous pyrolytic products could be rectified directly without any danger of corroding glass apparatus.

The pyrolysis products were analysed for the organic components present in the gas stream, carbonyl halides, and carbon dioxide and oxygen. The organic components present were analysed by condensing all of the pyrolytic products in a trap cooled with liquid nitrogen and then rectifying the contents of the cold trap as already mentioned above. From a comparison of known boiling points and gas densities, the identity of the unknown fractions could be determined in most cases. The quantity of each fraction present was calculated from the rectification chart which is automatically plotted by the Podbielniak instrument.

The following procedure was used for the quantitative determination of carbonyl halides: Air and the halogen compound were passed into the hot zone as already described. Gaseous products were led through a dry Pyrex Wool filter to remove iron compounds suspended in the gas stream and then into an absorption train similar to the one described by Yant and coworkers.³³ The train consisted of a layer of calcium chloride for drying the gas, a layer of amalgamated tin for removal of elemental halogen, and a layer of mossy zinc for removal of hydrogen halides. The gas then entered the carbonyl halide absorption bulbs containing water saturated with aniline and sym-diphenylurea. A Wet Test meter following the absorption bulbs recorded the liters of gas passed

through. Carbonyl halides were converted to sym-diphenylurea by reaction with the aniline. The sym-diphenylurea was filtered on tared Gooch crucibles was dried at 70°C. and weighed. The sym-diphenylurea was then dissolved out with 5 milliliters of warm, absolute ethanol into a tared weighing bottle. The alcohol was evaporated at room temperature and the residue was dried at 70°C. and weighed as sym-diphenylurea. The Gooch crucible was also dried at 70°C. and reweighed. The loss in weight was used as a check for the analysis. Melting points and qualitative chemical analysis of the sym-diphenylurea were made to check the purity of the product. In all cases, only traces of halogen were detected in the sym-diphenylurea and the melting point found varied from 224 to 239°C. The literature value for sym-diphenylurea is 238-239°C. The amount of carbonyl halides was calculated from the weight of sym-diphenylurea as parts per million on a gas volume basis at temperatures and pressures of experimental conditions. No attempt was made to identify the exact formula of the carbonyl halide that was formed. Depending upon the halogen compound undergoing decomposition, there is a possibility of various carbonyl halides being produced and the values reported here represent the summation of all.

In addition to the determinations of organic components and carbonyl halides, an analysis was made on some of the products using for carbon dioxide and oxygen a Burrell Gas Analysis Apparatus of the Orsat type. The values found are reported in Table XVII, along with other data for these experiments.

Rectification analyses for several of the products are as follows:

Pyrolysis No. 3 - Carbon tetrafluoride was the only organic compound present.

Pyrolysis No. 4 - Dichlorodifluoromethane was recovered to the extent of 43.1 per cent. A second fraction boiled at -82.0°C. and had a molecular weight of 104 as determined by a gas density determination. The compound is chlorotrifluoromethane and was present to the extent of 19.3 per cent of the dichlorodifluoromethane originally introduced. A third compound boiled at -125°C. and was present in a trace amount only. The latter compound is probably carbon tetrafluoride. In addition to these compounds, a few grams of an organic solid was found at the exit end of the iron pipe. The solid was purified by sublimation and its melting point and qualitative chemical analysis were determined. The compound melted in the range 181-189°C. in a sealed tube and contains chlorine but no fluorine. The compound was established to be hexachloroethane.

Pyrolysis No. 5 - The pyrolysis of 0.274 mole of dibromodifluoromethane and 0.174 mole of air through an iron pipe at 800°C. resulted in the formation of a compound having a boiling point of -57°C. and a molecular weight of 149 as determined from the gas density. The structure of this compound was not established. The pyrolysis was also accompanied by the liberation of elemental bromine which was converted to an equivalent amount of iodine and then

Table XVII

Analytical Data of Pyrolysis of Halogen Compounds and Air over Iron at 800°C.

Pyrolysis Number	3	4	6	8	9	10	11	12
Halogen Compound	CF ₄	CCl ₂ F ₂	CBr ₂ F ₂	C ₃ F ₈	CBrF ₃	CH ₃ Br	CCl ₄	CBrF ₂ CBrcClF
Moles	0.278	0.176	0.274	0.248	0.209	0.228	0.116	0.051
moles/hr.	1.58	1.06	3.29	0.744	2.51	1.368	0.696	0.382
Air, moles	0.347	0.347	0.174	7.711	0.174	0.347	0.347	0.277
moles/hr.	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08
Analytical Data								
Pyrolysis Gas Vol., liters	9.0	9.57	6.76	15.3	10.5	8.3	7.16	8.6
sym. Diphenylurea, grams	1.6m	0.0254	0.0044	0.0497	0.0012	Trace	0.056	0.0515
Carbonyl Halide, P.P.M. of Gas on Volume basis	None	344	84	422	15	Trace	1035	786
Carbon Dioxide, % by vol.	0.3	3.0	11.0	1.8				
Oxygen, % by vol.	12.0	1.6	1.4	1.3				
Original Halogen Compound Recovered, %	93.2	43.1	0.0	67.0				

104.

titrated with a standard sodium thiosulfate solution. By calculation, it was found that a total of 0.733 g. of elemental bromine was formed. No dibromodifluoromethane was recovered.

Pyrolysis No. 6 -The pyrolysis of 0.121 mole of octafluoropropane and 0.347 mole of air through an iron pipe at 800°C. resulted in the recovery of 67.0 per cent of the octafluoropropane introduced. Trace amounts of compounds boiling at -86°C. and -79°C. were also present but not identified.

Pyrolysis Studies in the Absence of Air - The same apparatus was used for these experiments that was described for pyrolysis experiments in the absence of air. The amount of halogen compound used was determined by the difference in weight of a small steel cylinder before and after the experiment. The pyrolysis products from the hot zone were condensed in a trap cooled by liquid nitrogen. Generally only one pass was made through the hot zone. The product in the trap cooled with liquid nitrogen was analysed for breakdown products by fractional distillation on the Hyd-Robot Low Temperature column.

Dichlorodifluoromethane - The pyrolysis of 0.307 mole of dichlorodifluoromethane through the iron pipe resulted in the formation of four breakdown products. Carbon tetrafluoride b.p. -130°C., was present to the extent of 0.004 mole. Chlorotrifluoromethane b.p. -82°C., was present to the extent of 0.121 mole. The recovery of dichlorodifluoromethane was 0.004 mole. A fraction boiling at -95°C. was present to the extent of 0.004 g. mole and material boiling above -18°C. was present to the extent of 0.003 mole. These materials were not identified.

The pyrolysis of dichlorodifluoromethane (0.164 mole) through a platinum tube at 800°C. resulted in the recovery of 0.119 mole of dichlorodifluoromethane. No other products were detected.

Octafluoropropane - The pyrolysis of 0.100 mole of octafluoropropane through the iron pipe at 800°C. resulted in the formation of 0.004 mole of unidentified material boiling at -80°C. The recovery of octafluoropropane was 0.082 mole.

The pyrolysis of 0.183 mole of octafluoropropane through a platinum tube at 800°C. resulted in the recovery of 0.164 mole of octafluoropropane. No other products were detected

Chlorotrifluoromethane - The pyrolysis of 0.363 mole of chlorotrifluoromethane through a platinum tube at 800°C. resulted in the recovery of 0.320 mole of chlorotrifluoromethane. No other products were detected.

Bromotrifluoromethane. - Bromotrifluoromethane (0.171 mole) was passed through the platinum tube at 800°C. six times by distilling the product back and forth. Upon analysis of the final product, the recovery of bromotrifluoromethane was 0.114 mole. Elemental bromine was present to the extent of 0.003 mole. An unidentified material boiling at -91°C. was present to the extent of 0.007 mole.

Carbon Tetrafluoride - The pyrolysis of carbon tetrafluoride (0.180 mole) through a platinum tube at 800°C. resulted in the recovery of 0.135 mole of carbon tetrafluoride. No other products were detected. It can be concluded from this series of experiments that decomposition of the halogen compounds is less extensive in the absence of air than in the presence of air. Also, more extensive decomposition is obtained in the iron tube.

Behavior of Halogen Compounds in an Electric Arc. - The object of this research was to determine the breakdown products formed by the fire extinguishing agent when subjected to an electric arc. To accomplish this, the following apparatus was constructed: A piece of Pyrex tubing, 24 mm. in diameter and 26 cm. long, was constricted in the middle to an inside diameter of 1 cm. Platinum electrodes were sealed into the tube wall in such a manner that the gap between the electrodes was directly across the constricted part. A separate cold trap was connected to each end of the Pyrex tube by means of ground glass ball joints to make an air tight seal. The system was also connected to a mercury manometer, one end of which was open to the atmosphere so that the internal pressure during the arcing process could be measured at all times. The spark source was a Model-T Ford spark coil having eight volts D.C. on the primary. For the experiments described herein, the electrode gap was 0.4 to 0.5 cm.

A quantity of the fire extinguishing agent was distilled into the system and condensed into one of the cold traps cooled with liquid nitrogen. Liquid nitrogen was chosen as a cooling medium to make certain that no possible decomposition products would escape from the system. By distilling the compound back and forth from cold trap to cold trap, the vapors were forced through the arc. After arcing, the contents of the system were analysed by rectification on the Podbielniak Hyd-Robot low temperature fractionating column.

Octafluoropropane - Octafluoropropane was subjected to five passes through the arc. Etching of the Pyrex tube was noticed. On rectification, the bulk of the material was found to be octafluoropropane. A trace of material boiling at -81°C. was also found.

Methyl Bromide. - Methyl bromide was subjected to a single pass. Some soot formation was noticed on the surface of the electrodes. No elemental bromine was found. On rectification the bulk of material was found to be methyl bromide. A trace of material boiling at -74°C. was also found.

Dibromodifluoromethane. - Dibromodifluoromethane was subjected to five passes. A small quantity of elemental bromine was liberated as a result of the arcing. On rectification, the bulk of the material was dibromodifluoromethane. A trace of material boiling at -70°C. and a trace boiling at -55°C. were also found.

Carbon Tetrafluoride. - Carbon tetrafluoride was subjected to seven passes. C_n rectification, only carbon tetrafluoride was found.

Bromotrifluoromethane. - Bromotrifluoromethane was subjected to seven passes. A small quantity of elemental bromine was formed as a result of the arcing. On rectification, the bulk of material was bromotrifluoromethane. A trace of material boiling at $-109^\circ C.$ was also found.

Toxicity

No attempt has been made at Purdue to determine the toxicity of the substances under investigation.

The Freons have been studied extensively and, in general, they are considered to be non-toxic. Fluoroform (Freon 23) has been shown to produce no ill effect upon a guinea pig when the test animal was subjected to an atmosphere comprising 80% trifluoromethane and 20% oxygen⁹.

As a part of a cooperative research program at Purdue University a number of fluorine-containing compounds have been made available for evaluation as anesthetics. Many of the compounds tested have been shown to possess desirable anesthetic properties.^{2*} Among these compounds are 2-bromo- and 3-bromo-1,1,1-trifluoropropane.

The literature contains information concerning the life hazards of several materials of interest as fire-extinguishing fluids. This information may be summarized as follows:

<u>Compound</u>	<u>Classification</u>	<u>Reference</u>
CH_3Br	2	30
CCl_4	3	30
$CHCl_3$	3	30
CH_2BrCl	3	31
CH_3CH_2Br	4	30
CO_2	5	30
CCl_3F	5	30
CCl_2F_2	6	30
$CCLF_2CCLF_2$	6	30

The classifications have been defined in the following manner:

"Group 1--Gases or vapors which in concentrations of the order of 1/2 to 1 per cent for durations of exposure of the order of 5 min. are lethal or produce serious injury: sulphur dioxide.

"Group 2--Gases or vapors which in concentrations of the order of 1/2 to 1 per cent for durations of exposure of the order of 1/2 hr. are lethal or produce serious injury: ammonia and methyl bromide.

"Group 3--Gases or vapors which in concentrations of the order of 2 to 2-1/2 per cent for durations of exposure of the order of 1 hr. are lethal or produce serious injury: methyl formate, chloroform, and carbon tetrachloride.

"Group 4--Gases or vapors which in concentrations of the order of 2 to 2-1/2 per cent for durations of exposure of the order of 2 hr. are lethal or produce serious injury: dichlorethylene, methyl chloride, and ethyl bromide.

"Group 5--This group includes gases or vapors much less toxic than Group 4 and (a) more toxic than Group 6: monofluoro-trichloromethane ("F-11") and carbon dioxide--and (b) those which available data indicate classify as either Group 5 (a) or Group 6: butane, ethane, and propane.

"Group 6--Gases or vapors which in concentrations up to at least about 20 per cent by volume for durations of exposure of the order of 2 hr. do not appear to produce injury: dichloro-difluoromethane ("Freon") and dichlorotetrafluoroethane ("F-114")."

Struck and Plattner²⁷ have reported that perfluorobutane is without anesthetic activity and that it is toxic in concentrations greater than 25%. No ill effects were observed in concentrations of about 5%. Perfluorocyclopentane was found to be more toxic than perfluorobutane.

A study of the toxicological properties of several of the compounds possessing the more favorable flame inhibition properties has been initiated at the Toxicology Branch of the Army Chemical Center. A formal report covering toxicity studies has not been issued.

Physical Properties

A library research project was initiated to determine whether or not a correlation exists between the flame inhibition properties of a compound and its physical characteristics. An attempt was made to find all of the physical characteristics reported for several gases. Materials chosen for this library study may be grouped into three classifications, namely, inert gases, flammable gases and gases supporting combustion. Representative materials in each of these groups are as follows:

Inert Gases

argon	krypton	chlorotrifluoromethane
helium	xenon	dichlorodifluoromethane
nitrogen	carbon dioxide	trifluoromethane
neon	methyl bromide	carbon tetrafluoride

Flammable Gases

methane
ethane
acetylene

Gases Supporting Combustion

oxygen
chlorine
fluorine

The appendix of this report contains tables showing data obtained in this search. Numerous attempts have been made to correlate the physical data reported in the Appendix (Tables 1 to 147 inclusive) with flame inhibition properties as indicated from the peak in the flammability curves. However, no correlation is apparent. Some of the relationships considered which were more promising than others are shown in Figures 50 to 55 inclusive. These figures show the relationship of vapor density and dielectric constants to flammability peaks.

It is our conclusion as a result of this library search that there are insufficient physical data reported for any given series of compounds to make a correlation feasible.

Test Materials

During the course of this research it has been the policy to use compounds of high purity. Whenever possible materials available from commercial supply houses have been used. Other materials were synthesized in the laboratories at Purdue following procedures which seemed most expedient. The following paragraphs summarize the source of the test compounds used on the project. Details are omitted from procedures described in the literature.

Freons - The following Freons were obtained from Kinetic Chemicals, Inc. and were used without further purification:

Dichlorodifluoromethane (Freon 12),	b.p., -30°C.
Chlorotrifluoromethane (Freon 13),	b.p., -82°C.
Chlorodifluoromethane (Freon 22),	b.p., -40°C.
Trifluoromethane (Freon 23),	b.p., -82.2°C.
1,1,2-Trichlorotrifluoroethane (Freon 113)	b.p., 46.5°C.
1,2-Dichlorotetrafluoroethane (Freon 114)	b.p., 3.6°C.
Tetrafluoroethylene (Freon 1114)	b.p., -76.3°C.

Carbon tetrafluoride (b.p. -128°C.) was prepared by the vapor-phase fluorination of carbon tetrachloride with silver difluoride. Before using, the carbon tetrafluoride was purified by rectification on a Podbielniak Heli-Grid low temperature column. In addition, carbon tetrafluoride was obtained from the New Products Division, Minnesota Mining and Manufacturing Co., St. Paul, Minnesota.

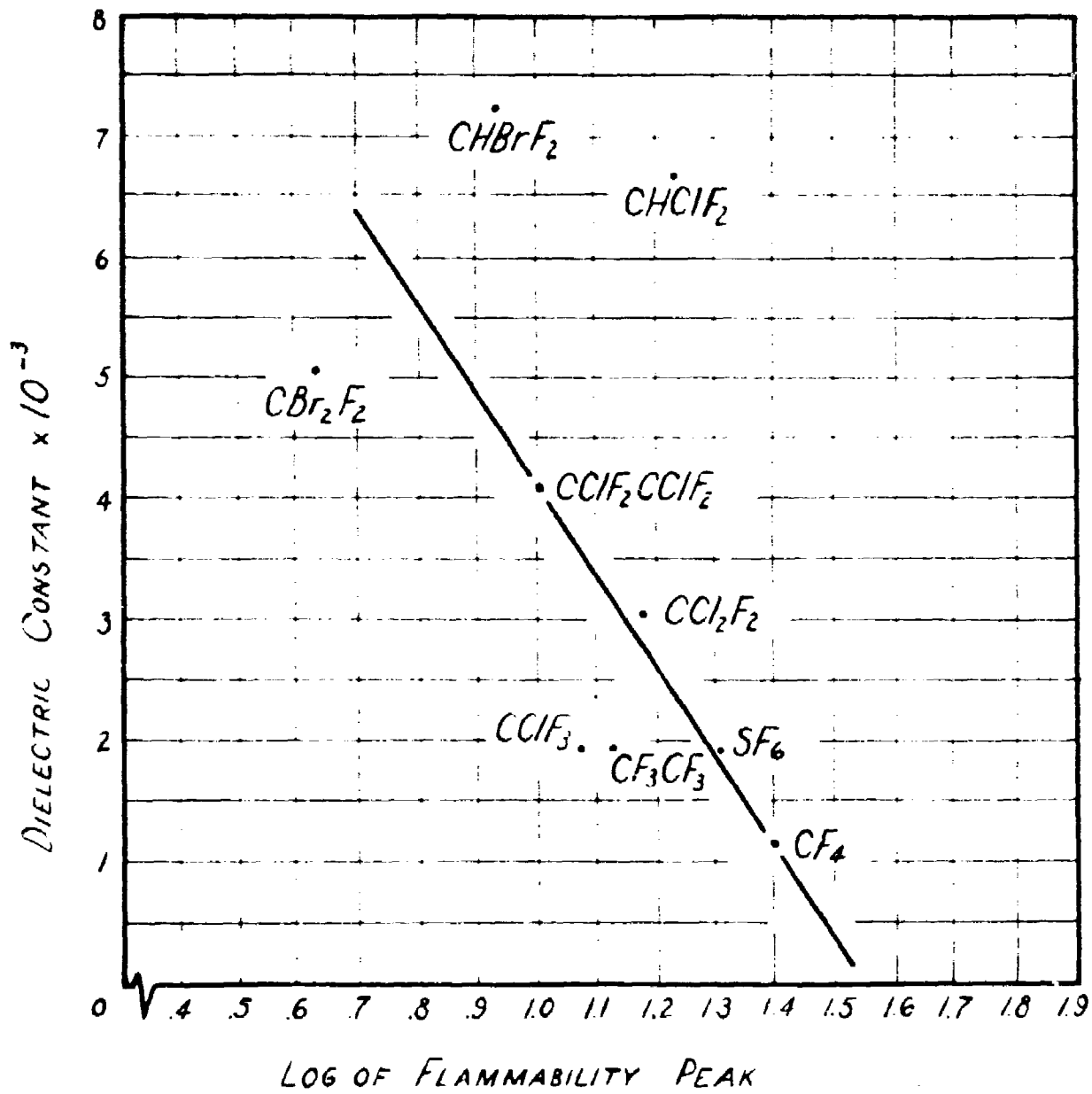


Figure 50 Relationship between Dielectric constant and Flammability Peak

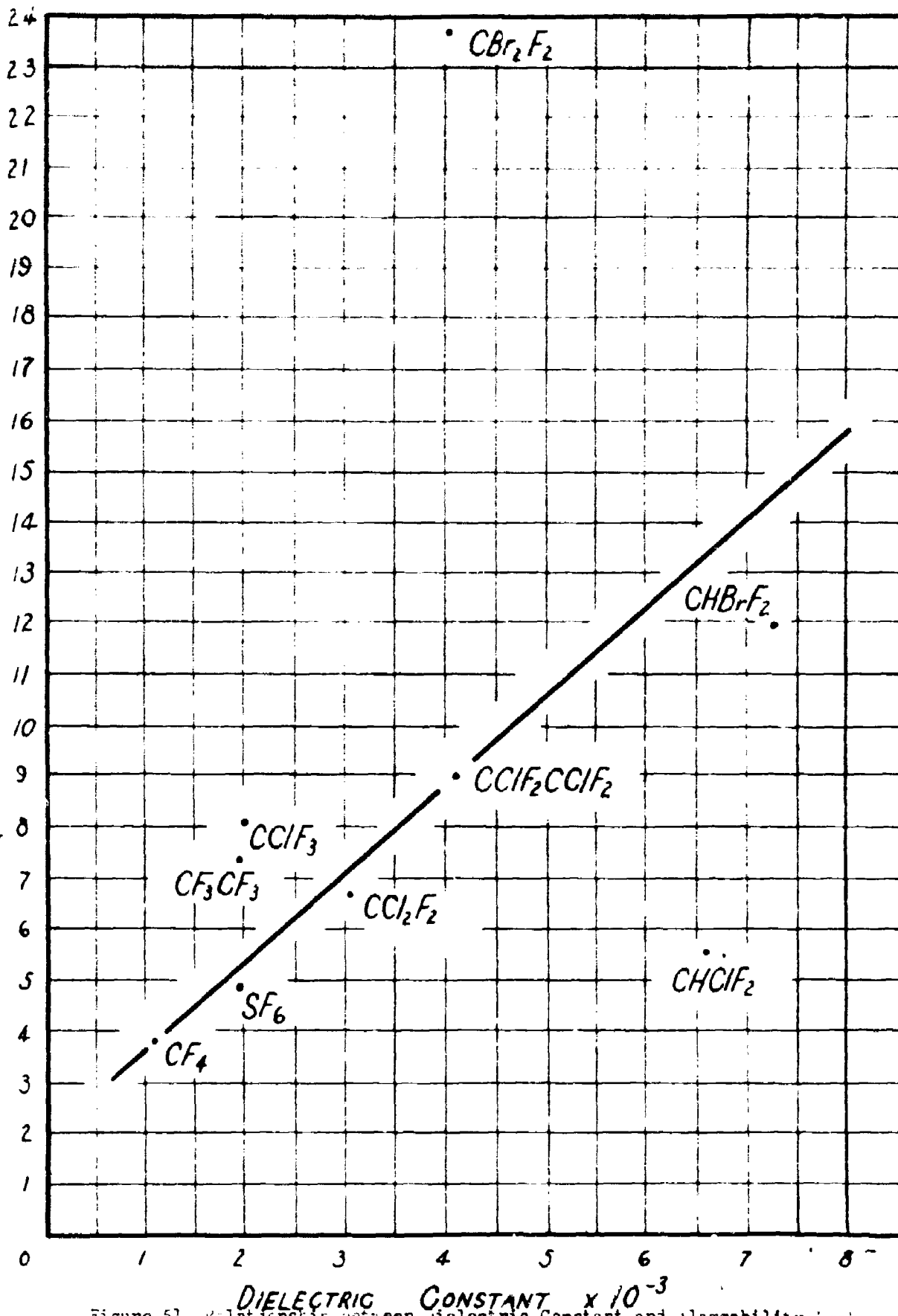
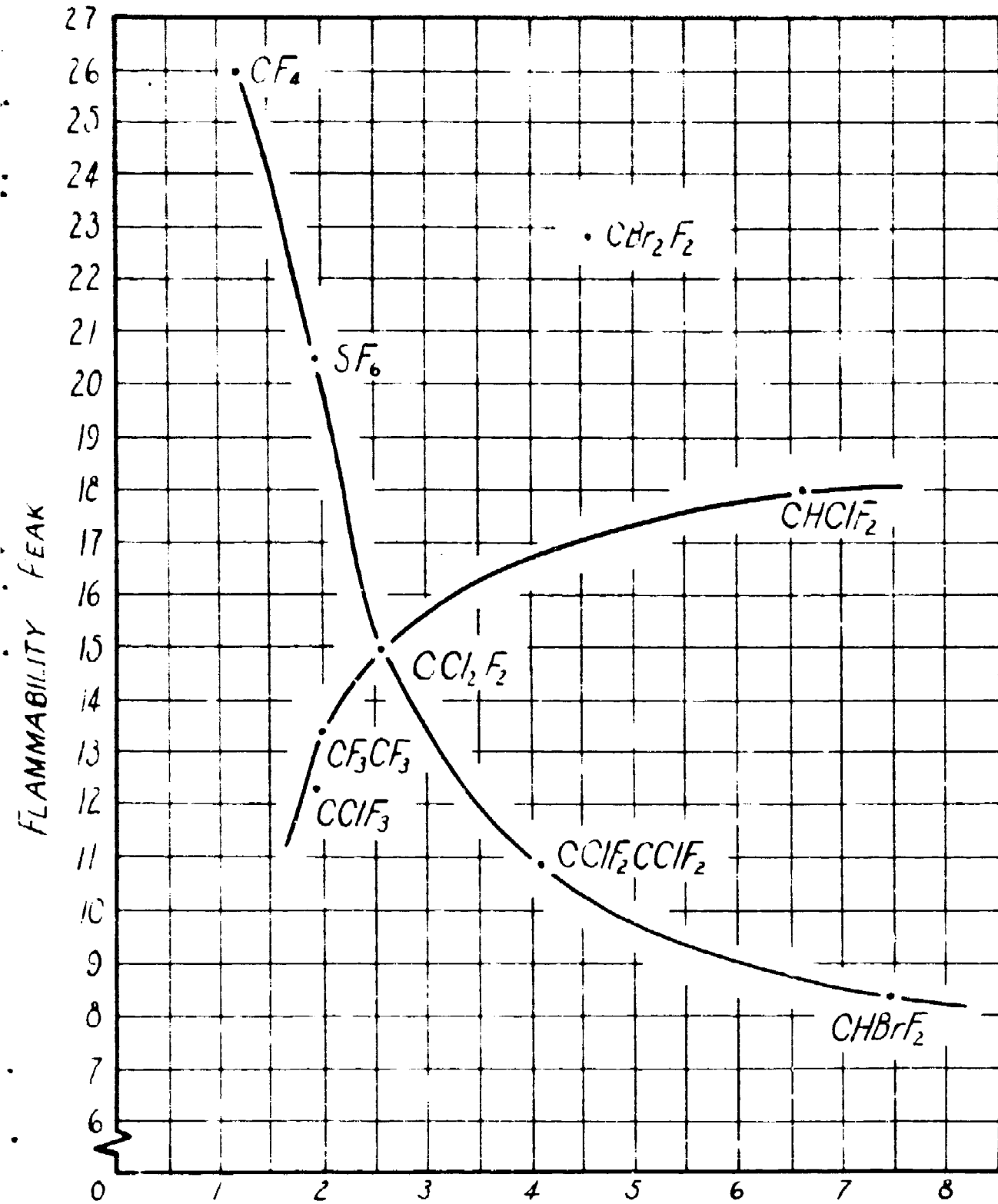


Figure 51. Relationship between Dielectric Constant and Permittivity Peak



DIELECTRIC CONSTANT $\times 10^{-3}$
 Figure 50. Relationship between Dielectric
 Constant and flammability peak

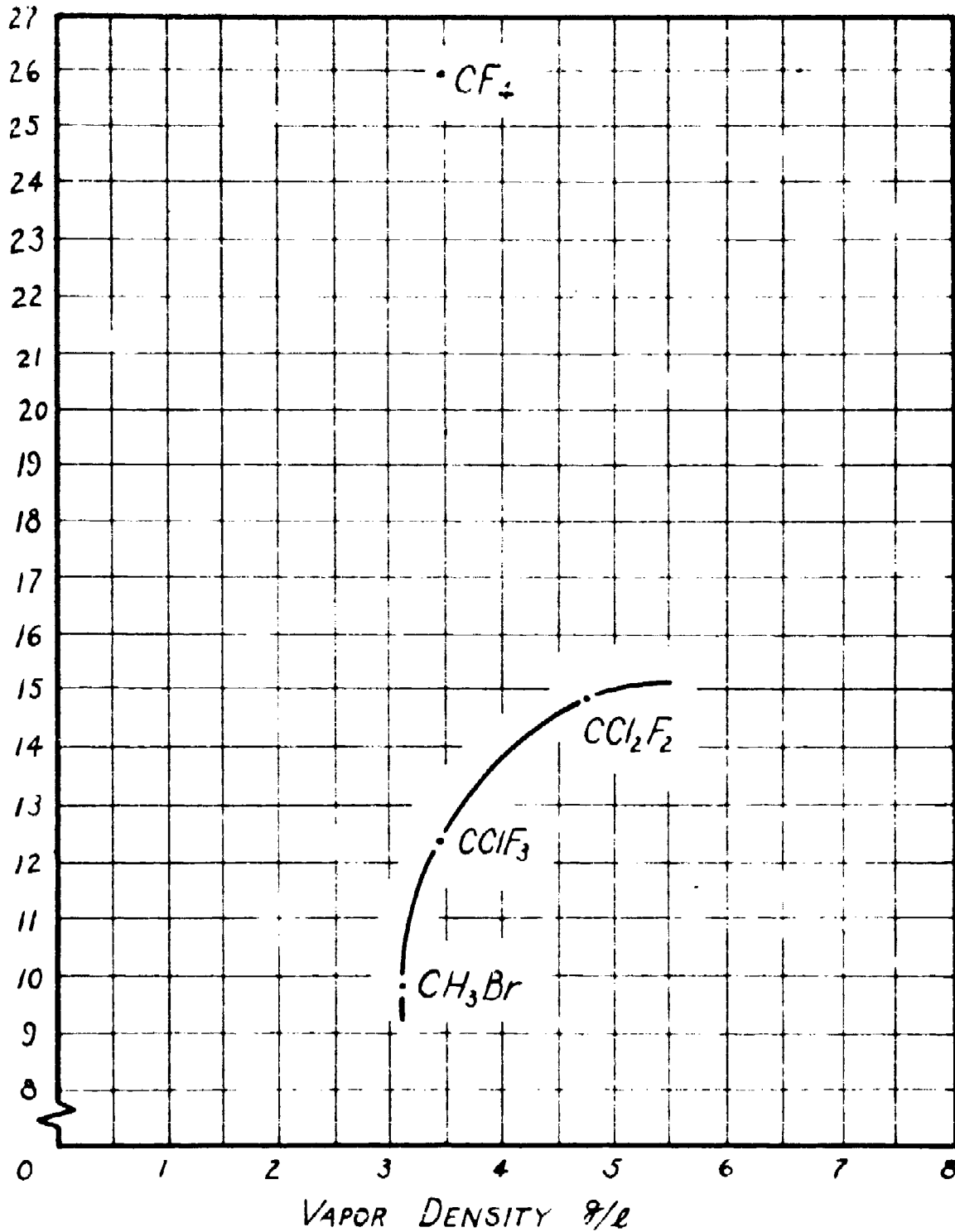


Figure 53 Relationship between Vapor Density and Flammability Peak

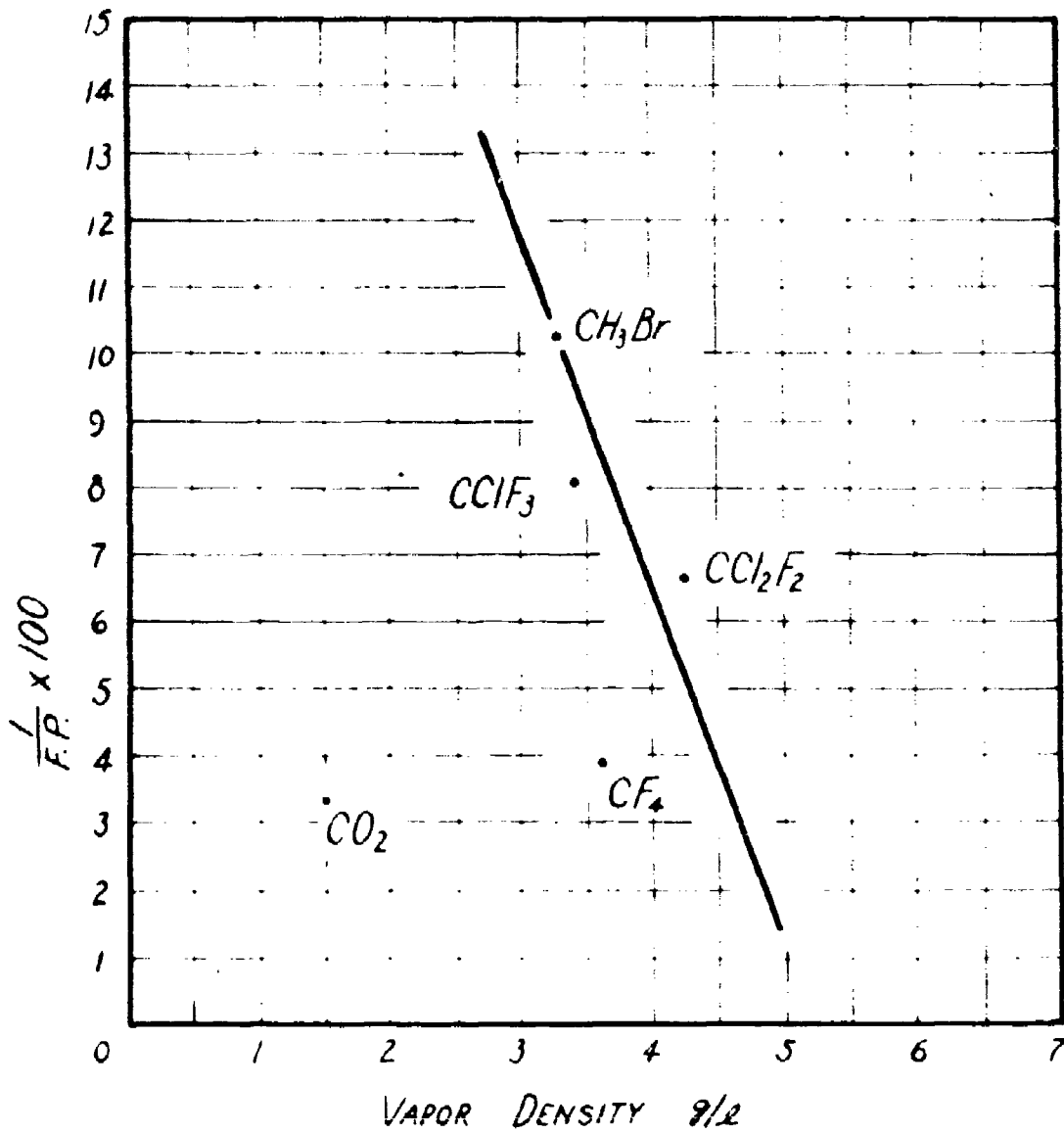


Figure 54 Relationship between Vapor Density and Flammability Peak

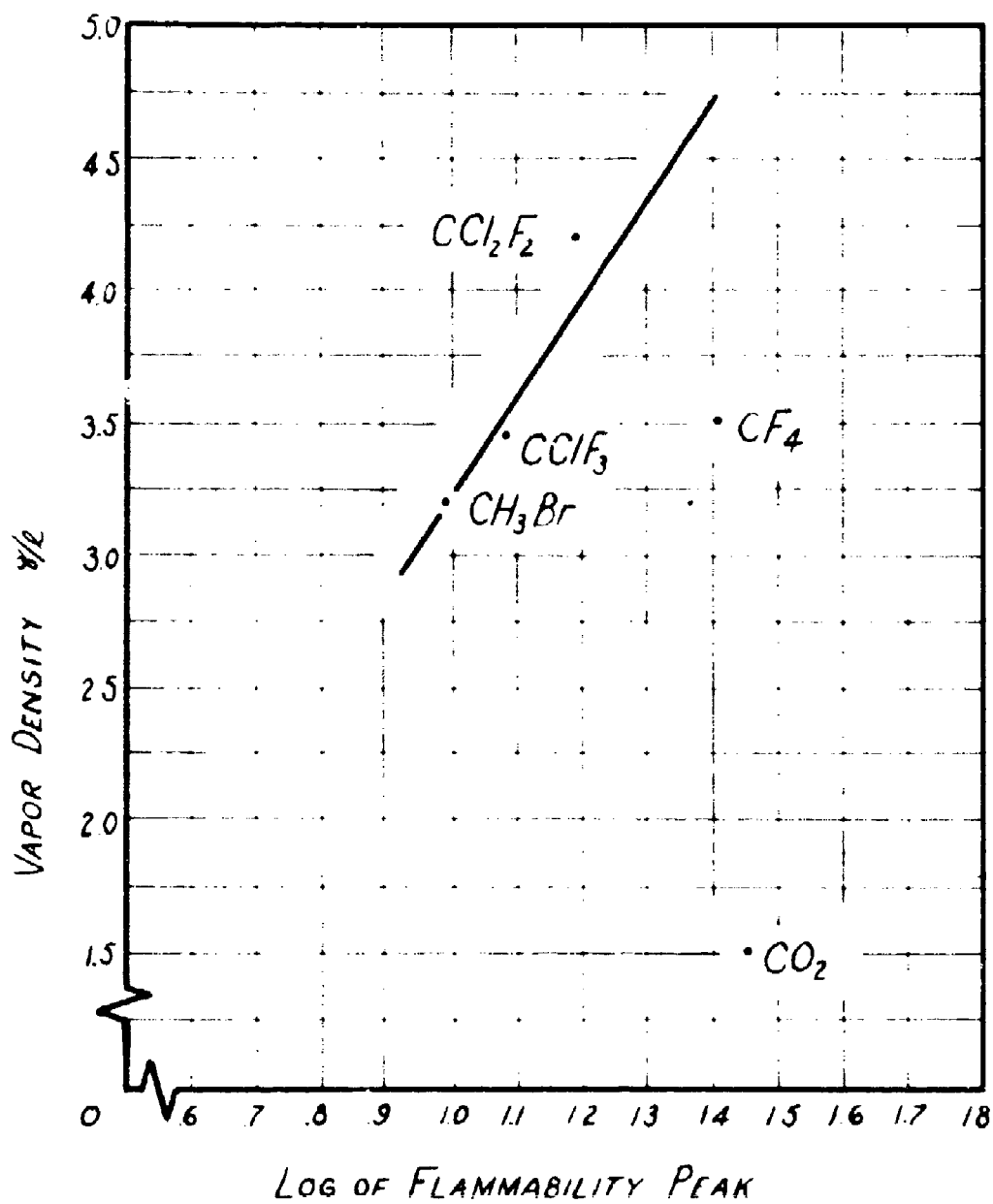


Figure 55 Relationship between Vapor Density and Flammability Peak

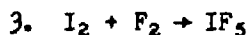
Carbon tetrachloride (Fire Extinguishing Grade) was made available through the courtesy of the Purdue Physical Plant.

Bromotrifluoromethane (b.p. $-60^{\circ}\text{C}.$) was prepared by the thermal bromination of trifluoromethane (Freon 23)³. The reaction was carried out at $600^{\circ}\text{C}.$ in a glass tube packed with glass beads.



Also a part of the bromotrifluoromethane was supplied by the Army Engineers.

Trifluoroiodomethane, (b.p. $-22.5^{\circ}\text{C}.$) was prepared from carbon tetraiodide and iodine pentafluoride, following a procedure described by Emeleus and coworkers⁶. Reactions involved in this synthesis are illustrated by equations 2, 3, and 4:



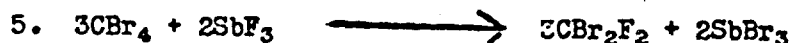
The procedure used in the preparation of carbon tetraiodide was adapted from the one described by Sorros and Hinkamp²⁶. The techniques involved are illustrated by the following example: Two hundred and sixteen grams (1.4 moles) of carbon tetrachloride and 936 g. (6.6 moles) of methyl iodide were mixed in a 2-liter, 3-necked flask equipped with a motor driven stirrer, a brine-cooled condenser, and a nitrogen inlet. Before mixing, the carbon tetrachloride and the methyl iodide were dried by distilling from anhydrous aluminum chloride. Aluminum chloride (0.03 mole, 4. g.) was added to the solution and the flask flushed with dry nitrogen for 10 minutes. The mixture was heated rapidly to $42^{\circ}\text{C}.$ (about 10 minutes), and the temperature maintained at $42^{\circ}\text{C}.$ until only a small amount of methyl iodide remained in the flask (approximately 60 minutes). Then 400 ml. of 20% sodium bisulfite was added to the reaction mixture in the flask. The mixture was filtered and the residue washed with copious amounts of sodium bisulfite solution. The carbon tetraiodide was placed in a crystallizing dish and washed with distilled water. The wet carbon tetraiodide was placed in a vacuum desiccator and dried for several days. Seven hundred and two grams (1.35 moles) of dried carbon tetraiodide was obtained, representing a yield of 97% based on the carbon tetrachloride used.

Iodine pentafluoride (b.p. $97^{\circ}\text{C}.$) was prepared by direct union of the elements, iodine and fluorine. In a typical experiment, 1.5 lb. of iodine was placed in a nickel tube, 36 in. long and 1 in. in diameter, surrounded by a water jacket. Fluorine from 3 cells operated at 30 amperes was passed into the tube for a period of 6 hours, at the end of which time the iodine pentafluoride was distilled from the reactor. The distillation was conducted in an atmosphere of fluorine. Approximately 500 g. of iodine pentafluoride was obtained, representing a yield of 84%, based upon the iodine charged to the reactor.

Trifluoriodomethane was prepared from carbon tetraiodide by a halogen exchange reaction using iodine pentafluoride. In a typical experiment, 160 g. of thoroughly dried carbon tetraiodide was placed in a 2-liter, 3-necked flask equipped with a mercury sealed stirrer, a dropping funnel, and a condenser connected in series with a receiver cooled by a mixture of Dry Ice and trichloroethylene. The flask and its contents were cooled to 0°C. and 60 g. of iodine pentafluoride was added dropwise during a period of 30 minutes. No change in temperature was observed during the period in which iodine pentafluoride was added. The mixture was heated to 90-100°C. within 45 minutes, during which time large quantities of vapors were evolved. The products from 3 such experiments were combined, and approximately 60 g. of trifluoriodomethane was obtained representing a yield of 33%. Yields as high as 65% were obtained in later experiments. In conducting these experiments, it was observed that the desired reaction does not proceed if the reagents are not anhydrous.

Other experiments which were tried and which were not productive of the desired trifluoriodomethane include the halogen exchange reaction between carbon tetraiodide and antimony trifluoride, in the presence of and in the absence of antimony pentachloride. Carbon tetraiodide was recovered. These experiments were conducted under conditions known to give the desired halogen exchange reaction with carbon tetrachloride and with carbon tetrabromide.

Dibromodifluoromethane (b.p., 24.5°C.) was prepared in accordance with the following sequence:



Two hundred grams of carbon tetrabromide was ground with 500 g. of antimony trifluoride and the mixture was placed in a 3-necked flask fitted with a stirrer and a water condenser. The temperature of the condenser water was adjusted to about 25°C. to permit the distillation of dibromodifluoromethane from the reaction mixture as formed. The reaction mixture was heated, with stirring, to 120°C. until all of the halogenated methanes had been distilled off and collected in receivers cooled in ice water. The product was washed with ice cold sodium hydroxide solution and then with ice water. After drying over anhydrous sodium sulfate, it was rectified and 54 g. of dibromodifluoromethane was obtained. There was a residue of about 7 g. of tribromofluoromethane which apparently had been entrained through the water condenser.

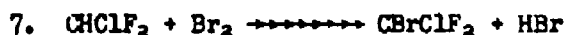
Tribromofluoromethane (b.p. 106°C.) was prepared in accordance with the following equation:



Carbon tetrabromide (200 g.) was mixed with 400 g. of antimony trifluoride and the mixture was placed in a 3-necked flask equipped with a Hirschberg stirrer and an air-cooled condenser which was connected in series with receivers cooled by wet ice and by Dry Ice. About 5 ml. of bromine was added to the mixture in the flask and the mixture was warmed with stirring to 100°C. Tribromofluoromethane distilled from the

reaction flask as formed and collected in the ice cooled receiver. The material was washed with a cold concentrated sodium hydroxide solution and dried over anhydrous sodium sulfate. Upon rectification at atmospheric pressure, there was obtained 79 g. of tribromofluoromethane representing a yield of 49%.

Bromochlorodifluoromethane (b.p., $-6^{\circ}\text{C}.$) was obtained by thermal bromination of chlorodifluoromethane (Freon 22). The reaction involved may be illustrated by the following sequence:

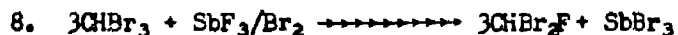


A Vycor tube, 5 cm. by 2.5 cm., was packed with Kimble glass beads 5 mm. in diameter. This reactor was placed in an electric furnace and heated to $570^{\circ}\text{C}.$ Chlorodifluoromethane was introduced below the surface of liquid bromine maintained at a temperature of $40-50^{\circ}\text{C}.$ The mixture of bromine and chlorodifluoromethane was then passed into the reactor. The effluent gases were scrubbed with aqueous sodium hydroxide (20%), dried by anhydrous calcium chloride and finally condensed in a receiver cooled by Dry Ice. Upon rectification of the product which collected in the receiver there was obtained 43 g. of chlorodifluoromethane, 77 g. of bromochlorodifluoromethane and 47 g. of dibromodifluoromethane.

Chloroform (b.p. $61.2^{\circ}\text{C}.$; m.p. $-63.5^{\circ}\text{C}.$) was obtained from the Dow Chemical Company. It was used without further purification.

Bromodifluoromethane (b.p. $-14.5^{\circ}\text{C}.$) was obtained from the Army Engineers and was used without further purification.

Dibromofluoromethane (b.p. $65^{\circ}\text{C}.$) was prepared in accordance with the following equation:



Bromoform (CHBr_3 ; 253 g.) was mixed with antimony trifluoride (330 g.) and the slurry was poured into a 3-necked flask equipped with a stirrer and an air-cooled condenser connected in series with a receiver cooled by wet ice and by Dry Ice. About 5 ml. of bromine was added and the mixture was heated with stirring to $110^{\circ}\text{C}.$ Dibromofluoromethane distilled from the reaction vessel as formed and collected in the ice-cooled receiver. The distillate was washed with cold concentrated sodium hydroxide solution and dried over anhydrous sodium sulfate. Upon rectification at atmospheric pressure, there was obtained 64 g. of dibromofluoromethane representing a yield of 46%.

Dichloromethane (b.p., $40-41^{\circ}\text{C}.$) was obtained from the Eastman Kodak Company and used without further purification.

Dibromomethane (b.p. $98.5^{\circ}\text{C}.$) was obtained from the Columbia Organic Chemicals Inc. This material was rectified before using.

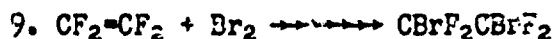
Bromochloromethane (b.p. 68-69°C.) was obtained from the Michigan Chemical Company and from the Columbia Organic Chemical, Inc. These materials were used without further purification.

Methyl Bromide (b.p., 4.5°C.) was obtained from the Mathieson Company and used without further purification.

Methyl Iodide (b.p., 42.4°C.) was obtained from the Paragon Testing Laboratories and used without further purification.

Hexafluoroethane (b.p. -78°C.) was made available for test purposes on this project after it was obtained on another project as a by-product in the synthesis of chloropentafluoroethane by the reaction between 1,1,2-trichlorotrifluoroethane and silver difluoride.

1,2-Dibromotetrafluoroethane (b.p. 46.4°C.) and Bromopentafluoroethane (b.p., -23°C.) were prepared in accordance with the following reaction sequence:



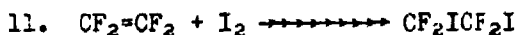
1,2-Dibromotetrafluoroethane was prepared by the addition of bromine to tetrafluoroethylene following the procedure described by Ruff²⁵. The following example is illustrative of the technique used. Bromine vapors and tetrafluoroethylene were mixed in a reaction chamber illuminated with one 200 Watt incandescent lamp. The rate of introduction was such that the bromine color disappeared as a result of addition to tetrafluoroethylene. After 3 moles of bromine had been utilized, the crude product was washed with cold sodium hydroxide solution to remove excess bromine. The organic product was then steam distilled, dried over calcium chloride and rectified. Six hundred and forty-three grams of 1,2-dibromotetrafluoroethane was obtained, representing a yield of 83% based on bromine consumed.

Lead tetrafluoride was tried for the halogen exchange reaction to convert 1,2-dibromotetrafluoroethane to bromopentafluoroethane. However, after several attempts proved unsuccessful, efforts were directed to the use of the more active silver difluoride. In the first experiment with silver difluoride, 75 g. of 1,2-dibromotetrafluoroethane was passed over silver difluoride maintained at a temperature of 110°C. The time required for the addition of the organic material was one hour. The effluent gases were passed from the reactors into a receiver cooled by wet ice and then into a receiver cooled by Dry Ice. Approximately 10 ml. of product collected in the Dry Ice-cooled receiver. There was some evidence indicating that the dibromotetrafluoroethane decomposed to give bromine and tetrafluoroethylene. A second experiment was conducted in which 75 g. of the dibromotetrafluoroethane was passed over silver difluoride at 75°C. The time for introducing the 1,2-dibromotetrafluoroethane was 0.5 hour. Approximately 20 ml. of product was obtained from

this experiment. The products from these two experiments were combined, scrubbed free of bromine by bubbling through sodium hydroxide, and dried by contacting the vapor from the scrubber with phosphorus pentoxide. Rectification on a low temperature column gave 28 g. of bromopentafluoroethane boiling at -23°C .

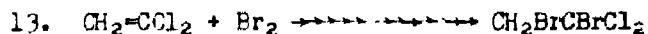
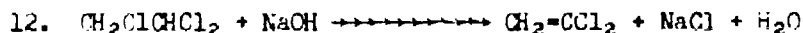
Pentafluoriodoethane (b.p., $16-16.5^{\circ}\text{C}$) Emeleus and coworkers⁶ reported the preparation of pentafluoriodoethane by the reaction of iodine pentafluoride with acetylenetetraiodide. After a consideration of available materials and reactions involved, it was decided to prepare a quantity of this compound for testing with respect to fire extinction properties by the reaction of iodine pentafluoride with tetrafluoro-1,2-diiodoethane. Several experiments were performed and the following example may be considered typical of the techniques involved: Fifty grams of tetrafluoro-1,2-diiodoethane was placed in a one-liter, 3-necked flask equipped with a stirrer, a dropping funnel, and a condenser connected in series to a wash bottle containing a 5% solution of sodium hydroxide and a receiver which was cooled by a mixture of Dry Ice and trichloroethylene. Thirty-one grams of iodine pentafluoride was added dropwise over a period of 15 minutes. The mixture was heated to 70°C . within 20 minutes, during which time a small amount of gas was evolved. The temperature was then raised rapidly to 75°C . (about 5 minutes) and maintained at 75 to 82°C . until the evolution of gases ceased. Approximately 24 g. of pentafluoriodoethane, boiling at $16-16.5^{\circ}\text{C}$., was obtained. This represents a yield of 69%.

Tetrafluoro-1,2-Diiodoethane (b.p., 112°C .) was prepared by adding iodine to tetrafluoroethylene, according to the procedure of Reasch²² and illustrated by the following sequence:



One pound of iodine and one pound of diethyl ether were mixed in a 2-liter iron autoclave. After securing in position, the autoclave and its contents were heated to 60°C . Then a portion of the ether was discharged to remove the air which was in the autoclave and tetrafluoroethylene was added from a cylinder to a pressure of 330 lb./sq. in. The autoclave and its contents were rocked for 7 hours, during which time a pressure drop of 30 lb./sq. in. was observed. Tetrafluoroethylene was added at frequent intervals during the next 48 hours, so that a pressure of 330 lb./sq. in. was maintained. After discharging the fixed gases, the autoclave was opened, and the contents were poured onto crushed ice. No free iodine was present. The organic material was steam distilled from a sodium thiosulfate solution. The diethyl ether was removed by distillation at atmospheric pressure, and the 1,2-diiodo-tetrafluoroethylene was distilled at reduced pressure.

2-Bromo-1,1,1-trifluoroethane was prepared in accordance with the following sequence:



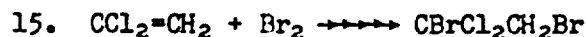


In brief, this process involved the dehydrochlorination of 1,1,2-trichloro-ethane to form 1,1-dichloroethane which was converted to 1,2-dibromo-1,1-dichloroethane by the reaction with bromine. 1,2-Dibromo-1,1-dichloroethane was converted to 2-bromo-1,1,1-trifluoroethane using the hydrogen fluoride in the presence of antimony pentachloride. This latter step represents a modification of a procedure described in the literature.¹⁴

1,2-Dibromo-2-chloro-1,1,2-trifluoroethane (b.p., 93-94°C.) was obtained from the Army Engineers and was used without purification.

1,2-Dibromo-1,1-difluoroethane (b.p. 94; m.p. -56.5°C.) was obtained from the Army Engineers and was used without further purification.

2-Bromo-1-chloro-1,1-difluoroethane (b.p., 68°C.) was prepared from vinylidene chloride in accordance with the following sequence:



Bromine was added dropwise to an equivalent amount of vinylidene chloride contained in a 3-liter, 3-necked flask. The rate of addition of bromine was controlled by the rate of the reaction as evidenced by the disappearance of the color of bromine from the contents of the flask. After the reaction was essentially complete, the product was washed with dilute sodium hydroxide to remove excess bromine and then with water. The dried product, essentially 1,2-dibromo-1,1-dichloroethane, was used in subsequent fluorinations.

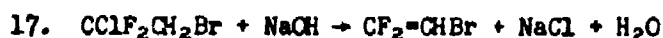
A one-liter, 3-necked flask was fitted with a Hershberg stirrer and a Vigreux column. 1,2-Dibromo-1,1-dichloroethane (300 g.) and antimony trifluoride (260 g.) were mixed in the flask and then antimony pentachloride (25 g.) was added slowly with stirring. The mixture was heated rapidly and the product allowed to distill from the flask. The distillate was treated with a small amount of sodium bisulfite and steam distilled. The organic layer was washed with water and dried over anhydrous sodium sulfate. Upon rectification there were obtained 51 g. of 2-bromo-1-chloro-1,1-difluoroethane and 110 g. of 2-bromo-1,1-dichloro-1-fluoroethane representing a 24% conversion of 1,2-dibromo-1,1-dichloroethane to 2-bromo-1-chloro-1,1-difluoroethane.

1-Bromo-2-chloroethane (b.p. 106.7°C.) was obtained from the Eastman Kodak Company and was used without further purification.

Ethyl Bromide (b.p. 38.4°C.; m.p. -117.8°C.) was obtained from the Dow Chemical Company and used for test purposes without further purification.

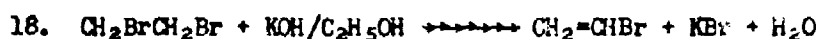
Ethyl iodide (b.p. 72.4°C.; m.p. -117.8°C.) was obtained from Columbia Organic Chemicals, Inc. The material was used for determination of fire extinction properties without purification.

2,2-Difluorovinyl bromide. (b.p. +6°C.) was prepared by the dehydrochlorination of 2-bromo-1-chloro-1,1-difluoroethane as illustrated in the following equation.



2-Bromo-1-chloro-1,1-difluoroethane was added dropwise to an alcoholic solution of sodium hydroxide at 60°C. The solution was contained in a 1-liter, 3-necked flask equipped with a dropping funnel, a stirrer and a reflux condenser. Difluorovinyl bromide distilled from the reaction mixture as formed and collected in a receiver cooled by a mixture of Dry Ice and trichloroethylene. The difluorovinyl bromide was purified by rectification. Due to the rapidity with which difluorovinyl bromide undergoes polymerization, the purified material was stabilized with hydroquinone.

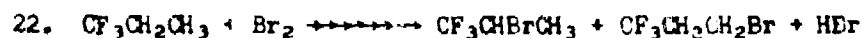
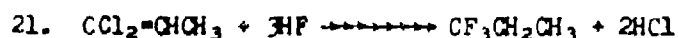
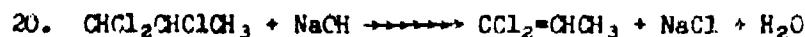
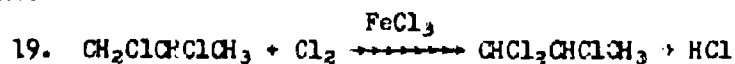
Vinyl bromide (b.p. 16°C.) was prepared in accordance with the following sequence:



A solution of potassium hydroxide in ethanol was charged into a 3-necked, round-bottom flask equipped with a dropping funnel, a motor driven stirrer and a reflux condenser. The reflux condenser was connected in series with a receiver cooled by wet ice. 1,2-Dibromoethane was added dropwise from a separatory funnel and the vinyl bromide, distilling cut as formed, was collected in a receiver cooled by ice. Vinyl bromide was purified by rectification through a low temperature column.

2-Chloro-1,1,1-trifluoropropane (b.p. 30°C.) and 3-chloro-1,1,1-trifluoropropane (b.p. 45°C.) were prepared by the chlorination of 1,1,1-trifluoropropane¹³.

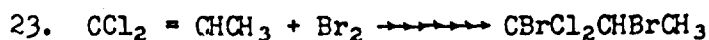
2-Bromo-1,1,1-trifluoropropane (b.p. 36.5°C.) and 3-bromo-1,1,1-trifluoropropane (b.p. 62°C.) were prepared in accordance with the following sequence:



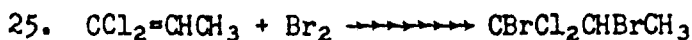
1,2-Dichloropropane (propylene chloride) was chlorinated in the liquid phase and in the presence of ferric chloride to produce polychloropropanes, a large proportion of which was 1,1,2-trichloropropane. 1,1-

Dichloropropene was prepared from the 1,1,2-trichloropropane by dehydrochlorination using aqueous sodium hydroxide. 1,1-Dichloropropene was converted to 1,1,1-trifluoropropane by treatment with an excess of hydrogen fluoride at autogenous pressure and at about 125°C. The thermal bromination of the trifluoropropane at about 600°C. resulted in the formation of a mixture containing both 2-bromo- and 3-bromo-1,1,1-trifluoropropane¹⁶.

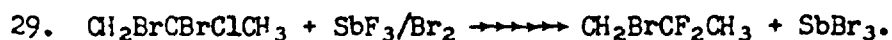
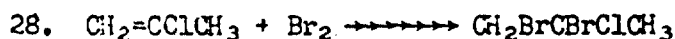
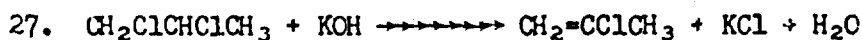
2-Bromo-1,1,1-trifluoropropane can also be prepared by the fluorination of 1,2-dibromo-1,1-dichloropropane with antimony trifluoride containing elemental bromine according to the reaction sequence outlined in equations 23 and 24.



2-Bromo-1-chloro-1,1-difluoropropane (b.p. 68°C.) was prepared by the fluorination of 1,2-dibromo-1,1-dichloropropane with antimony trifluoride and elemental bromine. The reactions involved may be illustrated by the following sequence.



1-Bromo-2,2-difluoropropane (b.p., 76°C.) was prepared in accordance with the following sequence:



2-Chloropropene ($\text{CH}_2 = \text{CClCH}_3$) was prepared by the dehydrochlorination of 1,2-dichloropropane following a procedure described by Reboil²³.

A one-liter, 3-necked flask was equipped with a mercury-sealed stirrer and a dropping funnel. The flask was surrounded by ice-water and then charged with 1.44 moles of 2-chloropropene. Liquid bromine (1.44 moles) was added dropwise from the separatory funnel. After the reaction was essentially complete, the flask was fitted with a condenser set downward for distillation. Then a mixture of antimony trifluoride (1.44 moles) and bromine (1.44 moles) was added to the contents of the flask. The mixture was heated with stirring until the flask was free of bromine vapors. The product which collected in the ice-cooled receiver was steam distilled from aqueous sodium hydroxide. After drying, the product was rectified. Seventy-six grams of 1-bromo-2,2-difluoropropane was obtained.

1-Bromopropane (b.p. 70.8°C.; m.p. -109.9°C.) used for test purpose was obtained from Halogen Chemicals, Inc. and used without further purification.

2-Bromopropane (b.p. 48.4°C.; m.p. -125°C.) was obtained from the Halogen Chemicals Company. It was used without further purification.

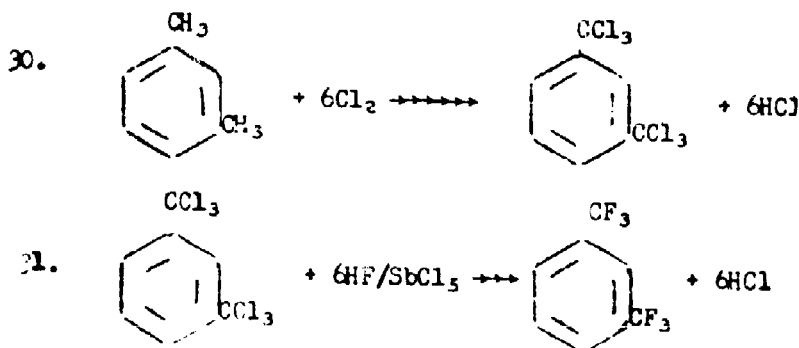
Perfluorobutane was prepared by the fluorination of 1-bromobutane with silver difluoride at temperatures ranging from 200-300°C. The product from the fluorination was washed with a sodium hydroxide solution to remove acidic materials and then with a solution of potassium permanganate to remove unsaturated compounds. The perfluorobutane was dried prior to rectification on a highly efficient column.

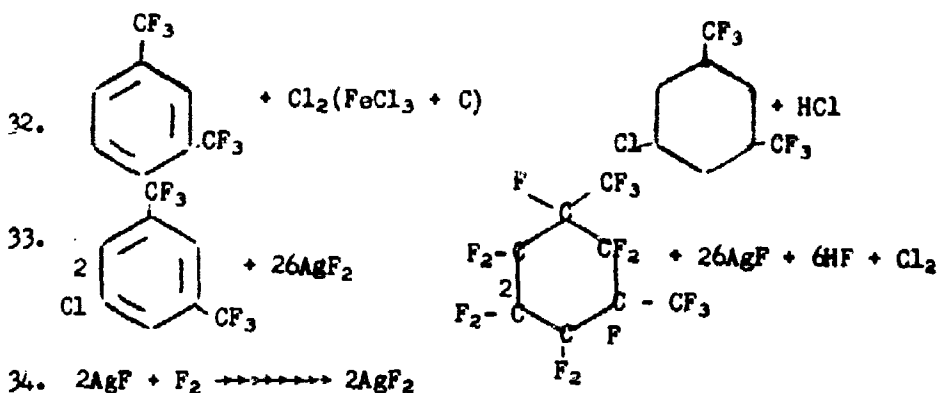
Octafluorocyclobutane (FC-318) (b.p. -5°C.; m.p. -48°C.) was obtained as a research sample from the Jackson Laboratories of the E. I. duPont de Nemours Co., Inc. This material was used without purification.

Benzotrifluoride (b.p. 102.5°C.) was obtained from the Hooker Electrochemical Company.

Perfluoro(ethylcyclohexane) (b.p. 99.5°C.), perfluoronaphthalene, (b.p. 140°C.), perfluoroindane (b.p. 116-117°C.), perfluoro(methylcyclohexane) (b.p. 75-76°C.) and perfluoroheptane (b.p. 82.4°C.) were prepared by the fluorination of ethylbenzene, naphthalene, indene, toluene, and n-heptane respectively.^{1,4,11,18} These reactions were carried out in the vapor phase using silver difluoride as a fluorinating agent. The hydrocarbon was fluorinated with the silver difluoride at 200-250°C. and then the product from the first pass recycled over silver difluoride at 300-350°C. Cobalt trifluoride could have been used with equal facility. However, a higher temperature would have been required to insure complete conversion to a saturated, hydrogen-free material.

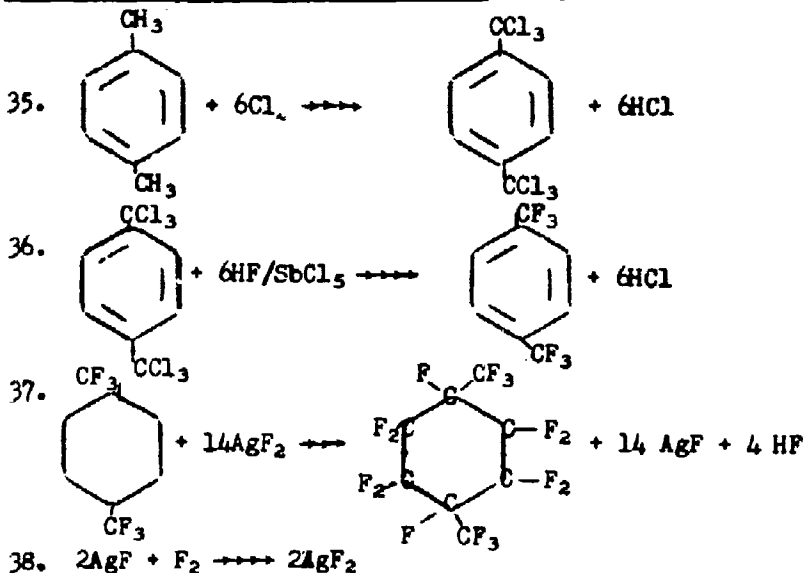
Perfluoro(1,3-dimethylcyclohexane) was prepared according to the following sequence.





Commercial xylene is a mixture comprising essentially m (about 70%) and p (about 20%) xylenes²¹. This mixture contains some o-xylene as well as some ethylbenzene. In order to obtain perfluoro(1,3-dimethylcyclohexane) free of isomeric materials the sequence outlined in equations 30-34, inclusive, was followed in accordance with procedures described previously.^{1,11,12,13,17,21}

Perfluoro(1,4-dimethylcyclohexane) was prepared according to the sequence:



Para xylene from the Oronite Chemical Company was chlorinated photochemically to produce 1,4-bis(trichloromethyl)benzene, (m.p. 112°C.) which was purified by recrystallization. The 1,4-bis(trichloromethyl)benzene was treated with hydrogen fluoride and antimony pentachloride at room temperature to produce 1,4-bis(trifluoromethyl)benzene which was converted to perfluoro(1,4-dimethylcyclohexane) by vapor-phase fluorination with silver difluoride.

Heptadecafluoro(N,N-diethylpropylamine) was obtained from the Minnesota Mining and Manufacturing Company as a research sample. It was used as such without purification.

Ethyl trifluoroacetate (b.p., 61.7°C.) was prepared by the simultaneous hydrolysis and esterification of sodium trifluoroacetate. The reactions involved in this synthesis may be illustrated by the following sequence:



In carrying out the reaction, an excess of both sulfuric acid and ethanol was used and the reaction was forced to completion by the continuous distillation of the product from the reaction mixture. The distillate was treated with anhydrous calcium chloride at 0°C. to remove residual alcohol and distilled from a small amount of phosphorus pentoxide.

Nitrogen Trifluoride (b.p. -110°C.) was prepared by the vapor-phase fluorination of ammonia using silver difluoride. Nitrogen trifluoride was purified by scrubbing with aqueous alkali, drying and rectifying.

Silicon tetrachloride (b.p. 57.6°C.; m.p. -70°C.) was obtained from the Stauffer Chemical Company and was used without further purification.

Hydrogen bromide (b.p. -67°C.) was prepared by the reaction between bromine and tetralin. In the preparation of hydrogen bromide 135 ml. of bromine added slowly to an excess of tetralin contained in a Florence flask. The gas evolved was dried by passing it through calcium chloride and collected in traps cooled by Dry Ice. To prevent bromine from passing over with the reaction product an ice trap was utilized together with water cooling of the reaction flask.

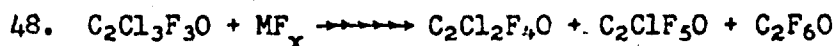
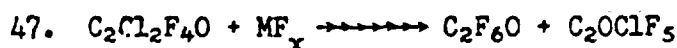
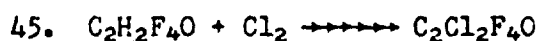
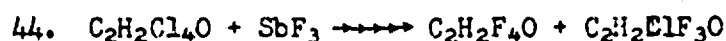
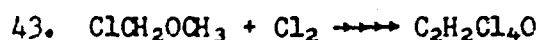
Hydrogen Chloride (b.p. -85°C.) was obtained from the Hanshaw Chemical Company and used without further purification.

Phosphorus Trichloride (b.p. 75.9°C.) was obtained from the Mallinckrodt Chemical Company and used without further purification.

Carbon Dioxide was obtained from the Liquid Carbonic Company.

Other Materials. Most of compounds evaluated with respect to their fire extinction properties have been either halocarbons or halo-hydrocarbons. The desirability of preparing and evaluating representative compounds from other classes of materials is evident from an inspection of the few data available from the evaluation of such compounds. Considerable effort has been directed to the preparation of fluorinated derivatives of ether, sulfides, silicones and amines. The proposed methods of synthesis of these compounds and a discussion of the progress and failures to date are reported herein.

Fluorinated Ethers. It was decided to attempt the preparation of fluorinated dimethyl ethers by two methods which are described by the following equations:



The method of equations 40 and 41 represents the more direct approach and accordingly experiments were performed in which an attempt was made to react trifluoromethyl iodide with sodium methoxide and with silver oxide. The reactions when carried out in Carius tubes usually ended with the demolition of the tubes, indicating the formation of hexafluoroethane. One experiment was conducted in a small nickel autoclave. Forty grams of trifluoroiodomethane, 26 g. of silver oxide and 20 g. of methanol were placed in a small nickel autoclave and heated at 50°C. for 96 hours and then at 100°C. for 24 hours. The autogenous pressure had reached 600 lb./sq. in. at 100°C. and was 200 lb./sq.in. at room temperature. The autoclave was connected to a series of traps and the valve was opened. No gas was collected in the Dry Ice traps and upon heating the autoclave a quantity of methanol was collected. The autoclave was opened and the solid was removed. The solid material gave a positive test for silver iodide but also seemed to have hydrogen fluoride occluded on the surface. The fact that there was a pressure increase during the reaction and yet no gas was collected in the Dry Ice traps indicated that a more complicated reaction had taken place than expected from equation 41. It appears that a metallic surface is not beneficial to the desired reaction. Since no glass lined autoclave was available and since only small quantities of materials could be used in the Carius tubes it was decided to abandon this approach.

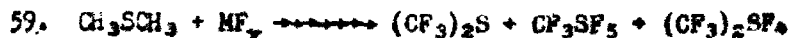
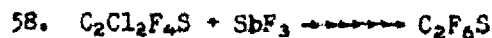
The synthesis concerned with the preparation of the polychlorinated dimethyl ethers as the intermediates was considered the next logical approach to the preparation of the desired polyfluorinated dimethyl ethers. Monochloromethyl ether was chosen as the starting material and four kilograms were prepared by the directions given in Organic Synthesis⁷. The next step in the preparation of fluorinated methyl ethers was the preparation of polychlorinated methyl ethers from the monochloromethyl ether. Booth² mentioned the preparation of poly-

chlorinated methyl ethers but does not give experimental details. It was found that in the presence of carbon tetrachloride and ultraviolet radiation further chlorination of monochloromethyl ether with chlorine could be achieved. A typical preparation is as follows: Three hundred grams of monochloromethyl ether was placed in a large glass tube 4 feet long and 2 inches in diameter and equipped with cooling coils, a gas dispersion disc and a reflux condenser. Two hundred and fifty grams of carbon tetrachloride was added and chlorine was passed into the solution for 20 minutes at -15°C ., and for 16 hours at approximately 35 to 40°C . The solution was dried with calcium chloride and fractionated. There was obtained 300 grams of polychlorinated dimethyl ether boiling at 128 to 130°C ., and 100 grams of dichloro(dimethyl ether) boiling at 102 to 105°C . It has not been determined if the higher boiling fraction is the tri- or tetrachloro(dimethyl ether). There are conflicting reports in the literature as to the boiling points of the two materials.

Booth² gives the preparation of fluorinated dimethyl ethers by the reaction of antimony trifluoride with the polychlorinated methyl ethers. Three hundred grams of the polychlorinated ether was placed in a 500 ml., round-bottom, 3-necked flask equipped with a stirrer, a condenser and a nitrogen inlet. Five hundred grams of antimony trifluoride was added and the mixture was heated at reflux for several hours. There was obtained 25 grams of material boiling at 30 - 31°C . and 7 grams of material boiling at 53°C . This would indicate that the starting material was trichloro(dimethyl ether) since the boiling points correspond to these given by Booth for trifluoro(dimethyl ether) and chlorodifluoro(dimethyl ether.)

Fluorinated Sulfides. Among the sulfur compounds desired for evaluation with respect to their fire extinction properties were the following: CClF_3S , CF_3SF_5 , CF_3SF , CF_3SCF_3 , and $(\text{CF}_3)_2\text{SF}_4$. The proposed methods of synthesis of these compounds are given by the following unbalanced equations:

49. $\text{CS}_2 + \text{Cl}_2 \rightarrow \text{CCl}_3\text{SCl}$
50. $\text{CCl}_3\text{SCl} + \text{SbF}_3 \rightarrow \text{CCl}_2\text{F}_2\text{S} + \text{CClF}_3\text{S}$
51. $\text{CCl}_3\text{SCl} + \text{AgF}_2 \rightarrow \text{CF}_3\text{SF}_6 + \text{CF}_3\text{SF}$
52. $\text{CH}_3\text{SCH}_3 + \text{Cl}_2 \rightarrow \text{C}_2\text{H}_4\text{Cl}_2\text{S} + \text{C}_2\text{H}_2\text{Cl}_4\text{S}$
53. $\text{C}_2\text{H}_4\text{Cl}_2\text{S} + \text{SbF}_3 \rightarrow \text{C}_2\text{H}_4\text{F}_2\text{S}$
54. $\text{C}_2\text{H}_4\text{F}_2\text{S} + \text{Cl}_2 \rightarrow \text{C}_2\text{Cl}_4\text{F}_2\text{S}$
55. $\text{C}_2\text{Cl}_4\text{F}_2\text{S} + \text{SbF}_3 \rightarrow \text{C}_2\text{F}_6\text{S}$
56. $\text{C}_2\text{H}_2\text{Cl}_4\text{S} + \text{SbF}_3 \rightarrow \text{C}_2\text{H}_2\text{F}_4\text{S}$
57. $\text{C}_2\text{H}_2\text{F}_4\text{S} + \text{Cl}_2 \rightarrow \text{C}_2\text{Cl}_2\text{F}_4\text{S}$



Several attempts were made to prepare thiocarbonyl perchloride (CCl_3SCl) without success by the method given in Organic Synthesis⁶. No explanation has been found and this particular synthesis has been abandoned.

The chlorination of dimethyl sulfide has been done by Moos²⁰. However, upon chlorination of dimethyl sulfide, products were obtained whose boiling points were different from those given by Moos.

Fluorinated Amines. In order to make the study on amines more complete, it was decided to attempt the preparation of perfluoro(trimethyl amine). Ten experiments were performed in which trimethylamine was fluorinated to various degrees by passing the compound over fluorides consisting of ether lead tetrafluoride, cobalt trifluoride or silver difluoride. The experiments were varied with respect to temperature and time of contact. From the ten experiments approximately 70 grams of a material boiling at 30-33°C. and analyzing for 6.9% N, 19.4% C and 1.6% H as compared to 6.33% N, 16.28% C and 0% H for perfluoro(trimethylamine) was obtained. This material was recycled over cobalt trifluoride at 180-200°C. The resulting product was rectified on a low temperature column. Seven fractions were obtained and are as follows:

<u>Weight of distillate (g.)</u>	<u>Boiling Range (°C.)</u>
Less than 1.0	below -15.0
5.0	-14.0 to +7.0
5.0	+7.5 to 15.0
9.0	15.0 to 27.0
Less than 1.0	27 to 40
1.9	40 to 65
7.5	65 to 70

Since these experiments were not indicative of better results, further work was abandoned.

Performance Tests

Early in this research program it was mutually agreed that large scale tests should be conducted at Fort Belvoir and not at Purdue. This report would not be complete without including results of some actual tests. These results, supplied by the research group at Fort Belvoir, are summarized in Table XVIII. An inspection of these data in this table bear out the conclusion that bromofluorocarbons are effective fire extinguishing agents. The correlation between the peak in the flammability curve (Table I) and the behavior of these materials in extinguishing a tub fire is not readily apparent. However, if the

TEC 474, Belvoir, Ft. Belvoir, Va.
 Weight Effectiveness, in Percent, of Selected Agents Against
 Class B and C Fires (Average of 10 tests unless otherwise noted)

Table VIII

Agent	Formula	Halon No.	Class E 24-in. Tub Fire, Agent at 800 psig Initial Discharge Pressure ^a			Class B 24-in. Tub Fire, Agent at 400 psig Initial Discharge Pressure ^a			Class C 2- by 4-ft. Cotton Waste Fire, Agent at 400 psig Initial Discharge Pressure ^a		
			To extinguish Avg. Wt. Agent (Oz)	Time (Sec)	Weight Effectiveness (%)	To extinguish Avg. Wt. Agent (Oz)	Time (Sec)	Weight Effectiveness (%)	To extinguish Avg. Wt. Agent (Oz)	Time (Sec)	Weight Effectiveness (%)
Dibromodifluoromethane	CF ₂ Br ₂	1202	7.6	1.9	148	6.6	1.4	120	20	5.7	100
Bromotrifluoromethane	CF ₃ Br	1301	7.7	3	146	7.6	3	105 ^c	15.6	4.7	126
Carbon dioxide	CO ₂	-	9.1	5.4	124	9.1	5.2	88	32+g	-	-
Dibromotetrafluoroethane	CF ₂ BrCF ₂ Br	2402	10.5	2	107	10.8	2.3	74	19.8 ^g	-	-
Dichlorodifluoromethane	CF ₂ Cl ₂	122	10.8	3	104	12	4.1	68	(27) ^f	(10) ^f	(74) ^f
Methyl bromide	CH ₃ Br	1001	11.3	3.4	100	8.0 ^d	2.1	100	20	5	100
Ethyl bromide	C ₂ H ₅ Br	2001	11.7	2.8	96	(16) ^d	(5.5) ^d	(50) ^d	...	...	...
Methyl iodide	CH ₃ I	10001	11.7	2.8	96	...	...	...	...	...	...
Chlorobromomethane	CH ₂ ClBr	1011	12.7 ^d	2.7	80	...	...	...	...	...	...
Carbon tetrachloride	CCl ₄	104	(15) ^d	(3) ^d	(75) ^d	11.4	2.0	68	32+g	...	...
Perfluoro (methylcyclohexane)	C ₆ F ₁₁ CF ₃	GM(M)	...	...	...	(24) ^e	(7) ^c	(23) ^e	...	...	...
Bromochlorodifluoromethane	CF ₂ ClBr	1211	...	...	...	10.7	2.3	75	...	...	...
Dibromodifluoroethane	CF ₂ BrH ₂ Br	2402	...	...	...	12	2.2	66	...	...	...

a. Agents were discharged from a 2 1/2-lb. CO₂ extinguisher charged with 2 lb. of agent, and then pressurized with nitrogen at 70°F. Carbon dioxide discharge pressure in all cases was approximately 800 psig.

b. Methyl bromide taken as 100%

c. Five tests

d. Six failures in the 10 tests; data recorded are average values for successful extinguishments only.

e. Three failures in 5 tests; see above (d)

f. Two failures in 5 tests; see above (d)

g. Not effective in combatting the fires.

product of the time required for extinguishment and quantity of material required is compared with the peak in the flammability curve (Table XIX). There is a qualitative relationship.

It is noted that the method of application influences the effectiveness of a given substance as a fire-extinguishing agent. Perhaps a closer correlation would have been obtained between small scale tests and large scale tests if all large scale tests had been conducted using conditions for the application which had been demonstrated as being most effective for the compound in question.

Table XIX
 THE CORRELATION BETWEEN PERFORMANCE TEST AND
 PEAKS IN THE FLAMMABILITY CURVES
 (Class B Tub Fire)

<u>Agent</u>	<u>Time, min.</u>	<u>Quantity, oz.</u>	<u>Product</u>	<u>Flammability Peak, %</u>
Agent at 800 psig.				
CBr_2F_3	1.9	7.6	14.44	4.2
$\text{CBrF}_2\text{CBrF}_2$	2	10.5	21.00	4.9
CBrF_3	3	7.7	23.10	6.1
CH_3I	2.8	11.7	32.76	6.1
$\text{C}_2\text{H}_5\text{Br}$	2.8	11.7	32.76	6.2
CH_2BrCl	2.7	12.7	34.29	7.6
CH_3Br	3.4	11.3	38.42	9.7
CO_2	5.2	9.1	47.32	29.5
Agent at 400 psig.				
CBr_2F_2	1.4	6.6	9.24	4.2
$\text{CBrF}_2\text{CBrF}_2$	2.3	10.8	24.84	4.9
CBrF_3	3.0	7.6	22.80	6.1
$\text{CBrF}_2\text{CH}_2\text{Br}$	2.2	12	26.40	6.8
CBrClF_2	2.3	10.7	24.61	9.3
CH_3Br	2.1	8.0	16.80	9.7
CCl_4	2.0	11.4	22.80	11.5
CCl_2F_2	4.1	12	49.20	14.9

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Appendix

The desirability of having all of the data obtained during the course of research on this project is apparent. Consequently, detailed information not pertinent to the discussions in the body of this report are collected in the appendix. Tables are included which show the flammability of various mixtures. Whenever possible plots are included showing the flammable areas of the various mixtures. The data obtained in the literature search for physical properties of several gases are summarized in tabular form in this section.

In the tables showing the flammability, + indicates that the mixture burned, i.e. the flame travelled to the top of the tube; - indicates that the mixture did not burn or if the mixture ignited, the flame did not travel to the top of the tube.

Table 1

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND
 DIBROMODIFLUOROMETHANE
 (Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume %		Result
C_7H_{16}	CBF_2F_2	C_7H_{16}	CBF_2F_2	
8	8	2.0	2.0	-
8	12	2.0	3.0	-
12	8	3.0	2.0	+
12	12	3.0	3.0	-
16	8	4.0	2.0	+
12	6	3.0	1.5	+
8	4	2.0	1.0	-
16	6	4.0	1.5	+
20	4	5.0	1.0	+
14	8	3.5	2.0	+
22	6	5.5	1.5	-
14	10	3.5	2.5	+
14	12	3.5	3.0	+
12	10	3.0	2.5	-
10	6	2.5	1.5	-
18	6	4.5	1.5	+
22	2	5.5	0.5	+
10	4	2.5	1.0	+
22	4	5.5	1.0	+
16	12	4.0	3.0	+
18	10	4.5	2.5	+
16	14	4.0	3.5	+
18	12	4.5	3.0	+
16	16	4.0	4.0	-
18	16	4.5	4.0	+
20	14	5.0	3.5	-
18	18	4.5	4.5	-
24	4	6.0	1.0	+
20	8	5.0	2.0	+
14	12	3.5	3.5	-

Table 2

FLAMMABILITY OF MIXTURES OF *n*-HEPTANE, AIR AND
 TRIBROMOFLUOROMETHANE
 (Total Pressure = 400 mm. Hg)

<u>Pressure, mm. Hg</u>		<u>Volume %</u>		<u>Result</u>
<u>C₇H₁₆</u>	<u>CB₃F</u>	<u>C₇H₁₆</u>	<u>CB₃F</u>	
8	8	2.0	2.0	-
8	12	2.0	3.0	-
10	8	2.5	2.0	+
10	12	2.5	3.0	-
12	16	3.0	4.0	+
10	10	2.5	2.5	-
12	20	3.0	5.0	-
12	18	3.0	4.5	-
14	18	3.5	4.5	-
16	14	4.0	3.5	-
18	10	4.5	2.5	-
14	14	3.5	3.5	-
20	6	5.0	1.5	-

Table 3

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND 2-BROMO-1,1,1-TRIFLUORO-PROPANE

Pressure, mm. Hg			Volume %		Result
n-C ₇ H ₁₆	C ₂ H ₂ BrF ₃	Total	n-C ₇ H ₁₆	C ₂ H ₂ BrF ₃	
4.0	4.0	400	1.0	1.0	-
5.0	8.0	400	1.3	2.0	-
6.0	6.0	397	1.5	2.0	+
8.0	9.0	396	2.0	2.3	-
9.0	9.0	400	2.3	2.3	+
9.0	12.0	400	2.3	3.0	±
9.0	14.0	396	2.3	3.5	-
10.0	14.0	398	2.5	3.5	+
11.0	16.0	400	2.8	4.0	+
14.0	20.0	400	3.5	5.0	-
14.0	19.0	400	3.5	4.8	+
15.0	19.0	400	3.8	4.8	±
16.0	18.0	400	4.0	4.5	-
16.0	17.0	397	4.0	4.0	+
18.0	15.0	398	4.5	3.8	-
18.0	14.0	400	4.5	3.5	+
19.0	10.0	400	4.8	2.5	±
20.0	8.0	400	5.0	2.0	-
20.0	7.0	400	5.0	1.8	-
20.0	6.0	400	5.0	1.5	±
20.0	4.0	398	5.0	1.0	+
21.0	4.0	400	5.3	1.0	-

Table 4

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND 2,2-DIBROMO
TETRA-FLUOROETHANE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume %		Result
<u>n-C₇H₁₆</u>	<u>C₂Br₂F₄</u>	<u>C₇H₁₆</u>	<u>C₂Br₂F₄</u>	
7.0	4.0	1.8	1.0	+
6.0	4.0	1.5	1.0	-
7.0	8.0	1.8	2.0	+
7.0	6.0	1.8	1.5	-
7.0	10.0	1.8	2.5	+
8.0	12.0	2.0	3.0	+
9.0	14.0	2.3	3.5	+
10.0	16.0	2.5	4.0	+
11.0	18.0	2.8	4.5	-
14.0	18.0	3.5	4.5	+
15.0	19.0	3.8	4.8	+
15.0	20.0	3.8	5.0	-
17.0	18.0	4.3	4.5	+
18.0	16.0	4.5	4.0	-
20.0	14.0	5.0	3.5	-
21.0	10.0	5.3	2.5	+
21.0	8.0	5.3	2.0	+
22.0	8.0	5.5	2.0	-
19.0	14.0	4.8	3.5	+

Table 5

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR, AND 1,2-DIIODOTETRAFLUOROETHANE
(Total Pressure = 400 mm. Hg)

<u>Pressure, mm. Hg.</u>		<u>Volume, %</u>		<u>Result</u>
<u>C₇H₁₆</u>	<u>CF₂ICF₂I</u>	<u>C₇H₁₆</u>	<u>CF₂ICF₂I</u>	
16	16	4.0	4.0	+
20	16	5.0	4.0	+
16	18	4.0	4.5	+
12	16	3.0	4.0	+
24	16	6.0	4.0	-
8	16	2.0	4.0	+
16	24	4.0	6.0	-
12	24	3.0	6.0	-
16	20	4.0	5.0	-
12	20	3.0	5.0	-
12	18	3.0	4.5	+
20	18	5.0	4.5	-
8	18	2.0	4.5	-
14	19.2	3.5	4.8	+
6	16	1.5	4.0	-
14	20	3.5	5.0	-

Table 5

FLAMMABILITY OF MIXTURES OF n-H. PT. LNE, AIR, AND DIBROMOMETHANE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Results
n-C ₇ H ₁₆	CH ₂ Br ₂	n-C ₇ H ₁₆	CH ₂ Br ₂	
14.0	16.0	3.5	4.0	+
12.0	20.0	3.0	5.0	-
15.0	16.0	3.8	4.0	-
11.0	20.0	2.8	5.0	+
18.0	10.0	4.5	2.5	-
6.0	14.0	1.5	3.5	-
7.0	14.0	1.8	3.5	+
8.0	16.0	2.0	4.0	+
7.0	12.0	1.8	3.0	+
6.0	10.0	1.5	2.5	-
6.0	8.0	1.5	2.0	-
8.0	18.0	2.0	4.5	-
6.0	4.0	1.5	1.0	+
9.0	20.0	2.3	5.0	+
10.0	21.0	2.5	5.3	-
17.0	10.0	4.3	2.5	+
20.0	4.0	5.0	1.0	-
19.0	4.0	4.8	1.0	+

Table 7

FLAMMABILITY OF MIXTURES OF N-HEPTANE, AIR, AND PENTAFLUORO-
 IODOETHANE

<u>Pressure, mm. Hg.</u>		<u>Volume, %</u>		<u>Result</u>
<u>C₇H₁₆</u>	<u>CF₃CF₂I</u>	<u>C₇H₁₆</u>	<u>CF₃CF₂I</u>	
12.0	16.0	3.0	4.0	+
12.0	20.0	3.0	5.0	+
10.0	18.0	2.5	4.5	-
12.0	24.0	3.0	6.0	-
14.0	20.0	3.5	5.0	-
12.0	22.0	3.0	5.5	-
10.0	14.0	2.5	3.5	-
16.0	14.0	4.0	3.5	+
10.0	10.0	2.5	2.5	-
20.0	10.0	5.0	2.5	+
10.0	6.0	2.5	1.5	-
18.0	16.0	4.5	4.0	+
24.0	10.0	6.0	2.5	+
18.0	18.0	4.5	4.5	+
26.0	10.0	6.5	2.5	-

Table 8

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR, AND 3-BROMO-1,1,1-TRIFLUOROPROPANE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
n-C ₇ H ₁₆	C ₃ H ₂ BrF ₃	n-C ₇ H ₁₆	C ₃ H ₂ BrF ₃	
12.0	16.0	3.0	4.0	+
13.0	16.0	3.3	4.0	-
12.0	18.0	3.0	4.5	-
6.0	18.0	1.5	4.5	+
16.0	10.0	4.0	2.5	+
6.0	20.0	1.5	5.0	+
18.0	10.0	4.5	2.5	-
6.0	21.0	1.5	5.3	+
5.0	20.0	1.3	5.0	-
8.0	21.0	2.0	5.3	-
6.0	22.0	1.5	5.5	-
5.0	21.0	1.3	5.3	-
5.0	14.0	1.3	3.5	+
10.0	20.0	2.5	5.0	-
5.0	10.0	1.0	2.5	-
10.0	19.0	2.5	4.8	+

Table 9

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND
ETHYL IODIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume %		Result
C_7H_{16}	C_2H_5I	C_7H_{16}	C_2H_5I	
12	16	3.0	4.0	+
12	20	3.0	5.0	+
12	24	3.0	6.0	-
12	22	3.0	5.5	-
10	22	2.5	5.5	+
14	22	3.5	5.5	-
10	24	2.5	6.0	-
14	18	3.5	4.5	-
8	24	2.0	6.0	-
16	14	4.0	3.5	-
8	22	2.0	5.5	+
16	10	4.0	2.5	+
6	16	1.5	4.0	+
20	8	5.0	2.0	-

Table 10

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR, AND
BROMOPENT-FLUOROETHANE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume %		Result
C ₇ H ₁₆	CF ₃ CF ₂ Br	C ₇ H ₁₆	CF ₃ CF ₂ Br	
14	20	3.5	5.0	-
12	20	3.0	5.0	-
16	20	4.0	4.0	+
20	20	5.0	5.0	-
16	16	4.0	4.0	+
20	16	5.0	4.0	-
14	16	3.5	4.0	+
12	16	4.5	4.0	+
12	16	3.0	4.0	+
18	20	4.5	5.0	-
17.2	22	4.3	5.5	-
16	22	4.0	5.5	+
10	18	2.5	4.5	-
16	24	4.0	6.0	+
19.2	16	4.8	4.0	+
16	26	4.0	6.5	-
10	16	2.5	4.0	+
15.2	24	3.8	6.0	-
8	16	2.0	4.0	-
14	20	3.5	5.0	+
10	24	4.2	6.0	-
16	24.8	4.0	6.2	-
12	20	3.0	5.0	+

Table 11

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND METHYL IODIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
n-C ₇ H ₁₆	CH ₃ I	n-C ₇ H ₁₆	CH ₃ I	
14.0	12.0	3.5	3.5	-
13.0	12.0	3.3	3.0	+
12.0	16.0	3.0	4.0	+
8.0	20.0	2.0	5.0	+
13.0	16.0	3.3	4.0	-
8.0	18.0	2.0	4.5	+
8.0	16.0	2.0	4.0	+
9.0	22.0	2.3	5.5	+
7.0	16.0	1.8	4.0	-
9.0	23.0	2.3	5.8	-
8.0	22.0	2.0	5.5	+
7.0	20.0	1.8	5.0	-
10.0	20.0	2.5	5.0	+
8.0	23.0	2.0	5.8	-
11.0	20.0	2.8	5.0	+
12.0	20.0	3.0	5.0	+
14.0	12.0	3.5	3.0	+

Table 12

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND BROMOTRIFLUORO-
METHANE
(Total Pressure = 400 mm. Hg)

<u>Pressure, mm. Hg</u>		<u>Volume, %</u>		<u>Result</u>
<u>n-C₇H₁₆</u>	<u>CF₃Br</u>	<u>n-C₇H₁₆</u>	<u>CF₃Br</u>	
5.0	0.0	1.3	0.0	-
6.0	0.0	1.5	0.0	+
28.0	0.0	7.0	0.0	+
29.0	0.0	7.3	0.0	-
11.0	21.0	2.8	6.0	-
13.0	21.0	3.3	6.0	-
6.0	8.0	1.5	2.0	-
7.0	8.0	1.8	2.0	+
8.0	16.0	2.0	4.0	-
9.0	16.0	2.3	4.0	+
20.0	0.0	5.0	2.0	-
16.0	16.0	4.0	4.0	-
12.0	24.0	3.0	6.0	+
12.0	25.0	3.0	6.3	-
10.0	20.0	2.5	5.0	+
13.0	23.0	3.3	5.8	-
9.0	20.0	2.3	5.0	-
15.0	16.0	3.8	4.0	+
19.0	8.0	4.8	2.0	+
14.0	20.0	3.5	5.0	+
24.0	4.0	6.0	1.0	-

Table 13

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND
ETHYL BROMIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume %		Result
C_7H_{16}	CH_3CH_2Br	C_7H_{16}	CH_3CH_2Br	
24	16	6.0	4.0	-
2	16	0.5	4.0	-
20	16	5.0	4.0	-
6	16	1.5	4.0	+
18	16	4.5	4.0	+
4	16	1.0	4.0	+
19.2	16	4.8	4.0	-
5.2	16	1.3	4.0	-
18	32	4.5	8.0	-
14	32	3.5	8.0	-
14	24	3.5	6.0	-
6	24	1.5	6.0	-
10	24	2.5	6.0	+
12	24	3.0	6.0	-
8	24	2.0	6.0	+
10	26	2.5	6.5	-
11.2	24	2.8	1.0	+
7.2	24	1.8	6.0	-
6	25.2	2.5	6.3	-
9.2	25.2	2.3	6.3	+
8	25.2	2.0	6.3	-
9.2	26	2.3	6.5	-

Table 14

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND
1-BROMO-2,2-DIFLUOROPROPANE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume%		Result
C ₇ H ₁₆	CH ₂ BrCF ₂ CH ₃	C ₇ H ₁₆	CH ₂ BrCF ₂ CH ₃	
4	4	1.0	1.0	-
4	8	1.0	2.0	-
8	4	2.0	1.0	+
8	8	2.0	2.0	+
8	12	2.0	3.0	+
6	4	1.5	1.0	+
6	8	1.5	2.0	+
6	12	1.5	3.0	+
8	16	2.0	4.0	+
4	16	1.0	4.0	+
4	12	1.0	3.0	+
2	16	0.5	4.0	-
4	20	1.0	5.0	-
4	24	1.0	6.0	-
6	20	1.5	5.0	+
6	24	1.5	6.0	+
6	28	1.5	7.0	-
8	32	2.0	8.0	-
8	28	2.0	7.0	-
12	24	3.0	6.0	+
12	28	3.0	7.0	-
8	26	2.0	6.5	-
12	26	3.0	6.5	-
16	26	4.0	6.5	-
14	26	3.5	6.5	-
16	24	4.0	6.0	-
10	24.8	2.5	6.2	+
14	24	3.5	6.0	-
26	12	6.5	3.0	-
8	25.2	2.0	6.3	-
22	12	5.5	3.0	-
8	24	2.0	6.0	+
18	12	4.5	3.0	+

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND 2-BROMO-1-CHLORO-1,1-DIFLUOROPROPANE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg.		Volume, %		Result
n-C ₇ H ₁₆	C ₃ H ₂ BrClF ₂	n-C ₇ H ₁₆	C ₃ H ₂ BrClF ₂	
10.0	20.0	2.5	5.0	+
14.0	16.0	3.5	4.0	-
12.0	20.0	3.0	5.0	-
8.0	24.0	2.0	6.0	+
10.0	22.0	2.5	5.5	+
10.0	24.0	2.5	6.0	-
8.0	25.0	2.0	6.3	-
4.0	20.0	1.0	5.0	+
4.0	24.0	1.0	6.0	+
6.0	25.0	1.5	6.3	+
6.0	26.0	1.5	6.5	-
3.0	24.0	0.8	6.0	-
4.0	25.0	1.0	6.3	-
3.0	16.0	0.8	4.0	-
13.0	16.0	3.3	4.0	+
4.0	10.0	1.0	2.5	+
18.0	8.0	4.5	2.0	-
16.0	8.0	4.0	2.0	+
3.0	10.0	0.8	2.5	-
2.0	4.0	0.5	1.0	-

Table 16

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND
 DIBROMOFLUOROMETHANE
 (Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume %		Result
C_7H_{16}	$CHBr_2F$	C_7H_{16}	$CHBr_2F$	
12	20	3.0	5.0	+
6	12	1.5	3.0	-
12	28	3.0	7.0	-
12	24	3.0	6.0	-
8	12	2.0	3.0	-
12	23	3.0	5.75	+
10	12	2.5	3.0	+
10	24	2.5	6.0	-
28	12	7.0	3.0	-
14	24	3.5	6.0	-
20	12	5.0	3.0	-
10	22	2.5	5.5	-
16	12	4.0	3.0	+
14	22	3.5	5.5	+
18	12	4.5	3.0	+
13	24	3.25	6.0	+
13	25	3.25	6.25	+
16	22	4.0	5.5	-
13	26	3.25	6.5	-

Table 17

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR, AND 1,2-DIBROMO-
1,1-DIFLUOROETHANE
(Total Pressure = 400 mm. Hg)

n-C ₇ H ₁₆	Volume, %		Result
	n-C ₇ H ₁₆	CBrF ₂ CH ₂ Br	
1.0		5.0	-
4.0		4.0	+
1.0		2.0	-
4.0		5.0	+
2.0		5.5	-
4.0		6.0	-
2.0		5.0	+
5.5		2.0	-
2.0		6.0	-
3.0		6.5	+
5.0		4.0	-
3.0		7.0	-
2.5		6.5	-
3.5		6.5	-

Table 18

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND 2-BROMO-1,1,1-
TRIFLUOROETHANE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
n-C ₇ H ₁₆	CF ₃ CH ₂ Br	n-C ₇ H ₁₆	CF ₃ CH ₂ Br	
29.0	6.0	7.3	1.5	+
29.0	7.0	7.3	1.8	-
27.0	10.0	6.8	2.5	+
28.0	10.0	7.0	2.5	-
26.0	12.0	6.5	3.0	-
25.0	12.0	6.3	3.0	+
25.0	14.0	6.3	3.5	+
22.0	18.0	5.5	4.5	-
21.0	18.0	4.3	4.5	+
19.0	22.0	4.8	5.5	-
18.0	22.0	4.5	5.5	+
16.0	26.0	4.0	6.5	+
11.0	26.0	2.8	6.5	+
13.0	27.0	3.3	6.8	-
10.0	22.0	2.5	5.5	+
9.0	18.0	2.3	4.5	-
9.0	18.0	2.3	4.5	-
9.0	10.0	2.3	2.5	-
10.0	10.0	2.5	2.5	+
9.0	6.0	2.3	1.5	-
8.0	4.0	2.0	1.0	-
9.0	4.0	2.3	1.0	+

Table 19

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND PERFLUOROETHYL-
CYCLOHEXANE

Pressure, mm. Hg			Volume, %		Result
n-C ₇ H ₁₆	C ₆ F ₁₁ C ₂ F ₆	Total	n-C ₇ H ₁₆	C ₆ F ₁₁ C ₂ F ₆	
5.0	5.0	500	1.0	1.0	-
30.0	5.0	500	6.0	1.0	+
6.0	5.0	499	1.2	1.0	+
31.0	5.0	500	6.2	1.0	+
5.0	10.0	499	1.0	2.0	+
4.0	10.0	499	0.8	2.0	-
5.0	15.0	501	1.0	3.0	+
4.0	15.0	502	0.8	3.0	-
24.0	8.0	401	6.0	2.0	+
6.0	20.0	503	1.2	4.0	-
25.0	8.0	401	6.2	2.0	-
7.0	20.0	500	1.4	4.0	+
24.0	12.0	401	6.0	3.0	-
10.0	25.0	503	2.0	5.0	-
23.0	12.0	400	5.8	3.0	+
11.0	25.0	501	2.2	5.0	+
22.0	16.0	399	5.5	4.0	-
10.0	24.0	400	2.5	6.0	-
21.0	16.0	399	5.3	4.0	+
11.0	24.0	401	2.7	6.0	+
18.0	18.0	349	5.2	5.2	-
9.0	21.0	300	3.0	7.0	-
16.0	17.0	340	4.7	5.0	-
15.0	17.0	340	4.4	5.0	+
9.0	20.0	300	3.0	6.7	+
12.0	18.0	300	4.0	6.0	+
10.0	20.0	300	3.3	6.7	-
13.0	18.0	300	4.3	6.0	-
11.0	20.0	300	3.7	6.7	+
12.0	21.0	310	3.9	6.8	-

Table 20

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND PERFLUORO-1,3-DIMETHYLCYCLOHEXANE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
<u>n-C₇H₁₆</u>	<u>C₆F₁₀(CF₂)₂</u>	<u>n-C₇H₁₆</u>	<u>C₆F₁₀(CF₂)₂</u>	
25.0	4.0	6.3	1.0	+
23.0	12.0	5.8	3.0	+
22.0	16.0	5.5	4.0	-
20.0	16.0	5.0	4.0	+
18.0	22.0	4.5	5.5	+
13.0	27.0	3.3	6.8	+
9.0	24.0	2.3	6.0	+
7.0	16.0	1.8	4.0	+
6.0	16.0	1.5	4.0	-
4.0	4.0	1.0	1.0	-
5.0	4.0	1.3	1.0	+

Table 21

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND PERFLUORO-1,4-DIMETHYLCYCLOHEXANE

Pressure, mm. Hg			Volume %		Result
n-C ₇ H ₁₆	C ₆ F ₁₀ (CF ₂) ₂	Total	n-C ₇ H ₁₆	C ₆ F ₁₀ (CF ₂) ₂	
3.0	6.0	299	1.0	2.0	-
20.0	3.0	300	6.7	1.0	+
4.0	6.0	300	1.3	2.0	+
21.0	3.0	300	7.0	1.0	-
4.0	12.0	300	1.3	4.0	-
17.0	9.0	302	5.6	3.0	+
5.0	12.0	299	1.7	4.0	+
18.0	9.0	300	6.0	3.0	-
7.0	15.0	300	2.3	5.0	+
13.0	15.0	300	4.3	5.0	+
6.0	15.0	300	2.0	5.0	+
14.0	15.0	302	4.6	5.0	+
5.0	15.0	300	1.7	5.0	-
15.0	15.0	299	5.0	5.0	-
7.0	18.0	301	2.3	6.0	-
16.0	15.0	300	5.3	5.0	-
8.0	18.0	301	2.7	6.0	+
19.0	6.0	300	6.3	2.0	-
11.0	21.0	300	3.7	7.0	-
18.0	6.0	300	6.0	2.0	+
11.0	20.0	303	3.6	6.6	+
14.0	19.0	300	4.7	6.3	-
9.0	20.0	302	3.0	6.6	+
13.0	19.0	299	4.3	6.3	-
9.0	21.0	307	2.9	6.8	-
16.0	12.0	300	5.3	4.0	-
5.0	5.0	499	1.0	1.0	-
15.0	12.0	300	5.0	4.0	+
6.0	5.0	499	1.2	1.0	+
13.0	18.0	300	4.3	6.0	+
15.0	17.0	299	5.0	5.7	-
29.0	0.0	401	7.2	0.0	+
15.0	17.0	305	4.9	5.6	-
30.0	0.0	405	7.4	0.0	-

Table 32

FLAMMABILITY OF MIXTURES OF N-HEPTANE, AIR AND TRIFLUORO-
 IODOMETHANE
 (Total Pressure = 400 mm. Hg.)

Pressure, mm. Hg.		Volume %		Result
C_7H_{16}	CF_3I	C_7H_{16}	CF_3I	
12.0	20.0	3.0	5.0	+
12.0	28.0	3.0	7.0	-
12.0	24.0	3.0	6.0	+
12.0	26.0	3.0	6.5	-
10.0	26.0	2.5	6.5	+
14.0	26.0	3.5	6.5	-
10.0	28.0	2.5	7.0	-
16.0	20.0	4.0	5.0	+
8.0	26.0	2.0	6.5	-
8.0	20.0	2.0	5.0	+
20.0	20.0	5.0	5.0	+
6.0	20.0	1.5	5.0	-
24.0	20.0	6.0	5.0	-
8.0	24.0	2.0	6.0	+
22.0	20.0	5.5	5.0	+
14.0	24.0	3.5	6.0	+
18.0	24.0	4.5	6.0	+

Table 23

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND 1-BROMO-2-CHLORO-ETHANE

Pressure, mm. Hg			Volume %		Result
CH ₂ ClCH ₂ Br	n-C ₇ H ₁₆	Total	CH ₂ ClCH ₂ Br	n-C ₇ H ₁₆	
6.0	4.0	353	1.7	1.1	+
6.0	20.0	300	2.0	6.7	-
6.0	3.0	300	2.0	1.0	-
6.0	19.0	300	2.0	6.3	-
12.0	3.0	300	4.0	1.0	-
6.0	18.0	300	2.0	6.0	-
12.0	..0	300	4.0	1.3	+
6.0	16.0	300	2.0	5.3	-
18.0	4.0	300	6.0	1.3	+
6.0	14.0	310	1.9	4.5	+
18.0	3.0	300	6.0	1.0	-
6.0	15.0	299	2.0	5.0	-
21.0	4.0	300	7.0	1.3	-
12.0	11.0	301	4.0	3.7	-
12.0	10.0	299	4.0	3.3	+
21.0	5.0	301	7.0	1.7	+
18.0	8.0	300	6.0	2.7	-
23.0	6.0	301	7.7	2.0	-
18.0	7.0	300	6.0	2.3	+
22.0	6.0	300	7.3	2.0	-
21.0	7.0	300	7.0	2.3	-
21.0	6.0	300	7.0	2.0	-
22.0	5.0	300	7.3	1.7	-
3.0	17.0	300	1.0	5.7	+
3.0	18.0	300	1.0	6.0	-

Table 24

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND 2-BROMO-1-
CHLORO-1,1-DIFLUOROETHANE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume %		Result
C_7H_{16}	$CClF_2CH_2Br$	C_7H_{16}	$CClF_2CH_2Br$	
8	8	2.0	2.0	+
8	12	2.0	3.0	+
12	8	3.0	2.0	+
8	16	2.0	4.0	-
8	20	2.0	5.0	-
12	16	3.0	4.0	+
12	20	3.0	5.0	+
12	24	3.0	6.0	+
12	28	3.0	7.0	+
12	36	3.0	9.0	-
12	44	3.0	11.0	-
12	32	3.0	8.0	-
16	28	4.0	7.0	-
12	30	3.0	7.5	-
16	24	4.0	6.0	+
14	30	3.5	7.5	-
20	20	5.0	5.0	-
14	28	3.5	7.0	-

Table 25

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND PERFLUOROMETHYL-
CYCLOHEXANE

Pressure, mm. Hg			Volume %		Result
n-C ₇ H ₁₆	C ₆ F ₁₁ CF ₃	Total	n-C ₇ H ₁₆	C ₆ F ₁₁ CF ₃	
27.0	15.0	501	5.4	3.0	+
28.0	15.0	500	5.6	3.0	-
6.0	20.0	502	1.2	4.0	-
7.0	20.0	500	1.4	4.0	+
12.0	35.0	500	2.4	7.0	-
13.0	35.0	499	2.6	7.0	+
14.0	38.0	520	2.7	7.3	+
14.0	38.0	500	2.8	7.6	-
14.0	37.0	500	2.8	7.4	+
11.0	30.0	500	2.2	6.0	-
12.0	30.0	500	2.4	6.0	+
9.0	25.0	504	1.8	5.0	+
21.0	30.0	500	4.2	6.0	+
8.0	25.0	498	1.6	5.0	-
12.0	33.0	500	2.4	6.6	+
22.0	30.0	500	4.4	6.0	-
19.0	33.0	488	3.9	6.8	+
18.0	35.0	505	3.6	6.9	+
19.0	35.0	495	3.8	7.1	-
16.0	37.0	499	3.2	7.4	-
16.0	36.0	502	3.2	7.2	+
5.0	10.0	500	1.0	2.0	+
4.0	10.0	499	0.8	2.0	-
6.0	20.0	500	1.2	4.0	-
7.0	20.0	499	1.4	4.0	+
5.0	15.0	501	1.0	3.0	-
6.0	15.0	502	1.2	3.0	+
24.0	24.0	500	4.8	4.8	-
23.0	24.0	500	4.6	4.8	+
5.0	5.0	500	1.0	1.0	+
4.0	5.0	501	0.8	1.0	-

Table 26

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR, AND n-PERFLUORO-
HEPTANE

(Total Pressure = 400 mm. Hg)

<u>Pressure, mm. Hg</u>		<u>Volume, %</u>		<u>Result</u>
<u>n-C₇H₁₆</u>	<u>n-C₇F₁₆</u>	<u>n-C₇H₁₆</u>	<u>n-C₇F₁₆</u>	
28.0	4.0	7.0	1.0	+
26.0	12.0	6.5	3.0	-
24.0	12.0	6.0	3.0	+
22.0	16.0	5.5	4.0	+
18.0	24.0	4.5	6.0	-
15.0	26.0	3.8	6.5	+
13.0	24.0	3.3	6.0	+
10.0	16.0	2.5	3.0	+
7.0	8.0	1.8	2.0	+
6.0	8.0	1.5	2.0	-
6.0	4.0	1.5	1.0	+
5.0	4.0	1.3	1.0	-

Table 27

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND BROMOCHLORO-
METHANE

Pressure, mm. Hg			Volume %		Result
n-C ₇ H ₁₆	CH ₂ BrCl	Total	n-C ₇ H ₁₆	CH ₂ BrCl	
9.0	20.0	499	1.8	4.0	-
10.0	20.0	501	2.0	4.0	+
11.0	35.0	498	2.2	7.0	+
10.0	35.0	507	2.0	6.9	-
23.0	15.0	505	4.6	3.0	-
22.0	15.0	502	4.4	3.0	+
18.0	25.0	500	3.6	5.0	+
19.0	25.0	497	3.8	5.0	-
14.0	35.0	496	2.8	7.1	+
15.0	35.0	495	3.0	7.1	-
13.0	37.0	512	2.5	7.2	-
12.0	36.0	502	2.4	7.2	+
12.0	38.0	498	2.4	7.6	-
12.0	37.0	505	2.4	7.3	+
10.0	37.0	492	2.0	7.5	+
11.0	38.0	502	2.2	7.6	-

Table 28

FLAMMABILITY OF MIXTURES OF N-HEPTANE, BROMODIFLUOROC-
METHANE AND AIR

(Total Pressure = 400 mm. Hg)

<u>Pressure, mm. Hg.</u>		<u>Volume %</u>		<u>Results</u>
<u>C₇H₁₆</u>	<u>CHBrF₂</u>	<u>C₇H₁₆</u>	<u>CHBrF₂</u>	
16.0	32.0	4.0	8.0	+
12.0	24.0	3.0	6.0	+
20.0	24.0	5.0	6.0	-
16.0	40.0	4.0	10.0	-
20.0	16.0	5.0	4.0	-
16.0	36.0	4.0	9.0	-
12.0	32.0	3.0	8.0	-
8.0	24.0	2.0	6.0	-
20.0	8.0	5.0	2.0	-
12.0	28.0	3.0	7.0	-
8.0	8.0	2.0	2.0	+
20.0	32.0	5.0	8.0	-
20.0	1.0	5.0	1.0	+
32.0	0.0	8.0	0.0	-

Table 29

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND 1,1,2-TRICHLORO-
FLUOROETHYLENE

Pressure, mm. Hg			Volume %		Result
n-C ₇ H ₁₆	C ₂ Cl ₃ F ₃	Total	n-C ₇ H ₁₆	C ₂ Cl ₃ F ₃	
5.0	5.0	500	1.0	1.0	-
6.0	5.0	500	1.2	1.0	+
5.0	10.0	500	1.0	2.0	-
6.0	10.0	499	1.2	2.0	-
6.0	10.0	500	1.2	2.0	-
7.0	10.0	500	1.4	2.0	+
7.0	15.0	499	1.4	3.0	-
8.0	20.0	500	1.6	4.0	Blew off safety cap
28.0	2.0	409	6.9	0.5	+
28.0	4.0	399	7.0	1.0	-
27.0	4.0	400	6.7	1.0	+
27.0	8.0	400	6.7	2.0	-
26.0	8.0	400	6.5	2.0	+
26.0	12.0	399	6.5	3.0	+
27.0	12.0	401	6.8	3.0	-
26.0	16.0	400	6.5	4.0	-
25.0	16.0	404	6.2	4.0	-
24.0	16.0	401	6.0	4.0	+
6.0	16.0	399	1.5	4.0	+
22.0	20.0	400	5.5	5.0	+
6.0	20.0	400	1.5	5.0	-
23.0	20.0	401	5.7	5.0	-
7.0	21.0	400	1.7	5.2	-
5.0	15.0	400	1.3	4.0	-
20.0	24.0	400	5.0	6.0	+
8.0	20.0	399	2.0	5.0	+
10.0	24.0	403	2.5	6.0	+
21.0	24.0	399	5.2	6.0	-
9.0	25.0	400	2.3	6.2	+
17.0	28.0	400	4.3	7.0	+
8.0	24.0	400	2.0	6.0	-
18.0	28.0	400	4.5	7.0	+
10.0	28.0	400	2.5	7.0	+
9.0	28.0	400	4.7	7.0	+
19.0	28.0	401	2.2	7.0	+
8.0	28.0	400	2.0	7.0	-
21.0	28.0	400	5.2	7.0	-
12.0	32.0	401	3.0	8.0	+
16.0	32.0	400	4.0	8.0	+
12.0	34.0	400	3.0	8.5	-
16.0	34.0	399	4.0	8.5	+
16.0	36.0	401	4.0	9.0	+
10.0	31.0	399	2.5	7.7	+

Table 29 (continued)

Pressure, mm. Hg			Volume %		Result
<u>n-C₂H₆</u>	<u>C₂Cl₃F₃</u>	<u>Total</u>	<u>n-C₂H₆</u>	<u>C₂Cl₃F₃</u>	
16.0	38.0	400	4.0	9.5	-
10.0	32.0	400	2.5	8.0	-
20.0	32.0	407	4.9	7.9	-
12.0	33.0	406	3.0	8.1	+
19.0	32.0	400	4.7	8.0	-
12.0	33.0	401	3.0	8.3	+
18.0	32.0	400	4.5	8.0	+
16.0	37.0	406	4.0	9.1	-
17.0	25.0	400	4.3	8.8	-
20.0	28.0	400	5.0	7.0	-
18.0	28.0	400	4.5	7.0	+
18.0	35.0	411	4.4	8.5	-
19.0	28.0	400	4.8	7.0	+
14.0	35.0	400	3.5	8.8	-
20.0	28.0	399	5.0	7.5	-
14.0	34.0	400	3.5	8.5	-

Table 30

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND BROMOCHLORO-
DIFLUOROMETHANE
(Total Pressure = 400 mm. Hg)

<u>Pressure, mm. Hg</u>		<u>Volume %</u>		<u>Result</u>
<u>C₇H₁₆</u>	<u>CBrClF₂</u>	<u>C₇H₁₆</u>	<u>CBrClF₂</u>	
8	24	2.0	6.0	+
20	24	5.0	6.0	+
8	32	2.0	8.0	-
12	28	3.0	7.0	+
4	24	1.0	6.0	-
8	28	2.0	7.0	+
6	24	1.5	6.0	-
12	32	3.0	8.0	+
8	30	2.0	7.5	-
14	34	3.5	8.5	-
12	36	3.0	9.0	+
16	32	4.0	8.0	-
10	34	2.5	8.5	-
12	38	3.0	9.5	-
18	34	4.5	8.5	-
14	34	3.5	8.5	-
20	28	5.0	7.0	-
6	12	1.5	3.0	-

Table 31

FLAMMABILITY OF MIXTURES OF N-HEPTANE, AIR, AND HYDROGEN
BROMIDE
(Total Pressure = 400 mm. Hg.)

<u>Pressure, mm. Hg.</u>		<u>Volume %</u>		<u>Result</u>
<u>C₇H₁₆</u>	<u>HBr</u>	<u>C₇H₁₆</u>	<u>HBr</u>	
16.0	40.0	4.0	10.0	-
24.0	40.0	6.0	10.0	-
16.0	20.0	4.0	5.0	+
24.0	20.0	6.0	5.0	-
16.0	28.0	4.0	7.0	+
20.0	20.0	5.0	5.0	-
16.0	32.0	4.0	8.0	-
8.0	20.0	2.0	5.0	-
16.0	36.0	4.0	9.0	+
12.0	20.0	3.0	5.0	+
12.0	38.0	3.0	9.5	-
20.0	36.0	5.0	9.0	-
16.0	38.0	4.0	9.5	-
12.0	36.0	3.0	9.0	-
24.0	4.0	6.0	1.0	-
8.0	8.0	2.0	2.0	+

Table 32

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND METHYL BROMIDE

<u>Pressure, mm. Hg</u>			<u>Volume %</u>		<u>Result</u>
<u>n-C₇H₁₆</u>	<u>CH₃Br</u>	<u>Tot. l</u>	<u>n-C₇H₁₆</u>	<u>CH₃Br</u>	
6.0	20.0	498	1.2	4.0	-
7.0	20.0	508	1.4	3.9	+
6.0	40.0	500	1.2	8.0	-
7.0	40.0	500	1.4	8.0	+
10.0	43.0	500	2.0	8.6	+
10.0	44.0	501	2.0	8.8	-
15.0	27.0	500	3.0	5.4	+
15.0	30.0	499	3.0	6.0	-
17.0	25.0	500	3.4	5.0	-
16.0	25.0	504	3.2	5.0	+
13.0	35.0	498	2.6	7.0	-
12.0	35.0	500	2.4	7.0	+
11.0	40.0	501	2.2	8.0	-
10.0	40.0	501	2.0	8.0	+
8.0	46.0	501	1.6	9.2	+
8.0	47.0	499	1.6	9.4	-
7.0	48.0	501	1.4	9.6	+
7.0	49.0	500	1.4	9.8	-
25.0	9.0	503	5.0	1.8	+
26.0	9.0	503	5.2	1.8	-

Table 33

FLAMMABILITY OF MIXTURES OF N-HEPTANE, AIR AND DIFLUORO-
VINYL BROMIDE
(Total Pressure = 400 mm. Hg.)

Pressure, mm. Hg.		Volume %		Result
C_7H_{16}	$CF_2=CHBr$	C_7H_{16}	$CF_2=CHBr$	
8.0	24.0	2.0	6.0	+
20.0	24.0	5.0	6.0	-
4.0	24.0	1.0	6.0	-
16.0	24.0	4.0	6.0	-
4.0	36.0	1.0	9.0	-
12.0	24.0	3.0	6.0	+
8.0	28.0	2.0	7.0	+
10.0	32.0	2.5	8.0	+
12.0	28.0	3.0	7.0	+
10.0	36.0	2.5	9.0	+
10.0	40.0	2.5	10.0	-
10.0	38.0	2.5	9.5	+
12.0	38.0	3.0	8.5	-
8.0	38.0	3.0	9.5	-
20.0	10.0	5.0	2.5	-
20.0	14.0	5.0	3.5	-
20.0	6.0	5.0	1.5	-

Table 34

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND PERFLUOROBUTANE

Pressure, mm. Hg			Volume %		Result
n-C ₇ H ₁₆	C ₄ F ₁₀	Total	n-C ₇ H ₁₆	C ₄ F ₁₀	
30.0	4.0	400	7.5	1.0	-
29.0	4.0	400	7.2	1.0	+
29.0	8.0	400	7.2	2.0	-
28.0	8.0	400	7.0	2.0	+
24.0	16.0	400	6.0	4.0	-
23.0	16.0	401	5.7	4.0	+
20.0	23.0	400	5.0	5.7	+
21.0	24.0	402	5.2	6.0	-
20.0	29.0	400	5.0	7.2	-
19.0	29.0	400	4.7	7.2	+
17.0	35.0	402	4.2	8.7	-
13.0	31.0	400	4.2	8.5	+
13.0	39.0	400	3.3	9.7	+
5.0	40.0	400	3.3	10.0	-
4.0	4.0	400	1.2	1.0	-
4.0	4.0	401	1.0	1.0	+
4.0	12.0	398	1.0	3.0	+
5.0	12.0	400	1.2	3.0	-
5.0	20.0	400	1.2	5.0	+
6.0	20.0	399	1.5	5.0	-
7.0	26.0	400	1.7	6.5	+
8.0	26.0	400	2.0	6.5	-
8.0	31.0	400	2.0	7.7	+
9.0	31.0	400	2.2	7.7	-
11.0	35.0	401	2.7	8.7	+
11.0	36.0	400	2.7	9.0	+

Table 35

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND SILICON
TETRACHLORIDE
(Total Pressure = 400 mm. Hg)

<u>Pressure, mm. Hg</u>		<u>Volume %</u>		<u>Result</u>
<u>C₇H₁₆</u>	<u>SiCl₄</u>	<u>C₇H₁₆</u>	<u>SiCl₄</u>	
16	32	4.0	8.0	+
12	24	3.0	6.0	+
20	24	5.0	6.0	+
16	34	4.0	8.5	+
10	24	2.5	6.0	-
12	36	3.0	9.0	+
14	36	3.5	9.0	+
16	36	4.0	9.0	-
14	38	3.5	9.5	-
12	38	3.0	9.5	+
12	40	3.0	10.0	-
10	40	2.5	10.0	-
10	38	2.5	9.5	-

Table 36

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR, AND 1,2-DIBROMO-
-2-CHLORO-1, 1-DIFLUOROETHANE

(Total Pressure = 400 mm. Hg)

<u>n-C₇H₁₆</u>	<u>CB₂F₂CB₂Cl₂F</u>	<u>Result</u>
2.0	4.0	+
2.0	5.0	+
2.0	6.0	+
2.0	7.0	+
2.0	8.0	+
2.0	9.0	-
2.5	9.0	-
3.0	9.0	+
3.0	9.5	-
3.5	9.0	+
4.0	9.3	+
3.5	9.5	+
3.5	10.0	+
4.0	10.0	-
4.5	9.0	+
1.5	8.0	-
5.0	9.0	+
1.5	5.0	-
5.5	9.0	-
3.5	10.0	+
3.5	10.5	+
3.5	11.0	-

Table 37

FLAMMABILITY OF MIXTURES OF *n*-HEPTANE, AIR AND
1,2-DICHLOROTETRAFLUOROETHANE (FREON 114)
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume %		Result
C ₇ H ₁₆	CClF ₂ CClF ₂	C ₇ H ₁₆	CClF ₂ CClF ₂	
8	4	2.0	1.0	+
10	8	2.5	2.0	+
6	8	1.5	2.0	-
8	12	2.0	3.0	+
8	8	2.0	2.0	+
6	12	1.5	3.0	-
8	16	2.0	4.0	+
8	20	2.0	5.0	-
8	24	2.0	6.0	-
10	20	2.5	5.0	-
10	26	2.5	6.5	-
12	20	3.0	5.0	+
14	24	3.5	6.0	+
12	29	3.0	7.25	+
20	24	5.0	6.0	+
12	36	3.0	9.0	+
16	32	4.0	8.0	+
12	40	3.0	10.0	+
20	32	5.0	8.0	+
12	44	3.0	11.0	-
12	42	3.0	10.5	+
20	32	5.0	8.0	+
14	42	3.5	10.5	-
10	42	2.5	10.5	-
24	32	6.0	8.0	-
12	41	3.0	10.25	+
22	32	5.5	8.0	+
24	22	6.0	5.5	+
26	22	7.0	5.5	-

Table 36

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND CARBON TETRACHLORIDE

Pressure, mm. Hg			Volume %		Result
<u>n</u> -C ₇ H ₁₆	CCl ₄	Total	<u>n</u> -C ₇ H ₁₆	CCl ₄	
7.0	20.0	493	1.4	4.1	+
6.0	20.0	522	1.2	3.8	-
8.0	30.0	517	1.5	5.8	-
7.0	30.0	517	1.4	5.8	+
13.0	50.0	531	2.4	9.4	-
14.0	50.0	536	2.6	9.3	+
13.0	46.0	409	3.2	11.2	+
13.0	47.0	406	3.2	11.6	-
21.0	45.0	468	4.5	9.6	-
20.0	45.0	492	4.1	9.2	+
29.0	20.0	506	5.7	3.9	+
30.0	20.0	509	5.9	3.9	-

Table 39

FLAMMABILITY OF MIXTURES OF n-NEPTANE, AIR AND 2-CHLORO-1,1,1-TRI-
FLUOROPROPANE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
n-C ₇ H ₁₆	CF ₃ CHClCH ₃	n-C ₇ H ₁₆	CF ₃ CHClCH ₃	
22.0	16.0	5.5	4.0	-
4.0	16.0	1.0	4.0	+
2.0	16.0	0.5	4.0	-
12.0	32.0	3.0	8.0	+
14.0	32.0	3.5	8.0	-
8.0	40.0	2.0	10.0	-
6.0	40.0	1.5	10.0	+
4.0	44.0	1.0	11.0	+
0.0	32.0	0.0	8.0	-
6.0	44.0	1.5	11.0	+
4.0	48.0	1.0	12.0	-
6.0	46.0	1.5	11.5	+
0.0	42.0	0.0	10.5	+
6.0	47.0	1.5	11.8	-
4.0	47.0	1.0	11.8	+
0.0	28.0	0.0	7.0	-
7.0	44.0	1.8	11.0	-
0.0	29.0	0.0	7.3	+
0.0	43.0	0.0	10.8	-
3.0	44.0	0.8	11.0	-
1.0	24.0	0.3	6.0	+
21.0	16.0	5.3	4.0	+

Table 40

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND 2-CHLORO-1,1,1-TRI-
FLUOROPROPANE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume %		Result
n-C ₇ H ₁₆	C ₂ H ₂ ClF ₃	n-C ₇ H ₁₆	C ₂ H ₂ ClF ₃	
22.0	12.0	55.5	3.0	-
21.0	12.0	5.3	3.0	+
14.0	28.0	3.5	7.0	-
13.0	28.0	3.3	7.0	+
4.0	44.0	1.0	11.0	+
16.0	20.0	4.0	5.0	+
1.0	36.0	0.3	9.0	+
0.0	36.0	0.0	9.0	-
17.0	20.0	4.3	5.0	-
0.0	40.0	0.0	10.0	-
4.0	48.0	1.0	12.0	-
1.0	44.0	0.3	11.0	-
2.0	48.0	0.5	12.0	+
4.0	46.0	1.0	11.5	-
2.0	49.0	0.5	12.3	-
3.0	46.0	0.8	11.5	+
1.0	48.0	0.3	12.0	-
3.0	48.0	0.8	12.0	+
3.0	49.0	0.8	12.3	-
1.0	28.0	0.3	7.0	-
3.0	20.0	0.8	5.0	+
2.0	28.0	0.5	7.0	+
2.0	20.0	0.5	5.0	-
10.0	36.0	2.5	9.0	-
9.0	36.0	2.3	9.0	+

Table 41

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND CHLOROTRIFLUOROMETHANE
(FREON 13)
(Total Pressure = 400 mm. Hg)

<u>Pressure, mm. Hg</u>		<u>Volume %</u>		<u>Result</u>
<u>n-C₇H₁₆</u>	<u>CClF₃</u>	<u>n-C₇H₁₆</u>	<u>CClF₃</u>	
12.0	48.0	3.0	12.0	+
14.0	48.0	3.5	12.0	-
12.0	50.0	3.0	12.5	-
14.0	44.0	3.5	11.0	+
10.0	40.0	2.5	10.0	-
20.0	24.0	5.0	6.0	+
21.0	24.0	5.3	6.0	-
11.0	48.0	2.8	12.0	-
13.0	48.0	3.3	12.0	+
13.0	50.0	3.3	12.5	-
7.0	24.0	1.8	6.0	+
6.0	24.0	1.5	6.0	+

Table 42

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND HEXAFLUOROETHANE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume %		Result
n-C ₇ H ₁₆	C ₂ F ₆	n-C ₇ H ₁₆	C ₂ F ₆	
24.0	20.0	6.0	5.0	+
6.0	2.0	1.5	5.0	-
25.0	20.0	6.3	5.0	-
7.0	20.0	1.8	5.0	+
8.0	40.0	2.0	10.0	-
9.0	40.0	2.3	10.0	+
10.0	52.0	2.5	13.0	-
10.0	48.0	2.5	12.0	-
16.0	44.0	4.0	11.0	-
11.0	48.0	2.8	12.0	+
16.0	40.0	4.0	10.0	+
17.0	40.0	4.3	10.0	-
14.0	48.0	3.5	12.0	+
12.0	54.0	3.0	13.0	-
15.0	48.0	3.8	12.0	+
14.0	50.0	3.5	12.5	-
13.0	52.0	3.3	13.0	-
12.0	53.0	3.0	13.3	+

Table 43

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND DICHLORODIFLUOROMETHANE
(FREON 12)
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
n-C ₇ H ₁₆	CCl ₂ F ₂	n-C ₇ H ₁₆	CCl ₂ F ₂	
6.0	32.0	1.5	8.0	+
20.0	32.0	5.0	8.0	-
6.0	16.0	1.5	4.0	+
22.0	16.0	5.5	4.0	-
21.0	16.0	5.3	4.0	+
19.0	32.0	4.8	8.0	+
5.0	16.0	1.3	4.0	-
5.0	32.0	1.3	8.0	-
18.0	44.0	4.5	11.0	+
19.0	44.0	4.8	11.0	-
12.0	44.0	3.0	11.0	+
18.0	52.0	4.5	13.0	-
17.0	52.0	4.3	13.0	+
14.0	58.0	3.5	14.5	+
11.0	44.0	2.8	11.0	-
14.0	59.0	3.5	14.5	-
16.0	58.0	4.0	14.5	+
18.0	58.0	4.5	14.5	-
16.0	60.0	4.0	15.0	-
10.0	38.0	2.5	9.5	+
9.0	38.0	2.3	9.5	-
17.0	58.0	4.3	14.5	+

Table 44

FLAMMABILITY OF MIXTURES OF *n*-HEPTANE, AIR AND
 CHLOROFORM
 (Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume %		Result
C_7H_{16}	$CHCl_3$	C_7H_{16}	$CHCl_3$	
8	4	2.0	1.0	-
8	8	2.0	2.0	+
12	4	3.0	1.0	+
8	12	2.0	3.0	+
8	16	2.0	4.0	+
8	20	2.0	5.0	-
8	24	2.0	6.0	-
12	20	3.0	5.0	+
12	48	3.0	12.0	+
12	24	3.0	6.0	+
12	52	3.0	13.0	+
16	56	4.0	14.0	+
12	60	3.0	15.0	+
12	68	3.0	17.0	-
12	72	3.0	18.0	-
12	64	3.0	16.0	+
16	60	4.0	15.0	+
12	66	3.0	16.5	+
16	64	4.0	16.0	+
20	60	5.0	15.0	+
24	36	6.0	9.0	+
14	68	3.5	17.0	+
28	68	7.0	9.0	-
14	72	3.5	18.0	-
14	70	3.5	17.5	+
16	68	4.0	17.0	-
20	64	5.0	16.0	-

Table 45

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND TRIFLUOROMETHANE
(FREON 23)

(Total Pressure = 400 mm. Hg)

<u>Pressure, mm. Hg</u>		<u>Volume %</u>		<u>Result</u>
<u>n-C₇H₁₆</u>	<u>CHF₃</u>	<u>n-C₇H₁₆</u>	<u>CHF₃</u>	
24.0	16.0	6.0	4.0	-
5.0	24.0	1.3	6.0	+
4.0	24.0	1.0	6.0	-
22.0	16.0	5.5	4.0	+
6.0	40.0	1.5	10.0	+
18.0	40.0	4.5	10.0	-
4.0	40.0	1.0	10.0	-
16.0	40.0	4.0	10.0	+
14.0	60.0	3.5	15.0	-
12.0	60.0	3.0	15.0	+
6.0	56.0	1.5	14.0	+
10.0	68.0	2.5	17.0	+
8.0	68.0	2.0	17.0	+
12.0	68.0	3.0	17.0	+
6.0	68.0	1.5	17.0	-
10.0	71.0	2.5	17.8	-
12.0	71.0	3.0	17.8	-
8.0	71.0	2.0	17.8	-
13.0	68.0	3.3	17.0	-

Table 46

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND CHLORODIFLUOROMETHANE
(FREON 22)
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
n-C ₇ H ₁₆	CHClF ₂	n-C ₇ H ₁₆	CHClF ₂	
24.0	16.0	6.0	4.0	-
4.0	16.0	1.0	4.0	+
20.0	28.0	5.0	7.0	+
3.0	16.0	0.8	4.0	-
23.0	16.0	5.8	4.0	+
4.0	28.0	1.0	7.0	+
21.0	28.0	5.3	7.0	-
18.0	40.0	4.5	10.0	+
19.0	40.0	4.8	10.0	-
4.0	40.0	1.0	10.0	+
3.0	28.0	0.8	7.0	-
3.0	40.0	0.8	10.0	-
6.0	60.0	1.5	15.0	+
5.0	60.0	1.3	15.0	-
12.0	66.0	3.0	16.5	+
13.0	66.0	3.3	16.5	-
12.0	68.0	3.0	17.0	-
10.0	72.0	2.5	18.0	-
11.0	70.0	2.8	17.5	-
10.0	71.0	2.5	17.8	+
8.0	70.0	2.0	17.5	+
16.0	52.0	4.0	13.0	-
6.0	68.0	1.5	17.0	-
7.0	68.0	1.8	17.0	+
8.0	71.0	2.0	17.8	-
4.0	52.0	1.0	13.0	-
15.0	52.0	3.8	13.0	+
5.0	52.0	1.3	13.0	+

Table 47

FLAMMABILITY OF MIXTURES n-HEPTANE, AIR AND
 OCTAFLUOROCYCLOBUTANE (FC-318)
 (Total Pressure = 400 mm. Hg)

<u>Pressure, mm. Hg</u>		<u>Volume %</u>		<u>Result</u>
<u>C₇H₁₆</u>	<u>C₈F₈</u>	<u>C₇H₁₆</u>	<u>C₈F₈</u>	
8	8	2.0	2.0	+
8	12	2.0	3.0	+
8	16	2.0	4.0	+
8	20	2.0	5.0	+
8	24	2.0	6.0	+
8	28	2.0	7.0	+
8	32	2.0	8.0	+
8	36	2.0	9.0	+
8	40	2.0	10.0	+
8	44	2.0	11.0	+
8	48	2.0	12.0	+
8	60	2.0	15.0	+
8	72	2.0	18.0	+
12	72	3.0	18.0	-
8	80	2.0	20.0	-
8	76	2.0	19.0	-
10	76	2.5	19.0	-
10	74	2.5	18.5	-
8	74	2.0	18.5	-
14	64	3.5	16.0	-
6	36	1.5	9.0	-
16	52	4.0	13.0	-
6	16	1.5	4.0	+
20	36	5.0	9.0	+
4	12	1.0	3.0	+
26	24	6.5	6.0	+
4	24	1.0	6.0	-
28	24	7.0	6.0	+
30	30	7.5	7.5	-
2	12	0.5	3.0	-

Table 48

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND SULFUR HEXAFLUORIDE

<u>Pressure, mm. Hg</u>		<u>Volume %</u>		<u>Result</u>
<u>n-C₇H₁₆</u>	<u>SF₆</u>	<u>n-C₇H₁₆</u>	<u>SF₆</u>	
26.0	16.0	6.5	4.0	+
6.0	16.0	1.5	4.0	-
27.0	16.0	6.8	4.0	-
7.0	16.0	1.8	4.0	+
8.0	32.0	2.0	8.0	+
7.0	32.0	1.8	8.0	-
10.0	48.0	2.5	12.0	+
9.0	48.0	2.3	12.0	-
10.0	60.0	2.5	15.0	-
22.0	48.0	5.5	12.0	-
21.0	48.0	5.3	12.0	+
11.0	60.0	2.8	15.0	+
26.0	32.0	6.5	8.0	-
24.0	32.0	6.0	8.0	+
12.0	72.0	3.0	18.0	-
22.0	60.0	5.5	15.0	-
13.0	72.0	3.3	18.0	+
21.0	60.0	5.3	15.0	+
20.0	72.0	5.0	18.0	+
21.0	72.0	5.3	18.0	-
16.0	82.0	4.0	20.5	-
18.0	80.0	4.5	20.0	+
18.0	81.0	4.5	20.3	-
16.0	81.0	4.0	20.3	+
20.0	80.0	5.0	20.0	+
14.0	80.0	3.5	20.0	+
13.0	80.0	3.3	20.0	-
21.0	80.0	5.3	20.0	-
14.0	81.0	3.5	20.3	+
14.0	82.0	3.5	20.5	-
20.0	81.0	5.0	20.3	-

Table 49

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND
BORONTRIFLUORIDE
(Total Pressure = 400 mm. Hg.)

Pressure, mm. Hg		Volume %		Results
C ₇ H ₁₆	BF ₃	C ₇ H ₁₆	BF ₃	
8.0	8.0	2.0	2.0	+
20.0	16.0	5.0	4.0	+
16.0	24.0	4.0	6.0	+
4.0	8.0	1.0	2.0	-
16.0	32.0	4.0	8.0	+
24.0	16.0	6.0	4.0	+
16.0	100.0	4.0	25.0	-
28.0	16.0	7.0	4.0	-
16.0	80.0	4.0	20.0	+
8.0	24.0	2.0	6.0	-
16.0	84.0	4.0	21.0	-
24.0	32.0	6.0	8.0	-
12.0	80.0	3.0	20.0	-
12.0	64.0	3.0	16.0	+
20.0	80.0	5.0	20.0	-
10.0	64.0	2.5	16.0	+
20.0	64.0	5.0	16.0	-
6.0	64.0	1.5	16.0	-
16.0	64.0	4.0	16.0	+

Table 30

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR
AND PHOSPHOROUS TRICHLORIDE
(Total Pressure = 400 mm, Hg.)

<u>Pressure, mm. Hg.</u>		<u>Volume %</u>		<u>Results</u>
<u>C₇H₁₆</u>	<u>PCl₃</u>	<u>C₇H₁₆</u>	<u>PCl₃</u>	
16.0	24.0	4.0	6.0	+
16.0	48.0	4.0	12.0	+
16.0	52.0	4.0	13.0	+
16.0	80.0	4.0	20.0	-
16.0	60.0	4.0	15.0	-
16.0	56.0	4.0	14.0	+
20.0	56.0	5.0	14.0	-
12.0	56.0	3.0	14.0	+
12.0	60.0	3.0	15.0	+
12.0	64.0	3.0	16.0	+
12.0	68.0	3.0	17.0	+
12.0	72.0	3.0	18.0	+
12.0	76.0	3.0	19.0	+
12.0	80.0	3.0	20.0	+
12.0	88.0	3.0	22.0	+
12.0	100.0	3.0	25.0	-
12.0	96.0	3.0	24.0	-
12.0	92.0	3.0	23.0	-
8.0	88.0	2.0	22.0	-

Table 51

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND
HYDROGEN CHLORIDE
(Total Pressure = 400 mm. Hg.)

<u>Pressure, mm. Hg.</u>		<u>Volume %</u>		<u>Results</u>
<u>C₇H₁₆</u>	<u>HCl</u>	<u>C₇H₁₆</u>	<u>HCl</u>	
12.0	40.0	3.0	10.0	+
12.0	80.0	3.0	20.0	+
12.0	120.0	3.0	30.0	-
12.0	100.0	3.0	25.0	+
12.0	112.0	3.0	28.0	-
8.0	80.0	2.0	20.0	+
12.0	104.0	3.0	26.0	-
4.0	80.0	1.0	20.0	-
16.0	100.0	4.0	25.0	-
16.0	80.0	4.0	20.0	-
8.0	100.0	2.0	25.0	-
20.0	40.0	5.0	10.0	+
4.0	24.0	1.0	6.0	-
24.0	40.0	6.0	10.0	-

Table 52

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND CARBON TETRAFLUORIDE
(Total Pressure = 400 mm. Hg)

<u>Pressure, MM. Hg</u>		<u>Volume %</u>		<u>Result</u>
<u>n-C₇H₁₆</u>	<u>CF₄</u>	<u>n-C₇H₁₆</u>	<u>CF₄</u>	
29.0	8.0	7.3	2.0	+
30.0	8.0	7.5	2.0	-
28.0	20.0	7.0	5.0	+
29.0	20.0	7.3	5.0	-
24.0	36.0	6.0	9.0	+
25.0	36.0	6.3	9.0	-
21.0	48.0	5.3	12.0	+
21.0	52.0	5.3	13.0	±
16.0	72.0	4.0	18.0	±
14.0	84.0	3.5	21.0	+
12.0	92.0	3.0	23.0	±
5.0	100.0	1.3	25.0	±
4.0	84.0	1.0	21.0	±
4.0	64.0	1.0	16.0	±
4.0	44.0	1.0	11.0	±
4.0	20.0	1.0	5.0	±
3.0	12.0	0.8	3.0	-
3.0	8.0	0.8	2.0	-

Table 53

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR AND CARBON DIOXIDE
(Total Pressure = 400 mm. Hg)

<u>Pressure mm. Hg</u>		<u>Volume %</u>		<u>Result</u>
<u>n-C₇H₁₆</u>	<u>CO₂</u>	<u>n-C₇H₁₆</u>	<u>CO₂</u>	
3.0	4.0	0.8	1.0	-
3.0	12.0	0.8	3.0	-
3.0	16.0	0.8	4.0	-
4.0	32.0	1.0	8.0	+
3.0	32.0	0.8	8.0	-
4.0	64.0	1.0	16.0	-
4.0	80.0	1.0	20.0	+
6.0	100.0	1.5	25.0	+
5.0	100.0	1.3	25.0	-
12.0	116.0	3.0	29.0	+
12.0	118.0	3.0	30.0	-
16.0	96.0	4.0	24.0	+
20.0	80.0	5.0	20.0	-
23.0	40.0	5.8	10.0	±
24.0	8.0	6.0	2.0	-

Table 54

FLAMMABILITY OF MIXTURES OF ISOBUTANE, AIR AND
BROMOTRIFLUOROMETHANE AT -78°C .

<u>Volume, %</u>		<u>Results</u>
<u>C₄H₁₀</u>	<u>CB₂F₃</u>	
3.5	1.5	-
3.5	2.5	-
5.5	1.0	-
6.0	1.0	-
5.5	2.0	-
6.0	2.0	-
5.0	1.0	-
5.0	2.0	+
4.0	1.0	-
4.5	1.0	+
3.5	0.5	-
4.0	0.5	+
5.0	0.5	+
5.5	0.5	+
5.0	1.5	+
6.0	0.5	+
6.5	0.0	-
6.5	0.5	-
2.5	0.0	+
3.0	0.0	+
2.0	2.0	-
2.5	2.0	-
3.0	2.0	-
3.5	2.0	+
3.0	4.0	-
3.5	4.0	-

Table 55

FLAMMABILITY OF MIXTURES OF ISOBUTANE, AIR AND
BROMOTRIFLUOROMETHANE AT 26°C

Volume, %		Results
<u>C₄H₁₀</u>	<u>CF₃Br</u>	
3.5	1.5	-
3.5	2.5	-
5.5	1.0	-
6.0	1.0	-
2.0	0	-
2.5	0	-
2.5	2.0	-
3.0	2.0	-
3.5	2.0	+
3.5	4.0	+
4.0	4.0	-
4.5	4.0	-
3.5	3.0	-
4.0	3.0	+
3.5	3.5	-
4.0	3.5	-
4.5	3.5	-
5.0	3.5	-
4.5	3.0	+
5.0	3.0	+
5.5	3.0	-
6.0	3.0	-

Table 56

FLAMMABILITY OF MIXTURES OF ISOBUTANE, AIR AND
BROMOTRIFLUOROMETHANE AT +145°C

Volume, %		Results
C_4H_{10}	CF_3Br	
2.5	1.0	+
3.0	1.0	+
2.0	1.0	-
2.5	1.0	+
2.5	2.0	+
3.0	2.0	+
2.0	2.0	-
2.5	3.0	-
3.0	3.0	-
3.5	3.0	-
4.0	3.0	-
4.5	3.0	-
3.0	4.0	-
4.0	4.0	-
6.0	3.5	+
5.0	3.5	+
5.0	3.0	+
5.0	4.0	+
4.5	4.0	+
6.0	4.0	+
4.5	5.0	+
5.0	5.0	+
4.0	5.0	+
4.0	6.0	+
3.5	5.0	+
3.5	6.0	+
3.0	5.0	-
3.0	6.0	-
3.5	7.0	-
4.0	7.0	+
4.0	7.5	-
4.5	7.5	-
4.5	7.0	-
5.0	7.0	-
5.5	5.0	+
6.0	5.0	-
6.5	3.0	+
7.0	3.0	-
7.0	2.0	+
7.5	2.0	+
8.0	2.0	-
8.5	2.0	-
8.0	1.0	-
8.5	1.0	-
9.5	0.0	-
10.0	0.0	-

Table 57

FLAMMABILITY OF MIXTURES OF ISOBUTANE, AIR AND
METHYL BROMIDE AT -78°C

Volume, %		Results
C_4H_{10}	CH_3Br	
4.5	3.5	-
4.0	4.0	-
4.0	3.0	-
4.5	3.0	-
4.0	2.0	+
4.0	3.0	-
4.5	2.0	+
5.0	2.0	+
5.5	2.0	+
6.0	2.0	+
6.0	1.0	+
6.5	1.0	+
4.0	2.0	-
4.0	4.0	-
3.0	4.0	-
3.5	4.0	-
2.0	1.0	-
3.0	1.0	-
3.5	1.0	+
4.0	1.0	+
2.5	2.0	-
2.5	3.0	-
3.0	3.0	+
3.5	3.0	+
3.0	3.5	+
3.5	3.5	+
2.5	3.5	-
4.0	3.5	+

Table 58

FLAMMABILITY OF MIXTURES OF ISOBUTANE, AIR AND
METHYL BROMIDE AT 26°C

<u>Volume, %</u>		<u>Results</u>
<u>C₄H₁₀</u>	<u>CH₃Br</u>	
1.0	4.0	+
3.0	4.0	-
1.0	5.0	-
3.0	5.0	+
1.0	1.0	-
6.5	1.0	-
5.5	1.0	+
2.0	1.0	+
4.0	6.0	+
4.0	5.0	+
4.0	7.0	+
4.0	8.0	-
4.0	7.5	-
4.0	3.0	+
5.0	3.0	-
5.0	4.0	-
5.0	6.0	+
5.0	5.0	-
5.0	8.0	-
5.0	7.0	-
4.0	6.0	+
4.0	10.0	-
4.0	9.0	-
2.5	5.0	+
4.0	8.0	-
2.0	5.0	-
6.0	2.0	+
4.0	7.0	-
7.0	2.0	-
4.0	6.5	-
3.0	6.0	+
5.0	6.0	-

Table 59

FLAMMABILITY OF MIXTURES OF ISOBUTANE, AIR AND
METHYL BROMIDE AT +145°C

Volume, %		Results
C_4H_{10}	CH_3Br	
1.0	0.0	-
0.5	0.0	-
1.5	0.0	-
1.0	0.0	-
2.0	0.0	-
1.5	0.0	-
2.5	0.0	-
3.0	0.0	-
3.5	0.0	+
4.0	0.0	+
6.5	0.0	+
7.0	0.0	+
7.5	0.0	+
8.0	0.0	+
9.0	0.0	+
10.0	0.0	-
4.0	2.0	+
4.5	2.0	+
3.5	2.0	-
3.5	4.0	+
3.0	4.0	-
2.5	4.0	-
3.0	6.0	-
3.5	6.0	-
3.0	5.0	-
4.0	5.0	-
4.5	5.0	+
4.5	5.5	+
4.0	5.5	-
4.0	6.0	-
4.0	7.0	+
4.5	7.0	+
4.5	6.0	+
4.5	8.0	+
3.5	7.0	+
3.5	8.0	+
3.0	7.0	+
3.0	8.0	-
3.5	9.0	-
4.0	8.0	-
5.0	8.5	-
5.0	9.0	-
4.0	8.0	+
4.0	8.5	-

Table 59(Cont'd)

<u>Volume, %</u>		<u>Results</u>
<u>C₂H₁₀</u>	<u>CH₃Br</u>	
5.5	8.0	-
6.0	8.0	-
5.0	7.0	+
5.5	7.0	-
5.5	6.0	-
6.0	6.0	-
5.0	5.0	+
5.5	5.0	-
5.5	3.0	+
6.0	3.0	+
6.5	3.0	+
7.0	3.0	-
7.0	2.0	+
7.5	2.0	-
7.0	1.0	+
7.5	1.0	+
5.0	4.0	+
5.5	4.0	+
4.5	1.0	+
4.5	3.0	+
6.5	4.0	-
8.0	1.0	-

Table 60

FLAMMABILITY OF MIXTURES OF ISOBUTANE, AIR AND
CHLOROTRIFLUOROMETHANE AT -78°C

Volume, %		Results
C_4H_{10}	CClF_3	
4.0	2.0	-
4.5	2.0	-
3.0	2.0	-
3.5	2.0	-
2.0	2.0	-
2.5	2.0	-
3.0	2.0	-
6.0	1.5	+
4.0	2.0	-
4.5	2.0	-
7.0	1.0	-
7.5	1.0	-
6.5	1.0	-
6.5	7.0	-
6.0	1.0	+
6.5	2.0	-
6.0	2.0	-
6.0	0.0	+
5.5	2.0	-
6.5	0.0	+
5.0	2.0	-
7.5	0.0	-
4.5	2.0	-
7.0	0.0	-

Table 61

FLAMMABILITY OF MIXTURES OF ISOBUTANE, AIR AND
 CHLOROTRIFLUOROMETHANE AT 26°C.

Volume, %		Results
C_4H_{10}	$CClF_3$	
3.0	6.5	-
3.5	7.0	+
3.0	8.0	-
3.5	8.0	+
2.0	3.0	-
2.0	5.0	-
2.5	3.0	-
2.5	5.0	-
4.5	7.0	-
4.5	9.0	-
3.0	9.0	-
3.5	9.0	-
4.0	9.0	-
4.5	9.0	-
4.0	8.5	-
4.5	8.5	-
4.0	10.5	+
4.5	10.5	+
5.0	10.5	-
5.5	10.0	-
3.5	10.0	-
3.5	10.5	-
5.0	10.0	+
5.0	12.0	-
4.0	10.0	+
4.0	12.0	-
4.5	10.0	+
4.5	12.0	-
5.0	5.0	-
5.5	6.0	-
4.5	5.0	+
5.0	4.0	+
5.5	3.0	+
5.5	4.0	+
5.0	4.5	+
6.0	4.0	+
5.5	4.5	+
6.5	4.0	-
6.5	2.0	+
6.5	6.0	-
7.0	2.0	+
6.0	6.0	+
7.5	2.0	-
6.0	9.0	-

Table 61 (Cont'd)

<u>Volume, %</u>		<u>Results</u>
<u>C₂H₂</u>	<u>CClF₄</u>	
5.5	9.0	+
5.5	13.0	-
6.0	6.5	+
6.0	3.0	+
6.5	3.0	+
6.5	6.5	+
7.0	3.0	-
7.0	6.5	-

Table 62

 FLAMMABILITY OF MIXTURES OF ISOBUTANE, AIR AND
 CHLOROTRIFLUOROMETHANE AT +14.5°C

Volume, %		Results
C_4H_{10}	$CClF_3$	
1.5	0.0	-
2.0	0.0	-
2.0	0.0	+
2.5	0.0	+
1.5	2.0	-
2.0	2.0	-
2.5	2.0	+
3.0	2.0	+
2.0	4.0	-
2.5	4.0	+
2.0	6.0	-
2.5	6.0	-
2.5	6.0	-
3.0	6.0	+
3.0	8.0	-
3.5	8.0	-
4.0	8.0	+
4.5	8.0	+
4.0	10.0	+
4.5	10.0	+
3.0	10.0	-
3.5	10.0	+
3.5	12.0	-
4.0	12.0	+
3.5	13.0	-
4.5	2.0	+
4.5	6.0	+
4.5	14.0	-
5.0	14.0	-
4.5	13.0	-
5.0	13.0	-
4.0	12.5	+
4.5	12.5	-
3.5	13.0	+
4.0	13.0	-
4.5	12.0	+
5.0	12.0	-
5.0	10.0	+
5.5	10.0	+
6.0	8.0	+
6.5	8.0	-
6.0	6.0	+
6.5	6.0	-
6.0	4.0	+
6.5	4.0	+
7.5	2.0	+
8.0	2.0	+

Table 62 (Cont'd)

<u>Volume, %</u>		<u>Results</u>
<u>C₂H₂</u>	<u>CClF₃</u>	
9.5	0.0	+
10.0	0.0	+
6.0	10.0	-
5.0	11.0	+
3.5	12.0	+

Table 63

FLAMMABILITY OF MIXTURES OF ISOBUTANE, AIR AND
SULFUR HEXAFLUORIDE AT -78°C

Volume, %		Results
C_4H_{10}	SF_6	
3.0	0.0	+
5.0	10.0	+
4.5	10.0	+
4.0	10.0	-
5.0	12.0	+
4.5	12.0	+
4.0	12.0	-
4.0	14.0	-
4.5	14.0	-
4.5	16.0	-
3.0	4.0	+
3.0	6.0	+
2.5	0.0	-
2.5	2.0	-
3.0	2.0	-
2.0	6.0	-
2.5	6.0	-
5.0	11.0	-
5.0	12.0	-
4.5	12.0	-
4.5	12.5	-
3.5	0.0	-
3.5	0.0	+
3.5	0.0	+
4.5	11.0	-
5.5	14.0	-
5.0	14.0	-
5.0	13.0	-
4.5	13.0	-
5.0	12.5	-
4.5	12.5	-
3.5	0.0	+
3.5	0.0	+
5.5	12.0	-
6.0	12.0	-
5.0	11.0	-
5.5	11.0	-

Table 64

FLAMMABILITY OF MIXTURES OF ISOPUTANE, AIR AND
SULFUR HEXAFLUORIDE AT 26°C.

Volume, %		Results
C_4H_{10}	SF_6	
1.0	4.0	-
4.0	4.0	+
2.0	4.0	-
3.0	4.0	-
2.5	4.0	-
6.0	4.0	+
2.0	0.0	+
8.0	0.0	-
1.0	0.0	+
7.0	0.0	-
0.5	0.0	-
6.0	0.0	+
6.0	0.0	+
6.5	0.0	+
4.0	13.5	+
7.0	5.0	+
5.0	18.0	-
5.5	14.0	+
5.0	17.0	-
4.5	15.0	+
5.5	16.0	+
5.0	16.5	+
4.5	16.0	+
3.5	13.0	+
6.0	13.0	-
3.0	10.0	-
5.0	11.0	+
5.0	12.0	+
5.0	13.0	-
5.0	14.0	+
4.5	11.0	-
4.5	12.0	-
3.5	0.0	-
3.5	0.0	+
4.0	0.0	-
4.0	0.0	+
4.0	0.0	+
4.0	0.0	+
5.0	12.0	+
4.5	12.0	-
5.0	8.0	-
5.5	9.0	-
4.0	0.0	+
4.0	0.0	+
4.5	8.0	-
5.0	8.0	+
5.0	6.0	+

Table 65

FLAMMABILITY OF MIXTURES OF ISOBUTANE, AIR AND
SULFUR HEXAFLUORIDE AT +14.5°C

Volume, %		Results
C ₄ H ₁₀	SF ₆	
2.0	2.0	-
2.5	2.0	-
3.0	2.0	+
3.5	2.0	+
3.5	4.0	+
4.0	4.0	+
3.5	8.0	+
4.0	8.0	+
2.5	4.0	+
2.5	8.0	-
3.5	12.0	-
4.0	12.0	+
4.0	14.0	+
4.5	14.0	+
3.5	14.0	-
6.0	14.0	+
4.0	16.0	-
4.5	16.0	-
5.0	18.0	-
5.5	18.0	-
4.5	17.0	-
5.0	17.0	-
5.0	16.0	+
5.5	16.0	+
6.0	16.0	+
6.0	16.5	+
5.5	17.0	-
6.0	17.0	-
6.5	16.0	-
7.0	16.0	-
6.5	14.0	+
7.0	14.0	-
6.5	12.0	+
7.0	12.0	-
6.5	10.0	+
7.0	10.0	+
8.0	10.0	-
7.5	10.0	-
7.0	8.0	-
7.5	8.0	+
8.0	6.0	-
8.5	6.0	-
7.5	6.0	+
7.5	3.0	+
3.0	10.0	-
3.5	10.0	-
2.0	6.0	-
2.5	6.0	-

Table 66

FLAMMABILITY OF MIXTURES OF ISOBUTANE, AIR AND
CARBON TETRAFLUORIDE AT -78°C

Volume, %		Results
C_4H_{10}	CCl_4	
6.0	18.0	-
7.0	18.0	-
5.5	18.0	-
5.5	18.5	-
3.0	0.0	+
3.0	0.0	+
5.0	13.5	-
5.0	15.0	+
4.5	13.5	+
5.5	13.5	+
4.0	10.0	+
6.0	16.0	-
5.5	10.0	+
6.0	10.0	-
6.5	10.0	-
5.5	8.0	+
6.0	8.0	+
6.5	8.0	+
7.0	8.0	+
7.5	8.0	+
6.0	9.0	+
6.5	9.0	+
7.0	9.0	+
7.5	9.0	+
8.0	8.0	-
8.0	9.0	-
7.0	6.0	-
7.5	6.0	-
6.5	6.0	+
7.0	7.0	-
6.5	4.0	-
7.0	4.0	-
6.0	4.0	+
5.5	4.0	+
6.0	2.0	+
6.5	2.0	+
4.5	15.0	+
3.5	13.0	+
4.5	7.0	+
4.5	10.0	+
4.5	3.0	+
4.5	5.0	+
2.5	6.0	-
3.0	6.0	+
2.5	6.0	-

Table 66 (Cont'd)

<u>Volume, %</u>		<u>Results</u>
<u>C₂H₁₀</u>	<u>CF₄</u>	
2.5	10.0	-
3.0	10.0	+
3.5	10.0	+
2.5	14.0	-
3.0	14.0	-
3.5	14.0	-
4.0	14.0	-
4.5	14.0	-
5.0	14.0	+
4.5	18.0	-
5.0	18.0	+
4.5	22.0	-
5.0	22.0	-
4.5	14.0	-
4.5	18.0	-
5.0	22.0	-
6.0	22.0	-
6.5	22.0	-
7.0	22.0	-
4.5	20.0	-
5.0	20.0	-
5.0	20.0	-
6.0	20.0	-
7.6	20.0	-
8.0	20.0	-
5.0	19.0	-
5.5	19.0	-

Table 67

FLAMMABILITY OF MIXTURES OF ISOBUTANE, AIR AND
CARBON TETRAFLUORIDE AT 26°C

Volume, %		Results
C_4H_{10}	CF_4	
6.5	10.0	-
6.5	14.0	-
6.0	13.0	+
6.0	16.0	-
5.5	16.0	-
5.5	18.0	-
5.0	16.0	-
6.0	15.0	-
5.5	15.0	-
4.5	16.0	+
5.0	15.0	+
5.0	18.0	-
4.5	18.0	+
4.5	20.0	-
4.0	21.0	-
4.5	21.0	+
4.5	22.0	-
5.0	22.0	-
2.5	9.0	+
3.0	9.0	+
2.5	13.0	-
3.0	13.0	+
2.5	15.0	-
3.0	15.0	+
2.5	18.0	-
3.0	18.0	-
3.0	12.0	+
2.5	12.0	+
3.0	14.0	+
3.5	14.0	+
1.5	0.0	-
2.0	0.0	-
4.0	23.0	+
7.5	4.0	-
4.0	23.5	+
7.5	5.0	+
8.0	1.0	-
8.0	2.0	-
8.0	3.0	-
7.0	4.0	+
7.0	6.0	+
7.0	8.0	-
6.5	8.0	+
6.5	11.5	-
6.0	12.0	-
6.0	14.0	+
5.0	3.0	+
5.5	5.0	+
5.0	2.0	-

FLAMMABILITY OF MIXTURES OF ISOBUTANE, AIR AND
CARBON TETRAFLUORIDE AT +14.5°C.

Volume, %		Results
C_4H_{10}	CF_4	
3.0	0.0	+
3.5	0.0	+
2.5	0.0	+
2.0	0.0	+
1.5	0.0	-
1.0	0.0	-
9.0	0.0	+
9.5	0.0	+
2.0	3.0	-
2.5	3.0	+
2.0	6.0	-
2.5	6.0	+
2.5	9.0	-
3.0	9.0	+
3.0	12.0	+
3.5	12.0	+
2.5	15.0	-
3.0	15.0	-
2.5	12.0	-
3.5	15.0	-
3.5	18.0	-
4.0	18.0	-
4.5	18.0	-
5.0	18.0	-
4.0	15.0	-
4.5	15.0	-
3.5	13.5	+
4.0	13.5	-
2.5	13.5	-
3.0	13.5	-
4.0	12.0	+
4.5	12.0	+
5.0	12.0	+
5.0	15.5	-
5.5	12.0	+
6.0	12.0	-
5.5	13.5	+
5.5	15.0	-
6.0	9.0	-
6.5	9.0	-
7.0	6.0	-
7.5	6.0	-
7.0	3.0	+
7.5	3.0	+
4.0	3.0	+
4.0	9.0	+
2.0	1.5	-
2.5	1.5	+

Table 69

FLAMMABILITY OF MIXTURES OF PENTANE, AIR AND METHYLENE DIBROMIDE
(Total Pressure = 400 mm. Hg)

<u>Pressure, mm. Hg</u>		<u>Volume %</u>		<u>Result</u>
<u>C₆H₁₂</u>	<u>CH₂Br₂</u>	<u>C₆H₁₂</u>	<u>CH₂Br₂</u>	
12	24	3.0	6.0	+
8	8	2.0	2.0	+
12	32	3.0	8.0	+
6	8	1.5	2.0	-
12	28	3.0	7.0	-
24	12	6.0	3.0	-
12	22	3.0	5.5	+
12	26	3.0	6.5	-
10	26	2.5	6.5	+
14	24	3.5	6.0	-
10	28	2.5	7.0	-
18	16	4.5	4.0	-
8	26	2.0	6.5	-
18	12	4.5	3.0	+
8	16	2.0	4.0	+

Table 70

FLAMMABILITY OF MIXTURES OF PENTANE, AIR AND BROMO-
TRIFLUOROMETHANE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg.		Volume, %		Result
C_5H_{12}	CF_3Br	C_5H_{12}	CF_3Br	
12	16	3.0	4.0	+
16	16	4.0	4.0	+
12	22	3.0	5.5	+
16	20	4.0	5.0	+
12	26	3.0	6.5	-
16	26	4.0	6.5	-
12	24	3.0	6.0	+
14	24	3.5	6.0	+
10	24	2.5	6.0	-
14	26	3.5	6.5	-
8	20	2.0	5.0	-
16	24	4.0	6.0	-
8	16	2.0	4.0	-
20	20	5.0	5.0	-
10	16	2.5	4.0	-
20	16	5.0	4.0	-
10	14	2.5	3.5	+
20	12	5.0	3.0	+
8	12	2.0	3.0	-
20	8	5.0	2.0	+
8	8	2.0	2.0	-
20	4	5.0	1.0	+
8	4	2.0	1.0	+
20	0	5.0	0.0	-
24	12	6.0	3.0	-
24	8	6.0	2.0	-
24	4	6.0	1.0	+

Table 71

FLAMMABILITY OF MIXTURES OF PENTANE, AIR AND ETHYL BROMIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg.		Volume, %		Result
C_5H_{12}	C_2H_5Br	C_5H_{12}	C_2H_5Br	
12	16	3.0	4.0	+
12	24	3.0	6.0	-
12	28	3.0	7.0	-
12	20	3.0	5.0	-
12	22	3.0	5.5	-
12	28	3.0	4.5	-
10	20	3.5	5.0	+
10	22	2.5	5.5	+
4	12	1.0	3.0	-
10	24	2.5	6.0	+
6	12	1.5	3.0	+
8	26	2.0	6.5	+
6	18	1.5	4.5	+
10	26	2.5	6.5	-
6	26	1.5	6.5	-
8	30	2.0	7.5	-
12	22	3.0	4.5	-
8	28	2.0	7.0	-
16	10	4.0	2.5	+
22	4	5.5	1.0	+

FLAMMABILITY OF MIXTURES OF PENTANE, AIR AND METHYL BROMIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume %		Result
C_5H_{12}	CH_3Br	C_5H_{12}	CH_3Br	
4	12	1.0	3.0	-
28	12	7.0	3.0	-
6	12	1.5	3.0	-
24	12	6.0	3.0	-
8	12	2.0	3.0	+
12	24	3.0	6.0	+
20	12	5.0	3.0	+
12	32	3.0	8.0	+
22	12	5.5	3.0	-
12	34	3.0	8.5	-
16	24	4.0	6.0	+
10	32	2.5	8.5	+
18	24	4.5	6.0	-
8	36	2.0	9.0	-
8	24	2.0	6.0	+
8	32	2.0	8.0	+
6	24	1.5	6.0	-
8	34	2.0	8.5	-
10	34	2.5	8.5	-
10	35	2.5	8.75	-

Table 73

FLAMMABILITY OF MIXTURES OF PENTANE, AIR AND SULFUR
HEXAFLUORIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
C_5H_{12}	SF_6	C_5H_{12}	CF_4	
12	72	3.0	18.0	-
16	76	4.0	19.0	+
12	70	3.0	17.5	+
16	78	4.0	19.5	-
25	76	5.0	19.0	-
14	76	3.5	19.0	+
18	70	4.5	19.0	-
14	78	3.5	19.5	+
18	72	4.5	18.0	+
14	80	3.5	20.0	-
10	56	2.5	14.0	-
20	68	5.0	17.0	-
8	32	2.0	8.0	+
22	52	5.5	13.0	+
10	32	2.5	8.0	+
24	52	6.0	13.0	-
6	32	1.5	8.6	-
28	24	7.0	6.0	-
26	24	6.5	6.0	-
24	24	6.0	6.0	+

Table 74

FLAMMABILITY OF MIXTURES OF PENTANE, AIR AND CARBON
TETRAFLUORIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
C_5H_{12}	CF_4	C_5H_{12}	CF_4	
12	72	3.0	18.0	+
14	72	3.5	18.0	+
12	80	3.0	20.0	-
19	80	3.5	20.0	+
12	76	3.0	19.0	+
1	88	3.5	22.0	-
16	80	4.0	20.0	-
14	80	3.5	21.0	-
18	72	4.5	18.0	-
14	82	3.5	20.5	-
18	60	4.5	15.0	-
10	72	2.5	18.0	-
18	52	4.5	13.0	+
10	60	2.5	15.0	-
10	52	2.5	13.0	+
6	40	1.5	10.0	-
16	72	4.0	13.0	-
6	28	1.5	7.0	-
9	28	2.0	7.0	+

Table 75

FLAMMABILITY OF MIXTURES OF BENZENE, AIR AND METHYLENE DIBROMIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg.		Volume, %		Result
C_6H_6	CH_2Br_2	C_6H_6	CH_2Br_2	
12	0	2.5	0	+
12	28	3.0	7	+
30	0	2.5	0	+
12	30	3.0	7.5	-
8	12	2.0	3.0	+
10	28	2.5	7.0	-
4	12	1.0	3.0	-
14	28	3.5	7.0	-
6	12	1.5	3.0	-
36	0	2.0	0	-
8	20	2.0	5.0	-
3.	0	8.5	0	+
18	20	4.5	5.0	-
10	20	2.5	5.0	-
16	20	4.0	5.0	-
12	20	3.0	5.0	+
14	20	3.5	5.0	+
18	12	4.5	3.0	+
22	12	5.5	3.0	-
20	12	5.0	3.0	-

Table 76

FLAMMABILITY OF MIXTURES OF BENZENE, AIR AND BROMOTRI-
 FLUOROMETHANE
 (Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
<u>C₆H₆</u>	<u>CB₂F₅</u>	<u>C₆H₆</u>	<u>CB₂F₅</u>	
12	20	3.0	5.0	-
16	20	4.0	5.0	-
20	20	5.0	5.0	-
16	16	4.0	4.0	+
24	20	6.0	5.0	-
16	18	4.0	4.5	+
18	18	4.5	4.5	-
20	16	5.0	4.0	-
18	16	4.5	4.0	-
14	16	3.5	4.0	+
14	18	3.5	4.5	-
12	16	3.0	4.0	+
10	14	2.5	3.5	+
10	16	2.5	4.0	+
12	18	3.0	4.5	-
10	18	2.5	4.5	-
18	14	4.5	3.5	+
22	12	5.5	3.0	+
26	10	7.0	2.5	+
32	6	8.0	1.5	+
28	12	7.0	3.0	+

Table 77

FLAMMABILITY OF MIXTURES OF BENZENE, AIR AND ETHYL BROMIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
C_6H_6	C_2H_5Br	C_6H_6	C_2H_5Br	
12	24	3.0	6.0	+
12	32	3.0	8.0	-
12	28	3.0	7.0	+
12	30	3.0	7.5	-
10	30	2.5	7.5	+
14	8	3.5	7.5	-
10	32	2.5	8.0	+
16	2	4.0	6.0	+
10	34	2.5	8.5	-
25	25	5.0	5.0	-
8	34	2.0	8.5	-
24	12	6.0	3.0	-
8	26	2.0	6.5	-
18	20	4.5	5.0	-
16	26	4.0	6.5	-
20	10	5.0	2.5	+
8	14	2.0	3.5	+
32	0	8.0	0	+
6	14	1.5	3.5	+
4	0	1.0	0	-
6	0	1.5	0	-
4	14	1.0	3.5	-
8	0	2.0	0	-
12	0	3.0	0	+

Table 78

FLAMMABILITY OF MIXTURES OF BENZENE, AIR AND METHYL BROMIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
C_6H_6	CH_3Br	C_6H_6	CH_3Br	
12	24	3.0	6.0	+
8	16	2.0	4.0	-
12	32	3.0	8.0	+
10	16	2.5	4.0	+
12	40	3.0	10.0	-
8	8	2.0	2.0	-
12	36	3.0	9.0	-
24	16	6.0	4.0	+
12	34	3.0	8.5	-
28	16	7.0	4.0	-
14	32	3.5	8.0	-
32	10	8.0	2.5	+
10	32	2.5	8.0	+
26	15	6.5	4.0	-
8	32	2.0	8.0	-
16	24	4.0	6.0	+
10	34	2.5	8.5	-
18	24	4.5	6.0	-

Table 79

FLAMMABILITY OF MIXTURES OF BENZENE, AIR AND SULFUR HEX-
FLUORIDE

(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
C_6H_6	SF_6	C_6H_6	SF_6	
16	80	4.0	20.0	-
12	80	3.0	20.0	-
10	80	2.5	20.0	-
12	78	3.0	19.5	-
10	76	2.5	19.0	-
12	74	3.0	18.5	-
10	72	2.5	18.0	-
12	70	3.0	17.5	-
10	70	2.5	17.5	-
12	66	3.0	16.5	-
10	62	2.5	15.5	-
12	58	3.0	14.5	-
16	58	4.0	14.5	+
20	58	5.0	14.5	+
16	70	9.0	17.5	-
20	64	5.0	16.0	+
16	66	9.0	16.5	+
20	66	5.0	16.5	+
14	64	3.5	16.0	+
20	72	5.0	18.0	-
14	68	3.5	17.0	-
20	68	5.5	17.0	+
18	70	4.5	17.5	+
24	68	6.0	17.0	+
18	74	4.5	18.5	-
26	68	6.5	17.0	-
24	72	6.0	18.0	-
18	72	4.5	18.0	+
12	48	3.0	12.0	+
10	24	2.5	6.0	+
28	52	6.5	13.0	+
8	24	2.0	6.0	-
30	52	7.5	13.0	-
30	28	7.5	7.0	+

Table 80

FLAMMABILITY OF MIXTURES OF BENZENE, AIR AND CARBON
TETRAFLUORIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
<u>C₆H₆</u>	<u>CF₄</u>	<u>C₆H₆</u>	<u>CF₄</u>	
14	76	3.5	19.0	+
12	80	3.0	20.0	+
14	80	3.5	20.0	+
12	88	3.0	22.0	-
14	88	3.5	22.0	+
14	62	3.5	23.0	-
12	84	3.0	21.0	+
14	90	3.5	22.5	+
16	88	4.0	22.0	-
18	60	4.5	20.0	-
10	80	2.5	20.0	-
16	80	4.0	20.0	+
10	64	2.5	15.0	+
20	64	5.0	16.0	+
24	48	6.0	12.0	+
28	40	7.0	10.0	+
28	48	7.0	12.0	+?
2:	64	6.0	16.0	-

Table 81

FLAMMABILITY OF MIXTURES OF ETHANOL, AIR AND METHYLENE
DIBROMIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume %		Result
C ₂ H ₅ OH	CH ₂ Br ₂	C ₂ H ₅ OH	CH ₂ Br ₂	
32	12	8.0	3.0	+
32	20	8.0	5.0	+
28	28	7.0	7.0	-
32	24	8.0	6.0	-
32	22	8.0	5.5	-
28	22	7.0	5.5	-
34	20	8.5	5.0	-
30	20	7.5	5.0	+
28	16	7.0	4.0	+
30	22	7.5	5.5	+
20	10	5.0	2.5	-
30	24	7.5	6.0	-
24	12	6.0	3.0	-

Table 82

FLAMMABILITY OF MIXTURES OF ETHANOL, AIR AND BROMO-
TRIFLUOROMETHANE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
C ₂ H ₅ OH	CF ₃ Br	C ₂ H ₅ OH	CF ₃ Br	
28	20	7.0	5.0	-
32	20	8.0	5.0	-
28	16	7.0	4.0	-
32	16	8.0	4.0	-
36	16	9.0	4.0	-
36	14	9.0	3.5	+
32	14	8.0	3.5	-
40	14	10.0	3.5	-
34	14	8.5	3.5	-
38	14	9.5	3.5	-
40	0	10.0	0	+
32	10	8.0	2.5	-
40	10	10.0	2.5	-
32	6	8.0	1.5	-
40	6	10.0	1.5	-
32	4	8.0	1.0	-
40	4	10.0	1.0	-
32	0	8.0	0	+
40	2	10.0	0.5	+

Table 83

FLAMMABILITY OF MIXTURES OF ETHANOL, AIR AND ETHYL BROMIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume %		Result
C_2H_5OH	C_2H_5Br	C_2H_5OH	C_2H_5Br	
32	12	8.0	3.0	+
32	20	8.0	5.0	+
32	24	8.0	6.0	-
32	22	8.0	5.5	-
30	22	7.5	5.5	-
34	22	8.5	5.5	-
28	20	7.0	5.0	+
36	20	9.0	5.0	-
28	22	7.0	5.5	-
24	20	6.0	5.0	-
22	16	5.5	4.0	+
20	12	5.0	3.0	+
20	8	5.0	2.0	+
26	20	6.5	5.0	-

Table 84

FLAMMABILITY OF MIXTURES OF ETHANOL, AIR AND METHYL BROMIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg.		Volume, %		Result
C_2H_5OH	CH_3Br	C_2H_5OH	CH_3Br	
12	24	3.0	6.0	-
32	24	8.0	6.0	+
32	28	8.0	7.0	-
20	32	5.0	8.0	-
20	28	5.0	7.0	-
28	28	7.0	7.0	-
20	20	5.0	5.0	-
32	26	8.0	6.5	-
36	26	9.0	6.5	-
28	24	7.0	6.0	-
20	12	5.0	3.0	-
40	14	10.0	3.5	-
28	20	7.0	5.0	+
36	14	9.0	3.5	+
36	22	9.0	5.5	-
24	16	6.0	9.0	+

Table 85

FLAMMABILITY OF MIXTURES OF ETHANOL, AIR AND SULFUR HEXA-
FLUORIDE

(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
C ₂ H ₅ OH	SF ₆	C ₂ H ₅ OH	SF ₆	
20	64	5.0	16.0	-
20	16	5.0	4.0	-
32	64	8.0	16.0	-
24	16	6.0	4.0	-?
32	48	8.0	12.0	~
28	16	7.0	4.0	+
32	32	8.0	8.0	+?
48	12	12.0	4.0	+
32	40	8.0	10.0	-
32	36	8.0	9.0	+
28	36	7.0	9.0	+
28	40	7.0	10.0	+
24	40	6.0	10.0	-
24	16	6.0	4.0	+
28	44	7.0	11.0	-
40	32	10.0	8.0	-
56	16	14.0	4.0	+

Table 86

FLAMMABILITY OF MIXTURES OF ETHANOL, AIR AND CARBON-
TETRAFLUORIDE

(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
C ₂ H ₅ OH	CF ₄	C ₂ H ₅ OH	CF ₄	
20	80	5.0	20.0	-
24	80	6.0	20.0	-
26	80	7.0	20.0	-
32	80	8.0	20.0	-
28	74	7.0	18.5	-
32	76	8.0	19.0	+
28	68	7.0	17.0	-
32	78	8.0	19.5	+
28	60	7.0	15.0	-
34	78	8.5	19.5	+
36	80	9.0	20.0	-
24	32	6.0	3.0	-
34	80	8.5	20.0	-
28	32	7.0	8.0	-
36	72	9.0	18.0	-
30	32	7.5	8.0	-
36	56	9.0	14.0	+
30	60	7.5	15.0	+
40	40	10.0	10.0	+
30	32	7.5	8.0	-
44	40	11.0	10.0	-
32	32	8.0	8.0	-
30	78	7.5	19.5	-
36	32	9.0	8.0	+
30	68	7.5	17.0	+
20	0	5.0	0	-
32	12	8.0	3.0	+
28	0	7.0	0	+
24	0	6.0	0	+
28	8	7.0	2.0	+
22	0	5.5	0	+
24	6	6.0	2.0	-

Table 87

FLAMMABILITY OF MIXTURES OF DIETHYL ETHER, AIR AND METHYLENE
DIBROMIDE

(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
$(C_2H_5)_2O$	CH_2Br_2	$(C_2H_5)_2O$	CH_2Br_2	
12	10	3.0	4.0	+
12	24	3.0	6.0	+
12	28	3.0	7.0	+
12	32	3.0	8.0	-
12	36	3.0	9.0	-
12	30	3.0	7.5	-
10	30	2.5	7.5	-
14	30	3.5	7.5	+
10	24	2.5	6.0	-
14	32	3.5	8.0	-
10	16	2.5	4.0	+
16	30	4.0	7.5	-
24	20	6.0	5.0	-
24	12	6.0	3.0	+
18	24	4.5	6.0	-

Table 88

FLAMMABILITY OF MIXTURES OF DIETHYL TERP, AIR AND TRIMETHYL-
 FLUOROMETHANE
 (Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume %		Result
$(C_2H_5)_2O$	CF_3Br	$(C_2H_5)_2O$	CF_3Br	
12	20	3.0	5.0	-
15	20	4.0	5.0	+
20	20	5.0	5.0	+
16	24	4.0	6.0	+
20	24	5.0	6.0	-
16	28	4.0	7.0	-
16	30	4.0	7.5	-
14	24	3.5	6.0	-
16	26	4.0	6.5	-
18	24	4.5	6.0	+
12	16	3.0	4.0	-
18	26	4.5	6.5	-
12	12	3.0	3.0	-
20	22	5.0	5.5	+
12	8	3.0	2.0	+
24	20	6.0	5.0	-
14	22	3.5	5.5	-
24	16	6.0	4.0	+
14	16	5.5	4.0	+
28	12	7.0	3.0	+?
32	10	8.0	2.5	-

Table 89

FLAMMABILITY OF MIXTURES OF DIETHYL ETHER, AIR AND ETHYL
BROMIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
$(C_2H_5)_2O$	C_2H_5Br	$(C_2H_5)_2O$	C_2H_5Br	
12	24	3.0	6.0	+
8	10	2.0	2.5	-
12	28	3.0	7.0	-
10	10	2.5	2.5	+
16	32	4.0	8.0	-
18	24	4.5	6.0	-
16	28	4.0	7.0	-
16	24	4.0	6.0	-
10	20	2.5	5.0	+
14	24	3.5	6.0	-
10	24	2.5	6.0	+
12	26	3.0	6.5	-
10	26	2.5	6.5	+
22	12	5.5	3.0	+
10	28	2.5	7.0	+
24	12	6.0	3.0	+
10	30	2.5	7.5	-
26	12	6.5	3.0	+
26	12	6.5	3.0	+
28	12	7.0	3.0	+
32	12	8.0	3.0	+
36	12	9.0	3.0	-

Table 90

FLAMMABILITY OF MIXTURES OF DIETHYL ETHER, AIR AND
METHYL BROMIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume \bar{a}		Result
$(C_2H_5)_2O$	CH_3Br	$(C_2H_5)_2O$	CH_3Br	
12	12	3.0	3.0	+
36	12	9.0	3.0	+
8	12	2.0	3.0	-
36	12	9.5	3.0	-
16	12	2.5	3.0	-
12	24	3.0	6.0	+
12	36	3.0	9.0	-
12	44	3.0	11.0	-
12	32	3.0	8.0	-
14	30	3.5	7.5	-
12	28	3.0	7.0	+
16	26	4.0	6.5	-
12	30	3.0	7.5	-
28	25	6.25	6.25	+
16	20	4.0	5.0	+
24	20	6.0	5.0	+
36	16	9.0	4.0	-

Table 91

FLAMMABILITY OF MIXTURES OF DIETHYL ETHER, AIR AND SULFUR
HEX. FLUORIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
$(C_2H_5)_2O$	SF_6	$(C_2H_5)_2O$	SF_6	
20	40	5.0	10.0	+
10	12	2.5	3.0	+
20	56	5.0	14.0	+
20	72	5.0	18.0	+
12	56	5.0	14.0	+
20	80	5.0	20.0	+
12	76	3.0	19.0	-
20	88	5.0	22.0	-
12	68	3.0	17.0	-
20	84	5.0	21.0	+
12	66	3.0	16.5	-
20	86	5.0	21.5	+
12	60	3.0	15.0	-
24	84	6.0	21.0	-
16	76	4.0	19.0	+
24	76	6.0	19.0	+
36	48	9.0	12.0	-
32	48	8.0	12.0	-
22	88	5.5	22.0	-
28	48	7.0	12.0	+
18	88	4.5	22.0	-
36	16	9.0	4.0	+
16	84	4.0	21.0	-

Table 92

FLAMMABILITY OF MIXTURES OF DIETHYL ETHER, AIR AND CARBON-
TETRAFLUORIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
(C ₂ H ₅) ₂ O	CF ₄	(C ₂ H ₅) ₂ O	CF ₄	
10	16	2.5	4.0	+
38	16	9.5	4.0	-
8	16	2.0	4.0	-
34	16	8.5	4.0	-
14	26	3.5	6.5	+
30	16	7.5	4.0	+
10	26	2.5	6.5	+
26	36	6.5	9.0	+
10	36	2.5	9.0	+
30	36	7.5	9.0	+
10	44	2.5	11.0	-
28	60	7.0	15.0	-
12	52	3.0	13.0	+
24	60	6.0	15.0	-
12	80	3.0	20.0	-
22	60	5.5	15.0	+
16	80	4.0	20.0	+
20	80	5.0	19.0	+
16	84	4.0	21.0	+
38	0	9.5		+
16	88	4.0	22.0	-
14	84	3.5	21.0	-
18	84	4.5	21.0	+
20	84	5.0	21.0	-
18	88	4.5	22.0	+
18	90	4.5	22.5	-

Table 93

FLAMMABILITY OF MIXTURES OF ACETONE, AIR AND METHYLENE-
DIBROMIDE

(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
CH_3COCH_3	CH_2Br_2	CH_3COCH_3	CH_2Br_2	
20	16	5.0	4.0	+
20	20	5.0	5.0	+
16	16	4.0	4.0	+
20	24	5.0	6.0	-
12	16	3.0	4.0	-
20	22	5.0	5.5	+
16	20	4.0	5.0	-
16	22	4.5	5.5	+
22	22	5.5	5.5	+
18	24	4.5	6.0	-
22	24	5.5	6.0	-
24	22	6.0	5.5	-
12	12	3.0	3.0	-
28	16	7.0	4.0	-
28	14	7.0	3.5	+
36	8	9.0	2.0	-

Table 94

FLAMMABILITY OF MIXTURES OF ACETONE, AIR AND BROMOTRI-
FLUOROMETHANE

(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
CH_3COCH_3	CF_3Br	CH_3COCH_3	CF_3Br	
20	20	5.0	5.0	-
24	20	6.0	5.0	-
20	16	5.0	4.0	+
24	16	6.0	4.0	+
20	18	5.0	4.5	-
24	16	6.0	4.0	+
24	18	6.0	4.5	-
28	16	7.0	4.0	+
28	20	7.0	5.0	+
28	22	7.0	5.5	-
32	20	8.0	5.0	-
26	20	6.5	5.0	-
30	20	7.5	5.0	-
16	16	4.0	4.0	-
32	16	8.0	4.0	+
16	12	4.0	3.0	-
36	14	9.0	3.5	-
16	8	4.0	2.0	-
16	4	4.0	1.0	-

Table 95

FLAMMABILITY OF MIXTURES OF ACETONE, AIR AND ETHYL BROMIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hr.		Volume, %		Result
CH_3COCH_3	$\text{C}_2\text{H}_5\text{Br}$	CH_3COCH_3	$\text{C}_2\text{H}_5\text{Br}$	
20	16	5.0	4.0	+
20	20	5.0	5.0	+
16	20	4.0	5.0	+
20	24	5.0	6.0	-
16	24	4.0	6.0	-
20	22	5.0	5.5	-
18	22	4.5	5.5	-
14	20	3.5	5.0	+
24	20	6.0	7.0	-
14	22	3.5	5.5	+
16	22	4.0	5.5	+
14	24	3.5	6.0	-
28	16	7.0	8.0	-
28	12	7.0	8.0	+
32	8	8.0	2.0	+
32	12	8.0	3.0	-

Table 96

FLAMMABILITY OF MIXTURES OF ACETONE, AIR AND METHYL BROMIDE
(Total Pressure = 400 mm. Hg.)

Pres. ure. mm. Hg.		Volume, %		Result
CH ₃ COCH ₃	CH ₃ Br	CH ₃ COCH ₃	CH ₃ Br	
12	0	3.0	0	-
16	0	4.0	0	+
32	0	8.0	0	+
14	0	3.5	0	+
44	0	11.0	0	+?
16	12	4.0	3.0	+
48	0	12.0	0	+?
14	12	3.5	3.0	+
20	24	5.0	6.0	+
52	0	13.0	0	+?
14	24	3.5	6.0	-
12	12	3.0	3.0	-
20	28	5.0	7.0	+
24	28	6.0	7.0	-
20	32	5.0	8.0	-
16	28	4.0	7.0	-
20	30	5.0	7.5	-
28	24	7.0	6.0	-
36	14	7.0	3.5	-
28	20	7.0	5.0	-
32	14	8.0	3.5	-
28	16	7.0	4.0	-
32	8	8.0	2.0	+
29	20	6.0	5.0	+

Table 97

FLAMMABILITY OF MIXTURES OF ACETONE, AIR AND SULPHUR HEXA-
FLUORIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
CH_3COCH_3	SF_6	CH_3COCH_3	SF_6	
20	20	5.0	5.0	+
14	12	3.5	3.0	+
20	28	5.0	7.0	+
12	12	3.0	3.0	+
20	36	5.0	9.0	+
10	12	2.5	3.0	-
20	64	5.0	16.0	+
20	72	5.0	18.0	-
12	36	3.0	9.0	-
16	36	4.0	9.0	-
20	68	5.0	17.0	-
22	64	5.5	16.0	+
18	64	4.5	16.0	-
24	64	6.0	16.0	-
16	36	4.0	9.0	?
22	68	5.5	17.0	-
18	52	4.5	13.0	-
24	52	6.0	13.0	+
18	40	4.5	10.0	-
26	52	6.5	13.0	+
18	32	4.5	8.0	-?
30	52	7.5	13.5	+
18	16	4.5	4.0	-?
36	60	9.0	15.0	+
44	48	11.0	12.0	+
18	16	4.5	4.0	+
44	52	11.0	13.0	-
18	24	4.5	6.0	+
40	60	10.0	15.0	+

Table 98

FLAMMABILITY OF MIXTURES OF ACETONE, AIR AND CARBON TETRA-
FLUORIDE
(Total Pressure = 400 mm. Hg)

<u>Pressure, mm. Hg.</u>		<u>Volume, %</u>		<u>Result</u>
<u>CH₃COCH₃</u>	<u>CF₄</u>	<u>CH₃COCH₃</u>	<u>CF₄</u>	
20	72	5.0	18.0	-
16	72	4.0	15.0	-
24	72	6.0	18.0	-
20	64	5.0	16.0	+
20	68	5.0	17.0	-
24	68	6.0	17.0	+
28	72	7.0	18.0	+
32	72	8.0	18.0	-
28	76	7.0	19.0	-
32	68	8.0	17.0	-
28	74	7.0	18.5	-
32	64	8.0	16.0	-
14	48	3.5	12.0	-
32	56	8.0	14.0	-
14	40	3.5	10.0	-
32	48	8.0	12.0	+
16	40	4.0	10.0	+
36	44	9.0	11.0	-
40	40	10.0	10.0	-
36	36	9.0	9.0	-
36	28	9.0	7.0	+
26	74	6.5	18.5	+
26	76	6.5	19.0	-

Table 99

FLAMMABILITY OF MIXTURES OF ETHYL ACETATE, AIR AND METHYLENE-
 DIBROMIDE
 (Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
$\text{CH}_3\text{CO}_2\text{C}_2\text{H}_5$	CH_2Br_2	$\text{CH}_3\text{CO}_2\text{C}_2\text{H}_5$	CH_2Br_2	
16	0	4.0	0	+
12	0	3.0	0	+
38	0	9.0	0	+
8	0	2.0	0	-
44	0	11.0	0	+
10	0	2.5	0	-
36	20	9.0	5.0	-
12	12	3.0	3.0	-
36	12	9.0	5.0	-
14	12	3.5	3.0	-
36	4	9.0	1.0	-
16	12	4.0	3.0	-
36	2	9.0	0.5	+
16	16	4.0	1.0	-
16	20	4.0	5.0	-
24	16	6.0	4.0	+
28	16	7.0	4.0	-
24	20	6.0	5.0	-
28	12	7.0	3.0	+
20	18	5.0	4.5	-
24	18	6.0	4.5	-
20	12	5.0	3.0	+
22	16	5.5	4.0	+
16	8	..	2.0	-
22	18	5.5	4.5	-
32	6	8.0	1.5	+
20	16	5.0	4.0	+

Table 100

FLAMMABILITY OF MIXTURES OF ETHYL ACETATE, AIR AND BROMO-
TRIFLUOROMETHANE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
$\text{CH}_3\text{CO}_2\text{C}_2\text{H}_5$	CBrF_3	$\text{CH}_3\text{CO}_2\text{C}_2\text{H}_5$	CBrF_3	
16	24	4.0	6.0	-
12	4	3.0	1.0	-
16	16	4.0	4.0	-
32	4	8.0	1.0	+?
24	16	6.0	4.0	-
32	8	8.0	2.0	+
20	12	5.0	3.0	-
32	12	8.0	3.0	+
16	32	4.0	8.0	-
32	16	8.0	4.0	-
36	16	9.0	4.0	-
32	24	8.0	6.0	-
30	14	7.5	3.5	+
36	12	9.0	3.0	-
30	16	7.5	4.0	-
28	16	7.0	4.0	+
26	16	6.5	4.0	+
28	18	7.0	4.5	-
26	18	6.5	4.5	+
26	20	6.5	5.0	-
24	14	6.0	5.5	+
20	8	5.0	2.0	+

Table 101

FLAMMABILITY OF MIXTURES OF ETHYL ACETATE, AIR AND ETHYL
BROMIDE

(Total Pressure = 400 mm. Hg.)

Pressure, mm. Hg.		Volume, %		Result
$\text{CH}_3\text{CO}_2\text{C}_2\text{H}_5$	$\text{C}_2\text{H}_5\text{Br}$	$\text{CH}_3\text{CO}_2\text{C}_2\text{H}_5$	$\text{C}_2\text{H}_5\text{Br}$	
24	16	6.0	4.0	+
24	20	6.0	5.0	-
28	18	7.0	4.5	-
24	18	6.0	4.5	-
16	10	4.0	2.5	+
20	16	5.0	4.0	+
12	4	3.0	1.5	+
20	18	5.0	4.5	-
12	10	3.0	2.5	+
16	16	4.0	4.0	+
28	16	7.0	4.0	+
16	20	4.0	5.0	+
32	16	8.0	4.0	-
16	24	4.0	6.0	-
12	20	3.0	5.0	+
16	22	4.0	5.5	+
12	22	3.0	5.5	+
14	24	3.5	6.0	-
12	24	3.0	6.0	+
36	10	9.0	2.5	-
12	26	3.0	6.5	-
36	6	9.0	1.5	+
48	0	12.0	0	+?
52	0	13.0	0	+?

Table 102

FLAMMABILITY OF MIXTURES OF ETHYL ACETATE, AIR AND
METHYL BROMIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
$\text{CH}_3\text{CO}_2\text{C}_2\text{H}_5$	CH_3Br	$\text{CH}_3\text{CO}_2\text{C}_2\text{H}_5$	CH_3Br	
27	20	6.0	5.0	+
20	20	5.0	5.0	+
24	22	6.0	5.5	-
20	22	5.0	5.5	-
18	22	4.5	5.5	+
20	24	4.5	6.0	+
12	8	3.0	2.0	-
18	26	4.5	6.5	+
14	8	3.5	2.0	+
18	28	4.5	7.0	-
14	16	3.5	4.0	+
16	28	4.0	7.0	-
14	22	3.5	5.5	-
16	26	4.0	6.5	-
32	18	8.0	4.5	-
28	20	7.0	5.0	-
32	14	8.0	3.5	-
32	10	8.0	2.5	-
32	6	8.0	1.5	+
28	12	7.0	3.0	+

Table 103.

FLAMMABILITY OF MIXTURES OF ETHYL ACETATE, AIR AND SULFUR
HEXAFLUORIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
$\text{CH}_3\text{CO}_2\text{C}_2\text{H}_5$	SF_6	$\text{CH}_3\text{CO}_2\text{C}_2\text{H}_5$	SF_6	
12	24	3.0	6.0	-
24	24	6.0	6.0	+
12	12	3.0	3.0	?
24	32	6.0	8.0	+
12	12	3.0	3.0	-
24	40	6.0	10.0	+
14	12	3.5	3.0	+
24	56	6.0	14.0	-
16	24	4.0	6.0	+
24	48	6.0	12.0	+
18	40	4.5	10.0	+
40	24	10.0	6.0	-
24	52	6.0	13.0	+
32	24	8.0	6.0	+
20	52	5.0	13.0	+
28	52	7.0	13.0	+
28	52	7.0	13.0	+
20	56	5.0	14.0	+
2	60	5.0	15.0	+
32	44	8.0	11.0	-
20	68	5.0	17.0	-
36	24	9.0	6.0	-
20	64	5.0	16.0	-
16	56	4.0	14.0	
16	64	4.0	16.	
16	68	4.0	17.0	
12	64	3.0	16.0	
16	72	4.0	18.0	

Table 104

FLAMMABILITY OF MIXTURES OF ETHYL ACETATE, AIR AND CARBON
TETRAFLUORIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg		Volume, %		Result
$\text{CH}_3\text{CO}_2\text{C}_2\text{H}_5$	CF_4	$\text{CH}_3\text{CO}_2\text{C}_2\text{H}_5$	CF_4	
20	72	5.0	18.0	+
24	72	6.0	18.0	-
16	72	4.0	18.0	+
20	76	5.0	19.0	+
20	72	3.0	18.0	-
20	80	5.0	20.0	+
16	76	4.0	19.0	+
20	84	5.0	21.0	+
16	80	4.0	20.0	-
20	88	5.0	22.0	-
12	56	3.0	14.0	-
12	90	3.0	10.0	-
20	86	5.0	21.5	-
14	40	3.5	10.0	+
18	84	4.5	21.0	-
22	84	5.5	21.0	-
24	64	6.0	16.0	+
28	60	7.0	15.0	-

Table 105

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR, TRIBROMOFLUORO-
METHANE AND METHYLENE DIBROMIDE
(Total Pressure = 400 mm. Hg)

<u>Pressure, mm. Hg</u>			<u>Volume %</u>			<u>Result</u>
<u>C₇H₁₆</u>	<u>CH₂Br₂</u>	<u>CFBr₃</u>	<u>C₇H₁₆</u>	<u>CH₂Br₂</u>	<u>CFBr₃</u>	
12	9	9	3.0	2.25	2.25	+
8	6	6	2.0	1.5	1.5	-
12	10	10	3.0	2.5	2.5	+
10	6	6	2.5	1.5	1.5	+
12	11	11	3.0	2.75	2.75	-
18	6	6	4.5	1.5	1.5	+
10	10	10	2.5	2.5	2.5	-
14	9	9	3.5	2.25	2.25	+
14	11	11	3.5	2.75	2.75	-
22	6	6	5.5	1.5	1.5	-
18	8	8	4.5	2.0	2.0	-
24	4	4	6.0	1.0	1.0	-
6	4	4	1.5	1.0	1.0	-
20	5	5	5.0	1.25	1.25	-
8	4	4	2.0	1.0	1.0	-
22	3	3	5.5	0.75	0.75	-
10	4	4	2.5	1.0	1.0	+
20	3	3	5.0	0.75	0.75	-
8	2	2	2.0	0.5	0.5	+
20	2	2	5.0	0.5	0.5	+

Table 106

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR, METHYLENE DIBROMIDE
AND PERFLUOROETHYLCYCLOHEXANE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg			Volume %			Result
C_7H_{16}	CH_2Br_2	C_6F_{12}	C_7H_{16}	CH_2Br_2	C_6F_{12}	
12	14	14	3.0	3.5	3.5	-
12	10	10	3.0	2.5	2.5	+
8	6	6	2.0	1.5	1.5	+
12	12	12	3.0	3.0	3.0	-
4	6	6	1.0	1.5	1.5	-
12	11	11	3.0	2.75	2.75	-
6	6	-	1.5	1.5	1.5	+
10	10	10	2.5	2.5	2.5	+
22	6	0	5.5	1.5	1.5	-
16	8	8	4.0	2.0	2.0	+
14	10	10	3.5	2.5	2.5	+
16	10	10	4.0	2.5	2.5	+
8	10	10	2.0	2.5	2.5	+
18	10	10	4.5	2.5	2.5	-
6	10	10	1.5	2.5	2.5	-
14	11	11	3.5	2.75	2.75	-
16	11	11	4.0	2.75	2.75	-

Table 107

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR, ETHYL BROMIDE
WITH METHYLENE DIBROMIDE
(Total Pressure = 9.0 mm. Hg)

Pressure, mm. Hg			Volume %			Result
<u>C₇H₁₆</u>	<u>C₂H₅Br</u>	<u>CH₂Br₂</u>	<u>C₇H₁₆</u>	<u>C₂H₅Br</u>	<u>CH₂Br₂</u>	
12	8	8	3.0	2.0	2.0	+
20	6	6	5.0	1.5	1.5	-
12	12	12	3.0	3.0	3.0	-
16	6	6	4.0	1.5	1.5	-
12	11	11	3.0	2.75	2.75	+
8	8	8	2.0	2.0	2.0	-
14	10	10	3.5	2.5	2.5	+
10	8	8	2.5	2.0	2.0	-
8	4	4	2.0	1.0	1.0	+
12	8	8	3.0	2.0	2.0	-
4	4	4	1.0	1.0	1.0	-
12	8	8	3.0	2.0	2.0	-
6	4	4	1.5	1.0	1.0	-
8	3	3	4.0	0.75	0.75	+
12	8	8	3.0	2.0	2.0	+
20	3	3	5.0	0.75	0.75	+
14	12	12	3.5	3.0	3.0	-
24	3	3	6.0	0.75	0.75	-
13	11.5	11.5	3.25	2.87	2.87	-
22	3	3	5.5	0.75	0.75	+
11	11	11	2.75	2.75	2.75	+
15	11	11	3.75	2.75	2.75	-

Table 108.

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR, CARBON TETRACHLORIDE AND METHYLENE DIBROMIDE
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg			Volume %			Result
C_7H_{16}	CH_2Br_2	CCl_4	C_7H_{16}	CH_2Br_2	CCl_4	
12	10	10	3.0	2.5	2.5	+
6	3	3	1.5	0.75	0.75	-
12	13	13	3.0	3.25	3.25	+
8	3	3	2.0	0.75	0.75	+
12	16	16	3.0	4.0	4.0	-
20	6	6	5.0	1.5	1.5	+
12	14	14	3.0	3.5	3.5	+
24	6	6	6.0	1.5	1.5	-
12	15	15	3.0	3.75	3.75	-
16	11	11	4.0	2.75	2.75	+
10	14	14	2.5	3.5	3.5	+
18	11	11	4.5	2.75	2.75	+
8	14	14	2.0	3.5	3.5	-
20	11	11	5.0	2.75	2.75	-
10	15	15	2.5	3.75	3.75	-
8	10	10	2.0	2.5	2.5	+
14	14	14	3.5	3.5	3.5	-
6	10	10	1.5	2.5	2.5	-

Table 109

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR, METHYLENE DI-
BROMIDE AND CHLOROFORM
(Total Pressure = 400 mm. Hg)

Pressure, mm. Hg			Volume %			Result
C_7H_{16}	$CHCl_3$	CH_2Br_2	C_7H_{16}	$CHCl_3$	CH_2Br_2	
12	6	6	3.0	1.5	1.5	+
12	10	10	3.0	2.5	2.5	+
12	14	14	3.0	3.5	3.5	+
12	18	18	3.0	4.5	4.5	+
12	22	22	3.0	5.5	5.5	-
12	26	26	3.0	6.5	6.5	-
12	20	20	3.0	5.0	5.0	-
12	19	19	3.0	4.75	4.75	-
10	18	18	2.5	4.5	4.5	-
14	18	18	3.5	4.5	4.5	-
8	1	1	2.0	2.5	2.5	-
20	12	12	5.0	3.0	3.0	-
8	7	7	2.0	1.75	1.75	-
22	8	8	5.5	2.0	2.0	-
8	4	4	2.0	1.0	1.0	+
24	4	4	6.0	1.0	1.0	-
20	4	4	5.0	1.0	1.0	+

Table 110

FLAMMABILITY OF MIXTURES OF PENTANE, IR, METHYL BROMIDE AND SULFUR HEXAFLUORIDE

C ₆ H ₁₂ Volume, %	85%SF ₆ 15%CH ₃ Br		7%SF ₆ 25%CH ₃ Br		50%SF ₆ 50%CH ₃ Br		Result
	Volume, %	Result	Volume, %	Result	Volume, %	Result	
2.5	5.0	+	7.5	-	7.0	+	+
2.5	5.5	+	8.0	-	7.5	+	+
2.5	6.0	-	-	-	8.0	+	+
2.5	6.25	+	-	-	8.5	-	-
2.0	-	-	-	-	9.0	-	-
6.0	-	-	1.0	+	-	-	-
6.0	-	-	1.5	+	-	-	-
6.0	-	-	2.0	+	-	-	-
6.0	-	-	2.5	+	-	-	-
6.0	-	-	3.0	-	-	-	-

Table 110 (Continued)

FLAMMABILITY OF MIXTURES OF PENTANE, IR, METHYL BROMIDE AND SULFUR HEXAFLUORIDE					
C ₂ H ₁₂ Volume, %	25%SF ₆		10%CH ₃ Br		Result
	75%CH ₃ Br Volume, %	Result	Volume, %	Result	
2.5	5.0	+	-	-	-
2.5	7.0	+	-	-	-
2.5	7.5	+	-	-	-
2.5	8.0	-	-	-	-
2.5	8.5	+	-	-	-
2.5	8.75	-	-	-	-
2.5	9.0	-	-	-	-
2.5	12.0	-	-	-	-
4.0	5.0	+	-	-	-
4.0	5.5	-	-	-	-
4.0	6.0	-	-	-	-
4.0	7.0	-	-	-	-
4.0	7.5	-	-	-	-
4.0	9.0	-	-	-	-
4.0	11.0	-	-	-	-
6.0	-	-	5.0	+	+
6.0	-	-	5.5	+	+
6.0	-	-	6.0	-	-
6.0	-	-	6.5	-	-
6.0	-	-	7.0	-	-
6.0	-	-	8.0	-	-
6.0	-	-	8.5	-	-

Table III

FLAMMABILITY OF MIXTURES OF PENTANE, AIR, METHYL BRADIE, AND PERFLUOROCUT, NE									
C ₆ H ₁₂ Volume, %	10% C ₆ H ₁₂		12.5% C ₆ H ₁₂		15% C ₆ H ₁₂		17.5% C ₆ H ₁₂		Result
	Volume, %	Result	Volume, %	Result	Volume, %	Result	Volume, %	Result	
2.5	5.0	+	7.0	+	6.5	+	6.5	+	
2.5	7.0	+	7.5	+	7.0	+	7.0	+	
2.5	7.5	+	8.0	-	7.5	-	7.5	+	
2.5	8.0	-	-	-	8.0	-	8.0	-	
2.5	8.5	-	-	-	-	-	-	-	
2.5	9.0	-	-	-	-	-	-	-	
4.0	3.5	+	8.0	+	3.5	+	3.5	+	
4.0	6.0	+	6.5	+	6.0	+	6.0	+	
4.0	6.0	+	-	-	6.5	+	6.5	+	
4.0	7.5	+	-	-	6.0	+	6.0	+	
4.0	8.0	-	-	-	6.5	+	6.5	+	
4.0	9.5	+	-	-	7.0	-	7.0	-	
4.0	10.0	+	-	-	-	-	-	-	
4.0	10.5	+	-	-	-	-	-	-	
4.0	11.0	-	-	-	-	-	-	-	
4.0	12.5	-	-	-	-	-	-	-	
6.0	4.0	+	3.5	+	1.0	+	1.0	+	
6.0	5.5	+	4.0	-	1.5	+	1.5	+	
6.0	6.0	-	-	-	2.0	+	2.0	+	
6.0	6.5	-	-	-	2.5	-	2.5	-	
6.0	7.0	-	-	-	3.0	-	3.0	-	
6.0	8.5	-	-	-	4.5	-	4.5	-	

Table III(Continued)

FLAMMABILITY OF MIXTURES OF PENTANE, AIR, METHYL BROMIDE AND PERFLUOROBUTANE

C ₅ H ₁₂ Volume, %	5% C ₄ F ₁₀ 50% CH ₃ Br		25% C ₄ F ₁₀ 75% CH ₃ Br		Result
	Volume, %	Result	Volume, %	Result	
2.5	6.5	+	7.0	+	
2.5	7.0	+	7.5	-	
2.5	7.5	+	8.0	-	
2.5	8.0	-	-	-	
4.0	4.5	+	4.0	+	
4.0	5.0	+	4.5	+	
4.0	5.5	+	5.0	-	
4.0	6.0	-	-	-	
4.0	6.5	-	-	-	
4.0	8.0	-	-	-	
6.0	0.5	+	1.0	+	
6.0	1.0	+	1.5	-	
6.0	1.5	-	-	-	
6.0	2.0	-	-	-	
6.0	2.5	-	-	-	
6.0	4.0	-	-	-	

Table 112

FL MM.BILITY OF MIXTURES OF PENTANE, AIR, METHYL BROMIDE AND ETHYL BROMIDE		90.3% C ₂ H ₆ Br		82.5% C ₂ H ₆ Br	
C ₅ H ₁₂ Volume, %	Volume, %	Result	Vol. mg, %	Result	Volume, %
2.5	3.0	+	5.0	+	5.0
2.5	4.0	+	5.5	-	6.0
2.5	4.5	+	6.0	-	6.5
2.5	5.0	-	-	-	7.0
2.5	7.0	-	-	-	-
4.0	-	-	2.5	+	2.0
4.0	-	-	3.0	+	3.5
4.0	-	-	3.5	-	4.0
4.0	-	-	5.0	-	4.5
6.0	-	-	0.5	+	1.0
6.0	-	-	1.0	+	1.5
6.0	-	-	1.5	-	2.0
6.0	-	-	2.0	-	3.0
6.0	-	-	2.5	-	-

Table 11: (Continued)

FLAMMABILITY OF MIXTURES OF PENTANE, AIR, METHYL BROMIDE AND ETHYL BROMIDE									
C ₂ H ₆ Volume, %	66 2/3% C ₂ H ₆ Br		50% C ₂ H ₆ Br		50% CH ₃ Br		40% C ₂ H ₆ Br		Result
	Volume, %	Result	Volume, %	Result	Volume, %	Result	Volume, %	Result	
2.5	-		5.5	+	5.5	+	5.5	+	+
2.5	-		5.75	+	6.0	+	6.0	+	+
2.5	-		6.0	-	6.5	-	6.5	-	-
2.5	-		6.5	-	2.5	+	7.0	-	-
4.0		+	4.0	+	4.0	+	3.0	+	+
4.0		+	4.25	+	4.5	+	3.5	-	-
4.0		+	4.5	-	-	-	4.0	+	+
4.0		-	-	-	-	-	5.0	-	-
6.0		+	2.0	+	2.0	+	6.0	-	-
6.0		+	3.0	+	3.0	+	1.0	+	+
6.0		-	-	-	-	-	1.5	-	-
6.0		-	3.0	-	-	-	2.0	-	-

Table 112 (Continued)

C ₅ H ₁₂ Volume, %	25% C ₂ H ₅ Br 75% CH ₃ Br		20% C ₂ H ₅ Br 80% CH ₃ Br		15% C ₂ H ₅ Br 85% CH ₃ Br		Result
	Volume, %	Result	Volume, %	Result	Volume, %	Result	
2.5	5.0	+	5.0	+	5.5	+	+
2.5	6.0	+	6.0	+	7.0	+	+
2.5	6.5	+	6.5	+	7.5	+	-
2.5	7.0	-	7.0	-	8.0	-	-
2.5	7.5	-	-	-	-	-	-
4.0	3.5	-	3.0	+	3.0	+	+
4.0	4.0	-	3.5	+	3.5	+	+
4.0	6.0	-	4.0	+	4.0	+	-
4.0	-	-	4.5	-	4.5	-	-
6.0	2.0	•	0.5	+	5.5	+	+
6.0	2.5	-	1.0	+	1.0	+	-
6.0	3.0	-	1.5	-	1.5	-	-
6.0	3.5	-	3.0	-	2.5	-	-

Table

C ₃ H ₁₂ Volume, %	FLAMMABILITY OF MIXTURES OF PENTANE, AIR, ETHYL ALCOHOL AND ETHYL BROMIDE						
	10% C ₂ H ₅ Br Volume, %	90% CH ₃ Br Volume, %	Result	5.2% C ₂ H ₅ Br 94.8% CH ₃ Br Volume, %	Result	100% CH ₃ Br Volume, %	Result
2.5	5.5	-	+	7.0	+	5.0	+
2.5	7.0	-	+	-	-	7.0	+
2.5	7.5	-	-	-	-	7.5	+
2.5	8.0	-	-	-	-	8.0	+
2.5	-	-	-	-	-	8.5	-
4.0	-	-	+	2.5	+	9.0	+
4.0	3.0	-	+	3.0	-	3.5	+
4.0	4.0	-	+	3.5	-	5.0	+
4.0	4.5	-	-	3.5	-	6.0	+
4.0	5.0	-	-	4.0	-	7.5	+
6.0	1.0	-	+	1.0	+	0.5	+
6.0	1.5	-	-	1.5	-	1.0	+
6.0	2.0	-	-	-	-	1.5	-
6.0	3.0	-	-	-	-	3.0	-

Table 113

FLAMMABILITY OF MIXTURES OF PENTANE, AIR, ETHYL BROMIDE AND METHYL IODIDE									
C ₅ H ₁₂ Volume, %	100% CH ₃ I		73.8% CH ₃ I		50% CH ₃ I		50% C ₂ H ₅ Br		Result
	Volume, %	Result	Volume, %	Result	Volume, %	Result	Volume, %	Result	
2.5	3.0	+	3.0	+	5.5	+	5.5	+	
2.5	4.0	+	5.0	+	5.5	+	5.5	-	
2.5	4.5	-	5.5	-	6.0	-	6.0	-	
2.5	5.0	-	6.0	-	7.0	-	8.0	-	
2.5	6.0	-	7.0	-	10.0	-	10.0	-	
4.0	3.0	+	1.0	+	1.0	+	1.0	+	
4.0	3.5	-	2.0	+	2.0	+	2.0	+	
4.0	4.0	-	2.5	+	3.0	+	3.0	+	
4.0	-	-	3.0	+	3.5	+	3.5	-	
4.0	-	-	3.5	+	4.5	+	4.5	-	
4.0	-	-	4.0	-	5.0	-	5.0	-	
4.0	-	-	-	-	6.0	-	6.0	-	
4.0	-	-	-	-	8.0	-	8.0	-	
6.0	0.5	+	0.5	+	0.5	+	0.5	+	
6.0	1.0	-	1.0	-	1.0	-	1.0	-	
6.0	1.5	-	1.5	-	2.0	-	2.0	-	
6.0	3.0	-	2.0	-	3.0	-	3.0	-	
6.0	-	-	2.5	-	4.0	-	4.0	-	
6.0	-	-	3.0	-	8.0	-	8.0	-	
6.0	-	-	3.5	-	-	-	-	-	
6.0	-	-	4.0	-	-	-	-	-	

Table 113(Continued)

C ₅ H ₁₂ Volume, %	FLAMMABILITY OF MIXTURES OF PENTANE, AIR, ETHYL BROMIDE AND METHYL IODIDE		Result
	25% C ₅ H ₁₂ Volume, %	75% C ₂ H ₅ Br Volume, %	
2.5	5.5	4.0	+
2.5	7.0	4.5	+
2.5	10.0	5.0	+
2.5	-	5.5	+
2.5	-	6.0	-
4.0	1.0	3.0	+
4.0	1.5	3.5	-
4.0	2.5	4.0	-
4.0	3.0	5.0	-
4.0	3.5	-	-
4.0	4.0	-	-
4.0	7.0	-	-
6.0	0.5	1.0	+
6.0	1.0	1.5	+
6.0	2.0	2.0	-
6.0	3.0	3.0	-
6.0	4.0	5.5	-
6.0	5.0	-	-
6.0	6.0	-	-
6.0	7.0	-	-

Table 114

FLAMMABILITY OF MIXTURES OF PENTANE, AIR, METHYLENE DICHLORIDE AND ETHYL BROMIDE

C ₂ H ₅ Br Volume, %	100% CH ₂ Cl ₂		75% CH ₂ Cl ₂		50% CH ₂ Cl ₂		Result
	Volume, %	Result	Volume, %	Result	Volume, %	Result	
2.5	7.0	+	15.0	+	-	-	-
2.5	11.0	+	16.0	+	-	-	-
2.5	13.0	+	16.5	+	-	-	-
2.5	15.0	+	17.0	-	-	-	-
2.5	16.0	+	-	-	-	-	-
2.5	17.0	-	-	-	-	-	-
4.0	5.0	+	5.0	+	4.5	+	+
4.0	10.0	+	7.0	+	5.0	+	+
4.0	15.0	+	7.5	+	5.5	-	-
4.0	20.0	-	8.5	+	6.0	-	-
4.0	-	-	9.0	-	7.0	-	-
4.0	-	-	11.0	-	10.0	-	-
4.0	-	-	14.0	-	-	-	-
6.0	-	-	2.0	+	1.5	-	-
6.0	-	-	2.5	+	2.0	-	-
6.0	-	-	3.0	+	3.0	-	-
6.0	-	-	3.5	-	3.5	-	-
6.0	-	-	4.0	-	4.0	-	-
6.0	-	-	5.0	-	5.0	-	-
6.0	-	-	10.0	-	10.0	-	-

Table 114 (Continued)

FLAMMABILITY OF MIXTURES OF PENTANE, AIR, METHYLENE DICHLORIDE AND ETHYL BROMIDE

C ₅ H ₁₂ Volume, %	25% CH ₂ Cl ₂		75% C ₂ H ₅ Br		100% C ₂ H ₅ Br		Result
	Volume, %	Result	Volume, %	Result	Volume, %	Result	
2.5	4.0	+	-	-	-	-	-
2.5	6.0	+	-	-	-	-	-
2.5	6.5	+	-	-	-	-	-
2.5	7.0	+	-	-	-	-	-
2.5	7.5	-	-	-	-	-	-
2.5	8.0	-	-	-	-	-	-
4.0	5.0	+	-	-	-	-	-
4.0	5.5	-	-	-	-	-	-
4.0	6.0	-	-	-	-	-	-
4.0	7.0	-	-	-	-	-	-
4.0	8.0	-	-	-	-	-	-
4.0	11.0	-	-	-	-	-	-
4.0	14.0	-	-	-	-	-	-
6.0	0.5	+	-	-	1.0	+	+
6.0	1.0	-	-	-	1.5	-	-
6.0	2.0	-	-	-	2.0	-	-
6.0	4.0	-	-	-	3.0	-	-
6.0	10.0	-	-	-	5.5	-	-

Table 115

FLAMMABILITY OF MIXTURES OF PENTANE, AIR, ETHYL BROMIDE AND CHLOROTRIFLUOROMETHANE									
C ₅ H ₁₂ Volume, %	100% CClF ₃		75% CClF ₃		50% CClF ₃		50% C ₂ H ₅ Br		Result
	Volume, %	Result	Volume, %	Result	Volume, %	Result	Volume, %		
2.5	6.0	-	4.0	+	8.0	+	8.0	+	
2.5	7.0	-	6.0	+	8.0	+	8.0	-	
2.5	8.0	-	7.0	+	8.5	+	8.5	-	
2.5	9.0	-	7.5	+	9.0	+	9.0	-	
2.5	9.5	-	8.0	-	9.5	-	9.5	-	
2.5	10.0	+	16.0	-	10.0	-	10.0	-	
4.0	9.0	+	5.0	+	5.5	+	5.5	+	
4.0	9.5	+	8.0	+	6.0	+	6.0	+	
4.0	10.0	+	8.5	-	6.5	-	6.5	-	
4.0	11.0	+	9.0	-	7.0	-	7.0	-	
4.0	12.0	+	9.5	-	8.0	-	8.0	-	
4.0	12.5	-	10.0	-	10.0	-	10.0	-	
4.0	13.0	-	-	-	12.0	-	12.0	-	
4.0	14.0	-	-	-	18.0	-	18.0	-	
6.0			1.0	+	1.0	+	1.0	+	
6.0			1.5	-	1.5	-	1.5	-	
6.0			2.0	-	2.0	-	2.0	-	
6.0			2.5	-	2.5	-	2.5	-	
6.0			3.0	-	3.0	-	3.0	-	
6.0			4.0	-	4.0	-	4.0	-	
6.0			10.0	-	10.0	-	10.0	-	

Table 115 (Continued)

FLAMMABILITY OF MIXTURES OF PENTANE, AIR, ETHYL BROMIDE AND CHLOROTRIFLUOROMETHANE

C ₂ H ₁₂ Volume, %	25% CClF ₃ 75% C ₂ H ₅ Br		Result
2.5	5.0		+
2.5	8.0		+
2.5	8.5		+
2.5	9.0		-
2.5	10.0		-
2.5	11.0		-
2.5	14.0		-
4.0	5.0		+
4.0	7.0		+
4.0	7.5		-
4.0	8.0		-
4.0	8.5		-
4.0	9.0		-
4.0	10.0		-
4.0	12.0		-
6.0	0.5		-
6.0	1.0		+
6.0	1.5		+
6.0	2.0		+
6.0	2.5		+
6.0	3.0		-
6.0	5.0		-
6.0	14.0		-

Table 116

FLAMMABILITY OF MIXTURES OF PENTANE, AIR, CARB. TETRACHLORIDE AND 1,1,1,2-TRICHLOROETHYLENE

C ₅ H ₁₂ Volume, %	100% CCl ₄		75% CCl ₄		55% CCl ₄		45% C ₂ HCl ₃		Result
	Volume, %	Result	Volume, %	Result	Volume, %	Result	Volume, %	Result	
2.5	1.0	+	5.0	+	11.5	+	11.5	+	
2.5	12.0	+	5.5	+	12.0	+	12.0	-	
2.5	15.5	-	6.0	+	16.0	+	16.0	-	
2.5	16.0	-	7.0	+	17.0	+	17.0	-	
2.5	-	-	9.5	+	20.0	+	20.0	-	
2.5	-	-	10.0	-	-	-	-	-	
4.0	20.0	+	10.0	+	25.0	+	25.0	+	
4.0	21.0	+	11.0	+	27.0	+	27.0	-	
4.0	21.5	-	13.0	+	28.0	+	28.0	-	
4.0	22.0	-	14.0	+	-	-	-	-	
4.0	23.0	-	16.0	+	-	-	-	-	
4.0	26.0	-	16.5	+	-	-	-	-	
4.0	-	-	17.0	-	-	-	-	-	
4.0	-	-	18.0	-	-	-	-	-	
4.0	-	-	19.0	-	-	-	-	-	
4.0	-	-	20.0	-	-	-	-	-	
6.0	12.0	+	13.0	+	10.0	+	10.0	+	
6.0	13.0	+	13.5	-	11.0	-	11.0	+	
6.0	13.5	-	14.0	-	11.5	-	11.5	-	
6.0	14.0	-	15.0	-	12.0	-	12.0	-	
6.0	16.0	-	16.5	-	14.0	-	14.0	-	
6.0	-	-	18.0	-	-	-	-	-	
6.0	-	-	19.0	-	-	-	-	-	
6.0	-	-	20.0	-	-	-	-	-	

Table 116 (Continued)

C ₅ H ₁₂ Volume, %	FLAMMABILITY OF MIXTURES OF PENTANE, AIR, CARBON TETRACHLORIDE AND 1,1,2-TRICHLOROETHYLENE					
	37% CCl ₄ 63% C ₂ HCl ₃ Volume, %	Result	20% CCl ₄ 80% C ₂ HCl ₃ Volume, %	Result	100% C ₂ HCl ₃ Volume, %	Result
2.5	10.0	+	15.0	+	5.0	+
2.5	12.0	+	16.0	+	10.0	+
2.5	14.0	+	17.0	+	11.0	+
2.5	14.5	-	17.5	+	12.0	+
2.5	15.0	-	18.0	+	13.5	+
2.5	-	-	18.5	+	15.0	-
2.5	-	-	19.0	-	18.0	-
2.5	-	-	19.5	-	19.0	-
2.5	-	-	20.0	-	20.0	-
2.5	-	-	-	-	21.0	-
4.0	15.5	+	9.5	+	10.0	+
4.0	16.0	-	10.0	-	11.0	+
4.0	-	-	12.0	+	11.5	+
4.0	-	-	12.5	+	12.0	-
4.0	-	-	13.0	+	13.0	+
4.0	-	-	13.5	+	14.0	+
4.0	-	-	14.0	-	15.5	-
4.0	-	-	-	-	16.0	-
4.0	-	-	-	-	17.0	-
4.0	-	-	-	-	18.0	-
6.0	12.0	-	-	-	8.0	+
6.0	14.0	-	-	-	8.5	-
6.0	15.0	-	-	-	10.0	-
6.0	16.0	-	-	-	12.0	-
6.0	-	-	-	-	14.0	-
6.0	-	-	-	-	16.0	-

Table 117

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR, AND METHYL BROMIDE
(Total Pressure = 100 mm. Hg.)

<u>n-Heptane</u>	<u>Volume, %</u>	<u>Methyl Bromide</u>	<u>Result</u>
3.0		4.5	-
2.0		3.0	-
2.0		2.0	-
3.0		2.0	-
2.0		1.0	-
4.0		1.0	-
3.0		0.5	-
4.0		0.5	-
5.0		-	-
10.0		-	-
9.0		-	-

Table 118

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR, AND METHYL BROMIDE
(Total Pressure = 200 mm. Hg.)

<u>n-Heptane</u>	<u>Volume, l</u>	<u>Methyl Bromide</u>	<u>Result</u>
3.0		5.0	+
2.0		5.0	-
3.0		5.5	-
2.0		4.0	-
4.0		5.0	-
2.0		3.0	+
4.0		3.0	+
1.0		1.0	-
2.5		5.5	+

Table 119

Flammability of mixtures of n-Heptane, Air, and Methyl Bromide.
(Total Pressure=300 mm. Hg.)

<u>n-Heptane</u>	<u>Volume, % Methyl Bromide</u>	<u>Result</u>
2.0	6.0	-
2.0	5.0	+
3.0	5.0	-
2.0	5.5	+
1.0	5.0	-
1.5	5.5	-
2.5	5.5	+
1.5	3.0	+
2.5	6.0	+
4.0	3.0	-
2.5	6.5	+
3.5	3.0	+
2.5	7.0	-
1.0	3.0	-

Flammability of mixtures of n-Heptane, Air, and Methyl Bromide.
(Total Pressure=500 mm. Hg.)

<u>Volume, %</u>		
<u>n-Heptane</u>	<u>Methyl Bromide</u>	<u>Results</u>
1.5	10	-
2.0	7.0	-
1.5	9.5	-
1.5	9.0	-
4.0	3.0	-
1.5	7.0	+
1.5	8.0	-
1	7.0	-
1.5	7.5	-
4.0	2.5	+
1.0	3.0	-
6.0		+
1.0	<u>1.0</u>	-
7.0	—	+
1.0	—	-
8.0	—	-
1.5	—	+
2.5	<u>5.0</u>	+

Flammability of mixtures of n-Heptane, Air, and Bromotrifluoromethane.
(Total Pressure=200 mm. Hg.)

<u>Volume %</u>		
<u>n-Heptane</u>	<u>Bromotrifluoromethane</u>	<u>Results</u>
3.0	5.0	-
3.0	3.0	+
3.0	4.0	-
2.0	3.0	-
3.0	3.5	+
3.5	3.0	-
2.5	3.5	+
3.5	3.5	-
2.5	4.0	+
2.5	4.5	-
4.0	1.5	+
5.0	1.5	-
2.0	1.0	+

Table 162

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR, AND BROMOTRIFLUOROMETHANE
(Total Pressure = 300 mm. Hg.)

<u>n-Heptane</u>	<u>Volume, %</u> <u>Bromotrifluoromethane</u>	<u>Result</u>
3.0	5.0	+
3.5	4.0	-
3.0	5.5	+
2.0	4.0	-
3.0	6.0	+
1.5	2.0	-
3.5	6.0	-
3.0	6.5	-
2.5	6.0	-
2.0	2.0	+
4.5	2.0	+
5.0	2.0	+
5.5	2.0	+
6.0	2.0	-

Table 123

FLAMMABILITY OF MIXTURES OF n-HEPTANE, AIR, AND BROMOTRIFLUORO-
METHANE

(Total Pressure = 500 mm. Hg)

<u>n-Heptane</u>	<u>Volume, %</u> <u>Bromotrifluoromethane</u>	<u>Result</u>
3.0	6.5	-
3.0	6.0	+
1.5	3.0	-
2.5	6.0	-
3.5	6.0	+
2.0	3.0	+
3.5	6.5	-
4.0	6.0	-
5.0	3.0	-
4.0	4.5	-
4.0	3.0	+
5.0	1.5	+
4.5	3.0	-
6.5	1.5	-

Table 124

PHYSICAL DATA FOR GASES SUPPORTING COMBUSTION

Material	Chlorine	Oxygen	Fluorine
Boiling Point, °C.	-34.6 (10,42,79) -33.6 (42)	-183.0 (11,42) -182.7 (23,25)	-187. (11,23,42)
Melting Point, °C.	-101.6 (11,42,79) -102. (23) -103.5 (79)	-218.4 (11,42) -218. (23) -218.8 (25)	-233. (10,23,42 79)
Molecular Weight	35.457 (11) 35.46 (23)	16.000 (11) 16 (23)	19.000 (11) 19.0 (23)
Critical Temperature, °C.	141 (23) 144 (79)	-118 (23) -118.8 (79)	-129.1 (8)
Critical Pressure, atm.	83.9 (23) 76.1 (79)	49.7 (79) 50.0 (3)	55 (8)
Critical Density, g./cc.	0.5739 (79) 0.573 (79)	0.430 (79) 0.6044 (23)	
Heat of Fusion,	0.812 kg.cal/g.atom 142) 3.40 kg.joules/g. atom (79) 96.1 joules/g.(at m.p.) (79)	0.053 kg.cal/g. atom (42)	0.19 kg. cal/g.atom at b.p. (42) 0.8g-joules/ g.atom (79)
Triple Point, °A	417.1 at 76.1 atm. (59)	54.3 (25)	1 atm. P. 50° (52)
Density STP			
Liquid, (g./l.)	3.214 (23,79)	1.4290 (23)	1.695 (23,79)
Vapor	2.491 (23)	1.1053 (23)	1.26 (23)
Heat of Vaporization atom (at b.p.)	10.0kg. joules/g. (79) 2.39kg.cal/g.atom (42)	1630.7±1.5 cal/mole (24) 50.97 cal/kg. (23)	

Table 10F.

THERMAL CONDUCTIVITIES FOR OXYGEN (29)

Thermal Conductivity $\times 10^5$ Cal./sec./cm./ $^{\circ}$ A	Temperature, $^{\circ}$ A
1.701	80
1.721	81.7
1.930	90
2.159	100
2.387	110
2.614	120
2.840	130
2.064	140
3.287	150
3.508	160
3.728	170
3.946	180
4.162	190
4.292	194.7
4.375	200
4.584	210
4.730	220
4.993	230
5.194	240
5.392	250
5.586	260
5.780	270
5.70	273
5.970	280
6.159	290
6.350	300
6.547	310
6.798	320
6.954	330
7.164	340
7.378	350
7.594	360
7.182	370
7.427	373
8.033	390

Table 126

Heat Capacities for Oxygen

Cp-cal/mole/°A (78)	(5)	Temperature °A
6.961	_____	200
6.970	_____	250
7.017	<u>7.019</u>	298.16
7.019	7.021	300
7.194	7.194	400
7.429	7.430	500
7.670	7.669	600
7.885	7.882	700
8.064	8.062	800
8.212	8.211	900
8.335	8.335	1000
8.440	8.439	1100
8.530	8.528	1200
8.570	_____	1250
8.608	8.606	1300
8.676	8.675	1400
8.739	8.739	1500
8.885	_____	1750
9.024	_____	2200
9.035	_____	2500
9.518	_____	3000
9.711	_____	3500
9.879	_____	4000
10.003	_____	4500
10.105	_____	5000

Heat Capacities for Chlorine (6)

Cp-cal/mole/°A	Temperature °A
0.89	15
1.87	20
2.90	25
3.97	30
5.73	40
6.99	50
8.00	60
8.68	70
9.23	80
9.71	90
10.10	100
10.47	110
10.87	120
11.29	130
11.73	140
12.20	150
12.68	160
13.17	170

Table 128

THERMAL CONDUCTIVITIES FOR OXYGEN

Thermal Conductivity, cal./cm. sec.	Temperature, °A	Ref.
1.851	86.53	34
2.035	94.55	34
2.113	98.02	34
2.774	127.22	34
2.861	130.99	34
3.166	144.56	34
3.316	151.24	34
3.676	167.25	34
4.051	185.17	34
4.488	205.38	34
4.981	229.36	34
5.408	250.87	34
5.819	272.07	34
6.175	290.90	34
6.828	323.86	34
7.201	341.99	34
7.547	357.63	34
7.956	376.30	34
5.768	273.1	78
5.83		37
5.839		35
5.89		55
5.89		31
5.90		18

Table 129

PHYSICAL DATA FOR SOME FLAMMABLE GASES

Material	Ethane	Acetylene	Methane
Boiling Point, °C	-88.3 (11)	-83.6 (16)	-161.5 (11,79)
	-89.1 (81)	-83.8 (38)	-161.37(70)
	-89.0 (28)	-85. (23)	-161.4 (16)
	-93. (23)	-82.9 (42)	-164. (38)
	-88.9 (42)	-85.0 (79)	-165. (23)
	-88.62(79)		-161.1 (42)
Melting Point, °C	-172. (42)	-31.8 (11,38)	-184. (11,23,38)
	-171. (23)	-31.0 (16,23)	-182.5 (16)
	-172. (11)		-184.4 (42)
	-183.2(16)		
	-183.23(81)		
	-172.2 (42)		
Molecular Weight	30.27 (11)	26.04 (11)	16.04 (11)
			16.03 (82)
Critical Tempera- ture, °C	32.27 (2)	36.1 (16)	-82.4 (70)
	32.2 (79)	36. (79)	-82.8 (16)
	32.1 (23)		-82.1 (79)
			-82. (82)
Critical Pressure, atm.	49.0 (23)	61.7 (79)	45.8 (16,79,82)
	45.8 (16)	62. (16)	
	48.2 (2)		
	48.8 (79)		
Critical density, g/cc.	0.220 (79)	0.230 (79)	0.1615 (30,91)
	0.203 (2,16)	0.231 (16)	0.162 (16)
Heat of Fusion, cal/mole	682.9		224 (25)
	(at b.p.) (81)		
	682 (25)		
Triple Point, °A	89.9 (25)	81.5 (79)	

Table 129 (Cont'd)

PHYSICAL DATA FOR SOME FLAMMABLE GASES

Material	Ethane	Acetylene	Methane
Vapor Density (g./l.) at STP	1.0494 (23)	0.92 (23)	0.415 (16)
Liquid Density (g./l.)			0.415 (23)
Heat of Vaporization, cal/mole	3415 \pm 4 (81)		2036 \pm 2 (24) (-173.6°C.)
cal/g	116.9 (at b.p.) (16)		136.3 (16) (at b.p.)

Table 130

HEAT CAPACITIES OF FLAMMABLE GASES

Materials	C_v , cal/mole	C_p , cal/mole	Temperature °A	Ref.
Ethane	6.57	-	92.4	40
	6.51	-	93.1	40
	6.55	-	93.5	40
	6.55	-	94.3	40
	6.59	-	97.4	40
	6.60	-	98.4	40
	6.64	-	99.6	40
	6.64	-	100.5	40
	7.72	-	134.1	40
	7.10	-	143.0	39
	7.43	-	163.0	39
	8.13	-	191.1	42
	8.02	-	193.0	39
	-	11.834	272.07	41
	9.408	-	288.1	42
	-	12.733	302.70	42
	-	13.719	335.82	41
	-	14.589	364.78	41
	-	12.59	298.16	5
	-	12.65	300.0	5
	-	15.68	400.0	5
	-	18.66	500.0	5
	-	21.34	600.0	5
	-	23.71	700.0	5
-	25.82	800.0	5	
-	27.68	900.0	5	
-	29.31	1000.0	5	
-	30.75	1100.0	5	
-	32.00	1200.0	5	
-	33.10	1250.0	5	
-	34.05	1300.0	5	
-	34.89	1400.0	5	
Methane	5.104	7.20	158.1	42
	5.92	7.963	195.1	42
	6.4512	8.45	288.1	42
	-	8.47	288.6	16
	-	9.49	283.1	23
Acetylene	29.12	-	202.1	42
	-	10.452	291.1	42

Table 131

DIELECTRIC CONSTANTS OF SOME GASES
SUPPORTING COMBUSTION

Material	Dielectric Constant	Pressure, mm. Hg	Temperature, °A	Ref.
Oxygen	1.000,523,3	760	273	31
	1.000,799	1217	291.1	50
	1.000,862	2863	291.1	50
	1.000,595	763	291.7	50
	1.000,986	1507	291.7	50
	1.001,314	2035	291.7	50
	1.000,504	765	292.6	50
	1.000,941	2873	292.6	50
	1.004,241	6610	294.4	50
	1.002,781	4395	294.6	50
	1.001,889	2955	295.1	50
	1.004,202	6675	295.4	50
	1.003,328	5352	296.1	50
	Chlorine	1.9	760	274.1	13
2.0		760	274.1	22
1.97		760	274.1	49

Table 132

RATIO OF C_p/C_v FOR SOME FLAMMABLE GASES

Materials	C_p/C_v	Temperature, °A	Ref.
Methane	1.47	158.1	42
	1.35	199.1	42
	1.31	288.1	42
	1.316	284.1 to 300.1	23
Ethane	1.22	288.1	42
	1.21	323.1	42
	1.19	373.1	42
Acetylene	1.31	202.1	79
	1.26	268.1	79
	1.28	191.1	42

Table 133

THERMAL CONDUCTIVITIES FOR SOME FLAMMABLE GASES

Material	Thermal Conductivity $\times 10^6$ Cal/cm./sec./°A	Temperature, °A	Ref.
Acetylene	4.40	273.1	29
Ethane	2.727	202.7	29
	4.306	273.1	29
	7.673	373.1	29
Methane	2.248	81.5	29
	2.272	90	33
	2.536	100	33
	2.800	110	33
	3.065	120	33
	3.331	130	33
	3.595	140	33
	3.860	150	33
	4.128	-	33
	4.396	170	33
	4.667	180	33
	4.940	190	33
	4.940	197.5	29
	5.216	200	33
	5.496	210	33
	5.778	220	33
	6.063	230	33
	6.351	240	33
	6.643	250	33
	6.940	260	33
	7.242	270	33
	7.200	273.1	29
	7.549	280	33
	7.862	290	33
	8.186	300	33
	8.518	310	33
	8.862	320	33
	9.219	330	33
	9.590	340	33
	9.978	350	33
	10.372	360	33
	10.797	370	33
	11.220	380	33

Table 134

DIELECTRIC CONSTANTS OF SOME FLAMMABLE GASES

Material	Dielectric Constant	Temperature, °C.	Pressure, atm.	Ref.	
Methane	1.01918	0	20	75	
	1.04044	0	40	75	
	1.06439	0	60	75	
	1.09082	0	80	75	
	1.1198	0	100	75	
	1.0134	100	20	75	
	1.02750	100	40	75	
	1.04164	100	60	75	
	1.05615	100	80	75	
	1.07113	100	100	75	
	1.09005	100	125	75	
	1.1089	100	150	75	
	1.1275	100	170	75	
	Ethane	1.0015			73
	Acetylene	1.00134			73

Table 135

PHYSICAL DATA FOR SOME INERT GASES

Material	Argon	Helium	Krypton
Boiling Point, °C.	-185.7 (11, 33, 42) -186.1 (23) -185.76 (45)	-268.9 (11, 33, 42) -268.884 (61) -267.0 (23)	-152.9 (11) -151.7 (23) -151.8 (33, 42)
Melting Point, °C.	-190.0 (79) -189.2 (79) -188.0 (23)	-272.2 (11) (26. atm) -272.2 (33, 42)	-169.0 (23, 42) -157.0 (11) -157.1 (33)
Molecular Weight	39.944 (11) 39.94 (72) 39.91 (91) 39.88 (23)	4.003 (11, 42) 3.99 (23)	83.7 (11, 42, 82) 82.92 (23)
Heat of Fusion	265.2 cal/mole at 83.6° (21) 28.1 Joules/g. (79) 0.268 kg-cal/g. atom (42)	0.835 cal/cm ³ at 2.5°1 (69) 1.089 cal/cm ³ at 3°1 (69) 1.365 cal/cm ³ at 3.5°1 (69)	0.36 kg-cal/g. atom (42)
Triple Point, °K.	83.93 at 517 mm. (4) 83.85 at 516.3 mm. (12) 83.8 at 515.65 mm. (14) 83.55 at 760 mm. (24) 83.81 at 521.4 mm. (44) 83.5 at 760 mm. (57)	5.19 at 2.26 atm. (99)	115.94 ± 0.3 at 209.39 mm. (48) 274.

Table 135 (Cont'd.)
 Physical Data For Some Inert Gases

Material	Neon	Nitrogen	Xenon	Carbon Dioxide
Boiling Point, °C.	-245.9 (11, 33, 42) -239 (23) -246 (25)	-195.8 (42) -195.8 (11) -195 (23) -194.4 (10)	-109.1 (23) -109.1 (42) -107.1 (11)	-78.2 (25) -78.5 (11)
Melting Point, °C.	-248.67 (11, 33, 42) -252. (23)	-209.86 (42) -209.6 (11) -211. (23) -210.06 (25)	-112. (11) -140. (42) -140. (23) -111.74 (25) -140. (33)	-56.6 (11) at 5.2 atm. -57.5 (25)
Molecular Weight	20.183 (11) 20.183 (42) 20.2 (23)	14.008 (42) 14.01 (23) 14.008 (11)	131.3 (11, 42) 130.2 (23)	44.01 (11)
Heat of Fusion kg. cal/g. atom cal/mole	0.057 (42)	0.0851 (42)	0.490 (42) 0.548 (25)	0.196 (25)* 1900.3 at 215.6° (21)
Triple Point, °C.	-248.1 (25)	-209.9 (25)	-16.6 (59) (58.2 atm.)	-31.1 (59) (73 atm.)

* kcal/mole

Table 135 (Cont'd.)

Physical Data For Some Inert Gases

Material	Trifluoro- methane	Carbon tetra- fluoride	Chlorotri- fluoromethane	methyl bromide	Dichlorodi- fluoro methane
Boiling Point, °C.	-82.2 (at 23 atm.) (11)	-130 (70)	-80 (9,11)	3.56 (11,19)	-29.8 (70)
	-90 (70)	-128.5 (70)	-80.5 (70)		-30 (9)
	-82.2 (32)	-126 (43)	-82. (56)	4.44 (42)	-24.8 (7)
	-81 (17)		-81.5 (60)	4.5 (38)	-29.8 (42)
	-82 (47)			(757.6 mm. Hg)	
Melting Point, °C.	-163 (11)	-184 (30)	-181 (11)		-127 (11)
	-163 (32)	-186 (65)	-180 (66)	-93.66 (11,19)	-155 (51)
	-160 (68)	-183.6 (25)		-93. (38)	-155 (42)
				-92.77 (42)	
Molecular Weight	70.02 (11)	519.69 (11)	104.47 (11)	94.95 (11,19)	120.914 (42) 120.90 (11)
Heat of Fusion kg.cal/mole	---	0.167 (25)	---	1.429 (19,25)	8.2 (1) *
Triple Point, °C.	---	-183.6 (25,49)	---	---	---

* cal/g.

Table 136

PHYSICAL DATA FOR SOME INERT GASES

Material	Argon	Helium	Krypton	Neon
Critical Temperature, °C.	-117.4 (23) -122.4 (79,82) -122 (79)	-268 (23) -247.91 (33,72) -267.9 (29)	-63.1 (82) -62.5 (33) -65.5 (23)	-205.0 (23) -228.7 (33) -228.65 (82)
Critical Pressure, atm.	48.0 (79) 47.96 (33) 47.966 (82) 52.9 (23)	2.26 (33) 2.75 (29) 2.161 (82)	54.3 (23,33) 54. (8)	28.86 (43,82) 29.0 (23) 25.9 (79)
Critical Density, g./cc.	0.531 (79) 0.53078 (82)	0.066 (29) 0.06930 (82) 0.125 (81) 0.0693 (79)	0.78 (79,82)	0.4835 (82) 0.484 (79)
Heat of Vaporization kg. cal./g. atom cal./g. cal./mole	--- 38.93 (24)	0.024 (at b.p.) (42) 5.5 (69) ---	2.2 (b.p.) (42) --- ---	0.416 (b.p.) (42) --- ---
Liquid Density, g./ml.	---	---	---	0.4935 (62)
Vapor Density, g./liter as compared to air	1.7824 (42) 1.732 (79) 1.3796 (23) 1.379 (79)	0.1785 (42) 0.1368 (23)	3.708 (42) 2.868 (23,33)	0.40698 (11) 0.4068 (23)

Table 134 (Cont'd.)

Material	Nitrogen	Xenon	Carbon Dioxide	Methyl bromide
Critical Temperature, O°C.	-147.1 (79) -146.0 (23)	16.5 (33) 16.7 (82)	31.2 (23) 31.6 (79)	
Critical Pressure, atm.	35.5 (79) 35.0 (23)	58.22 (82) 58.2 (33)	73.0 (23,79)	
Critical Density, g/cc.	0.3110 (79) 0.44 (23)	1.154 (82) 1.155 (79) 3.06 (33)	0.46 (23,79)	
Heat of Vaporization, Kg.cal/g.atom cal/g.	0.669 (42) 0.04745 (-195.6°C.) (23)	3.20 (42) --- ---		52.06 (54)
Liquid Density g./ml. at °C.	---	---	2481 (at 0°C.) (46)	1.73 (53) 1.755 at 10 1.770 at 20 1.805 at 30 1.830 at 40 1.85 at 50 1.880 at 60 1.905 at 70 1.930 at 80 1.955 at 90 1.980 at 100
Vapor Density, g./l. compared to air	1.2506 (3) 0.9673 (23)	---	1.5291 (23)	---

Table 136 (Cont'd.)

	Trifluoromethane	Carbon tetrafluoride	Chlorotrifluoromethane	Dichlorodifluoromethane
Critical Temperature, °C.	15. (70) 32.9 (28)	-49 (70)	30. (70) 36.8 (57)	115.5 (70) 111.7 (42) 111.5 (77)
Critical Pressure, atm.	46. (28)	---	---	39.4 (42)
Heat of Vaporization, kg. cal/kg. cal/mole at °C.	53.42 (70)	31.0 (70) 2947 (71) 3209 (at 273.1 (49))	-35.8 (64) ---	40.4 (70) 4890 (-29.8) (7) 4100 (23°C.) (7) 3960 (28°C.) (7)
Vapor Density g./l. compared to air	---	3.451 (26)	3.430 (26)	5.44 (42) 4.709 (26) 4.21 (42)

Table 137

THERMAL CONDUCTIVITIES OF INERT GASES

Material	Thermal Conductivity x 10 ⁵ Cal/sec./cm./°A	Temperature, °A	Ref.
Argon	1.42	90.6	29
	3.88	273.1	29
	5.097	373.1	29
Helium	6.0	3.3	60
	5.13	20.8	29
	15.34	80	33
	14.84	81.4	29
	16.43	90	33
	17.51	100	33
	18.53	110	33
	19.64	120	33
	20.63	130	33
	21.71	140	33
	22.73	150	33
	23.73	160	33
	24.72	170	33
	25.63	180	33
	26.63	190	33
	27.56	200	33
	28.49	210	33
	29.39	220	33
	30.28	230	33
	31.15	240	33
	32.00	250	33
	32.83	260	33
	33.65	270	33
	33.6	273.1	29
	34.45	280	33
	35.23	290	33
	36.00	300	33
36.74	310	33	
37.46	320	33	
38.15	330	33	
38.81	340	33	
39.44	350	33	
40.05	360	33	
40.62	370	33	
39.85	373.1	29	
41.17	380	33	
Neon	4.99	91.7	33
	8.79	198.7	33
	10.87	273.1	33
	13.44	378.9	33
Xenon	1.24	273.1	15

Table 137 (Continued)

Material	Thermal Conductivity x 10 ⁵ C.l/sec./cm./°A	Temperature, °A	Ref.
Nitrogen	1.829	81.7	29
	4.305	198.7	29
	5.68	273.1	29
	7.18	373.1	29
Krypton	2.12	273.1	15
Carbon dioxide	1.984	180	33
	2.126	190	33
	2.546	194.6	29
	2.272	200	33
	2.424	210	33
	2.580	220	33
	2.741	230	33
	2.907	240	33
	3.077	250	33
	3.251	260	33
	3.429	270	33
	3.393	273.1	29
	3.611	280	33
	3.796	290	33
	3.964	300	33
	4.175	310	33
	4.371	320	33
	4.571	330	33
	4.777	340	33
	4.988	350	33
5.202	360	33	
5.416	370	33	
5.06	373.1	29	
5.630	380	33	
14.20	819.1	29	
Methyl bromide	1.74	277.7	33

Table 138

DIELECTRIC CONSTANTS OF CARBON DIOXIDE

Material	Dielectric Constant	Pressure mm. Hg.	Temp. °A.	Ref.
Carbon dioxide	1.000862	714	294.1	76
	1.000862	722	294.1	76
	1.000873	724	294.1	76
	1.000929	763	291.1	76
	1.001449	1203	292.6	76
	1.001548	1275	292.1	76
	1.002145	1747	292.1	76
	1.002367	1946	292.6	76
	1.002377	1959	294.1	76
	1.002421	1997	292.6	76
	1.003042	2466	291.3	76
	1.003074	2511	292.6	76
	1.003595	2868	291.1	76
	1.004057	3329	294.1	76
	1.005540	4494	293.5	76
	1.008667	5384	294.4	76
	1.007452	5986	294.1	76
	1.007608	6088	293.5	76
	1.0280	25.79	298.15	50
	1.0343	30.48	298.15	50

*These values are expressed in atmospheres.

Table 139 (Cont'd)

<u>Material</u>	<u>Dielectric Constant</u>	<u>Pressure</u>		<u>Temp., °C.</u>	<u>Ref.</u>
		<u>atm.</u>			
Carbon dioxide	1.0415	35.24		298.15	50
	1.0494	39.99			50
	1.0563	44.65			50
	1.0707	50.17			50
	1.0838	54.62			50
	1.1022	59.33			50
	1.1317	65.14			50
	1.02486	25.80		322.81	50
	1.03578	35.25			50
	1.04566	42.91			50
	1.06343	54.67			50
	1.07513	61.21			50
	1.08574	66.43			50
	1.09712	71.27			50
	1.11124	76.53			50
	1.12444	80.74			50
	1.15457	88.27			50
	1.01951	24.75		372.86	50
	1.04457	51.76			50
	1.06939	74.35			50
1.13914	123.50			50	
1.18008	146.20			50	
1.20654	160.31			50	
Helium	1.000,072,8				80
	1.000,068,4 ± 0.000,000,5			273.1	31
Neon	1.000,134			-	80
	1.000,127,4 ± 0.000,000,5			273.1	31
Argon	1.000,550			-	80
	1.000,545,1 ± 0.000,000,5			273.1	31
Krypton	1.000,838				80
Xenon	1.001,351				80
Methyl bromide	9.97			273.1	53
	10.42			263.1	53
	10.91			253.1	53
	11.43			245.1	53
	12.00			233.1	53
	12.63			223.1	53
	13.32			213.1	53
	14.07			203.1	53
	14.96			193.1	53
	16.02			183.1	53
	17.4			173.1	53

Table 140

Heat Capacities of Nitrogen (73)

<u>cp-cal/mole/°A</u>	<u>Temperature °A</u>
6.957	200
6.959	250
6.960	298.15
6.961	300
6.991	400
7.070	500
7.197	600
7.351	700
7.512	800
7.671	900
7.816	1000
7.947	1100
8.063	1200
8.116	1250
8.165	1300
8.253	1400
8.330	1500
8.486	1750
8.602	2000
8.759	2500
8.862	3000
8.934	3500
8.984	4000
9.036	4500
9.076	5000

Table 141.

Heat capacities of gaseous carbon dioxide

<u>cp-cal/mole/°A</u>	<u>Temperature, °A</u>	<u>Ref.</u>
8.827	292.9	41
8.874	298.16	78
8.894	300.0	78
9.240	351.86	41
9.503	358.4	41
9.595	367.72	41
9.871	400.0	78
10.662	500.0	78
11.311	600.0	78
11.849	700.0	78
12.300	800.0	78
12.678	900.0	78
12.995	1000.0	78
13.260	1100.0	78
13.49	1200.0	78
13.59	1250.0	78
13.68	1300.0	78
13.85	1400.0	78
13.99	1500.0	78
14.30	1750.0	78
14.50	2000.0	78
14.80	2500.0	78
15.00	3000.0	78
15.2	3500.0	78

Table 142
Heat Capacities of solid carbon dioxide

<u>cp-cal/mole/°A</u>	<u>Temperature, °A</u>	<u>Ref.</u>
0.540	15	27
1.225	20	
2.137	25	
3.093	30	
3.912	35	
4.690	40	
5.435	45	
6.095	50	
7.178	60	
8.172	70	
9.582	80	
9.105	90	
9.530	100	
9.915	110	
10.30	120	
10.67	130	
11.04	140	
11.39	150	
11.77	160	
12.17	170	
12.61	180	
13.07	190	

Table 143

HEAT CAPACITIES REPORTED FOR METHYL BROMIDE

<u>Cp. Cal/mole/°A.</u>	<u>Temperature. °A</u>	<u>Ref.</u>
1.54	15	6
2.56	20	6
3.60	25	6
4.54	30	6
6.37	40	6
7.93	50	6
9.16	60	6
10.02	70	6
10.79	80	6
11.42	90	6
11.92	100	6
12.34	110	6
12.67	120	6
12.96	130	6
13.21	140	6
13.44	150	6
13.88	160	74
10.18	298.1	74
11.07	350	74
11.96	400	74
13.60	500	74
15.05	600	74
16.27	700	74
17.30	800	74
18.24	900	74
19.06	1000	74
19.78	1100	74
20.41	1200	74

Table 144

HEAT CAPACITIES FOR DICHLORODIFLUOROMETHANE

C_v Cal/mole	C_p cal/mole	Temperature, °C.	μ
10.32	12.31	173.1	36
11.27	13.25	198.1	36
12.16	14.15	223.1	36
13.01	15.00	248.1	36
13.82	15.80	273.1	36
14.57	16.56	298.1	36
15.25	17.24	323.1	36
15.92	17.90	348.1	36
16.51	18.50	373.1	36
17.06	19.04	398.1	36
17.55	19.54	423.1	36
18.01	20.00	448.1	36
18.43	20.41	473.1	36
14.82		273.1	20
16.87		323.1	20
17.37		373.1	20
18.32		423.1	20
19.10		473.1	20
19.74		523.1	20
20.34		573.1	20

Table 145

HEAT CAPACITIES OF TRIFLUOROMETHANE (28)

(Cal./moles at °A)

<u>Cp</u>	<u>Temperature, °A</u>	<u>Cp</u>	<u>Temperature, °A</u>
11.37	250	16.24	450
12.01	273.1	16.68	473.1
12.68	298.1	17.15	500
12.73	300	17.95	550
14.02	350	18.65	600
14.58	373	19.27	650
15.19	400		

Table 146

HEAT CAPACITIES FOR CARBON TETRAFLUORIDE (20)

(Cal./mole at °A)

<u>Cv</u>	<u>Temperature, °A</u>
11.23	273.1
12.74	323.1
14.09	373.1
15.27	423.1
16.30	473.1
17.18	523.1
17.94	573.1

Table 147

THE RATIO C_p/C_v FOR SOME INERT GASES

Material	C_p/C_v	Temperature, °C.	Ref.
Nitrogen	1.41	-	23
	1.47	-181	42
	1.404	15	42
Helium	1.652	-	33
	1.660	-180	42
Argon	1.76	-180	42,79
	1.668	15	42
	1.65	15	79
Krypton	1.68	19	42
Neon	1.64	19	42
Dichlorodi- fluoromethane	1.138	-	42
	1.139	25	42
Methyl bromide	1.27	18	42
Carbon dioxide	1.37	-75	42
	1.310	1	42
	1.304	15	42
	1.281	100	42
	1.235	400	42
	1.195	1000	42
	1.171	2000	42
	1.2995	4-11	23
Xenon	1.66	292	63

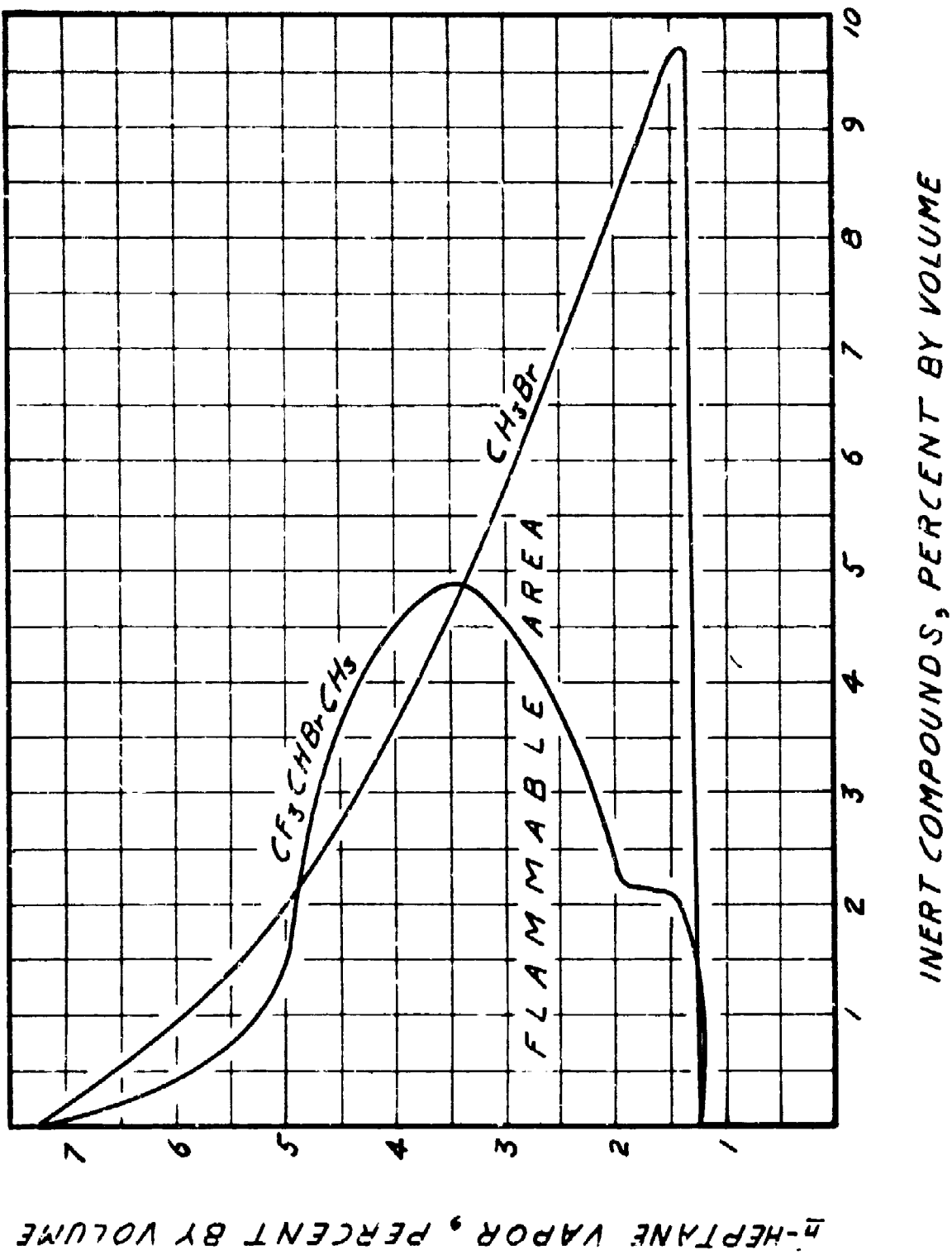
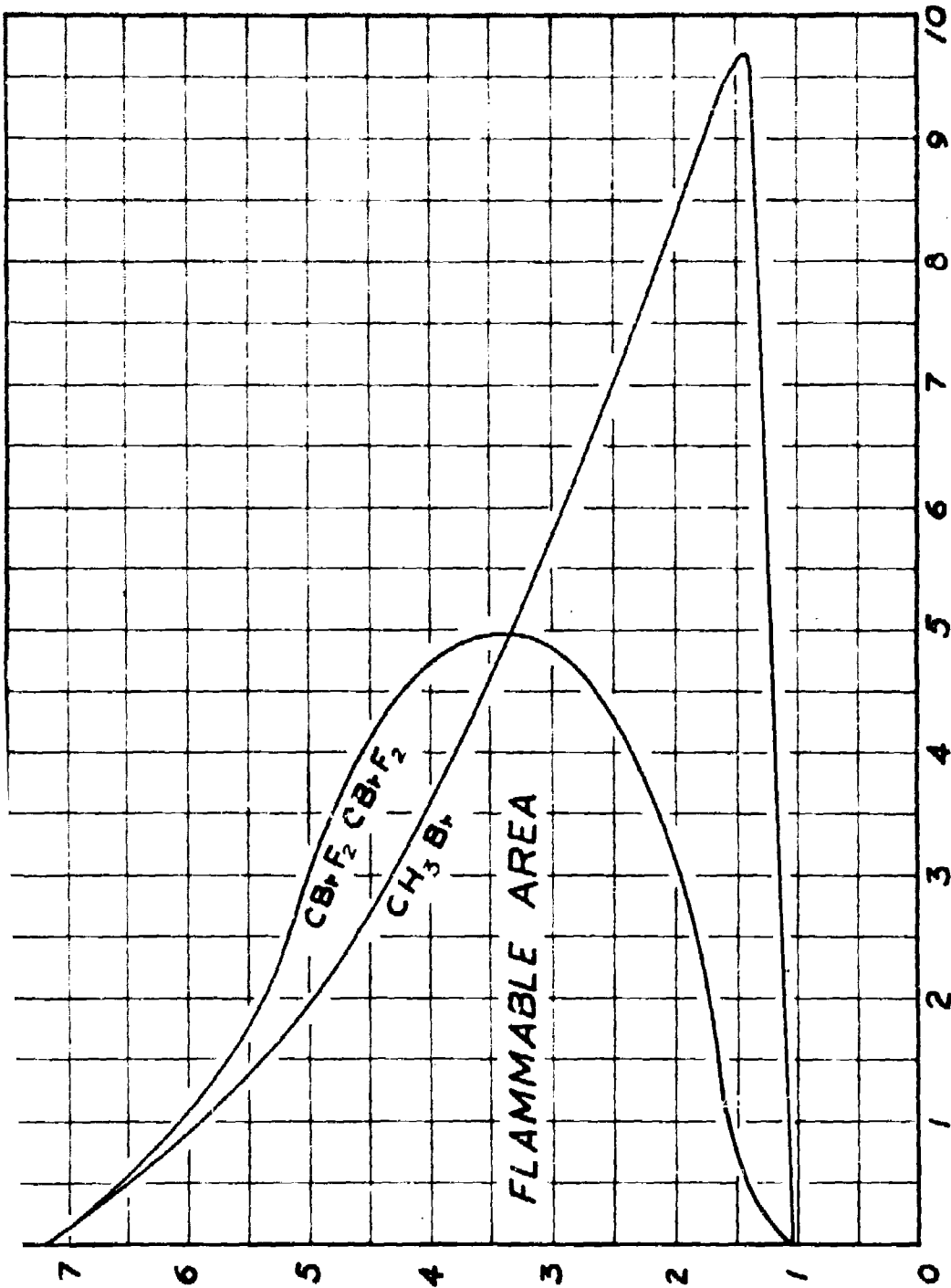


Figure 100 Flammable Area



INERT COMPOUNDS, PERCENT BY VOLUME

n-HEPTANE, PERCENT BY VOLUME

Figure 101 Flammable Area

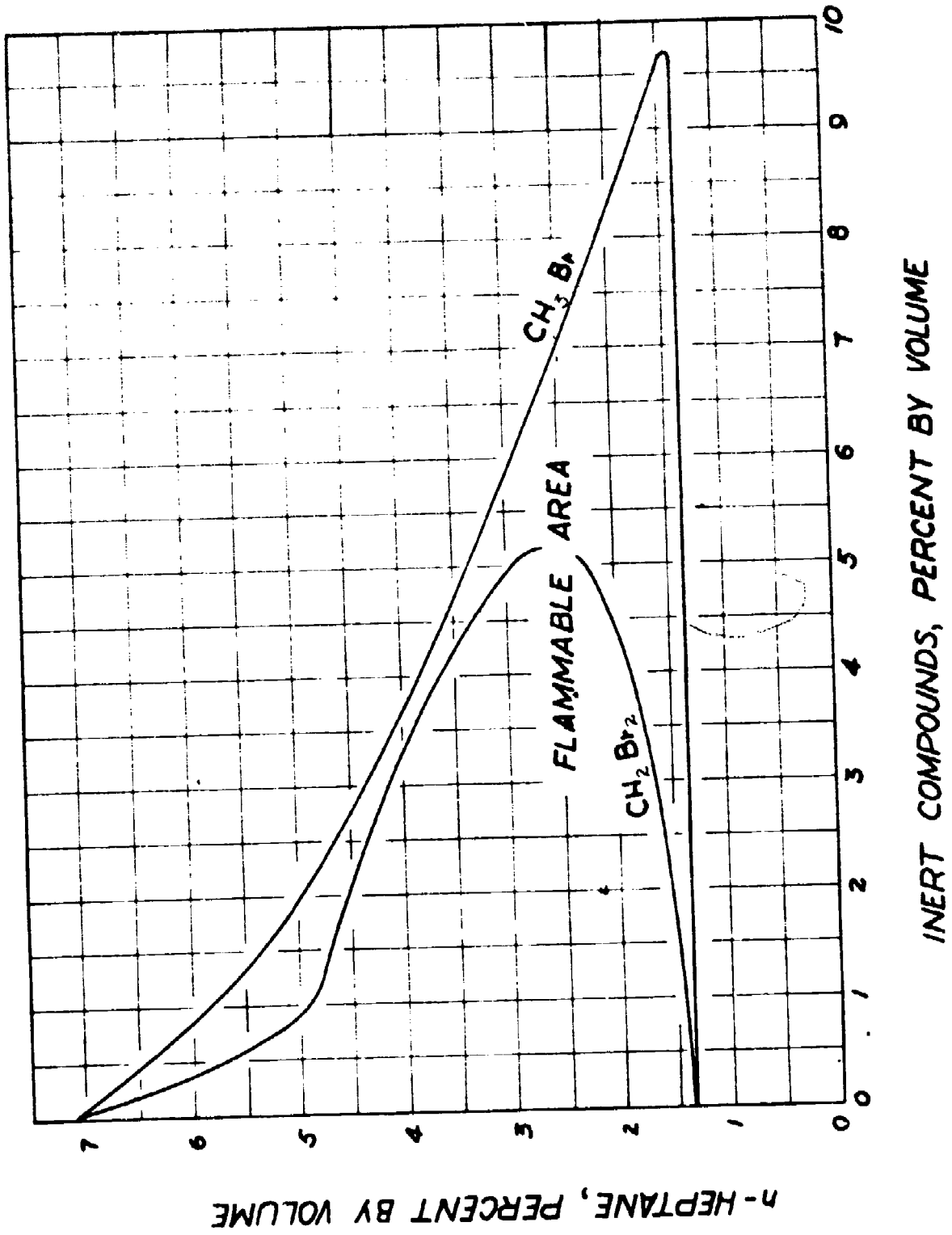


Figure 102 Flammable Area

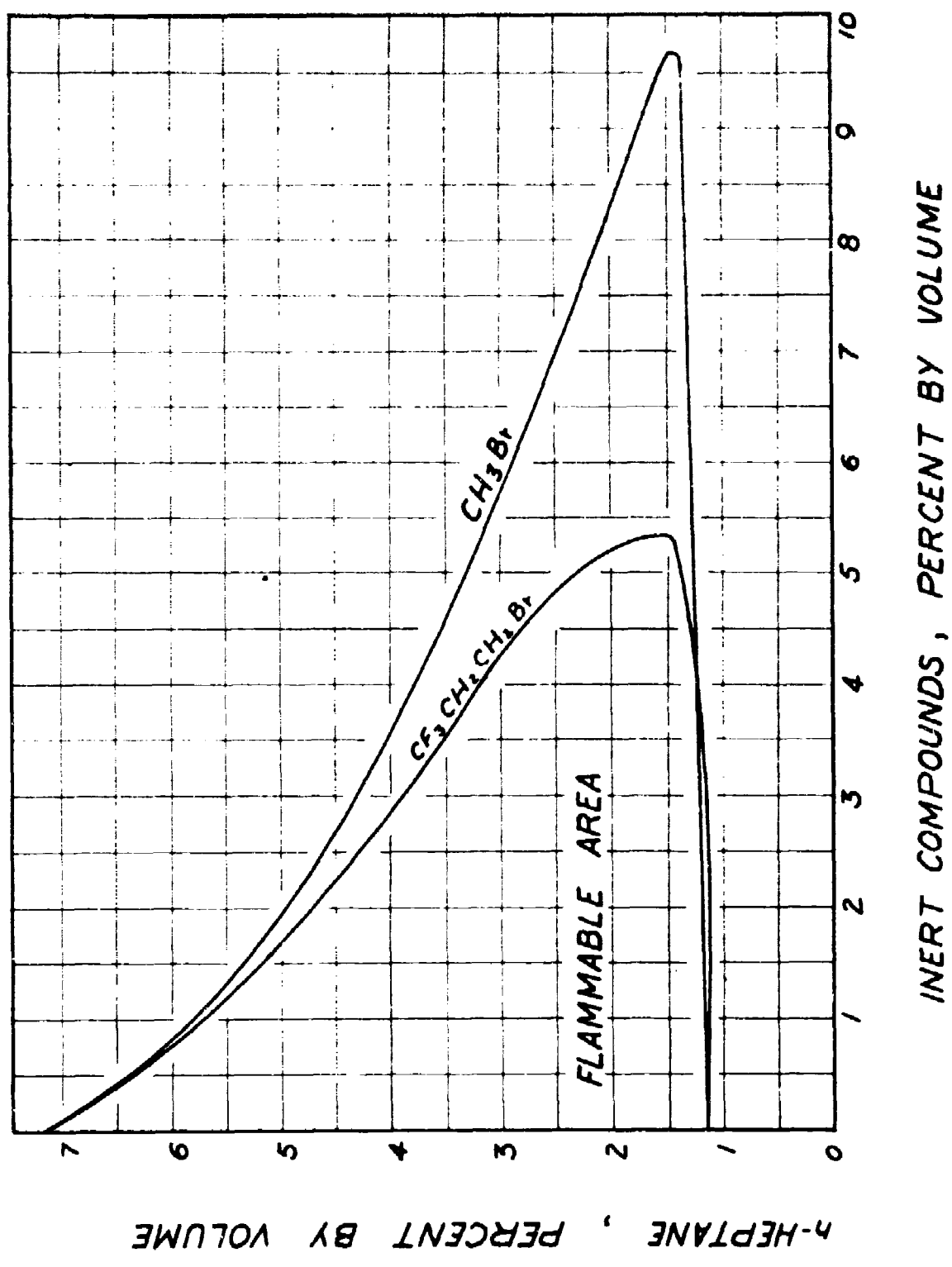
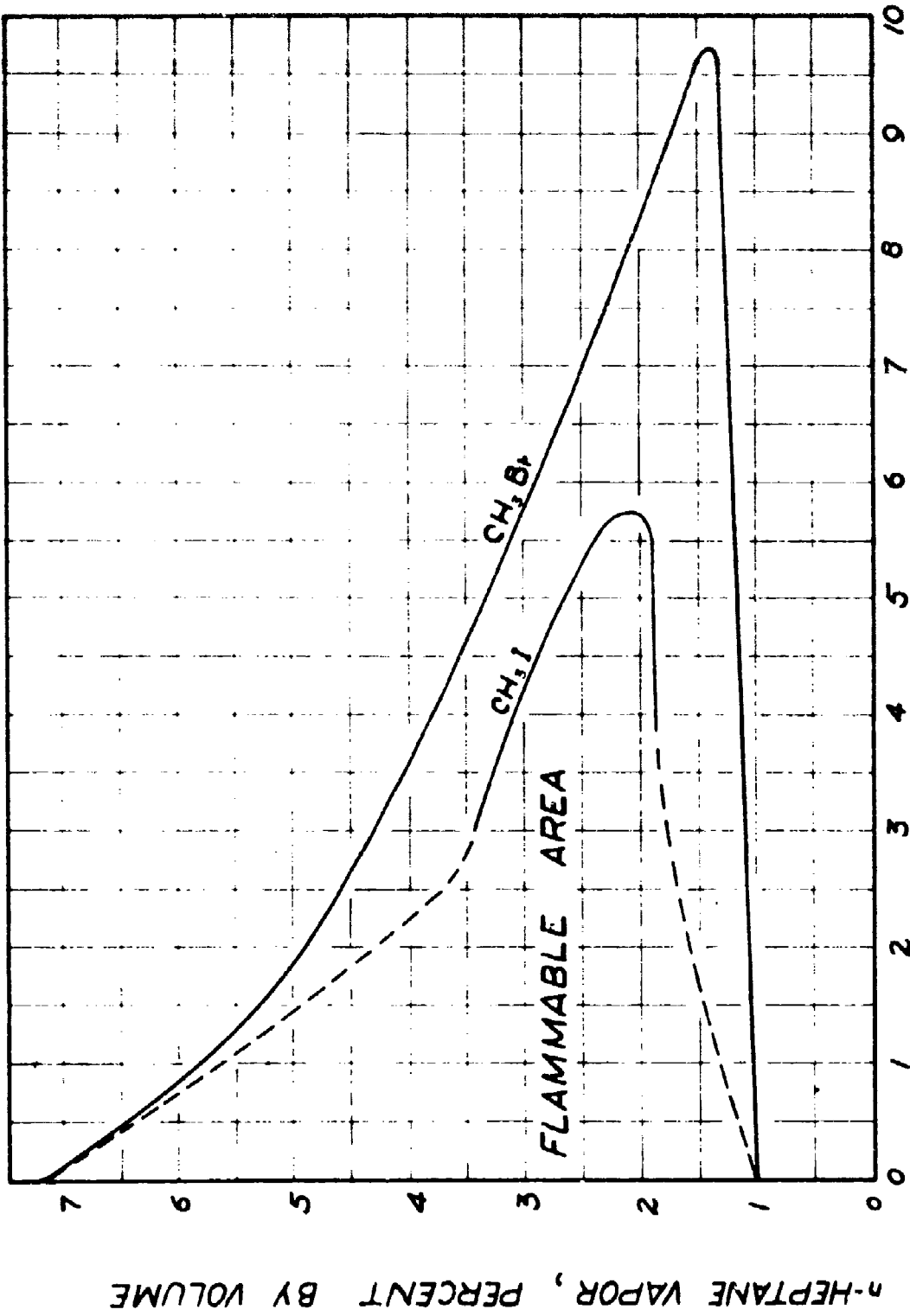


Figure 103 Flammable Area



INERT COMPOUNDS, PERCENT BY VOLUME

Figure 104 Flammable Area

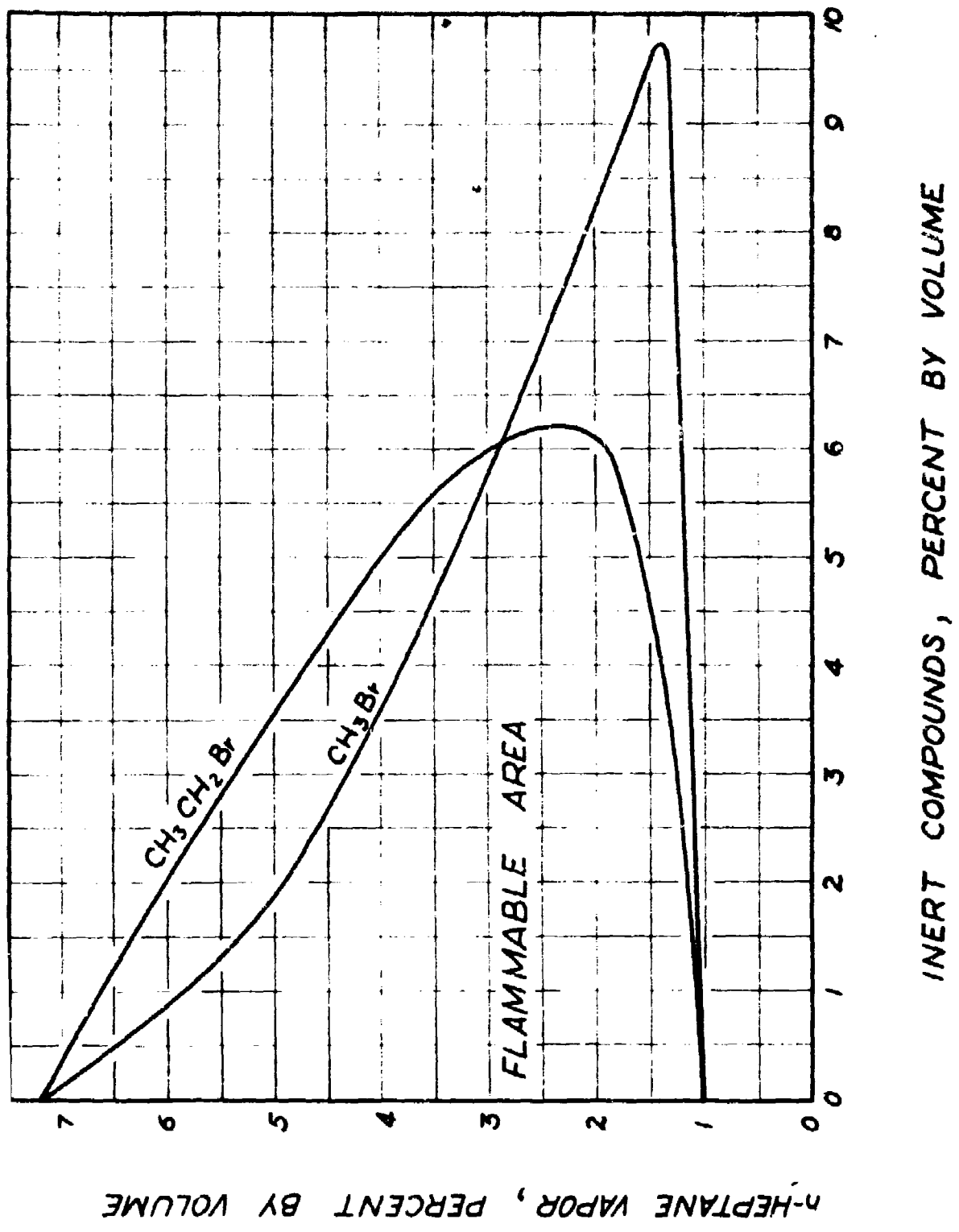
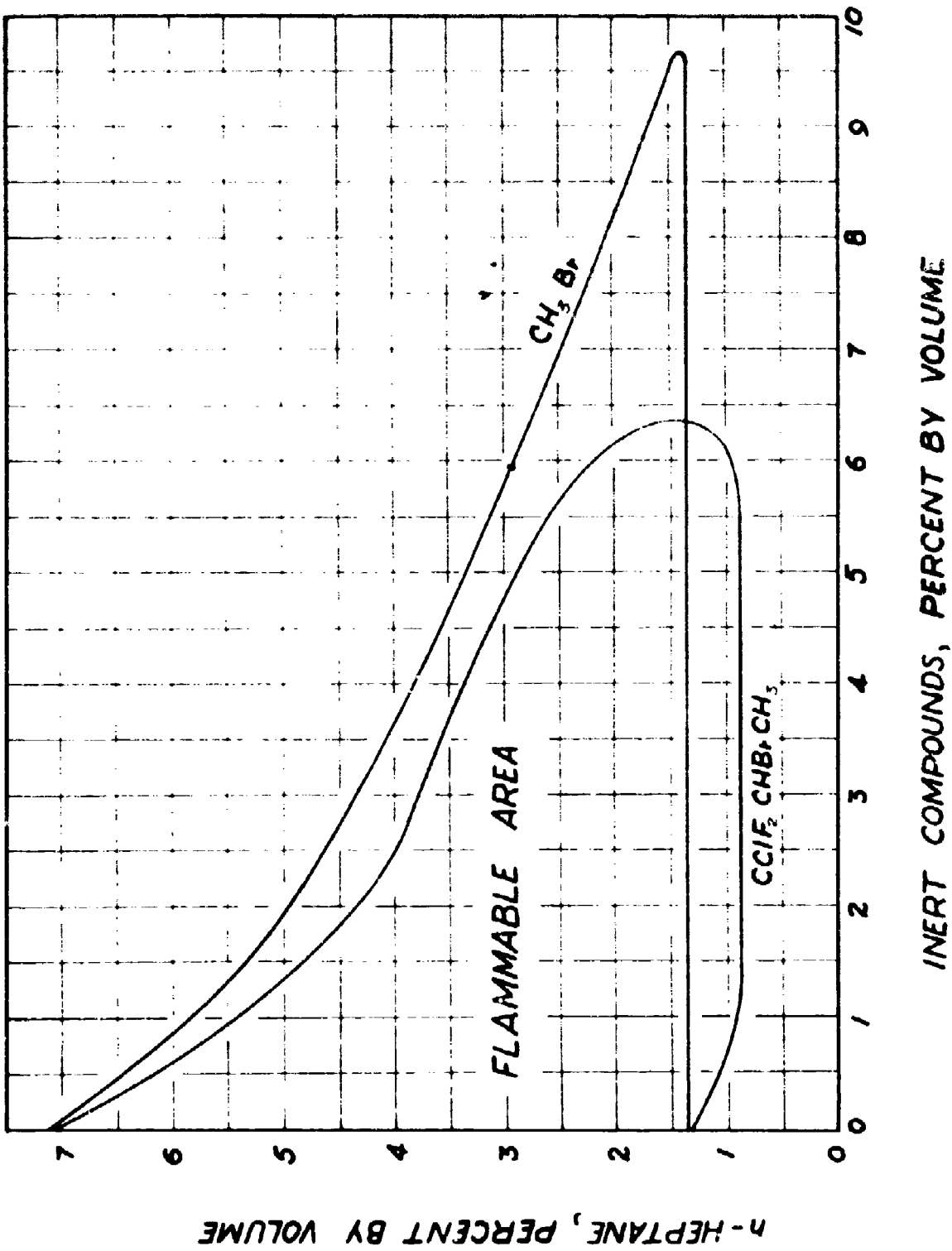


Figure 105 Flammable Area



n-HEPTANE, PERCENT BY VOLUME

Figure 106 Flammable Area

INERT COMPOUNDS, PERCENT BY VOLUME

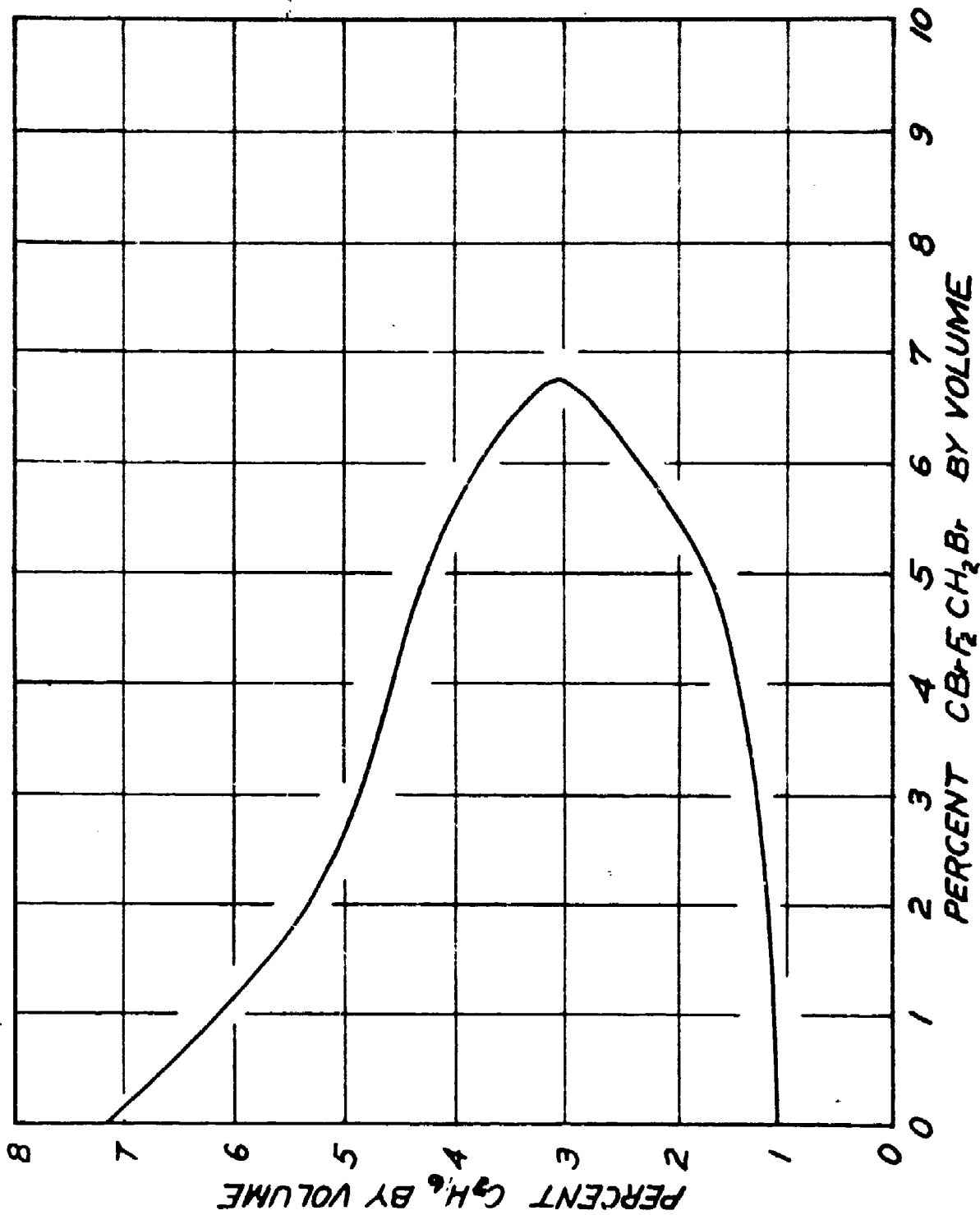
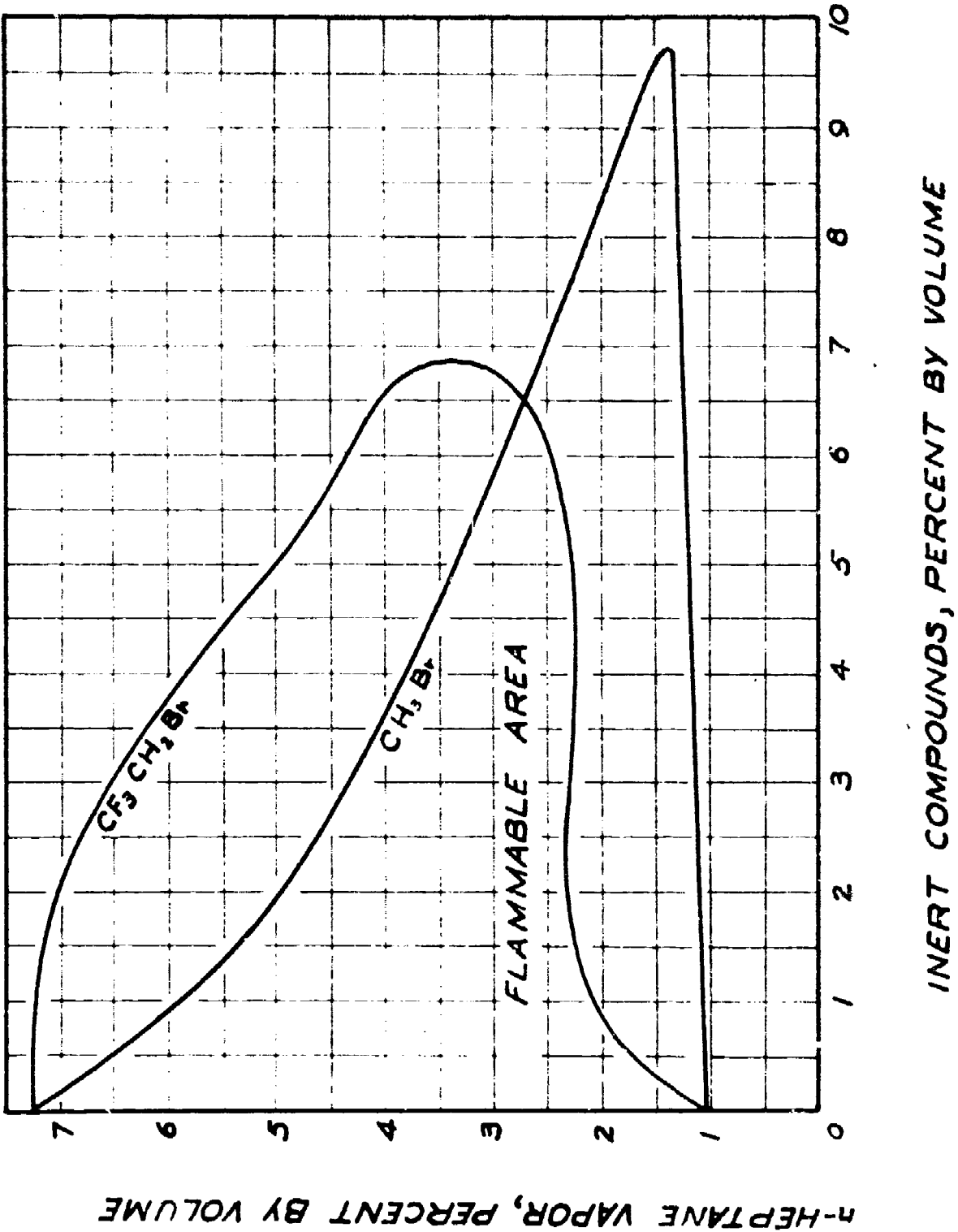


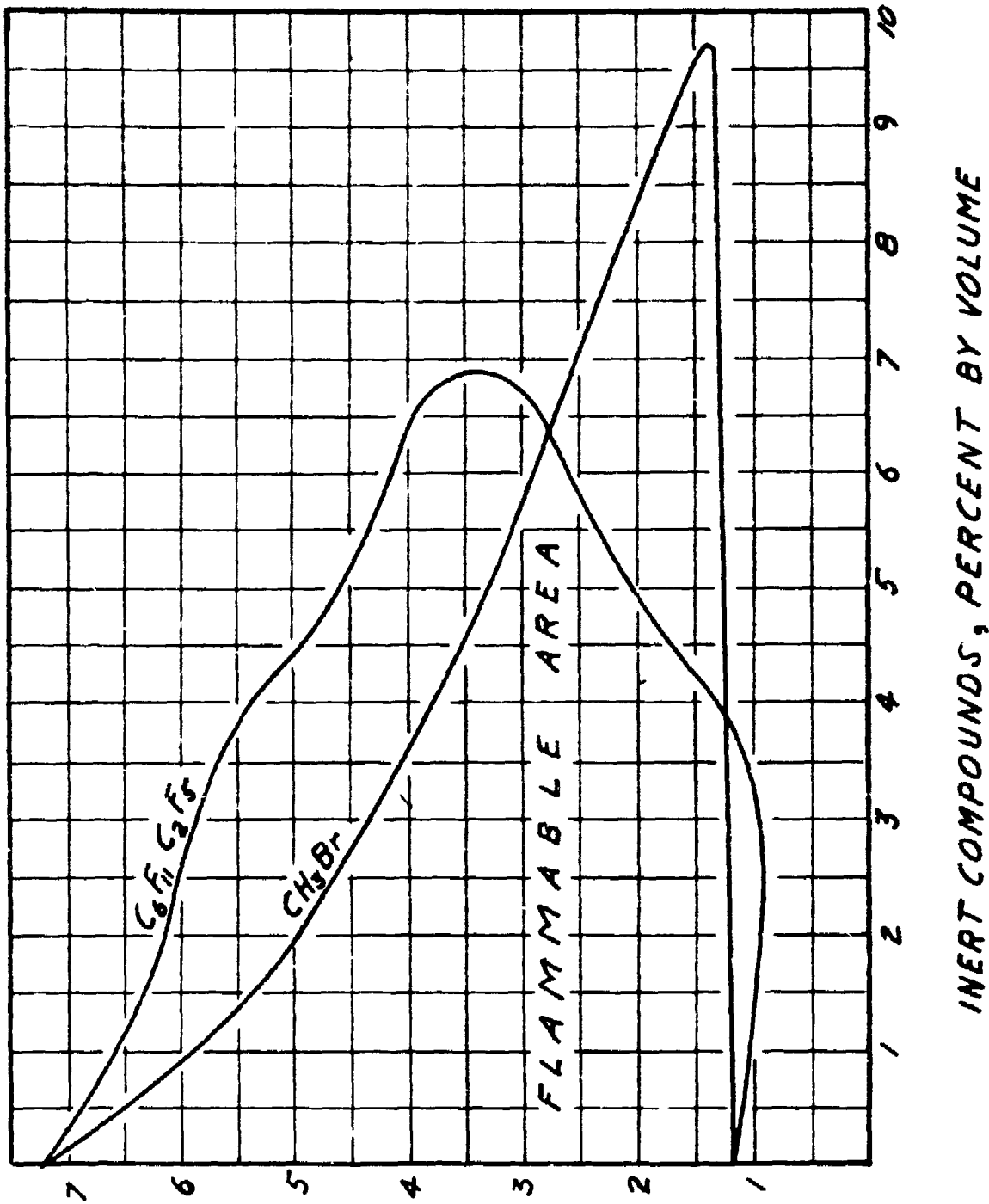
Figure 107 Flammable Area



n-HEPTANE VAPOR, PERCENT BY VOLUME

Figure 108 Flammable Area

INERT COMPOUNDS, PERCENT BY VOLUME



n-HEPTANE VAPOR, PERCENT BY VOLUME

Figure 109 Flammable Area

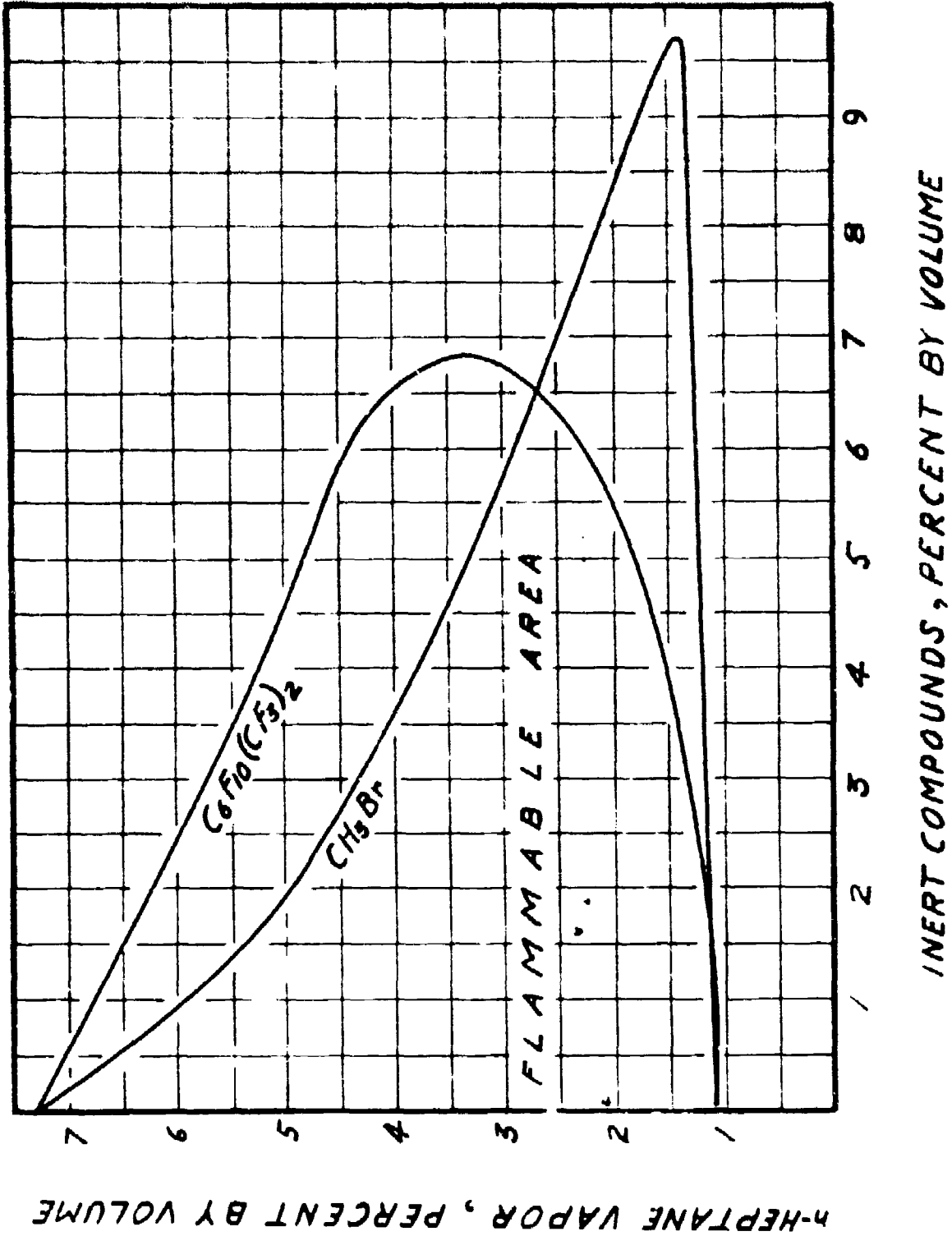


Figure 110 Flammable Area

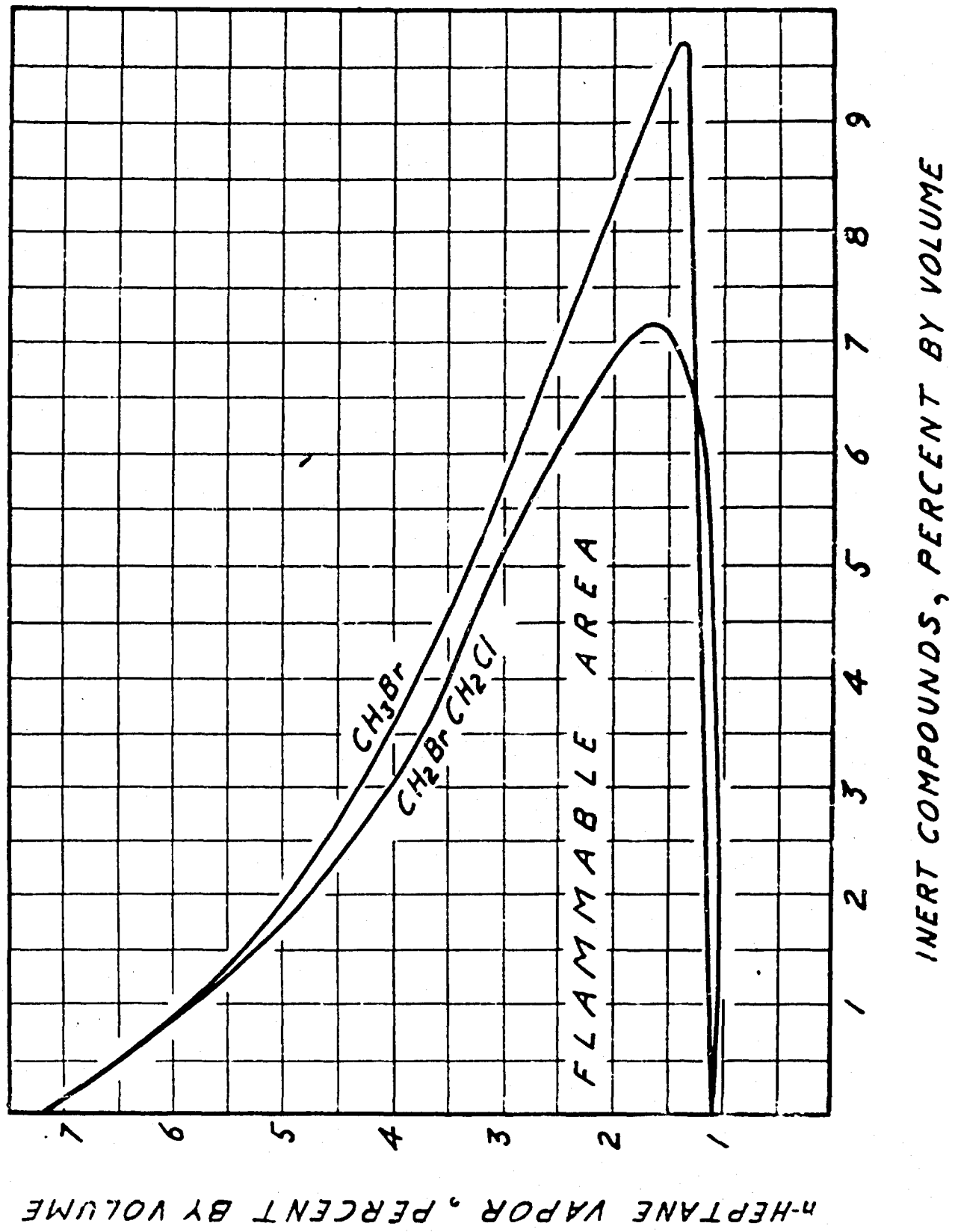


Figure 111 Flammable Area

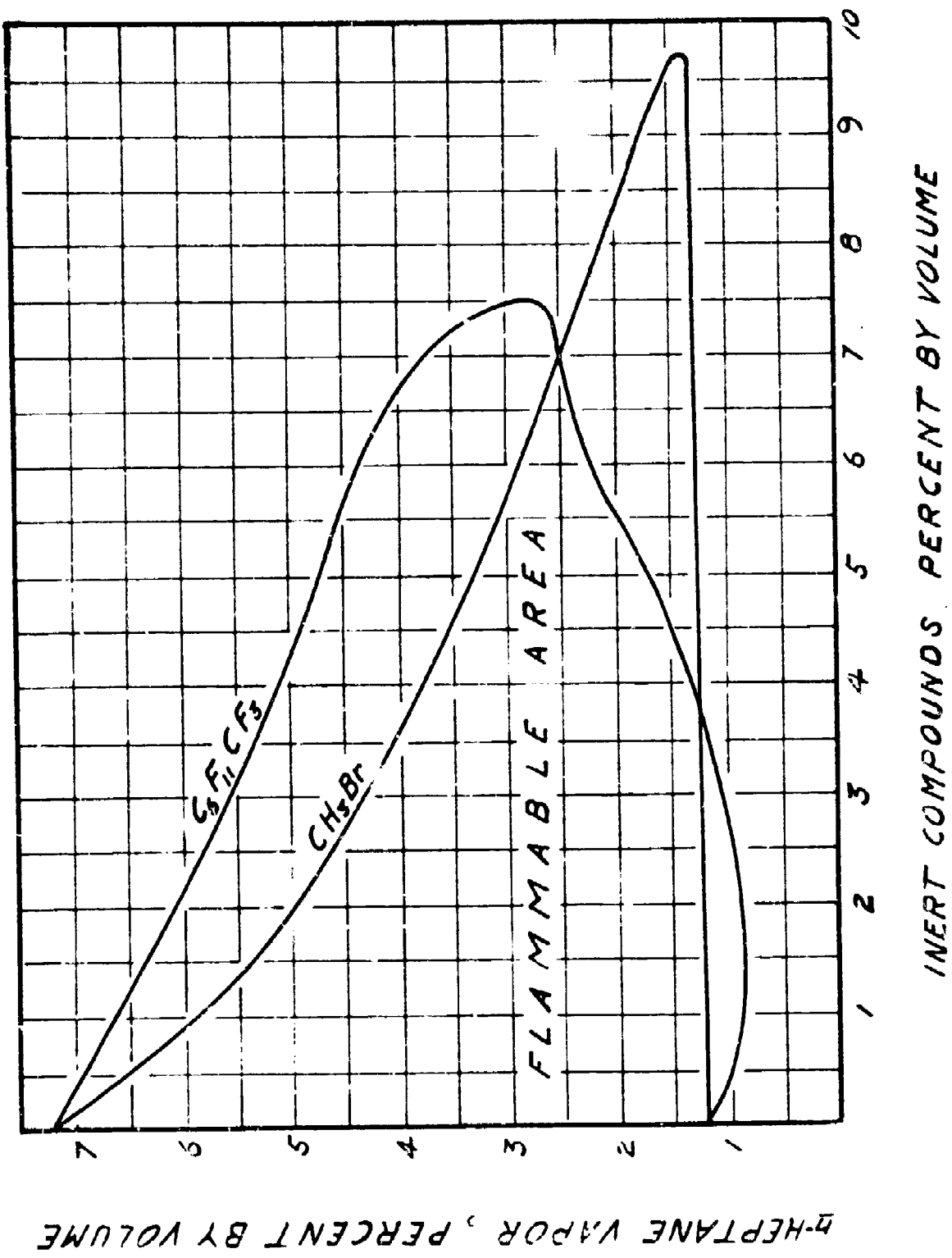
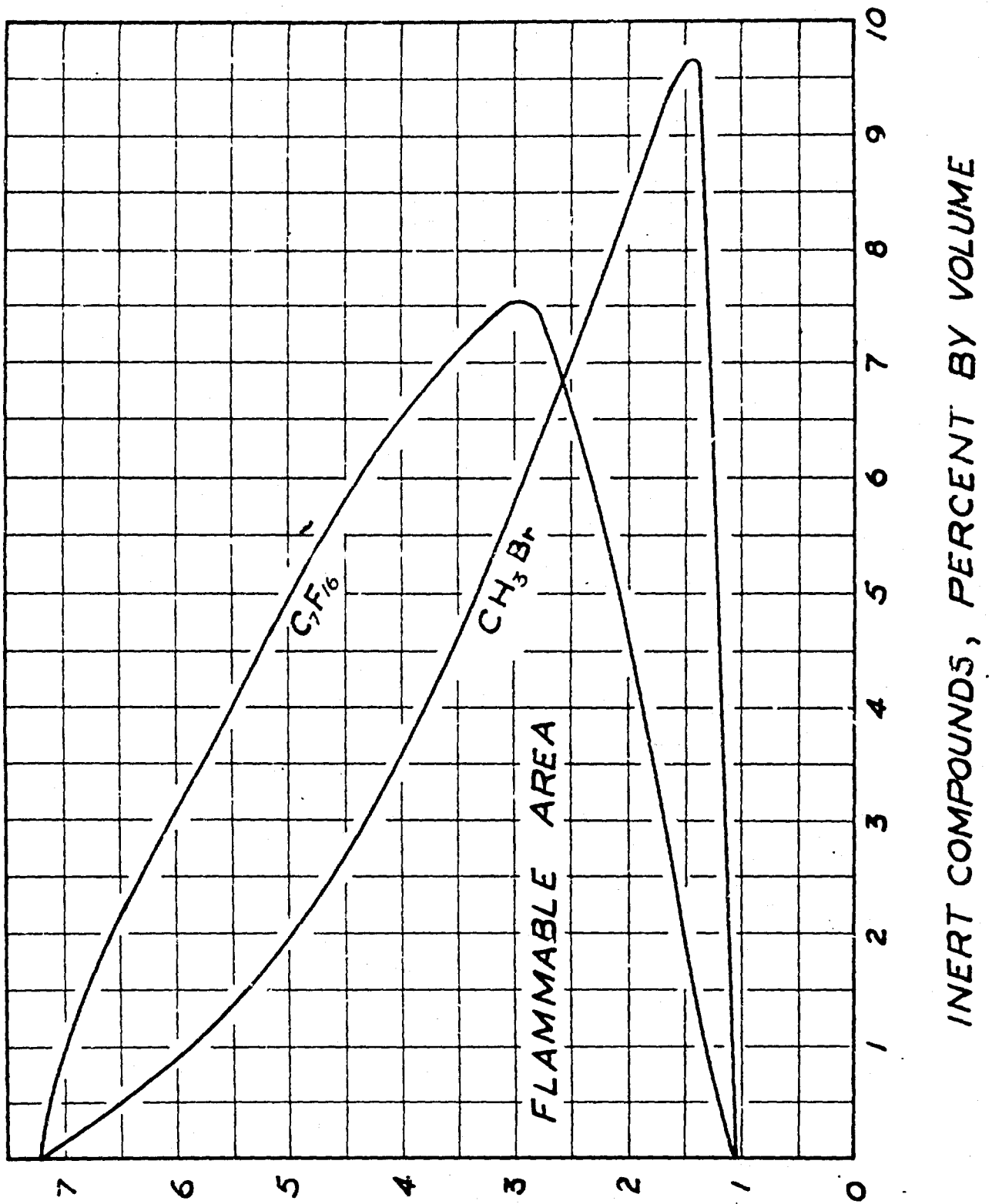


Figure 112 Flammable Area



n-HEPTANE, PERCENT BY VOLUME

Figure 113 Flammable Area

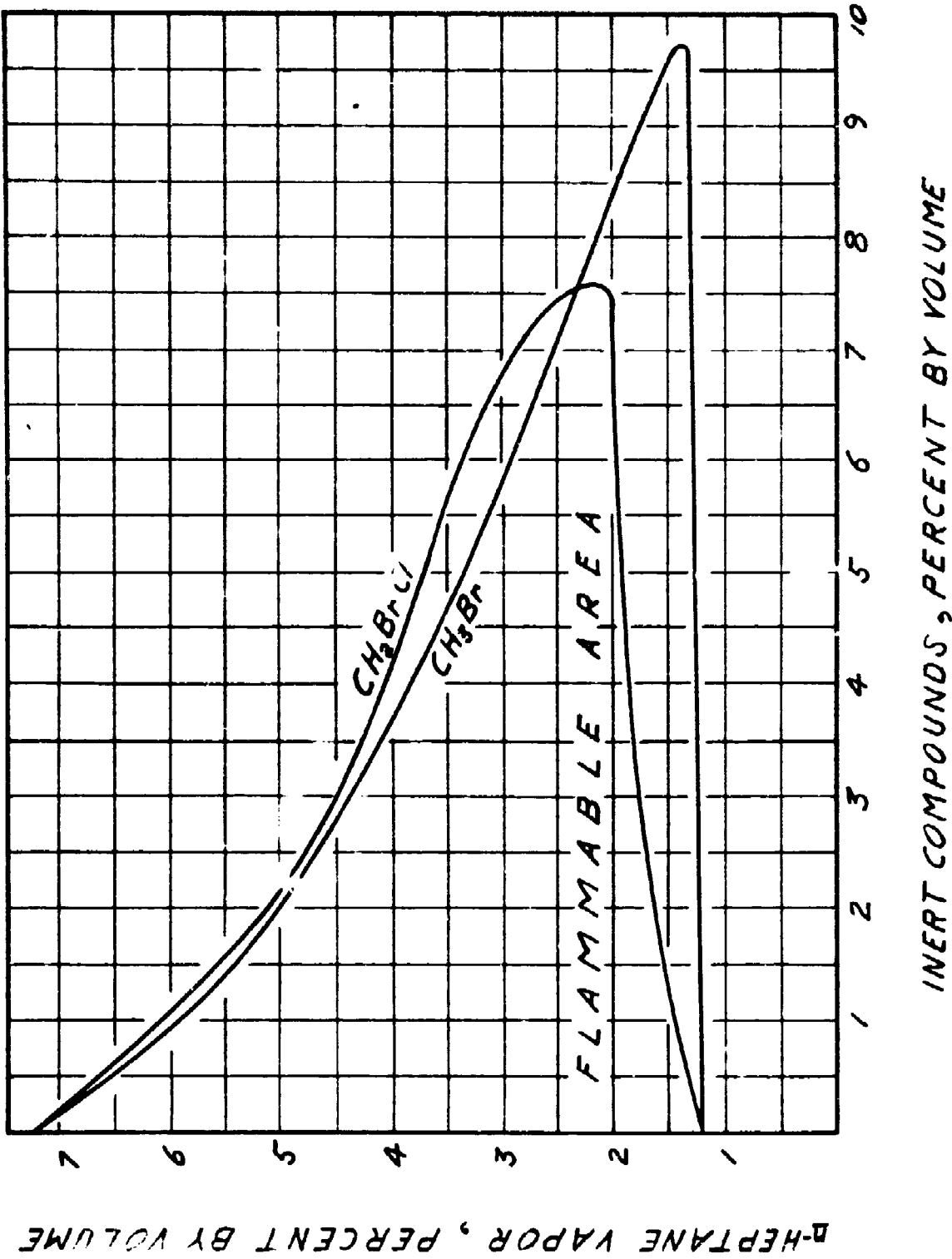


Figure 214 Flammable Area

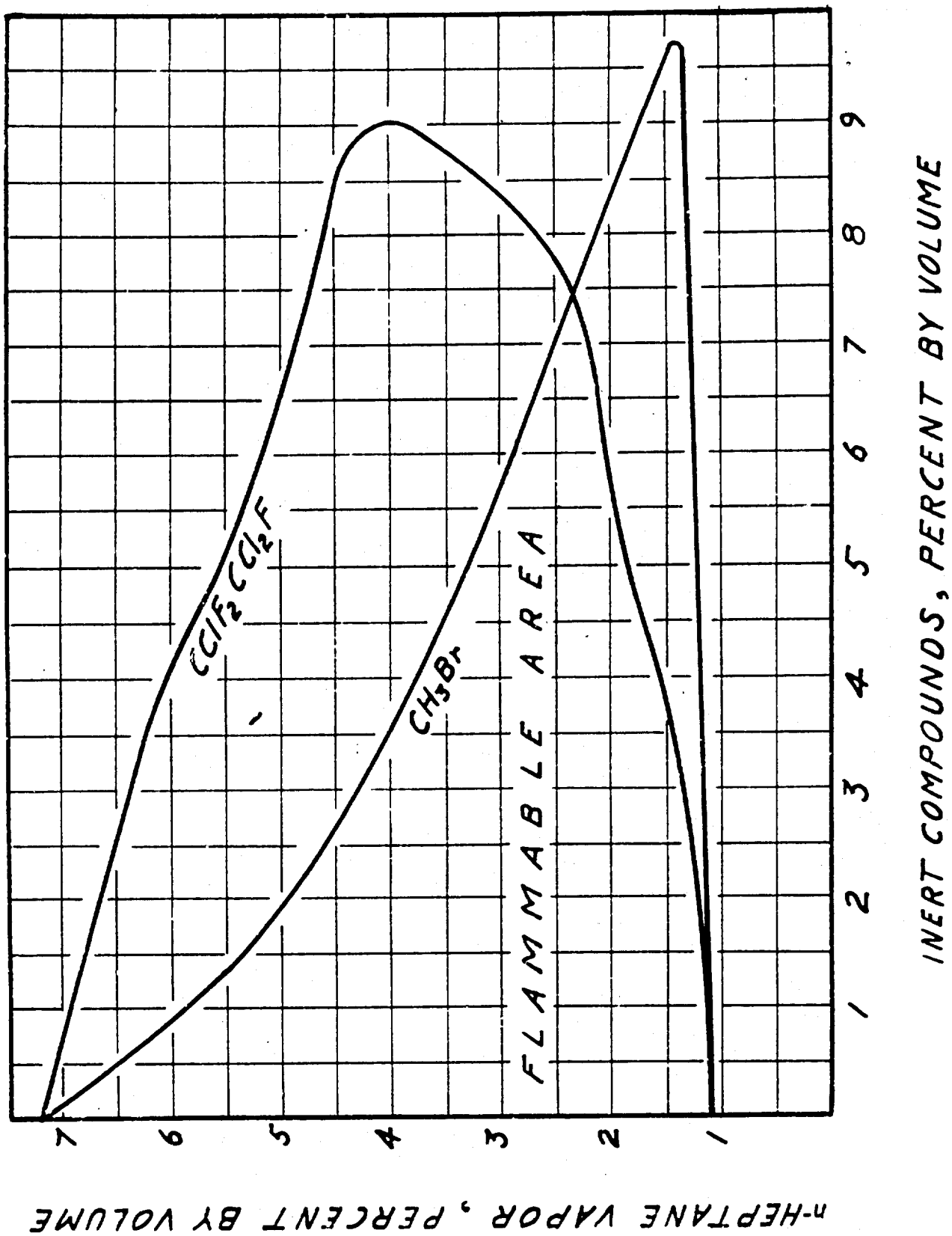
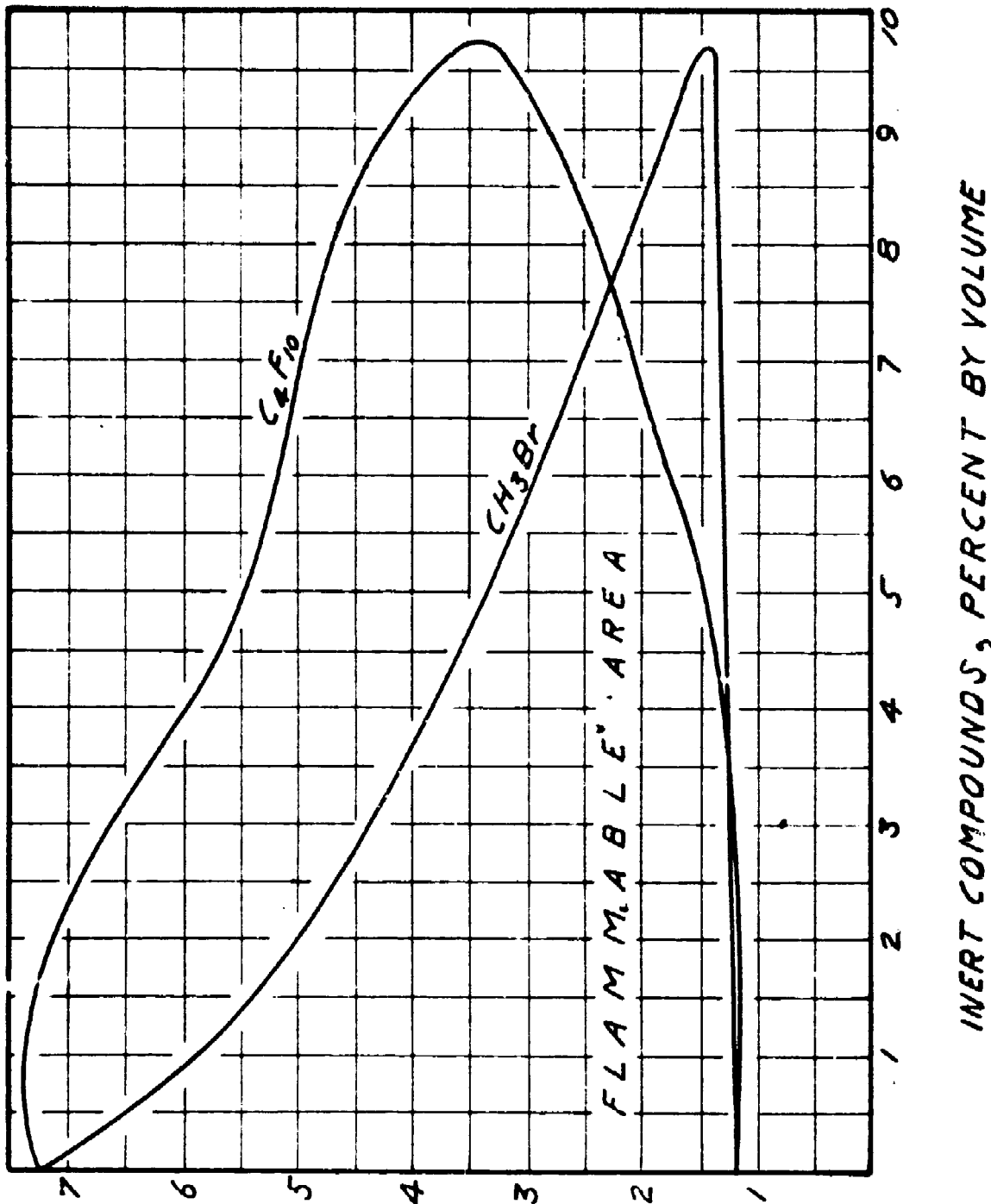


Figure 115 Flammable Area



n-HEPTANE VAPOR, PERCENT BY VOLUME

Figure 116 Flammable Area

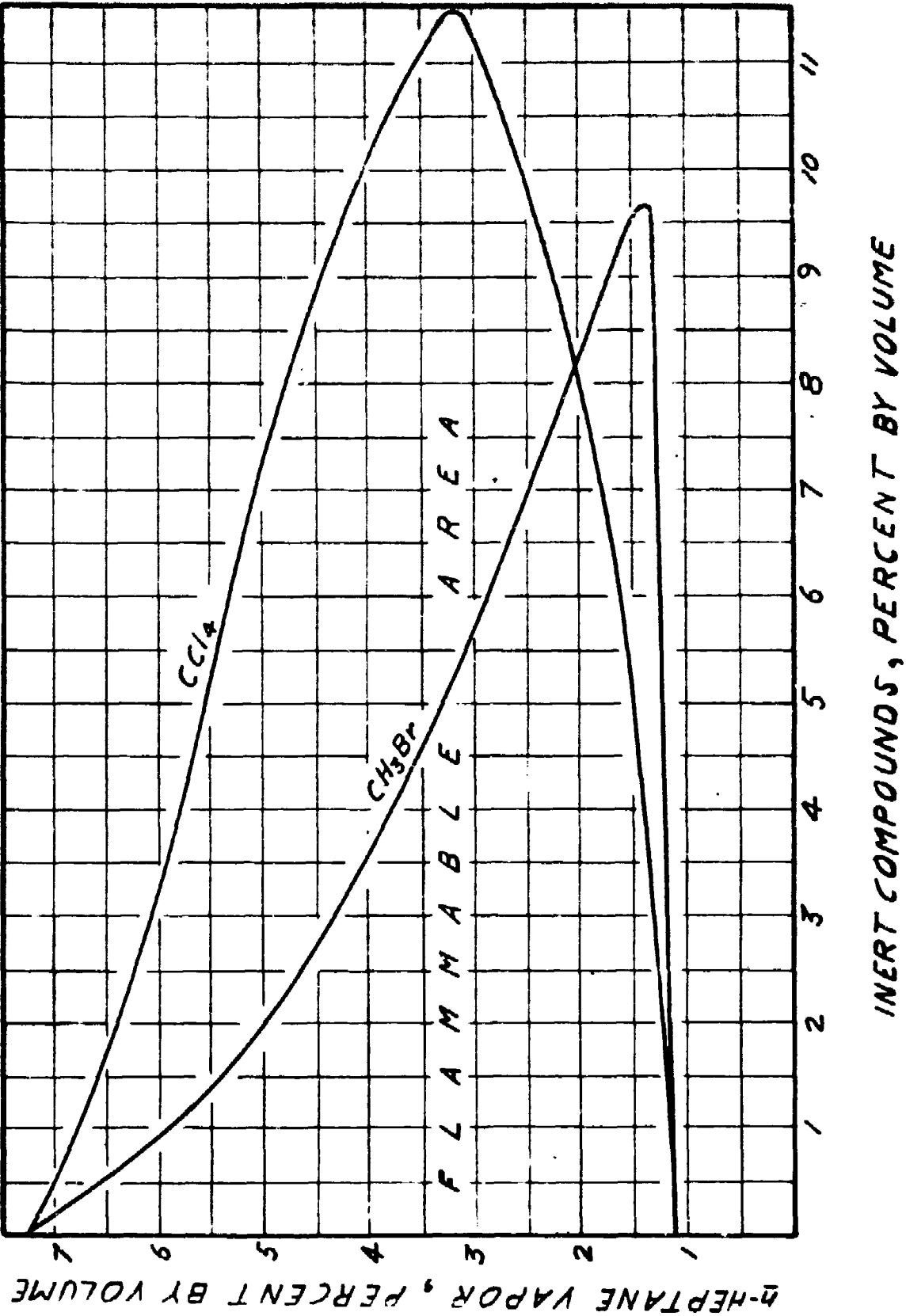


Figure 117 Flammable Area

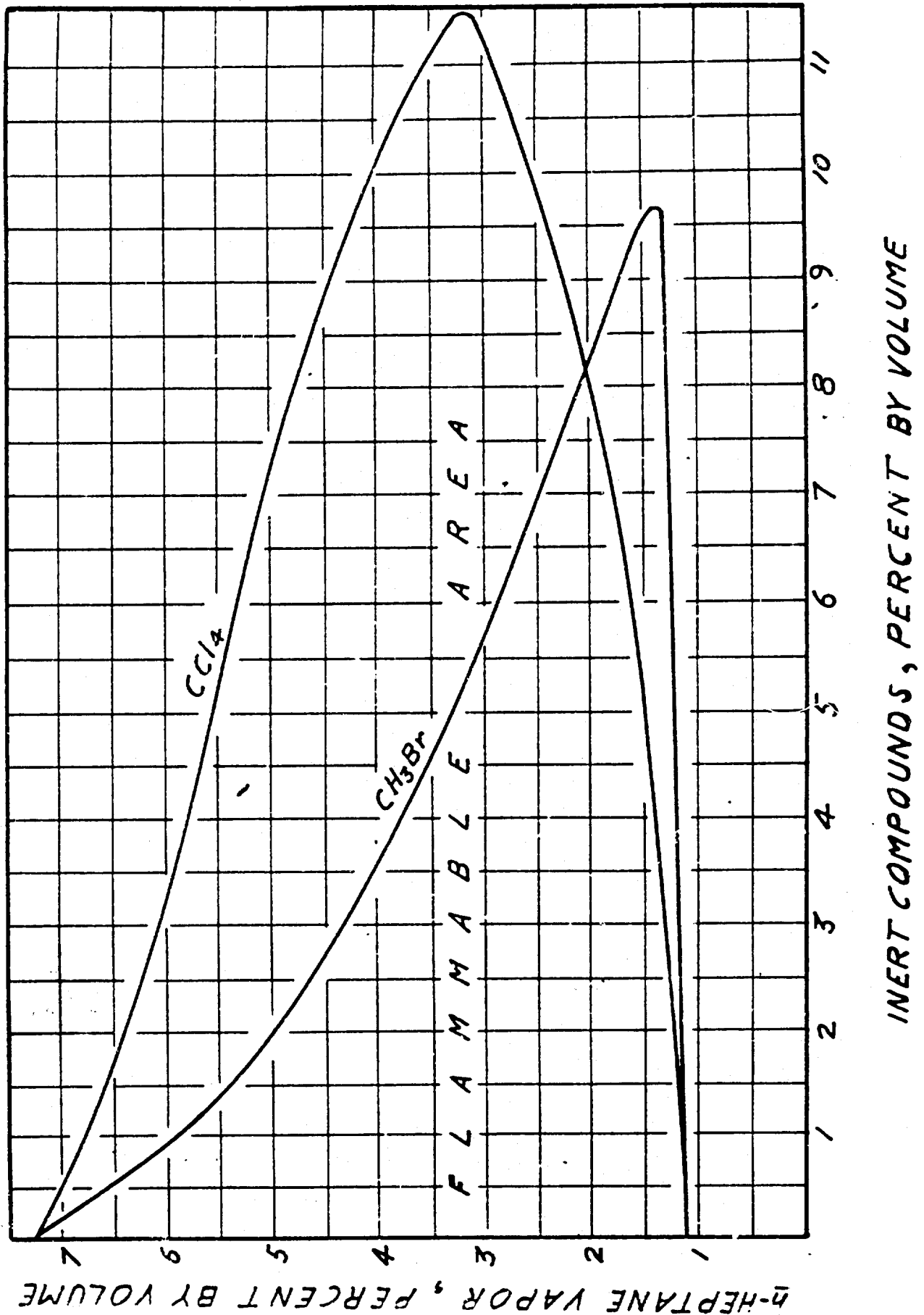
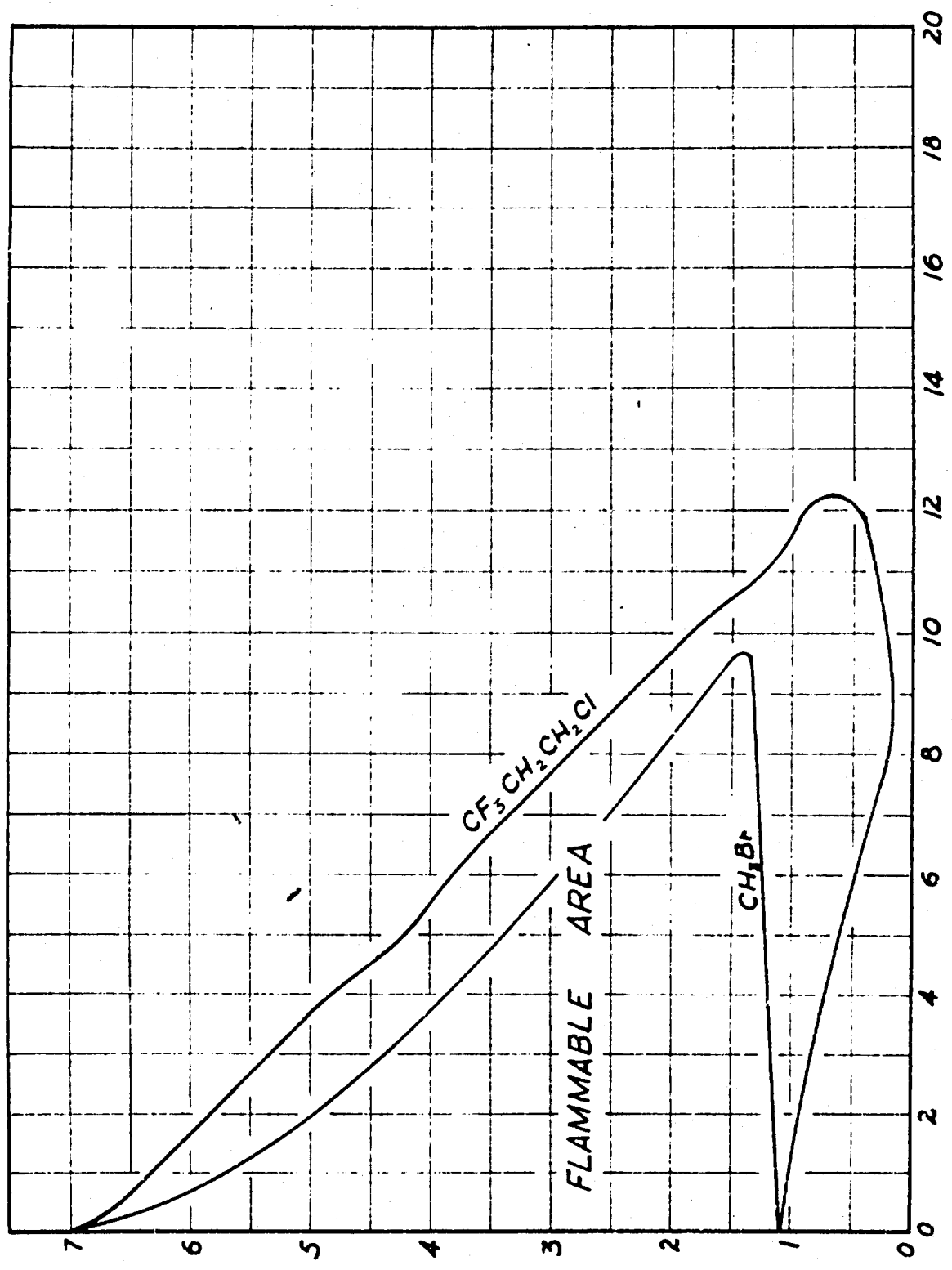


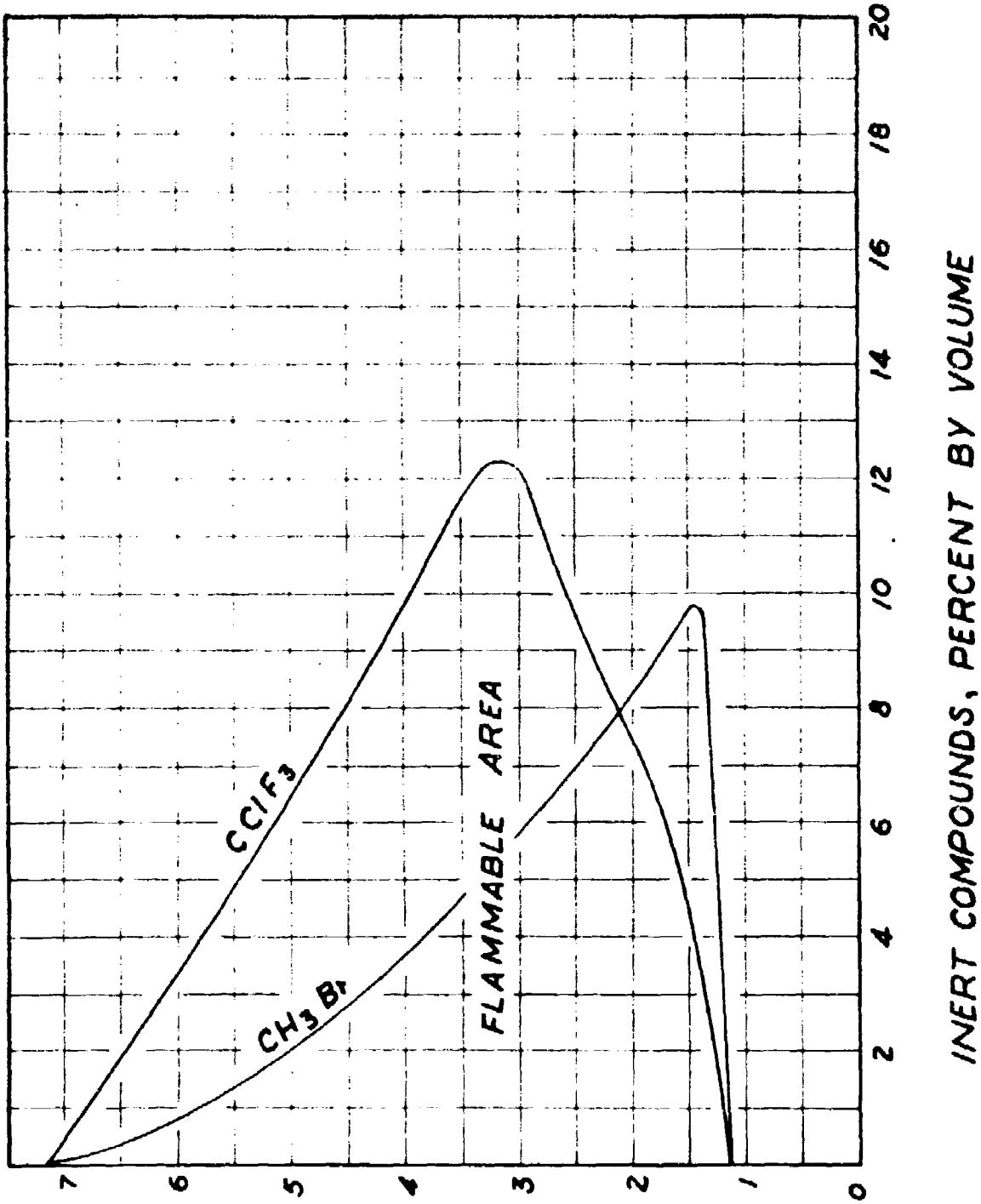
Figure 117 Flammable Area



n-HEPTANE VAPOR, PERCENT BY VOLUME

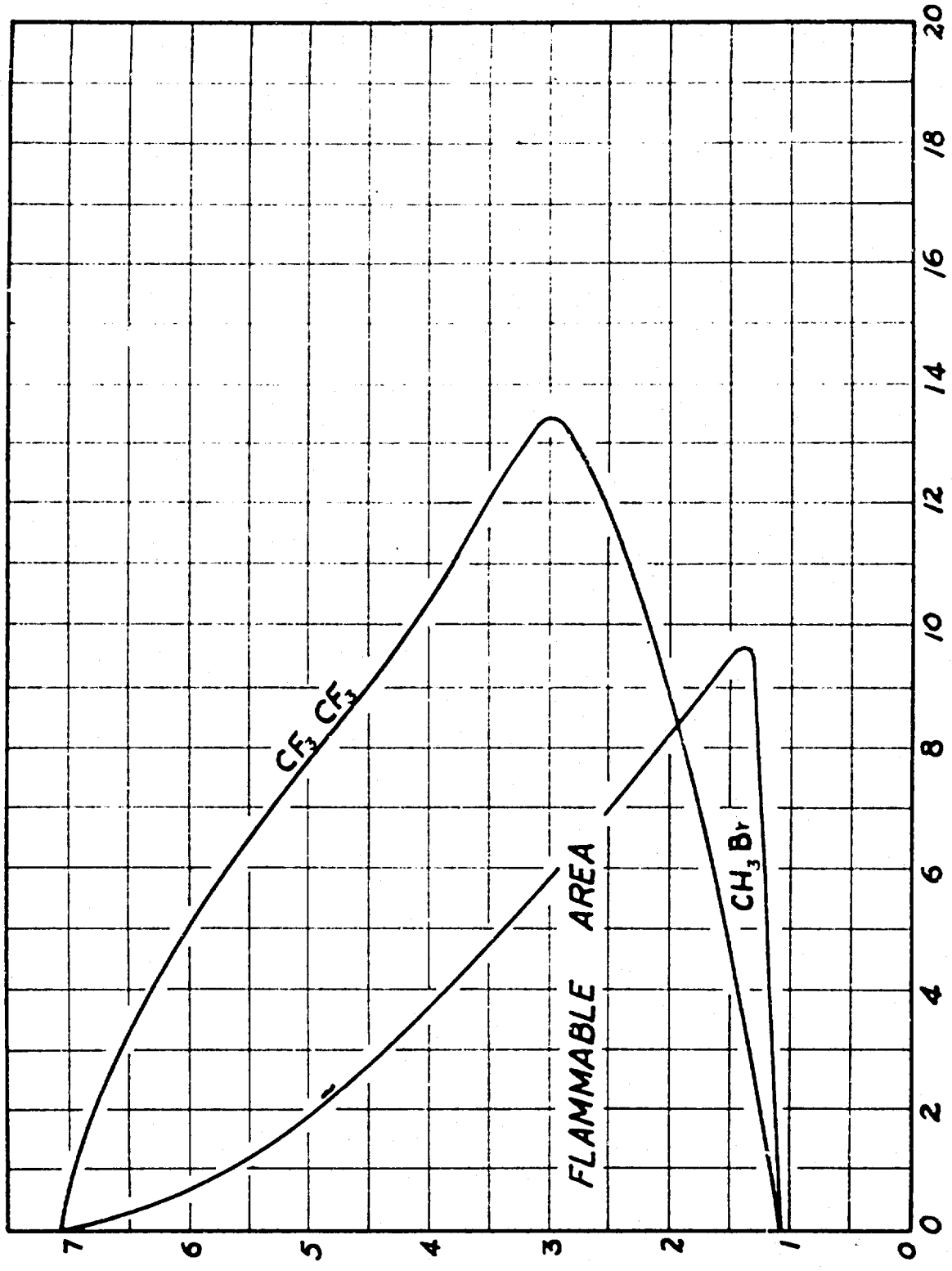
INERT COMPOUNDS, PERCENT BY VOLUME

Figure 119 Flammable Area



n-HEPTANE, PERCENT BY VOLUME

Figure 120 Flammable Area



n-HEPTANE VAPOR, PERCENT BY VOLUME

INERT COMPOUNDS, PERCENT BY VOLUME

Figure 121 Flammable Area

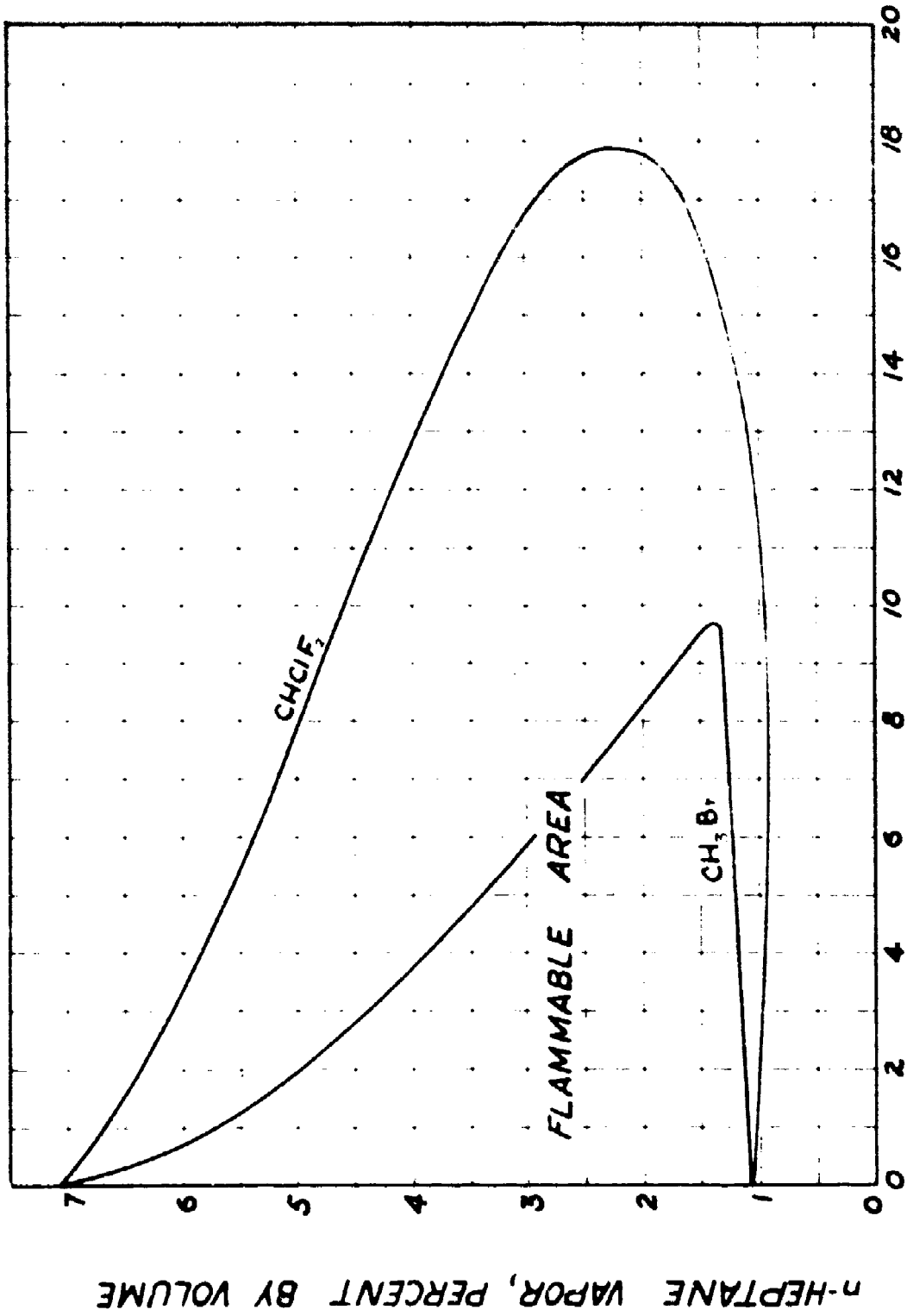
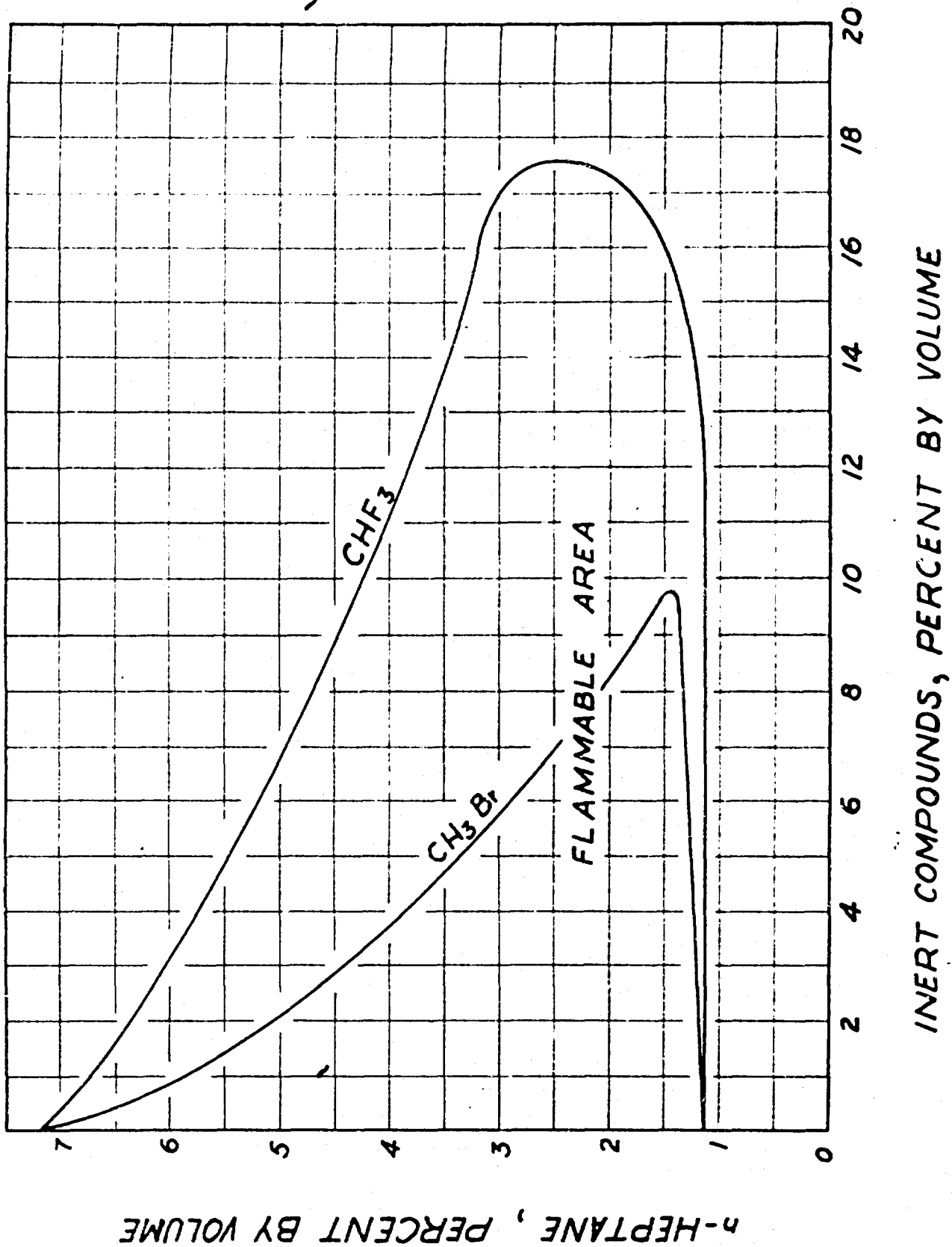


Figure 122 Flammable Area

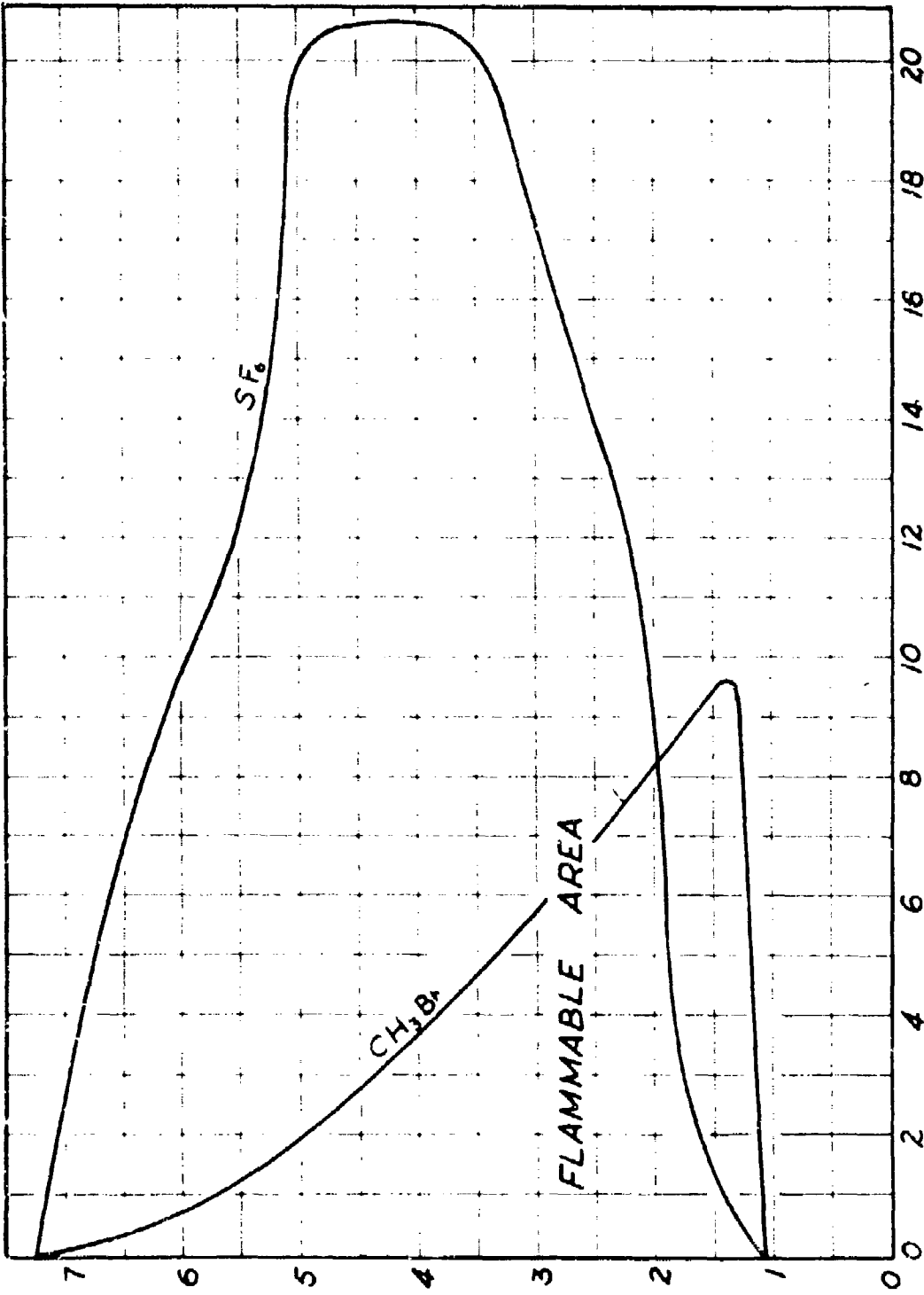
INERT COMPOUNDS, PERCENT BY VOLUME

n-HEPTANE VAPOR, PERCENT BY VOLUME



n-HEPTANE, PERCENT BY VOLUME

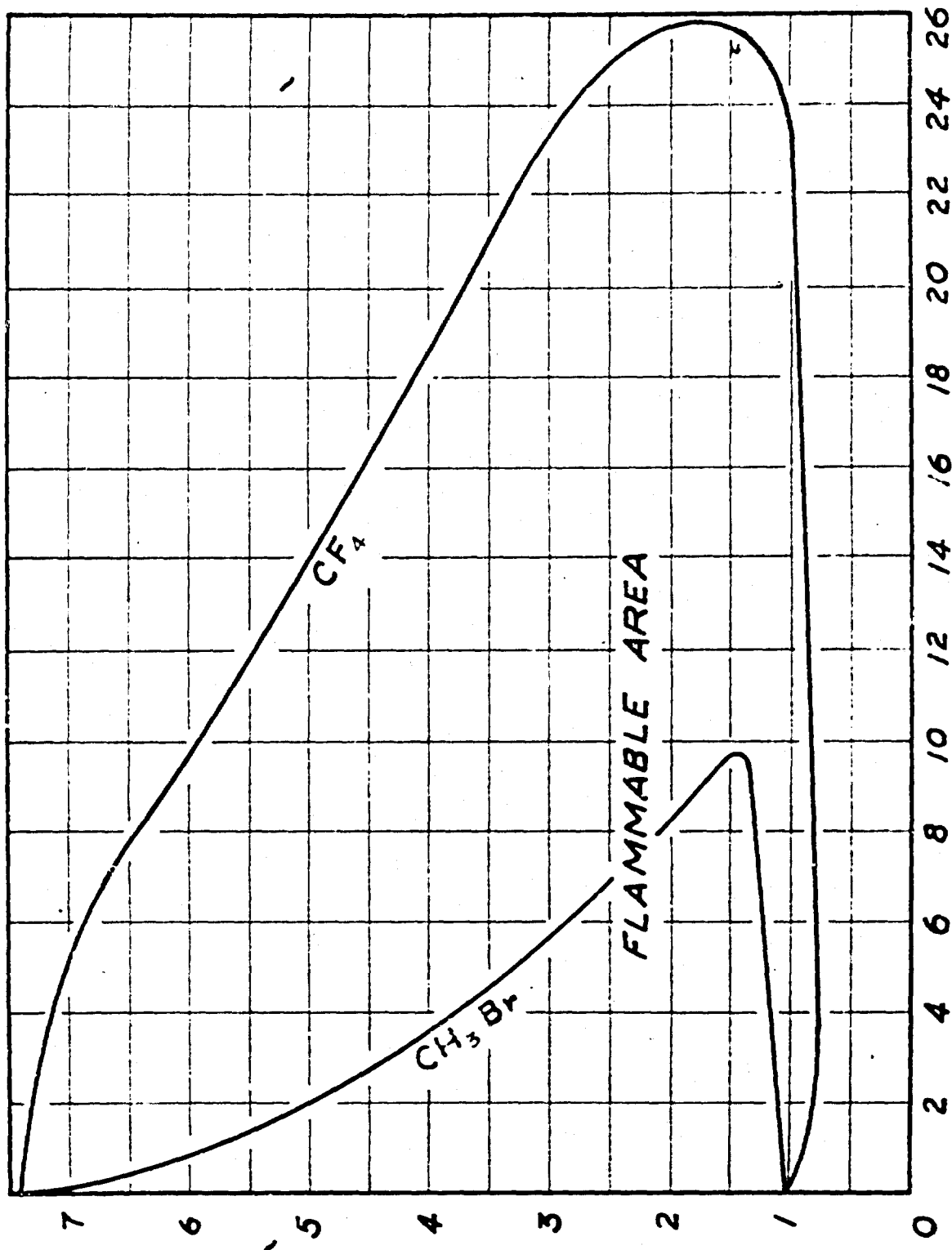
Figure 123 Flammable Area



n-HEPTANE VAPOR, PERCENT BY VOLUME

Figure 124 Flammable Area

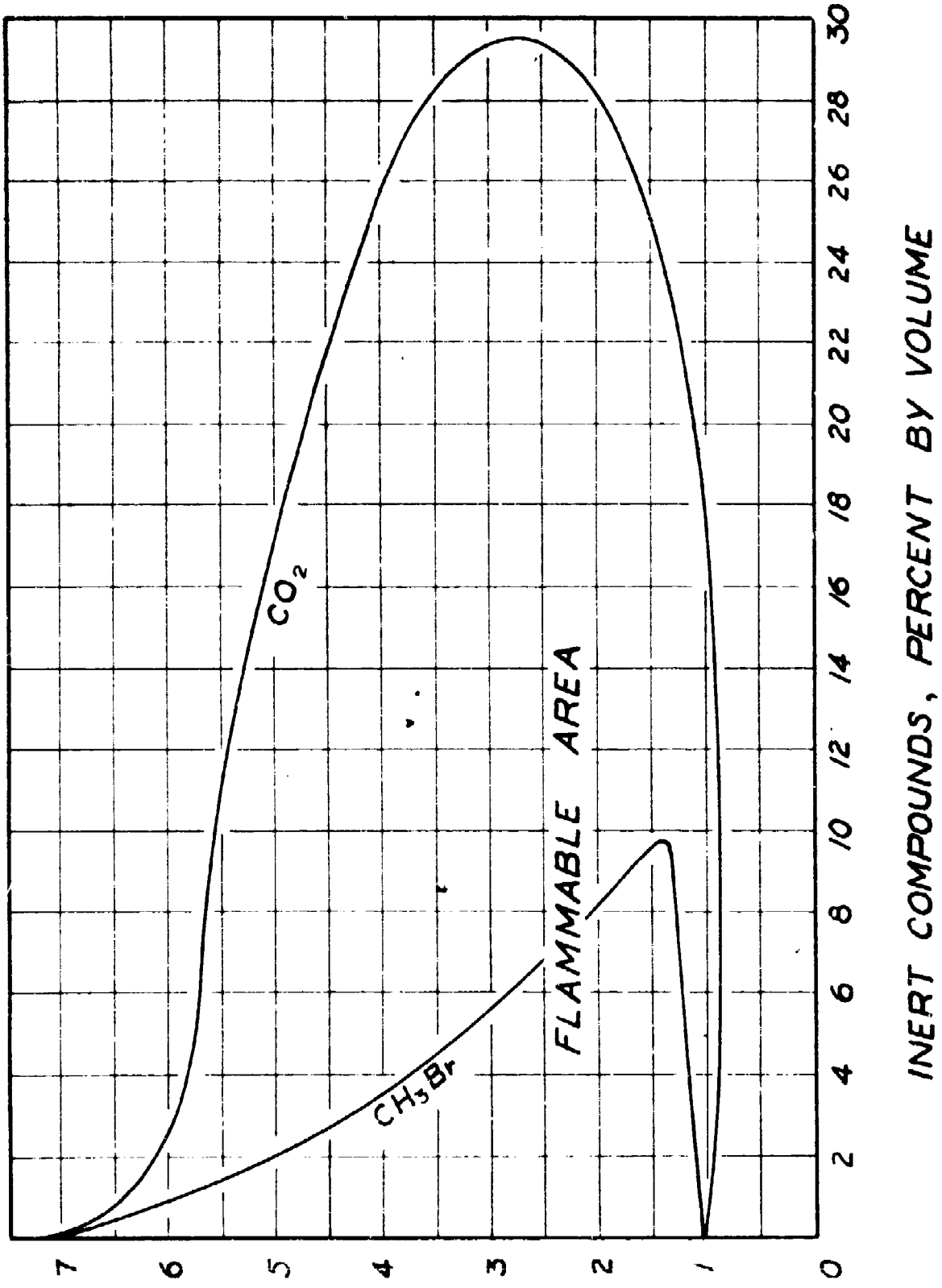
INERT COMPOUNDS, PERCENT BY VOLUME



n-HEPTANE, PERCENT BY VOLUME

INERT COMPOUNDS, PERCENT BY VOLUME

Figure 125 Flammable Area



n-HEPTANE VAPOR, PERCENT BY VOLUME

Figure 126 Flammable Area

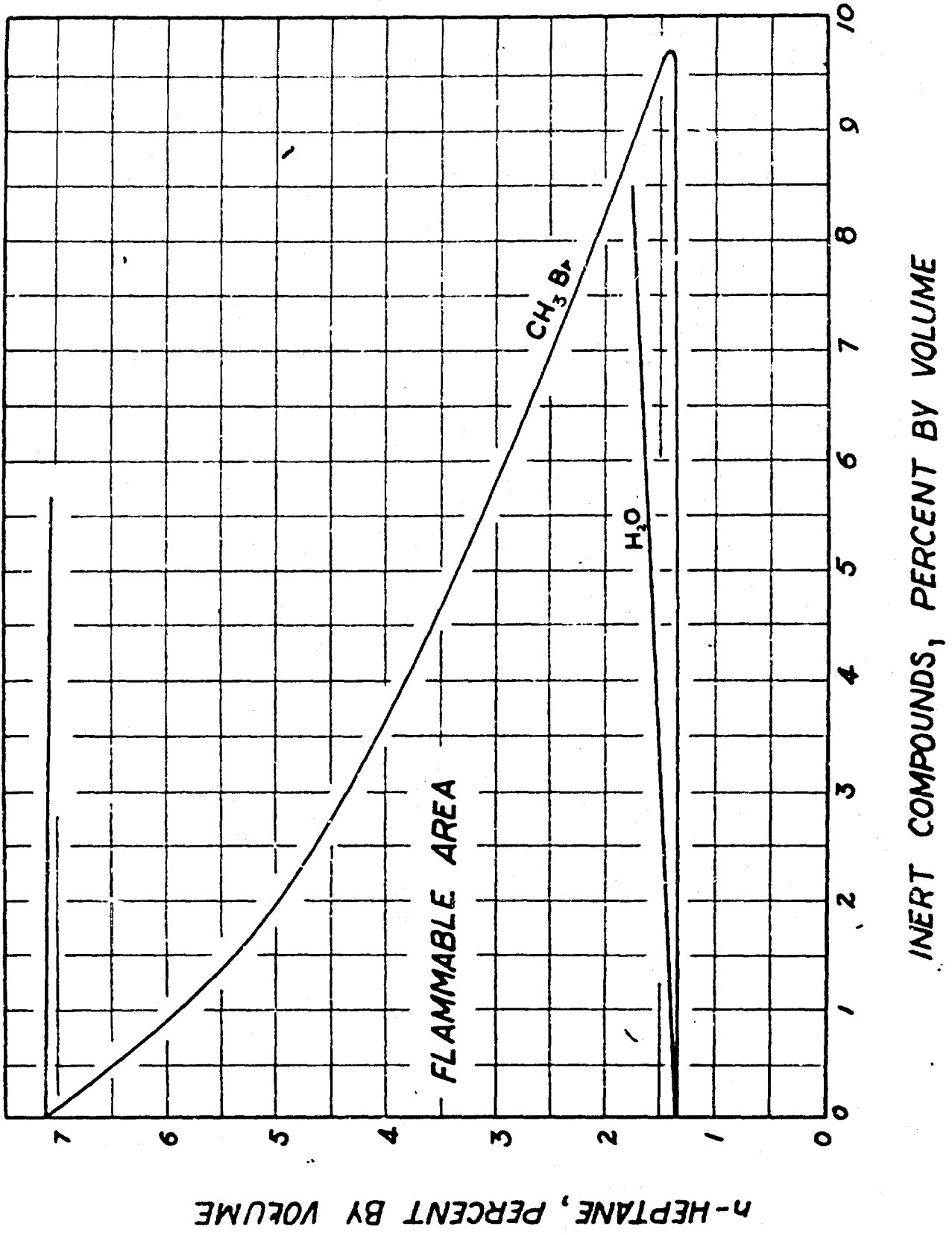


Figure 127 Flammable Area

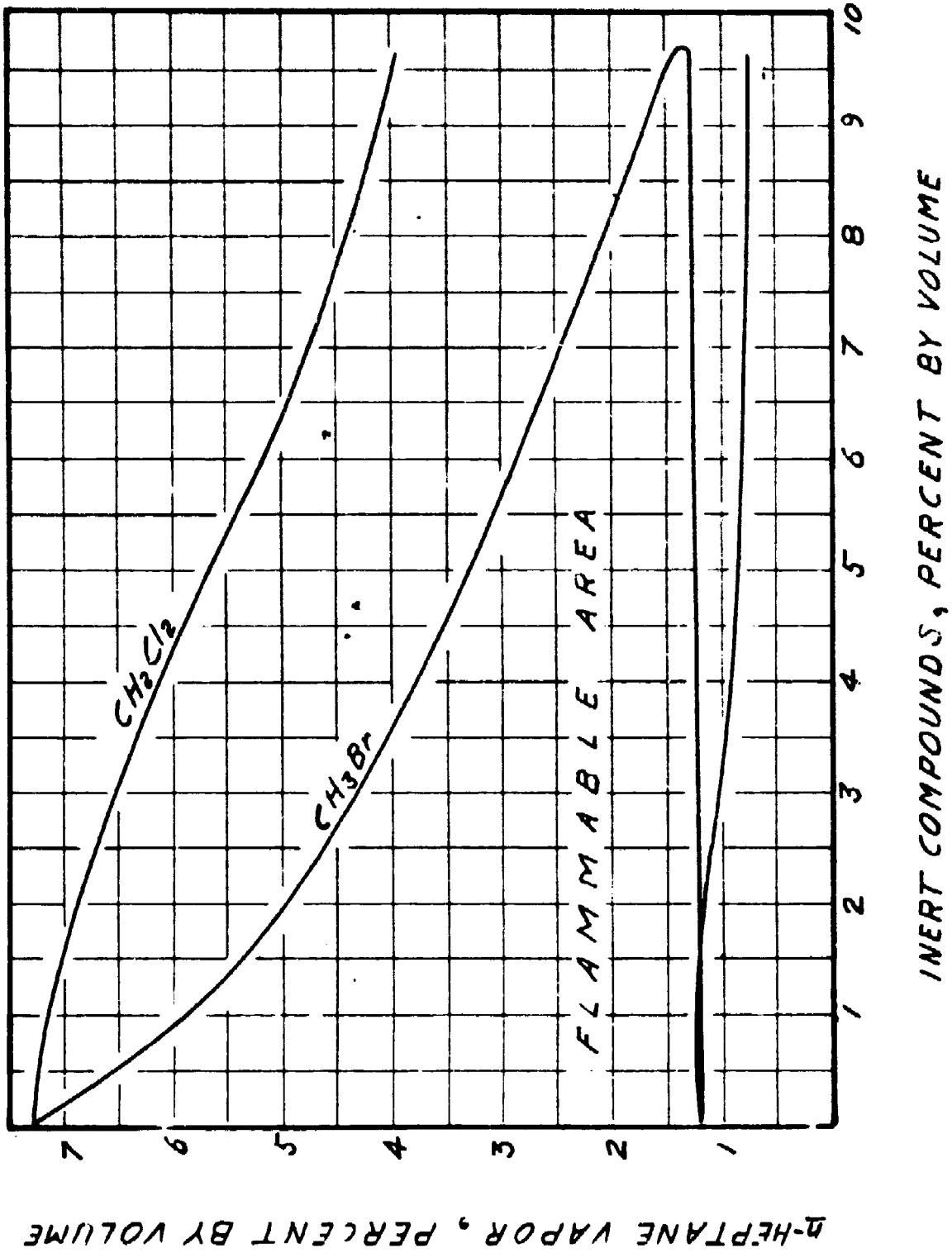


Figure 128 Flammable Area

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