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PHYSICAL AND THERMODYNAMIC PROPERTIES OF VARIOUS "FREONS"

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NOMENCLATURE

A, B, C, D, E,	constants in vapor-pressure equation
c_p	specific heat of the liquid at constant pressure, P, in Btu/(lb)(°R)
c_s	specific heat of the saturated liquid, in Btu/(lb)(°R)
C_v^o	specific heat of the vapor at constant volume for case of infinite volume, in Btu/(lb)(°R)
d	density of the vapor in lbs/cu ft
d_c	critical density in lbs/cu ft
d_L	density of liquid in lbs/cu ft
d_R	reduced density = RT_c/VP_c
log	logarithm to the base 10
P	pressure in psia
P_c	critical pressure in psia
P_R	reduced pressure = P/P_c
R	gas constant, 10.73 (cu ft)(lb force)/(sq in.)(lb mol mass)(°R)
t	temperature, °F
T	absolute temperature, °R
T_c	critical temperature
T_R	reduced temperature = T/T_c
V	volume of gas or liquid
w	wave number in cm^{-1}
Z	compressibility factor, PV/RT

INTRODUCTION

During the past twenty years a considerable amount of experimental data has been obtained on the physical and thermodynamic properties of the chlorine- and fluorine-substituted hydrocarbons, known by their trade name as the "Freons". It is the purpose of this report to collect and correlate all the data on the critical constants, vapor pressures, vapor and liquid densities, and vapor and liquid heat capacities of the "Freons". These properties have been selected because of their importance and use in the calculation of thermodynamic diagrams for the compounds. It is felt that such a compilation and correlation of existing data will be of assistance in determining thermodynamic properties of other compounds, as need may arise in the future. Furthermore, such correlations often serve to reveal significant errors in old data and allow predictions in ranges where no data have been obtained.

PHYSICAL AND THERMODYNAMIC PROPERTIES OF VARIOUS "FREONS"

I. CRITICAL CONSTANTS

The critical constants of the various "Freons" have been tabulated, together with reference as to their source, in Table I. Since the "Freons" considered in this report fall into closely related groups (structurally) it is reasonable to assume that there will exist regularities in their critical constants.

Critical Temperature

A chart, Fig. 1, shows the relation between critical temperature and the molecular weight. The data form straight lines except for the completely fluorinated "Freons", "F-23, 14, and 116". Since the lines are almost parallel, data on one compound of a new series such as the bromofluoromethanes would suffice to give estimations of critical temperature for the rest of the series.

Critical Pressure

In a similar manner, the critical pressures are plotted vs. molecular weight in Fig. 2. These values correlate fairly well but not quite as well as the critical temperatures. This may be due in part to the fact that the experimental determinations of critical pressures are more subject to error. In regard to new compounds, the same possibility of prediction exists as for critical temperature. Fig. 2 might suggest also that the critical pressure of both "F-11 and 113" are 5-10 pounds high. The critical

Table I

Critical Constants of the Various "Freons"

Compound	Molecular Wt.	T_c (°R)	P_c (psia)	d_c (lb/ft^3)	Reference
"Freon-10" (CCl_4)	153.838	1001.3	662	34.82	(*)
"Freon-11" (CCl_3F)	137.37	848.1	635.0	34.57	(9)
"Freon-12" (CCl_2F_2)	120.924	692.4	595	34.63	(5, this report)
"Freon-13" ($CClF_3$)	104.457	543.63	561.3	36.08	(1)
"Freon-14" (CF_4)	88.010	409.8	529	39.56	(5,*)
"Freon-20" ($CHCl_3$)	119.389	965.1	---	32.20	(*)
"Freon-21" ($CHCl_2F$)	102.92	813.0	749.7	32.57	(9)
"Freon-22" ($CHClF_2$)	86.46	664.5	735.0	32.76	(9, this report)
"Freon-23" (CHF_3)	70.018	551.1	691	32.20	(49)
"Freon-112" (CCl_2F-CCl_2F)	203.848	992.1	500	34.3	(13,33)
"Freon-113" ($CClF_2$-CCl_2F)	187.37	877.1	495.4	35.94	(9)
"Freon-114" ($CClF_2$-$CClF_2$)	170.91	754.0	471.9	36.32	(9)
"Freon-115" ($CClF_2$-CF_3)	154.477	635.59	453	37.21	(34)
"Freon-116" (CF_3-CF_3)	138.02	527.2	439.5(est.)	39.4	(41,53, this report)

(*) International Critical Tables

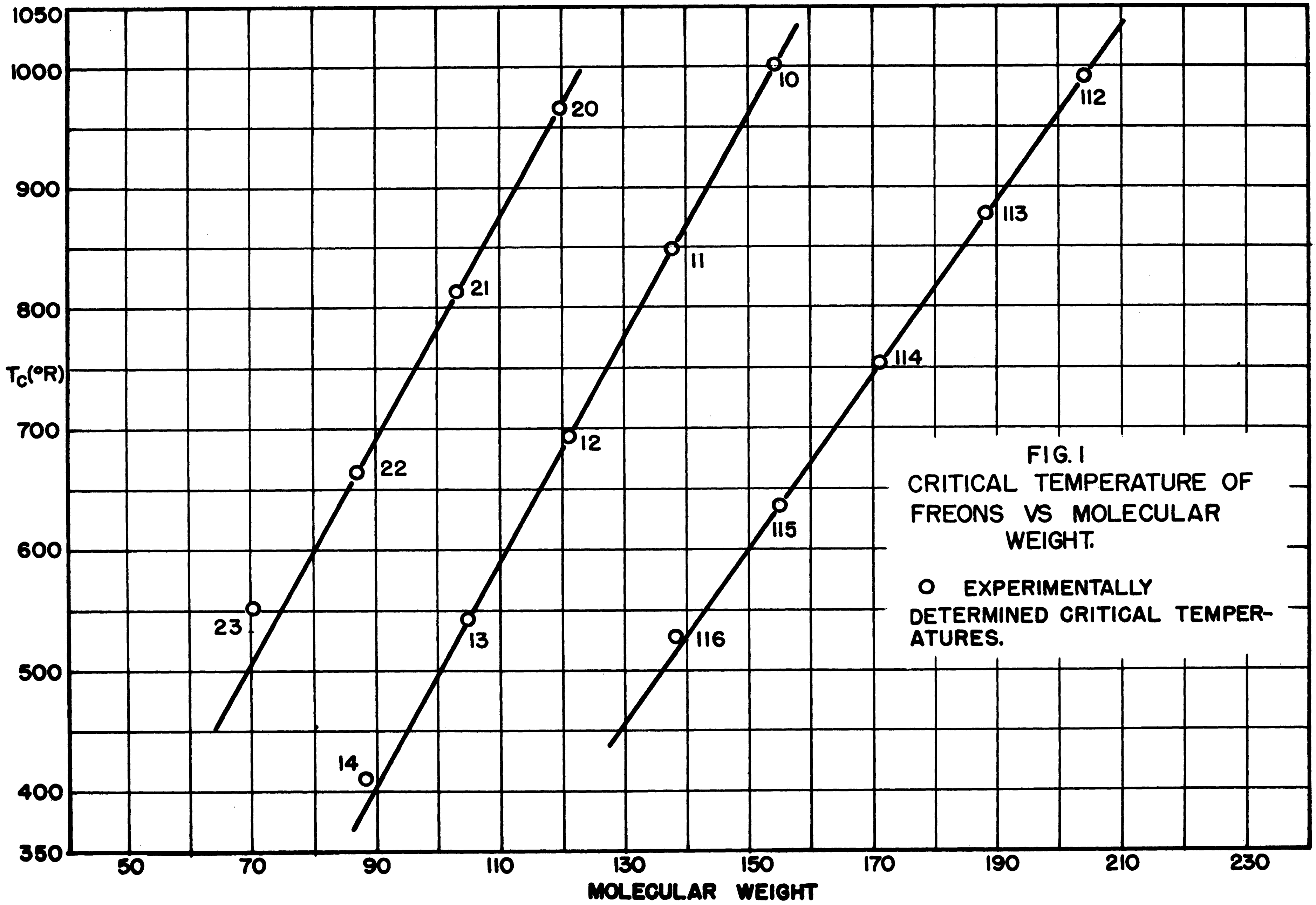


FIG. 1
CRITICAL TEMPERATURE OF FREONS VS MOLECULAR WEIGHT.

O EXPERIMENTALLY DETERMINED CRITICAL TEMPERATURES.

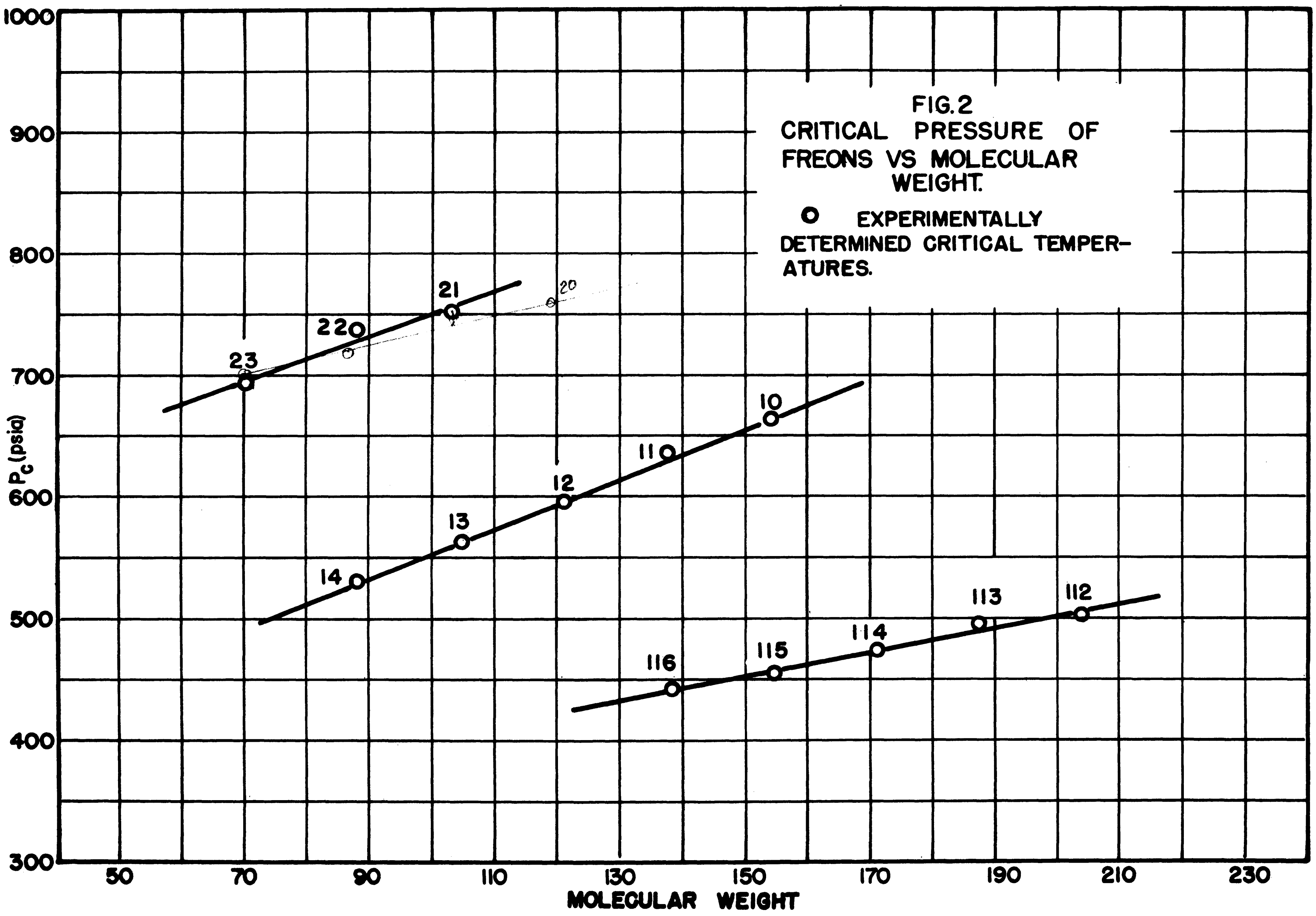


FIG. 2
CRITICAL PRESSURE OF FREONS VS MOLECULAR WEIGHT.
O EXPERIMENTALLY DETERMINED CRITICAL TEMPERATURES.

pressure of "F-20" could not be found. The critical pressure of "F-22" was estimated from the vapor pressure data of several investigators (6,14).

Critical Density

Critical densities are tabulated in Table I; they have not been correlated graphically. It will be noted that the average critical density is about 35 lb/ cu ft. The critical density of "F-116" was predicted by the rectilinear-diameter method from the data of Pace and Aston. (41)

II. VAPOR PRESSURE

It is a well-accepted fact that vapor pressures can be best represented by a log P-vs.-1/T plot on which they roughly tend to form straight lines. This means, of course, that the vapor pressures can be represented approximately by an equation of the form, $\log P = A + B/T$. It is found, however, that precise plotting of the data on the coordinates mentioned above results in a definite S curve, which can be observed in Fig. 3. Analytically this deviation from a straight line requires correction terms in the simplified equation for the straight line. Several types of equations have been proposed, but it seems likely that the ability of the equation to fit the data and yield accurate temperature derivatives depends principally on the number of constants or correction terms used rather than on the particular form. In the present report an equation of the form,

$$\log P = A/T^2 + B/T + C + DT + ET^2,$$

has been used. It is felt that this equation is capable of representing the vapor-pressure data within the experimental error for any of the "Freons".

The vapor pressures of the various "Freons" can be compared by plotting the data on the reduced coordinates of $\log P_R$ vs. $1/T_R$. The regularity observed in Fig. 3 suggests the possibility of representing the vapor pressures by a reduced equation in a manner similar to that often used in correlating PVT data (see Part III of this report). It is seen that within limits the "Freons" fall approximately into three distinct groups, as represented by the three curves. The shapes of the curves are similar except for slope. For each curve a reduced equation, $\log P_R = \phi\ (T_R)$, may be written. The slope, $d(\log P_R)\ /d(1/T_R)$, can be varied by dividing $\log P_R$ by a parameter characteristic of the compound. A more general reduced vapor-pressure equation was determined by plotting $(\log P_R)\ /\ a$, where a is the parameter, vs. $1/T_R$ and writing an equation for the single line which results (Fig. 4). Here approximate values for each group are as follows:

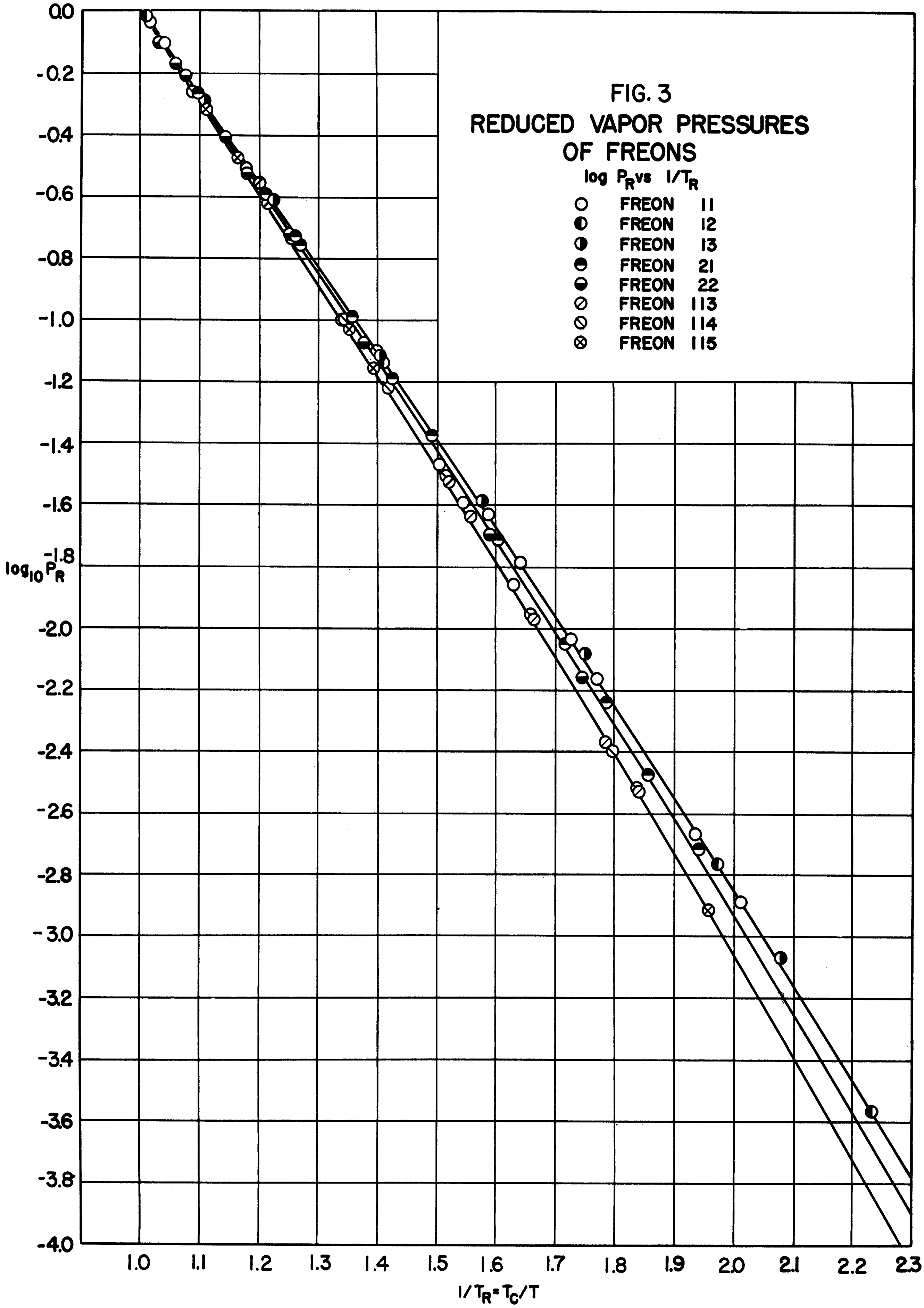


FIG. 3
REDUCED VAPOR PRESSURES
OF FREONS
log P_R vs $1/T_R$
FREON 11
FREON 12
FREON 13
FREON 21
FREON 22
FREON 113
FREON 114
FREON 115
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
-1.8
$\log_{10} P_R$
-2.0
-2.2
-2.4
-2.6
-2.8
-3.0
-3.2
-3.4
-3.6
-3.8
-4.0
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
$1/T_R = T_C/T$

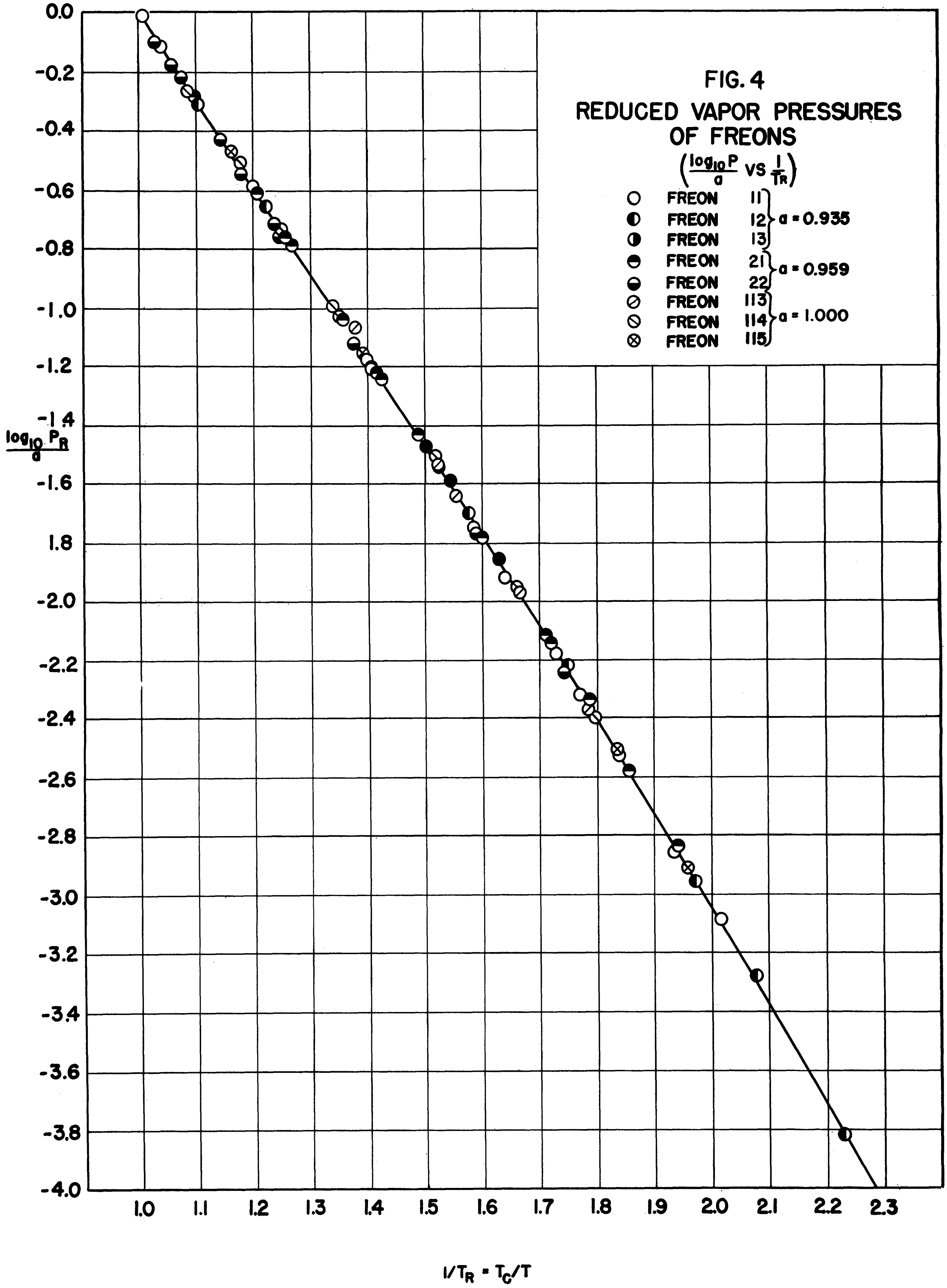


FIG. 4
REDUCED VAPOR PRESSURES
OF FREONS
($\frac{\log_{10} P}{a}$ VS $\frac{1}{T_R}$)
FREON 11
FREON 12
FREON 13
a = 0.935
FREON 21
FREON 22
a = 0.959
FREON 113
FREON 114
FREON 115
a = 1.000
$\frac{\log_{10} P_R}{a}$
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
1.8
-2.0
-2.2
-2.4
-2.6
-2.8
-3.0
-3.2
-3.4
-3.6
-3.8
-4.0
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
$1/T_R = T_C/T$

Approximate a for	"Freon-11, 12, and 13"	= 0.935
" a "	"Freon-21, and 22"	= 0.959
" a "	"Freon-113, 114, 115, and 116"	= 1.000

The resulting equation is:

$$\frac{\log P_R}{a} = -0.141631/T_R^2 - 3.06037/T_R + 4.615211 -2.50238T_R + 1.08917T_R^2$$

For the best representation of the data, it was found that slightly different values of a must be chosen for each compound in a given group. With the following values of the parameter a so selected, and with the respective critical temperatures and pressures, individual equations were obtained from the generalized equation above. These individual equations are compared with experimental data in Tables II through X.

a for "Freon-11"	= 0.935
a " -12"	= 0.934
a " -13"	= 0.927
a for "Freon-21"	= 0.959
a " -22"	≐ 0.976
a for "Freon-113"	= 1.000
a " -114"	= 1.000
a " -115"	= 0.996
a " -116"	= 0.993

III. COMPRESSIBILITY OF VAPORS

The PVT data of vapors were treated by plotting the compressibility factor, Z=PV/RT versus reduced pressure at certain reduced temperatures (Fig. 5 through 22). It can be seen from the compressibility plots that all the "Freons" considered seem to fall approximately on single reduced-temperature lines below the critical temperature. Above the critical temperature three different lines can be drawn for each isotherm. One line represents the data of "F-11, 12, and 13" another "F-21 and 22," and a third represents the data of "F-113, 114, 115, and 116". Three different reduced equations of state $Z = \phi\ (P_R, T_R)$ have been written for these three groups.

TABLE II

THE VAPOR PRESSURE OF "F-11"

$$\log_{10} P = -\frac{95249.8}{T^2} - \frac{2426.792}{T} + 7.11799 - 0.00275878T + 0.0_5141584T^2$$

T, °R	Experimental Psia	Calculation Psia	Per Cent Deviation	Experimental Investigator
421.81	0.8303	0.8272	+0.4	(11)
438.32	1.3667	1.4074	-2.9	(6)
479.45	4.354	4.413	-1.3	(11)
491.65	5.830	5.940	-1.9	(11)
491.71	5.837	5.949	-1.9	(6)
517.07	10.293	10.482	-1.8	(11)
534.92	14.828	15.058	-1.5	(6)
601.76	47.19	47.28	-0.2	(6)
606.35	50.47	50.63	-0.3	(11)
707.00	178.12	178.71	-0.3	(6)
816.89	494.8	496.2	-0.3	(6)
843.86	619.9	614.6	+0.9	(6)
848.1	635.0			

TABLE III

THE VAPOR PRESSURE OF "F-12"

$$\log P = -\frac{63419.0}{T^2} - \frac{1979.146}{T} + 7.08513 - 0.0_{2}337554T + 0.0_{5}212192T^2$$

T, °R	Experimental Psia	Calculation Psia	Per Cent Deviation	Experimental Investigator
310.61	0.16227	0.16302	-0.5	This report
350.84	1.0202	1.0131	+0.7	" "
491.58	44.75	44.670	+0.2	" "
688.09	573.15	571.31	+0.3	" "
692.4	595			

TABLE IV

THE VAPOR PRESSURE OF "F-13"

$$\log P = -\frac{38801.2}{T^2} - \frac{1542.258}{T} + 7.02750 - 0.00426707T + 0.0_{5}341640T^2$$

T, °R	Experimental Psia	Calculation Psia	Per Cent Deviation	Experimental Investigator
261.50	0.4797	0.47876	+0.2	(1)
310.84	4.674	4.6565	+0.4	(1)
344.92	14.623	14.610	+0.1	(1)
387.50	44.38	44.522	-0.3	(1)
444.47	137.44	137.90	-0.3	(1)
491.69	285.9	287.22	-0.5	(1)
540.06	537.9	537.92	0.0	(1)
543.63		561.3		

TABLE V

THE VAPOR PRESSURE OF "F-21"

$$\log_{10} P = -\frac{89775.5}{T^2} - \frac{2386.069}{T} + 7.30088 - 0.0_2295176T + 0.0_5158028T^2$$

T, °R	Experimental Psia	Calculation Psia	Per Cent Deviation	Experimental Investigator
418.61	1.3079	1.3485	-3.0	(10)
438.32	2.4704	2.5103	-1.6	(6)
455.08	4.030	4.0568	-0.7	(10)
473.65	6.612	6.5996	+0.2	(10)
475.92	7.003	6.9833	+0.3	(6)
507.74	14.696	14.518	+1.2	(10)
545.33	31.01	30.466	+1.8	(8)
570.76	48.20	47.298	+1.9	(6)
573.05	50.06	49.104	+1.9	(8)
599.87	75.88	74.429	+1.9	(8)
640.82	132.90	130.68	+1.7	(6)
644.33	138.97	136.65	+1.7	(8)
671.87	193.69	190.88	+1.5	(8)
742.03	402.1	400.00	+0.5	(6)
805.97	703.1	707.44	-0.6	(6)
813.00	749.7			

TABLE VI

THE VAPOR PRESSURE OF "F-22"

$$\log P = -\frac{61{,}037.7}{T^2} - \frac{1984.809}{T} + 7.37074 - 0.0_2367543T + 0.0_5240744T^2$$

T, °R	Experimental Psia	Calculation Psia	Per Cent Deviation	Experimental Investigator
381.43	5.0936	4.9652	+2.6	(6)
418.50	14.793	14.556	+1.6	(6)
482.69	61.679	60.759	+1.5	(6)
532.37	138.00	142.15	-2.9	(14)
536.96	152.40	152.49	-0.1	(6)
563.87	218.53	224.79	-2.8	(14)
582.23	285.98	286.98	-0.3	(14)
600.23	353.88	359.59	-1.6	(14)
620.39	449.99	456.29	-1.4	(14)
628.31	488.94	499.17	-2.0	(6)
645.41	576.52	602.02	-4.2	(14)
658.37	674.84	690.37	-2.2	(6)
664.5				

TABLE VII

THE VAPOR PRESSURE OF "F-113"

$$\log P = -\frac{108957.4}{T^2} - \frac{2684.251}{T} + 7.31017 - 0.0_2285302T + 0.0_5141579T^2$$

T, °R	Experimental Psia	Calculation Psia	Per Cent Deviation	Experimental Investigator
476.57	1.4623	1.4445	+1.2	(6)
491.69	2.1133	2.1864	-3.3	(29)
527.69	5.2700	5.2579	+0.2	(29)
528.03	5.3141	5.2981	+0.3	(6)
563.69	11.373	11.142	+2.1	(29)
577.31	14.696	14.403	+2.0	(6)
641.63	42.486	41.144	+3.3	(6)
723.35	118.86	116.98	+1.6	(6)
870.80	473.80	471.13	+0.6	(6)

TABLE VIII

THE VAPOR PRESSURE OF "F-114"

$$\log P = -\frac{80519.5}{T^2} - \frac{2307.519}{T} + 7.28906 - 0.00331881T + 0.0_5191581T^2$$

T, °R	Experimental Psia	Calculation Psia	Per Cent Deviation	Experimental Investigator
419.69	1.8752	1.8983	-1.2	(56)
454.59	5.2083	5.1356	+1.4	(6)
455.69	5.2215	5.2842	-1.2	(56)
495.14	13.786	13.388	+3.0	(16)
498.89	14.505	14.499	0.0	(56)
531.99	28.437	27.775	+2.4	(16)
561.89	47.306	46.491	+1.8	(16)
563.83	49.584	47.973	+3.4	(6)
602.50	86.530	85.745	+0.9	(16)
640.87	144.86	142.01	+2.0	(6)
641.12	142.07	142.45	+0.3	(16)
694.53	256.74	262.33	-2.1	(16)
743.65	430.89	428.49	+0.6	(6)
754.0	471.9			

TABLE IX

THE VAPOR PRESSURE OF "F-115"

$$\log P = -\frac{56986.4}{T^2} - \frac{1937.360}{T} + 7.25285 - 0.0_2392135T + 0.0_5268535T^2$$

T, °R	Experimental Psia	Calculation Psia	Per Cent Deviation	Experimental Investigator
324.16	0.55066	0.55593	-0.9	(34)
345.99	1.3802	1.3869	-0.5	(34)
412.90	11.682	11.620	+0.5	(34)
455.90	31.645	31.589	+0.2	(34)
470.35	42.335	42.263	+0.2	(34)
522.61	106.02	104.94	+1.0	(34)
547.03	152.37	151.11	+0.8	(34)
572.97	216.15	215.17	+0.5	(34)
600.26	302.86	302.62	+0.1	(34)
628.52	419.86	419.11	+0.2	(34)
632.18	436.09	436.41	-0.1	(34)
635.59	453.			

TABLE X

THE VAPOR PRESSURE OF "F-116"

$$\log P = -\frac{39089.3}{T^2} - \frac{1602.133}{T} + 7.22586 - 0.0_2471332T + 0.0_5389129T^2$$

T, °R	Experimental Psia	Calculation Psia	Per Cent Deviation	Experimental Investigator
323.93	6.1081	6.1509	-0.7	(41)
324.40	6.2113	6.2539	-0.7	(41)
338.94	10.1786	10.191	-0.1	(41)
342.09	11.2561	11.258	-0.0	(41)
350.77	14.6929	14.662	+0.2	(41)
350.82	14.7167	14.683	+0.2	(41)
351.18	14.8753	14.840	+0.2	(41)
351.38	14.9635	14.928	+0.2	(41)
527.2	439.5			

For example, the ethane derivatives, "F-113, 114, 115, and 116", are sufficiently similar that a single reduced equation of state has been written for them. Using this reduced equation, an equation of state may be determined for such compounds as "F-114" and "F-116", where very little data have been taken. These reduced equations are applicable up to the critical density.

In tables XI through XIX the PVT data of the various "Freons" are compared with equations of state determined by substituting the critical temperature and pressure into the proper reduced equations of state. The reduced equations of state are given here for each of the three groups of "Freons". For a discussion of the procedure for obtaining these equations, the reader is referred to Reference 34.

Reduced equation of state for "Freons- 21 and 22"

$$P_R = -0.738763d_R^2 + 0.093512d_R^3 - 0.0061284d_R^4$$
$$T_R(d_R + 0.396986d_R^2 - 0.044952d_R^3 + 0.0035423d_R^4)$$
$$-1/T_R^3\ (0.007564d_R^2 - 0.0005721d_R^4\ )$$

Reduced equation of state for "Freons-113, 114, 115 and 116"

$$P_R = -\ 0.74153d_R^2 + 0.06912d_R^3 - 0.0004279d_R^4$$
$$T_R\ (\ d_R + 0.39644d_R^2 - 0.01799d_R^3 - 0.0026148d_R^4)$$
$$-1/T_R^3(0.007564d_R^2 - 0.0005721d_R^4)$$

Reduced equation of state for "Freons-11, 12, and 13"

$$P_R = -\ 0.735995d_R^2 + 0.117905d_R^3 - 0.011829d_R^4$$
$$T_R\ (d_R + 0.397533d_R^2 - 0.071915d_R^3 + 0.0096994d_R^4\ )$$
$$-1/T_R^3(0.007564d_R^2 - 0.0005721d_R^4\ )$$

TABLE XI

COMPARISON OF AN EQUATION OF STATE* WITH EXPERIMENTALLY DETERMINED PVT DATA FOR "FREON-11"

$$*P = -\frac{5.08716}{V^2} + \frac{0.085031}{V^3} - \frac{0.0008901}{V^4} + T\left[\frac{0.07811}{V} + \frac{0.00323986}{V^2} - \frac{0.0_4 61153}{V^3} + \frac{0.0_6 8606}{V^4}\right] - \frac{1}{T^3}\left[\frac{31893000}{V^2} - \frac{26261}{V^4}\right],$$

Where P is psia, V is ft^3/lb., and T is °R(°F + 459.7)

Density lb/ft^3	Temperature °R	Obs. Pres. Psia	Calc. Pres. Psia	Per Cent Difference	Experimental Investigator
6.814	757.92	286.7	289.7	-1.0	(7)
	771.78	297.6	299.1	-0.5	
	787.08	309.1	309.4	-0.1	
5.557	740.46	240.0	242.6	-1.1	(7)
	771.78	258.5	259.3	-0.3	
	800.58	275.4	274.6	+0.3	
	834.60	293.3	292.7	+0.2	
	858.00	306.6	305.1	+0.5	
4.631	724.98	203.4	205.7	-1.1	(7)
	770.34	224.7	225.3	-0.2	
	822.18	248.1	247.6	+0.2	
	858.18	264.1	263.0	+0.4	
3.826	713.64	172.09	173.62	-0.9	(7)
	774.30	194.58	194.70	-0.1	
3.489	699.78	156.51	157.02	-0.3	(7)
	737.94	168.56	169.00	-0.3	
	777.54	181.94	181.40	+0.3	
	822.18	195.75	195.34	+0.2	
1.9175	650.82	85.68	86.42	-0.9	(7)
	714.18	96.38	96.74	-0.4	
	777.90	107.08	107.09	0.0	
	812.46	112.87	112.69	+0.2	
1.1620	613.38	51.19	51.37	-0.4	(7)
	678.90	57.89	57.65	+0.4	
	744.60	63.99	63.93	+0.1	
	812.46	70.58	70.40	+0.3	
0.8278	599.70	36.59	36.55	+0.1	(11)
0.6492	573.24	27.61	27.65	-0.1	(11)

TABLE XI (Cont.)

Density lb/ft^3	Temperature °R	Obs. Pres. Psia	Calc. Pres. Psia	Per Cent Difference	Experimental Investigator
0.6404	572.70	27.14	27.27	-0.5	(11)
0.6059	572.70	25.84	25.87	-0.1	(11)
0.5743	599.88	25.92	25.83	+0.3	(11)
0.3601	545.52	14.889	14.890	0.0	(11)
0.3409	572.34	14.889	14.846	+0.3	(11)
0.3239	599.70	14.889	14.829	+0.4	(11)

TABLE XII

COMPARISON OF AN EQUATION OF STATE* WITH EXPERIMENTALLY DETERMINED PVT DATA FOR "FREON-12"

*Equation is

$$P = -\frac{4.67204}{V^2} + \frac{0.077307}{V^3} - \frac{0.0008012}{V^4} + T\left[\frac{0.08876}{V} + \frac{0.003644}{V^2} - \frac{0.0000681}{V^3} + \frac{0.000000949}{V^4}\right] - \frac{1}{T^3}\left[\frac{15,939,000}{V^2} - \frac{12,862}{V^4}\right],$$

where P is psia, V is ft^3/lb, and T is °R (°F + 459.7)

Density lb/ft^3	Temperature °R	Obs. Pres. Psia	Calc. Pres. Psia	Per Cent Difference	Experimental Investigator
34.72	698.08	613.8	628.8	+2.5	This report
	732.64	829.7	836.8	+0.9	
	766.30	1042.0	1038.8	-0.3	
	796.45	1226.0	1219.9	-0.5	
	820.17	1371.1	1362.4	-0.6	
34.64	706.97	684	682.0	-0.3	(7)
	767.13	1027	1042.3	+1.5	
	807.81	1284	1285.9	+0.1	
	835.06	1453	1449.1	-0.3	
	846.47	1522	1517.4	-0.3	
34.38	694.89	600.3	609.3	+1.5	This report
	699.08	638.3	634.1	-0.7	
	730.40	810.1	819.8	+1.2	
	770.47	1058.5	1057.3	-0.1	
	797.89	1225.9	1219.7	-0.5	
32.46	670.09	467.3	472.5	+1.1	This report
	672.73	480.3	486.9	+1.4	
	676.75	500.3	509.0	+1.7	
	697.55	608.2	622.9	+2.4	
	734.80	823.2	826.8	+0.4	
	769.97	1022.7	1019.2	-0.3	
	806.15	1226.5	1216.8	-0.8	
	847.10	1450.5	1440.5	-0.7	
32.41	697.0	612.1	619.8	+1.3	This report
	709.9	684.7	690.3	+0.8	
	738.2	841.2	844.8	+0.4	
	781.9	1085.6	1083.2	-0.2	
	818.7	1288.7	1283.8	-0.4	
	852.1	1477.1	1465.8	-0.8	
31.73	695.4	616.5	610.8	-0.9	This report

TABLE XII (Cont.)

Density lb/ft^3	Temperature °R	Obs. Pres. Psia	Calc. Pres. Psia	Per Cent Difference	Experimental Investigator
	721.5	750.2	749.4	-0.1	This report
	736.1	829.3	826.8	-0.3	
	756.9	942.4	937.0	-0.6	
	772.7	1026.5	1020.7	-0.6	
	794.7	1146.9	1137.2	-0.8	
	818.7	1280.4	1264.2	-1.3	
20.27	709.8	630	627.9	-0.3	This report
	737.2	720	708.3	-1.6	
	757.8	781	768.7	-1.6	
	775.6	833	820.9	-1.5	
	794.1	885	875.0	-1.1	
14.06	676.91	470.3	480.9	+2.2	This report
	692.87	512.3	510.5	+0.4	
	750.97	612.5	617.7	+0.9	
	779.58	681.1	670.4	-1.6	
	805.4	716.3	717.8	+0.2	
11.936	663.46	416	426.0	+2.4	(7)
	704.09	477	487.8	+2.3	
	745.45	535	549.6	+2.7	
	786.53	600	611.2	+1.9	
	828.29	657	673.6	+2.5	
	869.83	715	735.7	+2.9	
10.75	682.43	424.0	429.7	+1.3	This report
	745.62	511.1	513.3	+0.4	
	814.12	601.5	603.5	+0.3	
	843.48	639.9	642.1	+0.3	
6.537	624.22	264.1	266.3	+0.8	This report
	627.88	266.1	268.9	+1.1	
	659.14	298.2	291.8	-2.2	
	696.65	312.4	319.1	+2.1	
	735.75	344.7	347.5	+0.8	
5.293	608.9	219.8	220.5	+0.3	(16)
	635.0	236.7	235.4	-0.4	
	659.8	251.2	249.6	-0.7	
	680.0	262.8	261.1	-0.7	
	699.8	273.9	272.3	-0.6	
5.187	600.14	211.6	212.46	+0.4	(7)
	628.13	227.3	228.10	+0.4	
	655.0	243.3	243.07	-0.1	
	683.07	256.5	258.68	+0.9	
	707.89	273.3	272.41	-0.3	
	734.87	288.9	287.41	-0.5	
	766.82	304	305.10	+0.4	

TABLE XII (Cont.)

Density lb/ft^3	Temperature °R	Obs. Pres. Psia	Calc. Pres. Psia	Per Cent Difference	Experimental Investigator
4.756	612.7	204.8	205.63	+0.4	(16)
	614.6	205.7	206.59	+0.4	
	641.6	220.2	220.21	0.0	
	669.7	235.2	234.36	-0.4	
	688.8	245.3	243.96	-0.5	
4.528	595.7	188.5	189.93	+0.8	(16)
	625.1	203.7	203.97	+0.1	
	639.8	210.5	210.98	+0.2	
	654.8	218.4	218.12	-0.1	
	678.0	229.5	229.15	-0.2	
	700.3	240.6	239.75	-0.4	
	718.7	249.8	248.48	-0.5	
3.770	590.7	164.8	162.71	-1.8	(16)
	671.7	197.6	194.08	-1.3	
3.337	588.9	149.2	146.81	-1.6	(16)
	671.7	177.7	174.78	-1.6	
3.170	570.86	132.8	134.91	+1.6	This report
	609.76	145.8	147.36	+1.1	
	663.49	162.8	164.49	+1.0	
	717.42	180.3	181.64	+0.7	
	764.04	195.3	196.44	+0.6	
3.00	558.25	122.5	125.18	+2.2	This report
	572.52	127.2	129.48	+1.8	
	622.06	142.0	144.38	+1.7	
	673.50	158.1	159.81	+1.1	
	715.98	169.9	172.52	+1.5	
	766.92	185.4	187.74	+1.3	
2.891	566.45	121.8	123.81	+1.6	This report
	577.69	124.9	127.07	+1.7	
	616.28	136.4	138.21	+1.3	
	658.20	148.5	150.28	+1.2	
	735.20	170.5	172.40	+1.1	
2.821	587.1	129.2	127.10	-1.6	(16)
	669.9	153.6	150.32	-2.1	
2.361	587.1	110.3	108.96	-1.2	(16)
	669.9	130.2	128.06	-1.6	

TABLE XII (Cont.)

Density lb/ft^3	Temperature °R	Obs. Pres. Psia	Calc. Pres. Psia	Per Cent Difference	Experimental Investigator
1.804	545.7	79.5	78.56	-1.1	(16)
	552.9	80.9	79.81	-1.2	
	588.9	87.5	86.04	-1.7	
	669.9	102.2	100.02	-2.1	

TABLE XIII

COMPARISON OF AN EQUATION OF STATE* WITH EXPERIMENTALLY DETERMINED PVT DATA FOR "FREON - 13"

*Equation is

$$P = -\frac{4.08722}{V^2} + \frac{0.065127}{V^3} - \frac{0.0006499}{V^4} + T\left[\frac{0.1027}{V} + \frac{0.00406092}{V^2} - \frac{0.0473072}{V^3} + \frac{0.069803}{V^4}\right] - 1/T^3\left[\frac{6749000}{V^2} - \frac{5049}{V^4}\right],$$

where P is psia, V is ft^3/lb, and T is °R (°F + 459.7)

Density lb/ft^3	Temperature °R	Observed Psia	Calculated Psia	Per Cent Difference	Experimental Investigator
44.45	543.63	562.2	582.0	-3.4	(1)
	579.16	904.0	930.4	-2.8	
	614.62	1262.2	1279.5	-1.4	
	652.01	1651.7	1648.9	+0.2	
	689.05	2037.3	2015.7	+1.1	
35.90	543.70	561.3	561.5	0.0	(1)
	546.22	578.0	579.6	-0.3	
	581.34	830.6	831.7	-0.1	
	616.91	1088.8	1086.9	+0.2	
	652.96	1352.9	1345.5	+0.5	
	689.29	1620.3	1606.1	+0.9	
	724.57	1881.5	1859.1	+1.2	
28.00	543.61	559.3	561.7	-0.4	(1)
	546.52	571.3	576.6	-0.9	
	576.01	734.1	727.7	+0.9	
	610.12	910.0	902.1	+0.9	
	645.91	1093.8	1084.6	+0.8	
	682.21	1278.9	1269.4	+0.7	
	720.89	1476.6	1466.1	+0.7	
26.75	543.56	558.3	560.6	-0.4	(1)
	545.29	568.3	568.9	-0.1	
	576.26	723.9	718.3	+0.8	
	607.21	873.9	867.2	+0.8	
	642.14	1042.1	1034.0	+0.7	
	678.76	1218.7	1210.4	+0.7	
	720.05	1417.4	1408.0	+0.7	
19.75	537.64	513.7	516.2	-0.5	(1)
	541.70	527.2	529.5	-0.4	
	570.85	628.3	624.4	+0.6	
	604.16	737.6	732.6	+0.7	
	638.02	846.9	842.1	+0.6	

TABLE XIII (Cont.)

Density lb/ft^3	Temperature °R	Observed Psia	Calculated Psia	Per Cent Difference	Experimental Investigator
19.75	670.21	948.7	946.1	+0.3	(1)
	689.52	1010.3	1008.3	+0.2	
	716.65	1094.3	1095.7	-0.1	
12.77	522.21	408.0	409.9	-0.5	(1)
	526.48	417.6	417.9	-0.1	
	557.49	478.2	476.3	+0.4	
	592.14	544.3	541.2	+0.6	
	623.19	601.6	599.2	+0.4	
	655.88	662.1	660.2	+0.3	
	685.58	715.7	715.5	0.0	
	710.27	758.0	761.4	-0.5	
10.82	509.00	354.4	356.9	-0.7	(1)
	522.03	375.2	377.0	-0.5	
	554.25	428.5	426.2	+0.5	
	587.41	479.9	477.1	+0.6	
	624.86	536.4	534.1	+0.4	
	650.41	574.9	573.0	+0.3	
	671.75	606.5	605.4	+0.2	
8.27	491.97	283.4	287.0	-1.3	(1)
	518.50	315.7	316.5	-0.2	
	543.86	344.5	344.5	0.0	
	575.02	379.9	378.9	+0.3	
	605.98	414.4	413.0	+0.3	
	631.00	440.9	440.5	+0.1	
6.00	472.33	214.4	217.1	-1.2	(1)
	473.87	220.4	218.3	+1.0	
	511.45	247.1	246.8	+0.1	
	535.58	266.0	265.1	+0.3	
	572.32	294.2	292.8	+0.5	
	599.99	314.9	313.7	+0.4	
4.27	455.48	159.0	160.1	-0.7	(1)
	460.83	161.8	162.8	0.0	
	500.02	183.0	183.0	0.0	
	537.89	203.0	202.4	+0.3	
	566.72	218.0	217.1	+0.4	
	604.88	237.4	236.6	+0.3	
	631.49	250.7	250.1	+0.2	
2.91	438.58	110.7	111.7	0.0	(1)
	472.78	123.2	123.1	0.0	
	506.60	134.8	134.5	+0.3	
	541.81	146.6	146.2	+0.3	
	581.95	159.8	159.6	+0.1	
	614.66	170.7	170.5	+0.1	

TABLE XIII (Cont.)

Density lb/ft^3	Temperature °R	Observed Psia	Calculated Psia	Per Cent Difference	Experimental Investigator
1.68	407.93	62.99	63.41	-0.7	(1)
	437.88	68.79	68.96	-0.2	
	476.24	75.92	76.06	-0.2	
	509.56	81.96	82.21	-0.3	
	537.15	87.21	87.30	-0.1	
	566.27	92.62	92.66	0.0	
1.15	338.24	41.76	42.44	-1.6	(1)
	391.35	42.25	42.82	-1.3	
	422.63	46.43	46.71	-0.6	
	458.06	50.95	51.11	-0.3	
	494.62	55.47	55.64	-0.3	
	531.26	59.96	60.17	-0.4	
	566.80	64.29	64.57	-0.4	

TABLE XIV

COMPARISON OF AN EQUATION OF STATE* WITH EXPERIMENTALLY DETERMINED PVT DATA FOR "FREON-21"

Equation is:

$$P = -\frac{7.08189}{V^2} + \frac{0.101379}{V^3} - \frac{0.00075139}{V^4} + T\left[\frac{0.10426}{V} + \frac{0.00468\,09}{V^2} - \frac{0.0_{4}59943}{V^3} + \frac{0.0_{6}5342}{V^4}\right] - 1/T^3\left[\frac{38964000}{V^2} - \frac{37693}{V^4}\right],$$

where P is psia, V is ft^3/lb., and T is °R(°F +459.7)

Density lb /ft^3	Temperature °R	Obs.Pres. Psia	Calc. Pres. Psia	Per Cent Deviation	Experimental Investigator
5.4940	720.32	302.6	306.9	-1.4	(7)
	732.53	312.3	315.6	-1.0	
4.4653	706.07	252.9	256.3	-1.3	(7)
	739.55	273.5	275.2	-0.6	
	776.63	294.7	295.6	-0.4	
	803.45	310.4	311.0	-0.2	
3.5472	685.01	203.4	205.7	-1.1	(7)
	717.77	218.7	219.9	-0.5	
	762.41	238.1	239.1	-0.4	
	801.83	255.4	256.0	-0.2	
2.5244	659.99	147.11	148.38	-0.9	(7)
	699.95	159.31	160.19	-0.6	
	735.59	170.03	170.70	-0.4	
	770.87	180.03	181.09	-0.6	
1.5002	618.59	86.85	87.18	-0.4	(7)
	656.21	93.03	93.51	-0.5	
	698.69	100.52	100.65	-0.1	
	771.05	112.42	112.78	-0.3	
0.9188	587.09	52.08	52.47	-0.7	(7)
	618.95	55.49	55.67	-0.3	
	689.51	62.59	62.74	-0.2	
	771.59	70.88	71.10	-0.3	

TABLE XIV (Cont.)

Density lb /ft^3	Temperature °R	Obs. Pres. Psia	Calc. Pres. Psia	Per Cent Deviation	Experimental Investigator
0.42752	533.81	22.68	22.91	-1.0	(7)
0.36455	533.27	19.428	19.628	-1.0	
0.27916	533.81	15.005	15.161	-1.0	
0.27717	533.09	14.916	15.034	-0.8	
0.27242	537.77	14.784	14.918	-0.9	
0.27004	537.95	14.652	14.796	-1.0	
0.18799	533.09	10.230	10.278	-0.5	
0.12824	537.77	7.064	7.111	-0.7	
0.10023	533.09	5.511	5.522	-0.2	
0.06933	537.59	3.852	3.852	0.0	

TABLE XV

COMPARISON OF AN EQUATION OF STATE* WITH EXPERIMENTALLY DETERMINED PVT DATA FOR "FREON -22"

*Equation is :

$$P = -\frac{6.71638}{V^2} + \frac{0.094564}{V^3} - \frac{0.00068934}{V^4} + T\left[\frac{0.12300}{V} + \frac{0.00543136}{V^2} - \frac{0.0_4 68409}{V^3} + \frac{0.0_6 59962}{V^4}\right] - \frac{1}{T^3}\left[\frac{20177000}{V^2} - \frac{18882}{V^4}\right],$$

where P is psia, V is $ft^3/lb.$, and T is °R (°F + 459.7)

Density lb/cu ft	Temperature °R	Obs. Pres. Psia	Calc. Pres. Psia	Per Cent Difference	Experimental Investigator
37.500	668.66	782.6	780.7	+0.3	This report
	691.27	993.6	1000.0	-0.6	
	723.22	1306.5	1310.6	-0.3	
	756.84	1649.3	1638.0	+0.7	
	789.28	1983.8	1954.4	+1.5	
36.200	661.98	715.7	713.9	+0.2	This report
	684.48	913.3	922.4	-1.0	
	721.83	1267.8	1269.1	-0.1	
	760.10	1630.5	1624.8	+0.4	
30.800	666.59	759.8	751.1	+1.2	This report
	679.54	847.6	848.4	-0.1	
	709.00	1064.0	1069.7	-0.5	
	735.62	1271.1	1269.4	+0.1	
	781.22	1611.0	1611.5	0.0	
	826.81	1954.9	1953.3	+0.1	
30.273	666.38	751.9	749.6	+0.3	This report
	684.77	882.9	884.7	-0.2	
	703.96	1026.9	1025.5	+0.1	
	735.64	1260.8	1257.9	+0.2	
28.300	660.11	691.8	707.2	-2.2	This report
	670.12	774.8	774.5	0.0	
	689.09	895.8	902.0	-0.7	
	696.06	931.8	948.8	-1.8	
	723.33	1119.6	1131.6	-1.1	
	770.87	1453.8	1450.7	+0.2	
	798.79	1638.8	1637.7	+0.1	

TABLE XV (Cont.)

Density lb/cu ft	Temperature °R	Obs. Pres. Psia	Calc. Pres. Psia	Per Cent Difference	Experimental Investigator
19.160	667.08	725.7	725.3	0.0	This report
	677.61	778.6	767.7	-1.4	
	688.09	820.6	809.8	+1.3	
	715.79	932.6	920.9	+1.3	
	761.65	1122.5	1104.3	+1.6	
	808.56	1309.3	1291.4	+1.4	
	830.72	1394.9	1379.6	+1.1	
18.900	651.29	635.0	660.6	-3.9	This report
	660.16	684.3	695.7	-1.6	
	666.88	719.4	722.3	-0.4	
	695.80	844.2	836.4	+0.9	
	750.29	1065.9	1050.7	+1.4	
	779.79	1185.6	1166.4	+1.6	
	823.91	1351.7	1339.1	+0.9	
17.760	660.08	684.1	686.3	-0.3	This report
	674.77	745.5	739.8	+0.8	
	685.37	786.5	778.3	+1.1	
	712.89	889.6	878.2	+1.3	
	768.33	1088.6	1078.9	+0.9	
	821.38	1288.2	1270.3	+1.4	
4.961	584.75	267.5	273.7	-2.3	(7)
	608.87	287.3	291.8	-1.5	
	633.53	308.6	310.1	-0.5	
4.568	578.81	248.1	253.6	-2.2	(7)
	608.87	269.7	274.0	-1.6	
	632.81	287.2	290.3	-1.1	
	668.63	308.8	314.3	-1.8	
3.813	565.67	209.9	213.7	-1.8	(7)
	625.97	245.1	247.0	-0.7	
	685.55	278.5	279.7	-0.4	
	738.11	307.6	308.5	-0.3	
2.986	552.17	166.80	170.10	-1.9	(7)
	616.61	195.31	197.07	-0.9	
	686.99	224.7	226.4	-0.8	
	743.51	248.1	249.9	-0.7	
2.197	549.29	129.32	130.44	-0.9	(7)
	615.35	149.46	150.14	-0.5	
	682.31	168.71	170.15	-0.8	
	740.45	186.05	187.32	-0.7	

TABLE XV (Cont.)

Density lb/cu ft	Temperature °R	Obs. Pres. Psia	Calc. Pres. Psia	Per Cent Difference	Experimental Investigator
1.4750	549.29	90.57	91.45	-1.0	(7)
	593.75	99.27	100.09	-0.8	
	628.85	106.08	106.89	-0.8	
	668.09	113.86	114.50	-0.6	
1.0343	551.99	65.78	66.18	-0.6	(7)
	625.43	75.68	75.98	-0.4	
	684.83	83.37	83.90	-0.6	
	741.35	90.88	91.43	-0.6	
0.4582	539.39	29.49	29.67	-0.6	(7)
0.3314	727.49	29.26	29.38	-0.4	
0.2508	727.49	22.24	22.28	-0.2	
0.2271	536.87	14.755	14.802	-0.3	
0.2266	538.67	14.814	14.822	-0.1	
0.16896	727.49	14.990	15.043	-0.4	
0.16504	727.13	14.637	14.688	-0.3	
0.12043	536.15	7.876	7.886	-0.1	
0.11177	727.49	9.940	9.967	-0.3	
0.10844	727.13	9.667	9.667	0.0	
0.06460	536.15	4.246	4.244	0.0	
0.05692	726.95	5.072	5.080	-0.2	
0.06454	727.49	5.764	5.764	0.0	

TABLE XVI

COMPARISON OF AN EQUATION OF STATE* WITH EXPERIMENTALLY DETERMINED PVT DATA FOR "FREON-113"

*Equation is

$$P = -\frac{3.77770}{V^2} + \frac{0.035714}{V^3} - \frac{0.0_4 2242}{V^4} + T\left[\frac{0.05727}{V} + \frac{0.0023027}{V^2} - \frac{0.0_4 10598}{V^3} - \frac{0.0_6 1562}{V^4}\right] - \frac{1}{T^3}\left[\frac{26000000}{V^2} - \frac{20228}{V^4}\right],$$

where P is psia, V is $ft^3/lb.$, and T is °R(°F +459.7)

Density lb/ft^3	Temperature °R	Obs. Pres. Psia	Calc. Pres. Psia	Per Cent Difference	Experimental Investigator
9.394	818.58	290.4	290.7	-0.1	(7)
	841.44	308.2	307.7	+0.1	
8.173	806.88	259.1	260.5	-0.5	(7)
	829.74	274.7	274.8	0.0	
	854.58	291.1	290.3	+0.3	
	878.16	307.1	305.0	+0.7	
6.785	793.02	223.7	224.2	-0.2	(7)
	822.18	239.0	238.8	+0.1	
	852.06	254.7	253.7	0.0	
	877.98	268.1	266.5	+0.6	
4.708	762.24	162.39	162.23	+0.1	(7)
	798.96	174.59	174.13	+0.3	
	839.46	187.81	187.22	+0.3	
	877.26	200.31	199.42	+0.4	
3.714	740.10	129.03	129.32	-0.2	(7)
	785.46	140.64	140.53	+0.1	
	836.94	153.72	153.21	+0.3	
	877.26	163.71	163.13	+0.4	
2.5242	704.10	87.38	88.09	-0.8	(7)
	754.50	96.07	96.13	-0.1	
	812.46	105.77	105.42	+0.3	
	858.90	113.26	112.86	+0.4	

TABLE XVI (Cont.)

Density lb/ft^3	Temperature °R	Obs. Pres. Psia	Calc. Pres. Psia	Per Cent Difference	Experimental Investigator
1.7814	679.26	62.18	62.41	-0.4	(7)
	734.52	68.59	68.27	+0.5	
	797.88	75.58	75.24	+0.5	
	858.90	82.47	81.94	+0.7	

*This equation of state is calculated from the same reduced equation of state as "F-115", "F-114".

Source of data is Benning and McHarness, JLR-30-89, No. 11, Serial No. 15954.

TABLE XVII

COMPARISON OF AN EQUATION OF STATE* WITH EXPERIMENTALLY DETERMINED PVT DATA FOR "FREON -114"

Equation is

$$P = -\frac{3.52179}{V^2} + \frac{0.032939}{V^3} - \frac{0.0_4 2046}{V^4} + T\left[\frac{0.06278}{V} + \frac{0.0024973}{V^2} - \frac{0.0_4 1137}{V^3} - \frac{0.0_6 1658}{V^4}\right] - \frac{1}{T^3}\left[\frac{15397000}{V^2} - \frac{11724}{V^4}\right],$$

where P is psia, V is ft^3/lb., and T is °R(°F + 459.7)

Density lb/ft^3	Temperature °R	Obs. Pres. Psia	Calc. Pres. Psia	Per Cent Difference	Experimental Investigator
10.429	708.24	293.5	308.1	-4.7	(7)
	724.98	311.0	323.3	-3.8	
7.769	690.06	236.2	236.6	-0.2	(7)
	706.80	247.9	247.4	+0.2	
	724.98	260.0	259.1	+0.4	
	745.68	274.4	271.9	+0.9	
	764.04	286.0	284.1	+0.7	
	781.86	297.9	295.5	+0.8	
	799.68	310.2	306.9	+1.1	
6.328	673.50	197.07	198.12	-0.5	(7)
	697.80	210.3	210.3	0.0	
	732.36	228.5	227.6	+0.4	
	764.04	245.3	243.5	+0.7	
	799.50	263.6	261.2	+0.9	
4.484	648.84	146.22	145.57	+0.5	(7)
	686.46	158.86	158.18	+0.4	
	725.16	172.09	171.12	+0.6	
	762.78	185.32	183.67	+0.9	
	799.32	197.51	195.84	+0.9	
2.5414	605.64	82.97	83.63	-0.8	(7)
	642.90	89.88	90.24	-0.4	
	703.02	100.98	100.88	+0.1	
	767.10	112.47	112.19	+0.2	

TABLE XVII (Cont.)

Density lb/ft	Temperature °R	Obs. Pres. Psia	Calc. Pres. Psia	Per Cent Difference	Experimental Investigator
1.5780	573.78	51.39	51.54	-0.3	(7)
	639.30	58.49	58.49	0.0	
	702.12	64.78	65.14	-0.6	
	767.10	71.98	72.00	0.0	
0.4539	536.88	14.784	14.832	-0.3	(7)

*This equation of state is calculated from the same reduced equation of state as "F-115", "F-113".

TABLE XVIII

COMPARISON OF AN EQUATION OF STATE* WITH EXPERIMENTALLY DETERMINED PVT DATA FOR "FREON - 115"

$$*P = -\frac{3.1857748}{V^2} + \frac{0.028919059}{V^3} - \frac{17.4448 \times 10^{-6}}{V^4} + T\left[\frac{0.06941}{V} + \frac{0.00267975}{V^2} - \frac{1.18424\times10^{-5}}{V^3} - \frac{1.67627\times10^{-7}}{V^4}\right] - \frac{1}{T^3}\left[\frac{8343505}{V^2} - \frac{5984.903}{V^4}\right],$$

Where P is psia, V is ft^3/lb, and T is °R (°F+459.7)

Density lb/cu ft	Temperature °R	Experimental psia	Calculated psia	PerCent Deviation	Experimental Investigator
42.01	633.5	439	439.1	0.0	(34)
	641.7	487	489.7	-0.6	
	663.7	626	625.6	+0.1	
	688.6	790	779.8	+1.3	
	713.1	948	931.6	+1.7	
	747.8	1180	1146.8	+2.8	
37.504	642.0	487.7	487.5	+0.4	(34)
	663.5	601.1	603.8	-0.4	
	688.0	735.4	736.6	-0.2	
	737.4	1008.3	1004.3	+0.4	
	790.7	1307.0	1292.7	+1.1	
27.721	639.1	465.9	467.9	-0.4	(34)
	674.4	595.8	597.7	-0.3	
	743.0	843.3	849.3	-0.7	
	813.9	1099.7	1108.5	-0.8	
	862.8	1274.1	1285.9	-0.9	
23.042	638.9	455.6	455.0	+0.1	(34)
	645.6	475.6	474.3	+0.3	
	696.9	623.6	621.6	+0.3	
	766.9	822.1	821.7	+0.0	
	786.6	876.4	877.9	-0.2	
	837.6	1016.9	1023.2	-0.6	
16.675	619.8	373.0	376.3	-0.9	(34)
	646.2	430.1	425.6	+1.0	
	718.0	564.3	559.2	+0.9	
	802.7	714.2	716.0	-0.2	
	886.9	866.3	871.4	-0.6	

TABLE XVIII (Cont.)

Density lb/cu ft	Temperature °R	Experimental Psia	Calculated Psia	Per Cent Deviation	Experimental Investigator
7.0000	575.5	202.9	204.3	-0.7	(34)
	593.7	214.6	215.7	-0.5	
	608.5	223.8	224.9	-0.5	
	646.1	247.8	248.2	-0.2	
	670.2	263.2	263.1	0.0	
	701.3	282.5	282.3	+0.1	
	730.2	299.9	300.2	-0.1	
	754.1	314.4	314.9	-0.2	
5.8850	571.6	179.4	179.1	+0.2	(34)
	614.1	201.7	200.6	+0.6	
	651.3	220.7	219.3	+0.6	
	668.9	230.0	228.2	+0.8	
	718.2	253.9	252.9	+0.4	
	764.4	276.5	276.1	+0.2	
2.9650	534.5	94.0	94.7	-0.7	(34)
	569.7	102.6	102.8	-0.2	
	611.0	112.8	112.4	+0.4	
	661.9	124.7	124.1	+0.5	
	745.7	142.3	143.4	-0.7	
1.2970	492.2	39.9	41.1	-3.0	(34)
	535.5	44.5	45.2	-1.6	
	579.3	49.1	49.4	-0.6	
	620.0	52.7	53.2	-1.0	
	668.8	57.4	57.9	-0.8	
	717.0	62.1	62.4	-0.5	
	761.2	66.3	66.6	-0.5	
1.1350	470.3	34.4	34.5	-0.3	(34)
	492.2	36.4	36.3	+0.2	
	531.2	39.6	39.5	+0.2	
	581.3	43.9	43.7	0.0	
	621.8	47.3	47.0	+0.6	
	668.1	51.3	50.8	+0.9	
	715.2	55.1	54.7	+0.7	
	757.9	58.7	58.2	+0.8	

TABLE XIX

COMPARISON OF AN EQUATION OF STATE* WITH EXPERIMENTALLY DETERMINED PVT DATA FOR "FREON-116"

$$* \quad P = -\frac{2.83115}{V^2} + \frac{0.024597}{V^3} - \frac{0.0_3 14192}{V^4} + T\left[\frac{0.0777}{V} + \frac{0.00287102}{V^2} - \frac{0.0_4 121430}{V^3} - \frac{0.0_6 16450}{V^4}\right] - 1/T^3 \left[\frac{4231666}{V^2} - \frac{1715}{V^4}\right],$$

where P is psia, V is ft^3/lb, and T is °R (°F+459.7)

Temperature °R	Density lb/cu ft	Experimental Psia	Calculation Psia	Per Cent Deviation	Experimental Investigator
536.69	0.35582	14.687	14.671	+0.11	(41)
536.69	0.35250	14.559	14.536	+0.16	(41)
536.69	0.27795	11.503	11.490	+0.11	(41)
536.69	0.24810	10.272	10.265	+0.07	(41)
536.69	0.24438	10.124	10.112	+0.12	(41)
536.69	0.22681	9.394	9.391	+0.03	(41)
536.69	0.16957	7.033	7.034	-0.01	(41)

IV. SATURATED VAPOR AND LIQUID DENSITIES

A number of different investigators have reported saturated-vapor and liquid densities for various "Freons". In the case of the liquids all the densities have been measured experimentally. However, in the case of the vapors, only a few saturated-vapor densities have been determined directly (indicated by asterisks in Tables XX-XXVIII). For the most part saturated-vapor densities have been obtained by extrapolation of the isometrics, on a P-T plot, to the vapor-pressure curve.

The simplest correlation of saturated vapor and liquid densities is by means of a compressibility plot such as Fig. 24. Reference to this plot shows that the saturated densities fall roughly into three groups, just as in the case of the vapor pressure and the PVT data of the vapor.

The three saturated-vapor lines which have been drawn on Fig. 24 were obtained by determining the intersection of the constant T_R lines (T_R below 1) on the compressibility plots (Figs. 5 through 22) and the three vapor-pressure lines in Fig. 3.

The three saturated-liquid lines were drawn through the data. The saturated-liquid data were found to fall in the same three groups as the vapor-pressure and PVT data. However, the group containing "F-21 and 22" now falls below the other two groups instead of between them. No generalized equations have been developed for the saturated-liquid densities; however, Tables XXIX to XXXVII present the experimentally determined densities compared to those calculated from equations suggested by the principal investigator in each case.

TABLE XX

SATURATED VAPOR DENSITY OF "F-11"

Density lb/ft^3	Temperature °R	Reduced Pressure	Compressibility Factor	Experimental Investigator
1.1620	604.08	0.0766	0.887	(7)
1.9175	641.88	0.1326	0.876	(7)
3.489	693.72	0.2435	0.876	(7)
3.826	700.92	0.2641	0.801	(7)
4.631	717.48	0.3148	0.770	(7)
5.551*	736.85	0.3820	0.758	(9)
5.557	733.68	0.3717	0.741	(7)
6.814	750.96	0.4436	0.705	(7)
12.04*	803.27	0.6991	0.587	(9)
12.47*	806.69	0.7195	0.581	(9)
15.03*	820.01	0.8026	0.529	(9)

* Dew-point determination

TABLE XXI

SATURATED VAPOR DENSITY OF "F-12"

Density lb/ft^3	Temperature °R	Reduced Pressure	Compressibility Factor	Experimental Investigator
1.804	521.9	0.1261	0.898	(16)
2.361	539.8	0.1666	0.876	(16)
2.821	552.4	0.2003	0.862	(16)
2.891	551.3	0.1970	0.829	This report
3.00	553.6	0.2039	0.823	" "
3.170	557.5	0.2150	0.816	" "
3.337	564.5	0.2368	0.843	(16)
3.770	572.7	0.2645	0.822	(16)
4.528	583.8	0.3071	0.779	(16)
4.756	587.3	0.3210	0.771	(16)
5.187	594.0	0.3489	0.759	(7)
5.293	595.1	0.3541	0.754	(16)
6.537	610.3	0.4259	0.716	This report
10.49 *	647.8	0.643	0.634	(12)
10.75	646.6	0.6279	0.606	This report
11.936	652.7	0.6728	0.579	(7)
12.61 *	661.6	0.741	0.596	(12)
14.06	664.0	0.7597	0.546	This report
20.27	678.7	0.8756	0.427	This report

*Dew-point determination.

TABLE XXII

SATURATED-VAPOR DENSITY "F-13"

Temperature °F	Temperature °R	lb/ cu ft Density	Reduced Pressure	Compressibility Factor	Experimental Investigator
-75.37	384.33	1.15	0.0743	0.920	(1)
-56.97	402.33	1.68	0.1127	0.911	(1)
-28.75	430.95	2.91	0.1950	0.850	(1)
-7.24	452.46	4.27	0.280	0.793	(1)
12.70	472.40	6.00	0.378	0.729	(1)
31.03	490.73	8.27	0.513	0.691	(1)
46.62	506.32	10.82	0.623	0.622	(1)
55.85	515.55	12.77	0.710	0.590	(1)
74.77	534.47	19.75	0.896	0.465	(1)
83.93	543.63	36.07	1.000	0.279	(1)

TABLE XXIII

SATURATED VAPOR DENSITY OF "F-21"

Density lb/ft^3	Temperature °R	Reduced Pressure	Compressibility Factor	Experimental Investigator
0.9188	573.48	0.0674	0.920	(7)
1.5002	606.78	0.1135	0.897	(7)
2.5244	646.02	0.1904	0.839	(7)
3.5472	673.56	0.2643	0.795	(7)
4.4653	693.0	0.3272	0.760	(7)
5.4940	711.0	0.3947	0.726	(7)
6.549 *	729.65	0.4765	0.716	(9)
12.22 *	777.89	0.7417	0.560	(9)
18.65 *	792.29	0.8380	0.485	(9)

*Dew-point determination.

TABLE XXIV

SATURATED VAPOR DENSITY OF "F-22"

Density lb/ft^3	Temperature °R	Reduced Pressure	Compressibility Factor	Experimental Investigator
1.4750	497.34	0.1097	0.883	(7)
2.197	523.26	0.1650	0.850	(7)
2.986	543.96	0.2222	0.810	(7)
3.813	560.34	0.2812	0.779	(7)
4.568	568.44	0.330	0.752	(7)
4.961	574.92	0.353	0.733	(7)
17.760	661.2	0.941	0.454	This report
18.900	661.8	0.948	0.554	" "
19.160	662.4	0.961	0.297	" "
28.300	662.8	0.967	0.305	" "
30.273	663.5	0.977	0.288	" "
30.800	664.2	0.990	0.287	" "

TABLE XXV

SATURATED VAPOR DENSITY OF "F-113"

Density lb/ft^3	Temperature °R	Reduced Pressure	Compressibility Factor	Experimental Investigator
1.7814	667.98	0.1231	0.895	(7)
2.5242	696.6	0.1739	0.855	(7)
3.714	727.38	0.2537	0.812	(7)
4.708	743.22	0.3157	0.780	(7)
6.785	768.06	0.4255	0.706	(7)
8.173	781.38	0.4884	0.661	(7)
9.394	794.16	0.5504	0.638	(7)
9.917*	815.87	0.5965	0.638	(9)
15.22 *	848.45	0.7919	0.531	(9)
18.21 *	859.61	0.8686	0.480	(9)

*Dew-point determination.

TABLE XXVI

SATURATED VAPOR DENSITY OF "F-114"

Density lb/ft^3	Temperature °R	Reduced Pressure	Compressibility Factor	Experimental Investigator
1.5780	564.66	0.1065	0.898	(7)
2.5414	597.6	0.1729	0.855	(7)
4.484	640.26	0.3037	0.795	(7)
6.328	667.98	0.4118	0.732	(7)
7.769	686.34	0.4966	0.684	(7)
9.730*	698 69	0.5808	0.649	(9)
10.429	701.82	0.6084	0.625	(7)
14.91 *	728.39	0.7844	0.547	(9)
19.34 *	741.89	0.8930	0.467	(9)

*Dew-point determination.

TABLE XXVII

SATURATED VAPOR DENSITY OF "F-115"

Temperature °F	Temperature °R	Density lb/cu ft	Reduced Pressure	Compressibility Factor	Experimental Investigator
-1.3	458.4	1.135	0.06535	0.9130	(34)
5.0	464.7	1.297	0.08985	0.8904	(34)
51.5	511.2	2.965	0.1939	0.8326	(34)
95.3	555.0	5.885	0.3777	0.7545	(34)
106.3	566.0	7.000	0.4402	0.7245	(34)
159.1	618.8	16.675	0.8320	0.5263	(34)
170.0	629.7	23.042	0.9351	0.4200	(34)
174.3	634.0	27.721	0.9772	0.3625	(34)
175.89	635.59	37.21	1.000	0.2757	(34)

TABLE XXVIII

SATURATED-VAPOR DENSITY OF "F-116"

Density lb/ft^3	Temperature °R	Reduced Pressure	Compressibility Factor	Experimental Investigator
0.57087*	351.38	0.03398	0.956	(41)
0.56820*	351.18	0.03384	0.956	(41)
0.56286*	350.82	0.03345	0.956	(41)
0.56278*	350.77	0.03340	0.956	(41)
0.44028*	342.09	0.02560	0.961	(41)
0.40052*	338.94	0.02314	0.963	(41)
0.25247*	324.40	0.01411	0.973	(41)
0.24838*	323.93	0.01389	0.976	(41)

*Calculated from liquid volume and heat of vaporization.

TABLE XXIX

SATURATED-LIQUID DENSITY "F-11"

$$d_L = 123.982 - 0.035565T - 0.0_4 44318T^2 \text{ (420°R to 600°R)}$$

$$d_L = 95.489 + 0.059498T - 0.0_3 12370T^2 \text{ (600°R to 720°R)}$$

Temperature °R	Experimental d_L	Calculated d_L	Per Cent Deviation	Experimental Investigator
835.32	50.01			(9)
821.82	55.97			(9)
797.70	61.91			(9)
766.74	67.66			(9)
719.72	74.24	74.24	0.00	(9)
658.11	81.07	81.07	0.00	(9)
598.37	86.80	86.80	0.00	(9)
598.37	86.80	86.83	-0.02	(9)
579.54	88.48	88.49	-0.01	(11)
564.60	89.77	89.77	0.00	(11)
538.68	92.08	91.97	+0.12	(11)
525.58	93.05	93.05	0.00	(9)
522.66	93.30	93.29	+0.01	(51)
518.70	93.61	93.61	0.00	(19)
491.70	95.78	95.78	0.00	(11)
439.14	99.83	99.82	+0.01	(11)

TABLE XXX

SATURATED-LIQUID DENSITY "F-12"

$d_L = 122.195-0.033276T-0.0_4775T^2$

Temperature °R	Experimental d_L	Calculated d_L	Per Cent Deviation	Experimental Investigator
423.66	94.24	94.19	+0.05	(21)
440.58	92.53	92.49	+0.04	(21)
448.68	91.70	91.66	+0.04	(21)
459.66	90.59	90.52	+0.08	(21)
474.60	88.99	88.95	+0.04	(21)
491.70	87.06	87.10	+0.04	(21)
516.54	84.41	84.33	+0.09	(21)
537.78	81.66	81.89	-0.28	(21)
554.88	79.44	79.87	-0.54	(21)
555.06	79.42	79.85	-0.54	(21)
576.12	76.54	77.30	-0.98	(21)
593.40	73.88	75.16	-1.70	(21)

TABLE XXXI

SATURATED-LIQUID DENSITY "F-13"

$$d_L = 36.07 + 0.01566\ (T_c - T) + 1.110\ (T_c - T)^{1/2} + 6.665 (T_c - T)^{1/3} + 3.245 \times 10^{-5} (T_c - T)^2$$

Temperature °R	Experimental d_L	Calculated d_L	Per Cent Deviation	Experimental Investigator
537.78	50.90	50.86	+0.08	(1)
529.52	56.55	56.57	-0.04	(1)
511.82	63.95	63.98	-0.05	(1)
499.84	67.64	67.66	-0.03	(1)
484.88	71.55	71.52	+0.04	(1)
466.43	75.62	75.60	+0.03	(1)
433.56	81.81	81.77	+0.05	(1)
380.86	90.11	90.03	+0.09	(1)
334.45	96.30	96.38	-0.08	(1)
301.67	100.51	100.56	-0.05	(1)
235.65	108.48	108.46	+0.02	(1)

TABLE XXXII

SATURATED-LIQUID DENSITY "F - 21"

$d_L = 116.385 - 0.031060T - 0.0_4 50098\ T^2$ (420° R to 620°R)

Temperature °R	Experimental d_L	Calculated d_L	Per Cent Deviation	Experimental Investigator
794.10	50.77			(9)
775.92	55.97			(9)
746.04	61.82			(9)
708.78	67.66			(9)
654.06	74.25	74.64	-0.52	(9)
645.42	74.04	75.47	-0.57	(8)
610.68	77.67	78.74	-0.09	(8)
584.94	81.08	81.08	0.00	(9)
576.30	80.91	81.85	+0.07	(8)
521.58	85.72	86.55	-0.20	(8)
518.48	86.81	86.82	-0.01	(9)
491.70	88.21	89.00	-0.89	(8)
491.70	89.03	89.00	+0.03	(52)
455.07	91.15	91.88	-0.79	(8)
438.59	93.06	93.05	+0.01	(9)
418.80	93.83	94.59	-0.25	(8)

TABLE XXXIII

SATURATED-LIQUID DENSITY "F-22"

$d_L = 105.045 + 0.018668T - 0.0_3 14066T^2$ (370°R to 540°R)

$d_L = - 23.871 + 0.491523T - 0.0_3 574202T^2$ (540°R to 610°R)

Temperature °R	Experimental d_L	Calculated d_L	Per Cent Deviation	Experimental Investigator
648.86	51.02			(9)
635.29	55.99			(9)
611.71	61.93	61.94	-0.01	(9)
582.11	67.67	67.68	-0.01	(9)
538.84	74.26	74.26	0.00	(9)
484.27	81.10	81.10	0.00	(9)
431.09	86.82	86.82	0.00	(9)
367.50	93.07	93.08	- 0.01	(9)

TABLE XXXIV

SATURATED-LIQUID DENSITY "F-113"

$d_L = 122.879 - 0.0128016\ T - 0.0_4635861T^2$ (440°R to 700°R)

Temperature °R	Experimental d_L	Calculated d_L	Per Cent Deviation	Experimental Investigator
868.44	51.00			(9)
857.46	55.96			(9)
838.02	61.91			(9)
810.66	67.65			(9)
769.62	74.24			(9)
715.12	81.07	81.21	-0.17	(9)
659.37	86.79	86.79	0.00	(9)
640.29	88.55	88.61	-0.07	(9)
602.31	92.03	92.10	-0.08	(9)
591.64	93.05	93.05	0.00	(9)
563.95	95.30	95.44	-0.15	(9)
563.70	95.38	95.46	-0.08	(29)
554.70	96.13	96.21	-0.08	(33)
540.30	97.33	97.40	-0.07	(37)
538.02	97.46	97.56	-0.10	(9)
536.70	88.65	97.69	-9.25	(13)
536.70	97.61	97.69	-0.08	(33)
527.70	98.39	98.41	-0.02	(29)
516.83	99.28	99.28	0.00	(9)
509.70	99.76	99.84	-0.08	(37)
498.18	100.64	100.72	-0.08	(9)
491.70	101.11	101.21	-0.10	(48)
491.70	101.14	101.21	-0.07	(54,33)
438.78	105.23	105.02	+0.20	(9)

TABLE XXXV

SATURATED -LIQUID DENSITY "F-114"

$d_L = 123.943 - 0.016098T - 0.0_4847815T^2$ (420°R -570°R)

$d_L = 63.324 + 0.19430T - 0.0_3267447T^2$ (570°R-670°R)

Temperature °R	Experimental d_L	Calculated d_L	Per Cent Deviation	Experimental Investigator
747.66	50.77			(9)
738.30	55.97			(9)
722.10	61.92			(9)
699.96	67.66			(9)
665.08	74.25	74.25	0.00	(9)
619.30	81.08	81.08	0.00	(9)
574.43	86.69	86.68	+0.01	(9)
573.38	86.80	86.80	0.00	(9)
573.38	86.80	86.84	-0.05	(9)
570.86	87.12	87.13	-0.01	(9)
565.14	87.78	87.77	+0.01	(9)
554.90	88.91	88.91	0.00	(9)
554.70	88.76	88.93	-0.19	(33)
546.62	89.82	89.81	+0.01	(9)
536.70	90.84	90.89	-0.06	(33)
534.90	91.08	91.07	+0.01	(9)
528.08	91.80	91.80	0.00	(9)
517.96	92.86	92.86	0.00	(9)
516.18	93.06	93.05	+0.01	(9)
510.06	93.67	93.68	-0.01	(9)
502.14	94.49	94.48	+0.01	(9)
491.75	95.52	95.52	0.00	(9)
491.74	95.51	95.52	-0.01	(9)
491.70	95.52	95.53	-0.01	(16)
491.70	95.59	95.53	+0.06	(33)
472.58	97.37	97.40	-0.03	(9)
453.09	99.24	99.24	0.00	(9)
435.18	100.89	100.88	+0.01	(9)

TABLE XXXVI

SATURATED-LIQUID DENSITY "F-115"

$$d_L = 37.210 + 0.03648\,(T_c - T) + 1.1893\,(T_c - T)^{1/2} + 6.6857\,(T_c - T)^{1/3} + 2.8894 \times 10^{-5}\,(T_c - T)^2$$

Temperature °R	Experimental d_L	Calculated d_L	Per cent Deviation	Experimental Investigator
632.53	49.189	49.064	+0.25	(34)
613.20	61.656	61.781	-0.20	(34)
577.79	72.200	72.408	-0.29	(34)
561.67	75.634	75.915	-0.37	(20)
528.02	82.333	82.072	+0.32	(34)
473.32	90.130	90.182	-0.06	(34)
470.41	90.455	90.571	-0.13	(20)
423.66	96.423	96.451	-0.03	(34)
420.55	96.860	96.832	+0.03	(34)
316.49	108.247	108.247	0.00	(34)

TABLE XXXVII

SATURATED-LIQUID DENSITY "F-116"

$$d_L = 148.29 - 0.1368\ T$$

Temperature °R	Experimental d_L	Calculated d_L	Per Cent Deviation	Experimental Investigator
351.38	100.20	100.22	-0.02	(41)
351.18	100.20	100.25	-0.05	(41)
350.82	100.20	100.30	-0.10	(41)
350.77	100.20	100.30	-0.10	(41)
342.09	101.38	101.49	-0.11	(41)
338.94	102.58	101.92	+0.65	(41)
324.40	103.82	103.91	-0.09	(41)
323.93	103.82	103.98	-0.15	(41)

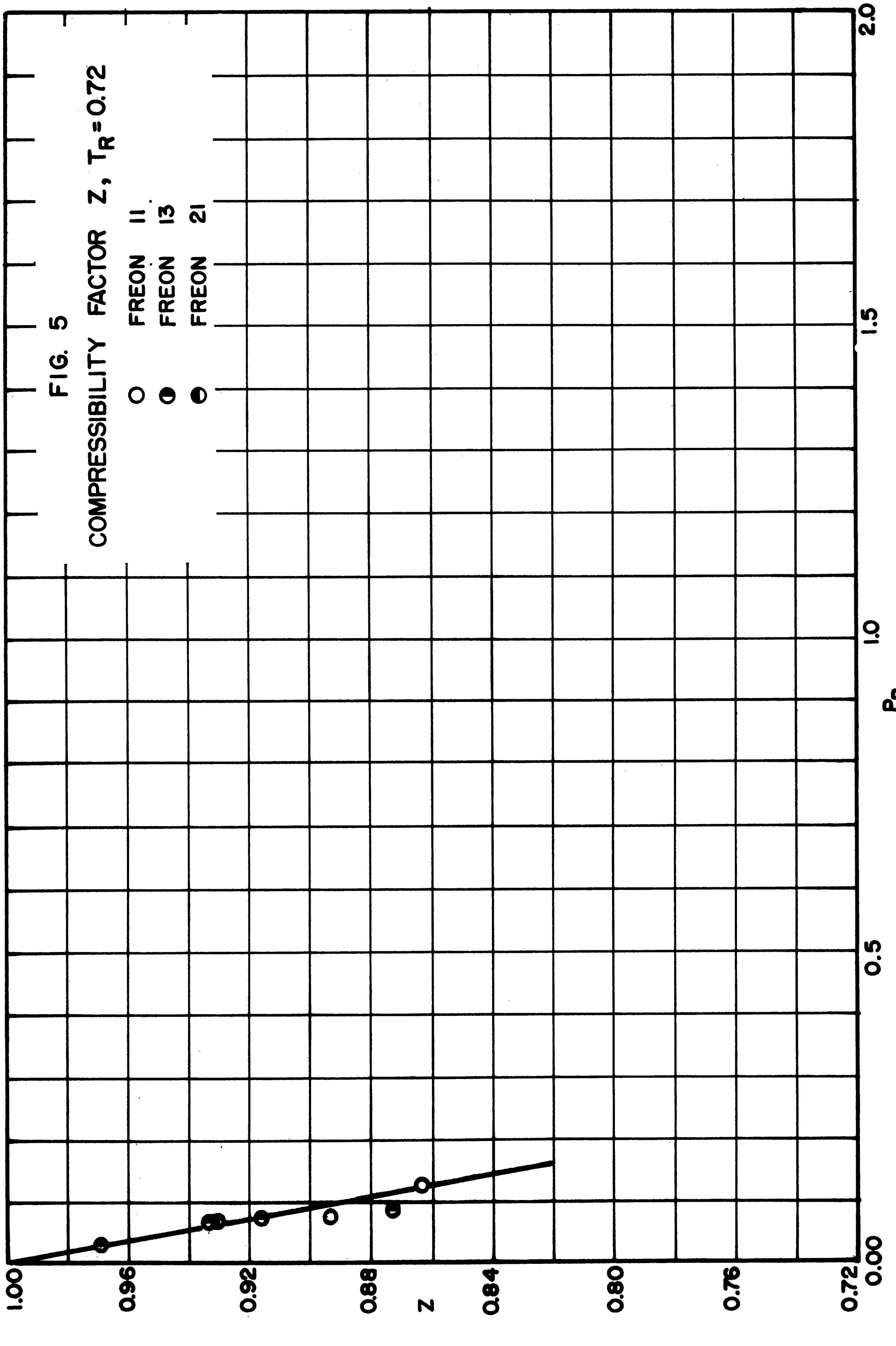


FIG. 5

COMPRESSIBILITY FACTOR Z, $T_R = 0.72$

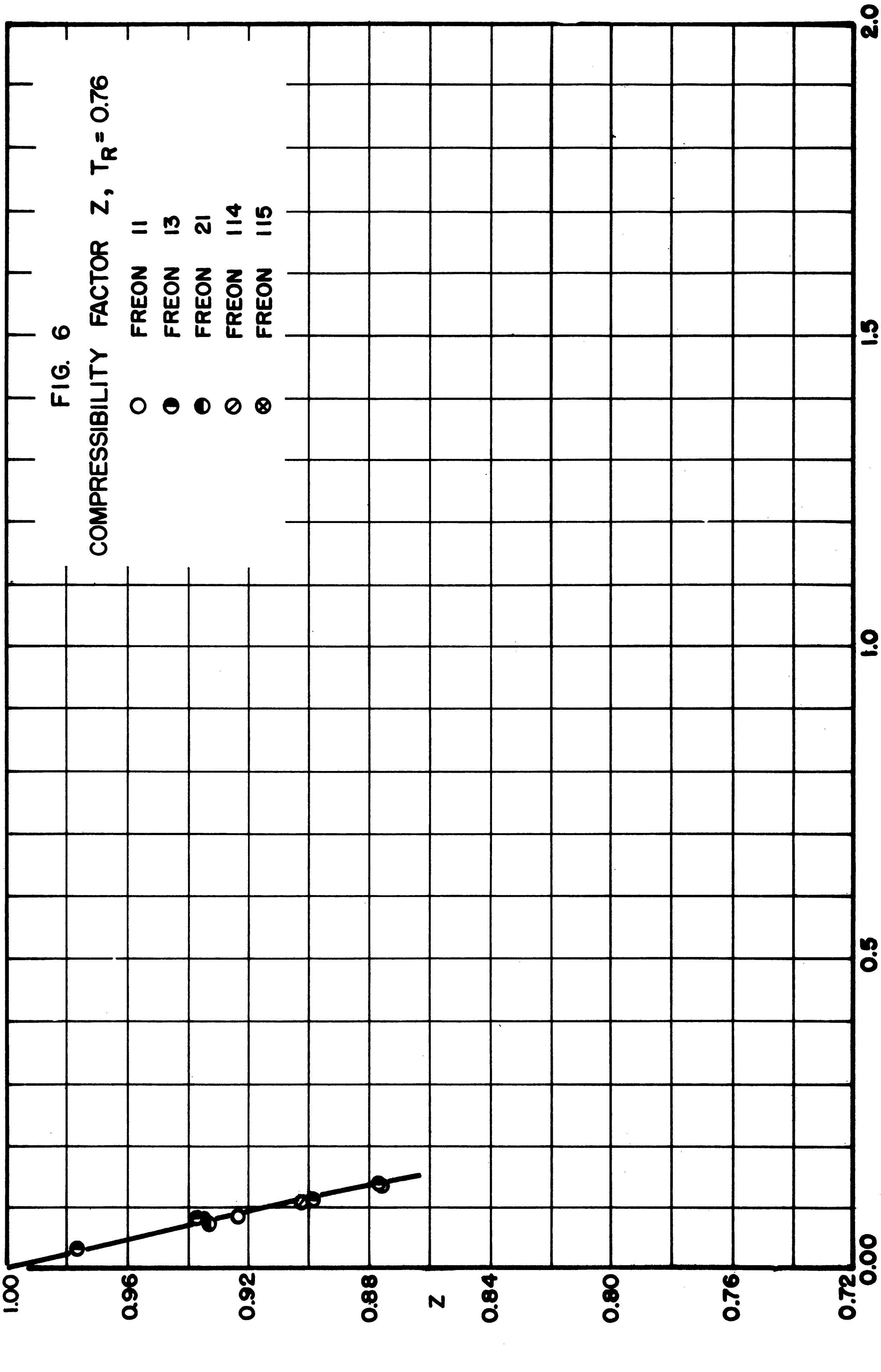


FIG. 6

COMPRESSIBILITY FACTOR Z, $T_R = 0.76$

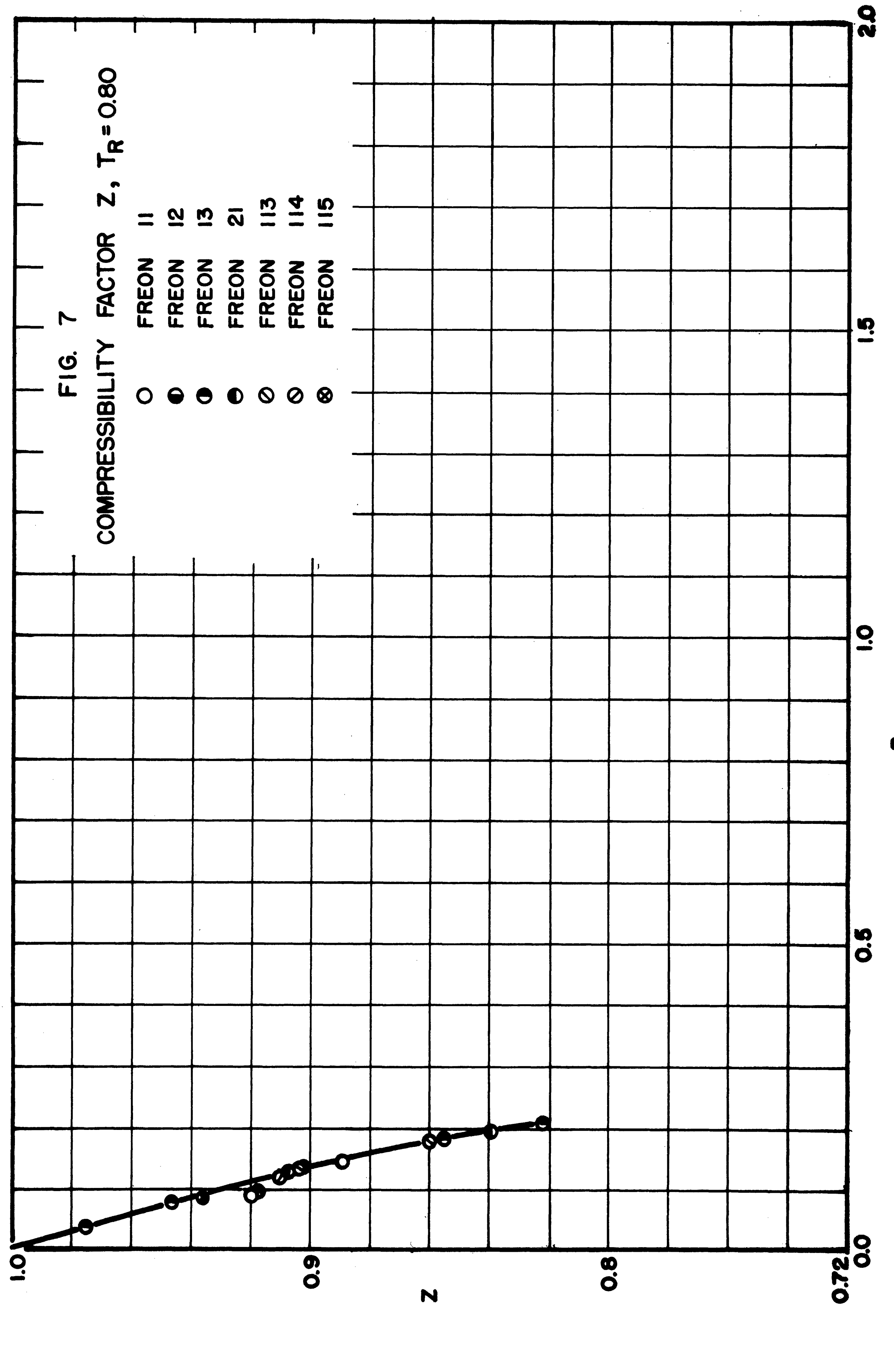


FIG. 7
COMPRESSIBILITY FACTOR Z, T_R = 0.80
FREON 11
FREON 12
FREON 13
FREON 21
FREON 113
FREON 114
FREON 115
Z
1.0
0.9
0.8
0.72
P_R
0.0
0.5
1.0
1.5
2.0

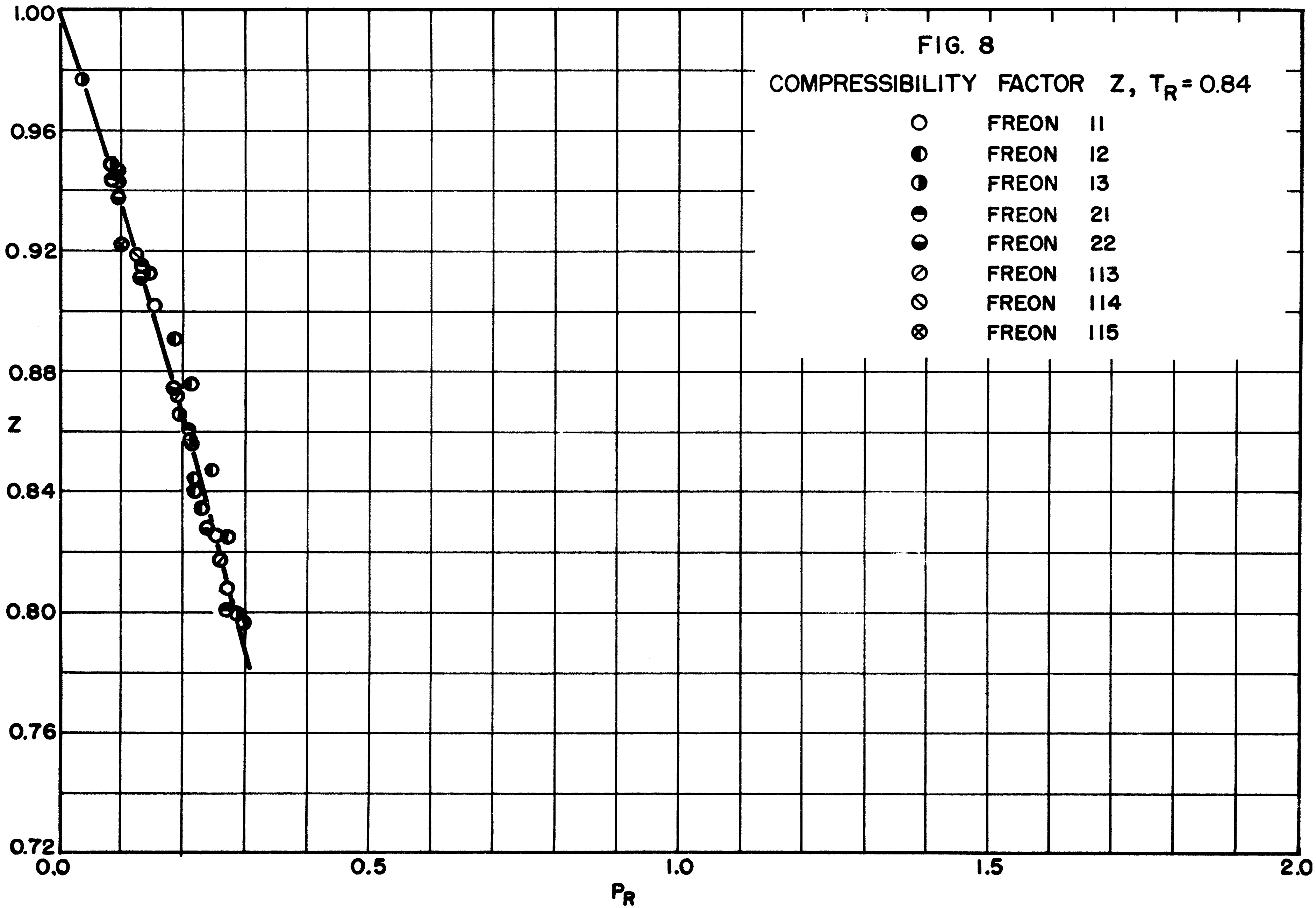


FIG. 8
COMPRESSIBILITY FACTOR Z, $T_R = 0.84$
FREON 11
FREON 12
FREON 13
FREON 21
FREON 22
FREON 113
FREON 114
FREON 115
1.00
0.96
0.92
0.88
Z
0.84
0.80
0.76
0.72
0.0
0.5
1.0
1.5
2.0
P_R

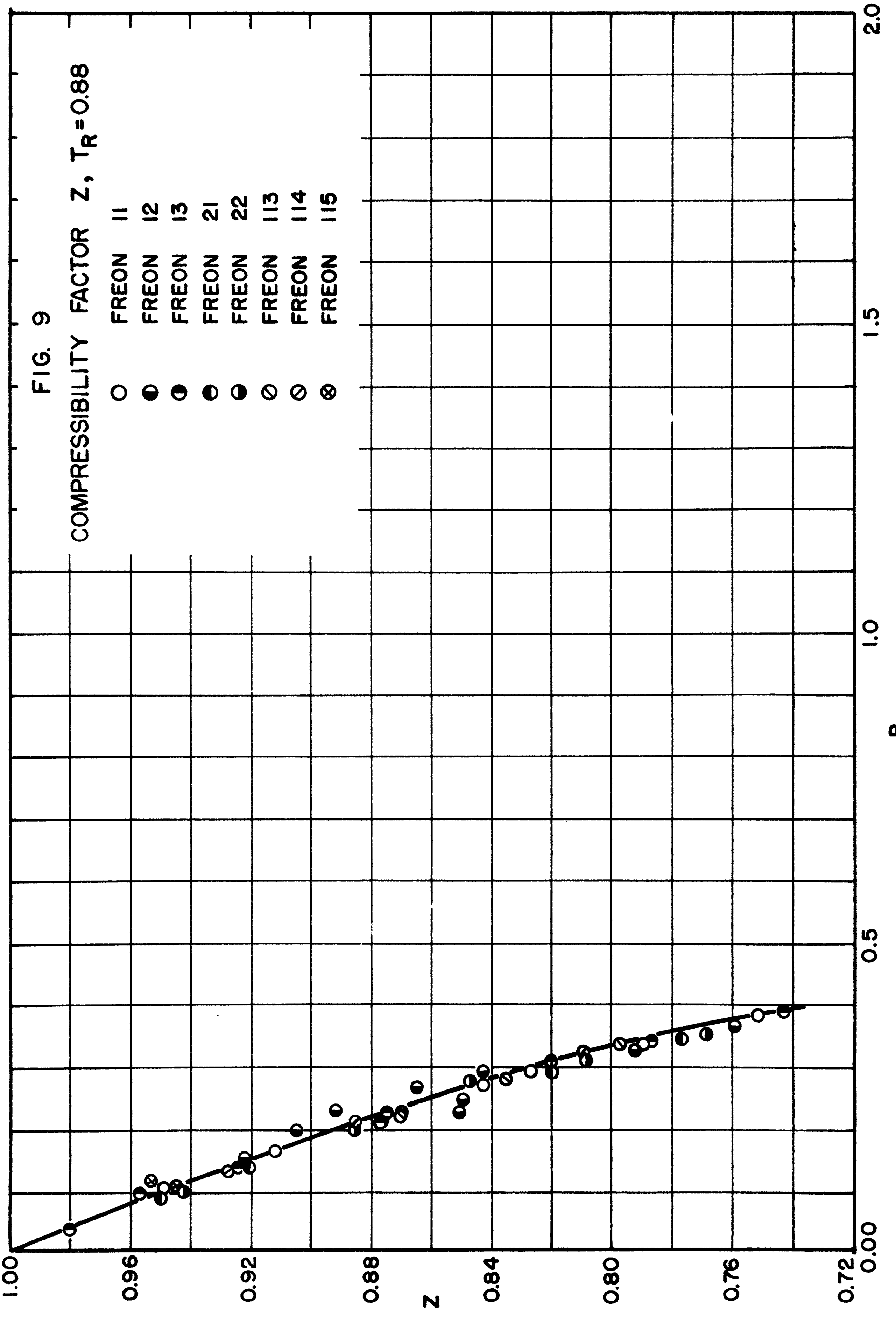


FIG. 9
COMPRESSIBILITY FACTOR Z, T_R=0.88
FREON 11
FREON 12
FREON 13
FREON 21
FREON 22
FREON 113
FREON 114
FREON 115
Z
1.00
0.96
0.92
0.88
0.84
0.80
0.76
0.72
P_R
0.00
0.5
1.0
1.5
2.0

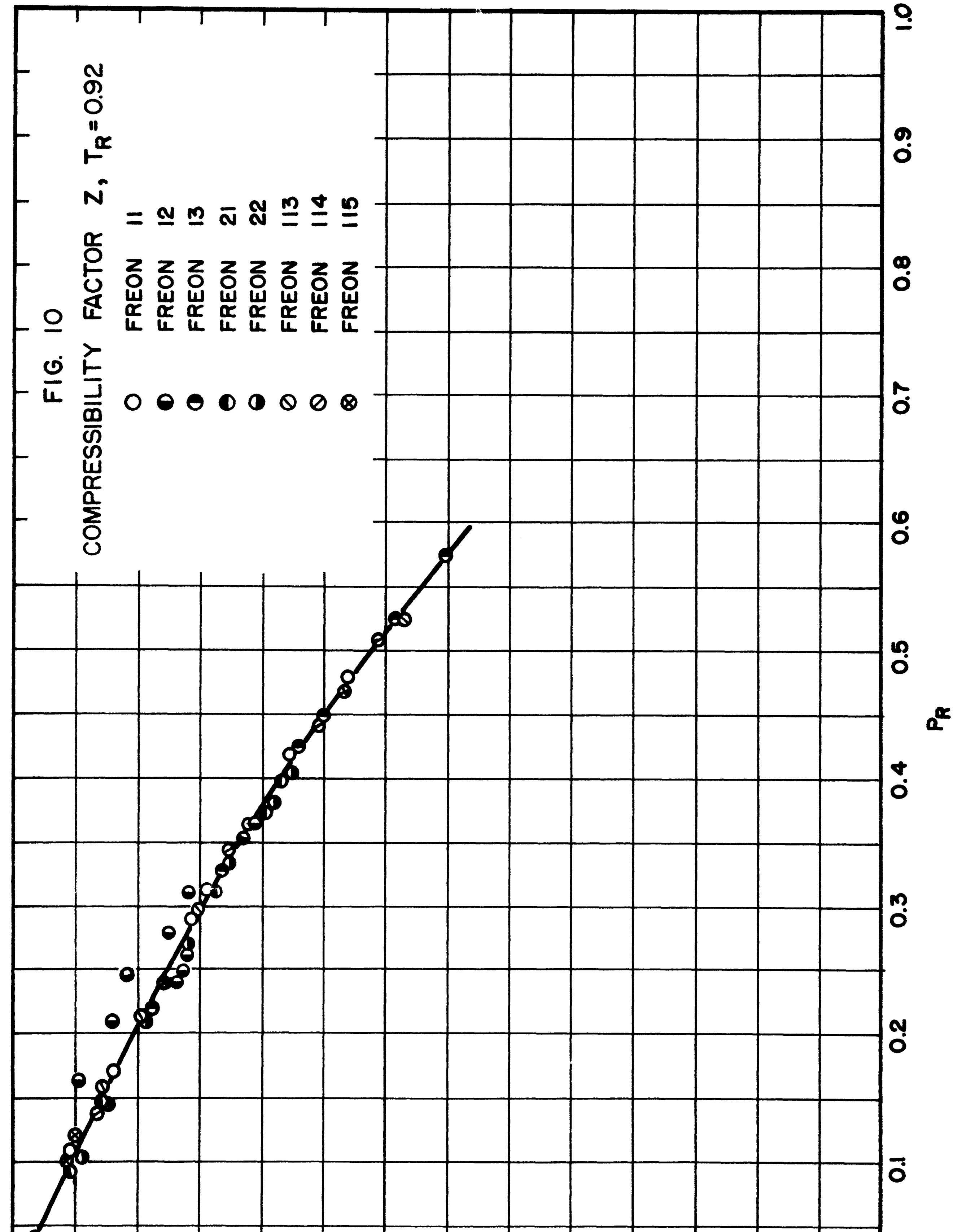


FIG. 10
COMPRESSIBILITY FACTOR Z, T_R = 0.92
FREON 11
FREON 12
FREON 13
FREON 21
FREON 22
FREON 113
FREON 114
FREON 115
Z
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
P_R
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

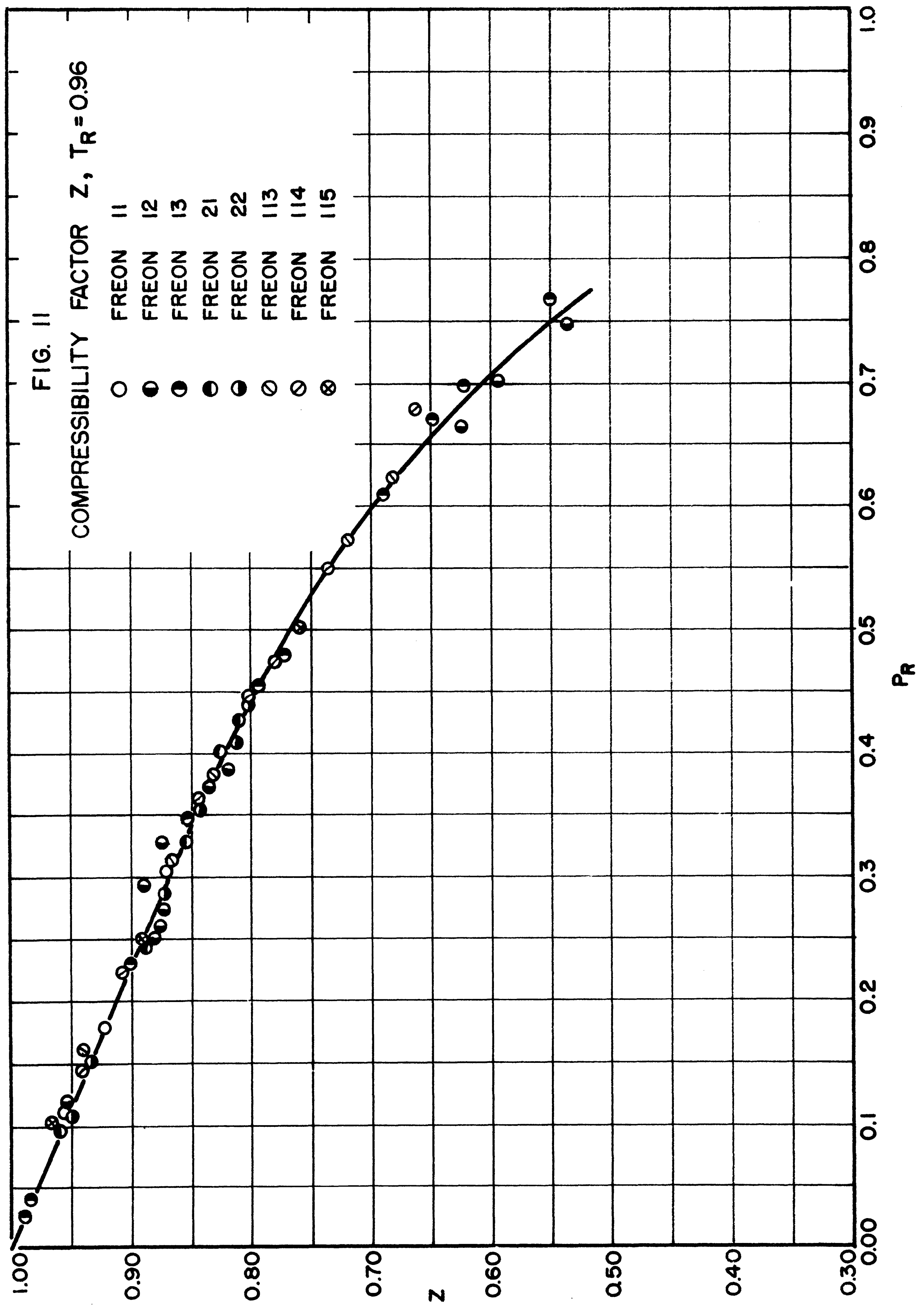


FIG. 11
COMPRESSIBILITY FACTOR Z, $T_R = 0.96$
FREON 11
FREON 12
FREON 13
FREON 21
FREON 22
FREON 113
FREON 114
FREON 115
Z
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
P_R
0.00
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

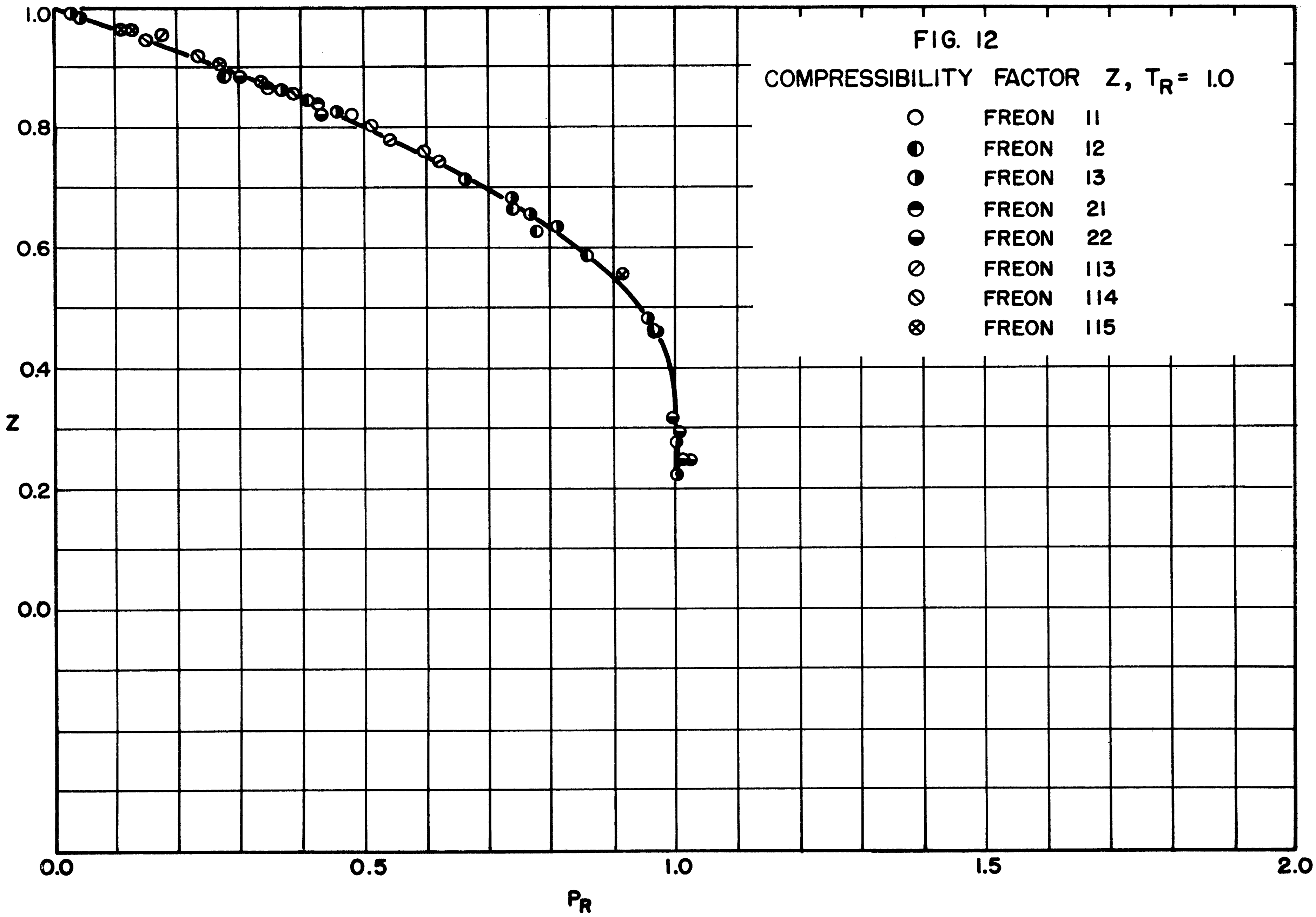


FIG. 12
COMPRESSIBILITY FACTOR Z, T_R = 1.0
FREON 11
FREON 12
FREON 13
FREON 21
FREON 22
FREON 113
FREON 114
FREON 115
1.0
0.8
0.6
0.4
Z
0.2
0.0
0.0
0.5
1.0
1.5
2.0
P_R

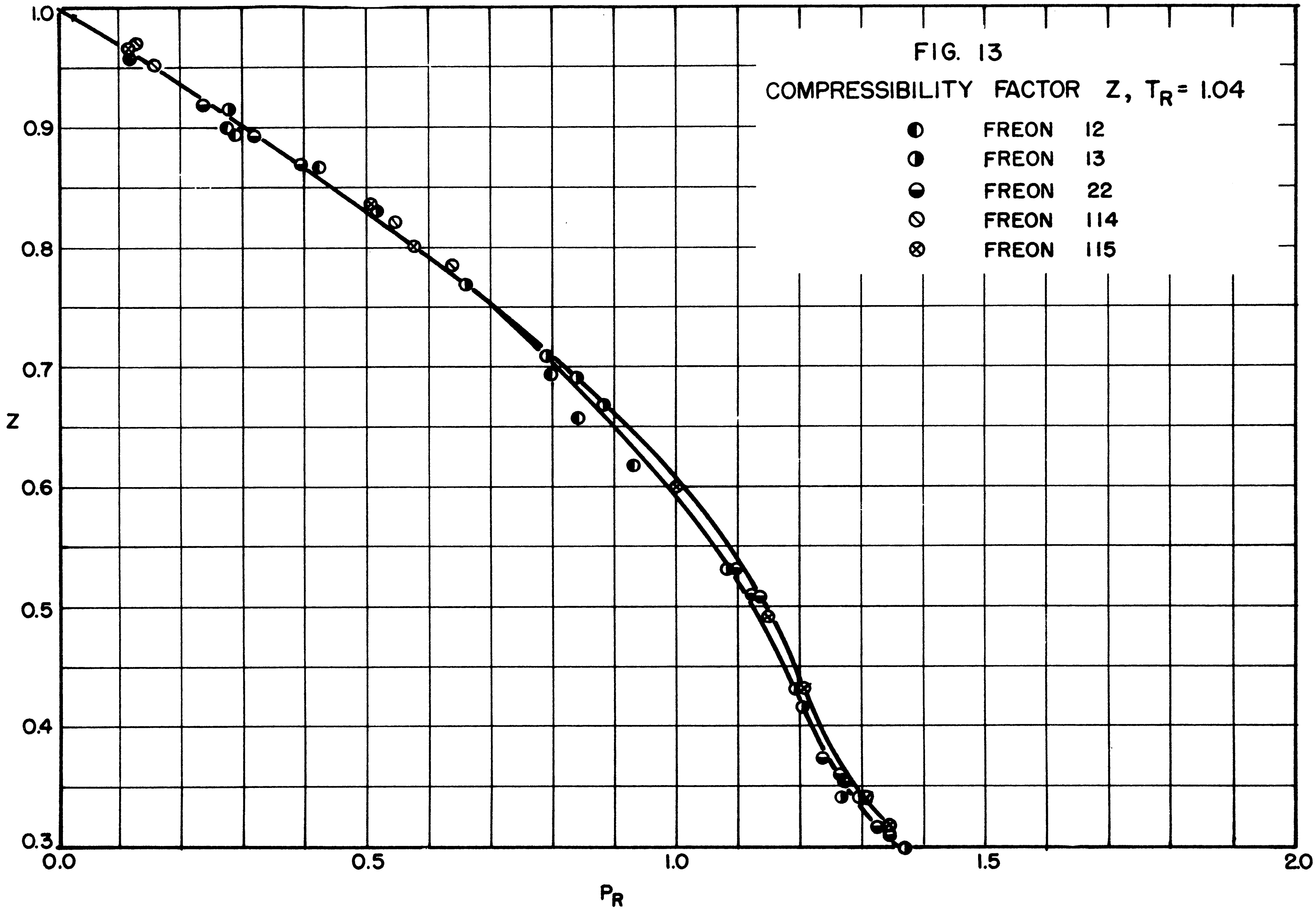


FIG. 13
COMPRESSIBILITY FACTOR Z, T_R = 1.04
FREON 12
FREON 13
FREON 22
FREON 114
FREON 115
Z
P_R
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.0
0.5
1.0
1.5
2.0

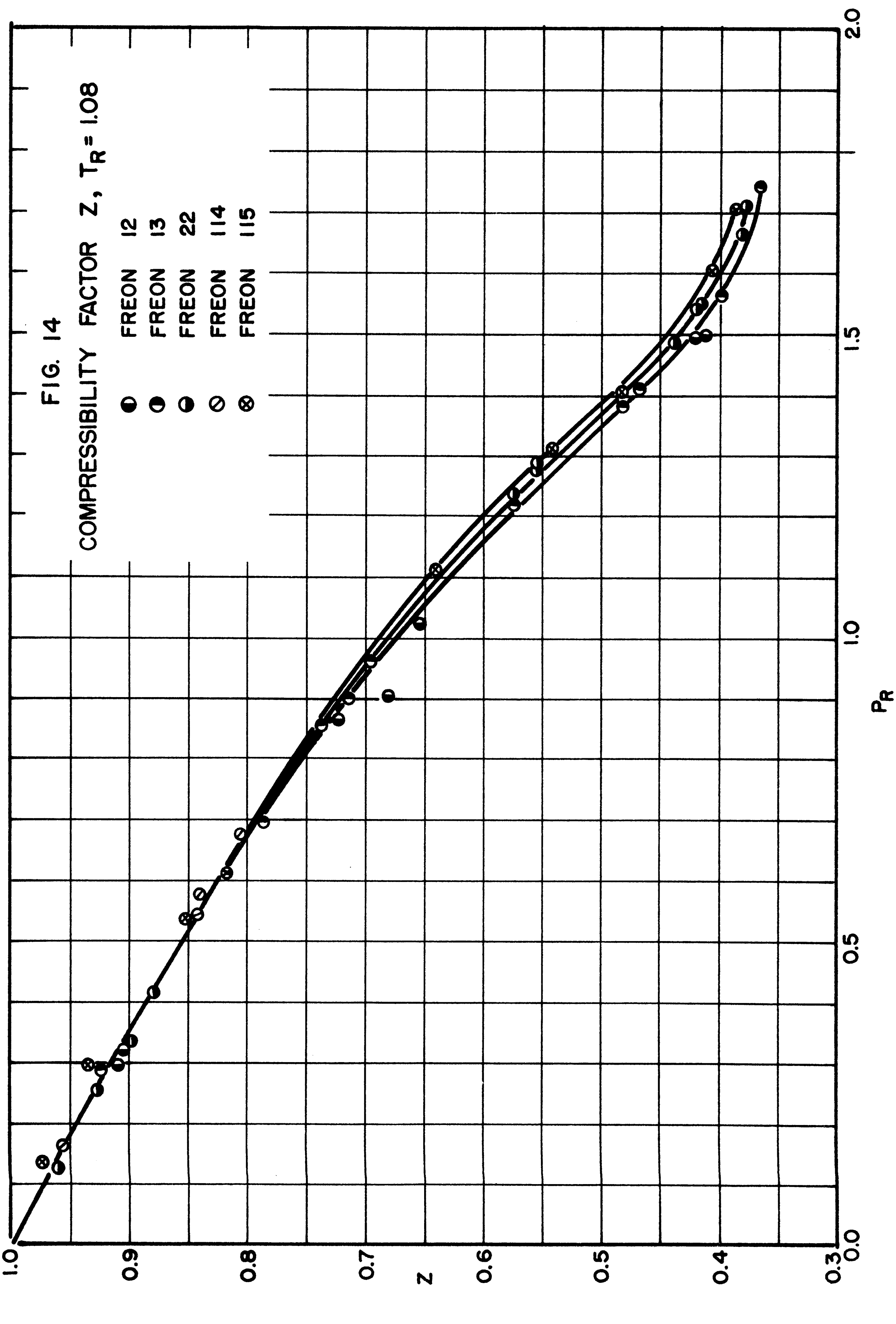


FIG. 14
COMPRESSIBILITY FACTOR Z, T_R = 1.08
FREON 12
FREON 13
FREON 22
FREON 114
FREON 115
Z
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.0
0.5
1.0
1.5
2.0
P_R

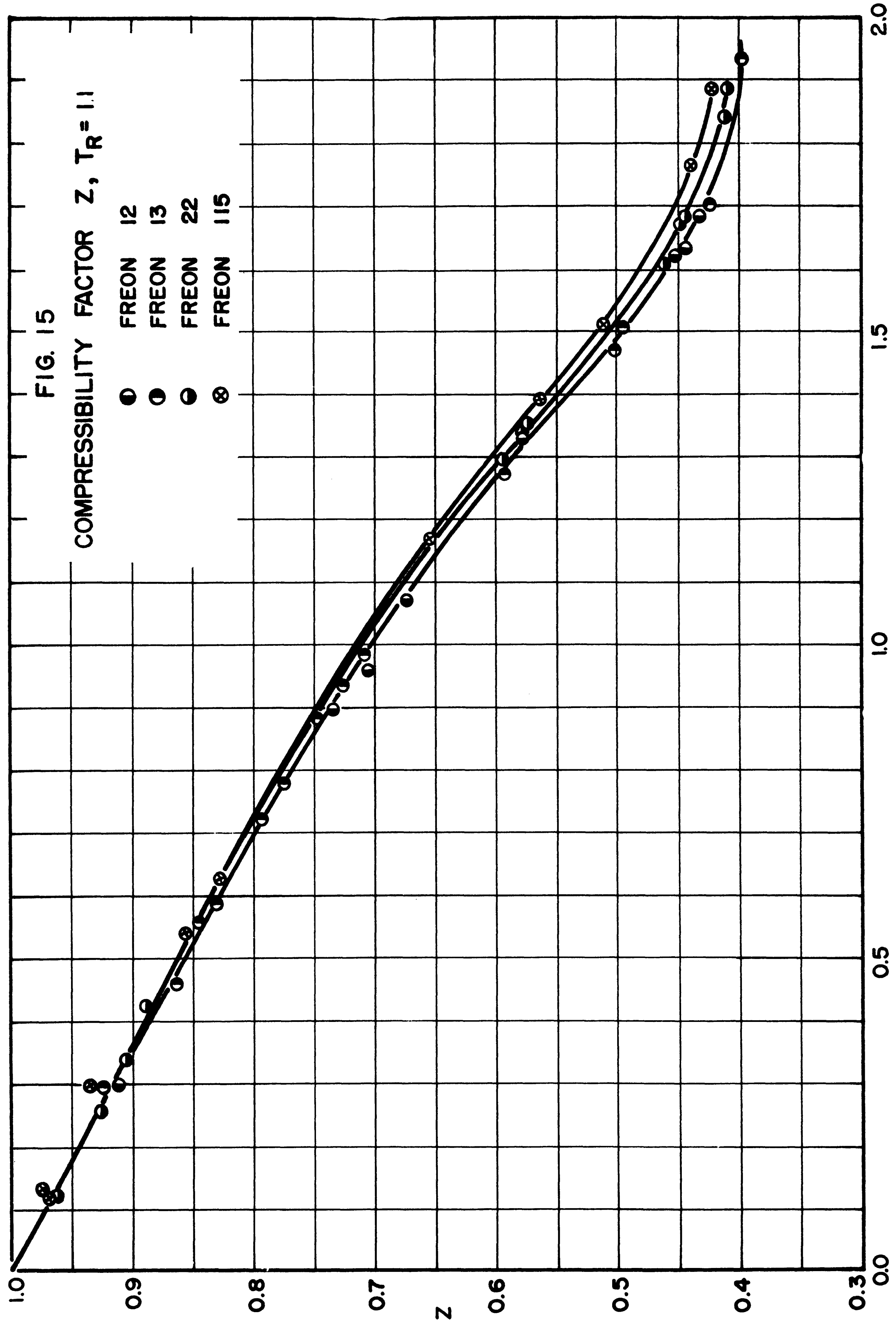


FIG. 15
COMPRESSIBILITY FACTOR Z, $T_R = 1.1$

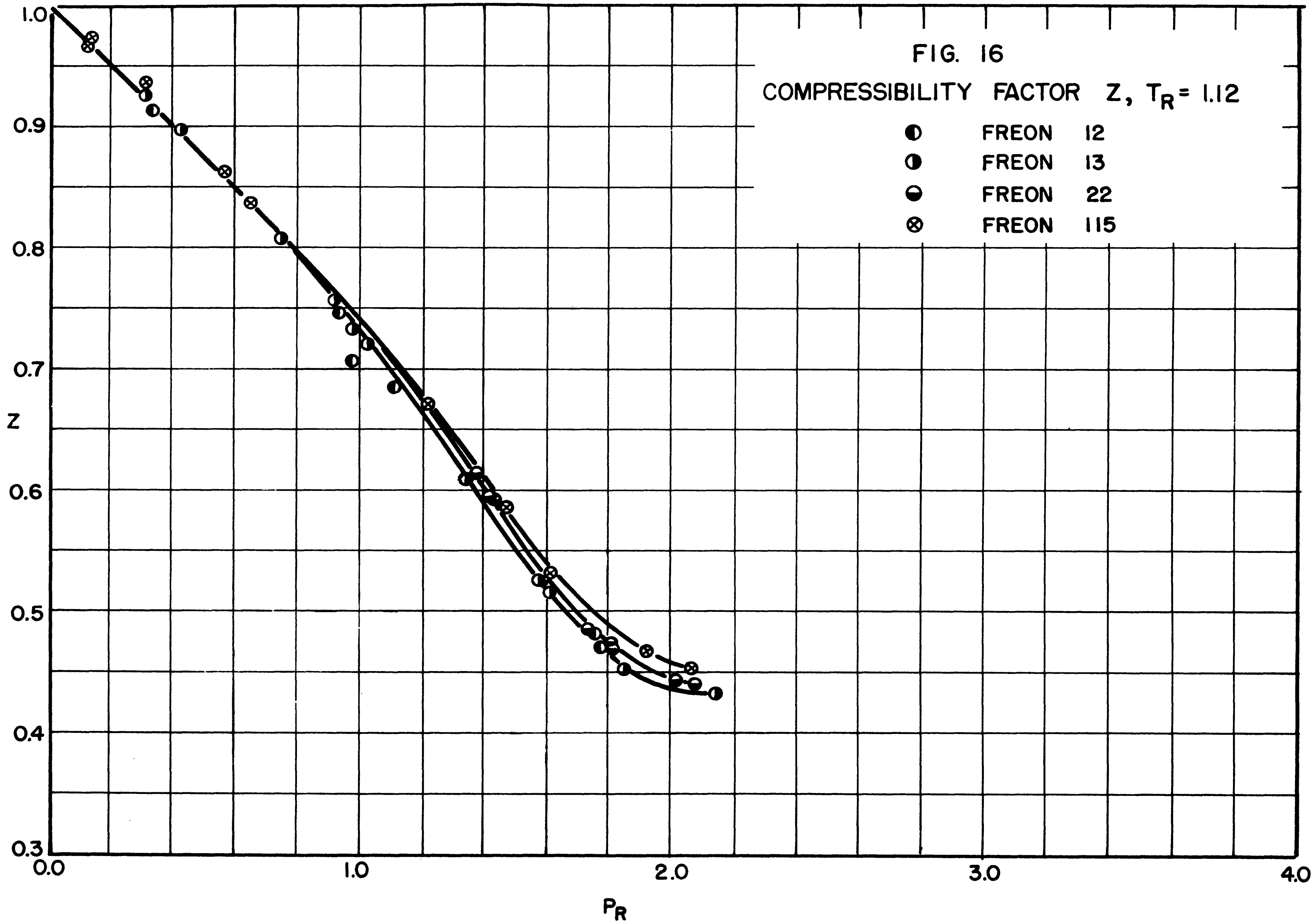


FIG. 16
COMPRESSIBILITY FACTOR Z, T_R = 1.12
FREON 12
FREON 13
FREON 22
FREON 115
Z
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.0
1.0
2.0
3.0
4.0
P_R

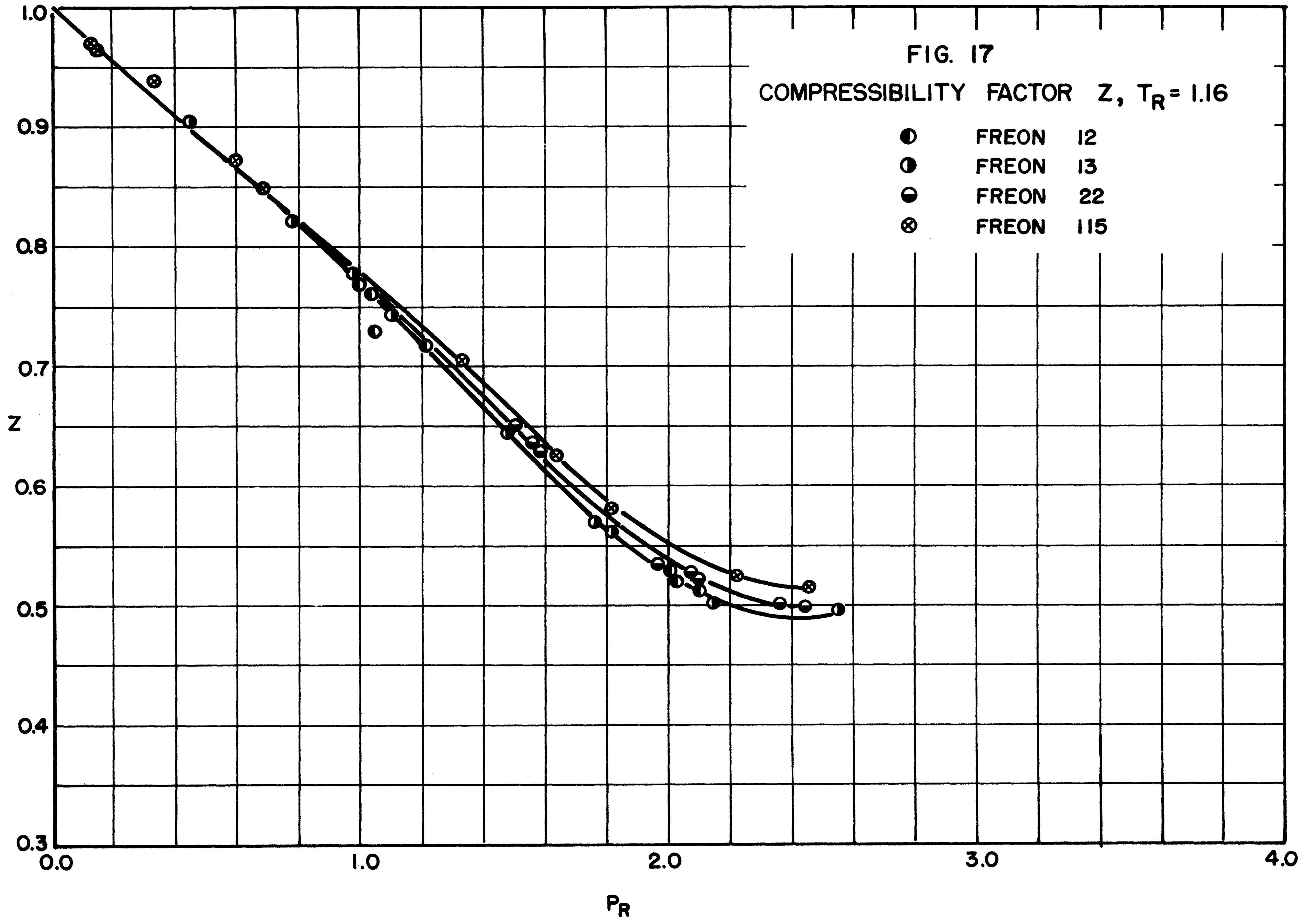


FIG. 17
COMPRESSIBILITY FACTOR Z, T_R = 1.16
FREON 12
FREON 13
FREON 22
FREON 115
Z
P_R
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.0
1.0
2.0
3.0
4.0

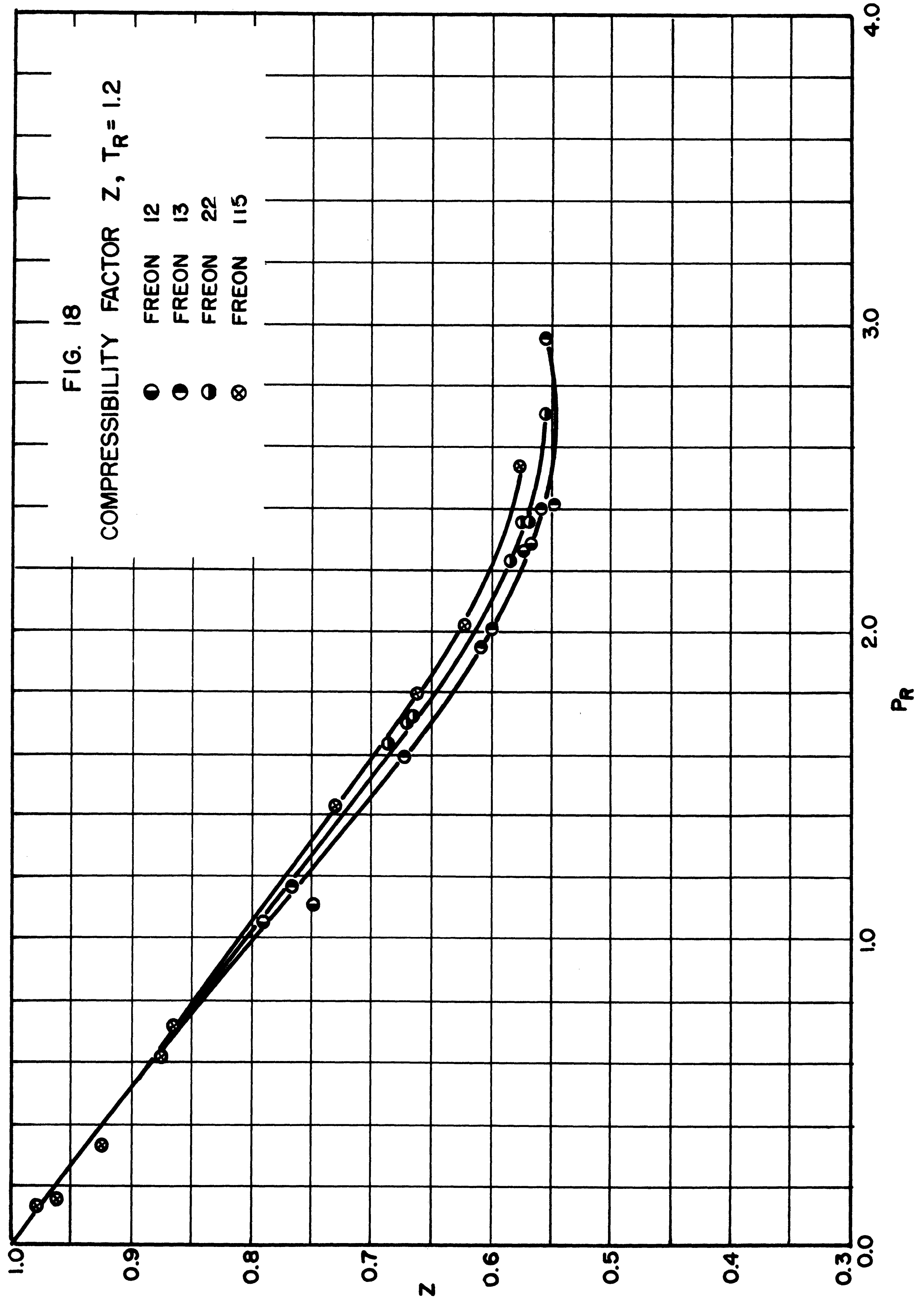


FIG. 18
COMPRESSIBILITY FACTOR Z, T_R = 1.2
FREON 12
FREON 13
FREON 22
FREON 115
Z
P_R
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.0
1.0
2.0
3.0
4.0

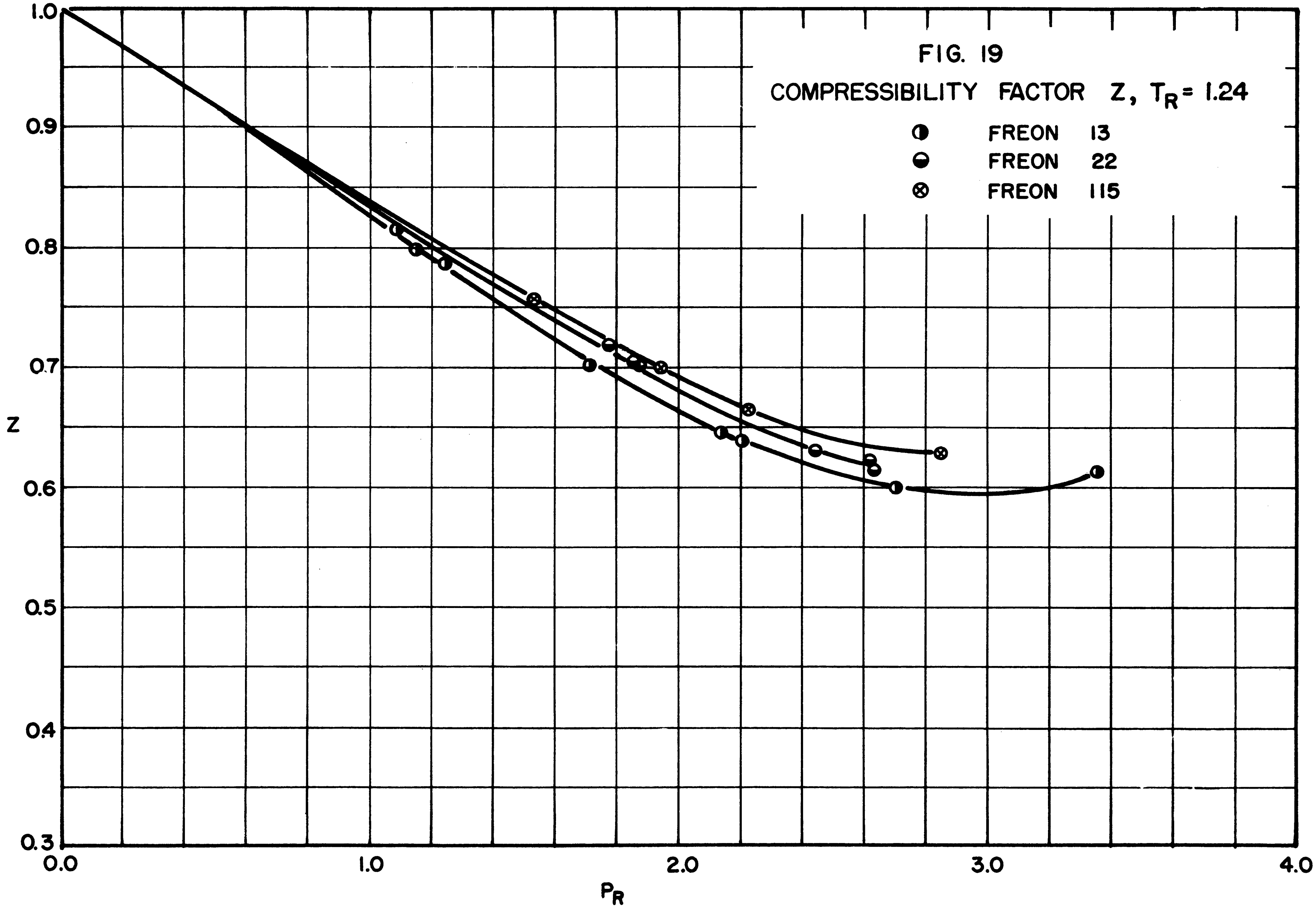


FIG. 19
COMPRESSIBILITY FACTOR Z, T_R = 1.24
FREON 13
FREON 22
FREON 115
Z
P_R
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.0
1.0
2.0
3.0
4.0

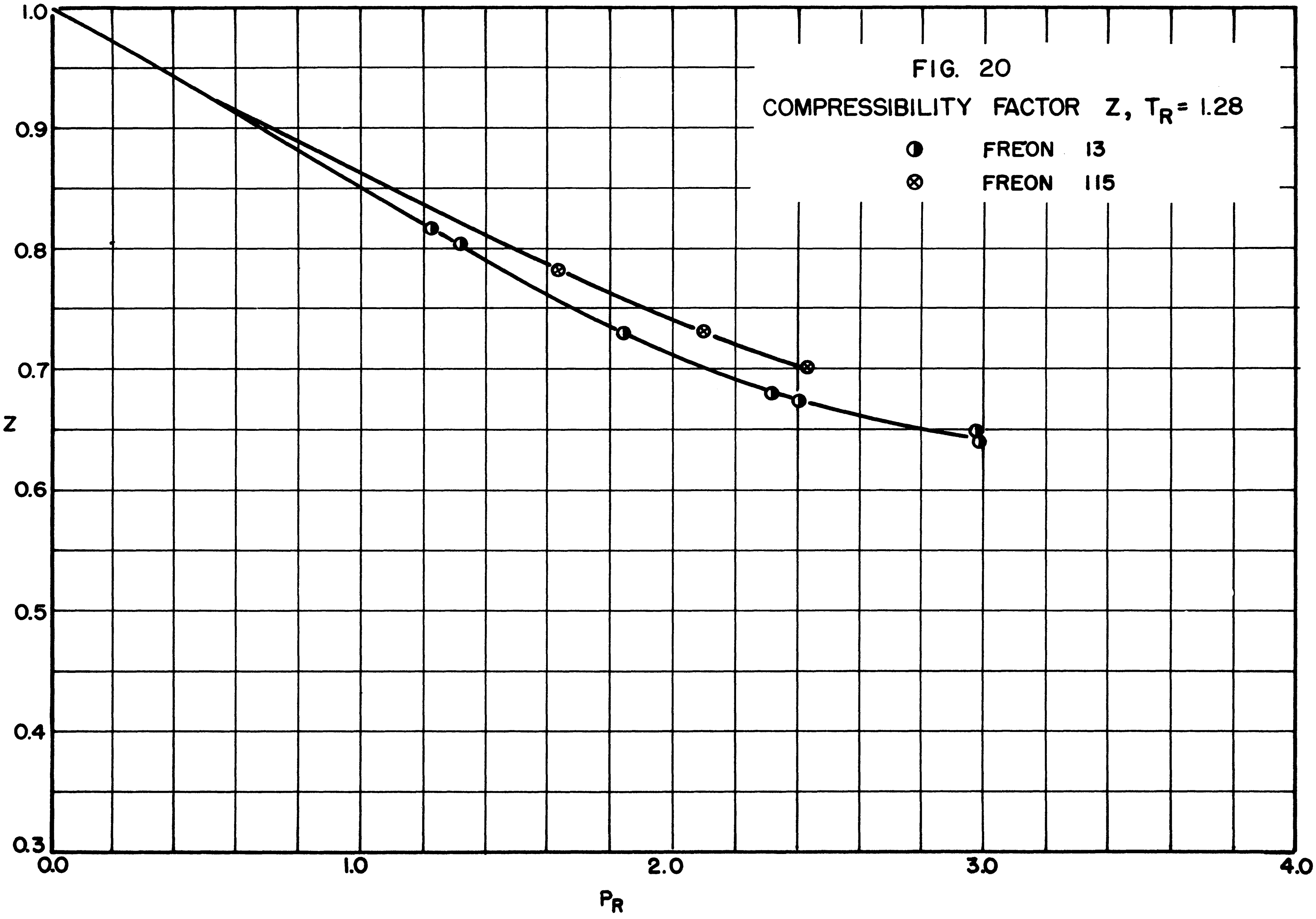


FIG. 20
COMPRESSIBILITY FACTOR Z, T_R = 1.28
FREON 13
FREON 115
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
Z
0.0
1.0
2.0
3.0
4.0
P_R

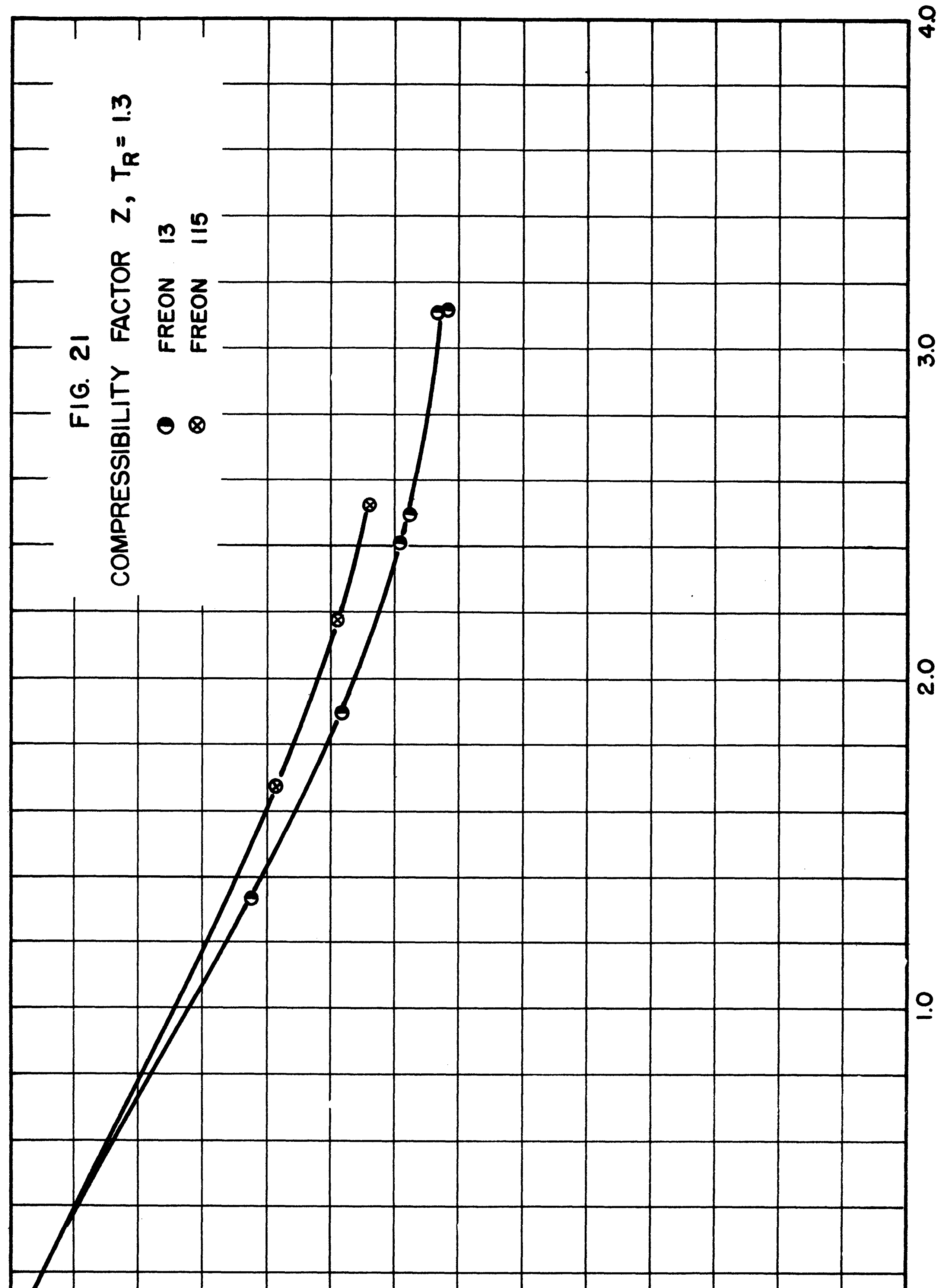


FIG. 21
COMPRESSIBILITY FACTOR Z, T_R = 1.3
FREON 13
FREON 115
Z
P_R
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.0
1.0
2.0
3.0
4.0

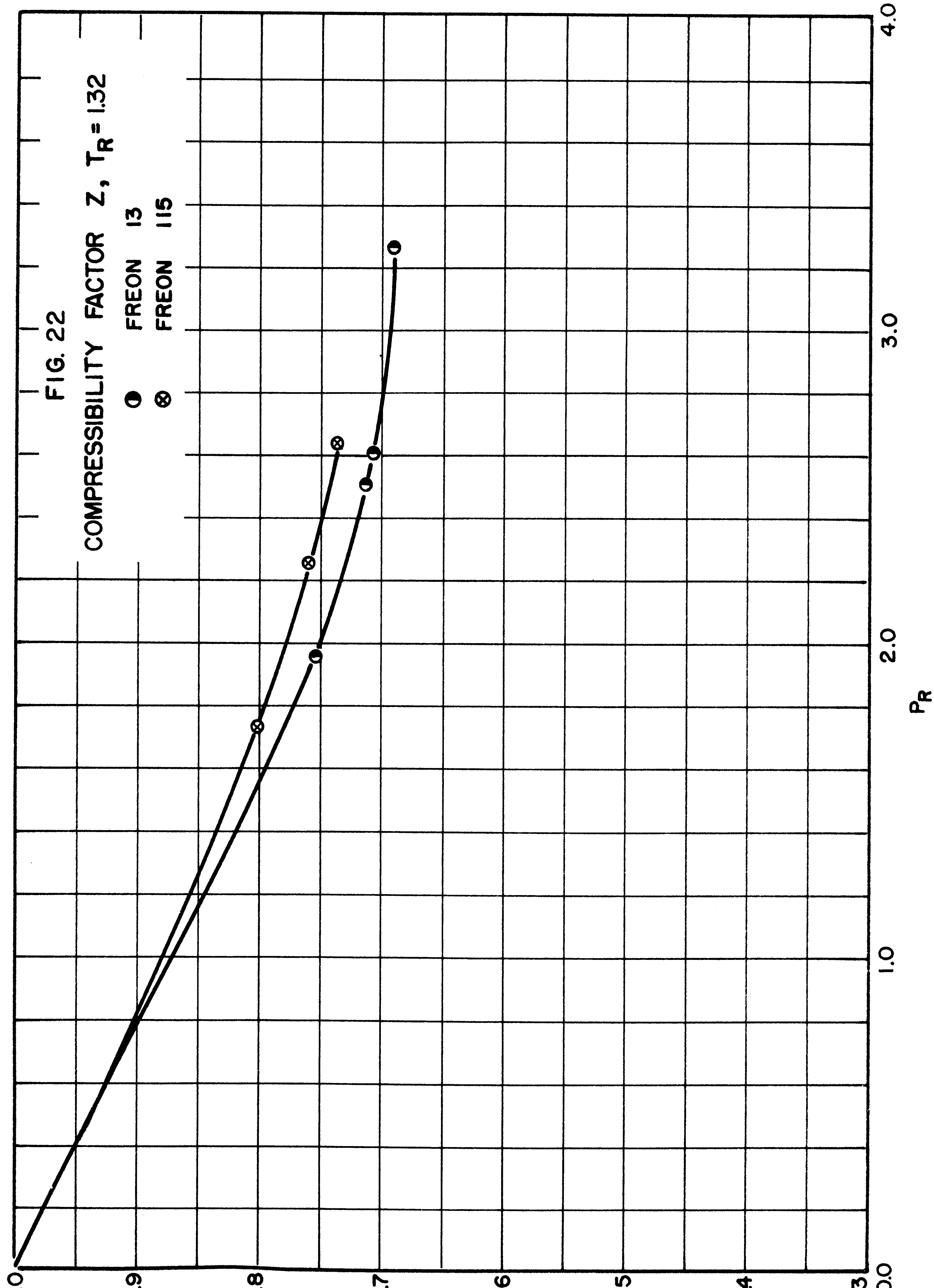


FIG. 22
COMPRESSIBILITY FACTOR Z, $T_R = 1.32$

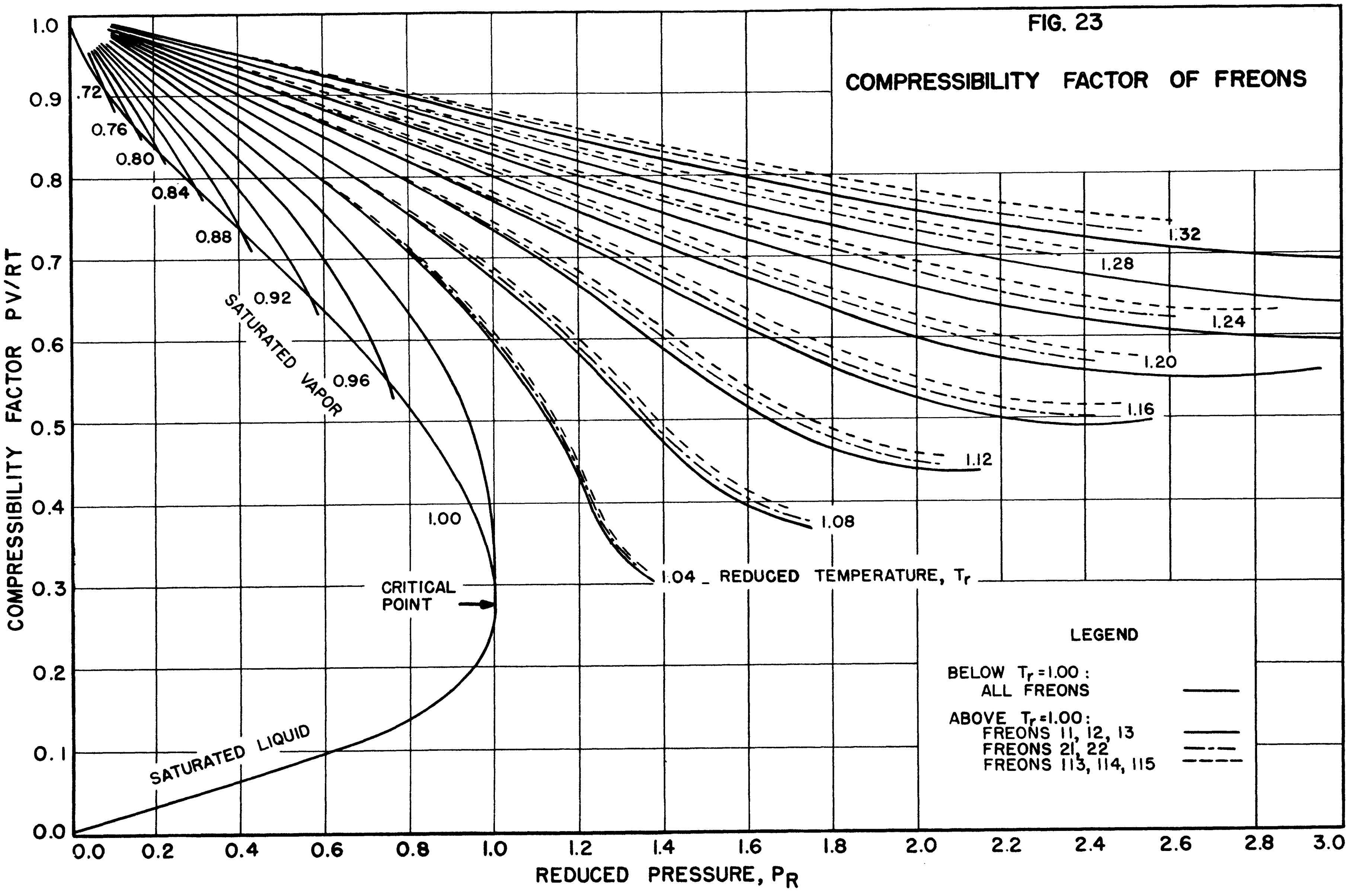


FIG. 23
COMPRESSIBILITY FACTOR OF FREONS
.72
0.76
0.80
0.84
0.88
0.92
0.96
1.00
1.04 _ REDUCED TEMPERATURE, Tr
1.08
1.12
1.16
1.20
1.24
1.28
1.32
SATURATED VAPOR
SATURATED LIQUID
CRITICAL POINT
LEGEND
BELOW Tr=1.00 :
ALL FREONS
ABOVE Tr=1.00:
FREONS 11, 12, 13
FREONS 21, 22
FREONS 113, 114, 115
COMPRESSIBILITY FACTOR PV/RT
REDUCED PRESSURE, PR

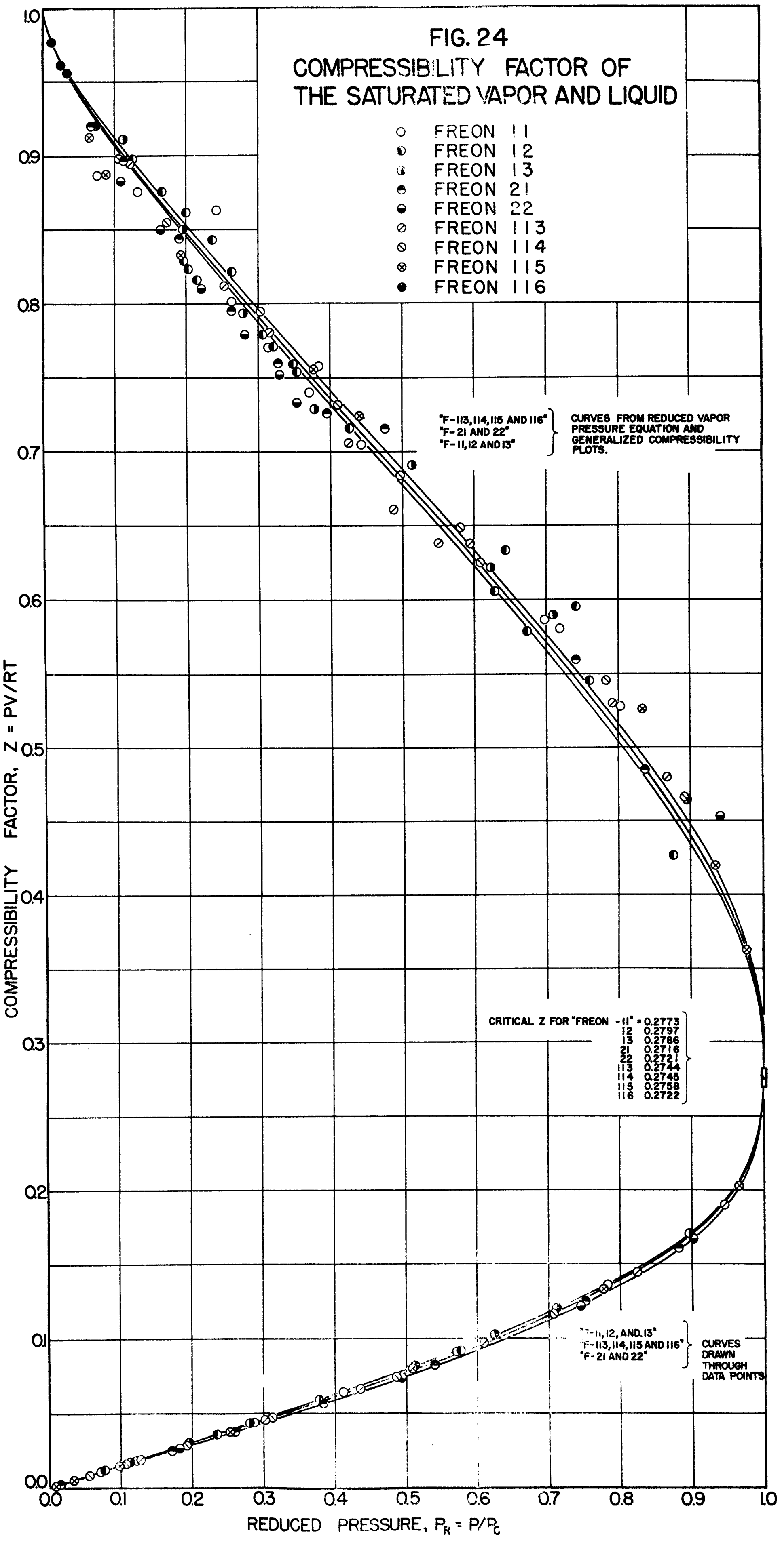


FIG. 24
COMPRESSIBILITY FACTOR OF THE SATURATED VAPOR AND LIQUID

V. SPECIFIC HEAT OF VAPORS AT INFINITE VOLUME

The specific heat of the vapor at infinite volume was calculated for several of the "Freons" from spectroscopic data available in the literature. These are called statistical specific heats.

The fundamental frequencies, w, of the "Freons" are shown in Tables XXXVIII, XXXIX AND XL, with references to the source of data.

Some doubt has been expressed (15,55) as to whether in the case of "Freon-12" both 885 and 920 cm^{-1} are fundamentals. The comparison of the specific heats of "Freons-10,11,12, 13, and 14" shown in Fig. 25 would also support this doubt. It looks as if the specific heat of "Freon-12" should be somewhat higher. The calorimetric specific heats of Buffington and Fleischer (17) fall in the expected range, about halfway between "Freons-11 and 13". These calorimetric data are plotted in Fig. 25. The specific heat of "Freon-12" was calculated using an assumed fundamental frequency of 500 cm^{-1} instead of 885 cm^{-1} (Table XLIV), and the result was plotted on Fig.25 as a dashed line. Further spectroscopic data on "Freon-12" would be most useful to settle this problem definitely.

The specific heat of the vapor at infinite volume was calculated at temperatures from -200°F to 500°F with the aid of the tables presented by Hougen and Watson (28), which give values of the vibrational contribution to the specific heat as a function of w/T.

For "Freon-115" (C_2ClF_5) a potential barrier of 1750 cal/gm mole as determined by Long, Service, and Martin (34) was used to calculate the contribution of hindered internal rotation to the specific heat. This contribution was calculated using the method outlined by Hougen and Watson (28). The partition function was calculated by using an F-C distance of 1.37Å and a C-C-F angle of 112° 10' as reported by Russel, Golding, and Yost (50) for $F_3C\text{-}CH_3$. The C-Cl distance was taken as 1.76Å and the C-C-Cl angle as 110° as reported by Rubin, Levedahl, and Yost (47) for $Cl_3C\text{-}CH_3$. These distances and angles gave moments of inertia about the axis through the two carbons of 1.524×10^{-38} (gm)(cm^2) for the CF_3Cl group or a reduced moment of inertia of 0.9641×10^{-38} (gm)(cm^2) for the molecule. The partition function Q_f then equalled $0.9143\ T^{1/2}$.

In the case of "Freon-116" (C_2F_6) a potential barrier of 4350 cal/gm mole as determined by Pace and Aston (41) was used. The C-F distance was taken as 1.37Å and the C-C-F angle as 112° 10', giving a reduced moment of inertia of 0.7618×10^{-38}(gm)(cm^2) and a partition function Q_f of $0.8127\ T^{1/2}$.

The specific heat of "Freon-113" was calculated from an equation developed by Whitney (58) from the experimental values of Markwood (35) and some estimated frequency assignments.

The statistical specific heats of the vapors are shown in Figs. 25, 26, and 27 as functions of temperature. Equations to represent these specific heats were calculated by the method of least squares and are compared with the statistical values in Tables XLI through LIII.

VI. SPECIFIC HEAT OF SATURATED LIQUIDS (c_s)

The specific heats of the saturated liquids are useful principally to check the values of other properties, that is, vapor pressure, vapor density, and the specific heat of the vapor. This utilization of specific heat of the saturated liquid is well exemplified by Long, Service, and Martin (34). In this case it is used to determine the contribution of hindered rotation to the specific heat of the vapor at infinite volume.

Saturated-liquid heat capacities have been experimentally determined for "Freon-13 and 115" by Aston and Wills (2) (who also represented their results by the equations in Tables LVI and LXI) and are known more accurately than for the other "Freons". When these data were plotted with reduced temperature as the abscissa, it was found that the curves were of the same form and approximately parallel. Therefore, when the limited saturated-liquid heat capacity data of other "Freons" were plotted on the same coordinates (Fig. 28), the curves for "F-13 and 115" were used as guides in drawing curves for the other compounds. For convenience in reading the values of c_s, these curves were redrawn in Fig. 29 with absolute temperature as the abscissa.

It should be borne in mind that c_s is the saturated-liquid heat capacity and that in terms of c_p, the heat capacity at constant pressure, is equal to

$$c_s = c_p - T(dV/dT)_p(dP/dT),$$

where (dP/dT) is the slope of the vapor-pressure curve. This difference becomes very important near the critical point.

TABLE XXXVIII

FUNDAMENTAL FREQUENCIES OF "FREONS - 10, 11, 12, 13, and 14"

	Fundamental frequencies	References
F-10 ($C\ Cl_4$)	217.9, 314, 458.3, 775	(18), (27), (31)
F-11 ($C\ Cl_3F$)	243.7, 349.5, 397.5, 534, 838, 1070	(18), (25), (30) (55), (60)
F-12 ($C\ Cl_2F_2$)	260, 320, 433, 455, 669, 885, 920, 1095, 1155	(15), (55)
F-13 ($C\ Cl\ F_3$)	356, 450, 563, 781, 1105, 1212	(1), (55)
F-14 ($C\ F_4$)	437, 630, 904, 1265	(3), (30), (31) (32), (60), (61)

TABLE XXXIX

FUNDAMENTAL FREQUENCIES ($cm.^{-1}$) of "FREONS-20,21,22, and 23"

										References
F-20 ($C\ H\ Cl_3$)	266		364	664		756		1205	3011	(31), (32), (39), (59), (60)
F-21 ($C\ H\ Cl_2F$)	277	366	457	(728-738)	795	1067	1252	1310	3019	(15), (18), (23), (55)
F-22 ($C\ H\ ClF_2$)	369	415	595	799	831	1099	1310	1350	3035	(22), (24), (26)
F-23 ($C\ H\ F_3$)	508.1		696.7	936.8		1116.5	1376.2		3062	(24), (26), (60)

TABLE XL

FUNDAMENTAL FREQUENCIES (cm^{-1}) of "FREONS-115 and 116"

F-115($C_2Cl F_5$)	F-116(C_2F_6)
75	216 (2)
189	349 (1)
264	380 (2)
316	518 (2)
333	620 (2)
367	714 (1)
448	809 (1)
560	1117 (1)
596	1237 (2)
648	1247 (2)
704	1420 (1)
762	
984	
1128	
1180	
1230	
1348	
References (4), (34)	(4), (38), (40), (41)

TABLE XLI

SPECIFIC HEAT OF "FREON-10" (CCl_4)

Temperature °F	C_V°(statis.) Btu/(mole)(°R)	C_V°(statis.) Btu/(lb)(°R)	C_V°(calc.)* Btu/(lb)(°R)	%Deviation $\frac{\text{Calc.-stat.}}{\text{calc.}} \times 100$
-200	12.0720	0.07847	0.07966	+1.49
-100	14.7405	0.09582	0.09484	-1.03
0	16.7473	0.10886	0.10773	-1.05
+100	18.2623	0.11871	0.11833	-0.32
200	19.3925	0.12606	0.12666	+0.47
300	20.2439	0.13159	0.13270	+0.84
400	20.8882	0.13578	0.13645	+0.49
500	21.3828	0.13900	0.13792	-0.78
			average	0.81

*Equation:

$$C_V^\circ = 0.029589+2.22471 \times 10^{-4}T - 1.14190 \times 10^{-7}T^2$$

TABLE XLII

SPECIFIC HEAT OF "FREON-11" (CCl_3F)

Temperature °F	C_V° (statis.) Btu/(mole)(°R)	C_V° (statis.) Btu/(lb)(°R)	C_V° (calc.)* Btu/(lb)(°R)	% Deviation $\frac{\text{Calc.-stat.}}{\text{calc.}} \times 100$
-200	10.8136	0.07871	0.07976	+1.32
-100	13.4095	0.09761	0.09675	-0.89
0	15.4410	0.11240	0.11137	-0.92
+100	17.0298	0.12396	0.12363	-0.27
200	18.2703	0.13299	0.13353	+0.40
300	19.2425	0.14007	0.14105	+0.69
400	20.0043	0.14561	0.14622	+0.42
500	20.6042	0.14998	0.14901	-0.65
			average	0.70

*Equation:

$$C_V^\circ = 0.024595 + 2.43143 \times 10^{-4}T - 1.18267 \times 10^{-7}T^2$$

TABLE XLIII

SPECIFIC HEAT OF "FREON-12" (CCl_2F_2)

Temperature °F	C_V° (statis.)* Btu/(mole)(°R)	C_V° (statis.) Btu/(lb)(°R)	C_V° (calc.)** Btu/(lb)(°R)	% Deviation $\frac{\text{Calc.-stat.}}{\text{calc.}} \times 100$
-200	9.1492	0.07566	0.07570	+0.05
-100	11.2822	0.09330	0.09330	0.00
0	13.1872	0.10905	0.10899	-0.06
+100	14.8587	0.12288	0.12276	-0.10
200	16.2812	0.13464	0.13461	-0.02
300	17.4587	0.14438	0.14455	+0.12
400	18.4238	0.15236	0.15257	+0.14
500	19.2142	0.15889	0.15868	-0.13
			average	0.08

*Using the fundamental frequencies reported in the literature.

**Equation:

$$C_V^\circ = 0.021040 + 2.35355 \times 10^{-4}T - 0.95798 \times 10^{-7}T^2$$

TABLE XLIV

SPECIFIC HEAT OF "FREON-12" (CCl_2F_2)

Temperature °F	C_V° (statis.)* Btu/(lb)(°R)	C_V° (statis.) Btu/(lb)(°R)	C_V° (calc.)** Btu/(lb)(°R)	% Deviation $\frac{\text{Calc.-stat.}}{\text{calc.}} \times 100$
-200	9.4688	0.07830	0.07896	-0.08
-100	11.8880	0.09831	0.09782	0.05
0	13.9111	0.11504	0.11435	0.06
+100	15.5799	0.12884	0.12853	0.02
200	16.9456	0.14013	0.14038	-0.02
300	18.0213	0.14903	0.14989	-0.06
400	18.9399	0.15663	0.15706	-0.03
500	19.6639	0.16261	0.16189	0.04
			average	0.045

* Using assumed value of $500 cm^{-1}$ instead of $885\ cm^{-1}$ reported in literature. All other fundamental frequencies remained the same.

**Equation:

$$C_V^\circ = 0.019069 + 2.60998 \times 10^{-4} T - 1.16887 \times 10^{-7} T^2$$

TABLE XLV

SPECIFIC HEAT OF "FREON-13" ($CClF_3$)

Temperature °F	C_V° (statis.) Btu/(mole)(°R)	C_V° (statis.) Btu/(lb)(°R)	C_V° (calc.)* Btu/(lb)(°R)	% Deviation $\frac{\text{Calc.-stat.}}{\text{calc.}} \times 100$
-200	8.4942	0.08131	0.08159	+0.34
-100	10.7434	0.10284	0.10272	-0.12
0	12.7335	0.12189	0.12149	-0.33
+100	14.4321	0.13815	0.13791	-0.17
200	15.8612	0.15183	0.15198	+0.10
300	17.0553	0.16326	0.16370	+0.27
400	18.0435	0.17272	0.17307	+0.20
500	18.8605	0.18054	0.18008	-0.26
			average	0.22

*Equation:

$$C_V^\circ = 0.015751 + 2.84064 \times 10^{-4}T - 1.17569 \times 10^{-7}T^2$$

TABLE XLVI

SPECIFIC HEAT OF "FREON-14" (CF_4)

Temperature °F	C_V°(statis.) Btu/(mole)(°R)	C_V° (statis.) Btu/(lb)(°R)	C_V° (calc.)* Btu/(lb)(°R)	% Deviation $\frac{\text{Calc.-stat.} \times 100}{\text{calc.}}$
-200	7.4189	0.08430	0.08345	-1.02
-100	9.3338	0.10605	0.10707	+0.95
0	11.2712	0.12807	0.12853	+0.36
+100	13.0279	0.14803	0.14785	-0.12
200	14.5595	0.16543	0.16501	-0.25
300	15.8703	0.18032	0.18002	-0.17
400	16.9740	0.19286	0.19289	+0.02
500	17.8976	0.20336	0.20360	+0.12
			average	0.38

*Equation:

$$C_V^\circ = 0.012080 + 3.02762 \times 10^{-4}T - 1.07536 \times 10^{-7}T^2$$

TABLE XLVII

SPECIFIC HEAT OF "FREON-20" ($CHCl_3$)

Temperature °F	C_V° (statis.) Btu/(mole)(°R)	C_V° (statis.) Btu/(lb)(°R)	C_V° (calc.)* Btu/(lb)(°R)	% Deviation $\frac{\text{Calc.-stat.}}{\text{calc.}} \times 100$
-200	9.2153	0.07719	0.07730	+0.14
-100	11.0234	0.09233	0.09229	-0.04
0	12.6333	0.10582	0.10568	-0.13
+100	14.0407	0.11760	0.11747	-0.11
200	15.2372	0.12763	0.12766	+0.02
300	16.2413	0.13604	0.13625	+0.15
400	17.0769	0.14304	0.14325	+0.15
500	17.7746	0.14888	0.14864	-0.16
			average	0.11

*Equation:

$$C_V^\circ = 0.030898 + 1.99432 \times 10^{-4}T - 0.79967 \times 10^{-7}T^2$$

TABLE XLVIII

SPECIFIC HEAT OF "FREON-21" ($CHCl_2F$)

Temperature °F	C_V° (statis.) Btu/(mole)(°R)	C_V° (statis.) Btu/(lb)(°R)	C_V° (calc.)* Btu/(lb)(°R)	% Deviation $\frac{\text{Calc.-stat.}}{\text{calc.}} \times 100$
-200	8.3443	0.08117	0.08118	+0.01
-100	10.0048	0.09731	0.09736	+0.05
0	11.5360	0.11218	0.11216	-0.02
+100	12.9274	0.12570	0.12557	-0 10
200	14.1658	0.13773	0.13760	-0.09
300	15.2376	0.14815	0.14825	+0.07
400	16.1569	0.15708	0.15751	+0.27
500	17.0428	0.16568	0.16538	-0.18
			average	0.10

*Equation:

$$C_V^\circ = 0.032689 + 2.04694 \times 10^{-4}T - 0.69218 \times 10^{-7}T^2$$

TABLE XLIX

SPECIFIC HEAT OF "FREON-22" ($CHClF_2$)

Temperature °F	C_V°(statis.) Btu/(mole)(°R)	C_V° (statis.) Btu/(lb)(°R)	C_V° (calc.)* Btu/(lb)(°R)	% Deviation $\frac{\text{Calc.-stat.} \times 100}{\text{calc.}}$
-200	7.5065	0.08681	0.08609	-0.84
-100	9.0700	0.10489	0.10561	+0.68
0	10.6396	0.12304	0.12358	+0.44
+100	12.1068	0.1400	0.14001	+0.01
200	13.4284	0.15529	0.15489	-0.26
300	14.5814	0.16862	0.16823	-0.23
400	15.5741	0.18010	0.18002	-0.04
500	16.4249	0.18994	0.19027	+0.17
				average 0.33

*Equation:

$$C_V^\circ = 0.028195 + 2.43008 \times 10^{-4}T - 0.77243 \times 10^{-7}T^2$$

TABLE L

SPECIFIC HEAT OF "FREON-23" (CHF_3)

Temperature °F	C°_V (statis.) Btu/ (mole)(°R)	C°_V (statis.) Btu/(lb)(°R)	C°_V (calc.)* Btu/(lb) (°R)	%Deviation $\frac{\text{calc.-stat.x100}}{\text{calc.}}$
-200	6.7408	0.09627	0.09426	-2.13
-100	8.0171	0.11450	0.11644	+1.67
0	9.5138	0.13588	0.13746	+1.15
+100	10.9998	0.15710	0.15732	+0.14
200	12.3974	0.17706	0.17601	-0.60
300	13.6448	0.19488	0.19353	-0.70
400	14.7352	0.21045	0.20990	-0.26
500	15.6751	0.22387	0.22509	+0.54
			average	0.90

*Equation:

$$C^\circ_V = 0.031220 + 2.57865 \times 10^{-4}T - 0.58193 \times 10^{-7}T^2$$

TABLE LI

SPECIFIC HEAT OF "FREON-113" ($C_2Cl_3F_3$)

Temperature °F	C_V (calc.)* Btu/(mole)(°R)	C_V (calc.)* Btu/(lb)(°R)
-200	16.078	0.0858
-100	19.938	0.1064
0	23.405	0.1249
+100	26.460	0.1412
200	29.102	0.1553
300	31.351	0.1673
400	33.168	0.1770
500	34.592	0.1846

*
$C_V = 0.1249 + 0.0001738t - 0.0010862 \times 10^{-4}t^2$

TABLE LII

SPECIFIC HEAT OF "FREON-115" ($F_3C\text{-}CF_2Cl$)

Temperature °F	C_V° (statis.) Btu/(mole)(°R)	C_V° (statis.) Btu/(lb)(°R)	C_V° (calc.)* Btu/(lb)(°R)	% Deviation $\frac{\text{Calc.-stat.}}{\text{calc.}} \times 100$
-200	16.4534	0.10651	0.10739	+0.82
-100	20.2945	0.13138	0.13064	-0.57
0	23.4805	0.15200	0.15114	-0.57
+100	26.1282	0.16914	0.16888	-0.15
200	28.3250	0.18336	0.18388	+0.28
300	30.1749	0.19534	0.19612	+0.40
400	31.6869	0.20512	0.20561	+0.24
500	32.9268	0.21315	0.21235	-0.38
			average	0.43

*Equation:

$$C_V^{\circ} = 0.034157 + 3.17723 \times 10^{-4}T - 1.37593 \times 10^{-7}T^2$$

TABLE LIII

SPECIFIC HEAT OF "FREON-116" (C_2F_6)

Temperature °F	C_V° (statis.) Btu/(mole)(°R)	C_V° (statis.) Btu/(lb)(°R)	C_V° (calc.)* Btu/(lb)(°R)	% Deviation $\frac{\text{Calc.-stat.}}{\text{calc.}} \times 100$
-200	13.8429	0.10030	0.10057	+0.27
-100	17.6544	0.12791	0.12773	-0.14
0	21.0401	0.15244	0.15206	-0.25
+100	23.9656	0.17364	0.17357	-0.04
200	26.5196	0.19214	0.19226	+0.06
300	28.6765	0.20777	0.20812	+0.17
400	30.4871	0.22089	0.22116	+0.12
500	31.9853	0.23174	0.23137	-0.16
			average	0.15

*Equation:

$$C_V^\circ = 0.016837 + 3.59098 \times 10^{-4}T - 1.41253 \times 10^{-7}T^2$$

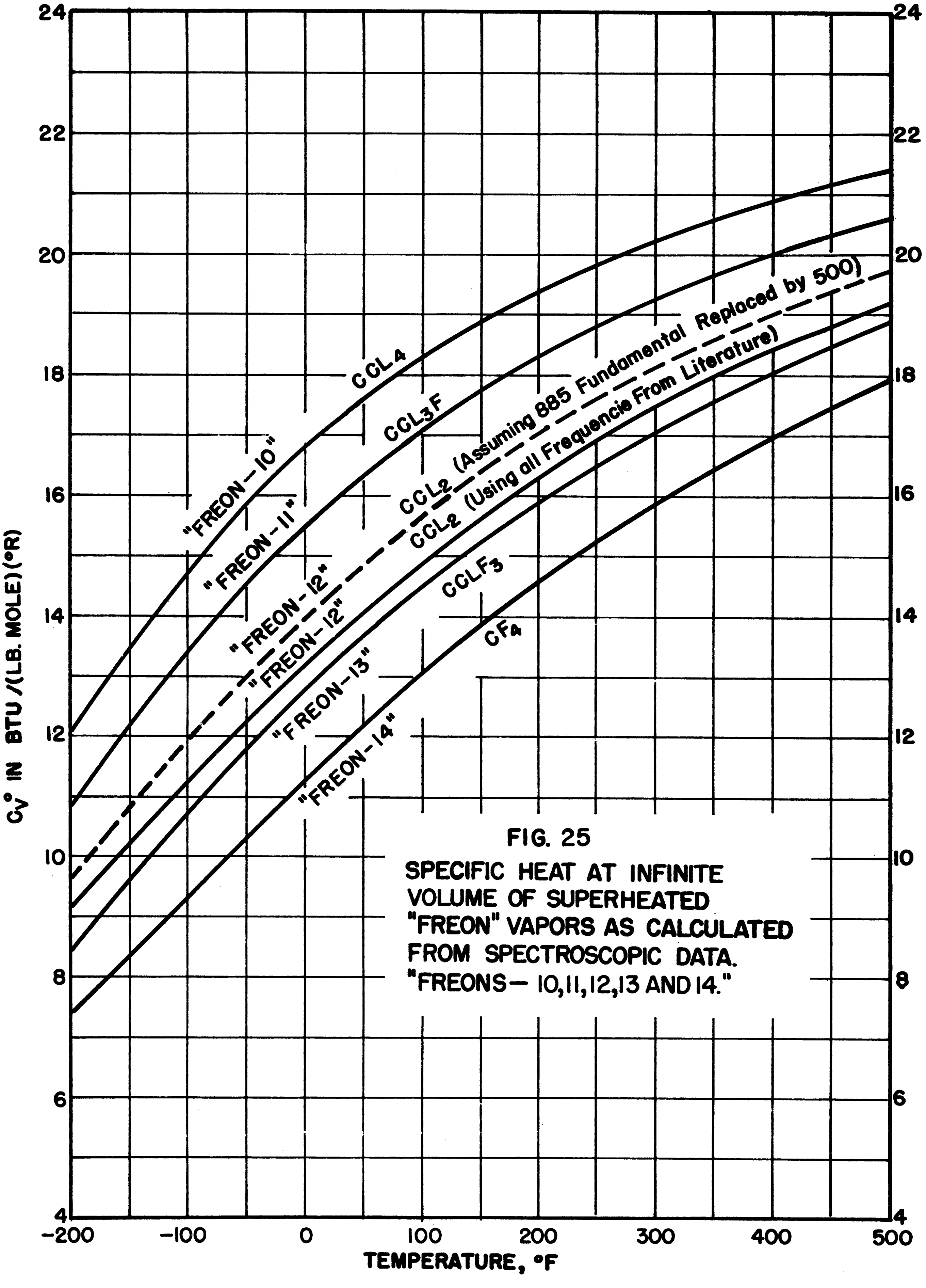


FIG. 25

SPECIFIC HEAT AT INFINITE VOLUME OF SUPERHEATED "FREON" VAPORS AS CALCULATED FROM SPECTROSCOPIC DATA. "FREONS— 10,11,12,13 AND 14."

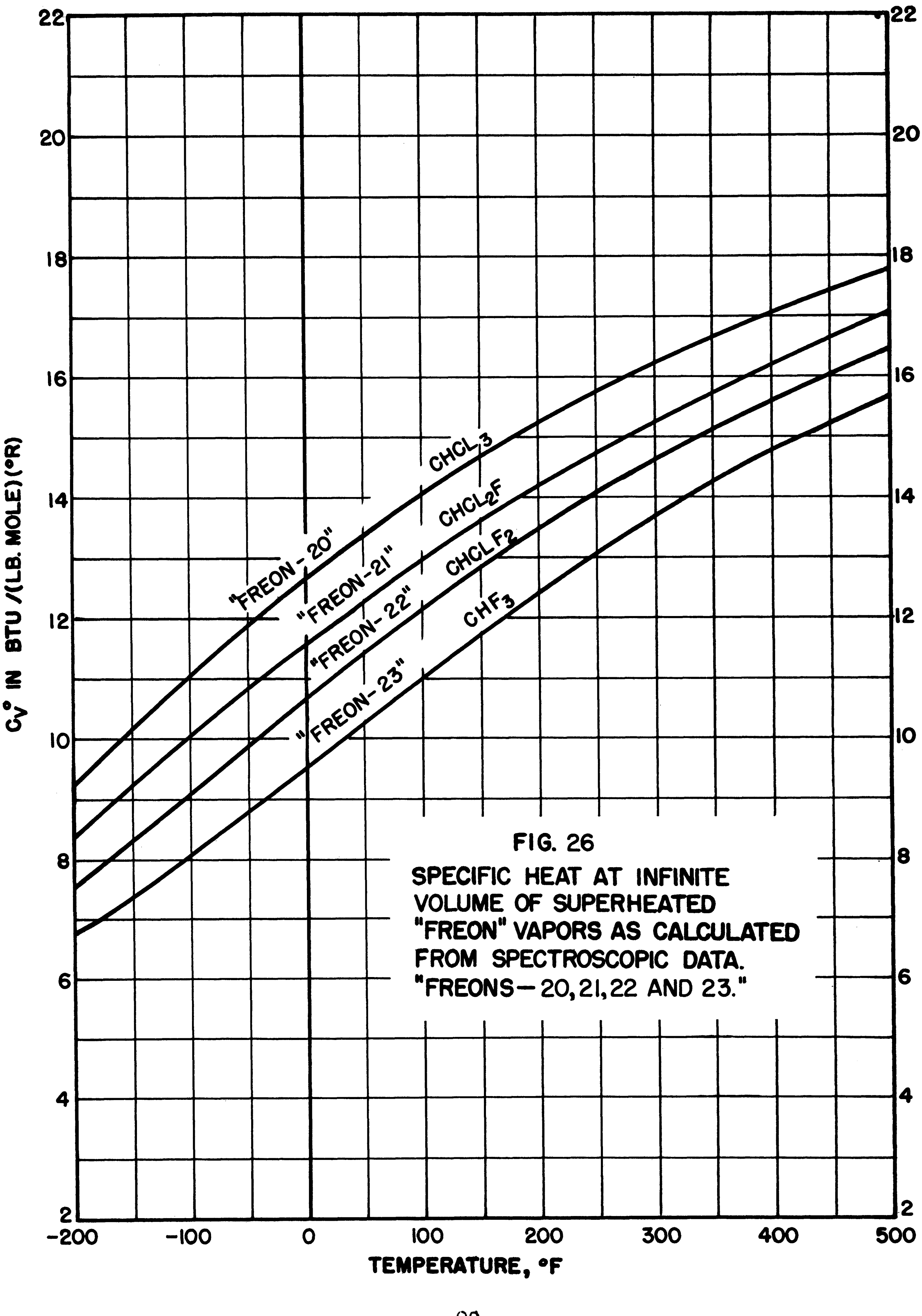


FIG. 26
SPECIFIC HEAT AT INFINITE VOLUME OF SUPERHEATED "FREON" VAPORS AS CALCULATED FROM SPECTROSCOPIC DATA. "FREONS—20, 21, 22 AND 23."

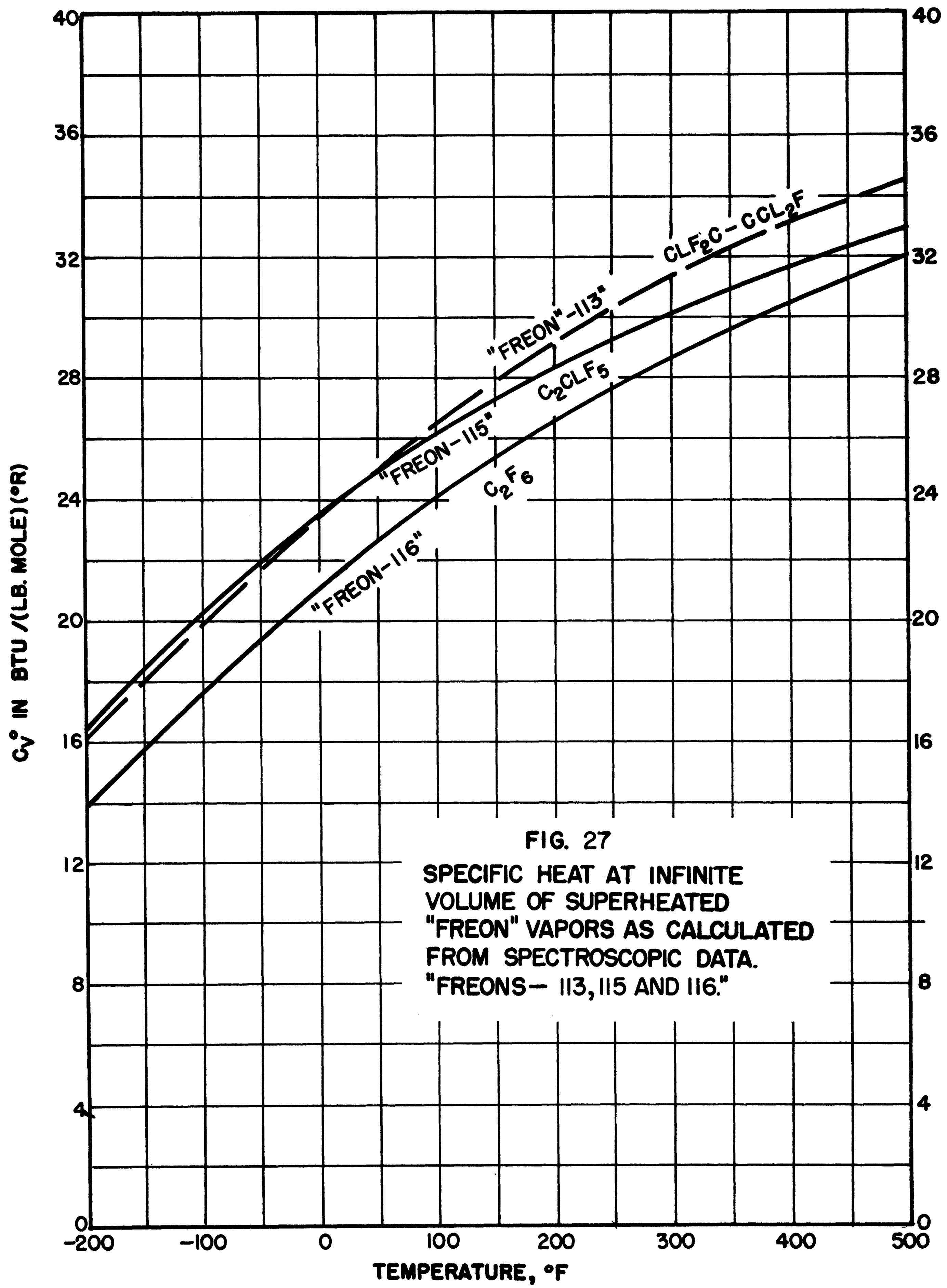


FIG. 27

SPECIFIC HEAT AT INFINITE VOLUME OF SUPERHEATED "FREON" VAPORS AS CALCULATED FROM SPECTROSCOPIC DATA. "FREONS— 113, 115 AND 116."

TABLE LIV

SATURATED HEAT CAPACITY (c_s) OF LIQUID "F-11".

Temperature °R	Experimental c_s	Experimental Investigator
470.64	28.63	(36)
489.72	28.92	(36)
607.98	30.25	(36)
625.44	30.45	(36)

TABLE LV

SATURATED HEAT CAPACITY (c_s) OF LIQUID "F-12"

Temperature °R	Experimental c_s	Experimental Investigator
522.3	30.3	(17)
414.3	25.4	(17)

TABLE LVI

SATURATED HEAT CAPACITY(c_s) OF LIQUID "F-13"

Temperature °R	Experimental c_s	Predicted c_s	Per cent Deviation	Experimental Investigator
179.23	20.23	20.21	+0.1	(2)
190.53	20.19	20.15	+0.2	(2)
201.89	20.17	20.13	+0.2	(2)
213.35	20.17	20.09	+0.4	(2)
226.76	20.21	20.09	+0.6	(2)
239.90	20.28	20.22	+0.3	(2)
248.85	20.34	20.36	-0.1	(2)
258.34	20.42	20.42	0.0	(2)
265.99	20.50	20.51	0.0	(2)
277.00	20.63	20.66	-0.1	(2)
287.15	20.76	20.81	-0.2	(2)
296.01	20.90	20.93	-0.1	(2)
305.39	21.06	21.07	0.0	(2)
314.53	21.23	21.37	-0.7	(2)
324.38	21.43	21.56	-0.6	(2)
333.79	21.64	21.77	-0.6	(2)
343.03	21.85	21.94	-0.4	(2)
353.65	22.13	22.12	0.0	(2)
365.44	22.45	22.42	0.0	(2)
375.71	22.74	22.79	-0.2	(2)
384.17	23.01	22.90	+0.5	(2)
392.15	23.27	23.37	-0.4	(2)

$c_s = 23.89 - 0.03632T + 0.0_4 8858T^2$

TABLE LVII

SATURATED HEAT CAPACITY (c_s) of liquid "F-21"

Temperature °R	Experimental c_s	Experimental Investigator
469.92	25.25	(36)
489.54	25.35	(36)
591.06	26.51	(36)
608.16	26.68	(36)

TABLE LVIII

SATURATED HEAT CAPACITY (c_s) of liquid "F-22"

Temperature °R	Experimental c_s	Experimental Investigator
460.56	23.40	(36)
480.18	23.82	(36)
573.60	26.91	(36)
590.88	27.59	(36)

TABLE LIX

SATURATED HEAT CAPACITY (c_s) OF LIQUID "F-113"

Temperature °R	Experimental c_s	Experimental Investigator
471.00	39.74	(36)
490.44	40.32	(36)
532.74	41.24	(36)
546.42	41.60	(36)
568.20	41.88	(36)
605.64	42.72	(36)

TABLE LX

SATURATED HEAT CAPACITY (c_s) OF LIQUID "F-114"

Temperature °R	Experimental c_s	Experimental Investigator
471.54	38.54	(36)
489.54	38.90	(36)
590.52	41.77	(36)
606.00	42.28	(36)

TABLE LXI

SATURATED HEAT CAPACITY (c_s) OF LIQUID "F-115"

Temperature °R	Experimental c_s	Predicted c_s	Per Cent Deviation	Experimental Investigator
325.22	31.43	31.36	+0.2	(2)
343.40	31.87	31.93	-0.2	(2)
352.94	32.27	32.27	0.0	(2)
364.57	32.69	32.70	0.0	(2)
375.17	33.17	33.13	+0.1	(2)
385.25	33.59	33.56	+0.1	(2)
394.78	33.93	33.99	-0.2	(2)
404.19	34.02	34.44	-1.0	(2)
412.87	34.59	34.86	-0.8	(2)
421.79	35.29	35.32	-0.1	(2)
431.59	35.62	35.85	-0.6	(2)
441.02	36.36	36.38	-0.1	(2)
450.95	36.91	36.96	-0.1	(2)
460.35	37.34	37.53	-0.5	(2)
470.88	38.20	38.20	0.0	(2)
480.08	38.80	38.80	+0.1	(2)
487.67	39.31	39.31	+0.5	(2)

$$c_s = 34.428 - 0.04841\ T + 0.0_{3}1198\ T^2$$

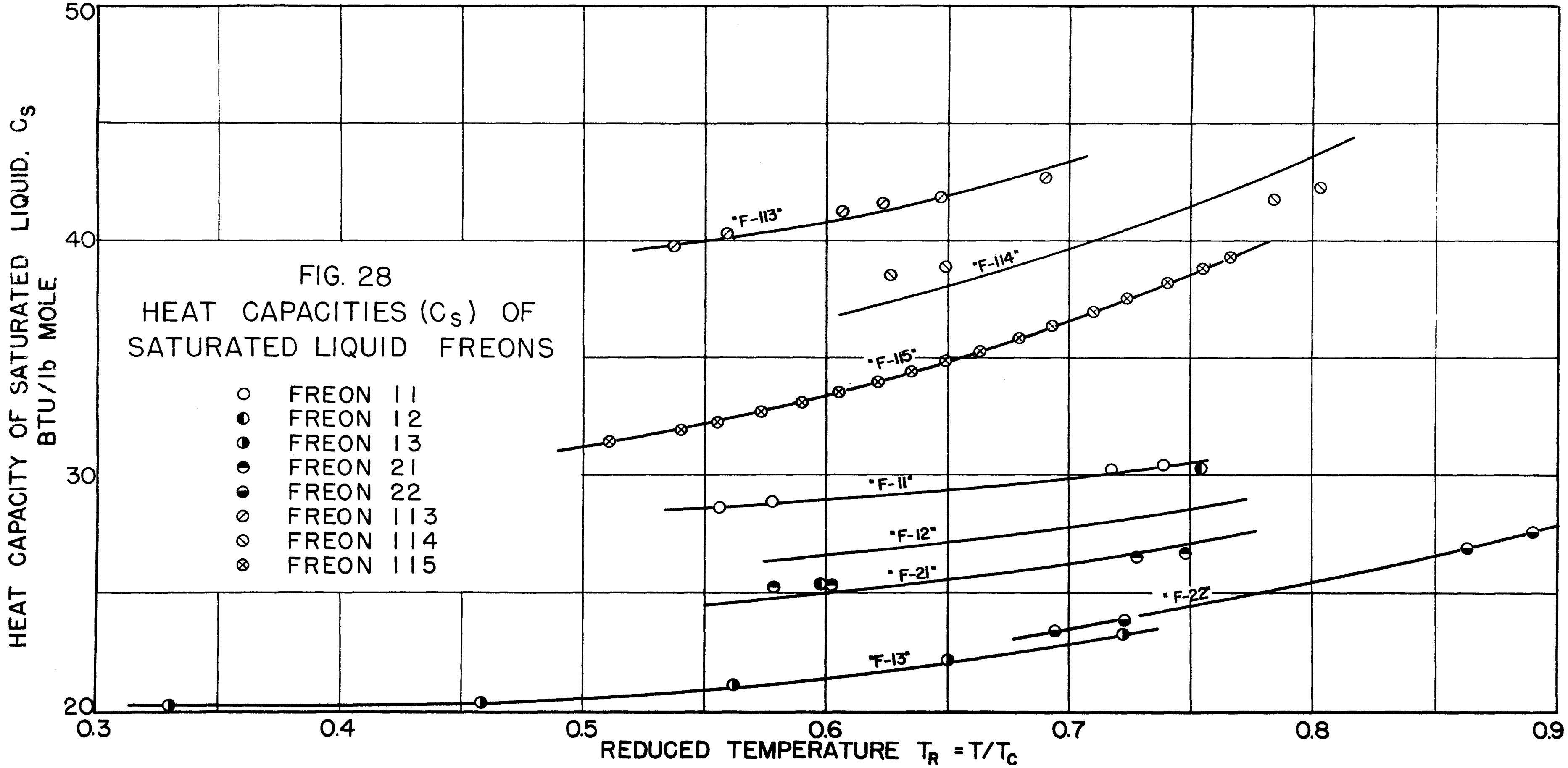
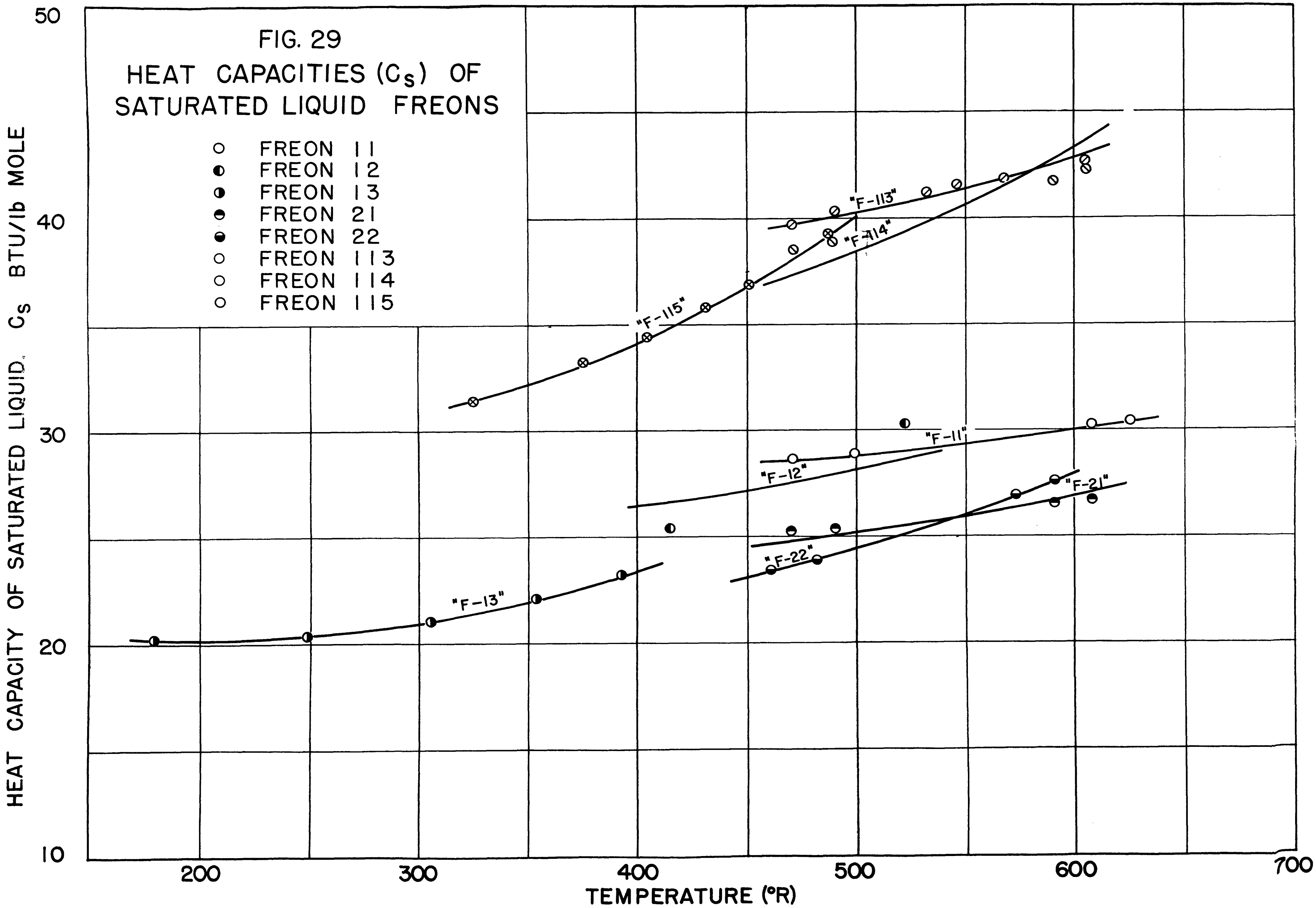


FIG. 28
HEAT CAPACITIES (C_S) OF
SATURATED LIQUID FREONS

FIG. 29
HEAT CAPACITIES (C_S) OF SATURATED LIQUID FREONS



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