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INDEX OF REFRACTION AND DISPERSION OF SEVERAL GASES IN CERENKOV COUNTER USE

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Measurements of index of refraction as a function of gas pressure are reported for several gases which are suitable for Cerenkov counter use. Samples of commercially marketed carbon dioxide, ethane, methane, sulfur hexafluoride, Freon 13 ($CClF_3$), Freon 14 (CF_4) and Freon 23 (CHF_3) have been studied. The data are summarized by Figures 1 and 2. These gases do not react with aluminum or silver mirror coatings, or other materials used in such counters, and have indices of refraction which are large enough to permit the use of the gases at reasonable pressures. Methane and ethane are both toxic and highly explosive; the remainder of the group listed are non-toxic and very stable.

An interferometric method was used in which a Fabry Perot device was enclosed by a pressure vessel maintained at constant temperature. When provided with a suitable optical system the Fabry Perot displays a pattern of concentric circular fringes. Very sharp bright fringes appear at angles θ measured with respect to the perpendicular to the interferometer mirror surfaces whenever the relation $n\lambda = 2d\mu \cos\theta$

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is satisfied. The index of refraction μ of the material between the interferometer mirrors is thus obtained from a knowledge of the wave length λ of the light incident upon the mirrors, the separation d between the two mirrors, and the order n of the interference pattern. In our application the fringe pattern is viewed at a fixed angle θ which is defined by the cross hair of a telescope focused at infinity. A change in μ caused by varying the pressure (density) of the gas between the mirrors leads to a change in n, which is observed as a movement of the fringe pattern in the field of view of the telescope. Our measurement of the index of refraction thus consists of a record of the gas pressure changes associated with the movement of an integral number of fringes Δn past the cross hair of a telescope. When Δn refers to the number of fringes counted during the filling of an initially evacuated pressure vessel, the index of refraction μ may be calculated from the relation

$$\mu - 1 = \frac{\lambda \Delta n}{2d \cos(\theta)} = f(p).$$

All measurements were performed at $22.0 \pm .1^{\circ}C$, and began with the pressure vessel evacuated. Gas pressure was adjusted until a given fringe was made to coincide with the telescope cross hair. Inasmuch as the compression or expansion of a gas in the vessel is accompanied by a temperature change, it is necessary to allow adequate time for the gas system to reach the temperature maintained on the vessel walls before taking pressure readings. Pressures were measured by a pair of precision Bourdon gauges manufactured by the Heise-Bourdon Company, each of which had been calibrated against their standards to a stated accuracy of ± .1%, or ± .3 psi at full scale. Two gauges were used in parallel to minimize meter hysteresis and friction errors, and to check the consistency of the calibrations. On a given sample of gas, successive trials for a fixed Δn reproduced pressure values consistently to within ± .2 psi. The number of fringes Δn could be obtained to within better than ± 1/10 fringe. Because $\underline{d}$ and $\underline{\lambda}$ are both precisely known, this method yields pressure versus index of refraction results which are essentially as reliable as the pressure gauge readings.

Commercial, presumably high purity samples of gases obtained from the Matheson Company, were studied. No further purification was attempted. Table I, reproduced from Matheson Company data,[1] lists the commercial specifications of the particular gases considered here. Gases of comparable standards may be obtained from other distributors as well. Samples drawn from different containers of each type of gas were measured in several cases to learn what degree of reproducibility might be expected in practical usage of these gases. Table II summarizes our results for the index of refraction expressed as μ-1 at a fixed pressure for the several samples of each gas tested. The spread of index values among these samples is noted to be consistent with the specifications of gas purity. Considered in terms of reproducibility of refractive index values, carbon dioxide would appear to be the most suitable gas of this group for a precise determination of high energy particle velocity in a

Cerenkov counter from pressure-refractive index calibration data.

The index of refraction-pressure data are presented in Tables III and IV, and also Figures 1 and 2. The values given are averages which include results from two trials for each of the samples noted in Table II. The green line, $\lambda = 5461$ A, of the mercury spectrum was used for all of these measurements. Except for the case of carbon dioxide, the differences in purity among the several samples tested are such that the figure to the right of the decimal is not significant in the average pressure quoted for a given refractive index. This figure is carried in the tables because it is still significant in the differences between successive readings in the pressure regions in which Cerenkov counters are normally operated.

An additional series of measurements was taken with $\lambda = 4358$ A to study the relative dispersion properties of these gases. The results are expressed in Table V in terms of the ratio $R = \frac{(\mu-1)_{\lambda=4358\ A}}{(\mu-1)_{\lambda=5461 A^{o}}}$.

The values of R in Table V were obtained from successive measurements at the different wave lengths made upon the <u>same</u> gas samples only; the variations in index due to dispersion are of approximately the same magnitude as those due to differing purities among the gas samples. The ratios were computed by comparing the differences in the two indices between successive pairs of pressure values. At least 200 fringes were included in each difference taken, with the exception of 120 fringes for CF_4. An uncertainty of approximately ± .1 psi is to be expected in each of the averaged pressure readings. This figure is responsible for the quoted probable error, which is based upon residuals which are encountered during the averaging of the successive differences of (μ-1). Our result of R = 1.00123 ±.00004 for CO_2 agrees within the errors with a similar measurement by Howell of 1.00118 (±.00003).[5]

The data presented indicate that methane and ethane have the highest dispersion of the gases of this group; Freon 23 (CHF_3) has the lowest dispersion. For all of these gases, dispersion is a more serious limitation to ultimate Cerenkov counter resolution at very high energies than is multiple scattering. In some Cerenkov counter applications a minimum of particle attenuation might be desirable; methane clearly offers the smallest nuclear cross section of these gases. The dispersion of methane is approximately the same as that of hydrogen[5], however, so hydrogen might be a more suitable candidate for a gas with low nuclear attenuation. These considerations must usually be compromised in practice because of the pressures required to achieve the desired operating range of the counters. Experience to date in this laboratory has indicated that carbon dioxide does not present major difficulties in attenuation or multiple scattering, and its dispersion appears to permit acceptable Cerenkov angular resolution within the range of particle energies encountered in AGS operation.

References:

1. Compressed Gas Catalog, Matheson Company, Rutherford, N. J.

2. Freon Technical Bulletin B-2, Freon Products Division, E. I. du Pont de Nemours & Co., Wilmington, Delaware.

3. Handbook of Physics and Chemistry, Chemical Rubber Publishing Company, Cleveland, Ohio.

4. Technical Bulletin TB B5602 (Sulfur Hexafluoride), General Chemical Division, Allied Chemical and Dye Corporation, N. Y.

5. J. Howell, Phys. Rev. 6, 81 (1915).

TABLE I

	Minimum Purity	70° F Pressure in Container	Approx. Cost/100 ft³ (at 1 atmosphere)	Critical Pressure	Critical Temperature
C_2H_8 (CP)	99.0% (1)	528 psig (1)	$ 24 (1)	718 (3)	32.1°C
C_2H_8 Tech	95.0%	528	11.		
SF_6	98.0%	320	120.	545.5 (4)	45.5
CF_4	95.0%	500	410.	36.9 (2)	-45.5
CHF_3	98.0%	635	135.	690 (2)	25.
$CClF_3$	99.0%	458	230.	561 (2)	28.9
CO_2 (Bone Dry)	99.8%	830	2.	1073 (3)	31.1
CH_4 (CP)	99.0%	1800	40.	673 (3)	-82.5

TABLE II

Index of Refraction for Various Gas Samples at 150 psig

	Sample 1	2	3	4
	$(\mu-1) \times 10^{-4}$			
CO_2	49.26	48.91	49.16	
CH_4	46.75			
CHF_3	53.76	54.06		
CF_4	52.11	50.89		
C_2H_6	86.32 (CP)	85.89 (Tech)		
SF_6	91.37	92.29	91.69	90.76
$CClF_3$	94.90			

$\lambda = 5461$ A

$T = 22.0^{\circ}C$

TABLE III

Index of Refraction - Pressure

$\mu-1$ $\times 10^4$	Carbon Dioxide CO_2 (psig)*	Methane CH_4 (psig)	Freon 14 and Freon 23 CHF_3 (psig)	CF_4 (psig)
5.38	4.4	4.7	3.1	3.2
10.75	23.1	24.0	20.9	20.9
16.13	41.7	43.1	38.2	38.5
21.50	59.9	62.1	55.1	56.
26.88	78.0	81.0	71.7	73.
32.26	95.7	99.8	87.9	90.
37.63	113.2	118.5	103.8	107.
43.01	130.4	137.2	119.4	124.
48.39	147.5	155.7	134.8	141.
53.76	164.2	174.2	149.6	157.
59.14	180.8	192.6	164.2	173.
64.51	197.0	210.9	178.4	189.
69.89	213.0	229.1	192.2	205.
75.27	228.8	247.3	205.9	221.
80.64	244.4	265.4	219.3	237.
86.02	259.8	283.5	232.3	253.
91.40	275.0		245.1	268.
96.77	290.0		257.6	283.
102.15			269.9	
107.52			282.0	
112.90			293.7	

$22.0 \pm .1^{o}C$; $\lambda = 5461$ A

* 0 psig corresponds to 14.7 psi atmospheric pressure.

TABLE IV

Index of Refraction - Pressure

μ-1 x 10^4	Ethane C_2H_6 (psig)*	Sulfur Hexafluoride SF_6 (psig)	Freon 13 $CClF_3$ (psig)
10.75	7.8	7.4	6.5
16.13	18.9	18.3	17.0
21.50	29.8	29.1	27.2
26.88	40.5	39.5	37.3
32.26	51.0	49.7	47.2
37.63	61.5	59.8	57.0
43.01	71.8	69.7	66.6
48.39	82.0	79.4	76.2
53.76	92.0	88.9	85.4
59.14	101.8	98.2	94.6
64.51	111.5	107.2	103.8
69.89	121.1	116.2	112.8
75.27	130.7	125.0	121.5
80.64	140.1	133.5	130.1
86.02	149.4	141.9	138.7
91.40	158.6	150.1	147.1
96.77	167.7	158.1	155.4
102.15	176.6	165.9	163.5
107.52	185.3	173.5	171.5
112.90	194.0	181.0	179.4
118.28	202.5	188.5	187.1
129.03	219.2	202.4	202.1
139.78	235.4	215.8	216.8
150.53	251.4	228.5	231.3
161.29	266.8	240.5	245.3
172.04	281.7	252.1	258.7
182.79	296.3	261.7	271.6
193.54		272.0	284.1

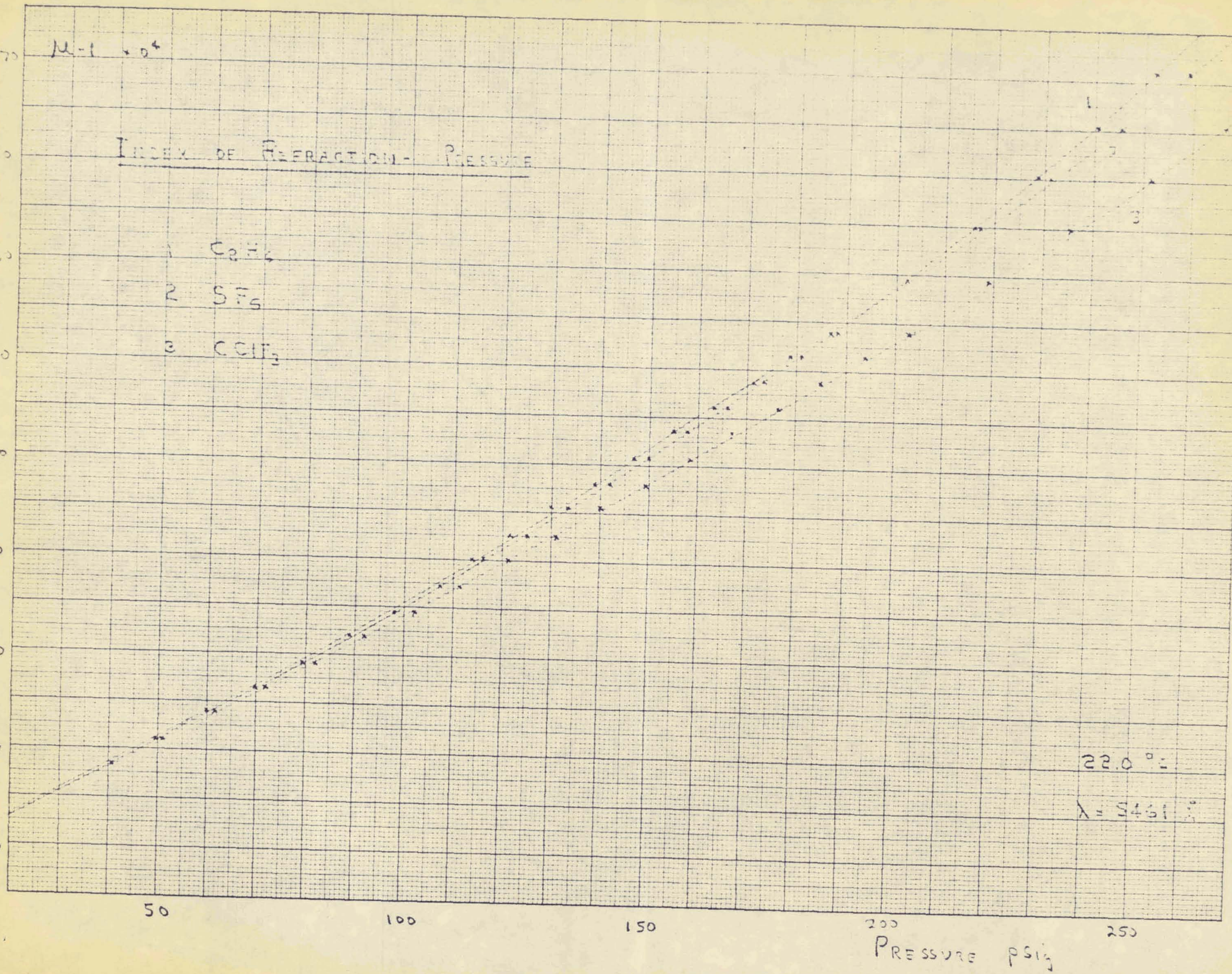
22.0 ± .1°C; λ = 5461 A

* 0 psig corresponds to 14.7 psi atmospheric pressure.

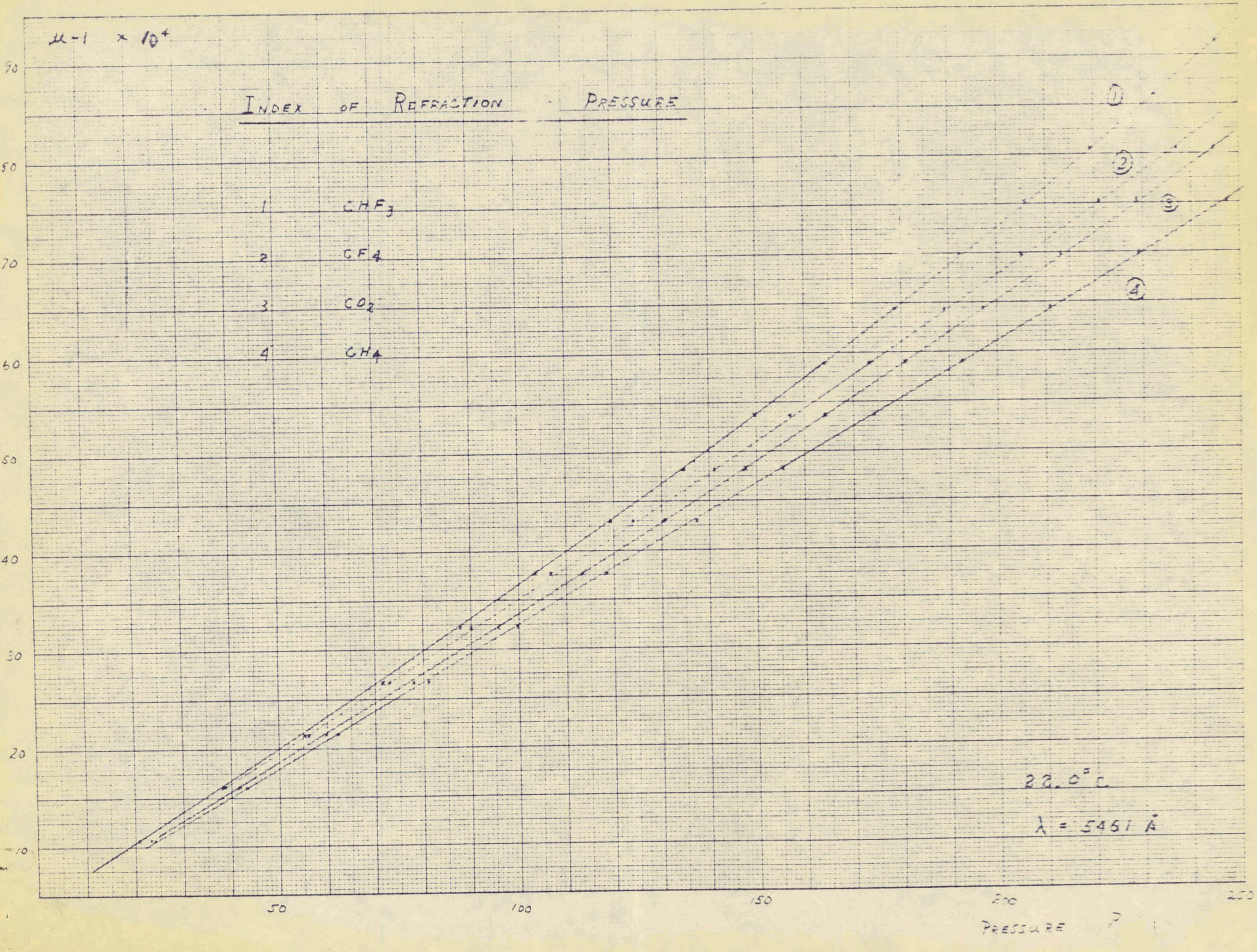
TABLE V

Dispersion

	$(\mu-1)_{4358}/(\mu-1)_{5461}$
CO_2	1.0123 ± .0004
CH_4	1.0147 ± .0005
CF_4	1.0102 ± .0009
CHF_3	1.0089 ± .0006
C_2H_6	1.0150 ± .0006
$CClF_3$	1.0137 ± .0005
SF_6	1.0110 ± .0007



INDEX OF REFRACTION - PRESSURE
μ-1 ×10⁴
1 C2H4
2 SF6
3 CClF3
22.0 °C
λ = 5461 Å
170
150
130
110
90
70
50
30
10
50
100
150
200
250
PRESSURE psig



μ-1 × 10⁴
INDEX OF REFRACTION - PRESSURE
1 CHF₃
2 CF₄
3 CO₂
4 CH₄
22.0°C
λ = 5461 Å
90
80
70
60
50
40
30
20
10
50
100
150
200
250
PRESSURE