between a line in the R branch of the (1,0) band corresponding to $m=n-u$ and a line in the P branch of that band corresponding to $m=n-u+r$ is given by:

$$(0.998r+0.0169r^2+0.013u+0.0003u^2-0.0338ur)$$
$$(-0.013+0.0338r-0.0006u)n+0.0003n^2. \quad (4)$$

From (3), the wave number of a line in the R branch of the (0,0) band corresponding to n and a line in the P branch of that band corresponding to $n+s$ differ by:

$$(0.903s+0.0185s^2)+(0.0370s)n. \quad (5)$$

With $r=19$, $s=17$, $u=7$ and n as given in the first column of Table I, (4) and (5) represent the calculated combination differences listed in the second and fourth columns, respectively. No other set of integer values of r, s and u gives satisfactory agreement. The third and fifth columns of Table I list the corresponding differences between measured lines in the (1,0) and (0,0) bands, respectively. Observed values of Δ_2F'' have been omitted wherever one of the band lines involved is obscured by an atomic line or where blending makes the measurement too uncertain to have significance.

One-quarter of the difference of successive values of Δ_2F'' gives $B''=0.157$ cm^{-1}. Then $r_e''=2.01$A. The complex isotope structure of the other bands in the system prevents a direct check on the values of Δ_2F' but from the branch formulae of the (1,0) band, $B''-B'=0.017$ so that $B'=0.140$ cm^{-1} and $r_e'=2.18$A.* Allen and Longair[8] have noted that for the lighter molecules the product $\omega_e r_e^3\mu^{\frac{1}{2}}$ is approximately proportional to the number of completed shells in the molecule. For the ground state of SnS this product is 27.4×10^{-33} g$^{\frac{1}{2}}$ cm^2 while for the corresponding state of PBO it is 25.2×10^{-33} g$^{\frac{1}{2}}$ cm^2. This is somewhat better agreement than that obtained from the simpler Morse rule which gives $\omega_e r_e^3\mu^{\frac{1}{2}}=4.25\times10^{-21}$ cm^2 for SnS and 5.10×10^{-21} cm^2 for PbO.

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* From these considerations we may estimate very roughly the values of J for the lower levels of the lines measured. In Fig. 1(a), $J=m+21$; in Fig. 1(b), $J=m+38$; in Fig. 1(c), $J=n+16$ for the P branch and $J=n+31$ for the R branch. These numbers are probably in error by several units, but all by the same amount.

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The Diamagnetism of Some Organic Binary Mixtures at Different Temperatures

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Measurements of the magnetic susceptibilities of mixtures consisting of binary combinations of carbon tetrachloride, benzene and nitrobenzene, made with the improved manometric balance of Wills and Boeker over the range of temperatures from 10°C to 50°C, are described. The results for mixtures of benzene and nitrobenzene, each of which shows no variation of mass susceptibility with temperature, show that the principle of additivity of susceptibilities is valid within the limits of precision of measurement. For mixtures of either benzene or nitrobenzene with carbon tetrachloride, a systematic deviation from additivity is found. The deviations for both groups show a definite dependence upon both concentration and temperature.

INTRODUCTION

IN a recent article, N. N. Pal[1] reported the results of his measurements on the dielectric polarization of mixtures of nitrobenzene and carbon tetrachloride, and also the results of similar measurements on mixtures of nitrobenzene and benzene. The measurements were made with various concentrations over a considerable temperature range. The practically nonpolar liquids, carbon tetrachloride and benzene, were considered as solvents for the highly polar nitrobenzene. The results showed apparently a notable dependence of the polarization of nitrobenzene upon both concentration and temperature, which was accounted for by the author in his theoretical discussion by assuming the association of the nitrobenzene molecules to depend upon both concentration and temperature.

Since changes in association are sometimes accompanied by changes in magnetic suscep-

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[1] N. N. Pal, Phil. Mag. **10**, 265 (1930).

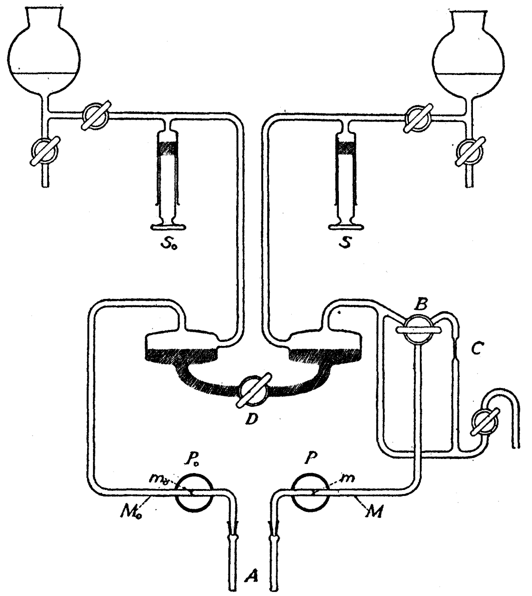

FIG. 1. The manometric balance.

tibility, the investigations described below on mixtures of nitrobenzene and carbon tetrachloride, suggested by Pal's results, were undertaken. Small but measurable deviations from the principle of additivity, dependent upon both concentration and temperature, were found. Later results of experiments on mixtures of nitrobenzene and benzene showed, however, that these deviations could not be ascribed to changes of association in nitrobenzene depending upon concentration and temperature. This conclusion was supported by measurements on mixtures of carbon tetrachloride and benzene, which also showed definite departures from the principle of additivity, depending upon both concentration and temperature.

APPARATUS AND METHOD

The apparatus used in the present investigations was the manometric balance of Wills and Boeker,[2] as modified by Woodbridge.[3] A schematic diagram of the balance is given in Fig. 1. The principle upon which this instrument operates depends upon balancing the force exerted by a magnetic field upon a standard liquid of known susceptibility against the force exerted by a second magnetic field upon the liquid whose susceptibility is to be measured. The liquids terminate in Pyrex tubes of small diameter (M_0, M). The free surface (meniscus), m_0, of one of the liquids is maintained at a fixed position in the field, the meniscus, m, of the other liquid being moved, when a balance is to be obtained, to a determined position in the second field, whose gradient along the tube is known, until the two forces equilibrate.

If the liquids contained in the menisci tubes have volume susceptibilities κ_0 and κ, respectively, the free surfaces being in contact with a medium of volume susceptibility κ_a, then the condition for balance under the action of the magnetic fields, when the field strengths at the menisci are H_0 and H respectively, is

$$\tfrac{1}{2}(\kappa_0-\kappa_a)H_0^2=\tfrac{1}{2}(\kappa-\kappa_a)H^2. \qquad (1)$$

In measuring temperature variations of susceptibility,[4] both menisci are in contact with helium, for which κ_a is negligible in comparison with κ_0 and κ. In this case we obtain from (1) for the mass susceptibility, χ, at any temperature in terms of the mass susceptibility, χ_{T_0}, at the standard temperature

$$\chi=\frac{\rho_{T_0}}{\rho}\frac{H^2}{H_0^2}\chi_{T_0}, \qquad (2)$$

where ρ represents the density.

The susceptibility, χ_{T_0}, of each binary mixture at the standard temperature, T_0, (21.85°C)[5] was determined by means of the balance in terms of a test solution of nickel chloride[6] whose susceptibility is known in terms of the susceptibility of water ($\chi_W=-0.7200\times10^{-6}$ at 20°C) in the manner described by Woodbridge.[3]

The method of calibrating the fields, i.e., the determination of the ratio H^2/H_0^2 for different settings of the variable meniscus has been described in previous papers.[3]

The density values for the various nitrobenzene-carbon tetrachloride mixtures and for the various nitrobenzene-benzene mixtures for all

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[2] A. P. Wills and G. F. Boeker, Phys. Rev. **42**, 687 (1932).

[3] D. B. Woodbridge, Phys. Rev. **48**, 672 (1935).

[4] The temperature is regulated by means of water jackets (not shown) surrounding M_0 and M.

[5] The standard temperature 21.85°C was the temperature of neutrality of the nickel chloride neutral solution used in preparing the test solutions.

[6] The volume susceptibility of organic liquids is generally too small to permit balancing directly against water in the manometric balance.

TABLE I. *Nitrobenzene-carbon tetrachloride mixtures.*

					MIXTURE		
c	$-\kappa_{21.85}\times10^6$	$-\frac{1}{\kappa_{20}}\frac{d\kappa}{dT}\times10^4$	T(°C)	ρ_T	$-\chi\times10^6$	$-\chi_{\text{cal.}}\times10^6$	$\Delta\chi\times10^{10}$
0.00000	0.6837	13.37	10	1.6135	0.4305	0.4305	0
			20	1.5939	.4300	.4300[1]	0
CCl_4			30	1.5746	.4295	.4295	0
		$\Delta_a=0.0002$	40	1.5547	.4290	.4290	0
			50	1.5352	.4285	.4285	0
.09757[3]	.6750	12.13	10	1.5650	.4375	.4376	− 1
			20	1.5473	.4372	.4372	0
			30	1.5295	.4369	.4367	+ 2
		$\Delta_a=$ .0004	40	1.5116	.4366	.4363	3
			50	1.4936	.4363	.4358	5
.15367	.6698	11.70	10	1.5381	.4416	.4417	− 1
			20	1.5211	.4414	.4413	+ 1
			30	1.5041	.4413	.4409	4
		$\Delta_a=$ .0002	40	1.4871	.4411	.4405	6
			50	1.4700	.4409	.4400	9
.29692	.6589	10.43	10	1.4731	.4526	.4521	+ 5
			20	1.4579	.4526	.4518	8
			30	1.4428	.4526	.4515	11
		$\Delta_a=$ .0003	40	1.4277	.4526	.4511	15
			50	1.4124	.4526	.4508	18
.47424	.6444	9.70	10	1.3967	.4667	.4651	+16
			20	1.3834	.4667	.4648	19
			30	1.3700	.4667	.4646	21
		$\Delta_a=$ .0002	40	1.3566	.4667	.4643	24
			50	1.3434	.4667	.4640	27
.59886	.6349	—	10	1.3479	.4760	.4742	+18
			20	1.3357	.4760	.4740	20
			30	1.3234	.4760	.4738	22
			40	1.3111	.4760	.4736	24
			50	1.2987	.4760	.4734	26
.72128	.6252	—	10	1.3035	.4847	.4831	+16
			20	1.2921	.4847	.4829	18
			30	1.2805	.4847	.4828	19
			40	1.2690	.4847	.4827	20
			50	1.2576	.4847	.4825	22
.85486	.6150	—	10	1.2587	.4936	.4928	+ 8
			20	1.2481	.4936	.4928	8
			30	1.2374	.4936	.4927	9
			40	1.2266	.4936	.4926	10
			50	1.2160	.4936	.4925	11
1.00000	.6048	8.20	10	1.2132	.5034	.5034[2]	0
			20	1.2033	.5034	.5034[2]	0
$C_6H_5NO_2$			30	1.1934	.5034	.5034[2]	0
		$\Delta_a=$ .0003	40	1.1835	.5034	.5034[2]	0
			50	1.1736	.5034	.5034[2]	0
			60	1.1637	.5034	.5034[2]	0

[1] The mean value of χ_{20} for carbon tetrachloride obtained from the results of seven other observers is -0.4308×10^{-6}.
[2] The mean value of χ_{20} for nitrobenzene obtained from the results of five other observers is -0.5026×10^{-6}.
[3] Density values obtained by interpolation with the aid of a large scale graph of experimental measurements.

temperatures were determined by pycnometer measurements. For the benzene-carbon tetrachloride mixtures, the data employed were those given in the *International Critical Tables*. The densities of several solutions of intermediate concentration (the susceptibilities of which were not measured) were measured for comparison. The values obtained are in good quantitative agreement with the *I. C. T.* data.

SUSCEPTIBILITY MEASUREMENTS

Nitrobenzene-carbon tetrachloride

The nitrobenzene and carbon tetrachloride used in these measurements were furnished by

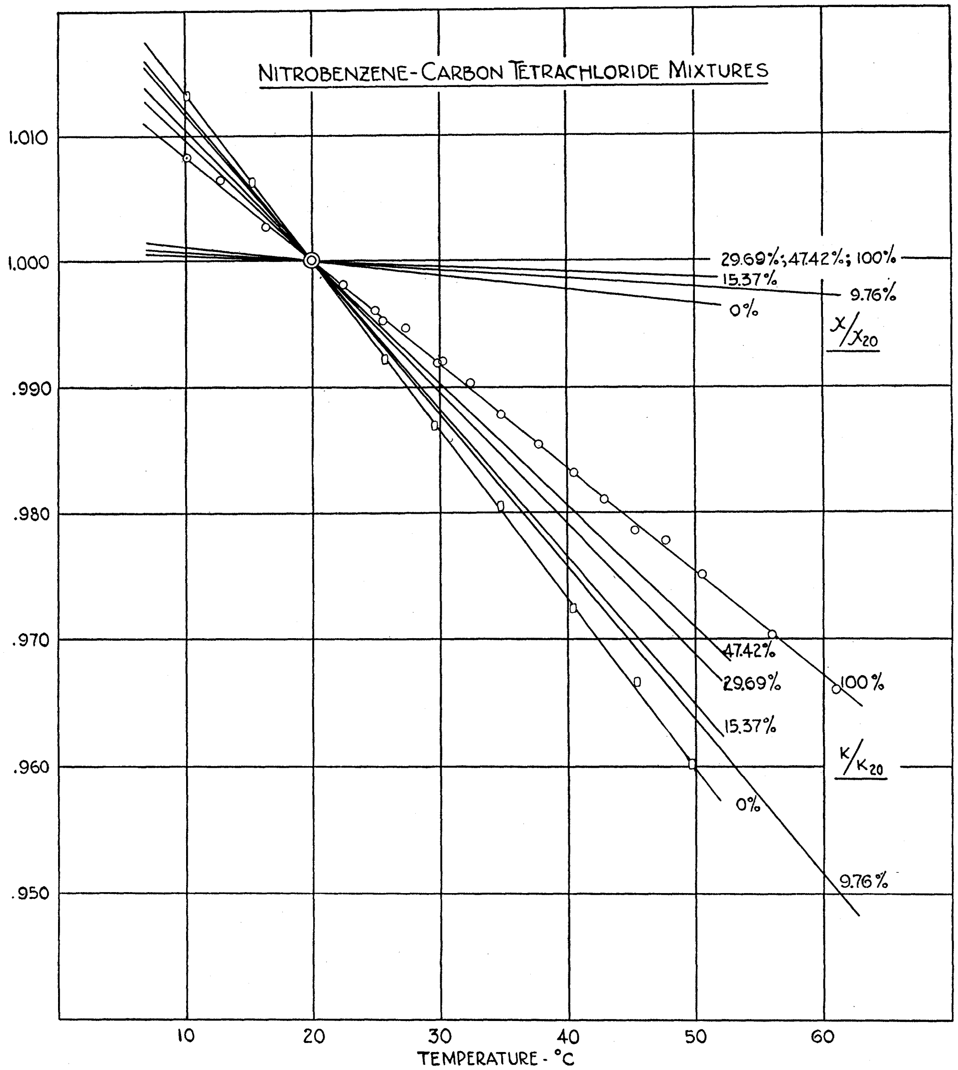

FIG. 2. Variation of χ/χ_{20} with temperature for nitrobenzene-carbon tetrachloride mixtures.

Eimer and Amend. Some Eastman Kodak Company nitrobenzene was measured for comparison with the Eimer and Amend product. The results were the same, within the limits of precision of measurement. All material were carefully distilled.

Measurements were made of the relative volume susceptibility κ/κ_{20} at various temperatures. For all concentrations used, it was found that κ/κ_{20} is a linear function of the temperature within the limits of precision of measurement. The straight lines representing κ/κ_{20} as a function of the temperature are reproduced in Fig. 2. In order to avoid confusion, the experimental points for the pure liquids only are shown; the deviations of the experimental points for the lines appertaining to the mixtures are about the same as the deviations for those of the pure liquids.

The data obtained for the nitrobenzene-carbon tetrachloride mixtures are all contained in Table I. In the first column are found the concentrations of nitrobenzene in carbon tetrachloride considered as the solvent for the several mixtures used. In the second column are found the experimental values obtained for the volume susceptibilities of the various mixtures, assuming the mass susceptibility of water to be

TABLE II. *Benzene-carbon tetrachloride mixtures.*

					MIXTURE		
c	$-\kappa_{21.85}\times10^6$	$-\frac{1}{\kappa_{20}}\frac{d\kappa}{dT}\times10^4$	T (°C)	ρ_T	$-\chi\times10^6$	$-\chi_{\text{cal.}}\times10^6$	$\Delta\chi\times10^{10}$
0.00000	0.6837	13.37	10	1.6135	0.4305	0.4305	0
			20	1.5939	.4300	.4300	0
CCl_4			30	1.5746	.4295	.4295	0
		$\Delta_a=0.0002$	40	1.5547	.4290	.4290	0
			50	1.5352	.4285	.4285	0
.01299		12.33 $\Delta_a=$ .0002					
.04266		12.13 $\Delta_a=$ .0002					
.09811		12.03 $\Delta_a=$ .0002					
.10972	.6709	—	10	1.4806	.4597	.4598	−1
			20	1.4626	.4598	.4594	+4
			30	1.4446	.4600	.4589	11
			40	1.4266	.4602	.4585	17
			50	1.4087	.4604	.4581	23
.22166	.6604	—	10	1.3667	.4898	.4897	+1
			20	1.3501	.4900	.4893	7
			30	1.3335	.4902	.4889	13
			40	1.3169	.4904	.4886	18
			50	1.3000	.4906	.4882	24
.33736	.6500	12.07	10	1.2656	.5210	.5206	+4
			20	1.2502	.5212	.5203	9
			30	1.2348	.5214	.5200	14
		$\Delta_a=$ .0002	40	1.2194	.5216	.5196	20
			50	1.2038	.5218	.5193	25
.45969	.6410	—	10	1.1740	.5539	.5533	+6
			20	1.1597	.5541	.5530	11
			30	1.1454	.5543	.5528	15
			40	1.1312	.5545	.5525	20
			50	1.1169	.5547	.5522	25
.55485	.6349	—	10	1.1114	.5794	.5787	+7
			20	1.0979	.5796	.5785	11
			30	1.0844	.5797	.5783	14
			40	1.0709	.5799	.5781	18
			50	1.0574	.5800	.5779	21
.61032	.6313	12.13	10	1.0779	.5942	.5936	+6
			20	1.0648	.5943	.5934	9
			30	1.0517	.5945	.5932	13
		$\Delta_a=$ .0002	40	1.0386	.5946	.5930	16
			50	1.0255	.5947	.5928	19
.69197	.6268	—	10	1.0322	.6159	.6154	+5
			20	1.0197	.6160	.6152	8
			30	1.0072	.6162	.6151	11
			40	.9946	.6163	.6149	14
			50	.9822	.6164	.6148	16
.78741	.6218	—	10	.9836	.6413	.6409	+4
			20	.9717	.6414	.6408	6
			30	.9598	.6414	.6407	7
			40	.9479	.6415	.6406	9
			50	.9360	.6416	.6405	11
1.00000	.6117	—	10	.8894	.6977	.6977[1]	0
			20	.8787	.6977	.6977[1]	0
C_6H_6			30	.8681	.6977	.6977[1]	0
			40	.8573	.6977	.6977[1]	0
			50	.8465	.6977	.6977[1]	0

[1] The mean value of χ_{20} for benzene obtained from the results of ten other observers is -0.7038×10^{-6}.

TABLE III. *Nitrobenzene-benzene mixtures.*

c	$-\kappa_{21.85}\times10^6$	$-\frac{1}{\kappa_{20}}\frac{d\kappa}{dT}\times10^4$	T (°C)	ρ_T	MIXTURE $-\chi\times10^6$	$-\chi_{\text{cal.}}\times10^6$	$\Delta\chi\times10^{10}$
0.00000	0.6048	8.20	10	1.2132	0.5034	0.5034	0
			20	1.2033	.5034	.5034	0
$C_6H_5NO_2$			30	1.1934	.5034	.5034	0
			40	1.1835	.5034	.5034	0
		$\Delta_a=0.0003$	50	1.1736	.5034	.5034	0
			60	1.1637	.5034	.5034	0
.10864	.6062	—	10	1.1674	.5245	.5245	0
			20	1.1575	.5245	.5245	0
			30	1.1476	.5245	.5245	0
			40	1.1377	.5245	.5245	0
			50	1.1278	.5245	.5245	0
.22961[1]	.6074	—	10	1.1200	.5481	.5480	+1
			20	1.1105	.5481	.5480	+1
			30	1.1010	.5481	.5480	+1
			40	1.0915	.5481	.5480	+1
			50	1.0820	.5481	.5480	+1
.33555	.6083	9.30	10	1.0819	.5685	.5686	−1
			20	1.0719	.5685	.5686	−1
			30	1.0619	.5685	.5686	−1
		$\Delta_a=$ .0002	40	1.0519	.5685	.5686	−1
			50	1.0420	.5685	.5686	−1
.43490	.6092	—	10	1.0479	.5879	.5879	0
			20	1.0379	.5879	.5879	0
			30	1.0279	.5879	.5879	0
			40	1.0179	.5879	.5879	0
			50	1.0080	.5879	.5879	0
.54844	.6100	10.03	10	1.0125	.6097	.6099	−2
			20	1.0023	.6097	.6099	−2
			30	0.9921	.6097	.6099	−2
		$\Delta_a=$ .0002	40	.9819	.6097	.6099	−2
			50	.9719	.6097	.6099	−2
.65307[1]	.6106	—	10	.9814	.6301	.6302	−1
			20	.9710	.6301	.6302	−1
			30	.9606	.6301	.6302	−1
			40	.9503	.6301	.6302	−1
			50	.9404	.6301	.6302	−1
.76962	.6113	10.67	10	.9485	.6531	.6529	+2
			20	.9379	.6531	.6529	+2
			30	.9273	.6531	.6529	+2
		$\Delta_a=$ .0002	40	.9169	.6531	.6529	+2
			50	.9068	.6531	.6529	+2
.88209[1]	.6115	—	10	.9190	.6747	.6747	0
			20	.9083	.6747	.6747	0
			30	.8976	.6747	.6747	0
			40	.8871	.6747	.6747	0
			50	.8769	.6747	.6747	0
1.0000[2]	.6117	—	10	.8894	.6977	.6977	0
			20	.8787	.6977	.6977	0
C_6H_6			30	.8681	.6977	.6977	0
			40	.8573	.6977	.6977	0
			50	.8465	.6977	.6977	0

[1] Density values obtained by interpolation with the aid of a large scale graph of experimental measurements.
[2] Density values taken from *International Critical Tables*.

-0.7200×10^{-6} at 20°C. These values represent the mean of from three to six independent observations, the maximum deviation from the mean being $\pm0.0003\times10^{-6}$. In the third column are found the temperature coefficients of the relative volume susceptibilities $(-1/\kappa_{20})(d\kappa/dT)$ obtained with the aid of the experimental curves for the volume susceptibilities reproduced in Fig. 2. The average deviations, Δ_a, of the experimental points from the curves are listed. In the fifth column are found the density values for the various concentrations used, at the various temperatures listed in the fourth column. In the sixth column are found the mass susceptibilities for the several mixtures determined from the experimental results. In the seventh column are found the corresponding mass susceptibilities found by calculation from the mass susceptibilities of the pure liquids assuming additivity. The differences between the experimental and the calculated values are found in the last column.

Inspection of the numbers in the sixth column of Table I giving the mass susceptibilities for the several mixtures at different temperatures brings out a number of interesting facts. In the first place, the mass susceptibility of carbon tetrachloride has a definite temperature coefficient, in agreement with the results of Boeker,[7] whereas nitrobenzene, although it is a highly polar liquid, has not. Furthermore, for intermediate concentrations having less than 30 percent nitrobenzene by weight, the mass susceptibilities are dependent upon the temperature; while for intermediate concentrations greater than 30 percent, the mass susceptibilities are independent of the temperature.

The departures from additivity indicated by the numbers in the last column of Table I show dependence upon both concentration and temperature. It does not appear possible to explain these facts on the basis of molecular association in the nitrobenzene. In fact, the anomalous character of the results would seem to depend more upon the behavior of the nonpolar carbon tetrachloride than upon that of the highly polar nitrobenzene. It was thought, therefore, that it would be of interest to investigate the magnetic susceptibilities of mixtures of carbon tetrachloride and nonpolar benzene.

Benzene-carbon tetrachloride

The benzene employed in these measurements was furnished by Mallinckrodt, the carbon tetrachloride by Eimer and Amend. Each of the liquids was carefully distilled.

The data obtained for the benzene-carbon tetrachloride mixtures are tabulated in Table II in quite the same manner as those for nitrobenzene and carbon tetrachloride in Table I, and their estimated precision is the same. In the last column, the deviations $\chi-\chi_{\text{cal.}}$ are given. A definite departure from additivity will be noted, which depends upon both concentration and temperature.

With benzene as the solvent, results are found which are notably different from the results obtained with nitrobenzene as the solvent. It is found that for mixtures containing less than 1.3 percent benzene by weight, the mass susceptibilities decrease with increasing temperatures. For mixtures containing more than this percentage of benzene, the mass susceptibilities increase with increasing temperatures, the relative change increasing with concentration for mixtures containing 20 percent benzene by weight or less. For mixtures of higher benzene concentration, the relative change with temperature gradually decreases.

Nitrobenzene-benzene

Mixtures of nitrobenzene and benzene were investigated as regards the effects of varying concentration and temperature. The data obtained for these mixtures are tabulated in Table III, in the same manner as those in Tables I and II.

The numbers in the last column of this table indicate that the principle of additivity of susceptibilities holds with close approximation for mixtures of these two liquids at all temperatures, the departures from additivity being within the limits of precision of measurements.

DISCUSSION OF ERRORS

The sources of error to be considered in connection with the absolute values given for the mass susceptibilities in Tables I, II and III, assuming the mass susceptibility of water to be

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[7] G. F. Boeker, Phys. Rev. **43**, 756 (1933).

-0.7200×10^{-6} at 20°C are: (1) errors of observation, (2) the differences in surface tension of the organic liquids and the nickel chloride solutions,[8] (3) slight variations in the neutral solution in the course of time, (4) uncertainties in the density values. The probable error in absolute values, based on an analysis of these factors, supplemented by experimental data to determine the effects owing to (2) and (3), is estimated to be $\pm0.0010\times10^{-6}$. Relative values, however, depend on only (1) and (4), and for such, the maximum error is estimated to be $\pm0.0006\times10^{-6}$.

If we may assume on the basis of the values listed in Table III, that the principle of additivity of susceptibilities applies for mixtures of nitrobenzene and benzene, it then follows that the departures relative to each other are considerably less than the estimated errors.

In connection with the measurements of relative volume susceptibilities at various temperatures, the figures for the average deviations, Δ_a, of the experimental points from the curve, given in the third columns of Tables I, II and III, may be considered as a measure of the precision of these measurements.

The probable error in density values given in Tables I and III is estimated to be ±0.0004. However, the average deviation of the experimental points from the density-temperature curves for the various measurements is ±0.0001.

Discussion

The measurements of the temperature variation of susceptibility of nitrobenzene indicates that the mass susceptibility is independent of the temperature, in agreement with the results of Cabrera and Fahlenbrach[9] and Rao and Varadachari.[10] If association of the molecules in nitrobenzene exists, depending upon concentration and temperature, the present experiments tend to show that changes in molecular association are not accompanied by appreciable changes in magnetic susceptibility

The measurements of the temperature variation of susceptibility of carbon tetrachloride shows that the mass susceptibility of this liquid decreases with increased temperatures. This might be regarded as due to an effective paramagnetic component, increasing with the temperature, but such an explanation would be difficult to justify on theoretical grounds. It is worthy of notice, perhaps, that carbon tetrachloride is anomalous as regards Pascal's law, in that its Pascal constitutive constant is exceptionally large.

The measurements of the temperature variation of susceptibility of the various benzene-carbon tetrachloride mixtures show that the relative mass susceptibilities depend upon the concentration in an irregular, though continuous, manner. Consistency of this variation requires that the relative mass susceptibilities of benzene be independent of the temperature, in agreement with the results of Boeker[7] and Cabrera and Fahlenbrach.[9]

The density values given in Table I for the nitrobenzene-carbon tetrachloride mixtures are in good agreement with the measurements of Pal,[1] provided that the values of Pal are so adjusted that the densities of the end points agree with the values given in the *I. C. T.* for the densities of the pure liquids. The values given for the densities of the pure liquids agree very well with the *I. C. T.* values. The density values at 25°C for mixtures of nitrobenzene and benzene interpolated from the experimental data listed in Table III are in good agreement with the data given in the *I. C. T.*

I wish to express my appreciation of the many helpful suggestions and criticisms given me by Professor A. P. Wills, under whose direction these experiments were performed.

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[8] Since the position of the two menisci are determined by setting the telescope cross hairs tangent to the images of the menisci, a slight error is introduced if the two menisci do not have the same shape.

[9] B. Cabrera and H. Fahlenbrach, Zeits. f. Physik **85**, 568 (1933); **89**, 682 (1934).

[10] Rao and Varadachari, Proc. Ind. Acad. Sci. **1-A**, 77 (1934).