Solubility of Nitrous Oxide in Some Nonpolar Solvents

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NITROUS OXIDE solubility has been determined at 1-atm. partial pressure and at temperatures ranging from −10° to 40° C. in five nonpolar liquid solvents: 2,2,4-trimethylpentane, *n*-heptane, carbon tetrachloride, benzene, and carbon disulfide. The results fit the general solubility map of Kobatake and Hildebrand for gases in nonpolar solvents.

Gas solubilities in liquids have been of theoretical and practical interest for many years. The solubilities of 15 gases in various nonpolar solvents at a partial pressure of 1 atm. have recently been collected and reviewed by Kobatake and Hildebrand (*5*). However, the solubility of nitrous oxide in nonpolar solvents has not been studied as extensively as other gases. The only experimental data available in the literature are those reported by Horiuti (*3*) for nitrous oxide in carbon tetrachloride (solubility parameter = 8.60) and in benzene (solubility parameter = 9.15). In the present investigation, Horiuti's data have been checked and, in addition, the solubility of nitrous oxide in three other nonpolar solvents, 2,2,4-trimethylpentane, *n*-heptane, and carbon disulfide, has been determined. These solvents cover a wide range of solubility parameter, 6.85 to 10.0. This information is useful to check the general solubility map presented by Kobatake and Hildebrand (*5*) and to supply basic information for correlating gas solubilities (including nitrous oxide) in polar, nonassociated solvents, such as diethyl ether, methyl acetate, and chlorobenzene (*12*).

EXPERIMENTAL

Materials. The nitrous oxide gas of 98+% purity was cooled to dry ice temperature. Part of the contents was blown off to remove the major impurity, nitrogen or air. The cylinder was then inverted and samples were drawn from the liquid phase. Mass spectrographic analysis showed a purity of 99.5% nitrous oxide. The cylinder was maintained in its inverted position in the actual measurements of solubility. The hydrogen was 99.7% pure. The carbon dioxide gas was Matheson research grade with a minimum purity of 99.9%. The five liquid solvents were fractionated in a laboratory fractionation column of about 30 theoretical plates packed with ¼-inch i.d., single-turn helices. Central cuts were collected and used. The sources and the physical properties of the liquid solvents are summarized in Table I.

Apparatus and Procedures. The solubility apparatus of Markham and Kobe (*8*) was modified as follows:

The ordinary stopcocks on the solubility bulbs were replaced by two three-way adjustable pressure stopcocks. Gas buret was jacketed in a silvered, double-walled glass cylinder, through which liquid of constant temperature was circulated by a centrifugal pump instead of an airlift (used by Markham and Kobe). The aspirator was replaced by a suitable vacuum system consisting of a dry ice cold trap, a McLeod gage, and two vacuum pumps. The gas saturator and liquid-degassing still were connected directly to the bulb for better operation. The bulb shaker was made of an acentric disk driven by a motor and connected to the bottom of the bulb.

The operating procedure was similar to that used by Markham and Kobe except that the degassed solvent was introduced into the solubility bulb under a vacuum of about 10 to 15 microns of Hg.

Results with this apparatus and procedure compare satisfactorily with results of previous investigators (Table II).

RESULTS

The solubility of nitrous oxide was determined at a partial pressure of 1 atm. and temperatures ranging from −10° to 40° C. in 2,2,4-trimethylpentane, *n*-heptane, carbon tetrachloride, benzene, and carbon disulfide. The solubility data (Table II) were calculated in units of both mole fraction and Bunsen coefficient (volume of gas at 1 atm. and 0° per unit volume of solvent when the partial pressure of gas is 1 atm.). For a total of 53 runs, the reproducibility of the results was better than 1%. The solubility of nitrous oxide in carbon tetrachloride and in benzene is in good agreement with the data reported by Horiuti (*3*).

Kobatake and Hildebrand (*5*) have constructed a general solubility map for nonpolar gases in nonpolar liquid solvents by plotting the logarithm of mole fraction of gas at 1 atm. of partial pressure and 25°, log x_2, *vs.* the solubility parameters of the solvents, δ_1. A good agreement can be seen if the solubility of nitrous oxide at 25° is interpolated from Table II and added to the Kobatake-Hildebrand map.

Kobatake and Hildebrand have also shown that for different nonpolar gases in the same solvent, log x_2 increases linearly with increasing Lennard-Jones force constant, ϵ/k, of the gas. This relation is applicable to nitrous oxide, since the results of this work fit adequately the plot of log x_2 *vs.* ϵ/k.

Nitrous oxide is weakly polar with a dipole moment of 0.17 Debye units. Theoretical considerations including dipole-dipole interactions between nitrous oxide molecules require insignificant corrections in accord with the above treatments where nitrous oxide was considered as essentially nonpolar. Similar treatment was used by Kobatake and Hildebrand for carbon monoxide which has a dipole moment of 0.11 Debye units.

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Table I. Sources and Physical Properties of Liquid Solvents

Solvent	Source	Grade	Refractive Index at 25° C. Exptl.	Refractive Index at 25° C. Ref.	Normal B. P., ° C. Exptl.	Normal B. P., ° C. Ref.
Iso-octane	Phillips Petroleum Co.	Pure	1.3888	1.38901 (*9*)	99.2	99.238 (*9*)
n-Heptane	Phillips Petroleum Co.	Pure	1.3852	1.38511 (*9*)	98.4	98.427 (*9*)
Carbon tetrachloride	J.T. Baker Chemical Co.	Baker analyzed	1.4574	1.4576 (*10*)	76.9	76.8 (*10*) 76.75 (11)
Benzene	J.T. Baker Chemical Co.	Baker analyzed	1.4976	1.49792 (*9*)	80.1	30.100 (9)
Carbon disulfide	Allied Chemical & Dye Corp.	ACS	1.6253	1.62543 (*10,11*)	46.3	46.26 (11)

Table II. Performance of Solubility Apparatus

Partial pressure of gas. 1 atm.
Solubility. In Bunsen Coeff.

CO_2(g), H_2O(l), 40° C.

Run No.	Soly.	Soly. Ref.
C-1	0.530	0.513 (*8*)
C-2	0.533	0.530 (*7*)
C-3	0.527	
C-4	0.535	
C-5	0.527	
C-6	0.531	
C-7	0.526	
C-8	0.530	
C-9	0.531	
C-10	0.526	
C-11	0.534	
Av.	0.530	
Av. dev.	0.44%	

CO_2(g), H_2O(l), 25° C.

Run No.	Soly.	Soly. Ref.
C-12	0.761	0.7565 (*8*)
C-14	0.760	0.761 (*7*)
C-15	0.756	0.749 (*4*)
C-16	0.763	
C-17	0.757	
C-18	0.760	
Av.	0.760	
Av. dev.	0.26%	

CO_2(g), H_2O(l), 0.2° C.

Run No.	Soly.	Soly. Ref.
C-19	1.714	1.7023 (*8*)
C-20	1.712	
C-21	1.715	
Av.	1.714	
Av. dev.	0.10%	

N_2(g), C_6H_6(l), 28° C.

Run No.	Soly.	Soly. Ref.
N-2	0.118	0.108 (*1*)
N-3	0.115	0.111 (*3*)
N-4	0.116	
N-6	0.113	
N-7	0.118	
N-8	0.113	
Av.	0.115	
Av. dev.	1.60%	

H_2(g), n-C_7H_{16}(l), 35° C.

Run No.	Soly.	Soly. Ref.
H-1	0.107	0.1082 (*2*)
H-2	0.108	
H-3	0.108	
H-4	0.108	
H-5	0.105	
H-7	0.110	
Av.	0.108	
Av. dev.	1.25%	

N_2O(g), H_2O(l), 25° C.

Run No.	Soly.	Soly. Ref.
NW-1	0.561	0.539 (*8*)
NW-2	0.558	0.567 (*6*)
NW-3	0.563	
Av.	0.561	
Av. dev.	0.33%	

Table III. Solubility of Nitrous Oxide in Nonpolar Liquids

Partial pressure of nitrous oxide. 1 atm.

Run No.	Solvent	Temp., ° C.	Soly. Bunsen Coeff.	Av.	Mole Fraction	Bunsen Coeff. (*3*)
NI-9	Iso-C_8H_{18}	0	4.598	4.587	0.03217	
NI-10			4.576			
NI-1		10	3.796	3.786	0.02701	
NI-2			3.778			
NI-3			3.785			
NI-4		20	3.159	3.155	0.02287	
NI-5			3.151			
NI-8		30	2.678	2.679	0.01972	
NI-11			2.679			
NI-12			2.681			
NI-6		40	2.275	2.273	0.01698	
NI-7			2.272			
NH-1	*n*-C_7H_{16}	0	4.133	4.136	0.02589	
NH-2			4.140			
NH-3			4.136			
NH-12		10	3.538	3.538	0.02250	
NH-4		20	3.026	3.042	0.01963	
NH-5			3.053			
NH-6			3.046			
NH-10		30	3.565	3.564	0.01681	
NH-11			3.562			
NH-7		40	2.239	2.244	0.01492	
NH-8			2.254			
NH-9			2.240			
NC-11	CCl_4	0	6.068	6.071	0.02506	
NC-12			6.073			
NC-8		10	5.100	5.096	0.02137	5.074
NC-9			5.095			
NC-10			5.093			
NC-6		20	4.263	4.262	0.1815	4.258
NC-7			4.261			
NC-3		30	3.627	3.634	0.01570	3.609
NC-4			3.640			
NC-5			3.637			
NC-1		40	3.119	3.111	0.01364	3.110
NC-2			3.104			
NB-6	C_6H_{16}	10	4.253	4.256	0.01652	4.290
NB-11			4.261			
NB-5		20	3.682	3.675	0.01446	
NB-9			3.666			
NB-10			3.677			
NB-4		30	3.176	3.173	0.01266	
NB-8			3.171			
NB-1		40	2.793	2.786	0.01127	2.724
NB-2			2.787			
NB-3			2.781			
NS-6	CS_2	−10	3.409	3.409	0.008842	
NS-1		0	2.797	2.801	0.007359	
NS-2			2.805			
NS-3		10	2.348	2.349	0.006250	
NS-7			2.349			
NS-4		20	2.129	2.124	0.005721	
NS-5			2.118			

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