XXXII.—*The Influence of Colloids and Fine Suspensions on the Solubility of Gases in Water. Part IV. Solubility of Nitrous Oxide at Pressures Lower than Atmospheric.*

By ALEXANDER FINDLAY and OWEN RHYS HOWELL (University Student in Chemistry).

IN previous communications have been given the values of the solubility of carbon dioxide in water in presence of colloids at pressures varying from about 250 up to about 1400 mm. of mercury; as also the solubility of nitrous oxide under pressures varying from 750 to 1400 mm. (T., 1910, **97**, 536; 1912, **101**, 1459; 1913, **103**, 636). In the present communication we complete the series by giving the values of the solubility of nitrous oxide under pressures lower than atmospheric. In order to be able to combine these results more satisfactorily with those previously obtained by Findlay and Creighton (T., 1910, **97**, 536), the solubility determinations were extended up to pressures of about 1000 mm.

The apparatus employed and the general method of working were as described by Findlay and Williams (T., 1913, **103**, 636). The nitrous oxide was prepared by heating carefully purified ammonium nitrate, as described by Findlay and Creighton (*loc. cit.*).

Solubility Determinations.

(a) *Water.*

The following values were obtained for the solubility of the nitrous oxide:

TABLE I.

Solubility of Nitrous Oxide in Water.

Pressure	282.5	396.1	562.9	664.5	789.3	1027.5
Solubility	0.585	0.585	0.584	0.585	0.585	0.585
Pressure	272.8	393.2	548.6	652.4	751.0	1021.7
Solubility	0.585	0.585	0.585	0.585	0.585	0.586

As mean value of the solubility, therefore, we obtain 0.585, a number somewhat lower than that obtained by Geffcken (*Zeitsch. physikal. Chem.*, 1904, **49**, 298), namely, 0.5992, or that obtained by Findlay and Creighton (*loc. cit.*), 0.592.

(b) *Ferric Hydroxide Solution.*

The ferric hydroxide solution was prepared by the method of A. A. Noyes (*J. Amer. Chem. Soc.*, 1905, **37**, 94). It was freed from salts by dialysis, and rendered air-free by boiling under diminished pressure. The values of the solubility are contained in table II (compare Fig. 1).

FIG. 1.

Nitrous oxide and ferric hydroxide (---).
Nitrous oxide and dextrin (—).

TABLE II.

Solubility of Nitrous Oxide in Ferric Hydroxide Solutions.

Concentration: 0.43 gram of $\text{Fe}(\text{OH})_3$ in 100 c.c. of solution.

Density = 1.001.

Pressure	291.2	409.1	574.7	648.5	767.5	1029.8
Solubility.....	0.594	0.594	0.591	0.589	0.583	0.580
Pressure	279.4	402.1	561.4	668.9	785.9	1043.7
Solubility	0.594	0.592	0.591	0.588	0.583	0.580

Concentration: 0.92 gram of $\text{Fe}(\text{OH})_3$ in 100 c.c. of solution.

Density = 1.003.

Pressure	287.0	415.0	571.6	681.4	787.9	1054.6
Solubility	0.589	0.587	0.584	0.582	0.578	0.576
Pressure	283.0	408.5	564.6	645.5	776.0	1026.7
Solubility	0.590	0.586	0.584	0.582	0.579	0.574

TABLE II (*continued*).Concentration: 3.82 gram of $\text{Fe}(\text{OH})_3$ in 100 c.c. of solution.

Density = 1.027.

Pressure	256.1	372.9	543.7	633.6	764.8	1014.3
Solubility	0.583	0.581	0.580	0.577	0.572	0.568
Pressure	247.9	363.3	524.4	646.4	747.9	987.3
Solubility	0.583	0.582	0.579	0.576	0.573	0.568

(c) *Dextrin*.

Kahlbaum's purest dextrin was employed. The concentration of the solutions was determined by evaporating to dryness, and weighing the residue after drying in the steam-oven. The solubility values are given in table III (compare Fig. 1).

TABLE III.

Solubility of Nitrous Oxide in Dextrin Solutions.

Concentration: 6.82 grams of dextrin in 100 c.c. of solution.

Density = 1.019.

Pressure	281.5	407.1	565.1	673.1	819.1	1004.5
Solubility	0.557	0.550	0.542	0.542	0.547	0.554

Concentration: 6.70 grams of dextrin in 100 c.c. of solution.

Density = 1.019.

Pressure	284.3	407.8	560.7	664.7	773.1	980.6
Solubility	0.555	0.550	0.544	0.544	0.546	0.554

Concentration: 12.41 grams of dextrin in 100 c.c. of solution.

Density = 1.037.

Pressure	283.8	407.7	574.8	660.5	785.7	985.0
Solubility	0.537	0.532	0.526	0.527	0.526	0.534

Concentration: 12.50 grams of dextrin in 100 c.c. of solution.

Density = 1.037.

Pressure	281.6	416.3	577.1	671.7	774.0	971.4
Solubility	0.535	0.530	0.526	0.526	0.524	0.532

Concentration: 13.24 grams of dextrin in 100 c.c. of solution.

Density = 1.060.

Pressure	293.0	421.5	598.7	695.5	799.3	997.5
Solubility	0.515	0.510	0.504	0.501	0.500	0.506

TABLE III (continued).

Concentration: 19.31 grams of dextrin in 100 c.c. of solution.

Density = 1.060.

Pressure	288.2	413.4	569.2	646.0	777.0	996.2
Solubility	0.516	0.510	0.504	0.502	0.500	0.506

(d) *Starch*.

Kahlbaum's pure soluble starch employed for the determinations. The solubility values are given in table IV (compare Fig. 2).

FIG. 2.

TABLE IV.

Solubility of Nitrous Oxide in Starch Solutions.

Concentration: 6.76 grams of starch in 100 c.c. of solution.

Density = 1.023.

Pressure	285.2	415.0	566.7	657.5	770.3	1054.0
Solubility	0.565	0.563	0.560	0.560	0.553	0.550

Concentration: 6.70 grams of starch in 100 c.c. of solution.

Density = 1.023.

Pressure	263.6	370.5	524.7	646.6	750.6	997.5
Solubility	0.566	0.563	0.561	0.558	0.554	0.549

Concentration: 9.58 grams of starch in 100 c.c. of solution.

Density = 1.030.

Pressure	267.6	373.7	504.8	627.7	747.1	1024.0
Solubility	0.554	0.551	0.549	0.546	0.541	0.539

TABLE IV (*continued*).

Concentration: 9.40 grams of starch in 100 c.c. of solution.

Density = 1.029.

Pressure	290.5	416.5	576.8	659.0	775.8	1003.6
Solubility	0.551	0.550	0.548	0.543	0.540	0.537

Concentration: 13.62 grams of starch in 100 c.c. of solution.

Density = 1.039.

Pressure	284.3	418.4	614.8	703.2	843.0	
Solubility	0.541	0.537	0.535	0.532	0.528	

Concentration: 13.60 grams of starch in 100 c.c. of solution.

Density = 1.039.

Pressure	263.8	378.6	496.9	624.0	755.1	973.5
Solubility	0.541	0.539	0.536	0.534	0.530	0.525

(e) *Gelatin*.

In these experiments French gelatin, free from salts, was employed.

TABLE V.

Solubility of Nitrous Oxide in Solutions of Gelatin (see also Fig. 3).

Concentration: 1.45 grams of gelatin in 100 c.c. of solution.

Density = 1.000.

Pressure	256.5	372.2	530.5	623.9	755.0	1009.6
Solubility	0.582	0.581	0.577	0.575	0.579	0.581

Pressure	260.9	379.4	542.5	646.5	763.4	1032.1
Solubility	0.581	0.582	0.575	0.577	0.579	0.579

Concentration: 3.12 grams of gelatin in 100 c.c. of solution.

Density = 1.004.

Pressure	251.5	367.3	530.3	632.4	750.7	1000.0
Solubility	0.577	0.576	0.568	0.569	0.572	0.576

Concentration: 3.16 grams of gelatin in 100 c.c. of solution.

Density = 1.004.

Pressure	287.8	414.5	569.2	658.5	796.3	1054.0
Solubility	0.577	0.574	0.570	0.570	0.572	0.576

Concentration: 6.10 grams of gelatin in 100 c.c. of solution.

Density = 1.008.

Pressure	257.7	381.0	546.4	637.4	762.9	1029.9
Solubility	0.556	0.556	0.548	0.546	0.550	0.557

TABLE V (continued).

Concentration: 6.14 grams of gelatin in 100 c.c. of solution.
Density = 1.008.

Pressure	259.0	380.6	546.5	639.8	759.6
Solubility	0.556	0.555	0.548	0.546	0.550

(f) *Egg-albumen.*

Commercial egg-albumen was employed. This was treated with water, and the solution, after filtration, submitted to dialysis.

FIG. 3.

TABLE VI.

Solubility of Nitrous Oxide in Solutions of Egg-albumen (see also Fig. 2).

Concentration: 0.38 gram of egg-albumen in 100 c.c. of solution.
Density = 0.998.

Pressure	248.7	361.3	530.7	633.7	755.7	996.2
Solubility	0.572	0.573	0.573	0.572	0.570	0.571
Pressure	262.1	370.5	537.3	634.5	733.5	915.0
Solubility	0.572	0.573	0.573	0.572	0.571	0.568

Concentration: 0.62 gram of egg-albumen in 100 c.c. of solution.
Density = 1.000.

Pressure	254.1	380.0	453.5	644.5	762.5	1020.5
Solubility	0.568	0.569	0.568	0.567	0.565	0.571

(g) *Silicic Acid.*

Pure silica was dissolved in potassium hydroxide solution, and the clear solution poured into excess of hydrochloric acid. The mixture was then submitted to dialysis until free from chloride. The concentration is expressed in terms of SiO_2 .

TABLE VII.

Solubility of Nitrous Oxide in Solutions of Silicic Acid (see also Fig. 3).

Concentration: 1.62 grams of SiO_2 in 100 c.c. of solution.
Density = 1.000.

Pressure	254.9	369.1	536.8	664.0	764.8	1007.1
Solubility	0.590	0.587	0.589	0.589	0.588	0.592
Pressure	255.1	370.4	537.6	676.0	765.4	1025.6
Solubility	0.594	0.591	0.589	0.588	0.588	0.591

Concentration: 3.50 grams of SiO_2 in 100 c.c. of solution.
Density = 1.004.

Pressure	250.2	375.2	546.5	687.5	758.7	1033.7
Solubility	0.600	0.595	0.594	0.593	0.594	0.598
Pressure	250.1	376.6	557.2	653.6	757.6	1004.0
Solubility	0.596	0.595	0.593	0.594	0.595	0.598

(h) *Suspensions of Silica and of Charcoal.*

For these experiments finely-powdered silica and animal charcoal were employed. The charcoal was boiled with water, and then, after being dried at 100° , was heated in a vacuum almost to redness.

The solubilities obtained with suspensions of silica did not differ appreciably from those in pure water. With charcoal the following values were obtained (see also Fig. 4):

Concentration: 3.0 grams of charcoal in 100 c.c. of water.

Pressure	252.6	366.8	527.7	626.6	749.8	989.5
Solubility	0.580	0.586	0.587	0.588	0.588	0.609
Pressure	255.3	374.3	545.3	639.0	760.3	1001.3
Solubility	0.583	0.581	0.586	0.591	0.588	0.610

Discussion of Results.

The solubility values which have now been obtained fit in exceedingly well with the values obtained at higher pressures by Findlay and Creighton (*loc. cit.*) if one allows for the slight difference in the value for the solubility in pure water. Since the

solubility values recorded here were carried out up to pressures of about 1000 mm. of mercury, whilst the pressures under which the experiments of Findlay and Creighton were carried out varied from about 750 mm. upwards, the two sets of solubility curves overlap over a considerable range; and we have found that over this range the two sets of curves are parallel with one another in the case of any particular solution. The two sets of experiments, therefore, mutually confirm each other.

Although it is hoped to discuss more generally at a later time the general question of the solubility curves obtained in the case of carbon dioxide and nitrous oxide, it may be mentioned here that an examination of the solubility curves for nitrous oxide as obtained by the present authors and, previously, by Findlay and Creighton, reveals a remarkable uniformity in general behaviour.

FIG. 4.

On considering the solubility curve for pressures varying from about 250 to 1400 mm. of mercury, it is found that in every case the curve exhibits a minimum, which is rather shallow indeed in the case of solutions of silicic acid, but is very well marked in most of the other cases, for example, in the case of solutions of gelatin, dextrin, and ferric hydroxide. Even in the case of solutions of starch we have found that the solubility of nitrous oxide passes through a quite distinct minimum value, although it is remarkable that no such behaviour was met with in the solubility of carbon dioxide in starch solutions (Findlay and Williams, *loc. cit.*). Although we have no reason to doubt the accuracy of any of the determinations, this somewhat exceptional behaviour, as it appears, of carbon dioxide in starch solutions makes it necessary for us to study more fully that particular case.

THE EDWARD DAVIES CHEMICAL LABORATORIES,
UNIVERSITY OF WALES,
ABERYSTWYTH.