

TABLE I

R ⁻	RPO(OC ₄ H ₉) ₃			B. p., Mm.			RPO(OC ₄ H ₉) ₂		Obs.	MR		RPO(OH) ₃		
	°C.	B. p., Mm.	°C.	B. p., Mm.	°C.	Mm.	n _D ²⁰	d ₄ ²⁵		Calcd.	Calcd.	M. p., °C.	Eq. wt.	Calc.
CH ₃ —	90	10 ^a										104–105 ^a		
C ₂ H ₅ —	86–88	9 ^a	137–139	17			1.4258	0.9623	59.09	59.13		61–62 ^b	55.6	55
CH ₃ (CH ₂) ₂ —	92–93	9 ^a										72.5–74.5 ^a		
CH ₃ (CH ₂) ₃ —			160–162	20 ^c			1.4302	.9462	68.28	68.4		103.4–104 ^c	68.8	69
CH ₃ (CH ₂) ₄ —			167–169	17			1.4318	.9428	72.60	72.98		120.5–121.5	75.9	76
CH ₃ (CH ₂) ₅ —	140–144	17	182–184	20			1.4332	.9366	77.17	77.60		104.5–106	82.7	83
CH ₃ (CH ₂) ₆ —			188–190	17			1.4355	.9313	82.20	82.22		103–103.5 ^d	89.8	90
CH ₃ (CH ₂) ₇ —			147–148	2			1.4370	.9262	86.56	86.84		99.5–100.5	97.2	97
CH ₃ (CH ₂) ₈ —	177–186	17	159–161	2			1.4391	.9253	90.98	91.45		99–100	104.3	104
CH ₃ (CH ₂) ₉ —	186–193	17	161	1			1.4402	.9232	95.37	96.05		102–102.5	110.8	111
CH ₃ (CH ₂) ₁₁ —	165–175	3	196–199	3			1.4482	.9153	104.9	105.3		100.5–101.5	124.9	125
CH ₃ (CH ₂) ₁₃ —	ca. 200	3	217–219	3			1.4460	.9114	114.1	114.55		97–98	139.1	139
CH ₃ (CH ₂) ₁₅ —			226–228	2			1.4481	.9090	123.2	123.8		94.5–95.5	153	153
CH ₃ (CH ₂) ₁₇ —			248–250	2			1.4499	.9037	132.6	133.02		98.5–99	167.2	167

^a P. Nylen, "Studien über org. Phosphorverbind.," Upsala, 1930. ^b Nylen (see above) reports m. p. 61.5–62.5°. ^c Arbuzov and Arbuzova²; they report m. p. 101–103°. ^d Fossek³ reported m. p. 106°.

fluxed with agitation, dibutylphosphite (9.7 g., 0.05 mole) was added dropwise over twenty to thirty minutes, after which the refluxing and stirring were continued until the sodium was completely dissolved; this generally required three to five hours. The alkyl bromide (0.05 mole) was then added over thirty to forty-five minutes and the mixture stirred with gentle reflux for five to six hours. The separation of sodium bromide generally began after fifteen to twenty minutes and was essentially complete in two to three hours. After cooling, the mixture was washed thoroughly with water, the organic layer separated, dried by the distillation of the solvent under reduced pressure at essentially room temperature, and distilled *in vacuo* in a fractionating apparatus. The dibutyl *n*-alkylphosphonate was refluxed with 50–75 ml. of concentrated hydrochloric acid overnight, after which the reflux condenser was set for downward distillation and the mixture was distilled from an oil-bath, with consequent removal of butyl chloride and most of the residual butanol, as well as approximately one-half of the volume of the hydrochloric acid. On cooling, at this point, the alkylphosphonic acids, higher than decyl, crystallized readily into a crust which was separated. The lower acids, due to their greater solubility in aqueous media, generally did not give a solid crust; hence, these mixtures were carefully evaporated to dryness. The crude alkylphosphonic acid so obtained was then repeatedly recrystallized from hexane, or heptane, to a constant melting point, followed by drying *in vacuo* over solid potassium hydroxide. The ethylphosphonic acid

was recrystallized from water, due to its poor solubility in petroleum solvents. All acids so obtained crystallized very readily frequently forming crystals 1–2 cm. long. These were generally clusters of flat needles, which were quite fragile, and upon drying greatly resembled naphthalene in their appearance.

The data obtained may be found in Table I.

It is interesting to note that the melting points of the acids studied do not present a regular "sawtooth" pattern vs. the number of carbons in the alkyl chain. There appears to be, instead, a grouping of melting points in the proximity of 100°.

Summary

A series of dibutyl alkylphosphonates has been prepared, with an even number of carbon atoms in the alkyl group, up to eighteen carbon atoms; similar esters of amyl-, heptyl- and nonylphosphonic acids were also prepared. The esters were converted into the corresponding alkylphosphonic acids, which were characterized.

A procedure giving good yields of the dibutyl esters and of the phosphonic acids has been evolved through the use of sodium dibutylphosphite.

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[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, DAVIDSON COLLEGE]

The Aqueous Solubility of Acetanilide

BY THOMAS S. LOGAN

Data for the aqueous solubility of acetanilide have been compiled by Seidell.¹ The data are not at all concordant. For instance, values at 25° vary from 0.54² to 0.61% acetanilide,³ an over-all difference of about 12%. Data for the solubility of solid acetanilide in water are not listed in the "International Critical Tables." This paper reports determinations of this solubility from 0 to

70°. Such measurements have been reported by Schoorl and de Weerd.⁴

Experimental

Determination of Solubility.—The determinations were run in 50-ml. flasks. The flasks were closed by two-hole rubber stoppers having inlet and outlet tubes for withdrawing the solutions. The outlet tube had a plug of cotton in its upper part. Water and acetanilide were put in a flask and alternately heated and cooled until cooling produced a cloud of crystals. The flask and contents were then heated to several degrees above the temperature

(1) Seidell, "Solubilities of Organic Compounds," third edition, Vol. II, pp. 600–604.

(2) Holleman and Antusch, *Rec. trav. chim.*, **13**, 293 (1894).

(3) J. Mahieu, *Bull. soc. chim. Belg.*, **45**, 667 (1936).

(4) Schoorl and de Weerd, *Rec. trav. chim.*, **41**, 15 (1922).

of the determination and held there sufficient time to insure the solution of the acetanilide. The rubber stopper and tubes, warmed where appropriate, were then inserted, and the whole was attached to a shaking device immersed in a thermostat. Temperature regulation was $\pm 0.05^\circ$, except at 70° , where it was $\pm 0.10^\circ$. The temperature of the thermostat was followed with a Beckmann thermometer, which was compared directly with a thermometer certified by the Bureau of Standards. The latter had scale divisions of 0.2° .

At 20° and above, shaking was continued for two hours, when two samples of saturated solution were withdrawn from one flask, or one sample from each of two flasks. After another hour, or longer, two other samples were similarly secured. Duplicate results were considered as indicative of saturation. In the measurement at 10° it was necessary to shake at intervals by hand. Samples were withdrawn at seven and ten hours. The measurements at 0° were effected by putting the solubility flasks in Dewar flasks and surrounding them with crushed ice and water. They were shaken at intervals by hand. Samples were taken at eight and eleven hours.

The solution samples were either sucked into previously weighed 200-ml. flasks, or were sucked into weighed, dried pipets, warmed where necessary. The methods of solution transfer were checked with solutions of known concentration, results within the error of analysis being obtained. The samples withdrawn contained from 0.05 to 0.08 g. of acetanilide. The flasks were kept immersed in the thermostat as the solutions were withdrawn, except for the inlet and outlet tubes. Connection with the pipets was made by a short piece of rubber tubing. In all cases the first two or three grams of solution were withdrawn separately and discarded.

Analysis.—The solution samples were diluted to 50 ml., 5 ml. of concentrated hydrochloric acid was added, and they were refluxed at the boiling point for one hour, being connected to the condensers by rubber stoppers. Experiments where solutions of aniline hydrochloride and hydrochloric acid were similarly refluxed showed that the rubber stoppers had no effect on the determination. The refluxed solution was titrated with 0.1 *N* potassium bromate-bromide solution to a faint yellow color. Five ml. of a 10% solution of potassium iodide was then added and the titration completed against 0.01 *N* sodium thiosulfate. For the original analysis of the acetanilide used in the measurements, the bromate-bromide solution was standardized against standard sodium thiosulfate by a method analogous to the Volhard method for potassium permanganate. The value of the bromate-bromide solution was checked regularly.

Materials.—The acetanilide was secured from the Eastman Kodak Company. Analysis of four samples, kept over sulfuric acid for some weeks, gave results of 100.34, 100.09, 100.00, and 99.81% acetanilide. This material was thereafter used in checking the concentration of the bromate-bromide solution. Consecutive solubility determinations, using the same portion of acetanilide, gave concordant results. The same results were obtained at 25° in determining the solubility of a sample of acetanilide from another source.

The water used was the distilled water of this Laboratory, having a pH of about 5. Two series of solubility determinations were run at 25° using this water, redistilled water, and water with its pH adjusted to 7 by addition of sodium hydroxide. The results obtained checked within the experimental error.

The reagents were all of C. P. grade.

The burets and weights used were calibrated. The weights of the solution samples were reduced to vacuum.

Results

Table I gives typical results secured at 50° . Part (a) shows results secured when several pieces of chopped rubber tubing were added to the mixture in the solubility flask. Part (b) shows results

secured when a solubility flask and contents were cooled several degrees below 50° before introduction into the thermostat. Similar experiments, from the side of undersaturation, at 25° , gave results in accord with those secured when solutions were cooled. Part (c) shows the data on which the measurement at 50° , recorded in Table II, is based.

TABLE I
SOLUBILITY OF ACETANILIDE AT $50.00 \pm 0.05^\circ$

	Solubility	Hours shaken	Deviation from Table II, %
(a)	1.331	2	+0.4
	1.329	3	+ .2
	1.327	3	+ .1
Av.	1.329		+ .2
(b)	1.326	4	.0
	1.324	4	— .2
Av.	1.325		— .1
(c)	1.322	2	— .3
	1.332	2	+ .5
	1.325	3.5	— .1
	1.327	3.5	+ .1
Av.	1.326		

Since the data secured are at considerable variance with published values, the solubility was determined at 25° by evaporating two samples

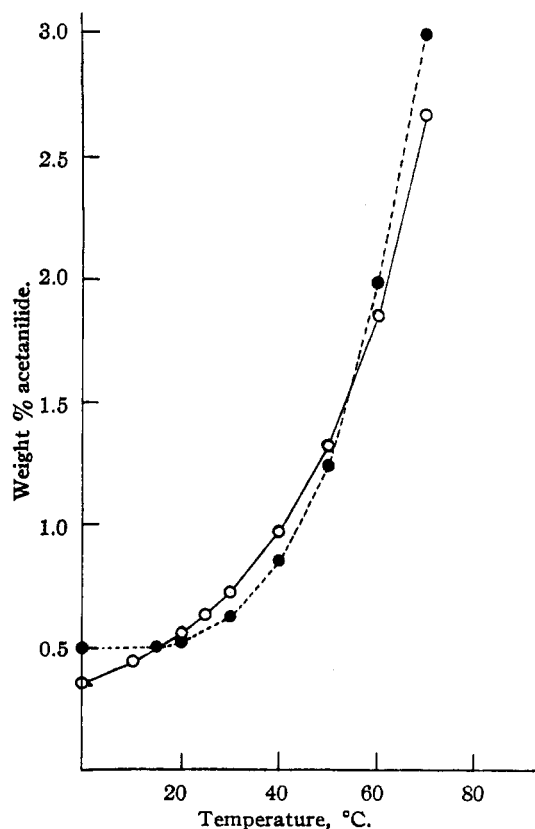


Fig. 1.—The solubility of acetanilide in water: ●, data of Schoorl and de Weerd

of saturated solution. These were evaporated to dryness by sweeping dried air over them at room temperature. Two weighed 0.1-g. samples of acetanilide in corresponding amounts of water were also so treated. When constant weight of ≈ 0.2 mg. was secured over a period of forty-eight hours, the two samples of known weight each retained about 0.6 mg. of water. This correction

was applied proportionately to the weights of the residues from the two solution samples. The solubility values thus obtained were 0.6400 and 0.6371% acetanilide, a satisfactory check for the value at 25° shown in Table II.

The results are given in Table II and are plotted in Fig. 1. For comparison, the data of Schoorl and de Weerd⁴ are also plotted. The maximum average deviation of the mean obtained in the measurements was 0.3%. For all cases this was equal to or smaller than the possible variation due to temperature fluctuation. It is thought that the measurements are accurate to $\approx 0.3\%$.

These determinations have been made as the preliminary to a study of the effect of electrolytes on the solubility of acetanilide. This work is now in progress.

Summary

The solubility of acetanilide in water has been determined from 0 to 70°.

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Temp., ° C.	Sol., wt. %
0.00	0.3598
10.13	.4414
20.00	.5612
25.00	.6390
30.00	.7285
40.00	.9737
50.00	1.326
60.00	1.857
70.00	2.676

* Regulation $\approx 0.05^\circ$, except at 70° where it was $\approx 0.10^\circ$.

[CONTRIBUTION FROM THE CONTROL LABORATORY OF GELATIN PRODUCTS CORP., AND THE DEPARTMENT OF CHEMISTRY, WAYNE UNIVERSITY, DETROIT, MICHIGAN]

A Study of the Binary System Nicotinamide-Ascorbic Acid^{1,1a}

BY CECIL W. BAILEY,² J. RUSSELL BRIGHT² AND JOSEPH J. JASPER³

Certain difficulties were encountered in the production of vitamin capsules in which the contents were mixtures containing varying amounts of nicotinamide and vitamin C (ascorbic acid). It has been shown that vitamin C forms salts with numerous metallic ions and with organic bases, *e. g.*, with the cinchona alkaloids,⁴ quinine, quinidine, hydroquinine and hydroquinidine. The purpose of the present study was to ascertain by means of a temperature-composition diagram whether or not a reaction takes place in the system nicotinamide-ascorbic acid. Similar measurements were made using nicotinic acid in place of nicotinamide, in order to elucidate on the type of linkage involved.

Experimental

Preparation of Mixtures.—Pure nicotinamide (m. p. 129–131°) and pure ascorbic acid (m. p. 188–190°) were dissolved in absolute methyl alcohol in separate beakers and then mixed. The alcohol was removed by evaporation to dryness on a steam-bath. All resulting mixtures were dried *in vacuo* over phosphoric oxide for 168 hours and stored in a desiccator over the same desiccant.

The yellow molecular addition compound of nicotinamide and vitamin C was also prepared in the dry state by

mixing equimolecular quantities of the two components in a ball mill. The product was identical with that prepared in solution. This addition compound is insoluble in acetone, ether, and petroleum ether; very slightly soluble in benzene, carbon tetrachloride, and chloroform; slightly soluble in ethylene dichloride; and soluble in alcohol, aniline, diethylene glycol, propylene glycol, and water. The solubility relations of the compound are noticeably different in comparison to the corresponding behavior of the separate components. For example, nicotinamide is moderately soluble in acetone but insoluble in diethylene glycol. Ascorbic acid is quite insoluble in aniline, diethylene glycol, and propylene glycol. Similarly, mixtures of nicotinic acid and ascorbic acid were prepared from alcoholic solutions.

Melting points on the various mixtures were determined in small open capillary tubes using a Thiele tube containing sulfuric acid which was kept stirred. Two Anschütz thermometers were used, one with a range of 90–150° and the other with a range of 145–200°.

Molecular Weight Determinations.—The usual Beckmann apparatus was used to make freezing point measurements. Cryoscopic determination of the molecular weight of the nicotinamide-ascorbic acid compound using distilled water as the solvent gave 180.0, 165.6 and 147.3; theoretical 298.12. Cryoscopic determination using aniline as the solvent gave discordant results, namely, 46.77, 62.01, 63.76, 49.54, 43.29 and 40.90. Ebullioscopic determination of the molecular weight by the method of Menzies and Wright⁵ using absolute ethyl alcohol as the solvent gave 176.2, 171.4 and 166.8.

Results

Experimental data for the nicotinamide-ascorbic acid system are presented in Table I and Fig. 1. These data show the formation of a 1,1-

(5) A. W. C. Menzies and S. L. Wright, *THIS JOURNAL*, **48**, 2314 (1921).

(1) Original manuscript received November 10, 1943.

(1a) Presented before the Symposium on Molecular Addition Compounds of the Division of Physical and Inorganic Chemistry at the Pittsburgh meeting of the American Chemical Society, September, 1943.

(2) Gelatin Products Corporation, Detroit, Michigan.

(3) Wayne University, Detroit, Michigan.

(4) Swiss Patents 208,852 and 214,108; British Patent 533,480.