TABLE I

YIELDS, PROPERTIES AND COMPOSITION OF ALKYLPIPERAZINES PREPARED

	Compound	Yield, %	B. p., °C.	Mm.	M. p., °C.	N analyses, % Found	Calcd.
1	N-Phenyl-N′-methylpiperazine[b]	42	109–110	5		15.95	15.91
2	N-Phenyl-N′-ethylpiperazine[b]	98	144–145	10		14.81	14.74
3	N,N′-Dimethylpiperazine[b]	88	130–135			24.51	24.56
4	N,N′-Dimethylpiperazine dihydrochloride[a]	74			263 (dec.)	14.83	14.97
5	N,N′-Diethylpiperazine[b]	92	174–177			19.69	19.70
6	N,N′-Dibutylpiperazine[c]	62	195–195.5	12		14.15	14.14
7	N,N′-Dibenzylpiperazine[c]	84			91.5–92.5	10.60	10.53
7	(From benzyl chloride)	75			92–93	10.83	10.53
8	N,N′-Di-(*p*-methylbenzyl)-piperazine[c]	31			101–102	9.54	9.53

[a] Prepared from N,N′-dimethylpiperazine by passing dry hydrogen chloride into the anhydrous ether solution of the free base. [b] Prepared by using zinc and hydrochloric acid as the reducing agent. [c] Prepared by using formic acid as the reducing agent.

mole of the aldehyde and two moles (twice the calculated amount) of powdered zinc. A quantity of concentrated hydrochloric acid sufficient to react with the zinc was added gradually with stirring and cooling. After the zinc had all reacted, the mixture was made alkaline and the free base was extracted with ether. The ether solution was dried over anhydrous sodium carbonate, filtered and the ether evaporated. The free base was purified by distillation.

Using Formic Acid as Reducing Agent.—A mixture of 0.1 equivalent of the secondary amine and 0.1 mole of the aldehyde was refluxed with 40 cc. of formic acid (90%) until the evolution of carbon dioxide had ceased. The excess formic acid was evaporated on a water-bath and the residue made alkaline. The free base was extracted with ether, dried, filtered and the ether evaporated. The derivative was purified by recrystallization or distillation.

Summary

Satisfactory methods are described for the preparation of alkyl piperazines by the condensation of piperazine or N-monophenylpiperazine with aldehydes in the presence of a reducing agent.

GAINESVILLE, FLORIDA RECEIVED JULY 8, 1935

[CONTRIBUTION FROM THE CHEMICAL LABORATORY, UNIVERSITY OF VERMONT]

The Free Energy Change that Accompanies Hydrogenation of Pyridine to Piperidine[1]

BY GEORGE H. BURROWS AND LOUIS A. KING, JR.

That pyridine is readily hydrogenated to piperidine, and that the reaction is reversible, has been shown by Zelinski and Borisov.[2] The purpose of the present investigation is to determine the free energy change of the reaction, through direct determination in the vapor phase of the equilibrium involved at each of several temperatures.

Attempts to achieve this equilibrium through initial use of hydrogen and pure pyridine or of hydrogen and pure piperidine did not lead to the desired results, and substantiated the conclusion of Sadikov and Mikhailow[3] that side products are extensively formed. It was also our experience that the active life of the platinum or nickel catalyst was short.

On these accounts experiments were devised to apply the use of trial mixtures of the several components, that mixture being deemed of equilibrium composition which underwent no appreciable change on being passed over the active catalyst at the selected temperature.

Materials and Experimental Details

Pyridine and piperidine of high quality were obtained from the Eastman Kodak Company. The pyridine was refluxed over solid potassium hydroxide and distilled. Its boiling point was 115.2–115.4°, its index of refraction $n^{25}\mathrm{D}$ was 1.50682. In some instances the piperidine was given this same treatment, in others no treatment was necessary, as shown by its refractive index. This had the value $n^{25}\mathrm{D}$ 1.45036.

The hydrogen, a commercial electrolytic product of high purity, was freed from possible oxygen contamination by palladinized asbestos and thoroughly dried before use.

The compositions of pyridine–piperidine mixtures were determined through their refractive

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[1] Grateful acknowledgment is made to the Elizabeth Thompson Science Fund for aid in financing this research.

[2] Zelinski and Borisov, *Ber.*, **57**, 150 (1924).

[3] Sadikov and Mikhailow, *J. Russ. Phys.-Chem. Soc.*, **58**, 527 (1927).

indices. The data for synthetic mixtures of known composition are shown in Table I.

TABLE I

% pyridine	% piperidine	n^{25}_D
0.00	100.00	1.45036
26.92	73.08	1.46394
53.03	46.97	1.47840
74.79	25.21	1.49134
100.00	00.00	1.50682

The composition–refractive index curve is almost linear, but is slightly concave toward the composition axis. The data of Table I may be expressed by the equation, $n_D = 1.45036 + 0.0_349$ (% pyridine) $+ 0.0_673$ (% pyridine)^2 with an average deviation of 0.0001. Precision of analysis is favored by the wide difference between the indices of the pure components.

The nickel used as catalyst in the final experiments was prepared from oxide reduced in place by hydrogen and on an unglazed porcelain support. Complete reduction and removal of moisture is necessary and was indicated by ultimate constancy in weight of a drying tube through which the effluent gas was passed.

The experimental procedure was as follows. A bubbler system immersed in a constant temperature bath contained a mixture of pyridine and piperidine. It was provided with tubes through which this mixture could be withdrawn and replaced for the purpose of change of composition. Hydrogen entering the bubbler at constant rate of flow passed with the vapors of pyridine and piperidine in constant ratio either through the catalyst chamber or through the by-pass. Both catalyst chamber and by-pass were supported in a furnace that maintained the temperature constant within 0.5°. The catalyst chamber or the by-pass, as the case might be, led to a weighed condensing tube immersed in a freezing mixture; beyond this the hydrogen was collected and measured. The condensed mixture of pyridine and piperidine was weighed and analyzed.

Through systematic change in composition of the bubbler mixture and alternate use of catalyst chamber and by-pass, it proved not difficult to fix upon a mixture that remained essentially unchanged by the catalyst.

Sadikov and Mikhailow[3] noted that use of nickel as catalyst led to opening of the pyridine ring, with formation of amylamine. Under the conditions of the present work, this side product could not have been present in other than relatively small amounts, for the condensate from the catalyst chamber gave negative results when subjected to the Van Slyke method of analysis for amines. Absence of significant amounts of this side product was deemed sufficient evidence that other side products were not formed in sufficient quantities to necessitate consideration, under the existing condition of brief contact with the catalyst, and at the temperatures of the experiments used in our calculations.

The indices of refraction and compositions of the final equilibrium mixtures at the several furnace temperatures used, and the partial pressures and equilibrium constants calculated from these are shown in Tables II and III.

TABLE II

Furnace temp., °C.	n_D catalyst condensate	n_D by-pass condensate	Wt. of catalyst condensate, g.	Vol. H_2, cc. (reduced)
150	1.45627	1.45627	1.3586	257.3
170	1.47948	1.47967	0.9924	250.5
180	1.48113	1.48142	.6848	255.3
180	1.48500	1.48568	.5984	258.7

TABLE III

Temp., °C.	Composition catalyst condensate % pyridine	Composition catalyst condensate % piperidine	Partial pressures (atm.) H_2	Partial pressures (atm.) C_5H_5N	Partial pressures (atm.) $C_5H_{11}N$	K_p
150	11.75	88.25	0.415	0.073	0.509	97.4
170	54.88	45.12	.486	.288	.220	7.45
180	57.70	42.30	.573	.251	.171	3.6
180	64.20	35.80	.607	.256	.132	2.3

Greater difficulty was experienced at 180° in gaining close agreement between the compositions of mixtures that passed over the catalyst and through the by-pass, than at the lower temperatures. This is thought to be due to increased formation of side products at the higher temperature. The results at this temperature, therefore, are not used in the free energy calculations. The equilibrium constant at 180° calculated from the values at 150 and 170° is 2.25.

From the constants at 150 and 170°, the free energy changes at these temperatures are $F^\circ_{423} = -3835$ cal. and $F^\circ_{443} = -1760$ cal., respectively, corresponding in each case to the reaction

$$C_5H_5N(g) + 3H_2 = C_5H_{11}N(g)$$

Heat capacity data for pyridine and for piperidine in the gaseous state are not available and cannot be estimated reliably; consequently reduction of the free energy change to that at 25° is not attempted.

The equilibrium constants at 150 and 170° give as the heat of reaction between these temperatures, $H = -47{,}680$ cal. Approximate reduction to 25° and pyridine and piperidine in liquid state gives for these conditions $H = -45{,}000$ cal. The corresponding value calculated from thermochemical data ("International Critical Tables") is −38,600 cal.

Summary

The equilibrium between pyridine, hydrogen and piperidine has been measured at 150 and at 170°, and more approximately at 180°. The heat of reaction and the accompanying free energy changes have been calculated.

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[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY, WASHINGTON SQUARE COLLEGE, NEW YORK UNIVERSITY]

Diffusion Coefficients in Alcohol–Water Mixtures

BY H. MOUQUIN AND W. H. CATHCART

The diffusion coefficients of a number of organic dyes dissolved in water–ethyl alcohol mixtures of varying composition were studied by Ostwald and Quast.[1] Their method, which essentially involves a continuously varying diffusion layer, seemed to contain some experimental difficulties. In view of this fact and the rather unusual nature of their results, the present authors attempted to repeat the original experiments with the intention of extending the work in this field. In spite of every effort to duplicate the conditions described in the original paper, the method proved too unreliable to permit verification of the previous findings.

The Ostwald method contained two obvious limitations: first, the solutions were placed in an unsealed vessel and were thus very sensitive to any disturbances capable of bringing about mass flow; second, the arrangement of the apparatus was such that it necessarily involved the tacit assumption that the density of the solution was greater than that of the solvent.

Testing the relative densities of crystal violet solutions and corresponding solvents at varying alcohol concentrations by means of the "schlieren" method, it was soon discovered that at least in the region between 25 to 50% (by weight) of alcohol the density of the 0.1% dye solution was actually less than that of the corresponding solvents. This no doubt is the major difficulty involved in the Ostwald method.

In recent years, a method first used for the measurement of diffusion coefficients by Northrup and Anson,[2] and greatly extended by McBain and co-workers, has become available. We refer to the so-called fritted glass membrane method, involving a constant diffusion-layer thickness. In two recent papers, McBain and Dawson[3] have pointed out the advantage of using a closed system. In a previous paper,[4] the disadvantages of stirring had been mentioned, but this was attempted only in an open cell.

The major requirements in the membrane cells not only include the existence of an undisturbed diffusion gradient in the membrane, but also adequate stirring in the bulk of the solutions right up to the surface of the fritted glass disk. If this last condition is not fulfilled, secondary diffusion layers build up beyond the strict confines of the membrane and this introduces a variable and unknown factor.

In the original technique, density difference between solvent and solution must be depended upon entirely for adequate mixing. Variations in viscosity must certainly affect the efficiency of this gravitational streaming, but, besides this, the density differences can vary over a wide range from case to case.

In the case at hand where the density differences may become vanishingly small, it is obvious that the traditional technique is impossible. In fact the formation of vague secondary diffusion layers beyond the physical boundaries of the membrane could easily be seen in the case of the more highly colored solutions.

The cell shown in Fig. 1 was designed to overcome the above difficulties and has been in use in this Laboratory for more than a year. First, it is entirely enclosed;[3] this effectively prevents any mass flow, outside of the most violent agitation. Second, the entire cell is slowly rotated at a speed somewhat under one r. p. m. by means of a wheel and belt drive placed in the thermostat. This motion coupled with the rise and fall of the en-

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(1) Ostwald and Quast, *Kolloid-Z.*, **48**, 83–95 (1929); **51**, 273 (1930).

(2) Northrup and Anson, *J. Gen. Physiol.*, **12**, 543 (1929).

(3) McBain and Dawson, THIS JOURNAL, **56**, 52 (1934); also *Proc. Roy. Soc.* (London), **A148**, 32 (1935).

(4) McBain and Liu, THIS JOURNAL, **53**, 59 (1931).