ing the points representing the total composition, the liquid phase and solid phase in any case converge in a point or area inside of the phase rule diagram, showing the presence of salt in the precipitate. This criterion does not admit of occluded solution as the source of the salt.

The gamma in B as well as the gamma bands observed in serum, in accordance with this theory, are due to the whole equilibrium system and do not correspond to any one of the three components involved but are a resultant of all. The free fast component if present in excess increases the apparent mobility, the free slow component decreases it. There is a constant dissociation and reassociation. The spreading of the boundary which occurs would be expected. The effect may well be related to that on sedimentation of a system in mobile equilibrium where the sedimentation rate is decreased by the slow component and increased by the faster one, with a resultant sedimentation velocity which does not correspond to that of the compound or either of its components but is a resultant of all. It may be noted also that the component of gamma with the greater mobility is salted out at the lower salt concentration. This is not in accordance with the generalization of Cohn[2] that with increasing salt concentration proteins of higher and higher mobilities are separated.

It is possible that the appearance of the T fraction seen in some immune sera and not in others, may indicate that in the former sera the complex is not held together in its usual manner. Its mobility is that of the gamma part of A_1.

The relationships of the various components of serum to each other are undoubtedly very complex. They are under further investigation.

We wish to acknowledge the helpful advice of Dr. J. W. McBain and Dr. Thomas Addis.

Summary

1. A method for the preparation of homogeneous constituents of gamma globulins has been described, in which emphasis is laid upon the use of potassium citrate in place of ammonium sulfate. The latter induces heterogeneous mixtures when used in the usual manner as shown by the solubility behavior.

2. Constant solubilities were found for two of our globulin fractions designated as A_2 and B.

3. Electrophoretic measurements were made on four different fractions of gamma globulin (range 1.1–1.7) The mobility of the gamma globulin of A_1 was 2.2; A_2, 1.7; B, 1.0–1.7; and C, 1.2, expressed in cm. per sec. per volt per cm. $\times 10^5$.

4. Both solubility behaviors and electrophoretic results are explained in terms of a mobile equilibrium between a complex and its components.

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[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY OF THE UNIVERSITY OF SOUTHERN CALIFORNIA]

The Phase Behavior of Lithium Palmitate with Water and with Lithium Chloride and Water

BY MARJORIE J. VOLD

This paper presents the results of a study of the phase behavior of lithium palmitate and water over the complete composition range at temperatures ranging from the melting point of the lithium palmitate down to about 100°; the solubility of lithium palmitate in water below 100° is inconsequential. The effect on the phase diagram of small additions of lithium chloride has also been determined.

Phase studies of binary systems of soap and water are now available for several sodium soaps in detail sufficient to show the effect of simple variations in the anion of a soap on its solubility in water. Vold, Reivere and McBain[1] have discussed this effect, pointing out that it is a complex one since the decrease in lattice stability (m. p.) and the increase in non-polar character with increasing carbon content of a soap molecule are factors opposing each other in their influence on its solubility in water. Similar study of a series of alkali soaps of the same fatty acid provides the simplest analog in which the cationic portion of the soap is varied systematically. In this case also, as with variations in the anion, the results

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[1] R. D. Vold, R. Reivere and J. W. McBain, THIS JOURNAL, 63, 1293 (1941).

are complex and subject at present only to qualitative interpretation.

Materials and Procedure.—Lithium palmitate was prepared from Eastman Kodak Co. best quality palmitic acid and Merck C. P. lithium chloride. The acid had an iodine value of < 0.2 and an equivalent weight by titration of 257.0 (theory 256.3). The lithium chloride was converted to the hydroxide by agitation with freshly prepared silver oxide, repeated until the supernatant liquid gave no further test for chloride ion. The solution of lithium hydroxide was then used to neutralize a solution of palmitic acid in hot 95% ethyl alcohol. The product was dried to constant weight in air at 105°. It was found by analysis to be exactly neutral, and free from both chloride and carbonate. The solubility data were obtained by the synthetic method (*i. e.*, observation of temperatures of phase change when a sample of known composition is heated or cooled). Details and limitations of this method have been described elsewhere.[2]

Results and Discussion

Lithium Palmitate–Water.—From room temperature to 102° lithium palmitate exists in a rhombic crystal form (I) whose habit is similar to that reported for sodium stearate by Thiessen and Stauff.[3] Form II, stable between 102 and 187°, may be a second crystal form. A second transition occurs at 187° to a form (III) resembling the waxy forms of sodium soaps. Melting occurs at 224–225°, in agreement with the result of Jacobson and Holmes.[4] A more complete investigation of the phases of the anhydrous soap will be reported elsewhere.

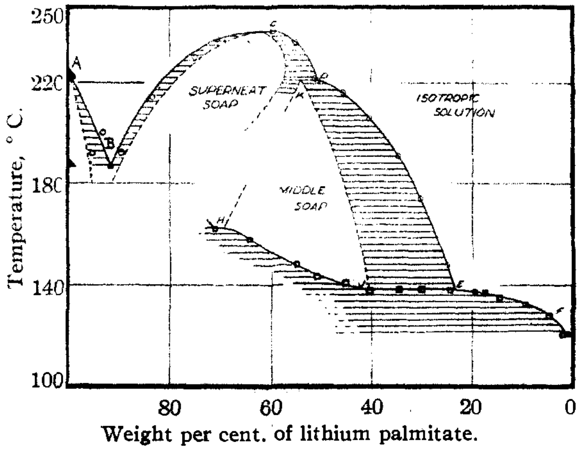

Fig. 1.—The phase behavior of lithium palmitate with water: ▲, transitions of anhydrous lithium palmitate; O, separation of liquid crystal occurs as isotropic liquid is cooled; □. crystals dissolve completely on heating; □, crystals dissolve completely on heating to form a phase different from middle soap or a mixture of phases.

The solubility data for lithium palmitate in water are shown in Fig. 1. Points on the left axis are the transition temperatures of the anhydrous soap. Curve AB of Fig. 1 gives the solubility of form III in water. Curve BCD gives the compositions of isotropic solutions in equilibrium with an aqueous liquid crystalline phase superficially resembling superneat soap. Curve DE gives these data for a second aqueous liquid crystalline form resembling middle soap. Curve EF gives the solubility of form II in isotropic solution. Curve HJ gives the solubility of form II in the middle soap phase. Between J and E three phases (solid, middle soap and isotropic solution) are in equilibrium.

From these data and from additional qualitative observations, it is possible to infer the course of additional phase boundaries which are shown in Fig. 1 as dotted curves. The region of coexistence of superneat soap with isotropic liquid is made narrow, since complete conversion from liquid to liquid crystal occurs when samples are cooled only a few degrees below curve BCD. When samples whose compositions fall along curve DE are cooled, some isotropic liquid remains over a wide temperature interval and actual separation into discrete layers occurs in a few hours. These observations, and also the width of the flat JE, support the inference (curve KJ) that the region of coexistence of middle soap and isotropic liquid is rather wide. The existence of a heterogeneous region between middle soap and superneat soap is necessary from phase rule considerations. The inference that this region begins at curve HK is based on the observation that samples to the left of this curve are so opaque that visual observations to extend curve HJE become suddenly impossible in contrast to the transparency of systems containing only middle soap.

Viewed as a phase diagram for the system lithium palmitate–water, Fig. 1 does not differ very much from that for sodium palmitate–water.[5,6] Temperatures and compositions of comparable points are given in Table I.

The phase diagram can also be regarded as an assembly of solubility curves of different types. Comparison of corresponding curves shows that the effect of substituting lithium for sodium is not the same in all phases.

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[2] R. D. Vold, *J. Phys. Chem.*, **42**, 1213 (1939).

[3] P. A. Thiessen and J. Stauff, **A176**, 397 (1936).

[4] C. A. Jacobson and A. Holmes, *J. Biol. Chem.*, **25**, 29 (1916).

[5] J. W. McBain, L. Lazarus and A. V. Pitter, *Z. physik. Chem.*, **A147**, 87 (1930).

[6] J. W. McBain, R. D. Vold and M. Frick, *J. Phys. Chem.*, **44**, 1013 (1940).

TABLE I

COMPARISON OF THE PHASE BEHAVIOR WITH WATER OF SODIUM AND LITHIUM PALMITATE

Point (Fig. 1)	Description	Composition (moles water/mole soap)		Temp., °C.	
		LiP	NaP	LiP	NaP
A	Melting point	0.00	0.00	224	295
B	$(I_{NS})^a$ isotropic solution in eq'm. with superneat and a more concentrated form	1.35	1.1	187	269
C	$(S)^a$ isotropic solution in eq'm. with superneat soap of the same composition	9.1	4.5	240	284
K	$(M)^a$ middle soap at its highest temperature of existence	*ca.* 12	20.5	221	171
D	$(I_{NM})^b$ isotropic solution in eq'm with both middle soap and superneat soap	14.2	16.2	221	159
E	$(I_{CM})^a$ isotropic solution in eq'm with both solid and middle soap	48.6	44.0	138	71

[a] Designation given by McBain, Vold and Frick, ref. 6. [b] In the sodium palmitate case the liquid crystalline phase designated N by McBain, Vold, Frick refers to soap boiler's neat soap which may or may not constitute a different phase from superneat soap.

As is apparent from Fig. 1, a region of composition exists wherein incorporation of water with the lithium palmitate produces a liquid crystalline structure more resistant to thermal destruction (melting) than the anhydrous liquid crystalline form existing between 187 and 224°. The numerical data of Table I show that anhydrous sodium palmitate melts at a higher temperature than does anhydrous lithium palmitate; the same is true of the superneat form. However, the difference in the maximum melting temperature of the superneat phases is much less (44°) than the difference in the melting points of the dry soaps (71°). This means that, allowing for the intrinsic difference in lattice stability reflected by the behavior of the dry soaps, the lithium superneat structure is bonded together more strongly by the incorporated water than is the sodium superneat structure. Consideration of available data for sodium and potassium oleates[7] and sodium and potassium laurates[8] shows that the binding power of water in the superneat structure is less for potassium soaps than for sodium. This order: Li > Na > K is logically associated with the similar order of the heats of hydration of the three cations. Confirmation of this idea is found in the fact that the amount of water in the structure at the composition of maximum thermal stability is in the same order, *i. e.*, Li > Na > K.

At the opposite extreme of composition (curve EF), where the solution of relatively small amounts of solid soap to form a dispersion of colloidal micelles in water is being considered, the influence of the three cations is the same as the order of their atomic numbers. At any given temperature the order of solubilities is potassium > sodium > lithium. Further, the solubility curves for soaps are characterized by an extremely rapid increase in solubility in a narrow temperature interval whose upper limit can be sharply defined as the temperature at which middle soap first forms. This temperature decreases in the order lithium > sodium > potassium.

Inspection of available data[9,10] on the relative solubility of other salts of these three cations reveals considerable lack of regularity; however, the salts of organic acids, such as acetates, benzoates, citrates and oxalates, exhibit the same order of increasing solubility as that found for the palmitates. Hildebrand[11] points out that for electrolytes in general solubility is promoted by low melting point and high solvation. Both these factors would operate to make the order of solubility of the palmitates the reverse of that found. A possible clue to the explanation of the order found is the observation by Hildebrand[11] that for substances of low solubility, ionization of the salts is a factor promoting solubility. In the case of the soaps the activity of simple undissociated molecules in equilibrium with the solid is reduced also by the formation of colloidal micelles. McBain[12] has shown that at the same composition and temperature potassium soaps are more col-

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(7) J. W. McBain and W. J. Elford, *J. Chem. Soc.*, 421 (1926).

(8) J. W. McBain and M. C. Field, *J. Phys. Chem.*, **30**, 1545 (1926). The separate existence of superneat soap had not been recognized when this work was done. Reconsideration of the data shows that it probably exists for potassium oleate[7] with a maximum point only 2° above the eutectic: neat-superneat-liquid. The superneat form probably does not exist for potassium laurate.

(9) Lange, "Handbook of Chemistry," fourth ed., Handbook Publisher's Co., Sandusky, Ohio, 1941.

(10) A. Seidell, "Solubilities of Inorganic and Metal Organic Compounds," 3rd ed., D. Van Nostrand Co., New York, N. Y., 1941.

(11) J. H. Hildebrand, "Solubility," Chemical Catalog Co. (Reinhold Pub. Corp.), New York, N. Y., first ed., 1924, p. 166.

(12) J. W. McBain, "International Critical Tables," Vol. V, p. 440.

loidal than are sodium soaps. This point has never been investigated for lithium soaps.

In the temperature range where the solubility increases so rapidly (along EF) some fundamental change in the character of the solution or the equilibrium solid form or both must occur, but no satisfying explanation has yet been advanced. It seems significant that at the upper limit of this range the saturation phase changes from relatively dry solid to the heavily hydrated middle soap. With this in mind one can speculate that some thermal loosening of the crystal lattice is required before water can permeate the relatively hydrophobic hydrocarbon portion and build a hydrous layer around the more polar carboxylate portion. Since lithium ion is the smallest and possibly thus draws the palmitate ions more closely together (*i. e.*, along their length, interchain spacings having been shown relatively constant by X-ray work on many paraffin chain compounds) the order of temperature to be expected on this hypothesis is Li > Na > K in accord with experiment.

The properties of the cations which lead to regular variations with atomic number for the solubility of superneat soaps (curve BCD) and for the solubility of the more nearly crystalline phases (curve EF) must operate in diverse ways upon the stability of middle soap, since for this phase no such regularity can be adduced. Thus for potassium and sodium oleates or laurates, the compositions at the maximum point are nearly the same and the order of temperatures is the same as the order of melting points. But for sodium and lithium palmitates the compositions are quite different, the lithium palmitate, curiously enough, being the less hydrated, and the order of temperatures is the reverse of the order of melting points.

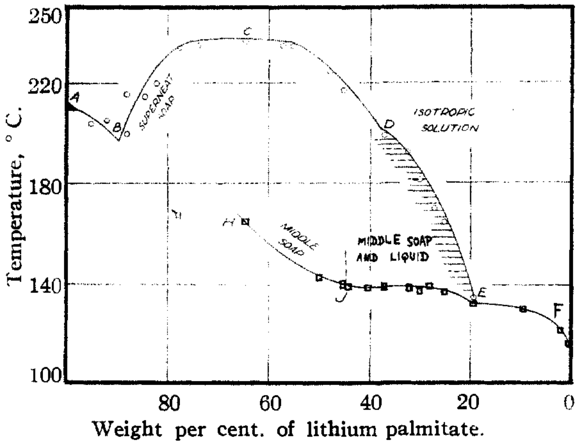

Fig. 2.—The effect on the phase behavior of lithium palmitate and water of lithium chloride present at a mole ratio of salt to soap of 0.048: ▲, melting point of lithium palmitate; O, separation of liquid crystal occurs as isotropic liquid is cooled; □, crystals dissolve completely on heating; ⌑, crystals dissolve completely on heating to form a phase different from middle soap or a mixture of phases.

Lithium Palmitate–Lithium Chloride–Water. —Figures 2 and 3 show the effects of small amounts of lithium chloride on the solubility curves of Fig. 1. These graphs are vertical sections through the three dimension model which must be used to represent phase data completely in such a ternary system. When the molar ratio of salt to soap is only 0.048 there is little qualitative difference from the diagram for the salt-free system. When this ratio is increased to 0.15, deviations from binary behavior become so marked that it is no longer possible to regard the system, even approximately, as one of two components. The most striking departure from binary behavior occurs in the region of superneat soap where (see Fig. 3) separation into two liquid layers occurs as superneat soap melts, the three phases coexisting at different temperatures with varying compositions.

Curve BC, along which superneat soap separates as a liquid crystalline solution more dilute than the isotropic solution in equilibrium with it, is shifted to *higher* soap concentrations in Fig. 2. On the other side of the maximum point, along curve CD where the superneat soap separates as a

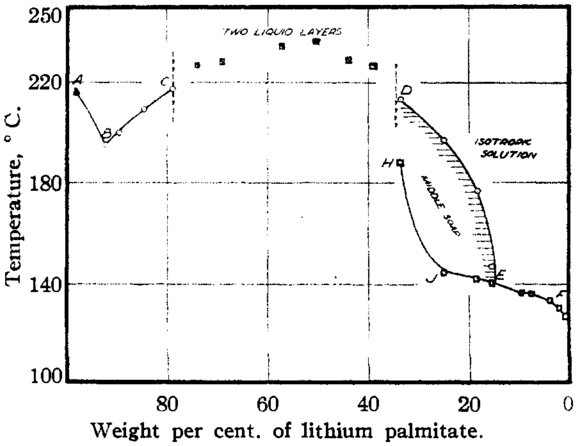

Fig. 3.—The effect on the phase behavior of lithium palmitate with water of lithium chloride present at a mole ratio of salt to soap of 0.15: ▲, melting point of lithium palmitate; O, liquid crystal separates on cooling isotropic liquid; ⧄, one of two isotropic layers separates liquid crystal on cooling; □, crystals dissolve completely on heating.

liquid crystalline solution more concentrated than the equilibrium isotropic phase, the first small additions of lithium chloride *lower* the soap concentration at which separation occurs. Thus lithium chloride appears to facilitate the formation of the more orderly molecular arrangement of lithium palmitate molecules, represented by superneat soap, regardless of whether the "concentration" of the soap is increased (as along BC) or decreased (as along CD). This result is analogous to the finding that addition of electrolytes to dilute isotropic solutions of detergents increases the proportion of dissolved material present as organized colloidal micelles as judged from solubilization experiments.[13,14]

Similarly, the isotropic solution from which middle soap separates is progressively more dilute as the salt content is increased. Reference to isothermal diagrams for systems of sodium soaps with sodium chloride and water[5] or potassium soaps with potassium chloride and water[7,8] shows that for these systems, the soap concentration at which middle soap separates is increased by the first small additions of salt and subsequently decreased by further additions. If such an effect occurs with lithium palmitate, the salt content for it must be less than 0.2%.

The other striking effect of small additions of lithium chloride on the phase behavior of lithium palmitate in water is the diminished solubility of the more solid phases in middle soap (Curves HJ). This effect is parallel to the results found for sodium and potassium soaps with salt.

Summary

The phase behavior of lithium palmitate in water has been determined and compared with that of sodium palmitate. Comparison has also been made of available phase diagrams for sodium and potassium soaps. In concentrated soap systems and in dilute ones, the temperatures and compositions of corresponding points vary in a regular manner with the atomic number of the alkali cation, but at intermediate compositions (involving the middle soap phase) no simple general trends are apparent.

The effect of up to 2% of lithium chloride on the phase behavior of lithium palmitate and water has also been determined. The effect of lithium chloride can be regarded as favoring the formation of more highly organized phases over those in which more nearly random molecular distribution occurs.

LOS ANGELES, CALIF. RECEIVED SEPTEMBER 14, 1942

[13] J. W. McBain, R. C. Merrill and J. R. Vinograd, THIS JOURNAL, **63**, 670 (1941).

[14] G. S. Hartley, *J. Chem. Soc.*, 1968 (1938).

[CONTRIBUTION FROM THE LABORATORY OF ORGANIC CHEMISTRY OF THE UNIVERSITY OF WISCONSIN]

The Preparation of Derivatives of Chrysene by Means of the Robinson–Mannich Base Synthesis of Unsaturated Ketones

BY A. L. WILDS AND C. H. SHUNK[1]

Robinson and his co-workers[2] have developed an ingenious method for converting a cyclic ketone into an unsaturated cyclic ketone containing one additional hydroaromatic ring. The method consists in treating the sodium enolate of the cyclic ketone, or of its carbethoxy derivative, with the methiodide of a Mannich base such as 1-diethylaminobutanone-3. The latter compound acts as a source of methylvinyl ketone for Michael addition, which is followed by cyclization. In this manner, for example, 2-carbethoxycyclohexanone was converted into 2-keto-4a-carbethoxyoctahydronaphthalene, which could be hydrolyzed and decarboxylated to the corresponding octalone.

We have now applied this series of reactions to 2-carbomethoxy-1-keto-1,2,3,4-tetrahydrophenanthrene (I), leading ultimately to the unsaturated ketone VII and to a number of other new derivatives of chrysene. However, in the application of the method of du Feu, McQuillin and Robinson[2] to the keto ester I, poor over-all yields of VII resulted and a pure product was obtained only with difficulty. These drawbacks, which are borne out by some of the experiences of Robinson and co-workers[2] in other examples, constitute a serious limitation in the application of the method to ketones which are not readily available. In the most favorable cases reported by these investiga-

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[1] Wisconsin Alumni Research Foundation Research Assistant, 1941–1942.

[2] du Feu, McQuillin and Robinson, *J. Chem. Soc.*, 53 (1937); for a recent paper in this series see McQuillin and Robinson, *ibid.*, 586 (1941).