

Electrolytic Constants and Solubilities of Humulinic Acid, Humulone, and Lupulone

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The dissociation constants, solubility products and intrinsic solubilities of humulinic acid, humulone, and lupulone have been determined at 25 and 40° C. The solubility and its pH-dependence including extrapolated values for 0 and 100° C are shown in a diagram.

The bitter acids of hops represent a complex mixture containing a few well-defined components, humulone, lupulone, and some recently discovered homologues. Although much work has been done on these substances, their electrolytic constants have hitherto not been determined*. The solubility of humulone and lupulone at some pH-values was determined by Wöllmer² by titrating buffer solutions with alcoholic solutions of these substances until turbidity occurred. More refined methods have not been tried.

In the present investigation the dissociation constants and solubility products of humulone and lupulone at 25 and 40° C have been determined by means of a titration method proposed by Back and Steenberg³. Determinations have also been made on humulinic acid which, though only feebly bitter, is closely related to the derivatives of humulone, so far ill-defined, which constitute the chief bitter substances of the finished beer^{4,5}. From these constants it is possible to calculate the solubility at all pH-values at 25 and 40° C and also extrapolated values for 0 and 100° C. At higher temperatures direct determination is not possible because of the low stability of humulone.

EXPERIMENTAL

Materials. The bitter acids were isolated from an ethereal extract of lupulin. Humulone was obtained by precipitating lead humulate from a solution of the lupulin extract in methanol, which was then decomposed in an ethereal solution by hydrochloric acid. The crude product was purified from oxidation products and the humulone homologues, adhumulone and cohumulone, by precipitating it twice more by lead acetate from methanol

* Cf., however, the two-phase titrations of Hedlund and Steninger¹.

and once by *o*-phenylenediamine from benzene. The *o*-phenylenediamine complex was recrystallized from benzene until its melting point reached 117.5° C, the value stated for the pure humulone complex ⁶ (adhumulone complex ⁷ m. p. 98° C, cohumulone complex ⁸ m. p. 93° C). Pure humulone m. p. 65° C was then obtained by treating the complex with hydrochloric acid.

Lupulone was crystallized from the residue of the lupulin extract dissolved in petroleum ether. It was purified by recrystallization alternately from petroleum ether and methanol-water mixtures. The finished product had m. p. 94° C.

Humulinic acid (m. p. 91° C) was prepared by treating humulone with alcoholic alkali and recrystallizing the product from ethanol as described by Wöllmer ⁹.

As far as possible all operations were performed under oxygen-free nitrogen and the products were stored in sealed nitrogen-filled ampullae.

Procedure. The titration was carried out in a thermostated, closed vessel equipped with a magnetic stirrer in an atmosphere of oxygen-free nitrogen to prevent the entrance of carbon dioxide and oxygen. The pH-value was measured with standard glass and calomel electrodes and an electronic pH-meter.

The concentration of the solution to be titrated cannot be chosen arbitrarily, but is determined to a certain extent by the dissociation constants and solubility products ³. In this case there were used a 15 mM solution of humulinic acid and 2.5 mM solutions of humulone and lupulone. In the latter case the concentration was the highest one attainable.

As an extra check of the purity of the products used titrations were carried out on samples from more than one batch of each of the different compounds.

The procedure and the calculations have been described in detail by Back and Steenberg ³.

ELECTROLYTIC CONSTANTS

Table 1 gives the mean values of the thermodynamic solubility products, dissociation constants and intrinsic solubilities of humulinic acid, humulone, and lupulone at 25 and 40° C. The figures are supposed to be accurate within ± 0.10 .

For comparison are included the figures obtained from Wöllmer's solubility values using eqn. 1 given below. If Wöllmer's values refer to room temperature the agreement with my values is not too good. The values for the intrinsic solubilities and thus for the solubility products also may have become too high in Wöllmer's experiments due to supersaturation. During the present investigation a tendency to supersaturation at the flocculation point was easy to observe, especially for lupulone. The values obtained in this region were therefore omitted from the calculations.

Table 1. Electrolytic constants for humulinic acid, humulone, and lupulone.

	Temp.	pKs	pK _A	p ^s _{HA}
Humulinic acid:				
Present author	25° C	5.64	2.35	3.29
	40° C	5.51	2.43	3.08
Humulone:				
Present author	25° C	9.00	4.22	4.78
	40° C	8.86	4.26	4.60
Wöllmer	not given	8.7	4.0	4.7
Lupulone:				
Present author	25° C	11.69	6.18	5.51
	40° C	11.65	6.30	5.35
Wöllmer	not given	10.9	6.2	4.7

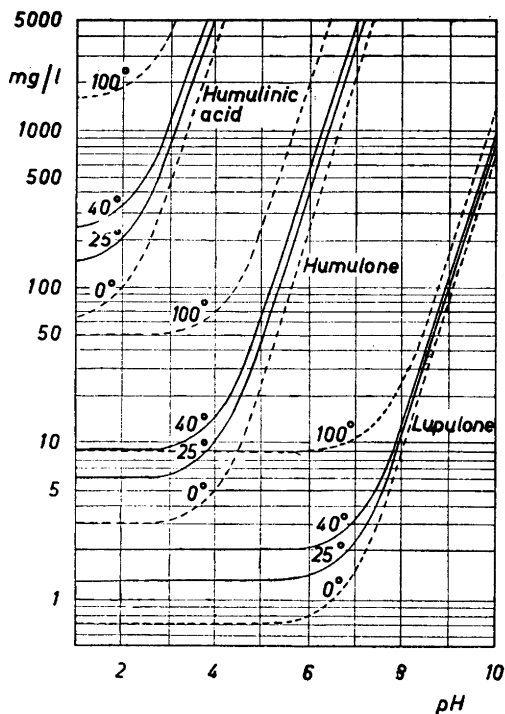


Fig. 1. Solubilities of humulinic acid, humulone, and lupulone.

SOLUBILITY DIAGRAM

The solubility s_{tot} of a slightly soluble acid HA is known to depend on the intrinsic solubility s_{HA} , the dissociation constant K_{A} , the solubility product K_{S} and the hydrogen ion activity $a_{\text{H}_3\text{O}^+}$, according to the equation

$$s_{\text{tot}} = s_{\text{HA}} + \frac{K_{\text{S}}}{a_{\text{H}_3\text{O}^+} \gamma_{\text{A}^-}} = s_{\text{HA}} \left(1 + \frac{K_{\text{A}}}{a_{\text{H}_3\text{O}^+} \gamma_{\text{A}^-}} \right) \quad (1)$$

where

$$K_{\text{S}} = K_{\text{A}} \cdot s_{\text{HA}}$$

The solubility can thus be computed for any pH-value at 25 and 40° C using the constants given in Table 1.

The pH- and temperature dependence of the solubility may be visualized by a diagram of the Bjerrum type. If $\log s_{\text{tot}}$ is plotted against pH we get a curve of a simple form which, as is readily seen from eqn. (1), passes point $(2 \log s_{\text{HA}}, \log K_{\text{S}})$ and has the two straight lines

$$\log s_{\text{tot}} = \log s_{\text{HA}} \quad (\text{pH} \ll \text{p}K_{\text{A}})$$

and

$$\log s_{\text{tot}} = \text{pH} + \log K_{\text{A}} s_{\text{HA}} \quad (\text{pH} \gg \text{p}K_{\text{A}})$$

intersecting in point $(\log s_{\text{HA}}, \log K_{\text{A}} s_{\text{HA}})$ as asymptotes.

Fig. 1 gives the solubility curves for 25 and 40° C, as well as approximate curves for 0 and 100° C, obtained from values which have been calculated by extrapolation using the Clapeyron equation.

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