Solubility of L-(+)-Ascorbic Acid in Water, Ethanol, Methanol, Propan-2-ol, Acetone, Acetonitrile, Ethyl Acetate, and Tetrahydrofuran from (293 to 323) K

Anvar Shalmashi* and Ali Eliassi

Chemical Industries Department, Iranian Research Organization for Science and Technology (IROST), Tehran, Iran

The solubility of L-(+)-ascorbic acid in water, ethanol, methanol, propan-2-ol, acetone, acetonitrile, ethyl acetate, and tetrahydrofuran was measured by a gravimetrical method from (293 to 323) K, and the solubility data were correlated against temperature. The solubility of L-(+)-ascorbic acid in water and methanol was high compared with other solvents.

Introduction

Ascorbic acid is one of the most essential nutrients for the maintenance of human health. It is a sugar acid with antioxidant properties. Its appearance is white to light-yellow crystals or powder. The L-enantiomer of ascorbic acid is commonly known as vitamin C. In industry, L-(+)-ascorbic acid (LAA) is produced from D-glucose by a Reichstein procedure via several complex chemical and biotechnological stages. The obtained solid ascorbic acid has mass fraction purity in the range from (96 to 98) %, which is achieved by several recrystallization stages from water.[1−4]

The experimental results from the addition of methanol, ethanol, and propan-2-ol as cosolvents to the main solvent, water, in the nucleation process of ascorbic acid have been reported previously.[5,6] Solubilities of LAA in four-component (LAA(+)MeOH(+)EtOH(+)H_2O) solutions also have been investigated.[7,8] To determine suitable solvents and to design an optimized production process, it is necessary to know the solubility of L-(+)-ascorbic acid in different solvents.

In this work, the solubility of L-(+)-ascorbic acid in water, ethanol, methanol, propan-2-ol, acetone, acetonitrile, ethyl acetate, and tetrahydrofuran was measured by a gravimetrical method from (293 to 323) K, and the solubility data were correlated against temperature. The experimental solubility of L-(+)-ascorbic acid in water was compared with literature data.[1,2]

Experimental Section

Chemicals. L-(+)-Ascorbic acid with a mass fraction purity of 0.997 (Merck, Darmstadt, Germany) was used as obtained. The organic solvents, ethanol, methanol, propan-2-ol, acetone, acetonitrile, ethyl acetate, and tetrahydrofuran, were of analytical purity grade and were purchased from Merck (Darmstadt, Germany). Double distilled−deionized water was used. All the chemicals were used without further purification.

Apparatus and Procedures. The solubility of L-(+)-ascorbic acid was measured using a procedure similar to that described in the literature[9−11] and described briefly here. The experiments were carried out in a magnetically stirred, jacketed equilibrium cell with a volume of 100 mL. To prevent the solvent evaporation, the equilibrium cell was sealed by a rubber plug, and its temperature was controlled by circulating water from a thermostat within ± 0.05 K. The sample mass was determined by an electronic balance (2842, Sartorius GMBH, Germany) with uncertainty of ± 0.1 mg.

The solubility of L-(+)-ascorbic acid in eight pure solvents has been determined gravimetrically in the temperature range from (293 to 323) K.[12] To find the suitable time for the equilibrium, the test experiments were carried out over 8 h, 6 h, 4 h, 2 h, and 1 h, respectively. The solubility data that were measured over 8 h, 6 h, 4 h, and 2 h showed better agreement, compared with those obtained over 1 h, so the equilibrium time of 2 h was chosen. For each measurement, an excess of known mass of L-(+)-ascorbic acid was added to a known mass of solvent. Then, the equilibrium cell was heated to the required temperature with continuous stirring. After 2 h, the stirring was stopped, and the solution was kept still for 2 h. Then, the excess solid could be observed in the lower part of the equilibrium cell. The sample of the upper part of the solution was withdrawn with a suitable warmed pipet to another weighed vial. The vial was closed tightly and weighed to determine the mass of the sample. Then, the vial was placed in an oven to evaporate the solvent. After the evaporation of the solvent, the vial was dried for another 6 h and reweighed to determine the mass of the solid. Thus, the solid concentration of the sample could be determined. An average value was taken from six measurements for each temperature. The uncertainty of the reported temperature was ± 0.07 K. The mole fraction of the solutes were calculated and reported with the uncertainty of ± 0.0001.

Results and Discussion

The mole fraction solubilities x of L-(+)-ascorbic acid in water, ethanol, methanol, propan-2-ol, acetone, acetonitrile, ethyl acetate, and tetrahydrofuran were measured from (293 to 323) K and are summarized in Table 1.

As shown in Figure 1, the mole fraction solubility x of L-(+)-ascorbic acid was correlated as a function of temperature as follows[11]

$$\ln x = A + B(T/\mathrm{K}) \tag{1}$$

The parameters A and B for the solvents and root-mean-square deviations are listed in Table 2. The root-mean-square deviation (σ) is defined as

$$\sigma = \left[\frac{\sum_{i=1}^{n}(x_{ci} - x_i)^2}{n-1}\right]^{\frac{1}{2}} \tag{2}$$

where x_{ci} and x_i are calculated and experimental mole fraction solubilities, respectively, and n is the number of experimental

* To whom correspondence should be addressed. E-mail: shalmashi@yahoo.com. Telfax: (+)982188838324.

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Table 1. Mole Fraction Solubility of L-(+)-Ascorbic Acid in Eight Solvents between (293 and 323) K

T/K	10^3x	T/K	10^3x
	Water		
293	28.96 ± 0.02	313	50.37 ± 0.03
298	33.07 ± 0.04	318	57.94 ± 0.03
303	37.79 ± 0.04	323	66.33 ± 0.06
308	43.78 ± 0.02		
	Methanol		
293	10.06 ± 0.05	313	15.12 ± 0.02
298	10.83 ± 0.06	318	16.76 ± 0.01
303	12.14 ± 0.01	323	18.32 ± 0.01
308	13.26 ± 0.02		
	Ethanol		
293	2.29 ± 0.03	313	4.63 ± 0.04
298	2.74 ± 0.05	318	5.35 ± 0.04
303	3.21 ± 0.04	323	5.93 ± 0.03
308	3.85 ± 0.02		
	Propan-2-ol		
293	0.51 ± 0.01	313	1.24 ± 0.01
298	0.63 ± 0.02	318	1.65 ± 0.02
303	0.78 ± 0.01	323	2.05 ± 0.02
308	1.00 ± 0.02		
	Acetone		
293	0.26 ± 0.01	313	0.51 ± 0.01
298	0.32 ± 0.01	318	0.58 ± 0.02
303	0.37 ± 0.01	323	0.64 ± 0.01
308	0.43 ± 0.01		
	Acetonitrile		
293	0.20 ± 0.01	313	0.40 ± 0.01
298	0.24 ± 0.01	318	0.45 ± 0.01
303	0.28 ± 0.01	323	0.60 ± 0.01
308	0.34 ± 0.01		
	Ethyl Acetate		
293	0.10 ± 0.01	313	0.30 ± 0.02
298	0.13 ± 0.01	318	0.38 ± 0.02
303	0.17 ± 0.01	323	0.48 ± 0.03
308	0.23 ± 0.01		
	Tetrahydrofuran		
293	0.53 ± 0.01	313	1.28 ± 0.07
298	0.67 ± 0.02	318	1.53 ± 0.04
303	0.87 ± 0.02	323	1.74 ± 0.04
308	1.05 ± 0.06		

points. The root-mean-square deviations of calculated solubility with respect to experimental solubility are reported in Table 2.

Within the temperature range of the measurements, solubility of L-(+)-ascorbic acid in the solvents increased with an increase in temperature. The experimental solubility of L-(+)-ascorbic acid in water was compared with the literature data shown in Figure 2. As can be seen, there is a satisfactory agreement between our solubilities of L-(+)-ascorbic acid in water and those reported in the literature.[1,2]

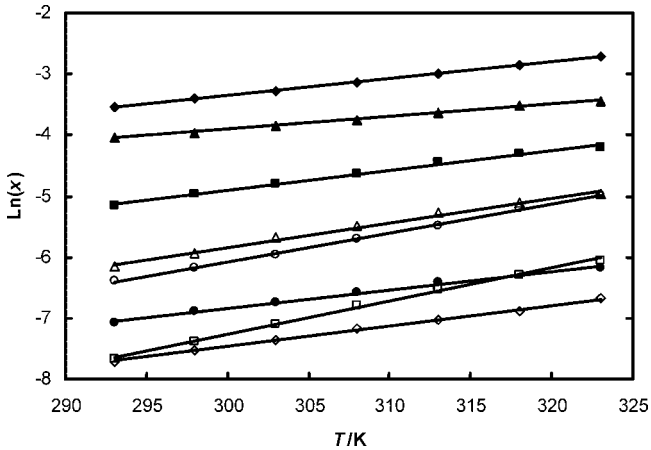

Figure 1. Solubility x of L-(+)-ascorbic acid as a function of temperature in: ♦, water; ▲, methanol; ■, ethanol; Δ, tetrahydrofuran; ○, propan-2-ol; ●, acetone; □, ethyl acetate; ◊, acetonitrile. Solid lines are values from eq 1 with coefficients from Table 2.

Table 2. A and B Values and the Root-Mean-Square Deviations (σ) of the Measured Solubility from the Calculated Results

solvent	A	B	$10^3\sigma$
water	−11.698	0.0278	0.37
methanol	−10.033	0.0204	0.38
ethanol	−14.588	0.0323	0.33
propan-2-ol	−20.152	0.0469	0.08
acetone	−15.875	0.0301	0.04
acetonitrile	−17.503	0.0335	0.01
ethyl acetate	−23.477	0.054	1.49
tetrahydrofuran	−17.881	0.0402	0.24

The solubility of L-(+)-ascorbic acid decreases in the order of water, methanol, ethanol, propan-2-ol, tetrahydrofuran, acetone, acetonitrile, and ethyl acetate. Ascorbic acid is a polar organic molecule of the general formula of $C_6H_8O_6$. The multiple hydroxyl groups in the ascorbic acid molecule impart their polar property and hydrogen bonding capability. It is believed that the hydrogen bonds exist among the molecules in

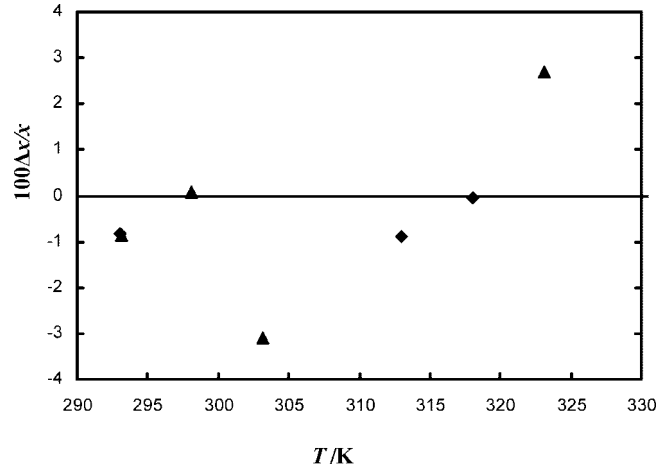

Figure 2. Fractional deviations $\Delta x = x - x$(lit.) of L-(+)-ascorbic acid solubility at various temperatures in water obtained in this work, x, from literature values, x(lit.). ♦, ref 1; ■, ref 2.

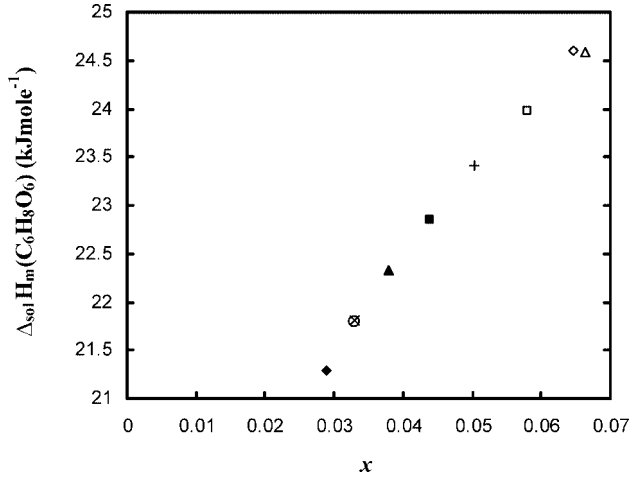

Figure 3. Molar enthalpies of saturated solutions of L-(+)-ascorbic acid, $\Delta_{sol}H_m(C_6H_8O_6)$, in water as a function of the mole fraction x at different temperatures in this work: Δ, T = 323 K; □, T = 318 K; +, T = 313 K; ■, T = 308 K; ×, T = 298 K; ♦, T = 298 K; and literature values: ◊, T = 298 K (ref 2); ○, T = 323 K (ref 2).

the mixture, which include the dissolved ascorbic acid and the solvent molecules. Furthermore, the polar environment present in the mixture also provides a favorable solubilizing vehicle for ascorbic acid. The ascorbic acid is a cyclic polar molecule, and its solubility increases in the solvent of higher polarity. The solubility of L-(+)-ascorbic acid in water showed a higher value than those in the other solvents. Thus, water may be a better solvent to separate and purify L-(+)-ascorbic acid from solutions.

The solubilities of ascorbic acid as a function of temperature in water in this work were compared with the LAA(+)-MeOH(+)EtOH(+)H2O and water−one alcohol system from the literature.[7,8] It showed that the highest solubility of ascorbic acid is measured in water, and the addition of ethanol and methanol as cosolvent decreases the solubility of ascorbic acid in water. Ascorbic acid is a cyclic polar molecule, and its solubility increases in the solvent system of the higher polarity. The addition of miscible cosolvents to the original solvent (water) effectively reduces the total polarity. So it was concluded that the presence of both aliphatic alcohols in this four-component system decreases the solubility of LAA compared to water or water−one alcohol solutions of LAA.

Dallos[2] introduced the following correlation for calculation of molar enthalpy of L-(+)-ascorbic acid in water

$$\Delta_{sol}H_m = (1 - x)\{a_1 + a_2(1 - 2x)\} \quad (3)$$

where x is L-(+)-ascorbic acid mole fractions, a_1 and a_2, are correlated parameters which are defined as

$$a_1/(\mathrm{J \cdot mol^{-1}}) = 6731 + 504.05(T - 273.15) \quad (4)$$

$$a_2/(\mathrm{J \cdot mol^{-1}}) = 13347 - 396.13(T - 273.15) \quad (5)$$

By using the measured solubilities and eq 3, the enthalpy of solutions can be calculated for a saturated solution of L-(+)-ascorbic acid in water at different temperatures. The results of these calculations are shown in Figure 3. According to this figure, the consistency between the predicted values based on the measured quantities and the experimental values, reported in the literature,[2] is good.

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