EFFECT ON THE VOLUME OF SOLVENTS AFTER DISSOLUTION OF SOLUTES

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The present paper deals with the change in volume of the solvent when a solid solute is dissolved into it. The results are presented with respect to the change of volume of solvent, the total volume of solvent and solute, and in terms of the molar concentration of solutions. Keywords: Solute, solvent. Solution, solvation, volume change, molar concentration

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Introduction

School Science Curriculum starts from the grouping of classifying objects on the various criteria at the middle stage. Solubility is one of the important criteria to group different materials into soluble and insoluble substances. The idea about the extent of dissolution of substances in water and formation of the saturated solution is also been discussed at this stage [NCERT 2006 A] When learner moves to the secondary stage particulate nature has been explained to them stating that in the liquids some spaces (intermolecular spaces) are available in which salt/sugar particles occupy the space when it is dissolved in them [NCERT 2006 B]. It also goes into the minds of students up to the secondary stage that when a pinch of a spoon of salt/sugar is added to a glass full of water, its volume does not change and the solute (salt/sugar) occupies the intermolecular spaces in the water so that there is no change in the volume. To make these things clearer efforts are made to explain that there will be a change of volume of solvent on dissolving solute into it.

Methodology

The data of densities of solid salt/ organic compounds and their 20 per cent w/w aqueous solutions were taken from the Chemical Engineer's Handbook [Mc Graw Hill 2008]. With the help of these data volume of the 20g of solid solute and volume of 80g water has been computed and presented in the Table-1.

Table 1: Basic data of densities and volumes of solute and solvent at the given temperature

S. No.	Name of Solute	Density of Solid Salt g/ mL	Amount of Solute (g)	Volume of the Solute (mL)	Amount of Solvent (water) (g)	Temperature °C	Density of Water	Volume of the Water (mL)	Density of 20% Aqueous Solution g/mL	Volume of 20% Aqueous Solution (mL)
	NaCl	2.16	20	9.259	80	25	0.9970470	80.237	1.14533	87.311
	KCl	1.98	20	10.101	80	25	0.9970470	80.237	1.13072	88.439
	NaNO3	2.26	20	8.849	80	20	0.9982067	80.144	1.14290	87.497
	NH4Cl	1.52	20	13.158	80	20	0.9982067	80.144	1.05670	94.634
	NH4NO3	1.72	20	11.628	80	20	0.9982067	80.144	1.08060	92.541
	CH3COONH4	1.17	20	17.094	80	20	0.9982067	80.144	1.03680	96.451
	CH3COONa	1.53	20	13.072	80	20	0.9982067	80.144	1.10210	90.736
	Na2SO4	2.66	20	7.519	80	20	0.9982067	80.144	1.19150	83.928
	Na2CO3	2.54	20	7.870	80	30	0.9956488	80.350	1.20860	82.740
	K2CO3	2.43	20	8.230	80	20	0.9982067	80.144	1.18980	84.048
	(NH4)2SO4	1.77	20	11.299	80	20	0.9982067	80.144	1.11540	89.654
	Sucrose	1.55	20	12.903	80	20	0.9982067	80.144	1.08100	92.507
	Urea	1.32	20	15.151	80	20	0.9982067	80.144	1.05300	94.967

Now with the help of the calculated volume of solvent (Water) and the Volume of the 20% w/w aqueous solution, an increase in the volume of solvent after the dissolution of solid solute is presented. An increase percentage in volume of solvent has also been computed and presented in Table 2

Table 2: Change in Volume after the dissolution of solute with reference to the solvent volume

S.No.	Name of Solute	Volume of Solvent (water) mL	Volume of Aqueous Solution (mL)	Increase in Volume (mL)	% Increase in Volume
		A	B	C = (B–A)	
	NaCl	80.237	87.311	7.074	8.82
	KCl	80.237	88.439	8.152	10.16
	NaNO3	80.144	87.497	7.353	9.17
	NH4Cl	80.144	94.634	14.490	18.08
	NH4NO3	80.144	92.541	12.397	15.47
	CH3COONH4	80.144	96.451	16.307	20.35
	CH3COONa	80.144	90.736	10592	13.22
	Na2SO4	80.144	83.928	3.784	4.72
	Na2CO3	80.350	82.740	2.390	2.97
	K2CO3	80.144	84.048	3.904	4.87
	(NH4)2SO4	80.144	89.654	9.510	11.87
	Sucrose	80.144	92.507	12.363	15.42
	Urea	80.144	94.967	14.823	18.49

Efforts have also been to calculate the change in volume of the solution with reference to a total volume that includes the volume of solid solute and of liquid solvent. Calculated data is presented in Table 3.

Table 3: Change in volume of the solution with reference to total volume of the mixture

S. No.	Name of Solute	Volume of the Solid solute (mL)	Volume of the water (mL)	Total volume of mixture before recitation (mL)	Volume of the Aqueous Solution (mL)	Change in Volume (mL)	Change in vol. in %
				A	B	C = (B – A)	
	NaCl	9.253	80.237	89.996	87.311	– 2.187	– 2.44
	KCl	10.101	80.237	90.338	88.439	– 1.899	– 2.10

	NaNO3	8.849	80.144	88.993	87.497	– 1.496	– 1.68
	NH4Cl	13.158	80.144	93.302	94.634	+ 1.332	+1.43
	NH4NO3	11.628	80.144	91.772	92.541	+ 0.769	+ 0.84
	CH3COONH4	17.094	80.144	97.238	96.451	– 0.787	– 0.81
	CH3COONa	13.072	80.144	93.216	90.736	– 2.48	– 2.66
	Na2SO4	7.519	80.144	87.663	83.928	– 3.735	– 4.26
	Na2CO3	7.870	80.350	88.220	82.740	– 5.480	– 6.21
	K2CO3	8.230	80.144	88.374	84.048	– 4.326	– 4.89
	(NH4)2 SO4	11.299	80.144	91.443	89.654	– 1.789	– 1.96
	Sucrose	12.903	80.144	93.047	92.507	– 0.540	– 0.58
	Urea	15.151	80.144	95.295	94.967	– 0.328	– 0.35

In order to have clear picture on the basis of molar concentration, the calculations were also made to find out the percentage change in volume with respect to volume of solvent and total volume of mixture of solute and solvent. The calculated values are presented in Table-4.

Table 4: Change in volume with reference to molar concentration (0.001M)

S. No.	Name of Solute	Mass of Solute taken (g)	Formula/ Molar Mass solute g/mol	Molar Amount	% change in vol. wrt volume of mixture per mili mole (0.001M) of solute	% increase in vol. wrt volume of solvent per mili mole (0.001M) of solute
1.	NaCl	20	58.44	0.342	0.71 (–)	2.58
2.	KCl	20	74.55	0.268	0.78 (–)	3.79
3.	NaNO3	20	84.99	0.235	0.71 (–)	3.90
4.	NH4Cl	20	53.49	0.374	0.38 (+)	4.83
5.	NH4CO3	20	96.09	0.208	0.40 (+)	8.69
6.	CH3COONH4	20	77.08	0.259	0.31 (–)	5.97
7.	CH3COONa	20	82.03	0.244	0.11 (–)	8.34
8.	Na2SO4	20	142.04	0.141	3.02 (–)	2.63
9.	Na2CO3	20	105.98	0.189	3.28 (–)	2.50
10.	K_2CO_3	20	138.20	0.145	3.37 (–)	2.05

SO^{2-}

11.	$(NH_4)_2 SO_4$	20	132.14	0.151	1.30 (–)	3.22
12.	Sucrose	20	342.30	0.058	1.00 (–)	20.46
13.	Urea	20	60.60	0.330	0.11 (–)	05.60

Result and Discussion

Data presented in Tables 1 and 2 show that the all the solutes under the study whether ionic or non-ionic, increase the volume of solvent on dissolving 20 per cent by mass of it. The highest increase is observed in the case of CH_3COONH_4 and lowest in the case of Na_2CO_3. This indicates that the solute particles (ions or molecules) do not fit completely in the intermolecular spaces present in the solvent (water). The amount of increase in volume of solvent on dissolving any solute depends on solute-solvent interaction, the size of ions/ molecules, charge, hydration of solute particles [Pederson and Hvidt Aase, 1985] percent increase in volume data of NaCl, KCl, Na_2CO_3 and K_2CO_3 and K_2CO_3 solutes clearly indicate that the size of K^+ is more than Na^+ ions. Similarly, data of Na_2SO_4 and Na_2CO_3 shows that size of SO_4^{2-} ion is larger than CO_3^{2-} ion. These inferences are of pedagogical importance that in some cases learners can be given exercises to compare the cationic or anion sizes by measuring and comparing the volumes of their appropriate salts.

In Table 3 data presents the change in volume with reference to the total volume of mixture (solute solvent). All the solutes under study show decrease in volume except NH_4Cl and NH_4NO_3 where the volume increase by 1.43 per cent and 0.84 per cent respectively. The observations from Tables 1, 2 and 3 show that all the cations, anions and organic molecules increase the volume of solvent and decrease the volume with respect to total volume of mixture of solute and solvent except NH_4^+ ions. It means most the ions and organic molecules have tendency to decrease the volume of mixture of solute and solvents that may be termed as shrinkage effect. In case of NH_4Cl and NH_4NO_3, the increase in volume of solution in observed with respect to total volume of solute and solvent. This swelling effect may be due to bifurcated hydrogen bonding formed by NH_4^+ ion in the solution [Guo J et al, 2018 and Hollas D et al, 2017] similar to the hydrogen bond formation in water when it is converted into ice leading to swell in volume of system. However, in case of CH_3COONH_4 and $(NH_4)_2SO_4$ there is decrease in volume. This observation indicates that shrinkage effect of CH_3COO^- and ions predominate over the swelling effect of ions in these salt solutions.

Conclusion

It may be concluded that on dissolving most of the solute decreases the volume of solutions with respect to the total volume of solute and solvent. Some ammonium salts show opposite effect.

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