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Determination of Molecular Weight of Synthetic Sugars by Measuring the Freezing Point Depression (Colligative Properties)

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Abstract: ***In this work, the molecular weight of synthetic sugar were determine by measuring the freezing point of a solution and then comparing the freezing point of that solution to that of the pure solvent (water).Solutions of synthetic sugars were prepared by adding 0.5g to water. The freezing point of the solutions were recorded when the first ice crystals appear. Then the molecular weight of synthetic sugars was calculated (table), using the freezing point depression (ΔT_f=T_f, pure–T_f, solution) and K_F is themolal freezing point depression constant, (for water = 1.853 K·kg/mol), these values were used to determine the molality of solution and the molecular weight as equations illustrate: ΔT_f= (K_f)(m). The molecular weights of prepared synthetic sugar weredetermined and it was found to be (205, 232, 272, 310, 323 and 355)(table).The molecular weight of synthetic sugar has the same numerical value as its molar mass.***

Keywords: Colligative properties, freezing point depression, molecular weight, molar mass, molality.

1. Introduction

Colligative properties are properties of solutions that depend on the ratio of the number of solute particles to the number of solvent molecules in a solution, and not on the nature of the chemical species present.[1, 2] The number ratio can be related to the various units for concentration of solutions.[3] They are essentially solvent properties which are changed by the presence of the solute. The solute particles displace some solvent molecules in the liquid phase and therefore reduce the concentration of solvent, so that the colligative properties are independent of the nature of the solute. [4, 5]

Colligative properties include freezing point depression, boiling point elevation and osmotic pressure.[6][7] Historically, colligative properties have been one means for determining the molecular weight of unknown compounds, because colligative properties depend on the number of molecules[8, 9, 10, 11].

Measurement of colligative properties for a dilute solution of a non-ionized solute such as urea or glucose in water or another solvent can lead to determinations of relative molar masses, both for small molecules and for polymers. Colligative properties are mostly studied for dilute solutions, whose behavior may often be approximated as that of an ideal solution. (5, 11, 12)

Freezing-point depression is the process in which adding a solute to a solvent decreases the freezing point of the solvent. Examples include salt in water, alcohol in water. The resulting solution or solid-solid mixture has a lower freezing point than the pure solvent or solid. This phenomenon is what causes sea water, (a mixture of salt and other things in water) to remain liquid at temperatures below 0 °C (32 °F), the freezing point of pure water. 5, 7, 8, 9, 12

The freezing point depression depends on the number of particles (ions or molecules) that are dissolved in the solvent and not on the identity of the particles or its concentration.12

The freezing point of a pure solvent is lowered by the addition of a solute, and the measurement of this difference is called cryoscopy4, 12, 13It is found that

$$\Delta T_F = K_F \cdot m \cdot i,$$

The terms (ΔT_F); $Tf_{pure\ solvent}°$-$Tf_{solution}°$ refer to the freezing-point temperatures of the pure solvent and the solution, respectively. The constant, Kf, (cryoscopy) is referred to the freezing-point-depression constant and is dependent only upon the solvent7, 11 (for eg., equal to 1.86 °C kg/mol for the freezing pointdepression constant of water), the term “m” indicates the molality of the solution, which is defined as the number of moles of solute per kg of solvent., i = the number of solute particles produced per formula unit that dissolves, (number of ion particles per individual molecule of solute, e.g. i = 1 for sugar, i = 2 for NaCl and 3 for $BaCl_2$).14This simple relation doesn't include the nature of the solute.The change in temperature is also dependent upon the number of solute particles in solution present.8, 9, 12, 13, 14

The molality of a solution can be expressed in terms of the molecular weight of the solute. Substituting this expression into the equation for freezing-point depression we obtain:

$\Delta T_f = (K_f)(m)\ (i)$ Where (i) =1

$(\Delta T_F)=T°_{f\ pure\ solvent} - T°_{f\ solution}$

$$(\mathrm{m}) = \frac{number\ of\ moles}{k_g\ of\ solvent}$$

$$number\ of\ moles = \frac{g\ of\ solute}{Mw}$$

$$(m) = \frac{g\ of\ solute}{Mw\ \times k_g\ of\ solvent}$$

$$(m) = \frac{\Delta T_f}{(K_f)}$$

$$(m) = \frac{g\ of\ solute}{Mw\ \times k_g\ of\ solvent} = \frac{\Delta T_f}{(K_f)}$$

$$\frac{g\ of\ solute}{Mw\ \times k_g\ of\ solvent} = \frac{\Delta T_f}{(K_f)}$$

$$Mw = \frac{g\ of\ solute \times (K_f)}{k_g\ of\ solvent \times \Delta T_f}$$

The molecular weight of sugar was determined by measuring the freezing point of a solution and then comparing the freezing point of solution to that of the pure solvent.The molecular weight of substance has the same numerical value as its molar mass.[14, 15, 16]

2. Material and Method

Material

Method

Solutions of synthetic sugars were prepared by adding about 0.1-0.5 g of synthetic sugars to 20 mL of water. Then the solutions were mixed until all crystals dissolve and placed in the ice path. The solutions were stirred gently with a thermometer. The temperature (freezing point of the solutions) was recorded when the first ice crystals appear. Then the molecular mass of these solutions was calculated (table), using the freezing point depression as equations illustrate:

$\Delta T_f = (K_f)(m)(i)$ i = 1

$(\Delta T_F) = T°_{f\ pure\ solvent} - T°_{f\ solution}$

$$(m) = \frac{g\ of\ solute}{Mw\ \times k_g\ of\ solvent}$$

$$Mw = \frac{g\ of\ solute \times (K_f)}{k_g\ of\ solvent \times \Delta T_f}$$

ΔT_f = freezing point desperation, K_f = freezing point desperation constant for the solvent (1.86°C·kg/mol for water), m (molality) = is the number of moles of solute in solution per kilogram of solvent, i is the number of particles (ions) produced per formula unit, Mw = molecular mass of solutions.

Table: The freezing point desperation and molecular weight of products

synthetic sugar (Solutes)	Chemical formula of synthetic sugar	Molecular weight (Mw) of synthetic sugar (Theoretical)	Freezing point of water (solvent) (F solvent) ˚C	Freezing point of solution (F solution) ˚C	ΔT_f˚C Freezing point depression	Mw of synthetic sugar (Solutes) Experimental
C7	$CH_2OH(CHOH)_nCHO$	210	0.0	2.7	2.7	205
C8	$CH_2OH(CHOH)_nCHO$	240	0.0	4.5	4.5	232
C9	$CH_2OH(CHOH)_nCHO$	270	0.0	5.0	5.0	275
C10	$CH_2OH(CHOH)_nCHO$	300	0.0	5.5	5.5	310
C11	$CH_2OH(CHOH)_nCHO$	330	0.0	3.0	3.0	323
C12	$CH_2OH(CHOH)_nCHO$	350	0.0	4.0	4.0	355

n= 5 or 6 or 7 or 8 or 9 or 10

Mw = Molecular weight calculated from the chemical formula

3. Results and Discussion

Colligative properties are properties of solutions that depend upon the ratio of the number of solute particles (ions) to the number of solvent molecules in a solution;they are independent of the nature of the solute particles.Freezing-point depression describes the phenomenon in which the freezing point of a liquid (a solvent) is depressed when another compound is added, meaning that a solution has a lower freezing point than a pure solvent. These properties ideally depend on changes in the entropy of the solution on dissolving the solute, which is determined by the number of the solute molecules or ions but does not depend on their structure. This happens whenever a non-volatile solute is added to a pure solvent, such as water, the change in temperature is directly related to the molecular weight of the solute. In this work the molecular weight was determine by using the freezing-point depression. Thefreezing point of synthetic sugar solution, as well as that of pure water was measured. The difference between these two temperatures allows for the calculation of the molality and molecular weight of the synthetic sugarand it was found to be (205, 232, 272, 310, 323 and 355). The theoretical molecular weight of synthetic sugar was (210, 240, 270, 300 and 330) (table).

The change in freezing point caused by the presence of a solute dissolved in water can be calculated from the equation:

$\Delta Tf = (K_f)(m)(i)$,

Where ΔT_f is the change in freezing point, K_f is the molal freezing point depression constant (1.86°C/m for water), m is the molality of the solution, and i is the number of particles or ions produced per formula unit e.g. i = 1 for sugar, = 2 for NaCl and 3 for $BaCl_2$).

Molality = moles of solute/kg solvent

Since colligative properties depend upon the number of particles in solution, a one molal solution of an electrolyte (NaCl), which dissociates in water, lowers the freezing point more than a one molal solution of a non-electrolyte (sugar).

Colligative properties have been one means for determining the molecular weight of unknown compounds. Because colligative properties depend on the number of molecules, that colligative property experiments give a number average molecular weight.

4. Conclusion

The molecular weight of synthetic sugar was determined by measuring the freezing point of a solution and then comparing the freezing point of that solution to that of the pure solvent (water).The molecular weight of synthetic sugar has the same numerical value as its molar mass.

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