Determination of the Molar Concentration of a Saturated Solution of Aqueous Urea

In this part of the experiment we will determine the molar concentration of a saturated solution of aqueous urea, [CON_2H_4(sat'd)]. This concentration is equal to the equilibrium constant, K_c, for the equilibrium:

$$CON_2H_4(s) \rightleftharpoons CON_2H_4(sat'd) \quad K_c = [CON_2H_4(sat'd)]$$

There are a number of challenges with determining the concentration of a saturated solution of urea. The following procedure will allow you to obtain good results.

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1. Set up a table in Excel as shown here:

	A	B	C	D	E	F	G	H
1	Expt	Mass urea (g)	vol	Adj vol	total mass urea	mass soln	density	molarity
2	0	0.000						
3	1							
4	2							
5	3							
6	Sat'd							

2. The 10-mL graduated cylinder you will be using may not be accurate. Usually the problem is that the printed marks and numbers are off a bit. Check your graduated cylinder by adding 5.00 mL water via a volumetric pipet to the graduated cylinder. Read the volume of the graduated cylinder and record the volume to the nearest 0.01 mL in Cell C2 in the table. In this example, the graduated cylinder reads 5.12 mL. Do this carefully. Even if your graduated cylinder is off, we can use it as the experiment is designed to compensate for this particular equipment error. The volumetric pipet is very accurate

3. Measure out three samples of urea, each about 1 g using an analytical balance. Label the weighting dishes "1," "2," and "3" so that you will not mix them up. Experiment 0 represents the blank water sample. Record the masses in the table as shown at right. These masses are just an example.

	A	B	C
1	Expt	Mass urea (g)	vol
2	0	0.000	5.12
3	1	0.991	
4	2	0.998	
5	3	0.988	
6	Sat'd		

4. Pour the contents of the graduated cylinder into a 30-mL beaker and add the first sample of urea (0.991 g) and stir and warm with the palm of your hand until dissolved: no solid evident. Make sure none of the solution sloshes out or you will have to start over. Return the solution to the graduated cylinder and record the new volume (in this example, 5.65 mL). Repeat this step twice more – with the other samples of urea.

	A	B	C
1	Expt	Mass urea (g)	vol
2	0	0.000	5.12
3	1	0.991	5.65
4	2	0.998	6.38
5	3	0.988	7.10
6	Sat'd		

5. Enter 5.00 into Cell D2. Enter the formula you see in D3 (=C3+5-C2). The $ signs in C2 keep that cell frozen so it doesn't progress when you copy Cell D3 and paste into Cells D4 and D6. The values in Column D are the adjusted volumes, compensating for volume errors with the graduated cylinder. The second table shows you the values that would appear using this data.

	A	B	C	D
1	Expt	Mass…	vol	Adj vol
2	0	0.000	5.12	5.00
3	1	0.991	5.65	=C3+5-C2
4	2	0.998	6.38	=C4+5-C2
5	3	0.988	7.10	=C5+5-C2
6	Sat'd			=C6+5-C2

	A	B	C	D
1	Expt	Mass…	vol	Adj vol
2	0	0.000	5.12	5.00
3	1	0.991	5.65	5.53
4	2	0.998	6.38	6.26
5	3	0.988	7.10	6.98
6	Sat'd			0.00

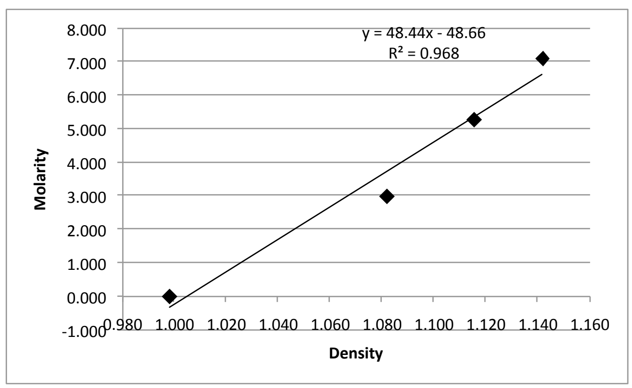
6. Next enter 0 in cell E2 and 4.99 in Cell F2. The latter is the mass of 5.00 mL water using the density 0.997 g/mL. Enter formulas for Cells G2, and H2, as well as E3 and F3. Then copy Cells E3 and F3 into the cells below (E4 … F5). Copy G2 and H2 and paste into Cells G3 … H5. The formula for is $d_{sol'n} = m_{sol'n}/V_{soln}$ (in mL) and for molarity: $Molarity_{urea} = m_{urea}/(MM_{urea} \times V_{soln}(\text{in L}))$

	A	B	C	D	E	F	G	H
1	Expt	Mass urea	vol	Adj vol	Total mass urea	total mass sol'n	density solution	molarity
2	0	0.000	5.12	5.00	0	4.99	=F2/D2	=(E2/60.0553)/(D2*0.001)
3	1	0.991	5.65	5.53	=E2+B3	=F2+B3	=F3/D3	=(E3/60.0553)/(D3*0.001)
4	2	0.998	6.38	6.26	=E3+B4	=F3+B4	=F4/D4	=(E4/60.0553)/(D4*0.001)
5	3	0.988	7.10	6.98	=E4+B5	=F4+B5	=F5/D5	=(E5/60.0553)/(D5*0.001)
6	Sat'd		10.00	9.88	(leave blank)		=F6/D6	(leave blank)

7. I will provide you with a sample of saturated urea solution. You will need 10 mL of the solution. Record the exact mass of the empty, dry 10.00 mL graduated cylinder – the same one you have been using. Fill the same graduated cylinder to the 10.00 mL mark with the saturated urea and determine the mass of the solution. Enter the volume 10.00 into Cell C6 and the mass of the solution (first subtracting the mass of the grad cylinder) into Cell F6 (in this example, 11.362 – your number will be different. Enter the formula shown in Cell G6. The number that will appear in Cell G6 is the density of the saturated urea solution.

	A	B	C	D	E	F	G	H
1	Expt	Mass urea	vol	Adj vol	total mass urea	mass soln	density	molarity
2	0	0.000	5.12	5.000	0.000	4.990	0.998	0.000
3	1	0.991	5.65	5.530	0.991	5.981	1.082	2.984
4	2	0.998	6.38	6.260	1.989	6.979	1.115	5.291
5	3	0.988	7.10	6.980	2.977	7.967	1.141	7.102
6	Sat'd		10.00	9.88		11.362	1.150	

7. Create a plot of Molarity vs Density (Column G as x and Column H as y). Include only Rows 2, 3, 4 and 5; not Row 6 – as highlighted in table. Display the trendline and the equation of the line (and R2). In this example,



$$y = 48.44x - 48.66$$

Molarity = [Urea(sat'd)] = 48.44 x density – 48.66

Finally, we calculate the molar concentration of the saturated urea solution using the density of this solution (Cell G6). In this example, the value in Cell G6 is 11.362/9.88 = 1.15 g/mL.

[Urea(sat'd)] = 48.44 x 1.15 – 48.66

= 7.046 mol/L

Recall that $K_c = [CON_2H_4(\text{sat'd})]$. From the equation $\Delta G^o = -R\,T\ln(K_c)$, we can use K_c to calculate ΔG^o. In this example, $\Delta G^o = -4.84$ kJ/mol urea.