#27 Molar Mass of Urea by Freezing Point Depression

Purpose: The freezing point depression of a solution of urea in water is used to determine the molar mass of urea.

Background:

The freezing point of a solution is always lower than the freezing point of the pure solvent. The difference between the freezing point T_f of a pure solvent and that of a solution is the freezing point depression, ΔT_f :

$$\Delta T_f \quad = \quad k_f \ \ x \ \ m$$

For water k_f is $1.86\,°C\ /\ m$ and m is the molality, mol solute/kg solvent. The freezing point depression gives the molality of the solution. Knowing the mass of the solute and solvent used to prepare the solution, the molar mass of the solute can be calculated.

Since freezing is difficult to observe by eye, a temperature vs. time graph called a *cooling curve* is used instead.

Apparatus:

The ring stand and the clamp holding the thermometer in place are not shown. There is enough room to insert the thermometer into the beaker so that the bulb is immersed in the liquid, but does not interfere with the stir bar.
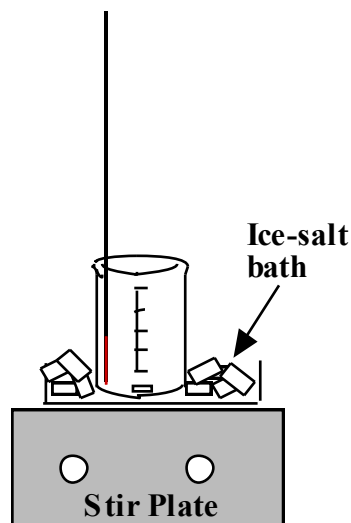
Safety and Waste Disposal:
Safety glasses are always required in the laboratory. The urea solution can be poured into the marked waste bottle.

Procedure:

Part A: Freezing Point of Pure Water

1. Using the volume markings on the beaker and a water wash bottle, measure 15 mL water into a clean dry 30-mL beaker. Record the volume and mass of water on the data sheet.

2. Place the beaker of water in a wide dish which will be used for the cooling bath. Put this assembly on a magnetic stir plate, place the small stir bar in the beaker of water and begin stirring. Immerse the thermometer into the water between the stir bar and the side of the beaker. The bulb should be close to the bottom of the beaker, without touching it. See the diagram.

3. Prepare an ice-salt mixture by packing ice (about the amount that fits in a polystyrene cup) in the dish around the beaker. Add about 25 g salt being very careful not to get any in the beaker.

4. Let the water cool to about 8°C , then start measuring the temperature at least to the nearest 0.5°C (you may be able to estimate to 0.2 °C) every 30 seconds until the temperature becomes constant for several minutes. Record time and temperature data.
 Note: It is not necessary to freeze the entire sample. "Supercooling" may occur, meaning that the temperature may fall below the freezing point, then climb back up before it remains constant. Stirring usually prevents this, but it may not.

5. Prepare a plot of temperature vs. time called the "cooling curve". The freezing point is the temperature at which the cooling curve levels off.
Note: The freezing point may not be 0°C. Since you will be measuring a difference in freezing points and using the same setup for both parts of the experiment, this will not make any difference.

6. Save the water sample setup with stir bar for the next part. Carefully lift the beaker out of the ice bath and let it warm up until any ice crystals melt. Remove the ice bath from the stir plate and drain away some of the excess water.

Part B: Freezing Point of Urea Solution

1. Weigh out 1.5 to 2.0 grams of urea using weighing paper and the top loading balance.
Note: You can weigh the urea to the nearest 0.01 g. Any mass in the range given will be fine. Record all three figures.

2. Carefully transfer the urea from the weighing paper into the same water you used for Part A. Put beaker with solution back on the stir plate and begin stirring. When the urea is completely dissolved, you can place the beaker into the ice bath and add more ice and salt as needed.

3. Carefully lower the thermometer into the solution and record the cooling curve data as above. Prepare a cooling curve and find the freezing point of the mixture.
Note: If the cooling is slow, just pour more salt over the ice.
Note: The freezing point of the mixture should be lower than it was for pure water. If not, see your instructor.

Data and Results (Molar Mass of Urea)

Name(s) _____Date_____

Part A: Freezing Point of Pure Water

    Volume of water _____ mL

    Mass of water used: _____ g = _____kg

Time (min)	Temp (°C)	Time (min)	Temp (°C)	Time (min)	Temp(°C)

Part B: Freezing Point of Urea Solution

    Mass of urea: _____ g

Time (min)	Temp (°C)	Time (min)	Temp (°C)	Time (min)	Temp(°C)

Data and Results Sheet (Molar Mass of Urea)

Freezing point of pure water (as read from the cooling curve): $T_f(H_2O)$ = _____ °C

Freezing point of urea solution (from cooling curve): T_f(urea solution) = _____ °C

Freezing point depression calculated from the two numbers above:
$\Delta T_f = T_f(H_2O) - T_f$(urea solution) ΔT_f = _____ °C

molality of solution calculated from this: m = _____ mol/kg H_2O
        $\Delta T_f = k_f \times m$ therefore: m = $\dfrac{\Delta T_f}{k_f}$

   (K_f for water = 1.86 °C /m)

Mass of water used (see previous page):_____kg

Moles of urea: mol = kg H_2O x m   = _____ mol

Mass of urea used (see previous page):_____ g.

Molar mass of urea calculated from the above two data: _____ g/mol
Retain only 2 significant figures here.

Error
Molar mass of urea, CH_4N_2O, known: _____ g/mol

Molar mass of urea measured: _____ g/mol

% Error = $((M_{measured} - M_{known}) / M_{known})$ x 100%

Attach the cooling curves used for freezing point determinations

Questions:

1. Why must you retain no more than two significant figures in your molar mass?

2. Sketch a cooling curve for pure water that would result if supercooling had taken place.

Instructor's Guide
(#27 Molar Mass)

Equipment and Materials:
Time:

Items	Amount/group	Comment
Balances		Several groups can share a balance
Weighing papers		
Distilled water bottle	1	
Urea	1-2 g	
30-mL beaker	1	
Ring stand	1	
Thermometer	1	
Thermometer clamp	1	
Petrie dish cover	1	or a crystallizing dish for the ice salt bath
Polystyrene cup	1	To "measure" ice
Salt	40 g (max)	Table salt is fine.
Ice	100 g	A polystyrene cup holds about 85 g
spatula	1	To measure urea
timer	1	
Magnetic stir plate/bar	1	small stir bar
Waste Bottle		

Ideas and Information

1. The standard thermometers used in this experiment can be read to the nearest 0.5 °C (at best to 0.2°C). Urea is chosen as the solute because of its relatively low molar mass (60 g/mol) and its solubility in water (1 g/1 mL) giving a freezing point depression of about 3 °C for the 10% solution used here. The resulting molar mass can have no more than 2 significant figures. To produce a freezing point depression greater than 10°C (giving an extra significant figure) the concentration would have to be increased to nearly 40%. However, the relationship, $\Delta T_f = k_f$ x m, is not valid for such a concentrated solution.
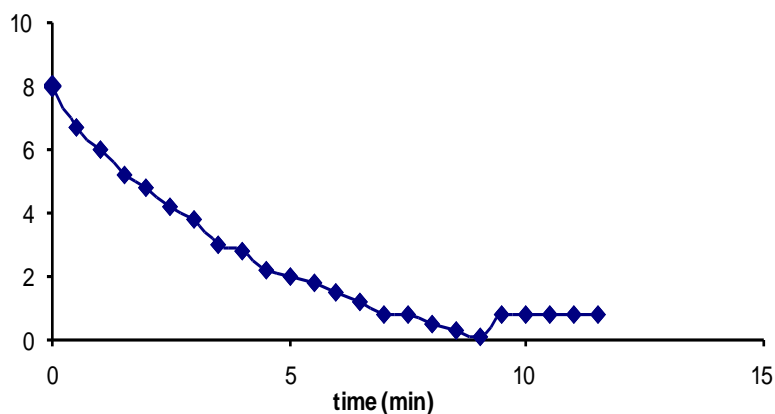
2. Urea , CH_4N_2O, with its easily available high N content (47%), is a component of fertilizers.

$$NH_2-\overset{\overset{\textstyle O}{\|}}{C}\sim NH_2$$
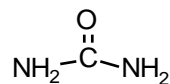
Typical Result:
Cooling curve for water. Note that supercooling occurred in this trial.

T_f (H_2O) $=$ 0.8°C (from cooling curve above)
T_f (solution) $=$ -2.2°C
$\Delta T_f = T_f$ (H_2O) $- T_f$ (solution) $= 0.8°C - (-2.2°C) =$ 3.0 °C
$\Delta T_f = k_f$ x m
3.0 °C $=$ 1.86 x m
m $= 3.0$ °C /1.86°C/ m $=$ 1.61 m

1.61 mol/kg water = 1.53 g urea/M /0.015 kg water
M =   62 g/mol (Keep only two significant figures)

Urea: CH_4N_2O M $= 60$ g/mol

Error: [(62 – 60) /60] x 100% = 3.3%

 Another result using 17 g water and 1.80 g urea gave 67g/mol, also reasonable with the thermometer used in this experiment.

Answers to Questions:

1. Why must you retain no more than two significant figures in your molar mass?

The temperature change is less than 10°C and the thermometer can be read only to the nearest half degree (perhaps 0.2)

2. Sketch a cooling curve for pure water that could result if supercooling took place.

There would be a dip in the curve, below the freezing point, before it levels off.   See cooling curve above for an example.