Chem 1B Objective 4:
Predict solution properties based on colligative properties

Key Ideas:
Important in making ice cream, melting ice, antifreeze, etc.

Chem 1A: ideal gases – gas molecules do not interact – no chemical forces between gas molecules. Ideal gas conditions: low P and high T conditions

Chem 1B: ideal solutions – mean strength of interactions are the same between all substances in the solution

Solution properties depend on concentration only.

Solute is non-volatile. Solvent is volatile. In other words, solvent evaporates but solute does not. (See vapor pressure.)

Ideal solution conditions: low concentration conditions

Each Colligative property is proportional to concentration and number of particles in solution (i = Van't Hoff factor)

b.p. elevation: $\Delta T_b = i K_b m$

where ΔT_b = b.p. elevation = b.p. of solution – b.p. of pure solvent, i = # of particles in solution, K_b = b.p. elevation constant of solvent, m = molality

f.p. depression: $\Delta T_f = i K_f m$

where ΔT_f = f.p. depression = f.p. of solution – f.p. of pure solvent, i = # of particles in solution, K_f = f.p. elevation constant of solvent, m = molality

v.p. lowering: $p_A = x_A p^o_A$

where p_A = vapor pressure of solution, x_A = mole fraction of A, p^o_A = vapor pressure of pure solvent (Raoult's law).

osmotic pressure: $\pi = iMRT$

where π = osmotic pressure, i = # of particles in solution, M = Molarity, R = gas constant = 0.082 l atm/mole K, T = temperature in K.

Determine what happens to properties when a solute is added to a solvent

Colligative Properties are solution properties that ***depend on the amount of solute present***

Colligative Properties Have ***Important*** Applications

Freezing point depression ==> make ice cream using salt (see Lab 2)

$$\Delta T_f = i K_f m$$

where i = Van't Hoff factor, K_f = fp depression constant

m = molality = moles solute/kg solvent

http://whatscookingamerica.net/Desserts/HomemadeIceCream.htm

Boiling point elevation ==> antifreeze in car cooling system

$$\Delta T_b = i K_b m$$ where K_b = bp elevation constant

Objective: Calculate b.p./f.p. of a solution
Add a solute to water, B.p. increases (elevation)
and f.p. decreases (depression)

K_f and K_b are Solvent Properties

For water: K_f = 1.86 $^oC/m$ K_b = 0.512 $^oC/m$

You add enough sugar to water to make a 1 m solution. (See Lab 2)
What is the b.p. of the solution?
What is the f.p. of the solution?

You add enough salt to water to make a 1 m solution.
What is the b.p. of the solution?
What is the f.p. of the solution?

Objective: Calculate b.p./f.p. of a solution

50 g of NaCl is dissolved in 1 cup (240 ml) of water. Calculate the b.p. of this solution.

$$\Delta T_b = i K_b m$$

i refers to solute. NaCl dissociates into Na^+ and Cl^- ions, so i = 2.

K_b refers to solvent. K_b of water = 0.512 $^oC/m$

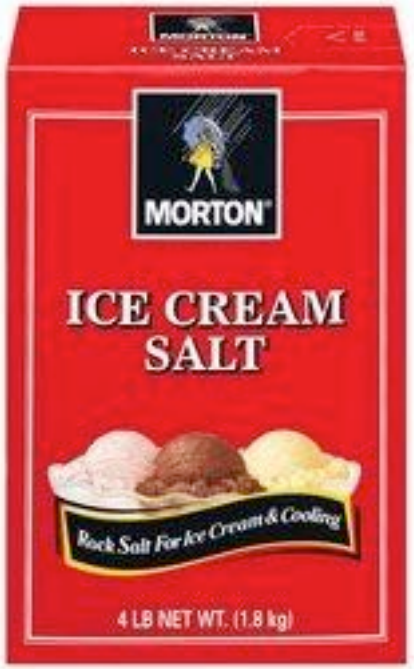
m is molal concentration = moles of solute (NaCl)/kg of solvent (water).

m = (50 g NaCl)/[(58.5 g/mole)(0.240 kg)] = 3.56 m

ΔT_b = (2) (0.512 $^oC/m$) (3.56 m) = 3.6^oC

So b.p. of this NaCl (aq) = 100^oC + 3.6^oC = 103.6^oC

Objective: Calculate b.p./f.p. of a solution



Why is rock salt used to make ice cream?
http://321delish.com/2011/09/16/guest-post-queen-of-ice-cream/

Calculate the freezing point of a salt/water solution when 50 g of salt is dissolved in 1 cup (240 ml) of water.
Would adding the same mass of road salt ($CaCl_2$) depress the freezing point of water the same amount as rock salt? Give reasons.
K_f of water = 1.86 $^oC/m$

Objective: Determine how "strong" is your cup of coffee using boiling point elevation

$$\Delta T_b = i K_b m$$

Stronger coffee ==> _____ m a. higher b. lower

Coffee has a _____ boiling point than water.
a. higher b. lower

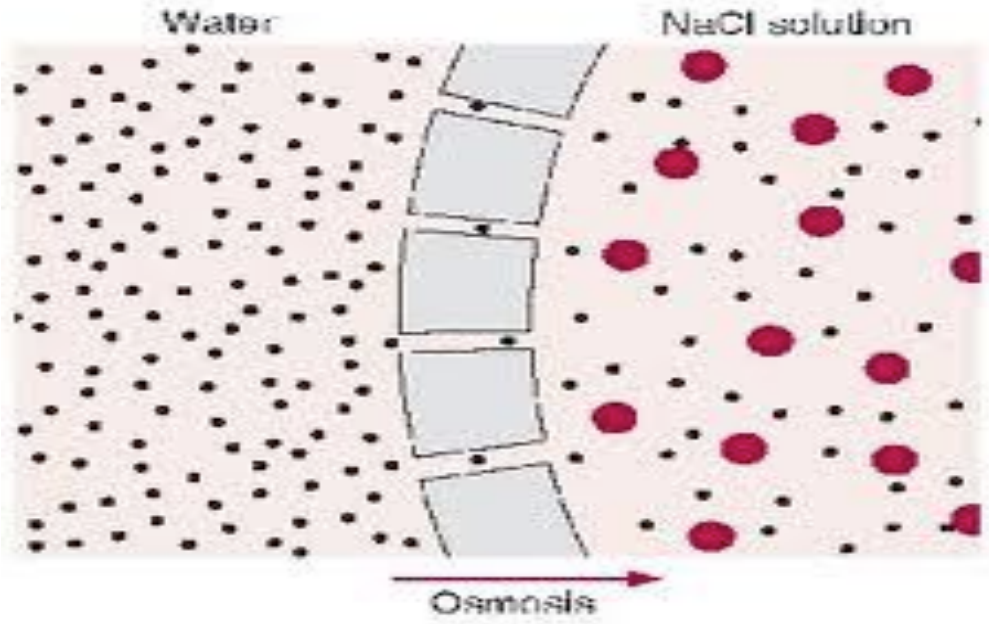
http://www.bubblews.com/news/106681-coffee

Experiment:
1. measure b.p. of pure water
2. Measure b.p. of coffee
3.

Objective: determine what happens to properties when a solute is added to a solvent

Osmosis is the passage of _____ through a semipermeable membrane due to a difference in _____.

http://highered.mcgraw-hill.com/sites/0072495855/student_view0/chapter2/animation__how_osmosis_works.html

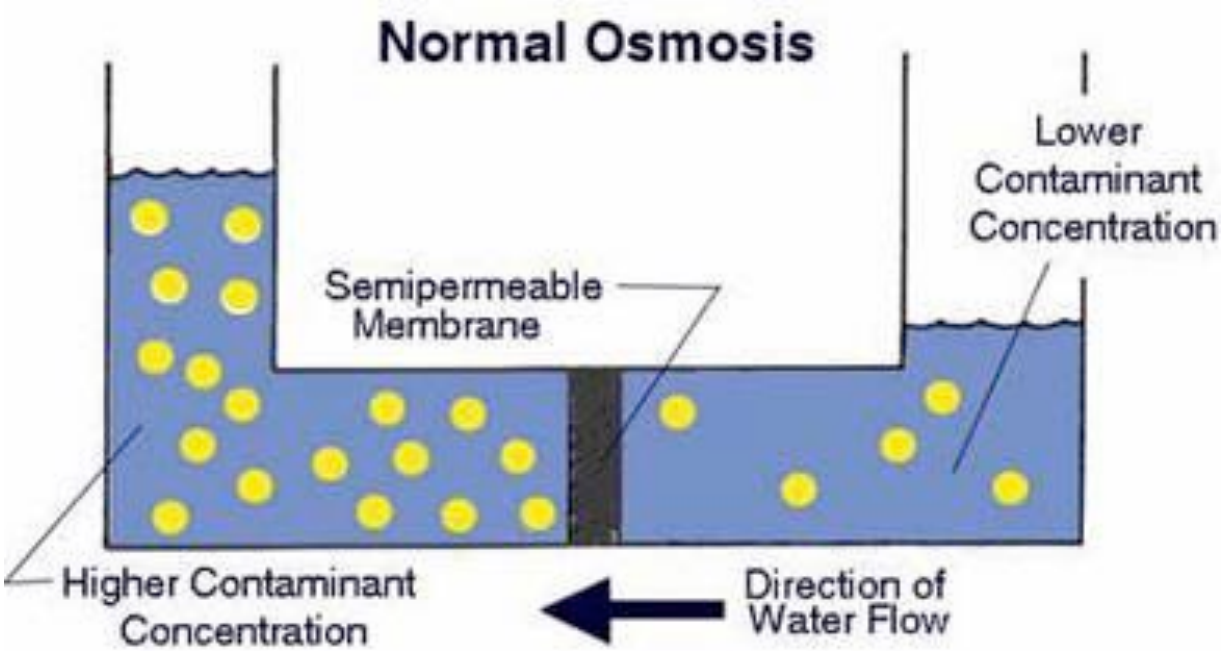


http://www.answers.com/topic/osmosis

How can you use osmosis to lose weight?

Osmotic pressure ==> is the pressure required to stop osmosis

$\Pi = i\ M\ R\ T$ where M = molarity, R = gas constant, T in K



http://www.wqa.org/sitelogic.cfm?ID=872

Where is pressure applied?

If osmotic pressure is **not** applied, will osmosis ever stop?

Objective: determine what happens to properties when a solute is added to a solvent

Salt is found in vegetables and fruit. How can you use **Osmosis** to keep veggies crisp?

http://www.wikihow.com/Make-Your-Lettuce-Extra-Crispy

How can limp lettuce be made crisp again?

What happens when a cucumber is placed in a very salty solution?

http://wackypedia.wikia.com/wiki/Forum:The_Illogic_Pickle_2.2

http://recipes.howstuffworks.com/question602.htm

You note regular and diet soda have the **same** sweetness. Regular soda is placed on one side of semipermeable membrane and diet soda on other side. 30 minutes later, you taste each soda and find one soda is sweeter than the other. Which soda tastes sweeter? Give reasons.

http://www.wisegeek.org/what-is-the-difference-between-jam-and-jelly.htm

Sugar is used to preserve home-made jam and jelly by killing bacteria that may cause botulism. The appropriate sugar concentration will allow water to pass out of the cell and collapse (crenation) the cell.

Should the sugar concentration that is used to preserve the jam be ***higher*** or ***lower*** than the sugar concentration inside bacteria cells? Give reasons.

http://cen.acs.org/articles/90/i42/Military-Meat-Roll-Ups-Golden.html

10/15/12, CEN, p. 48 "Military Meat Roll-Ups"

U.S. Army's Combat Feeding Directorate designs meat that can sit on a shelf for three years and still taste good (and become part of an MRE (Meal, Ready-to-Eat) that soldiers take on combat missions).

Beef jerky is popular but is very salty and becomes brittle after a year.

Meat roll-up: Osmotic dehydration gives meat a three-year shelf life.

Ground meat molded into thin sheets, meat sheets run through a 80% maltodextrin brine --> meat roll-up that's semidry, stable for years—and completely raw.

Meat is highly acidic (pH 2). The final product has a pH of 4.6 or 4.8, which is acidic enough to keep bacteria from growing even after months of sitting on the shelf.

On a “molecular basis”, DRAW A PICTURE that explains why:

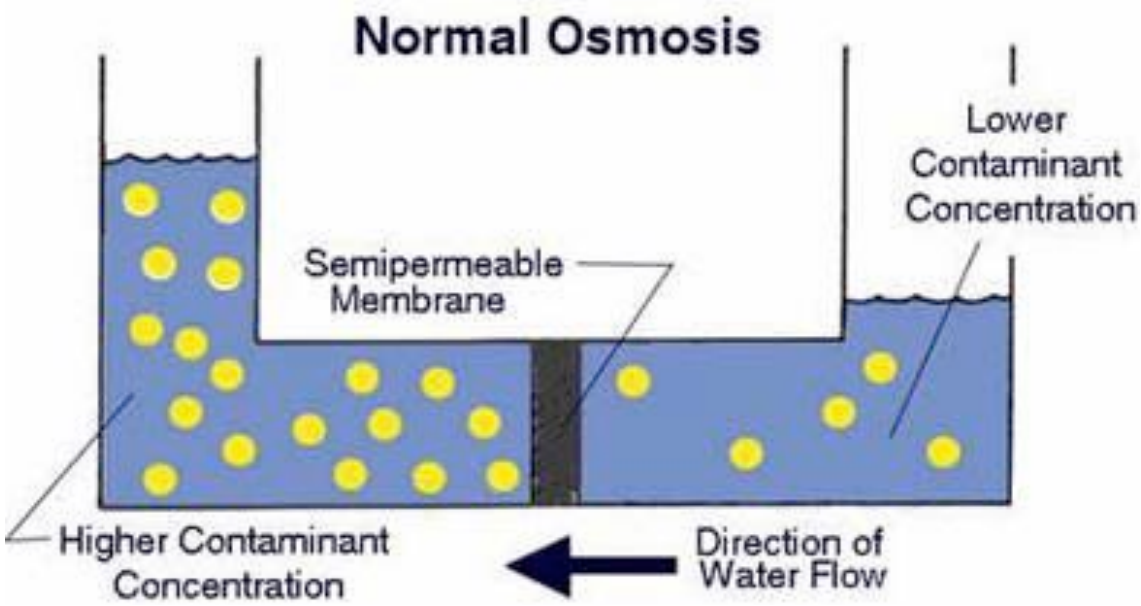
- the boiling point of a solution is higher than the pure solvent.
- The freezing point of a solution is lower than the pure solvent.
- Osmosis occurs.
- The vapor pressure of a solution is lower than the vapor pressure of a pure liquid.

Reverse Osmosis Is Used to Make Clean Water

(From Chang, "General Chemistry: The Essential Concepts", 6th ed., 2011, Problem 13.101)

Desalination is a process by which salts are removed from seawater. Three major ways to accomplish desalination are distillation, freezing, and reverse osmosis. The freezing method is based on the fact that when an aqueous solution freezes, the solid that separates from the solution is almost pure water. **Reverse osmosis uses water movement from a more concentrated solution to a less concentrated one through a semipermeable membrane.**

a. With reference to Fig. 13.8, p. 452, draw a diagram showing how reverse osmosis can be carried out.



http://www.wqa.org/sitelogic.cfm?ID=872

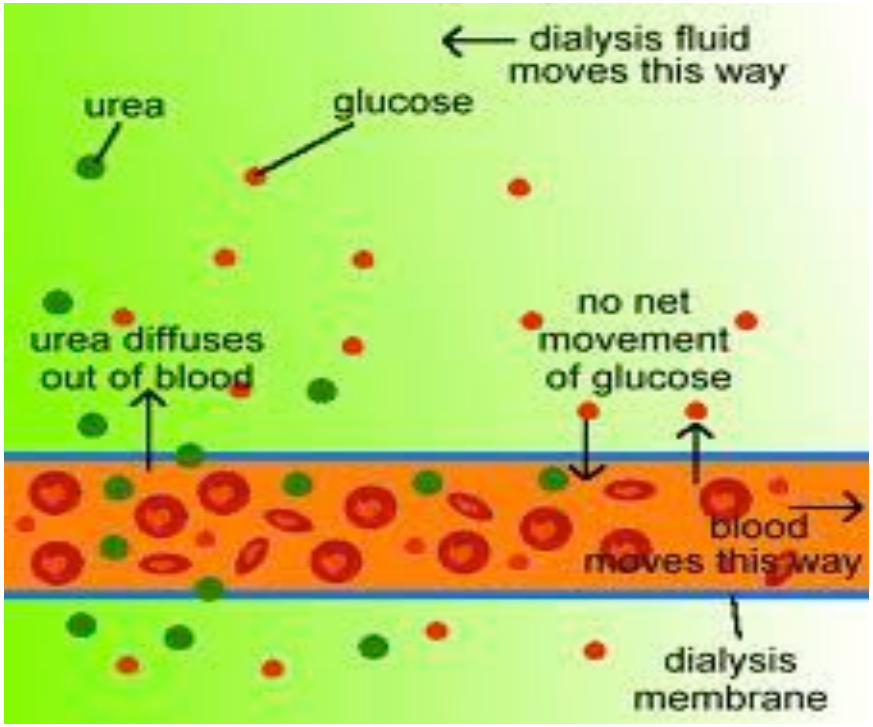
Reverse Osmosis Is Used to Make Clean Water

b. What are the advantages and disadvantages of reverse osmosis compared to the freezing and boiling methods?

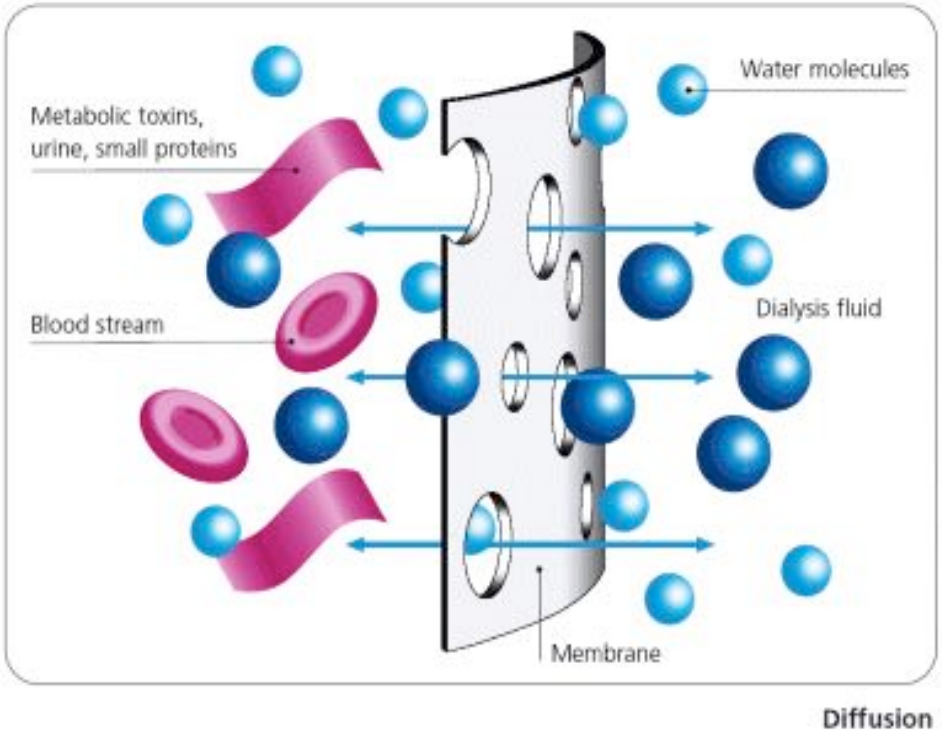
c. What minimum pressure (in atm) must be applied to seawater at 25^{o}C for reverse osmosis to occur? Treat seawater as a 0.60 M NaCl solution.

Reverse osmosis method and applications
http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1187618624228&lang=eng
http://en.wikipedia.org/wiki/Reverse_osmosis
RO animations http://www.geafiltration.com/html/technology/freverseosmosis.html
http://www.geafiltration.com/technology/reverse_osmosis.asp
Clean Water flash animations
http://www.agr.gc.ca/pfra/flash/index_e.htm

Dialysis (for kidney failure) removes waste and excess water from the blood.



http://www.woisd.net/moodle/mod/resource/view.php?id=67



Diffusion

http://www.fmc-ag.com/36.htm

What substance(s) pass through the dialysis membrane?
What is in the dialysis fluid (dialysate)?

Objective: determine what happens to properties when a solute is added to a solvent

Vapor pressure lowering ==> keep solvents from evaporating
(make a volatile liquid less volatile)

$$p = x_{solvent}\, p^o$$

where x = mole fraction of solvent, p^o = v.p. of pure solvent

What would you add to an open container of gasoline to keep it from evaporating?

http://jalopnik.com/5593997/mother-leaves-open-gas-cans-around-house-because-she-likes-the-smell

Objective: determine what happens to properties when a solute is added to a solvent

Which substance has the *highest* vapor pressure at 25°C?
a. Water
b. sea water
c. 0.9% NaCl

Look up or calculate the vapor pressure of each substance.

$p = x_{solvent}\ p^o$ where x = mole fraction of solvent

Which substance evaporates the fastest?
Which substance has the highest boiling point?

Objective: determine what happens to properties when a solute is added to a solvent

Which substance has the *highest* vapor pressure at 25°C?

$p = x_{solvent}\ p^o$ where x = mole fraction of solvent

Water vapor pressure = p^o = 23.8 mm Hg at 25°C.

Sea water = 0.6 moles NaCl/liter of solution

or ≈ 0.6 moles NaCl/liter of H_2O

1 liter H_2O = 1000 ml = 1000 g = 55.6 moles

x = Mole fraction of H_2O (solvent

= moles H_2O/(moles NaCl + moles H_2O)

= 55.6 moles/(0.6 moles + 55.6 moles)

= 0.99

Objective: determine what happens to properties when a solute is added to a solvent

Which substance has the *highest* vapor pressure at 25°C?

$p = x\ p^o$ where x = mole fraction

Water vapor pressure = p^o = 23.8 mm Hg at 25°C.

Sea Water:
x = Mole fraction of H_2O in sea water = 0.99

Vapor pressure of sea water = p
$p = x\ p^o$ = 0.99 x 23.8 mm Hg = 23.6 mm Hg
Vapor pressure lowered by 0.2 mm Hg

Vapor pressure of 0.9% NaCl = ?? (23.7 mm Hg)

Shade Balls in LA reservoirs

http://abcnews.go.com/US/los-angeles-reservoir-covered-96-million-shade-balls/story?id=33038319

1. The freezing point of a salt water solution is _____ than the f.p. of pure water. How to calculate f.p. of salt water?

(i) Higher (ii) same (iii) lower

2. The boiling point of a salt water solution is _____ than the b.p. of pure water. How to calculate b.p. of salt water?

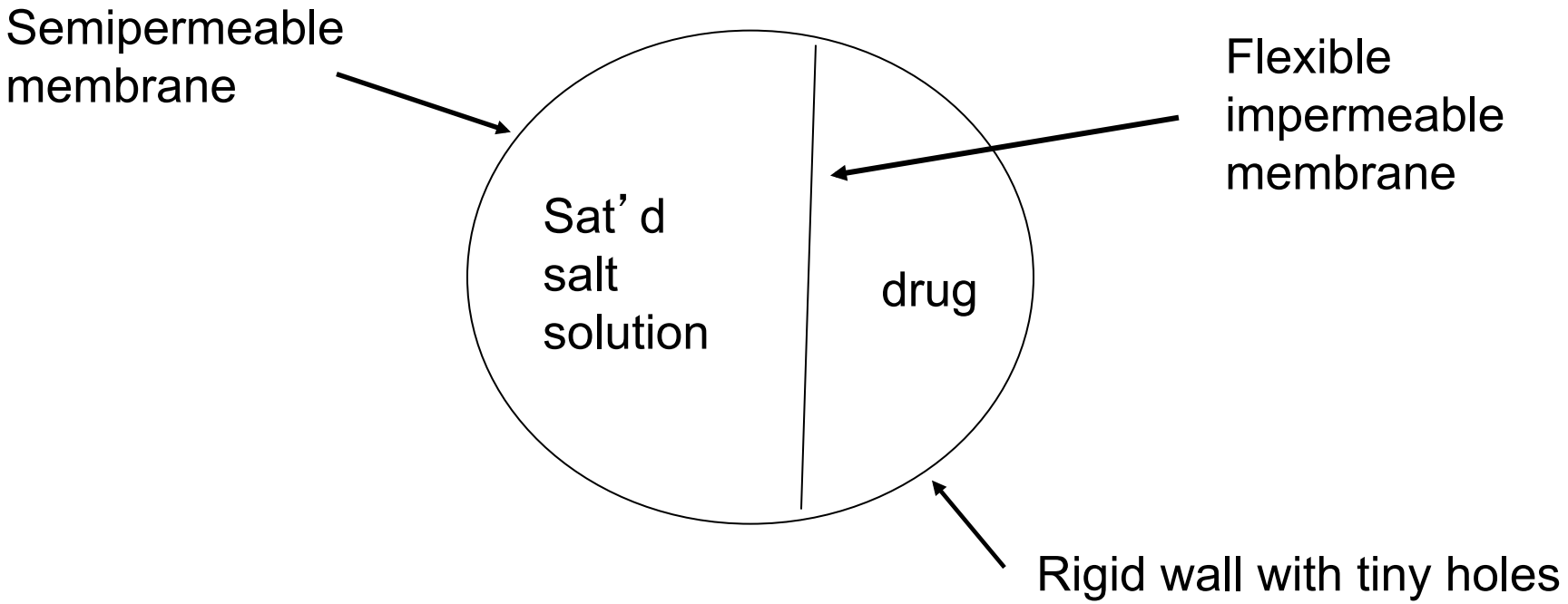
(i) Higher (ii) same (iii) lower

3. You ate way too much during the holidays and your exercise program is not working as quickly as you want. Someone tells you to soak in a concentrated salt water solution for an hour. You will

(i) gain weight (ii) maintain weight (iii) lose weight

4. You are lost at sea and have no pure water. Is it a good idea to drink sea water? Give reasons.

"Time-release" drugs have the advantage of releasing the drug to the body at a constant rate so that the drug concentration at any time is not so high to have harmful side effects or so low as to be ineffective. A schematic diagram of a pill that works on this basis is shown below. Explain how it works. (See Chang, 6th ed., p. 463, Problem 13.85.)



Salty solution: Cheesemakers soak cheese in brine tanks like this one.

1/27/14, C&EN, p. 40 ***Cheese On The Asphalt***
Milwaukee started a pilot program to remove ice from its streets with the salty liquid, a by-product of the cheese-making process. The city's road crews are mixing 8 gal of brine into each ton of rock salt they spread.

WHAT IS HAPPENING HERE?

Colligative Properties Are Used to Measure Molar Mass

a. 1.0 g of an unknown substance is dissolved in 10.0 g of benzene. The freezing point is measured to be 2.1^{o}C. What is the molar mass of the unknown substance?

See also Chang, "General Chemistry: The Essential Concepts", 6th ed., p. 463, Problem13.84.

b. Why is freezing point depression used to determine molar mass rather than boiling point elevation?

c. A 100.0 ml aqueous solution that contains 0.50 g of hemoglobin has an osmotic pressure of 1.78x10^{-3} atm. What is the molar mass of hemoglobin? (http://www.ausetute.com.au/osmoticp.html)

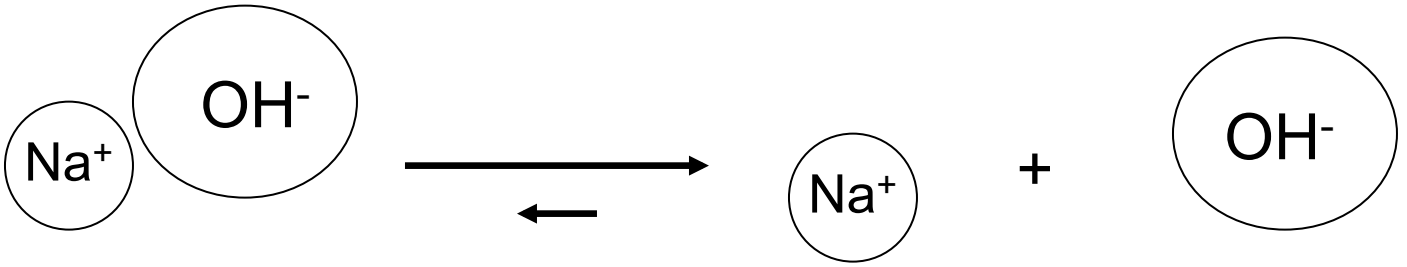
See also Chang, "General Chemistry: The Essential Concepts", 6th ed., p. 463, Problem 13.87

Colligative Properties Are Used to Measure Degree of Ionization

A 1.0 m NaOH solution has a freezing point of -3.44^{o}C.
a. Calculate i.
b. What is the theoretical freezing point of this solution?
c. Explain the difference between the experimental freezing point and theoretical freezing point based on f.p. depression.
(http://intro.chem.okstate.edu/1515sp01/lecture/chapter13/lec22601.html)

More Degree of Ionization in Strong/Weak Acids/Bases

Ion Pairing Occurs in Concentrated Solutions



"Complete" dissociation isn't really complete.

Theory works for **dilute** solutions.

Other solutions: 0.1 M NaCl ==> i = 1.81 (90% dissociation)

https://mindtouch.oneonta.edu/%40api/deki/files/904/%3DColligative_Properties_Lab.pdf

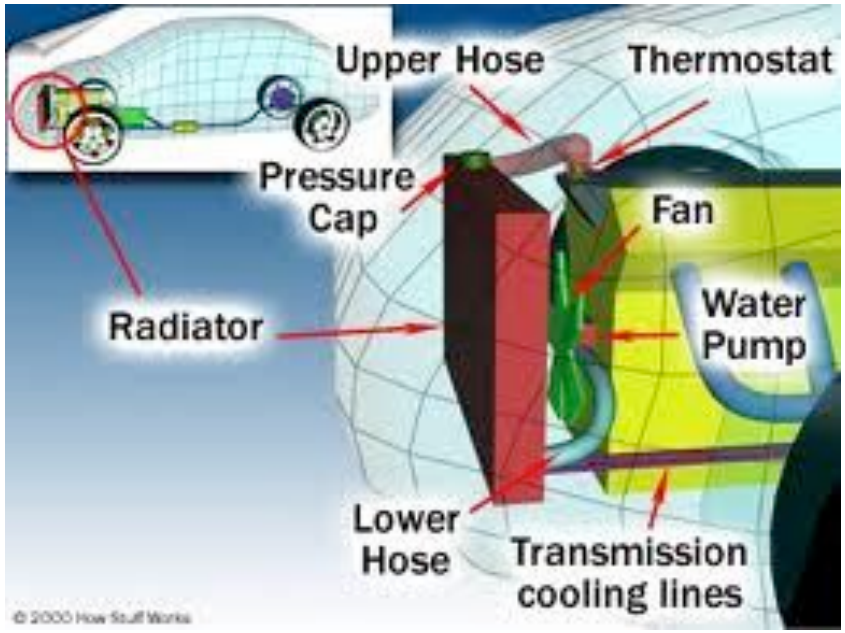
Coolant/Antifreeze in your car's cooling system uses b.p. elevation and f.p. depression

Antifreeze/Coolant Functions include:
engine cooling, freeze protection, inhibit corrosion and scale formation.
http://www.eetcorp.com/antifreeze/antifreeze-faq.htm

Coolant FAQ, Part 2: Coolants - Better Living Through Chemistry:
http://www.jcna.com/library/tech/tech0011.html

A Liquid Must Have Specific Properties to Work As A Coolant and Antifreeze:

- boiling point
- vapor pressure
- specific heat
- latent heat
- surface tension
- specific gravity



Prestone Coolant Contains Ethylene Glycol
($HOCH_2CH_2OH$, MW = 62 g/mole, density = 1.11 g/ml, m.p. = -16°C, b.p. = 197°C). http://www.prestone.com/

Prestone label:

50:50 Prestone/water protects your engine up to 265°F.

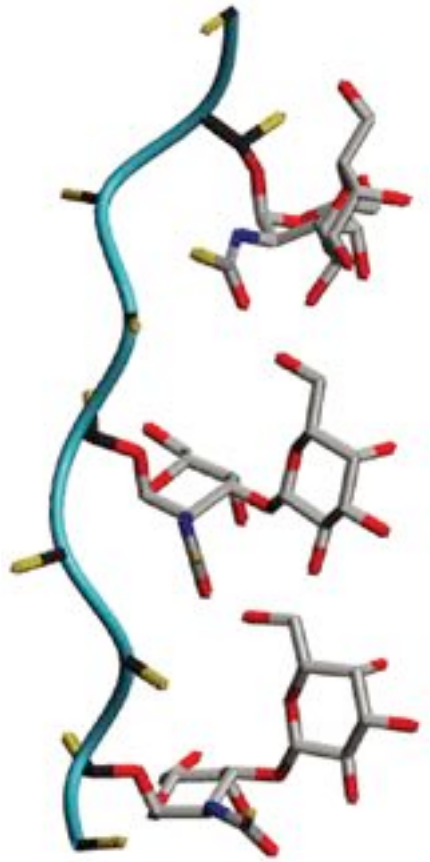
70:30 Prestone/water protects your engine up to 276°F.

Which substance is the solvent, water or ethylene glycol?

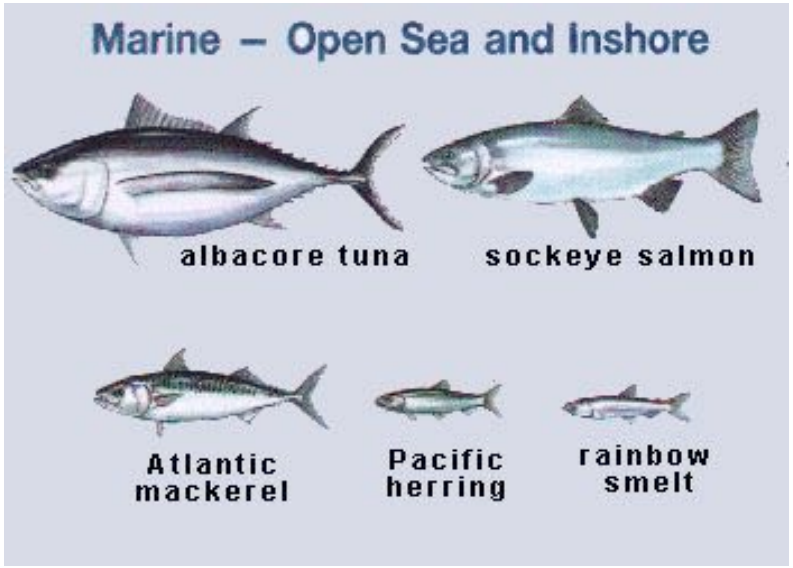
HOW ARCTIC FISH AVOID FREEZING

Antifreeze glycoproteins in fish prevent them from freezing in subzero waters. (CEN, February 16, 2004, p. 13)

AFGPs are one of two classes of antifreeze proteins that prevent marine teleost, or bony fish, from freezing in subzero waters by binding to and inhibiting the growth of ice crystals.



A molecular unit consisting of a tripeptide with a disaccharide attached to the middle residue is the secret to fish antifreeze glycoproteins. The glycoprotein shown here contains three units.



http://www.thecanadianencyclopedia.com/articles/fishes

Maxi protein in winter flounder incorporates sheets of water molecules in its structure

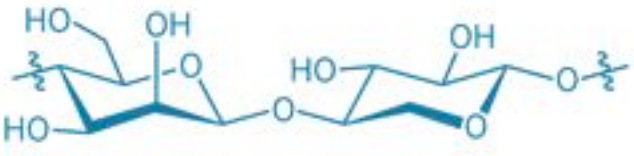
(http://cen.acs.org/articles/92/i7/Antifreeze-Protein-Works-Inside.html)

Maxi protein has four protein helices separated by two water sheets, with water molecules represented by spheres and hydrogen bonds by dashes.

The water sheets extend from the protein core outward between the helices where the sheets can merge with ice and inhibit its growth.

Insects have antifreeze in them - an ***Antifreeze Protein***

These proteins bind to ice crystals to prevent their growth and affects the organization of water molecules up to 20 A away from the ice binding site. fire-colored beetle Dendroides canadensis. (http://cen.acs.org/articles/91/i1/Insect-Version-Antifreeze-Works.html)



Other insects (darkling beetles) have an ***Antifreeze Sugar*** in them.

Adult beetles freeze at –6 °C, but the ice-binding agent helps prevent this from harming them, he suggests. They can tolerate temperatures as low as –60 °C. The isolated ice-binding factor lowers water's freezing point by 3.7 °C, on par with the most active antifreeze proteins.

I never thought I'd make ICE CREAM

in chemistry lab!

Better Living Through Chemistry

The Solvent in Ice Cream is:

The solute in ice cream is:

The freezing point of ice cream is:

Starting with 500 g of ice, _____ g of salt are needed to lower the f.p. to _____.

Ben &Jerry's Vanilla Ice Cream

http://www.theicecreaminformant.com/2013/08/review-ben-jerrys-vanilla.html

Fat – creamy texture (but a lot of calories)

Sugar – sweet (but a lot of calories)

Lower quality ice cream – water freezes out of mixture
(compare f.p. of ingredients)

Heat (q) depends on m, s, and T.
If you can use only 500 g (2 cups) of ice, how much ice cream mixture can you freeze?

(i) Less than 2 cups (ii) 2 cups (iii) More than 2 cups

http://whatscookingamerica.net/Desserts/HomemadeIceCream.htm

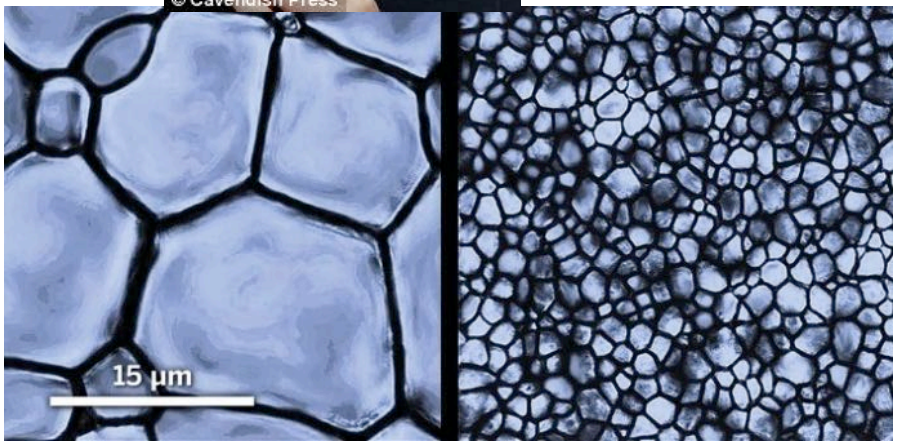
Gritty, Grainy Frozen Ice Cream – *Doesn't* Taste Good!

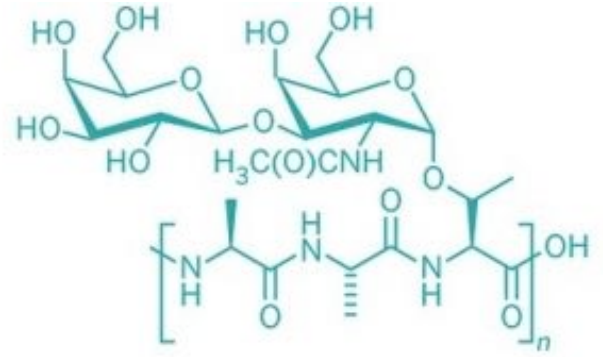
Cryoprotectant chemicals put the Freeze on Ice Crystal Growth

http://cen.acs.org/articles/92/i40/Cryoprotectant-Chemicals-Put-Freeze-Ice.html

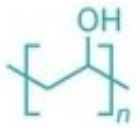
Use to store blood, stem cells, and other biomaterials by freezing

http://www.dailymail.co.uk/news/article-1277878/Schoolchildren-unimpressed-tasting-new-vegetable-ice-creams.html

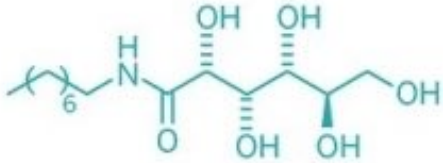




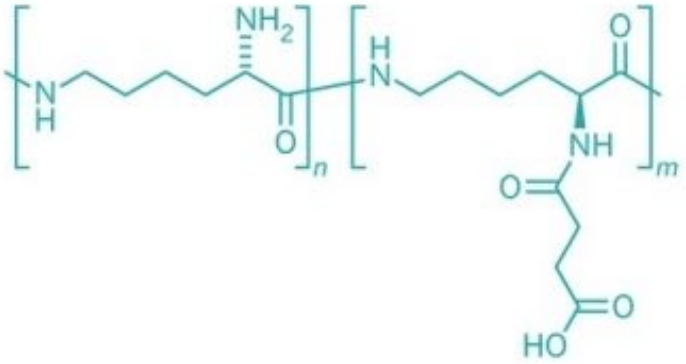
Antifreeze glycoprotein



Polyvinyl alcohol



N-Octyl-D-gluconamide

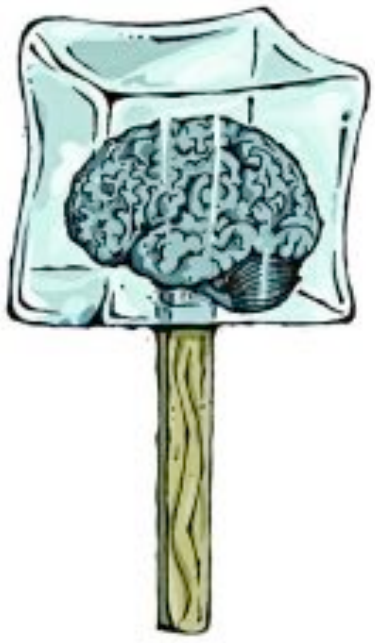


Carboxylated ε-poly-L-lysine

Brain Freeze!!

sphenopalatine ganglioneuralgia

http://cen.acs.org/articles/90/i23/Intentional-Brain-Freeze-Traffic-Ticket.html



The brain responds to cold temperatures by dilating its blood vessels to increase its blood flow and keep the brain warm. However, the brain is a somewhat-closed system, and the pressure caused by the rapid influx of blood could be what causes headaches. Researchers hope a better understanding of the inner workings of headaches might lead to better treatments for them.