Phase Diagram for $\text{CO}_2$
Phase Diagram for H$_2$O

![Phase Diagram of Water](image)
The Liquid State

- Density
- Compressibility
- Diffusion
- Evaporation
- Vapor pressure
- Surface tension
- Viscosity
- Adhesive/cohesive forces
- Capillary action
Density of Ice and Water
Compressibility
Surface Tension
Equilibrium Vapor Pressure
Vapor Pressure Curves

- Diethyl ether: Normal b.p. 34.6°C
- Ethyl alcohol: Normal b.p. 78.5°C
- H₂O: Normal b.p. 100°C

Temperature (°C):

Pressure (mmHg):

- 760 mm Hg
Trouton’s Rule

An interesting and useful “approximation:

• Says that the ratio of the heat of vaporization to the boiling point is (roughly) constant

\[ \frac{\Delta H_{\text{vap}}}{T_{\text{b.p.}}} \sim 88 \text{ J/mol} \]

• Boiling point of cyclohexane is 69°C. Therefore,

\[ \Delta H_{\text{vap}} = (69 + 273)(88) \sim 30 \text{ kJ/mol} \]

which is within 2-3% of the experimental value

• Works well for unassociated liquids and gives useful information about degree of association.
Trouton's Rule

Unassociated (ideal) liquids, $\Delta H_{vap}/T_{b.p.} \sim 88$ J/mol
- carbon tetrachloride
- benzene
- cyclohexane

Associated liquids, $\Delta H_{vap}/T_{b.p.} > 88$ J/mol
- water (110)
- methanol (112)
- ammonia (97)

Association in the vapor state, $\Delta H_{vap}/T_{b.p.} < 88$ J/mol
- acetic acid (62)
- hydrogen fluoride (26)
Colligative Properties

Thought Experiment

(a) Sea water

(b) Pure water
Colligative Properties

- Elevation of the normal boiling point
- Lowering of the normal freezing point
Elevation of the normal b.p.
Raoult’s Law

• Nonvolatile solute in volatile solvent:
  \[ p = p^\circ X_{\text{solute}} \]
  \[ p^\circ - p = p = p^\circ X_{\text{solute}} \]

• Elevation of the boiling point: \[ \Delta T = K_{bp}m \]

• Depression of the freezing point: \[ \Delta T = K_{fp}m \]

• Osmostic pressure: \[ \pi = cRT \]
Boiling and Freezing Point Constants for Some Solvents

<table>
<thead>
<tr>
<th>Solvent</th>
<th>$K_b(°C/m)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>water</td>
<td>0.52</td>
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<tr>
<td>ethyl alcohol</td>
<td>1.20</td>
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<tr>
<td>benzene</td>
<td>2.67</td>
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<tr>
<td>acetic acid</td>
<td>2.93</td>
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<tr>
<td>chloroform</td>
<td>3.85</td>
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<tr>
<td>carbon tetrachloride</td>
<td>5.02</td>
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</table>

<table>
<thead>
<tr>
<th>Solvent</th>
<th>$K_f(°C/m)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>water</td>
<td>−1.86</td>
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<tr>
<td>acetic acid</td>
<td>−3.90</td>
</tr>
<tr>
<td>chloroform</td>
<td>−4.68</td>
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<tr>
<td>benzene</td>
<td>−5.12</td>
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<tr>
<td>naphthalene</td>
<td>−7.00</td>
</tr>
<tr>
<td>camphor</td>
<td>−40.0</td>
</tr>
</tbody>
</table>
Phase Diagram for H$_2$O
Super Slurper
Super Slurper

- "Slurper" molecules are polymers with hydrophilic ends that grab onto water molecules.
- Sodium salt of poly(acrylic acid).
- R-COO\(^-\), Na\(^+\)

![Diagram showing "Slurper" molecules and water molecules](image)
Colligative Properties

- Elevation of the normal boiling point
- Lowering of the normal freezing point
Elevation of the normal b.p.
Natural de-icer means you'll have to shovel less this winter

All-natural grain juices dissolve away snow, prevent snow from adhering for 10-14 days! Perfect for clearing driveways, walks and protecting plants.

Snowy nights will never keep me awake again! Now I sleep through the storm like a baby. Next morning all the other guys on the block are up wrestling with shovels, ice choppers, bags of salt—but my driveway and sidewalk are easier to clear! I’m dreaming? No sir, this stuff is real. Put it on the ground before a storm and it reduces the amount of snow that accumulates. Yeah, I didn’t believe it either, until I heard what the toughest road crews in America were saying about Bare Ground. Storm-tested by state highway departments. These are the guys who stay up all night breaking through drifts, plowing, fighting hazardous road ice. If they swear by it, it must be good! And it is. Bare Ground Anti-Snow/De-Icer is a liquid you spray or stream on a road or sidewalk. It not only cuts up snow and ice but prevents future deposits from sticking for 10 to 14 days. It’s not expensive either, because a little goes a long, long way.

One gallon equals 50 pounds of salt. Already got snow or ice on your sidewalk or driveway? No problem. Just spray on some Bare Ground liquid. Instead of staying on top it sinks down to the bare pavement and dissolves the bond of snow or ice that holds it to the surface. No long waiting either—it starts working in about 20 minutes. Another reason the dollar-conscious pros use it: one gallon of Bare Ground is the equivalent of 50 pounds of salts or pellets.

Safe for pets, kids, shrubs and carpets. Bare Ground is environmentally safe, biodegradable and non-toxic. Harmless to plants and grass, Bare Ground won’t eat up the ball carpet like salt. Unlike other snow melters, you can use Bare Ground on any surface including rubber, roof shingles, slates, wood, brick or new concrete. In fact, Bare Ground is so safe, you may even wish to mix it with water and apply to trees and shrubs to prevent excessive ice buildup. It was discovered by two Hungarian distillery workers when they noticed that plant runoff water going into a local pond kept everything from freezing—even in the dead of frigid Hungarian winters. They isolated the key ingredient—all natural byproducts and patented the formula. And now you can throw away your shovel and fire your hernia doctor forever!

One gallon protects a 20’ x 50’ driveway. Think of it also as protection against a stranger ed back, even heart strain. If a storm is due, pre-coat your driveway and sidewalk and let it snow. It not only reduces the amount of snow which accumulates but applies a non-stick coating that keeps ice and falling snow from sticking. You can also forget about tickets for un-shoveled sidewalks.

Make your life easier when winter arrives! Apply Bare Ground about 2 hrs. before a snow or ice storm, or Bare Ground will begin to work about 30 minutes after its application to an existing snow or ice pack.

Bare Ground Solution System with Sprayer $39.95 S&H
Gallon Refill $12.95 S&H

For fastest service, call toll-free 24 hours a day
800-992-2966

To order by mail, send this page to your choice of the two points listed below. Checks must be drawn on U.S. banks and must be made payable to TechnoScout.

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Bare Ground Solution System with Sprayer $39.95 S&H
Gallon Refill $12.95 S&H

Please mention product code 7005-19671.
For fastest service, call toll-free 24 hours a day
800-992-2966
Another Estimate Problem

• .... the lowest temperature your car radiator fluid could withstand and still remain fluid if your car radiator fluid was... VODKA!

• Strategy/LOGIC
Osmosis/Osmotic Pressure

Applications:
- Treating industrial wastes
- Pulp and paper manufacture
- Reclamation of brackish/salt water
- Sewage treatment
- Electrodialysis
- Many biological/ecological processes
Colligative Properties

Thought Experiment

(a) Sea water

(b) Pure water
Glass tube

Cork

5% sugar
95% water

Selectively permeable membrane

Height of solution column

(a)

(b)
Osmosis/Osmotic Pressure
Osmosis/Osmotic Pressure

- DRIED PLUMS... “prunes”
- Carrots
- Eggs
- Blood cells
(a) Isotonic solution  (b) Hypertonic solution  (c) Hypotonic solution
Osmosis/Osmotic Pressure

In dilute solutions:

\[ \Pi V = n_2RT = \frac{g_2}{M_2}RT \]
\[ \Pi = cRT \text{ where } c \sim \text{mol/L} \]

Solubility of hemoglobin in water is 5.0 g/L

Strategy/LOGIC?

\[ \Pi = 1.80 \times 10^{-3} \text{ atm @ 25°C} \]
\[ C = \frac{\Pi}{RT} = \text{mol/L} \]
\[ MW = \frac{[g/L]}{\text{mol/L}} = g/mol \]
Normal and Reverse Osmotic Systems

\[
\pi > P
\]

\[
P > \pi
\]

Normal osmotic system

Reverse osmotic system
Desalting Water on Catalina Island

Reverse osmosis, a popular technology for small- and medium-sized desalting plants, will be used on Santa Catalina Island off California. It is the first seawater-desalting plant for an American residential community.

1. Salt water is filtered to remove big particles.
2. A pump pushes the salt water into a reverse osmosis unit.
3. Cylinders with membranes remove impurities and salt from the water.
4. The water is treated with chlorine, lime and carbon dioxide and stored.

Saltwater or media filters: Layers of gravel and sand that remove all big particles.

Chlorinators: Chemicals are used to disinfect the water and make it less acidic.

Source: Hamilton Cove Associates
Example

Estimate the “back pressure” needed to obtain pure water from sea water by “reverse” osmosis.

Strategy/LOGIC

\[ \Pi = cRT \text{ where } c \sim \text{mol/L} \]
Van’t Hoff i-Factor

- Colligative effects depend on number of particles.
- Ionization and dissociation multiply colligative effects.
- Association acts in the opposite sense.
Van't Hoff i-Factor

\[ i = \frac{\Delta T_{\text{electrolyte}}}{\Delta T_{\text{nonelectrolyte}}} \]

\[ T = iK_{bp}m \] (boiling point elevation)

\[ T = iK_{fp}m \] (freezing point depression)

\[ \Pi = icRT \] (osmotic pressure)
Simple Distillation

- Mixture of alcohol and water form a nearly ideal solution.
- Use Raoult’s law to calculate the composition of the solution.
- Use Dalton’s law to calculate the composition of the vapor above the solution.
- Vapor is “richer” in the more volatile component.
Partial Pressures and Total Pressure in a Binary Mixture

For the case where
\[ X_{C_2H_5OH} = 0.80 \]
\[ X_{H_2O} = 0.20 \]

From the graph,
\[ P_{H_2O} = 3.5 \text{ torr} \]
\[ P_{C_2H_5OH} = 34.5 \text{ torr} \]
\[ P_{\text{Total}} = 38.0 \text{ torr} \]
Binary mixtures of Volatile Components

- **Nearly ideal**: Minor differences between intra- and intermolecular forces between molecules.
- **Positive deviation**: Intramolecular forces favored: A–A and B–B types.
- **Negative deviation**: Intermolecular forces favored: A–B and B–A types.
Distillation

• Simple distillation...
  as recorded by Maxfield Parish
  in his freshman chemistry
  laboratory notebook.

• Fractional distillation...
  on a laboratory scale of 1000mL/h

• Separation of petroleum
  hydrocarbon mixtures on an
  industrial scale ~50,000 gal/d
Benzene and Toluene form an ideal solution