Physical Principles in Biology
Biology 3550
Fall 2016

Lecture 32

Quiz 3 Review

and

Introduction to Lipids and Membranes

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University of Utah
goldenberg@biology.utah.edu

Quiz 3: Problem 1

- What we want: 100 L of CO_2 gas at 250 μM
- Starting material: CO_2 gas at 23 μM
- Problem 1(a)
  - How many moles of CO_2?

$$\begin{aligned} \text{moles} &= \text{concentration} \times \text{volume} \\ &= 250\,\mu\text{M} \times 100\,\text{L} \\ &= 2.5\times10^{-4}\,\text{mol/L} \times 100\,\text{L} = 0.025\,\text{mol} \end{aligned}$$

  - Volume of starting CO_2 at 23 μM

$$0.025\,\text{mol} = V \times 23\,\mu\text{M}$$

$$V = \frac{0.025\,\text{mol}}{23\,\mu\text{M}} = \frac{0.025\,\text{mol}}{2.3\times10^{-5}\,\text{mol/L}}$$

$$= 1.1\times10^{3}\,\text{L}$$

Quiz 3: Problem 1

- Another way to calculate the starting volume:

$$C_1 \times V_1 = C_2 \times V_2 \qquad V_1 = \frac{C_2 \times V_2}{C_1}$$

$$C_1 = 23\,\mu\text{M}$$
$$C_2 = 250\,\mu\text{M}$$
$$V_2 = 100\,\text{L}$$

$$V_1 = \frac{C_2 \times V_2}{C_1} = \frac{250\,\mu\text{M} \times 100\,\text{L}}{23\,\mu\text{M}}$$

$$= 1.1 \times 10^3\,\text{L}$$

- This works because $C \times V =$ moles, and the number of moles doesn't change!

Quiz 3: Problem 1

- Problem 1(b): Calculate pressure of starting (and ending) CO_2
  - The ideal gas equation: $PV = nRT$.

$$P = \frac{n}{V} RT = C \text{ (mol/L)} \times RT$$

  - Which R?

$$R = 8.314\,\mathrm{J \cdot mol^{-1} K^{-1}}$$

$$R = 0.08206\,\mathrm{L \cdot atm \cdot K^{-1} mol^{-1}}$$

    There's really only one R, but with different units.

  - For starting CO_2, $C = 23\,\mu\mathrm{M}$

$$P = C \text{ (mol/L)} \times RT$$

$$= 2.3\times10^{-5}\,\mathrm{mol/L} \times 0.08206\,\mathrm{L \cdot atm \cdot K^{-1} mol^{-1}} \times 275\,\mathrm{K}$$

$$= 5.2\times10^{-4}\,\mathrm{atm}$$

Quiz 3: Problem 1

- Problem 1(c): Calculate the entropy change for compressing CO_2 to final volume of 100 L.

$$\Delta S = nR \ln \frac{V_2}{V_1} = nR \ln \frac{C_1}{C_2}$$

- Which R?

$$R = 8.314\,\mathrm{J \cdot mol^{-1} K^{-1}}$$

$$R = 0.08206\,\mathrm{L \cdot atm \cdot K^{-1} mol^{-1}}$$

- $n = 0.025\,\mathrm{mol},\ C_1 = 23\,\mu\mathrm{M},\ C_2 = 250\,\mu\mathrm{M}$

$$\begin{aligned}\Delta S &= nR \ln \frac{C_1}{C_2} \\ &= 0.025\,\mathrm{mol} \times 8.314\,\mathrm{J \cdot mol^{-1} K^{-1}} \ln \frac{23\,\mu\mathrm{M}}{250\,\mu\mathrm{M}} \\ &= -0.5\,\mathrm{J/K}\end{aligned}$$

Quiz 3: Problem 2

- The minimum amount of work to compress the gas.
- Minimum work requires a reversible process.
- For reversible process, $q = q_{\text{rev}}$ and

$$\Delta S_{\text{sys}} = \frac{q_{\text{rev}}}{T}$$

$$q_{\text{rev}} = T\Delta S_{\text{sys}}$$

$$q_{\text{rev}} = -0.5\,\text{J/K} \times 275\,\text{K} = -137\,\text{J}$$

- Because temperature is the same at beginning and end, $\Delta E = 0$.

$$\Delta E = q + w = 0$$

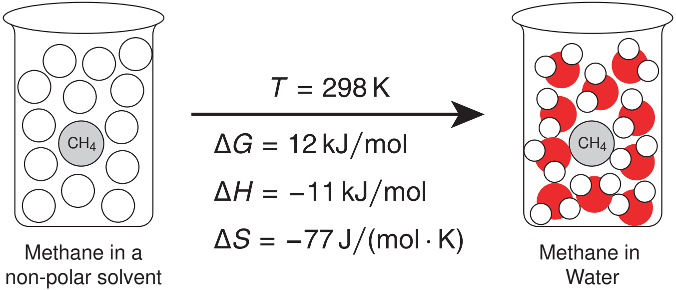
$$w = -q = 137\,\text{J}$$

Quiz 3: Problem 3

Parameters for compression of gas

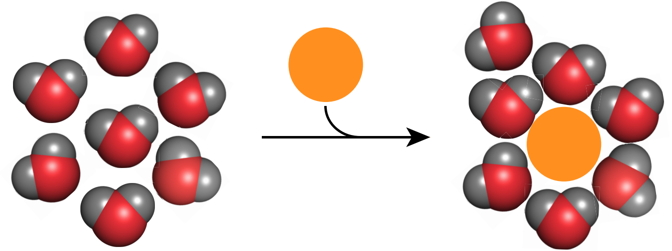
	Reversible	With 5 J extra work
ΔE	0	0
w	> 0	More positive
q	< 0	More negative
ΔS_{sys}	< 0	Same
ΔS_{surr}	$= -q/T > 0$	More positive

Thermodynamics of Transfer of a Non-polar Molecule to Water



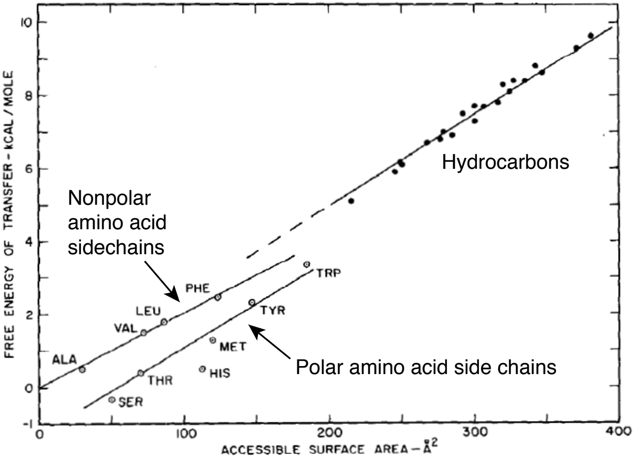
- $\Delta G = \Delta H - T\Delta S$
- ΔG is positive because ΔS is negative! (an "entropically driven" process).
- Something becomes more ordered when non-polar molecule is introduced into water.

The "Iceberg Model"



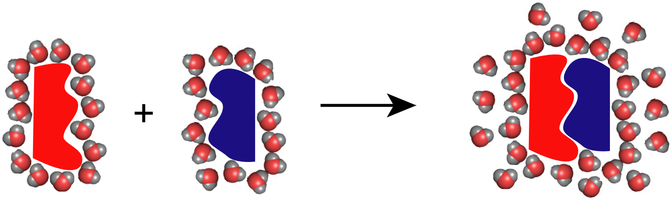
- Introduction of a non-polar molecule causes water molecules to become more ordered.
- Either new hydrogen bonds form or existing ones become stronger, leading to negative ΔH.
- Why do water molecules do this, instead of just allowing hydrogen bonds to break?
- I don't know! (And, I don't think that anyone else really does either.)

Transfer Free Energy versus Molecular Size



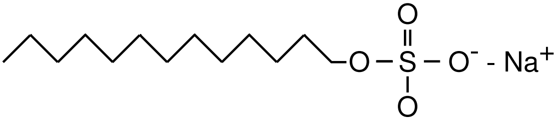
F. M. Richards. Areas, volumes, packing and protein structure. *Annu. Rev. Biophys. Bioeng.*, 6:151–176, 1977.

Bimolecular Association can be Entropically Favorable!



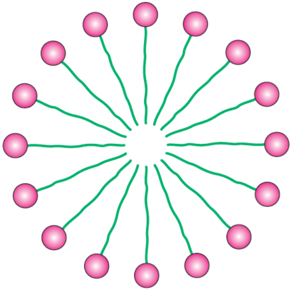
- Associating molecules lose entropy.
- Water molecules near hydrophobic surfaces become less ordered.
- Ions bound to charged groups can have similar effect.

An Amphiphilic Molecule: Sodium Dodecyl Sulfate



- Two parts:
  - Tail: 12-carbon hydrocarbon - highly insoluble in water
  - Head: Sulfate group - highly soluble in water
- Typical structure of ionic detergents
- Common ingredient of shampoos and other common cleaning products

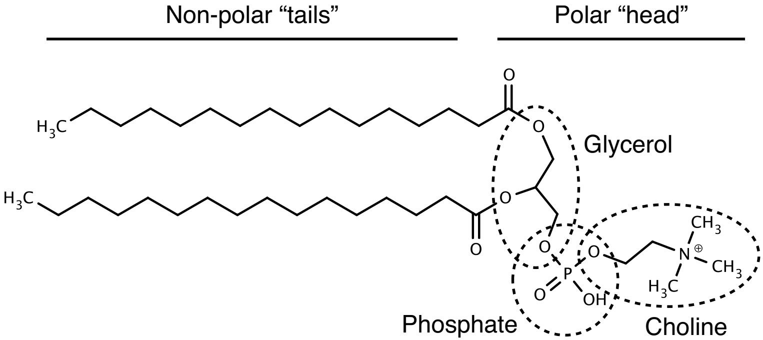
Self Assembly of Detergents: Micelles



From Berg, Tymoczko & Stryer, Biochemistry, 6th Ed

- Roughly spherical structures.
- Hydrocarbon tails are sequestered away from water.
- Polar tails interact with water.
- Structural specificity:
  For a given detergent, micelles will have limited range of sizes that optimizes packing of molecules.
- Soaps and detergents act by dissolving non-polar molecules in core of micelles.

A Phospholipid: Phosphatidylcholine



- Two hydrocarbon tails linked together through glycerol.
- Polar head includes glycerol, phosphate group, and choline.
- Lots of variety in both hydrocarbon tails and polar groups.

Phospholipids and Bilayers

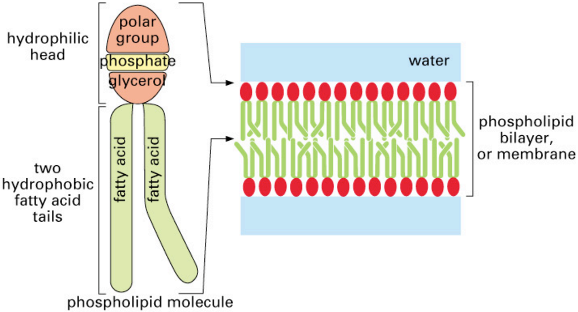
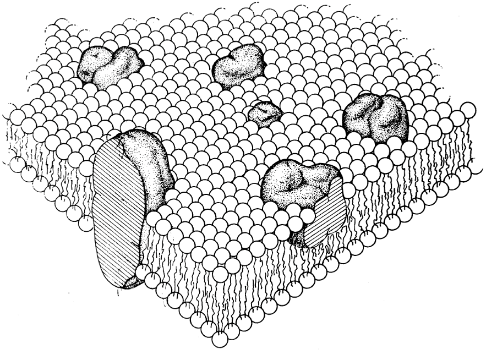


Figure 2–22. Molecular Biology of the Cell, 4th Edition.

- Large two dimensional sheets.
- Non-polar tails sequestered away from water.
- Polar head groups exposed to water on each side.
- Why don't phospholipids form micelles, like detergents do?

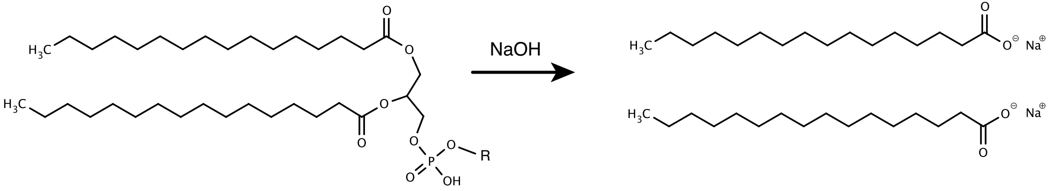
General Structure of Biological Membranes



- Proteins embedded in bilayer control passage of other molecules.
- Many other functions of membrane proteins!

Singer, S. & Nicolson, G. (1972). The fluid mosaic model of the structure of cell membranes. *Science*, 175, 720–731. http://dx.doi.org/10.1126/science.175.4023.720

Saponification of a Phospholipid



- Alkaline conditions (and high temperature) favor hydrolysis of ester bonds.
- Fatty acids have shapes that favor forming micelles rather than bilayers.
- Salts of fatty acids are called soap!