

Given:

$$\begin{aligned}
 g &= 9.81 \text{ m/s}^2 \\
 R &= 8.314 \text{ J mol}^{-1} \text{ K}^{-1} = 0.08206 \text{ L atm mol}^{-1} \text{ K}^{-1} \\
 1 \text{ a.m.u.} &= 1.67 \times 10^{-27} \text{ kg} \\
 \sigma &= 5.67 \times 10^{-8} \text{ W/m}^2/\text{K}^4 \\
 \text{Electron charge} &= 1.62 \times 10^{-19} \text{ C} \\
 \text{The Rydberg constant} &= 13.6 \text{ eV} = 109690 \text{ cm}^{-1} \\
 1 \text{ Debye} &= 3.33 \times 10^{-30} \text{ Cm} \\
 1 \text{ atm} &= 1.0133 \times 10^5 \text{ Nm}^{-2} = 760 \text{ Torr} \\
 P &= P_0 \exp\{-Mgh/RT\}
 \end{aligned}$$

$$P_2 = P_1 + \frac{\Delta_{trs}H_m}{\Delta_{trs}V_m} \ln\left(\frac{T_2}{T_1}\right) \quad , \quad \ln\left(\frac{P_2}{P_1}\right) = \frac{\Delta_{trs}H_m}{R} \left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$$\ln\left(\frac{K_2}{K_1}\right) = \frac{\Delta H_m}{R} \left(\frac{1}{T_1} - \frac{1}{T_2}\right) \quad \ln a_2 = \frac{\Delta H_m}{R} \left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$$\Delta S = -R \sum_{i=1}^N x_i \ln x_i \text{ where } N \text{ is the number of components}$$

$$\rho = mgh \quad , \quad P = \rho gh \quad , \quad dS \geq \frac{\delta q}{T} \quad , \quad dw = -PdV \quad , \quad dH = dU + PdV$$

$$\omega = \sqrt{\frac{k}{\mu}} \quad , \quad \dot{B} = \frac{h}{8\pi^2 c \mu R^2} \quad , \quad \mu = \frac{m_1 m_2}{m_1 + m_2} \quad , \quad \lambda = \frac{h}{p} \quad , \quad \left(\frac{T_2}{T_1}\right) = \left(\frac{V_1}{V_2}\right)^{R/C_V}$$

$$E_n = -\frac{ZR^2}{n^2} \quad , \quad -\frac{\hbar^2}{2\mu} \frac{\partial^2 \Psi}{\partial x^2} = E\Psi \quad , \quad U = \frac{q_1 q_2}{4\pi\epsilon_0 r} \quad , \quad u(r) = 4\epsilon \left\{ \left(\frac{\sigma}{r}\right)^{12} - \left(\frac{\sigma}{r}\right)^6 \right\} \quad ,$$

$$W = \sigma T^4 \quad , \quad \lambda_{\max} T = 2.88 \times 10^6 \text{ nm-K} \quad , \quad E_v = \left(v + \frac{1}{2}\right) h\nu \quad , \quad E = \frac{\hbar^2}{2\mu R^2} J(J+1)$$

$$\Delta E = \frac{RT}{nF} \ln\left(\frac{c_o}{c_i}\right) \quad , \quad \Delta G^\circ = -nF\Delta E \quad , \quad \Pi = cRT \quad , \quad P_i = K_{H,i} x_i \quad ,$$

$$\frac{P_2}{P_1} = e^{-\Delta E/kT} \quad , \quad P_{in} = P_{out} + \frac{2\gamma}{r} \quad , \quad k = Ae^{-E_a/RT} \quad , \quad k = \frac{kT}{h} e^{-\Delta G^\circ/RT}$$

Surface Tension Data

Substance	Surface tension (mN/m)	Temperature (°C)
Water	72	25
Water	59	100
Benzene	29	20
Acetone	24	20

Water Phase Data

Point	Pressure (atm)	Temperature (K)
Triple Point	0.006	273.16
Normal Boiling Point	1	373.15
Critical Point	218.3	647.4

For H₂O

$$\Delta H_{\text{fus}} = 6.0 \text{ kJ/mol}$$

$$\Delta H_{\text{vap}} = 40.65 \text{ kJ/mol}$$

Please answer all questions.

1. A plant supplies water to Santa Barbara, California using reverse osmosis. The process can be described as a piston that pushes a given volume of seawater through a membrane at constant pressure and at a constant temperature of 298 K.
 - A. Given that the electrolyte concentration in seawater is 4 M, calculate the pressure required to drive seawater through the membrane in the reverse osmosis process.

Osmotic Pressure = _____.

- B. Calculate the isothermal work required to push 100 L of seawater through the membrane.

Isothermal work = _____.

2. Calculate the height of a column of water that can be achieved in the xylem of a tree that has a radius of 10 microns.

Height = _____.

3. Calculate the molar mass of a protein determined from a measurement of the osmotic pressure. If 0.02 grams of the protein is dissolved in 1 ml. and osmotic pressure of 10^{-6} atm develops at a temperature of 310 K, what is the molar mass of the protein?

Molar mass = _____.

4. The vapor pressure of a solution of salt in ice is measured to be 0.004 atm at 268 K. Determine whether it is melted or not.

Prediction of State of Water _____.

5. What are the radiative losses from the surface of a lake if 1000 W/m^2 of sunlight are incident on the lake and the lake temperature is 35°C ?

Radiative Power Loss per Square Meter = _____.

6. A steam engine is used to drive water out of a mine shaft. The expansion occurs at 100°C and the exhaust temperature is 40°C . Calculate the thermodynamic efficiency of the steam engine.

Efficiency = _____.

7. Air is saturated to 50% of its vapor pressure at 298 K on the surface of the ocean. If the air rises adiabatically, calculate the height at which it will begin to rain.

Height = _____.

8. Calculate work of both isothermal and adiabatic compression for argon gas initially at 10 L and compressed to a final volume of 1 L under 10 atm of external pressure. Which is larger?

Isothermal Work = _____.

Adiabatic Work = _____.

9. A scientist is studying a surface using X-ray photoelectron spectroscopy. Three lines are observed. The first is a 1s electron at an energy of 81.6 eV. The second is a 2p-electron at an energy of 104.6 eV. The electron was ejected from a 3d-orbital with a binding energy of 74 eV. What are the effective nuclear charges of the three elements? What are the elements?

Elemental charge for 1s electron = _____.

Elemental charge for 2p electron = _____.

Elemental charge for 3d electron = _____.

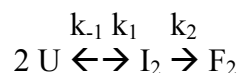
10. The fundamental vibration frequency of free gaseous $^{14}\text{N}^{16}\text{O}$ is 1904 cm^{-1} while the frequency of $^{14}\text{N}^{16}\text{O}$ bound to hemoglobin is 1615 cm^{-1} .
- Calculate the force constant for both free and bound using the harmonic oscillator model assuming that NO can be treated as an ideal diatomic in both cases.
 - Give a reason why the NO frequency shifts when it binds to hemoglobin.
 - Calculate the isotope shift in each case for $^{15}\text{N}^{16}\text{O}$.

The force constant of the vibration for free NO _____.

The force constant of the hemoglobin bound NO _____.

- iii. Sketch the orbitals of N_2 and NO that are involved in electronic transitions. Describe the selection rule in words. In what region of the electromagnetic spectrum is the vibrational spectrum observed?

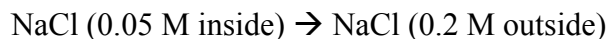
12. Domain swapped proteins have a folding pathway that involves formation of a dimer as an on-pathway intermediate:



- A. Mechanism I. I_2 has a negligible concentration (i.e. $k_2 \gg k_1$).
B. Mechanism II. I_2 is formed in a rapid pre-equilibrium step ($k_1 \gg k_2$).

For each of the mechanisms indicated, write an expression for the rate of formation of the folded dimer F_2 as a function of the concentration of the starting unfolded polypeptide $[U]$.

13. In living cells the concentration of sodium ions inside the cell is kept at a lower concentration than the concentration outside the cell. Consider the process of pumping sodium chloride from the inside to the outside of the cell at $37^\circ C$.



- A. What is the transmembrane potential due to the concentration difference?

- B. Calculate the chemical potential (molar free energy) for the process.

C. The standard free energy for hydrolysis of ATP to ADP is



The standard free energy change for the hydrolysis of ATP is $\Delta G^\circ = -31.3 \text{ kJ/mol}$ at 37°C and 1 atm. The free energy of this reaction can be used to power the sodium ion pump. For a concentration of $\text{ATP} = 1.5 \text{ mM}$ to $\text{ADP} = 150 \text{ }\mu\text{M}$, what must be the concentration of phosphate to obtain a sufficient chemical potential to pump 12 moles of NaCl across the membrane.

14. A polypeptide is denatured in guanidium chloride.

A. Calculate the statistical entropy of the polypeptide chain consisting of 150 subunits of length 4 \AA provided there are 7 conformers accessible to each subunit.

B. What is the approximation mean-square radius of the polypeptide if it obeys Gaussian chain diffusion?

15. Calculate the molar entropy of mixing of a 1 M solution of sucrose and fructose. You may assume ideal solution behavior.