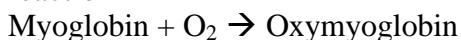


1. Calculate the surface tension of a liquid if the capillary rise in a tube of radius  $100 \mu$  is  $0.1 \text{ m}$  and the density is  $0.8 \text{ gm/cm}^3$ .

$$\text{Solution: } \rho gh = 2\gamma/R \rightarrow \gamma = \rho ghR/2 = (800 \text{ kg/m}^3)(9.8 \text{ m/s}^2)(0.1 \text{ m})(10^{-4} \text{ m})/2 = 0.039 \text{ J/m}^2.$$

2. Myoglobin is a skeletal protein that binds oxygen. The standard free energy for the reaction



is  $\Delta G^\circ = -30.0 \text{ kJ/mol}$  at  $298 \text{ K}$  and  $\text{pH } 7$ . The standard state of  $\text{O}_2$  is the dilute solution molarity scale; therefore the concentration of  $\text{O}_2$  must be in units of molarity (M). What is the ratio (oxymyoglobin)/(total myoglobin) in an aqueous solution at equilibrium with a partial pressure of oxygen  $P(\text{O}_2) = 30 \text{ Torr}$ ? Assume ideal behavior of  $\text{O}_2$  gas and that Henry's law holds for  $\text{O}_2$  dissolved in water ( $K(\text{O}_2) = 43 \times 10^3 \text{ atm}$ ).

Solution: The concentration of  $\text{O}_2$  in solution is given by Henry's law.

$$P(\text{O}_2) = K(\text{O}_2) x(\text{O}_2) \text{ or}$$

$$x(\text{O}_2) = P(\text{O}_2)/K(\text{O}_2) = 30 \text{ Torr}/43000 \text{ atm}(760 \text{ Torr/atm}) = 9.1 \times 10^{-7} \sim 10^{-6}.$$

Since the molarity of water is  $55.5 \text{ molar}$  the molarity of oxygen is approximately  $[\text{O}_2] = 9.1 \times 10^{-7}(55.5 \text{ M}) \sim 5.0 \times 10^{-5} \text{ M}$ .

$$K = \exp\{-\Delta G^\circ/RT\} = \exp\{30000/8.31/310\} = 1.14 \times 10^5$$

$$\theta = K[\text{O}_2]/\{1 + K[\text{O}_2]\} = (1.14 \times 10^5)(5.0 \times 10^{-5})/\{1 + (1.14 \times 10^5)(5.0 \times 10^{-5})\} = 0.85$$

3. According to the chemiosmotic theory, an electrochemical proton gradient is used to synthesize ATP in mitochondria. The enzyme that does this is located on the inside of the mitochondrial membrane. The oxidation of carbohydrates and fats is used to pump protons outside the mitochondrial membrane until the steady state membrane potential is  $-140 \text{ mV}$  and the pH gradient is  $\Delta \text{pH} = 1.5$  units. Inside the mitochondrion,  $\text{pH} = 7.0$ ,  $[\text{ATP}] = 1 \text{ mM}$ ,  $[\text{P}_i] = 2.5 \text{ mM}$ ,  $[\text{ADP}] = 1 \text{ mM}$ , and  $T = 310 \text{ K}$  and the standard free energy change is ( $\Delta G^\circ = 31 \text{ kJ/mol}$ ).

A. How much free energy is required to synthesize ATP inside the mitochondria?

B. How much free energy is made available by moving one mole of protons from the outside to the inside? Is this enough to drive ATP synthesis?

C. How many protons must be translocated per ATP synthesized?

Solution: A. The ATP phosphorylation reaction is  $\text{ADP} + \text{P}_i \rightarrow \text{ATP} + \text{H}_2\text{O}$  ( $\Delta G^\circ = 31 \text{ kJ/mol}$ ) and the equilibrium constant is  $K = [\text{ATP}]/[\text{ADP}][\text{P}_i]$ . In order to answer question A. we need to consider the driving force:

$$\Delta G = \Delta G^\circ + RT \ln Q$$

$$= 31,000 \text{ J/mol} + (8.31 \text{ J/mol-K})(310 \text{ K}) \ln(0.001/(0.0025)(0.001))$$

$$= 46.1 \text{ kJ/mol}$$

B. The free energy that can be obtained is determined by the magnitude of the concentration gradient. Since the pH is 7 inside then  $[H^+]_{\text{inside}} = 10^{-7}$  and given the difference of 1.5 we know that the pH is 5.5 on the outside of the mitochondrial membrane. Thus,  $[H^+]_{\text{outside}} = 3.16 \times 10^{-6}$  and  $\Delta G = -RT \ln([H^+]_{\text{outside}}/[H^+]_{\text{inside}}) = -(8.31 \text{ J/mol-K})(310 \text{ K}) \ln(3.16 \times 10^{-6}/10^{-7}) = 8.9 \text{ kJ/mol}$ .

C. The number of hydrogen ions needed per ATP synthesized is  $46.1/8.9 \sim 5$ .

4. How many photons of light strike a molecule on average if the wavelength of the radiation is 500 nm and the total energy per unit area is 1 nanoJoule/mm<sup>2</sup> and the concentration of molecules is 1 mM in a 1 mm cuvette?

Solution: The number of molecules encountered by the light is given by Avogadro's number times the concentration times the volume:

$$N_{\text{molecules}} = N_A CV = (6.023 \times 10^{23})(10^{-3} \text{ M})(1 \text{ mm}^3) = (6.023 \times 10^{23})(10^{-3} \text{ M})(10^{-18} \text{ m}^3) \\ = (6.023 \times 10^{23})(10^{-3} \text{ M})(10^{-15} \text{ L}) = 6.023 \times 10^5$$

The number of photons that pass through the 1 mm<sup>2</sup> surface area is given by the energy divided by the energy per photon.

$$\text{Energy per photon} = E = hv = hc/\lambda = (6.626 \times 10^{-34} \text{ Js})(2.99 \times 10^8 \text{ m/s})/(500 \times 10^{-9} \text{ m}) \\ = 3.96 \times 10^{-19} \text{ J/photon}$$

$$N_{\text{photons}} = 10^{-9} \text{ J}/(3.96 \times 10^{-19} \text{ J/photon}) = 2.5 \times 10^9$$

$$N_{\text{photons}}/N_{\text{molecules}} = 4150$$

5. A. What is the temperature at the surface of a burner on a stove if the maximum emission wavelength is 4240 nm?  
 B. The limit of visible detection is ca. 780 nm. How much radiant energy is emitted at 780 nm compared to that emitted at the peak of the blackbody emission spectrum?

Solution:

$$\text{A. } T = 2.88 \times 10^6 \text{ nm-K}/2240 \text{ nm} = 1285 \text{ K}$$

B. The Planck distribution law says that the radiant energy density is:

$$\rho = 8\pi hc/\lambda^5 (\exp\{hc/\lambda kT\} - 1)$$

$$\text{where } hc/kT = (6.626 \times 10^{-34} \text{ Js})(2.99 \times 10^8 \text{ m/s})/(1.38 \times 10^{-23} \text{ J/K})/1285 \text{ K} \\ = 1.12 \times 10^{-5} \text{ m} = 11,200 \text{ nm}$$

The ratio is:

$$\rho_2/\rho_1 = (\lambda_1/\lambda_2)^5 (\exp\{hc/\lambda_1 kT\} - 1)/(\exp\{hc/\lambda_2 kT\} - 1) \\ = (2240/780)^5 (\exp\{11200/780\} - 1)/(\exp\{11200/2240\} - 1) \\ = 0.016 \text{ or } 1.6 \%$$