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## CHAPTER 4      **Chemical Processes**

1. In what way do chemical reactions, the pressure of gases, or osmosis demonstrate that we cannot use mass as a measure of amount of substance?
2. Why does ice melt at 25°C?
3. Explain why the equilibrium concentrations of toluene in water and air are different. Why is the equilibrium concentration of salt in a body of water the same everywhere?
4. Why does a potato get heavier when placed in distilled water?
5. Explain how the concept of the chemical potential (and of chemical potential differences) can unify our explanations of phenomena such as chemical reactions, batteries, flow of chemicals in the environment or of drugs in the human body, diffusion, changes of boiling point of water by adding salt or sugar, vapor pressure, etc.
6. Give an example of forcing a chemical reaction to run into the opposite direction in which it normally runs.
7. Explain the difference between exothermic and endothermic reactions.
8. Research the establishment of the resting potential of cell membranes (such as nerve cells).
9. Calculate the masses of 1 mole of neon gas, oxygen gas, table salt, glucose.
10. If 10 g of table salt are dissolved in water, how many particles do we get in the solution?
11. The molar mass of water is 0.018 kg/mole. What is the molar volume of water?
12. Sugar is added to a bioreactor at a rate of 2 mole/min. It accumulates at a rate of 0.70 moles/minute. What is the rate of production of consumption of sugar?
13. 5.0 g of glucose are dissolved in 2.0 liters of water. What is the concentration (molar concentration) of the solution?
14. What is the chemical potential difference of the reaction of carbon and oxygen forming carbon dioxide?
15. Does gold rust? (Au and O<sub>2</sub> form Au<sub>2</sub>O<sub>3</sub>)
16. Can a 1 M (1 molar) salt solution be produced?

17. What is the chemical potential difference of burning of methane? ( $\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$ )
18. Does the formation of water from  $\text{H}_2$  and  $\text{O}_2$  run by itself, or the reverse reaction?
19. Ethyne ( $\text{C}_2\text{H}_2$ ) is formed from calcium carbide and water. It has a much higher chemical potential than either original substances. How is this possible? (Reaction is calcium carbide + water  $\rightarrow$  calcium hydroxide + ethyne,  $\text{CaC}_2 + 2\text{H}_2\text{O} \rightarrow \text{Ca}(\text{OH})_2 + \text{C}_2\text{H}_2$ .)
20. At what temperature do the liquid and the solid forms of water have the same chemical potential?
21. Is table salt more soluble at  $45^\circ\text{C}$  than at  $25^\circ\text{C}$ ?
22. What is the change of entropy when dissolving 1 mole of table salt?
23. How much entropy is produced in dissolving 1 mole of table salt? Is the process exothermal or endothermal?
24. When citric acid is dissolved in water, the temperature of the solution sinks noticeably. What does this mean for the relation between change of entropy of the substance and the amount of entropy produced?
25. By how much does the melting point of ice change if we increase the pressure to 10 bar?
26. By how much does the pressure of water change if we dissolve 1.0 mole of table salt in 1.0 liter of water?
27. Show that the chemical potential of water changes by  $-RT\chi$  when dissolving a substance.  $\chi$  is the mole fraction of the solute in the solution.
28. Sea water has a concentration of salt of about 35 parts per thousand. How many moles of salt is this per liter of water?
29. At what temperature does sea water with a concentration of 35 parts per thousand freeze?
30. Prove that the change of boiling point of a solvent is given by  $RT\chi/\Delta s_{\text{vap}}$ .  $\Delta s_{\text{vap}}$  is the molar entropy of vaporization of the solvent.
31. What is the difference upon the change of the boiling point if we dissolve 1 mole of sugar or 1 mole of salt?
32. How much entropy is produced in producing 1 kg of water by burning hydrogen and oxygen? (Have the reaction take place at standard conditions.)
33. What is the equilibrium constant of the reaction of hydrogen and oxygen forming water? What does this mean for the concentration of hydrogen gas in the resulting water vapor?

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34. Methane and oxygen gas burn to form carbon dioxide and water. For the following balances assume that initial substances and products are all at their standard states. Values of chemical potentials and molar entropies are found in tables.
- What is the chemical reaction formula?
  - Determine the entropy produced per mole of methane.
  - Determine the change of entropy in going from the initial substances to the products (per mole of methane).
  - How much entropy is emitted to or absorbed from the environment (per mole of methane)?
  - How much energy is transferred together with the entropy exchanged?
  - How much energy is this per kilogram of methane? Compare this result to the higher heating value in Table 4.1.
35. The chemical potential of substances decreases with increasing temperature (Table 4.3, and Equ. 4.10, 4.11). Does this mean that the chemical driving force of a reaction decreases with increasing temperature?
36. By how much does the chemical potential of air change if its pressure is raised by a factor of 10?
37. By how much does the chemical potential of dissolved salt change if it is diluted by a factor of 10?
38. Determine the molar mass of dry air.
39. How many moles of air are in  $1 \text{ m}^3$  at standard conditions? ( $25^\circ\text{C}$ , 1.013 bar)
40. What is the chemical driving force of the rusting of iron?
41. Estimate the boiling temperature of alcohol (ethanol).
42. Consider fructose and dextrose (glucose), both in watery solution.
- At standard conditions, which one could convert into which one of the two? (Actually, the reaction is inhibited. We need to change fructose to glucose enzymatically in our liver.)
  - What is the equilibrium constant of the reaction?
  - What is the ratio of the concentrations of the two in a watery solution?
43. Consider the conversion of  $\alpha$ -glucose into  $\beta$ -glucose (see Fig. 4.4).
- Determine the equilibrium constant.
  - What is the difference of the chemical potentials at standard conditions?
44. In biology, the equilibrium ratio of a substance in two different environments is called the partition coefficient. Determine the partition coefficient for toluene in water and air.
45. How much energy is released when  $1 \text{ m}^3$  of hydrogen gas (at standard condi-

- tions) is burned? Is that how much energy is exchanged with the environment?
46. Use the chemical potentials and the linear approximations to estimate the boiling temperature of toluene. How well does it agree with the listed value?
  47. If we had a 1 M solution of CO<sub>2</sub> in water, and a pure CO<sub>2</sub> atmosphere above it, would CO<sub>2</sub> go into the air or into the water?
  48. The partial pressure of CO<sub>2</sub> in our atmosphere is about 35 Pa.
    - a. What is the concentration of CO<sub>2</sub> in the atmosphere?
    - b. How much CO<sub>2</sub> should be dissolved in water exposed to the atmosphere (such as a lake or the ocean)?
    - c. How does the solubility of CO<sub>2</sub> change if the temperature of the air (and the water) is raised by 5 K?
  49. Solubility of O<sub>2</sub> in water is about 3.25 cm<sup>3</sup>/100cm<sup>3</sup> at 25°C.
    - a. Determine the difference of the chemical potentials of O<sub>2</sub> as a gas and in aqueous solution.
    - b. At 0°C, the solubility is about 5 cm<sup>3</sup>/100cm<sup>3</sup>. Determine the temperature coefficient of the chemical potential of aqueous oxygen.
  50. The solubility of table salt (NaCl) in water is about 37 g per 100 g of water. Determine the ratio of this value and the standard concentration. (Neglect the change of volume incurred by dissolving salt in water.)
  51. Determine the solubility of NaCl in water at a temperature of 25°C.
  52. A current of electric charge of 10 A is passed through melted copper sulphate for one hour. How much copper will be deposited at the cathode?
  53. The voltage measured for an electrochemical cell (fuel cell) converting hydrogen and oxygen to water has a maximum value of 1.23 V at standard conditions. Determine the chemical potential of water.
  54. a. Determine the half-cell reactions for a lead-acid battery. b. Determine the voltage of a lead-acid battery at standard conditions.

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## HINTS, SOLUTIONS

1. Chapter 4, p.51, p.54
2. Chapter 4, p.59, Table 4.2
3. Chapter 4, p.52
4. Chapter 4, p.54
5. Chapter 4, p.51-26, in particular, p.55
6. Chapter 4, p.56
7. Chapter 4, p.57
8. [http://sky.bsd.uchicago.edu/lcy\\_ref/synap/resting.html](http://sky.bsd.uchicago.edu/lcy_ref/synap/resting.html)
- 9.
10. Remember that NaCl gets dissociated
11. Equ. 4.4
12. Equ. 4.3
13. Equ. 4.9
14. Table 4.2
15. No.  $[\Delta\mu]$  is 326.6 kG (G. Job, Table for  $\mu$ ).
16. Yes.  $[\Delta\mu]$  is  $-9.11$  kG
17. Table 4.2
18. Table 4.2
19. G. Job, Table for  $\mu$
20. Equ. 4.10 and Table 4.3
21. Yes.  $[\Delta\mu]$  goes from  $-9.12$  kG to  $-9.99$  kG (Table 4.2 and Table 4.3)
22.  $\Delta s = +43.34$  J/(K·mole) (Table 4.3)
23.  $s_{\text{prod}} = 30.60$  J/(K·mole) (Table 4.2 and Section 4.4.4). The process is endothermal.
24. See Exercises 22 and 23.
25. Equ. 10 and 12, Table 4.2 and 4.3. (The temperature coefficients of the substances should be changed to a value for  $0^{\circ}\text{C}$ . See Fuchs, DoH, Chapter 4, Example 18).
26. Equ. 4.16
27. Equ. 4.16, 4.14, 4.7
28. 2 moles/liter

29. About  $-1.9^{\circ}\text{C}$
30. Equ. 4.16, 4.14, 4.10
31. The effect of salt is twice as large (dissociation of NaCl).
32. Table 4.2, Equ. 4.24
33. Equ. 4.21. (See also Fuchs, DoH, Chapter 4, Example 16.)
34. a.  $\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$ . b.  $2744.5 \text{ J}/(\text{K}\cdot\text{mole})$ . c.  $-242.64 \text{ J}/(\text{K}\cdot\text{mole})$ . d.  $-2987 \text{ J}/(\text{K}\cdot\text{mole})$  (emitted). e.  $-890 \text{ kJ}/\text{mole}$ . f.  $-55.6 \text{ MJ}/\text{kg}$ . (Values are found in G. Job: Chemisches Potential.)
35. No. For the driving force it matters, how all the chemical potentials of all participants in the reaction change.
36. Equ. 4.15
37. Equ. 4.17
38. About  $0.029 \text{ kg}/\text{mole}$
39. Equ. 4.16
40. Use the Internet to determine the reaction equation. G. Job: Chemical Potentials.
41. Equ. 4.10, G. Job: Chemical Potentials
42. a. G. Job: Chemical Potentials. b. Equ. 4.21. c. Equ. 4.22.
43. a. Equ. 4.22. b. Equ. 4.21.
44. Fig. 4.3, Equ. 4.29
45. Table 4.2, Equ. 4.16, Equ. 4.24. No.
46. Tables 4.2, 4.3, Equ. 4.10. Result:  $142^{\circ}\text{C}$ , listed:  $110.6^{\circ}\text{C}$ .
47. Table 4.2
48. Tables 4.2, 4.3. a. Equ. 4.16. b. Equ. 4.15, 4.17, Equ. 4.20. c. Equ. 4.10. Fuchs, DoH, Chapter 4, Example 21.
49. Table 4.2, 4.3, Equ. 4.20, 4.17, 4.10.
50. Equ. 4.5, 4.9
51. Table 4.2, Equ. 4.20, 4.17.
52. Fuchs DoH, Chapter 4, Example 1.
53. Fuchs DoH, Chapter 4, Example 9.
54. a. <http://www.av8n.com/physics/lead-acid.htm>. b. Fuchs DoH, Chapter 4, Example 10.