Problem Set 7.2
Fluid and Electrolyte Balance and Acid—Base Balance

1. The following were measured in a 24-hour urine collection:

Urine volume	=	1.2 L
Titratable acid	=	33 mmol L^{-1}
Urine $[HCO_3^-]$	=	4 mmol L^{-1}
Urine $[NH_4^+]$	=	90 mmol L^{-1}

Calculate the amount of HCO_3^- gained or lost from the body through renal mechanisms.

2. A patient with a history of bronchopulmonary disease was admitted to the hospital and the following laboratory data were obtained for arterial blood:

Na	143 mM
K	4.8 mM
pH	7.34
P_{O_2}	47 mmHg
Cl	78 mM
HCO_3^-	38 mM
P_{CO_2}	73 mmHg
Hemoglobin	17.1 g%

Classify the acid–base status of this patient in terms of acidosis/alkalosis, respiratory or metabolic, compensated or uncompensated.

3. The concept of **free water clearance** is sometimes used to assess the kidneys' ability to handle a water load. The free water clearance is *defined* as follows:

$$C_{H_2O} = Q_U - \left[\frac{(Q_U U_{osmol})}{P_{osmol}}\right]$$

Here C_{H_2O} is the free water clearance, Q_U is the flow of urine, in mL min^{-1}, U_{osmol} is the total concentration of materials in the urine, in $osmol^{-1}$ L^{-1}, and P_{osmol} is the osmolarity of plasma. The term in brackets is the clearance of osmolarity, and it represents the volume of plasma that contains the total osmolarity that is excreted. Calculate the free water clearance for the following conditions:

Condition	**Q_U (mL min^{-1})**	**U_{osmol} (mOsM)**	**P_{osmol} (mOsM)**	**C_{H_2O}**
A	0.8	900	300	
B	1.5	300	300	
C	6.0	70	300	

What does a negative free water clearance mean?

4. The acid NH_4^+ dissociates to its conjugate base (NH_3) and H^+, with a dissociation constant $K_D = 6.3 \times 10^{-10}$ M:

$$NH_4^+ \rightleftharpoons NH_3 + H^+$$

Suppose that NH_4^+ is originally present in two compartments separated by a cellular membrane. The membrane is freely permeable to NH_3, but it is impermeable to NH_4^+. The pH on one side is 9.0, and on the other side it is 7.4. Let T_1 and T_2 be the total concentration of $NH_3 + NH_4^+$ on sides 1 and 2, respectively. Calculate T_1/T_2.

5. The acid HA dissociates at physiological pH into its conjugate base (A^-) and H^+ with a dissociation constant K_D:

$$HA \rightleftharpoons A^- + H^+$$

Suppose that HA is originally present in two compartments separated by a membrane. The membrane is freely permeable to HA, but it is impermeable to A^-. The pH on one side of the membrane is pH_1, and on the other side it is pH_2. Derive an expression for the ratio of the total concentration of material ($[HA] + [A^-]$) on the two sides of the membrane in terms of its K_D and the two pHs.

6. Given the data below on the handling of urea by the kidneys of an adult man at varying rates of urine flow, calculate (a) the GFR (in mL min^{-1}), (b) filtered load of urea (in mmol min^{-1}), (c) excreted urea (in mmol min^{-1} and as % of filtered load), and (d) reabsorbed urea (in mmol min^{-1} and as % of filtered load).

Data	**Q_U, Urine Flow (mL min^{-1})**	**U_{inulin} (mg mL^{-1})**	**U_{urea} (mM)**	**P_{inulin} (mg mL^{-1})**	**P_{urea} (mM)**
A	0.4	144	300	0.5	5
B	0.8	75	263	0.5	5
C	1.0	60	240	0.5	5
D	3.1	20	119	0.5	5
E	10.2	5.8	37	0.5	5

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7. Suppose that the rate of reabsorption from the aggregate tubules can be described by the equation:

$$T = \frac{T_m P_x}{(k_t + P_x)}$$

where P_x is the plasma concentration of substance x, T is the rate of reabsorption, T_m is the maximum transport rate, and k_t is the transport constant, equal to the concentration at half-maximal transport.
   A. Write an equation for the rate of substance x excreted, $Q_U U_x$, as a function of plasma concentration, P_x, assuming that $\Theta_x = 1.0$.
   B. Show that for these assumptions the excretion rate can be zero only when $P_x = 0$.
   C. What interpretation would you give for negative values of the rate of excretion as predicted by the equation in part A?
   D. For values of $\text{GFR} = 120\ \text{mL min}^{-1}$, $R_m = 312.5\ \text{mg mL}^{-1}$, $k_t = 132\ \text{mg min}^{-1}$, plot the rate of excretion versus P_x. Can you identify a renal threshold? Is splay evident?
8. A 60-year-old woman was admitted to the hospital with a diagnosis of pneumonia. She had been on a thiazide diuretic for 6 months previously for treatment of heart failure. Her lab results were as follows:

K^+	2.1 mM
pH	7.64
P_{CO_2}	32 mmHg
P_{O_2}	75 mmHg
HCO_3^-	33 mM

   Classify her acid–base disturbance. *Hint*: Graph it out on the pH–HCO_3^- diagram.
9. Creatinine production in a particular well-muscled individual is 3 g day^{-1}. His plasma creatinine is 1.5 mg dL^{-1}. Estimate the GFR.
10. The renal blood flow into the kidney is 1200 L min^{-1} with a concentration of total solutes of 296 mOsM. Urinary output is 0.5 mL min^{-1} of 1150 mOsM.
   A. What is the flow and osmolarity of the renal venous blood?
   B. According to Figure 7.5.10, the fluid coming out of the vasa recta is hyperosmotic. How does the final renal venous blood become hyposmotic during antidiuresis?
11. During diuresis, inflow into the distal tubule is about 18 mL min^{-1} at 100 mOsM. Outflow from the distal tubule into the collecting duct is about 6 mL min^{-1} and 300 mOsM.
   A. How much fluid (per unit time) is reabsorbed in the distal tubule?
   B. How much solute (in osmoles per unit time) is reabsorbed in the distal tubule?
   C. Where does this fluid and solutes go?
   D. What does this do to the osmolarity of the venous blood that drains the kidney?
12. Using the figures for volume flow given in Figure 7.5.10, and given that plasma inulin is maintained at 10 mg dL^{-1}, indicate the inulin concentration during diuresis.
   A. At the end of the proximal tubule
   B. At the end of the thick ascending limb/early distal tubule
   C. At the late distal tubule
   D. In the final urine
13. Mannitol diuresis is generally provided by injecting a 10% or 20% solution of mannitol at a dose of 0.5–1.5 g kg^{-1} body weight. A patient weighs 180 lbs and we wish to give a dose of 1.0 g kg^{-1}. Plasma creatinine is 1.1 mg%. The ECF is 15 L in this person. The formula weight of mannitol is 182.17 g mol^{-1}.
   A. How much 20% mannitol should we infuse?
   B. Urine flow before administration of mannitol was 1.0 mL min^{-1} with a creatine concentration of 1.09 mg mL^{-1}. What is the GFR?
   C. Suppose that the person is at maximum antidiuresis, with a urine flow of 0.5 mL min^{-1} prior to mannitol injection, with a urine osmolarity of 1200 mOsM. What is the increase in urinary flow rate caused by mannitol infusion?
   D. How does mannitol increase urine flow?
14. A woman is admitted into the hospital with the following findings:

   pH = 7.25
   P_{CO_2} = 30 mmHg
   Plasma [creatinine] = 4 mg%

   A. Classify her acid–base status.
   B. Would you expect her renal acid secretion to be increased, normal, or decreased, and why?
15. An athlete weighs 80 kg. Total body water is 60% of his body mass and ECF is 20% of body mass. His plasma osmolarity before working out is 295 mOsM. He works out and loses 3 L of fluids containing 100 mOsM solutes: assume it is all NaCl. Assume ECF [Na] = 140 mM.
   A. What is his plasma osmolarity after the workout?
   B. How much urine at 1200 mOsM must he excrete to bring his plasma osmolarity back to normal?
16. A person has the following blood values:

   pH = 7.50
   P_{CO_2} = 50 mmHg
   [HCO_3^-] = 38.7 mmHg

   A. Classify this person's acid–base status.
   B. Is renal acid secretion increased or decreased in this person?
   C. Is the urine acidic or alkalotic? Why?

17. The following test results were obtained in a person who was infused with inulin to achieve a constant plasma concentration:

Urine volume in 4 hours	=	480 mL
Urine [inulin]	=	30 mg%
Plasma [inulin]	=	0.5 mg%
Urine [glucose]	=	200 mg%
Plasma [glucose]	=	400 mg%

A. What is the GFR?
B. What is the filtered load of glucose in mg min^{-1}?
C. What is the rate of glucose reabsorption?
D. Do you think this rate of glucose reabsorption is about equal to the T_m for glucose? Why or why not?

18. The following blood values were measured in a person:

$[HCO_3^-] = 38$ mM
pH = 7.15

A. Calculate the P_{aCO_2} using the Henderson–Hasselbalch equation.
B. Describe the persons acid–base condition.
C. What is the respiratory compensation for this condition?
D. What is the renal compensation for this condition?
E. What happens to ammonium excretion?
F. What happens to titratable acid excretion?