

# Problem Set 7.2

## Fluid and Electrolyte Balance and Acid–Base Balance

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

Urine volume	= 1.2 L
Titrateable acid	= 33 mmol L <sup>-1</sup>
Urine [HCO <sub>3</sub> <sup>-</sup> ]	= 4 mmol L <sup>-1</sup>
Urine [NH <sub>4</sub> <sup>+</sup> ]	= 90 mmol L <sup>-1</sup>

Calculate the amount of HCO<sub>3</sub><sup>-</sup> gained or lost from the body through renal mechanisms.

- 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 <sub>O<sub>2</sub></sub>	47 mmHg
Cl	78 mM
HCO <sub>3</sub> <sup>-</sup>	38 mM
P <sub>CO<sub>2</sub></sub>	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.

- 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:

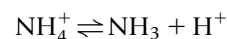
$$C_{H_2O} = Q_U - \left[ \frac{(Q_U U_{osmol})}{P_{osmol}} \right]$$

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

Condition	$Q_U$ (mL min <sup>-1</sup> )	$U_{osmol}$ (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?

- The acid NH<sub>4</sub><sup>+</sup> dissociates to its conjugate base (NH<sub>3</sub>) and H<sup>+</sup>, with a dissociation constant  $K_D = 6.3 \times 10^{-10}$  M:



Suppose that NH<sub>4</sub><sup>+</sup> is originally present in two compartments separated by a cellular membrane. The membrane is freely permeable to NH<sub>3</sub>, but it is impermeable to NH<sub>4</sub><sup>+</sup>. 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<sub>3</sub> + NH<sub>4</sub><sup>+</sup> on sides 1 and 2, respectively. Calculate  $T_1/T_2$ .

- The acid HA dissociates at physiological pH into its conjugate base (A<sup>-</sup>) and H<sup>+</sup> with a dissociation constant  $K_D$ :



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<sup>-</sup>. The pH on one side of the membrane is pH<sub>1</sub>, and on the other side it is pH<sub>2</sub>. Derive an expression for the ratio of the total concentration of material ([HA] + [A<sup>-</sup>]) on the two sides of the membrane in terms of its  $K_D$  and the two pHs.

- 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<sup>-1</sup>), (b) filtered load of urea (in mmol min<sup>-1</sup>), (c) excreted urea (in mmol min<sup>-1</sup> and as % of filtered load), and (d) reabsorbed urea (in mmol min<sup>-1</sup> and as % of filtered load).

Data	$Q_U$ , Urine Flow (mL min <sup>-1</sup> )	$U_{inulin}$ (mg mL <sup>-1</sup> )	$U_{urea}$ (mM)	$P_{inulin}$ (mg mL <sup>-1</sup> )	$P_{urea}$ (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

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.

- Write an equation for the rate of substance  $x$  excreted,  $Q_U U_x$ , as a function of plasma concentration,  $P_x$ , assuming that  $\Theta_x = 1.0$ .
  - Show that for these assumptions the excretion rate can be zero only when  $P_x = 0$ .
  - What interpretation would you give for negative values of the rate of excretion as predicted by the equation in part A?
  - 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:

$\text{K}^+$	2.1 mM
pH	7.64
$P_{\text{CO}_2}$	32 mmHg
$P_{\text{O}_2}$	75 mmHg
$\text{HCO}_3^-$	33 mM

Classify her acid–base disturbance. *Hint:* Graph it out on the  $\text{pH}-\text{HCO}_3^-$  diagram.

- Creatinine production in a particular well-muscled individual is  $3 \text{ g day}^{-1}$ . His plasma creatinine is  $1.5 \text{ mg dL}^{-1}$ . Estimate the GFR.
- The renal blood flow into the kidney is  $1200 \text{ L min}^{-1}$  with a concentration of total solutes of  $296 \text{ mOsm}$ . Urinary output is  $0.5 \text{ mL min}^{-1}$  of  $1150 \text{ mOsm}$ .
  - What is the flow and osmolarity of the renal venous blood?
  - 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?
- During diuresis, inflow into the distal tubule is about  $18 \text{ mL min}^{-1}$  at  $100 \text{ mOsm}$ . Outflow from the distal tubule into the collecting duct is about  $6 \text{ mL min}^{-1}$  and  $300 \text{ mOsm}$ .
  - How much fluid (per unit time) is reabsorbed in the distal tubule?
  - How much solute (in osmoles per unit time) is reabsorbed in the distal tubule?
  - Where does this fluid and solutes go?
  - 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  $10 \text{ mg dL}^{-1}$ , indicate the inulin concentration during diuresis.

- At the end of the proximal tubule
- At the end of the thick ascending limb/early distal tubule
- At the late distal tubule
- In the final urine

13. Mannitol diuresis is generally provided by injecting a 10% or 20% solution of mannitol at a dose of  $0.5\text{--}1.5 \text{ g kg}^{-1}$  body weight. A patient weighs 180 lbs and we wish to give a dose of  $1.0 \text{ g kg}^{-1}$ . Plasma creatinine is  $1.1 \text{ mg\%}$ . The ECF is 15 L in this person. The formula weight of mannitol is  $182.17 \text{ g mol}^{-1}$ .

- How much 20% mannitol should we infuse?
- Urine flow before administration of mannitol was  $1.0 \text{ mL min}^{-1}$  with a creatine concentration of  $1.09 \text{ mg mL}^{-1}$ . What is the GFR?
- Suppose that the person is at maximum antidiuresis, with a urine flow of  $0.5 \text{ mL min}^{-1}$  prior to mannitol injection, with a urine osmolarity of  $1200 \text{ mOsm}$ . What is the increase in urinary flow rate caused by mannitol infusion?
- How does mannitol increase urine flow?

14. A woman is admitted into the hospital with the following findings:

pH = 7.25  
 $P_{\text{CO}_2} = 30 \text{ mmHg}$   
 Plasma [creatinine] =  $4 \text{ mg\%}$

- Classify her acid–base status.
- 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  $295 \text{ mOsm}$ . He works out and loses 3 L of fluids containing  $100 \text{ mOsm}$  solutes: assume it is all NaCl. Assume  $\text{ECF} [\text{Na}] = 140 \text{ mM}$ .

- What is his plasma osmolarity after the workout?
- How much urine at  $1200 \text{ mOsm}$  must he excrete to bring his plasma osmolarity back to normal?

16. A person has the following blood values:

pH = 7.50  
 $P_{\text{CO}_2} = 50 \text{ mmHg}$   
 $[\text{HCO}_3^-] = 38.7 \text{ mmHg}$

- Classify this person's acid–base status.
- Is renal acid secretion increased or decreased in this person?
- 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%

- What is the GFR?
- What is the filtered load of glucose in  $\text{mg min}^{-1}$ ?
- What is the rate of glucose reabsorption?
- 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:

$$[\text{HCO}_3^-] = 38 \text{ mM}$$
$$\text{pH} = 7.15$$

- Calculate the  $P_{\text{aCO}_2}$  using the Henderson–Hasselbalch equation.
- Describe the person's acid–base condition.
- What is the respiratory compensation for this condition?
- What is the renal compensation for this condition?
- What happens to ammonium excretion?
- What happens to titratable acid excretion?