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BioE 110
Biomedical Physiology for Engineers
Final Exam
Spring 2013

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SID	

WRITE YOUR NAME AND SID ON THE TOP OF EACH PAGE!

If you need extra space, use the back of the sheet.
No computers or electronic communications devices allowed.

SCORE (for instructors only)

Question 1:		/30
Question 2:		/25
Question 3:		/35
Question 4:		/20
Question 5:		/25
Question 6:		/30
Question 7:		/20
Question 8:		/25
Question 9:		/30
TOTAL		/240

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Potentially useful constants and conversions

$R = 8.31\ J\ K^{-1}\ mol^{-1}$

$R = 0.0821\ L\ atm\ K^{-1}\ mol^{-1}$

$F = 96\ 485\ C\ mol^{-1}$

$N_A = 6.022 \times 10^{23}\ mol^{-1}$

$k_B = 1.38 \times 10^{-23}\ J\ K^{-1}$

1 atm = 101.325 kPa

1 atm = 760 mmHg

1 cP = 1 mPa s

$1000\ L = 1\ m^3$

ln x = 2.303 log x

Elementary charge (e) = 1.6×10^{-19} C

K = 863 mmHg (alveolar ventilation equation).

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1. Consider a rigid cylindrical capsule of diameter d, wall thickness w, and length L enclosing a solution of sucrose (molecular radius ~0.5 nm) at concentration C (mM).

A. If this capsule is placed in a sucrose-free solution, derive a general equation that describes the flow rate of sucrose across the capsule (J) in terms of d, L, and C, at a given viscosity μ and temperature T. Assume that the partition coefficient is 1. To the extent possible, consolidate/group together all constants (e.g. π) in your final equation. (10)

B. Suppose the diameter of the capsule is 1 μm, the length is 10 μm, the wall thickness is 0.01 μm, and the internal sucrose concentration is 100 mM. and the temperature is 37C. Calculate the rate at which sucrose leaves the capsule (mmol/hr) at steady state. Neglect any effects of osmotic pressure, and take the viscosity of the solution to be 0.7 mPa-s. (5)

C. Now consider a water-permeable membrane separating two 37C solutions of sucrose (10 mM and 100 mM). If the reflection coefficient of sucrose across the membrane is 0.75, calculate the osmotic pressure across the membrane. (10)

D. Now suppose you add glucose to each solution in (B) such that the glucose concentration on either side of the membrane is 50 mM. If the reflection coefficient of glucose is 0.8, calculate the new osmotic pressure difference. (5)

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2. Suppose you have successfully managed to reprogram fibroblasts into a new type of neuron that is not found physiologically but may have some interesting applications as a biosensor. You culture these cells in a defined medium and measure intracellular and extracellular ion concentrations :

Ion	Intracellular conc. (mEq/L)	Extracellular conc. (mEq/L)
Na+	15	135
K+	125	3
Cl-	8	32
Ca++	10^{-5}	2.2

A. If the resting membrane potential of this cell is -80 mV and the temperature is 37C, derive an equation that relates the conductances of Na+, K+, Cl-, and Ca++ and contains no other parameters or variables. Assume that the conductances are constant (i.e. membrane potential-independent) (15)

B. Suppose you conduct an electrophysiological experiment in which you suddenly change (i.e. as a step function) the membrane potential to the value of the equilibrium potential of Cl-. Sketch a plot of Cl- conductance vs time following imposition of this change in membrane potential. (5)

C. Based on the above information, the concentration of intracellular cations greatly exceeds the concentration of intracellular anions, yet we speak of the intracellular compartment as being electroneutral. What is the likeliest explanation for this discrepancy? (5)

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3. Consider a patient whose left ventricular end diastolic volume is 110 mL, whose left ventricular end systolic volume is 52 mL, and who has a blood pressure of 135/65 mmHg and a heart rate of 65 beats per minute.

A. Calculate the stroke volume, ejection fraction, and cardiac output (mL/min). (10)

B. At steady state, what will be the value of the venous return (mL/min) and why? (5)

C. Suppose a drug causes an increase in the caliber (diameter) of the arterioles that supply the kidneys by a factor of two. By what factor would you expect resistance in these arterioles to decrease, and by what factor would you expect blood flow to the kidneys to increase? (10)

D. If the radius of the left ventricle at the end of systole is 7 cm and the ventricular wall thickness is 1 cm, calculate the tension in the ventricular wall (10).

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4. Consider a patient who has the following pulmonary function test values. Assume all measurements are taken at atmospheric pressure (760 mmHg) and at so-called "body temperature pressure saturated" (BTPS) conditions. Note that the vapor pressure of water at BTPS is 47 mmHg and that the mole fraction of oxygen in inhaled air is ~0.21.

Pulmonary function tests:
Tidal volume (V_T) = 0.5 L
Vital Capacity (VC) = 5.5 L
Inspiratory Capacity (IC) = 3 L
Forced expiratory volume after 1 sec (FEV_1) = 2.0 L
Breathing rate: 12 breaths/min
Fraction of CO2 in expired air (F_{ECO2})= 0.05

Arterial Blood Gas:
pO2 = 90 mmHg
PCO2 = 37 mmHg
pH = 7.41
[HCO3-] = 24 mEq/L

A. Calculate the expiratory reserve volume (ERV). (5)

B. If the respiratory rate were to suddenly fall to 8 breaths/min and CO2 production remained constant, calculate the resulting pCO2. (5)

C. If the suppressed respiration rate were to persist, what would you expect to happen to the level of excreted $H_2PO_4^-$ in the patient's urine and why? (5)

D. Suppose this patient has a peanut allergy, such that when he inhales peanut allergen, he develops airway bronchiolar constriction. Plot the curves you would expect to see (exhaled volume vs. time) before and after exposure to the allergen during a forced expiration. Clearly state how FEV1 and FVC would change after the allergic reaction, and which parameter would change more. (5)

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5. Suppose you are working at a tissue engineering company where you are designing a replacement kidney based on decellularization.

A. Imagine you set up a bioreactor in which you perfuse the kidney with various solutions and measure the volume and composition of urine output. Suppose the input solution contains the following solutes:

Na^+: 135 mEq/L
Cl^-: 110 mEq/L
HCO_3^-: 25 mEq/L
Alanine: 1 mg/dL
Sucrose: 50 mg/dL
Creatinine: 4 mEq/L
Glucose 100 mg/dL
Para-aminohippuric acid: 1 mEq/L

And suppose the urine output (10 ml/hr) contains the following:

Na^+: 5 mEq/L
Cl^-: 20 mEq/L
HCO_3^-: 3 mEq/L
Alanine: trace amounts
Sucrose: 40 mg/dL
Creatinine: 1 mEq/L
Glucose: 10 mg/dL
Para-aminohippuric acid: 1 mEq/L

Calculate the glomerular filtration rate (GFR) and the renal plasma flow (RPF), in mL/min. (10)

B. Alanine appears only in trace amounts in the urine. At what point along the nephron is alanine most likely reabsorbed, and what is the mechanism? (5)

C. Estimate the clearance ratio of sucrose using only the information above and propose a hypothesis for how sucrose is handled in the nephron with respect to filtration, reabsorption, and secretion. (10)

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6. For patients with each of the following lab values, identify (10 pts each):

(1) His/her ongoing primary acid/base disorder, if any (your choices are acidosis, alkalosis, or no acid/base disorder).

If a primary acid/base disorder is present, also determine:

(2) The anion gap (and state whether this is elevated)

(3) Whether the primary acid/base disorder is likely respiratory or metabolic in origin.

Normal ranges are as follows:

P_aCO_2: 35-45 mmHg
P_aO_2: 80-100 mmHg
pH: 7.35-7.45
$[HCO_3^-]$ = 21-28 mEq/L
$[Na^+]$: 135-145 mEq/L
$[Cl^-]$: 98-108 mEq/L
Anion gap: 8-12 mEq/L

A. P_aCO_2= 30 mmHg; P_aO_2= 99 mmHg; pH = 7.22; $[HCO_3^-]$ = 16 mEq/L; $[Na^+]$= 142 mEq/L; $[Cl^-]$ = 106 mEq/L

B. P_aCO_2= 40 mmHg; P_aO_2= 100 mmHg; pH = 7.40; $[HCO_3^-]$ = 25 mEq/L; $[Na^+]$= 138 mEq/L; $[Cl^-]$ = 101 mEq/L

C. P_aCO_2 = 60 mmHg; P_aO_2= 97 mmHg; pH = 7.31; $[HCO_3^-]$ = 33 mEq/L; $[Na^+]$= 145 mEq/L; $[Cl^-]$ = 104 mEq/L

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7. Answer the following true/false questions and provide 1-2 sentences to justify your answer. (5 each)

A. True or false: The ratio of ventilation to perfusion is lowest at the lung bases because the hydrostatic pressure of blood varies with height.

B. True or false: A puncture wound to the left side of the chest will cause the right lung to collapse.

C. True or false: Moderate constriction of the efferent arteriole will increase glomerular filtration rate while decreasing renal plasma flow.

D. True or false: Urea recycling contributes to the corticopapillary osmotic gradient by preferentially secreting more urea in the interstitial space of the cortex than in the papilla.

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8. Respond to the following questions/statements in 3 sentences or less. (5 each)

A. What would happen to the kidney's ability to secrete H+ in the absence of urinary buffers and why?

B. Bicarbonate rather than phosphate is the key buffering system in plasma, despite the fact that the pKa of phosphate is much closer to 7.4 than is the pKa of bicarbonate. Provide two explanations for this fact.

C. One might expect that inhibitors of glutamine metabolism could lead to alkalinization of the urine. Why?

D. Protracted vomiting associated with severe gastroenteritis ("stomach flu") can simultaneously produce both a metabolic acidosis AND a metabolic alkalosis. How?

E. What is the Single effect and how (and where specifically) does it operate?

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9. You are scientist who has discovered an alien species *Alienus berkelius* on Mars with very similar acid/base physiology to humans, except that the **dominant** buffering system in this species is $HPO_4^{2-}/H_2PO_4^-$. The aliens also breathe in O_2 and exhale CO_2 as part of their metabolism, and phosphoric acid is still considered a fixed acid in the species.

A. If the normal concentrations of HPO_4^{-2} and $H_2PO_4^-$ are 33 mEq/L and 24 mEq/L respectively, what is the normal pH of the alien blood? (Hint: Assume that the pK_a of the $HPO_4^{-2}/H_2PO_4^-$ buffer is 6.8 for this blood system.) (10)

B. The scientists want to compare the acid/base physiology of *A. berkelius* and humans. To do this, they add 300 mEq of H^+ ions to one individual from each species (after IRB approval, of course!) and measure their new blood pH. Using the information provided below, **predict the new blood pH of each species**. (10)

Alien ECF volume: 42 L
Alien buffer concentrations and pKa: use values from part A
Human ECF volume: 42 L
pKa of the bicarbonate buffering system in blood: 6.1
Human normal $[HCO_3^-]$: 24 mEq/L
Human normal arterial P_{aCO2}: 40 mmHg
Human normal alveolar P_{ACO2}: 40 mmHg (assume this remains the same throughout the experiment)

Assumptions:

- For simplicity, assume that the alien species uses only phosphoric acid buffering, and that humans use only carbonic acid buffering.
- Assume the added H+ ions do not contribute any volume.
- Assume CO_2 concentrations equilibrate perfectly across the alveolar membrane.

C. A certain subset of the *A. berkelius* population has classic symptoms of type 1 diabetes: polyuria (frequent urination), polyphagia (increased hunger), and, interestingly, metabolic acidosis. You decide to compare your alien cases of metabolic acidosis with the human version, diabetic ketoacidosis, and note the following difference: "Humans with severe diabetic ketoacidosis often display Kussmaul breathing, a deep labored breathing pattern, while *A. Berkelius* patients display little or no labored breathing." Explain (max. 3 sentences) why this may be the case. (5)

D. Eventually, you notice that some of these *A. berkelius* patients are experiencing chronic kidney disease (CKD) as a result of their type 1 diabetes-like disease. Since there are not enough *A. Berkelius* donor kidneys, you cannot recommend a kidney transplant. Based on your studies with humans, make one dietary recommendation you can make to help your *A. Berkelium* patients manage their CKD? Why would you make this recommendation? Please keep your answer between 3-4 sentences. (5)

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