Biomedical Engineering Department
Cairo University

Time Allowed: Two Hours
Open-Book/Open-Notes

Medical Equipment I Term Exam

January 1, 2008

Solve as Much as You Can – Maximum Grade: 75 Points

Q1. Answer the following questions by marking the best answer among the choices given (1.5 points each):

1. A solute that can pass through a semipermeable membrane is called …
    a. Permeant (*)
    b. Semipermeant
    c. Impermeant

2. Osmotic pressure occurs when …
    a. There is a slow approach to steady state across a membrane
    b. A species on one side of a membrane cannot cross to the other side (*)
    c. There are membrane pores that follow a tortuous path

3. Headaches in renal dialysis occur due to …
    a. Low urea permeability of capillary-brain membrane (*)
    b. High water permeability of capillary-brain membranes
    c. Slow removal of urea from blood by hemodialysis equipment

4. Increasing urine volume by injecting a medium-weight molecule is called …
    a. Edema
    b. Osmotic fragility
    c. Osmotic diuresis (*)

5. Countercurrent transport is preferred in hemodialysis because …
    a. It maintains a concentration difference along the whole path (*)
    b. It maintains a very high concentration difference that decays along the path
    c. It generates an additional diffusion energy

6. The kinetic energy of heavy particles in Brownian motion is … that of light particles at very low temperatures.
    a. Higher than
    b. Lower than
    c. Same as (*)

7. Artificial kidney filter membrane is … to urea.
    a. Permeable (*)
    b. Semipermeable
    c. Impermeable

8. Cellular membrane of nerve cells is a … membrane.
    a. Permeable
    b. Semipermeable (*)
    c. Impermeable

9. The voltage across the cell membrane depends on …
    a. Concentration of all solutes on both sides of the membrane
    b. Concentration of any of the solutes on both sides of the membrane
    c. Concentration of only permeant solutes on both sides of the membrane **(*)**

10. Electrotonus spread means …
    a. Voltage dependent conductivity of membrane
    b. Current flux density dependent conductivity of membrane
    c. Membrane model that obeys Ohm's law (*)

11. Passive spread is a valid model for …
    a. Action potential
    b. Small membrane voltage changes (*)
    c. Large but slow membrane voltage changes

12. Conduction speed in myelinated nerve fibers is … that of unmyelinated.
    a. Slower than
    b. Faster than (*)
    c. Same as

13. The conduction speed in myelinated fibers depends on …
    a. Square root of fiber radius
    b. Fiber radius **(*)**
    c. Square of fiber radius

14. The normal vector to a plane defined by two vectors can be calculated using …
    a. Dot product of the two vectors
    b. Vector product of the two vectors (*)
    c. Direct product of the two vectors

15. In heat flow type of system energy change, …
    a. Work is done on the system to hold the conservation of energy
    b. Energy levels shift to higher energy with same population
    c. Average population in energy levels changes (*)

16. Kirchhoff's first law is derived from …
    a. Conservation of energy
    b. Conservation of mass
    c. Conservation of charge (*)

17. If the half life of ^{99m}Tc is 6 hours, then the length of time required for it to reach 1/8 is … hours.
    a. 18 (*)
    b. $6\sqrt{3}$
    c. $6 \log_e(3)$

18. In artificial kidney, if the time constant of the solute exchange is 1 hour for a fluid volume of 36 liters assuming a typical cellophane membrane of ωRT of 5×10^{-6} m/s then the membrane surface area is …
    a. 1.5 m^2
    b. 2 m^2 (*)
    c. 2.5 m^2

19. A biological system *y(x)* represented by the differential equation $\frac{dy}{dx} = 0.543y$ has a … form.
    a. Exponential decay
    b. Exponential growth (*)
    c. Linear

20. Fick's second law of diffusion combines Fick's first law and …
    a. Solvent drag
    b. Continuity equation (*)
    c. Viscosity

21. The buoyant force on aquatic animals in water is …
    a. Very small
    b. Approximately the same as their weight (*)
    c. Much larger than their weight

22. Macrostates of a biological system with many particles include ….
    a. Temperature (*)
    b. Particle velocity
    c. Particle energy

23. A particular disease in rabbits is linked to a defective X chromosome and appears only when all X and Y chromosomes present are defective. If the probability of a single X chromosome to be defective is 0.01 and that for Y chromosome is 0.001, The percentage of population carrying this disease if each rabbit has 2 X and 1 Y chromosomes is …
    a. 0.00001
    b. 0.0000001 (*)
    c. 0.0000000001

24. After 4 times the diffusion time, the diffusion distance will be …
    a. half
    b. Double (*)
    c. Four times

25. Isolation of an infectious compartment can be practically done using …
    a. Semipermeable membrane
    b. Adiabatic walls
    c. Laminar flow (*)

26. At equilibrium, probability of all microstates is …
    a. Equal (*)
    b. Zero
    c. 1

27. Changes in electric field within a dielectric material due to polarization electric field are accounted for by replacing ε_o by … in electric field equations.
    a. $\kappa\,\varepsilon_o$ (*)
    b. $\chi\,\varepsilon_o$
    c. $\varepsilon o/(1+\chi)$

28. Consider a charged hollow spherical shell of radius *r* with a charge of +*q*, then the electric field inside the shell is …
    a. $+q/2\pi\varepsilon_o r^2$
    b. Zero (*)
    c. $-q/2\pi\varepsilon_o r^2$

29. Action potential reaches a depolarized voltage of +50 mV due to …
    a. Opening sodium channels in the membrane (*)
    b. Opening chlorine channels in the membrane
    c. Closing potassium channels in the membrane

30. For a permeable membrane with initial concentration difference between its sides, the steady state will involve …
    a. Zero solute concentration on the two sides
    b. Nernst potential difference corresponding to the concentration difference
    c. Zero net solute transfer between the two sides (*)

31. Boltzmann factor determines the relative probability of two states having different …
    a. Kinetic energy
    b. Potential energy **(*)**
    c. Total energy = kinetic energy + potential energy (*) **(*) (Both are correct – same K.E.)**

32. The electrostatic field inside a human's body standing 100 m from a high voltage power line carrying 100 kV at 50 Hz is …
    a. Zero (*)
    b. 1 kV/m
    c. 0.01 kV/m

33. The Nernst potential for nerve cell membrane is calculated based on … on both its sides.
    a. Sodium and potassium concentrations
    b. Chlorine concentration
    c. All of the above (*) **(*)**

34. Pressure variation in the atmosphere can be explained by …
    a. Boltzmann's constant
    b. Boltmann's factor (*)
    c. Density of states factor

35. Edema can generally be explained by the presence of
    a. abnormal osmotic pressure (*) **(*)**
    b. abnormal hydrostatic pressure **(*) (Both are correct)**
    c. higher particle kinetic energy due to fever

Q2. Mark the following statement as either True (T) or False (F) (1 point each):

1. Nerve cell membrane changes its membrane potential by adjusting its permeability to different ions (T)
2. Kinetic energy of particles in Brownian motion is lower at higher temperatures. (F)
3. Conduction speed of nerve fibers is proportional to the characteristic length divided by the characteristic time (T)
4. In Brownian motion, particle velocity is constant and given by $\sqrt{3k_BT/m}$. (F)
5. Mean free path is much larger than particle size in liquids. (F)
6. In diffusion across a permeable membrane, net flux of solues stops at equilibrium. (T)
7. Drag forces are determined by the bulk flow in liquids. (T)
8. The entropy of a system is equal to the root mean square of entropies of its subsystems. (F)
9. Systems that are not at equilibrium tend to change until it reaches one of its steady state microstates. (F)
10. In Nernst equation, the voltage across the membrane is the result of the different concentrations of solutes across the membrane. (T)
11. Nernst potential depends on temperature (T).
12. If there is translational force equilibrium on an object, then the object must be at rest. (F)
13. Conservation of energy leads to Kirchhoff's second law. (T)
14. Variation of concentration with time is taken into account in Fick's first law of diffusion. (F)
15. Patients may suffer burns near the edges of electrosurgery electrodes due to high current density. (T)
16. Brownian motion involves collision of particles moving in random directions. (T)
17. The macrostate of a system **is determined** by specifying all external parameters. (F) **(F)**
18. First law of thermodynamics is based on conservation of mass. (F)
19. The derivative of entropy with respect to energy is equal to the inverse of temperature. (T)
20. Mean free path is in the order of particle size in gases. (F) **(F)**

Q3. [5 points] The potential energy of hydrogen nuclei in a magnetic field is equal to (γ m B h/2π) where γ is the gyromagnetic ratio (42.6 MHz/T), h is the Planck's constant given by 6.626×10^{-34} and B is the magnetic field, and m is the spin number that takes the values of either + ½ or – ½ . Calculate the probability of spins with m= ½ relative to that with m= – ½ at magnetic field B= 1.5 T and temperature of 300 °K. Assume a unity density of states factor.

Solution: substitute in Boltzmann factor = (density factor=1) x exp(-(U1-U2)/k_BT) where U= (γ m B h/2π) and m=+1/2 or –1/2

Q4. [5 points] Consider the problem of gas exchange between blood and air in alveoli. If the average radius for alveoli is 100 µm and that for capillaries is 4µm and given that the diffusion constant in air is 2.1×10^{-5} and in water is 2.4×10^{-9}, calculate time required for oxygen to diffuse from the center of an

alveolus to the center of a blood capillary in contact with it in case of a normal subject. Compare it to that of a patient of lung edema where the alveoli are lined with an additional small layer of fluid of thickness 4μm.

Solution: Same steps as problem 4.18 with only an added layer of the extra fluid **inside** the alveoli

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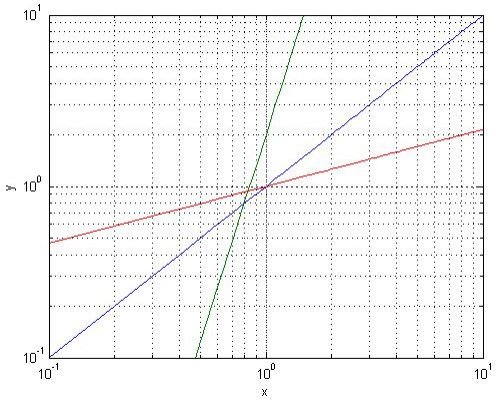
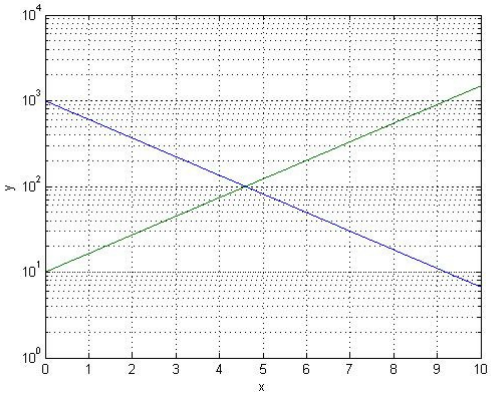
Q5. [5 points] In the solution to the Cable equation assuming electrotonus spread, use a different form for the membrane current per unit area j_m as $j_m = g_m (v-v_r) + j_{leakage}$ where $j_{leakage}$ is assumed constant. Derive the solution for the membrane voltage as a function of space assuming $c_m=0$. [Hint: derive a modified solution to the one given in textbook equation (6.58) under the new assumption].

Solution: Since $j_{leakage}$ is assumed constant, let $j_m = g_m (v-v_r) + j_{leakage} = g_m (v-v_r')$ where $v_r' = + j_{leakage}/g_m$ and you can obtain the solution as the one in the textbook for the required case by substituting v_r by v_r'.

Q6. [5 points] Estimate the functional relationship between x and y for the 5 curves represented in the following plots:





Matlab code that was used to generate the

```
x=0.1:0.1:10;
y= x;                          // first curve on log-log plot
y1= 2*x.^4;                    // second
y2= x.^0.3333;                 // third
figure(1)
loglog(x,y,x,y1,x,y2)
axis([0.1 10 0.1 10])
grid on
xlabel('x')
ylabel('y')

x= 0:0.01:10;
y3= 1000*exp(-0.5*x);          // first curve on semilog plot
y4= 10*exp(0.5*x);             // second
figure(2)
semilogy(t,y3,t,y4);
grid on
xlabel('x')
ylabel('y')
```

(Hint: you need to only estimate the slopes from the curves above and consider the type of plot to know whether it is $y=x^n$ or $y= e^{bx}$)

Best of Luck !