Biomedical Engineering Department
Cairo University

Time Allowed: One Hour
Open-Book/Open-Notes

Medical Equipment I Mid-Term Exam MODEL ANSWER
December 13, 2009

Solve as Much as You Can – Maximum Grade: 100 Points

Part I. Answer the following questions by marking the best answer among the choices given [3 points each]:

1. In artificial kidney using cellophane membrane dialyzer, if ωRT is 5×10^{-6} m/s and body fluid volume is 40 liters, if the surface area of dialyzer is increased from 2 m^2 to 4 m^2, the time constant of the treatment will be …

a) increased by a factor of 2
b) decreased by a factor of 2 (*)
c) decreased by a factor of e^2

2. Headaches in renal dialysis can be reduced by …

a) Reducing treatment time
b) Increasing treatment time (*)
c) Injecting urea in the blood

3. Stirring sugar in water dissolves sugar faster than not stirring due to the process of …

a) Solvent drag (*)
b) Buoyancy forces
c) Diffusion

4. Brownian motion of a particle implies that the root mean square velocity of the particle is …

a) 0
b) $\sqrt{3k_BT/m}$ (*)
c) $\sqrt{3k_BT/2m}$

5. The collision cross-section of an atom of radius a_1 in a medium with atoms of the same kind is …

a) 2 a_1
b) 4 π a_1^2 (*)
c) ½ π a_1^2

6. The assumptions used to derive expression for mean free path in gases were justified by …

a) Verifying that mean free path is more than 1000 times that of the size of the particle (*)
b) Verifying that collisions are indeed frequent
c) Verifying that the same expression is also valid in liquids

7. Fick's second law of diffusion can be driven from …

a) Flux density and time
b) Fick's first law of diffusion and Einstein relationship
c) Fick's first law of diffusion and the conservation of mass (*)

8. Entropy of a system is maximum at …

a) Low temperatures
b) High temperatures
c) Equilibrium (*)

9. The half-life time of the combined decay by three independent paths having the same decay constant of 1 s^{-1} is …

a) 0.693 s
b) 0.231 s (*)
c) 0.347 s

10. The plot of the function f(x)= $x^{3.43}$ appears … on a log-log plot

a) linear (*)
b) piecewise linear
c) nonlinear

11. The plot of the function f(x)= e^{2x} has an intercept of … on a semi-log plot.
a) 0
b) 1 (*)
c) x

12. Buoyancy force on aquatic animals in water is much less than that of terrestrial animals in air because …
a) Density of aquatic animals is close to that of water (*)
b) Density of terrestrial animals is close to that of air
c) Volume of acquatic animals is much smaller than that of terrestrial animals

13. To reach double the diffusion distance, the diffusion time required must be …
a) cut in half
b) increased to double
c) increased by 4 times (*)

14. Heavier particles in Brownian motion have kinetic energies that is … lighter particles of smaller size.
a) higher than
b) lower than
c) the same as (*)

15. Fick's first law of diffusion is derived from …
a) empirical observations (*)
b) conservation of mass
c) conservation of energy

16. In a disease that causes an increase in both the arterial and venous pressures by 10 mmHg combined with an increase in blood proteins leading to a +10 mmHg osmotic pressure increase results in …
a) No edema (*)
b) Minor edema
c) Massive edema

17. Compressibility if important for such applications as …
a) ultrasound imaging (*)
b) using a cane
c) lung mechanics

18. The First law of thermodynamics is equivalent to …
a) Conservation of mass
b) Conservation of energy (*)
c) Thermal equilibrium

19. Isolation of an infectious compartment can be done using an isolation system based on …
a) Laminar flow (*)
b) Solvent drag
c) semipermeable membranes

20. A particular disease in an animal is linked to a defective X chromosome and appears only when all X chromosomes present are defective. If the probability of a single X chromosome to be defective is 0.01, The percentage of population carrying this disease if each animal has 2 X chromosomes is …
a) 0.0001 (*)
b) 0.00001
c) 0.000001

21. Time gain compensation is used to compensate for … of tissues.
a) Acoustic impedance
b) Speed of ultrasound
c) Attenuation (*)

22. Oximetry relies on … measurement of the degree of oxygen saturation
a) mechanical b) colorimetric (*) c) electronic

23. Capnography is the measurement of …
a) end-tidal CO2 (*)
b) Noninvasive blood pressure
c) decrease in Oxygen in blood

24. To minimize cross-contamination in hemodialysis, … is used for the blood.
a) Degassing chamber
b) Air bubble detector
c) Peristaltic pump (*)

25. The selection of components for hemodialysis is difficult because of the … of the dialysate.
a) Conductivity
b) volume
c) Corrosive nature (*)

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

26. Osmotic pressure is associated with impermeable membranes. (F)
27. The rate of increase of a quantity in an exponential growth process is proportional to that quantity. (T)
28. It is not possible to use classical mechanics to describe systems of many particles. (T)
29. Formula to estimate mean free path in liquids is the same as that of gases. (F)
30. Diffusion happens as a result of Brownian motion of particles in a fluid. (T)
31. When the probability of one of the available microstate is 1, the system is at equilibrium. (F)
32. Mean free path is of the same order as particle size in gases. (F)
33. The entropy of a system is equal to the root mean square of entropies of its subsystems. (T)
34. Diffusion is the main mechanism for oxygen transport to capillaries through alveoli. (T)
35. Ultrasound imaging map acoustic impedance of tissues. (T)
36. Ultrasound imaging can be used to image the brain. (F)
37. Modular patient monitors are preferred because of their lower cost for same options. (F)
38. It is possible to estimate chemical composition of a tissue noninvasively using medical imaging. (T)
39. The future of medical imaging includes more qualitative imaging methods. (F)
40. Hemodialysis systems must be able to detect the presence of a series of microbubbles and total more than 1.5 mL/30 s. (T)
41. Hemodialysis relies on diffusion to remove unwanted water from the body. (F)
42. A system that has adiabatic walls does not interact with surroundings (T)
43. Entropy change is related to mechanical work (F)
44. Work is calculated as the area under the pressure-volume curve (T)
45. Countercurrent transport is better because it removes solutes at an exponential rate with distance (F)

46. **[5 points]** Compute an approximate figure for the number of cells in a cat.

Just like the first part of Chapter 1. Assume a cell size, assume cat shape and dimensions, then divide to get the number of cells.

47. **[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 2×10^{-5} and in water is 2×10^{-9} m^2s^{-1}, 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 patient with lung edema. Assume the lung edema to cause an additional small layer of fluid of thickness 1 μm between the capillary and the lung alveolus in contact with it. Assume also that the diffusion constants in blood and extracellular fluid are the same as that of water.
Solution: Same steps as problem 4.18 with only an added layer of the extra fluid between the alveolus surface and the capillary

48. **[5 points]** The potential energy of hydrogen nuclei in a magnetic field is equal to ($\gamma\, m\, B\, h/2\pi$) 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= 3 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

49. **[5 points]** Consider three systems A, A', and A" that are in thermal contact with each other but are isolated from the rest of the universe. Each of the 3 systems has two particles. The energy levels each particle may have u, 2u, 3u, etc. Let the total energy be U*= 10u. Compute the number of microstates for the whole system A*.

Solution:

System A		System A`		System A``		System A*
U	Ω	U’	Ω`	U``	Ω``	Ω*
2u	1	2u	1	6u	5	5
2u	1	3u	2	5u	4	8
2u	1	4u	3	4u	3	9
2u	1	5u	4	3u	2	8
2u	1	6u	5	2u	1	5
3u	2	2u	1	5u	4	8
3u	2	3u	2	4u	3	12
3u	2	4u	3	3u	2	12
3u	2	5u	4	2u	1	8
4u	3	2u	1	4u	3	9
4u	3	3u	2	3u	2	12
4u	3	4u	3	2u	1	9
5u	4	2u	1	3u	2	8
5u	4	3u	2	2u	1	8
6u	5	2u	1	2u	1	5
						$\Omega^*_{tot}=126$

Best of Luck!