L-4/T-2/BME

Date : ~~17/04/2024~~ 18/05/2024

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4/T-2 B. Sc. Engineering Examinations 2021-2022

Sub : **BME 407** (Quantitative Physiology)

Full Marks : 210 Time : 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

Question 1 is **MANDATORY**. Answer any **TWO** of the remaining **THREE** questions.

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1 (a) The cooperativity of ligand – receptor interaction can be graphically represented by a Hill plot. Derive the equation for a Hill plot and explain it's used. **15**

(b) Explain how alveoli size is stabilized by surfactant with proper illustration. Suppose, the diameter of an alveolus is 0.3 mm. The surface tension is about 70 dyne cm^{-1}. Surfactant lowers the surface tension by 42 dyne cm^{-1}. What would the pressure be in the alveolus? **15**

(c) Suppose a person is infused with 0.9% normal saline (NaCl) at a constant rate of 150 mL/hour. During this session, the person loses 2.5 L of fluid containing 1% (NaCl) through urination. Show the changes in the ECF, ICF, and plasma osmotic pressure after 24 hours of infusion using a Darrow-Yannet diagram. Assume the initial TBW = 42 L, ECF = 14 L and the plasma osmotic pressure = 300 mOsM. **15**

2 (a) Suppose the ratio of concentrations TF/P (tubular fluid/plasma) for inulin = 4.0. Now, derive the relation for fraction of water reabsorption and determine the value. **10**

(a) Derive an expression for glomerular capillary hydrostatic pressure and explain the mechanisms responsible for autoregulation of renal blood flow and GFR with proper illustration? **20**

3 (a) Assume, the glomerular hydrostatic pressure $P_{GC} = (60 - 10z)$ mmHg, the glomerular oncotic pressure, $\pi_{GC} = 25 + 10(1-e^{-50z})$ mmHg and the Bowman's capsule hydrostatic pressure $P_{BS} = 20$ mmHg. Assume the distance from the afferent arteriole to the efferent arteriole is 0.2 cm. Now, plot the Starling forces as a function of distance from the afferent arteriole to the efferent arteriole. **15**

(b) A man's leg was crushed by a car accident. His physician believed that the patient suffered kidney damage from myoglobin blocking glomerular **15**

Contd P/2

pores. The tests showed the following results:

Plasma creatinine: 25 mg/100mL plasma

Volume of urine collected in 24 hours: 1 L

Urine creatinine concentration: 28 mg/mL urine

Based on the above data, determine the GFR and comment whether the patient has sustained kidney damage or not.

4 (a) Why the clearance of inulin is equal to the GFR? Explain with proper illustration. **10**

(b) Explain mathematically why physiologic dead space is always greater than anatomic dead space. **10**

(c) Derive the relation between the half-life of a hormone and its Metabolic clearance rate (MCR). **10**

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SECTION – B

Question No. 5 is **MANDATORY**. Answer any **TWO** of the remaining **THREE** questions.

5. (a) A. V. Hill derived an empirical equation to describe the force-velocity relationship of muscle. **(20)**
He wrote:

$$(T + \alpha)(v + \beta) = (T_o + \alpha)\beta$$

Here, T is the tension or force, v is the velocity, and T_o is the force at which v = 0, the isometric tension.

(i) Express Hill's equation can be written in a normalized form.
(ii) Derive an expression for the maximum velocity in terms of T_o, Ω and β.
(iii)Derive an expression of power in terms of v, T_o, Ω and β.

(b) Consider the scenario where an individual is injected with n moles of an indicator. Develop and explain the mathematical model governing the change in indicator concentration over time in the bloodstream. Furthermore, it demonstrates how this concentration can serve as a valuable metric for determining his cardiac output. **(15)**

(c) An elderly woman has a hemoglobin concentration of 10 g dL^{-1}. Her O_2 dissociation curve is normal (when expressed as S_{O2}). Assume that her resting O_2 consumption (Q_{O2}) is within normal limits, 225 mL min^{-1}, and that Q_a, the cardiac output, is 4.5 L min^{-1}; Pa_{O2} = 95 mm Hg is normal. **(10)**

(i) What is the total oxygen content (in mL dL^{-1}) of her arterial blood?
(ii) What is the total oxygen content of her mixed venous blood?

6. (a) A person has a total Hb concentration of 14 g%, a hematocrit of 40% and an RBC count of 5 x 10^6 cells mm^{-3} **(10)**

(i) What is the MCV?
(ii) What is the MCHC?
(iii) Calculate the Hb content of an average RBC.
(iv) Calculate the number of molecules of Hb in an average RBC.
(v) If the density of Hb is 1.34 g cm^{-3}, what volume of the average RBC is occupied by Hb?
(vi) What fraction of the cell volume is occupied by Hb?

(b) Illustrate the neuronal activity, specifically the action potential firing rate, of both on-center and off-center ganglion cells in response to each light stimulus pattern depicted in the Figure for Question 6(b), providing rationale for each response. **(15)**

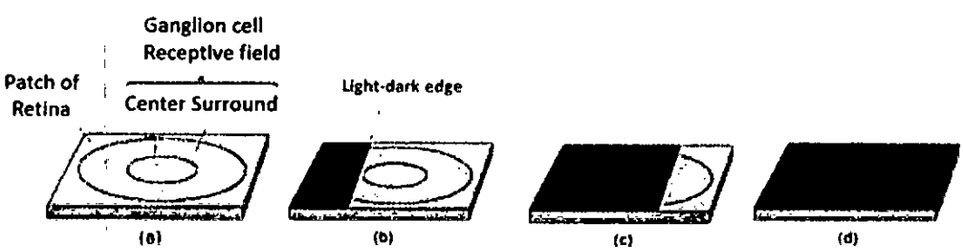

Figure: Question 6(b)

(c) "**Alveolar ventilation can alter the pH level of blood**"- explain the statement **(5)**

7. (a) The end-diastolic volume of a heart is 140 mL. Assume that it is a sphere. At the end of diastole, the intraventricular pressure is 7 mm Hg. The wall thickness at this time is 1.1 cm. At the end of the isovolumetric contraction, the intraventricular **(15)**

pressure is 80 mm Hg.

(i) What is the wall tension at end-diastole?
(ii) What is the wall tension at the end of the isovolumetric contraction?
(iii) At the end of systole, the intraventricular volume is 65 mL, the pressure is 100 mm Hg, and its wall thickness is 1.65 cm. What is the wall tension at this time?
(iv) The wall stress is related to tension by F = T/w, where F is the wall stress, T is the tension, and w is the wall thickness. Calculate the wall stress for (i), (ii), and (iii)

(b) Figure for Question 7(b) demonstrates the concentration profile of the solute within the capillary under seven distinct conditions while maintaining a constant interstitial fluid concentration. Now, derive the mathematical expression that governs this profile. Also, explain the reasons for the variation in profile patterns across different conditions. **(15)**

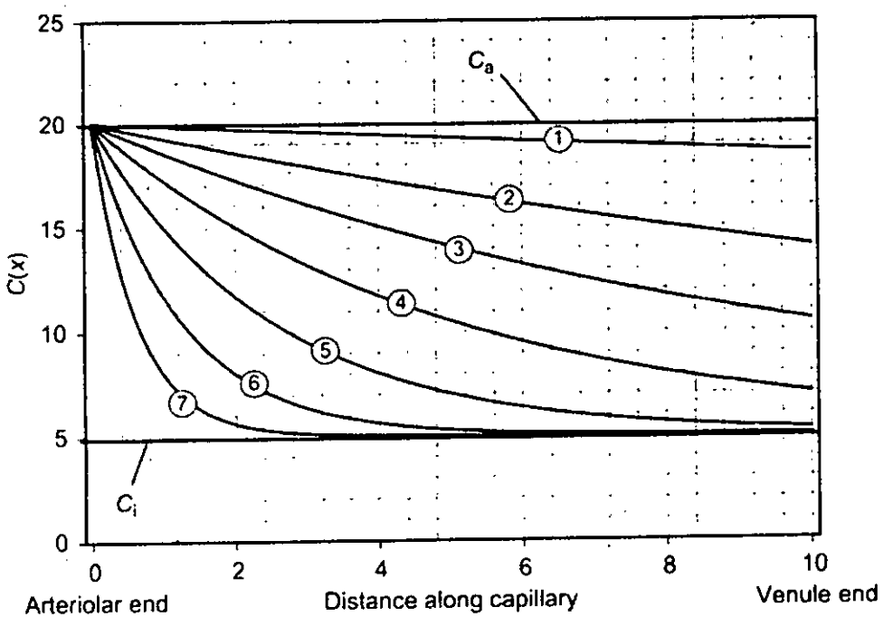

Figure: Question 7(b)

8. (a) The arterial glucose concentration is usually between 80-120 mg%. Assume it is 90 mg% (this is mg per dL (0.1 L) of blood). **(20)**

(i) The blood flow to a muscle at rest is 0.025 mL min^{-1} g^{-1}. Its venous glucose concentration in the blood draining the muscle is 80 mg%. What is the glucose consumption rate in mol $min^{-1}g^{-1}$? The molecular weight of glucose is 180.2 g mol^{-1}.
(ii) The interstitial fluid glucose concentration is about 75 mg %. What is the solute extraction at rest?
(iii) What is the diffusing capacity equal to the surface area times the permeability?
(iv) Suppose there are 250 capillaries open per mm^2 cross section of the muscle, and that each capillary is 500 μm long. Assume each capillary has a radius of 4 μm. If the density of muscle is 1.08 g cm^3, how much area of capillaries is available for glucose exchange?
(v) Using the results to (iii) and (iv), calculate the permeability of the capillaries to glucose.

(b) The Figure for Question 8(b) shows the range of audible intensities versus frequency. The human ear is most sensitive to frequencies near 3000 Hz. The audible range extends from about 20 to 20000 Hz. **(10)**

(i) How do you interpret the contour curves?

(ii) In 1976, during The WHO's record-setting concert, the sound intensity level(I_2) at a distance of 46 meters from the speakers reached a staggering 120 dB. What is the ratio of the intensity I_2 to the intensity I_1 of a jackhammer, which operates at a sound intensity level of 96 dB?

(iii) If a sound measures 30 dB and varies in frequency from 20 Hz to an upper limit, what frequencies within this range will the average human ear perceive ?

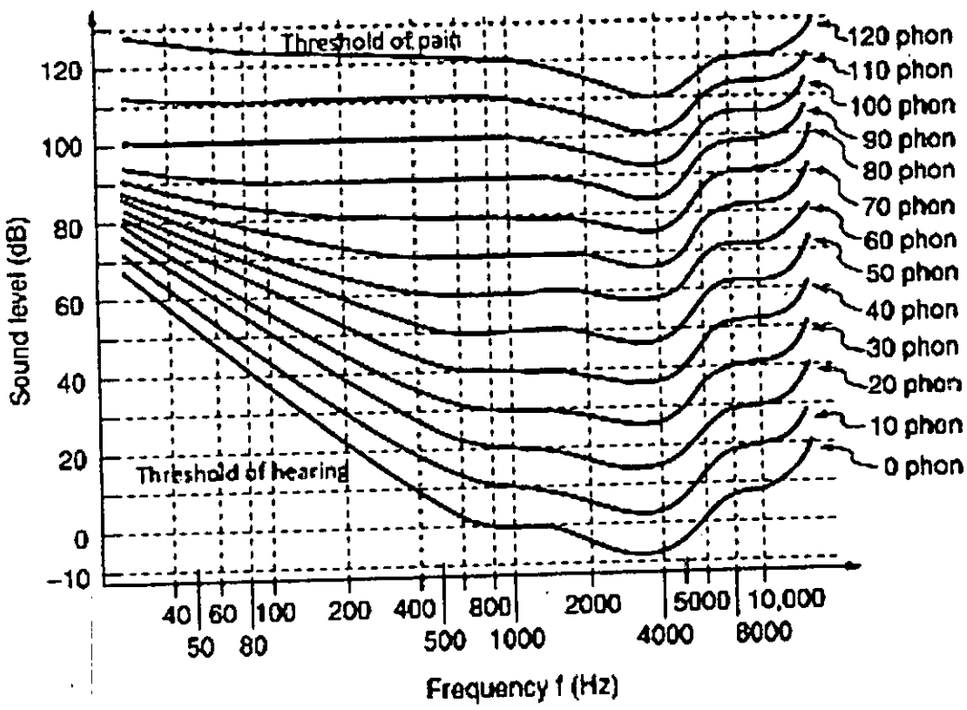

Figure: Question 8(b)

L-4/T-2/BME Date: 22/04/2024

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4/T-2 B.Sc. Engineering Examinations 2021-2022

Sub: **BME 431** (Telemedicine Systems)

Full Marks: 210 Time: 3 Hours

The figures in the margin indicate full marks.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

Question No. 1 is **MANDATORY**. Answer any **TWO** of the remaining **THREE** questions.

1. (a) In Bangladesh, the patient to doctor ratio is 3900:1 whereas the World Health Organization (WHO) recommends the ratio to be 1000:1. Most of the expert physicians are based in the urban areas. Explain if telemedicine and other advanced information technology-based solutions may or may not be able to address this problem in the near-term future. State your assumptions and provide your arguments for your answer. **(12)**

(b) Explain the importance of tele-surgery and its applications in the context of Bangladesh. What are the main challenges in implementing this technology in our country and how can we overcome them? **(12)**

(c) Briefly describe LAN and WAN and their application in telemedicine. **(9)**

(d) What are the advantages and disadvantages of using conducting cables for biomedical signal transmission? Describe how binary data is transmitted within a conducting cable. Provide illustrations of example transmitted signals for the most commonly used code. **(12)**

2. (a) Using illustrations, describe the physical structure of an optical fiber cable and explain the working mechanism of an optical communication system. What are the key advantages of optical communication compared to copper cables in the context of a healthcare facility? **(15)**

(b) Explain the importance of the cellular network for telemedicine applications. Briefly describe the benefits of 5G cellular networks compared to 4G and explain its implications in telemedicine applications. **(10)**

(c) You are designing a wireless monitoring system for a telemedicine system that will transmit heart sounds that has a bandwidth of 0 – 500 Hz. If the wireless transmission channel signal-to-noise-ratio (SNR) is 10dB, what is the maximum bit-rate that can be achieved in the given scenario to transmit the heart sounds? **(5)**

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3. (a) What are the functions of an EMR? Briefly discuss the relationship among EMR, EHR and PHR, and highlight their differences. **(10)**

(b) What is the importance of standards in medical data exchange? Name a few commonly used medical data standards and mention their applications. **(10)**

(c) With neat diagrams, explain the working mechanism of an RFID system. Mention a few examples of its application in the healthcare setting. **(10)**

4. (a) Explain the advantages and disadvantages of a satellite-based telemedicine system. Provide an example of an effective use of this technology in the context of Bangladesh. **(12)**

(b) An engineer is working on a Clinical Decision Support System (CDSS) for assisting doctors in detecting the severity of pneumonia in pediatric patients using a combination of lung ultrasound, pulse oximetry and a respiratory-rate counter. When the system suggests pneumonia (+ve outcome), it recommends the doctor to admit the patient to the hospital. This system is a machine learning model that has been trained on a large dataset collected in USA with a sensitivity and specificity of 95% and 80%, respectively. **(10)**

(i) For a particular patient in the USA, the system predicted that the patient should not be admitted to the hospital. What should be the course of action, based on the sensitivity and specificity of the CDSS?

(ii) The engineer was tasked to deploy the system in Bangladesh. She evaluated the CDSS on a local dataset and observed that the proportion of "false negative" errors has increased by 3 times, and the proportion of "false positive" errors reduced by half. For the same scenario in (i) what should be done if the patient was in Bangladesh?

(b) A telemedicine system needs to be setup between the radiology department and the emergency ward. The goal is to transmit brain CT images using the DICOM format for intracranial hemorrhage diagnosis for quick feedback. In some cases, the radiologist may need to view the images on their smartphones from within the hospital premises. What kind of data transmission method should be used? Can this be integrated within PACS? Explain your answer. **(8)**

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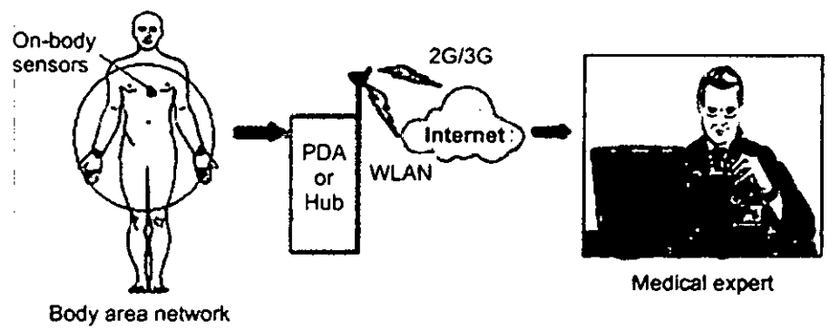
SECTION – B

Question No. 5 is **MANDATORY**. Answer any **TWO** of the remaining **THREE** questions.

5. (a) In 'Telestroke Medicine', healthcare professionals with specialized expertise in stroke management leverage technological infrastructure to deliver care to patients who suffered from stroke at distant locations. Design a telemedicine system where the specialists will work with local emergency healthcare providers to recommend a diagnosis and treatment. You may add additional components to the system. **(20)** ~~(CO-5)~~

(b) Parkinson's Disease (PD) can gradually affect people's lives, attracting tremendous attention. mHealth technologies have been explored in research to detect symptoms of PD. Analyze the potential pros and cons of mHealth applications in PD detection. **(15)** ~~(CO-4)~~

(c) In figure 5(a), an overview of a multi-tier system architecture of WBAN is depicted. Illustrate the intra-BAN and extra-BAN networks, emphasizing their purposes. **(10)** ~~(CO-3)~~



6. (a) Which components do affect the security of a healthcare system? Suggest preventive measures to ensure a secure system. **(20)**

(b) Discuss the features that enable Blockchain Technology to secure Personal Health Records. **(10)**

7. (a) Present a comparative analysis between the technology-based factors and acceptance factors that may act behind the success of a telemedicine system. **(15)**

(b) Explain how adversarial attacks may cause a CDSS to yield erroneous interpretation. **(10)**

(c) Distinguish between different encryption techniques. **(5)**

8. (a) Explain the desired features of motes, illustrating its architecture. **(15)**

(b) "mHealth applications have evolved with new generations of mobile hardware platforms"- elaborate the quote. **(10)**

(c) Briefly describe how tele-pharmacy enhances access to healthcare. **(5)**

L-4/T-2/BME **Date: 24/03/2024**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-4/T-2 B. Sc. Engineering Examinations 2021-2022

Sub: **BME 443** (Magnetic Resonance Imaging)

Full Marks: 210 Time: 3 Hours

The figures in the margin indicate full marks

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Question No. 1 is **MANDATORY.**

Answer any **TWO** of the remaining **THREE** questions.

1	(a)	Describe the spin-wrap pulse sequence technique with an illustration. Do you think it is better than 2-sided projection pulse sequence technique? Explain your answer.	**15**
	(b)	Why is magnetic shielding important in MRI instrumentation? Discuss how passive and active shielding are done.	**15**
	(c)	Briefly explain cardiac MRI, providing an example of its clinical application.	**15**
2	(a)	What are the safety hazards in MRI? Discuss any three kinds of such hazard.	**15**
	(b)	Explain the spin-echo pulse sequence technique for MRI imaging with proper illustration.	**15**
3	(a)	Explain the importance of selecting T_R, T_E and flip angle $\alpha°$ to obtain T1-weighted, T2-weighted and PD-weighted images.	**15**
	(b)	Using the spinning-top analogy derive the equation of Larmor frequency.	**8**
	(c)	What will be the bandwidth ($\Delta\omega$) and central frequency ($\bar{\omega}$) of the RF signal to excite a slice thickness of 1mm (Δz) at -5 cm ($\bar{z}$) from the origin in a 1.5T static magnetic field and $G_Z = \frac{1}{2\pi}$ rad^{-1}cm^{-1} (assume ^{1}H spin).	**7**
4	(a)	Explain aliasing in MRI imaging, and how does it affect the quality of the acquired images and what measures can be taken to mitigate their effects on image quality?	**10**
	(b)	What is Eddy current loss and what are its implications in MR imaging? Discuss different methods to reduce Eddy current loss?	**10**

Continued .... Page 2

(c) Suppose, two ^{1}H isochromats is in different locations in a 1.5T static magnetic field having difference in field strength of 20 ppm. Determine the phase difference between them after 4 ms of a 90° RF excitation? **10**

SECTION – B

There are **FOUR** questions in this section. Question No. 5 is **MANDATORY**.

Answer any **TWO** of the remaining **THREE** questions.

5. (a) Write all the steps of imaging in MRI in brief. **(6)**

(b) Starting from the full Block Equation below show that, during image acquisition, the received signal is the Fourier Transform of the object. Consider 2D image acquisition in x-y plane and a rotating frame of reference. Make any other necessary and accurate assumption for simplifying your derivation. Symbols have their usual meaning. **(17)**

$$\begin{bmatrix} \dot{M}_x \\ \dot{M}_y \\ \dot{M}_z \end{bmatrix} = \begin{bmatrix} -\frac{1}{T_2} & \gamma\vec{G}\cdot\vec{r} & -\gamma B_{1y} \\ -\gamma\vec{G}\cdot\vec{r} & -\frac{1}{T_2} & \gamma B_{1x} \\ \gamma B_{1y} & -\gamma B_{1x} & -\frac{1}{T_1} \end{bmatrix} \begin{bmatrix} M_x \\ M_y \\ M_z - M_0 \end{bmatrix}$$

(c) A MRI scanner is limited to a maximum gradient amplitude $G_{\max}$ = 4 G/cm and a slew-rate of $S_{\max} = \frac{dG(t)}{dt}$ = 15000 G/cm/s. Draw the wave-shape of the gradient by calculating all relevant timing and gradient parameters for a $\int_\tau G(\tau)d\tau = 2\times10^{-3}$ G.s/cm. Consider non-zero finite rise time and fall time. **(10)**

(d) Consider two 2DFT sequences. Sequence 1 acquires 256 samples. However, this sequence averages two acquisition to generate the final image. Sequence 2 collects 512 readout samples but no averaging is performed in this case. Same Gradient magnitude is used in both cases. Which acquisition has better SNR? **(12)**

6. (a) What is small tip-angle approximation. Modify the Block Equation for small-tip angle approximation. **(8)**

(b) Design a small tip-angle TBW 4 pulse with a 10 mT/m gradient for a slice thickness of 1 cm. What are the different ways you can make the slice profile sharper keeping the slice thickness same in this case. Explain with numbers calculated from the current example. The gyromagnetic ratio of proton is 2π×42.58 MHz/T. **(12)**

(c) Make a plot of 'area of the remaining gradient' for G_z in Figure: Question 6 (b). Draw the resultant RF wave-shape (k_z vs overall RF) for the corresponding RF excitation pulse sequence. Make necessary simplifying assumptions to finalize your sketch. **(10)**

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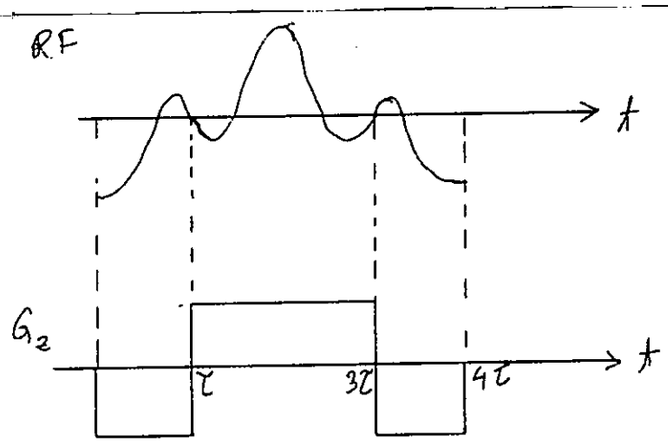

Figure: Question 6 (b)

7. (a) Draw the trajectory of multi-echo-gradient-echo pulse sequence showing corresponding RF, signal, slice selection, phase encode, and frequency encode gradients. **(8)**

(b) Make a plot of Free Induction Decay (FID), its alteration because of intrinsic inhomogeneities, and external gradients with respect to time. Explain why the signal changes this way. **(7)**

(c) Consider the pulse sequence in Figure: Question 7 (c). **(15)**

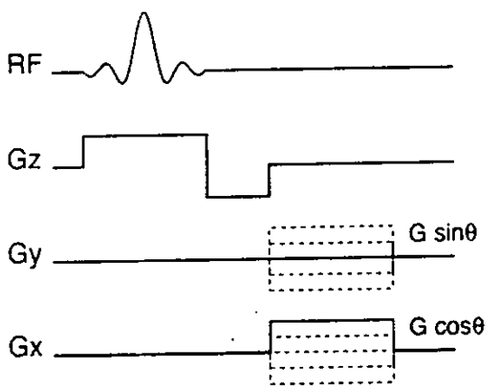

Figure: Question 7 (c)

(i) How does the k-space trajectory look like? Draw it. Consider all values of θ needed to cover the whole k-space.

(ii) How would you reconstruct the image?

(iii)Does it have better performance in terms of aliasing compared to a 'spin-warp' sequence? Why or why not?

(iv)What is the duration of the 'readout' gradient assuming a 1 cm resolution. Maximum value of gradient is 4 G/cm.

(v) Calculate k-space resolution in order to satisfy Nyquist criteria for a 10 cm field of view.

8. (a) Suppose you are instructed to generate a set of FLAIR and STIR images. Calculate the corresponding inversion times (TI) at 1.5T. The longitudinal relaxation time of water and fat at 1.5T are approximately 4 s and 250 ms respectively. **(12)**

continued...page 4

(b)Derive the expression of steady state signal in general-excitation recovery pulse sequence. From that, **(18)**

(i) Derive an expression for the *Ernst* angle.

(ii) Calculate *Ernst* angle for TR = $3T_1/4$.

(iii)Derive an expression for the maximum steady state signal.

(iv)Do you get maximum contrast at the *Ernst* angle?