L-3/T-1/BME **Date: 30/03/2023**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-3/T-1 B. Sc. Engineering Examinations 2021-2022

Sub: **BME 301** (Bioelectricity)

Full Marks: 210 Time: 3 Hours

The figures in the margin indicate full marks

The symbols have their usual meanings.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE** questions.

1. (a) Hyperkalemic periodic paralysis (HPP) is a deadly disease of muscle cells where elevation of potassium level in blood and genetic abnormalities in sodium channels (pores that allow the passage of sodium molecules are blocked) are observed. The rest of the ions and ion channels behave as usual. **(25)**

For studying the cellular level dynamics of HPP, a diseased cell of *Aplysia* is being investigated. The cell is spherical in shape, has a diameter of 9.25 μm and its membrane capacitance is 1.37 μF/cm^2. Assume that the cell membrane obeys the parallel-conductance model, but due to the diseased condition, Na^+ ions are not permeable to the membrane and as such, they should be excluded from all the calculations. The ionic concentrations, conductance and mobility for a typical cell are given below:

Table for Q. 1(a)

Ionic Concentrations (recorded at 10°C)		
Ions	Intracellular (mM)	Extracellular (mM)
K^+	285	12
Na^+	63	394
Ca^{2+}	0.008	2.4
Cl^-	51	476

$g_K = 0.243$ mS/cm^2 $u_K = 7.62 \times 10^{-4}$ cm^{2}V^{-1}s^{-1}

$g_{Na} = 0.018$ mS/cm^2 $u_{Na} = 5.19 \times 10^{-4}$ cm^{2}V^{-1}s^{-1}

$g_{Cl} = 0.672$ mS/cm^2 $u_{Cl} = 7.91 \times 10^{-4}$ cm^{2}V^{-1}s^{-1}

$g_{Ca} = 2.405$ pS/cm^2 $u_{Ca} = 6.16 \times 10^{-4}$ cm^{2}V^{-1}s^{-1}

(i) Determine the resting membrane potential.

(ii) What are the corresponding current densities? For each of these ion species, state whether he calculated current corresponds to an influx or efflux of ions.

(iii) Use the information provided to develop the parallel-conductance model for the cell being investigated. Indicate on the model, the value of all the parameters including Nernst potential, resting membrane potential and current directions with correct Nernst source polarities.

Contd P/2

BME 301

Contd.... for Q. No. 1(a)

(iv) Evaluate the membrane time constant (τ).

(v) Assume all the Ca^{2+} ions remain within a transition region (thickness 0.4 mm) around the membrane and a linear change occurs in concentration across the region. Using the electrically defined equation of diffusive flux, determine what fraction of the total Ca^{2+} current density is due to diffusion.

(vi) 17.5 pA current is injected into the intracellular space of the cell using a specific electrode setup, calculate the new steady-state transmembrane potential. Comment on whether the electrode is put into cathodic or anodic configuration.

(b) For a single small electrode placed in the bounded extracellular space just outside a cylindrical fiber, with a pair of electrodes lying extracellularly at $\pm\infty$ to remove the current, find the space constant and the value of transmembrane potential at a distanc of 12.7 mm from the origin. Assume, the fiber is at rest, infinitely long and the location of the proximal electrode identifies the coordinate origin (x = 0). The fiber structure satisfies the assumptions of the core conductor model and its characteristics is given below.

Table for Q. 1(b)

Membrane Radius	43 microns
Membrane width	500 microns (of segment)
Intracellular resistivity	120 Ωcm
Extracellular resistivity	30 Ωcm
Membrane capacitance	1.5 μF/cm^2
Membrane resistivity	1260 Ωcm^2 (at rest)
Total applied current	500 uA

2. (a) Meredith Parker is a 3rd year BME undergraduate student. She has taken Bioelectricity course this semester. As a part of her coursework, she clamped a Na^+ channel by the patch clamp technique (inside-out configuration) and showed the results to her professor. For ease of calculation, she took Na^+ concentration in a symmetric manner, i.e., the Na^+ concentration in the recording pipette and the surrounding bath was the same (64 mM). Te recording bandwidth was 1.5 kHz, membrane was clamped at 12 mV and the temperature was 26°C. Experimentally, it is already established that the single channel conductance of Na^+ channel is 117 pS, the average membrane channel resistance is 50 GΩ and the average leakage resistance is 10 MΩ. If the obtained signal to noise ratio (SNR) is minimum 32, the experiment is considered to be a fair one and termed as advanced patch clamp method, otherwise it is susceptible to the limitations of traditional patch-clamp technique. **(20)**

Contd P/3

BME 301

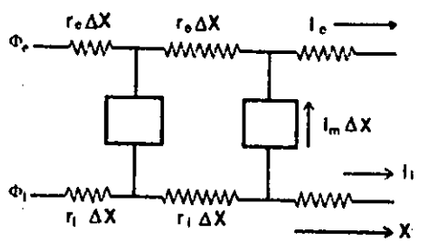
Contd.... for Q. No. 2(a)

Draw the corresponding circuit configuration for the experimental setup and calculate the corresponding SNR. Comment on whether the experiment conducted by Meredith was a fair one. If it was not fair, mention the factors she could have considered to ensure the fair use of patch clamp.

(b) Using the core-conductor model and the corresponding equation provided in Fig. 2(b), mention the necessary assumptions and derive the voltage-divider relationship between: **(15)**

(i) the voltage across the membrane and the intracellular voltage

(ii) the voltage across the membrane and the extracellular voltage.



$$I_i = \frac{-1}{(r_i + r_e)}\left[\frac{\partial V_m}{\partial x} - Ir_e\right]$$

Fig. for Q. 2(b)

3. The table below show the Hodgkin-Huxley membrane and environmental parameters and initial values of state variable respectively. **(35)**

Table for Q. 3(a)

Maximum K^+ conductivity	39	mS/cm²
Maximum Na^+ conductivity	117	mS/cm²
Leakage conductivity	0.25	mS/cm²
Membrane capacitance	1.0	μF/cm²
K^+ Nernst potential	-74.3	mV
Na^+ Nernst potential	+55.2	mV
Leakage Nernst potential	-47.4	mV
Resting potential	-64.5	mV
Stimulus current	0	μA/cm²
Total membrane current for patch if no stimulus	0	μA/cm²

Table for Q. 3(a)

V_m	-13.78	mV	Transmembrane potential
n	0.515	—	gating probability n
m	0.951	—	gating probability m
h	0.605	—	gating probability h

Contd P/4

BME 301

Contd.... for Q. No. 1(a)

The expressions for the rate constants:

$$\alpha_n = \frac{0.01(10 - v_m)}{\left[\exp\left(\frac{10 - v_m}{10}\right) - 1\right]} \qquad \alpha_m = \frac{0.1(25 - v_m)}{\exp[0.1(25 - v_m))] - 1} \qquad \beta_m = 4\exp\left(-\frac{v_m}{18}\right)$$

$$\beta_n = 0.125\exp\left(\frac{-v_m}{80}\right) \qquad \alpha_h = 0.07\exp\left(-\frac{v_m}{20}\right), \qquad \beta_h = \left\{\exp\left[\frac{(30 - v_m)}{10}\right] + 1\right\}^{-1}$$

Assume, $m^0 = m$, $n^0 = n$, $h^0 = h$. Later, Hodgkin and Huxley found that the gating parameters change according to the following curve fitting equations (**t in msec**):

$$n = 0.891 - 0.376e^{-t/1.7}$$

$$m = 0.963\,(1 - e^{-t/0.252})$$

$$h = 0.605e^{-t/0.84}$$

(i) At the beginning of the experiment, determine the expected sodium current through the open channels.

(ii) If there exist around 835 potassium channels per cm^2 of the membrane patch, determine the microscopic current for a K^+ channel.

(iii) At the peak of the action potential, determine the transmembrane potential.

(iv) After 0.015 sec of applying a particular step depolarization, the parameter n reaches to a steady-state value following the fitted curve. What is the expected conductance of K^+ at the steady state?

(v) Evaluate n^1 for a time step of 65 μs.

(vi) Using the given curve fitting equations, calculate the largest value of g_{Na} reached.

(vii) Promethazine is a specific drug that inhibits the movement of both Na^+ and K^+ movement through their respective channels. Roughly sketch a characteristic I vs. t plot if Promethazine was added to the bath five minutes before the experiment and suddenly the membrane patch is clamped to a control voltage of +20 mV via voltage clamp from the initial transmembrane potential. Explain in one or two sentences why your graph would have had such pattern.

4. (a) Professor Roger C. Barr and his research group's primary focus is on recording and understanding neural activity of different animal models like rats, frogs, monkeys etc. They do so by developing novel combinations of electrical stimulation circuitry and

Contd P/5

BME 301

Contd.... for Q. No. 4(a)

genetically encoded sensors. One of his PhD students recently conducted an experiment n a frog's sciatic nerve (a cylindrical structure with radius = 1.6 μm, height = 31 μm) using the set-up shown in Fig. 4(a). Upon applying high-frequency biphasic pulses, he obtained the response curve shown in the right-hand side and concluded that the action potential attributes have similarity with the classical study conducted on earthwork's nerve cord as the sciatic nerve is also formed of median and lateral fibers. The investigator then applied a long single pulse. He saw that with a long stimulus, the lowest stimulus current that would produce an action potential had a magnitude of 10 $\mu A/cm^2$, and the transmembrane voltage at the end of that stimulus was 20 mV. Moreover, the membrane was found to have a time constant of 2.4 msec. **(27)**

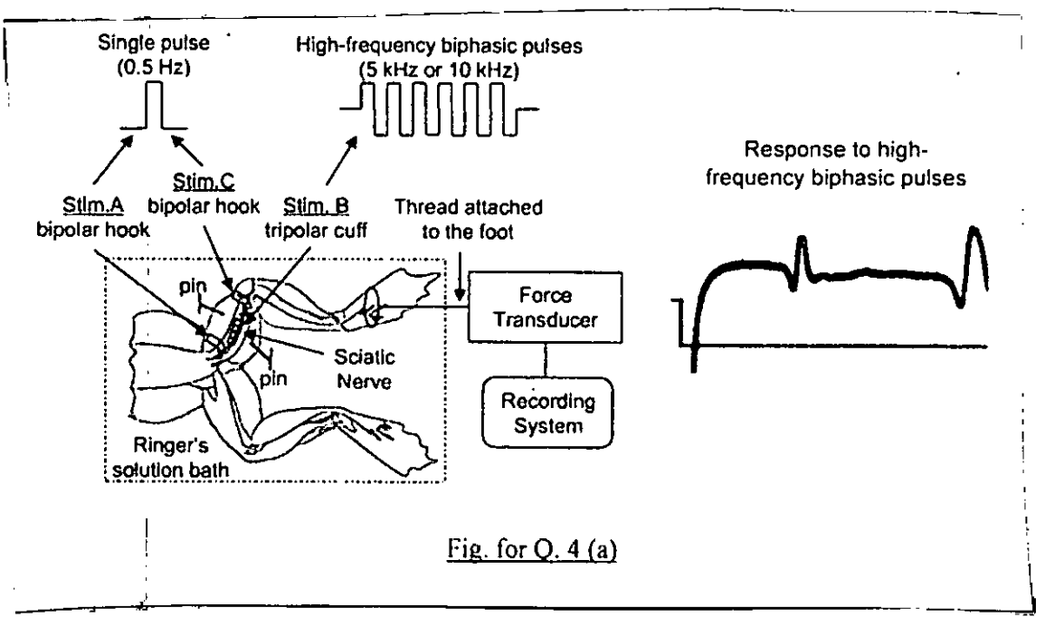


Fig. for Q. 4 (a)

Using shorter stimuli, the investigator set a stimulus duration and then carefully tried stimuli of different current magnitudes until the current was found that produced (at the end of the stimulus) the threshold voltage for an action potential. For stimulus duration of 1 and 3 msec, respectively, the investigator found the magnitude of the current to be 29. 346 $\mu A/cm^2$ and 14.015 $\mu A/cm^2$, respectively.

(i) Briefly explain the noteworthy attributes of action potential with respect to the pattern of the response curve shown in Fig. 4(a). You may assume that the findings of the conducted experiment are analogous to the study conducted on earthwork's nerve cord due to having similar anatomical structure.

(ii) Based on the investigator's experimental data, find the stimulus current needed for a stimulus duration of 0.2 msec? Determine the rheobase and chronaxie. Give numerical answers, in $\mu A/cm^2$.

Contd P/6

BME 301

Contd.... for Q. No. 4(a)

(iii) Another lab member of Barr research group is performing a numerical simulation on COMSOL to replicate the aforementioned experimental results in subthreshold condition. From the research literature, it is well-known that the membrane capacitance for frog sciatic nerve is 1.28 μF/cm while the intracellular membrane resistance is 1500 Ωcm. The taken spatial step size is 0.001 cm and the temporal step size is 0.5 msec. Comment on the computational stability of the obtained solution by calculating the mesh ratio.

(b) If you want to observe the leakage current in a squid giant axon, what other currents do you need to eliminate? How can you do it? **(8)**

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE** questions.

5. (a) The Fig. 5(a) shows the electrode arrangement for an international 10-20 system of measurement of clinical EEG. A clinician wants to measure a single-channel EEG. The clinician is particularly interested in measuring the EEG from the electrode C4. If the voltage measured by any electrode is given by Vx(t), where x is the name f the electrode (e.g., the voltage measured by electrode C3 will be Vc3(t)) what will be the voltage measurement on the single channel based on a **(15)**

(i) bipolar montage?

(ii) referential montage?

(iii) average referential montage?

(iv) laplacian montage?

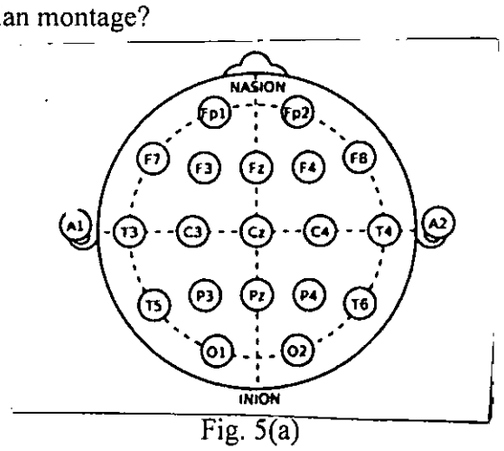


Fig. 5(a)

(b) What is a brain computer interface (BCI)? Discuss the brain responses useful for building a BCI system? **(10)**

(c) A scientists developed a drug call ed SLS. It could easily penetrate the cell membrane of muscle fibers. When the drug was applied to an isolated muscle-nerve preparation in a laboratory, it was found that the muscle did not contact when the nerve was stimulated, even though neurotransmitter was released from the respective nerve cells. Why did this happen? Explain with appropriate diagram. **(10)**

Contd P/7

BME 301

6. (a) For a frog neuromuscular junction, the parameters in electrical model of post-synaptic junction following release of transmitter (shown in Fig. 6(a)) could be $E_r = -90$ mV, $g_r = 5 \times 10^{-6}$S, $E_s = 0.20$ mV, and $g_s = 5 \times 10^{-6}$S. **(10)**

(i) Estimate the amplitude of the end-plate potentials under these conditions.

(ii) Assume the synaptic conductance is contributed by NA^+ and K^+ only. If $E_K = -90$ mV, what is the value of E_{Na}, assuming $g_K = g_{Na}$ in the activated synaptic conductance?

(iii) If $g_{Na}/g_K = 1.29$ and $E_K = -95$ mV and $E_{Na} = 50$ mV, what is the synaptic reversal potential?

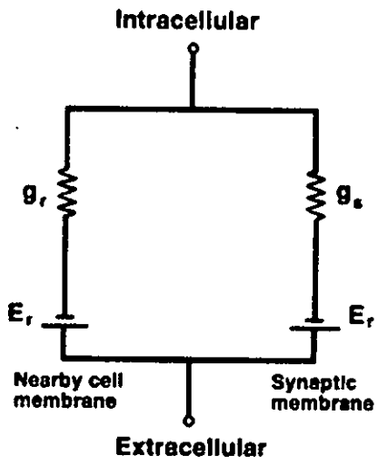


Fig. 6(a)

(b) The required presence of exracellular calcium for relase of transmitter at the neuromuscular junction is demonstrated by the absence of release when Ca is not present in the perfusate (even though postganglionic cells could still be directly depolarized by Ach). More recent experiments also demonstrate that intracellular calcium must bind to intracellular membrane proteins (release sites) for the release to take place. The pre-junctional terminal contains large numbers of Ca channels, and these facilitate Ca entry near release sites. Dodge and Rahamimoff proposed a model in which it is assumed that Ca^{++} and Mg^{++} bind to a presynaptic structure, X, so that **(15)**

$$Ca + X \rightleftharpoons CaX(K1)$$
$$Mg + X \rightleftharpoons MgX(K2)$$

Where K1 and K2 are dissociation constants, and CaX facilitates while MgX inhibits quantal release. Derive the expression for measure of the inhibition of transmitter release.

(c) Answer the following questions in brief- **(10)**

(i) When do we use Deep Brain Stimulation (DBS)? What are the components of a DBS system?

(ii) Which brain region is stimulated during DBS? How does DBS stop seizures?

(iii) What is the difference between targeted muscle reinnervation (TMR) and regenerative peripheral nerve interface (RPNI)?

Contd P/8

BME 301

7. (a) At the peak of the S wave, the cardiac vector now points horizontally from right to left with magnitude 1 mV/m. Find the voltage on lead I, lead II. **(10)**

(b) Proof that the minimum charge that can be delivered through the electrode (Qmin) is 39% lesser than the charge needed to stimulate the nerve at chronaxie (Qth). Also, derive a generalized equation for calculating the %excess charge injected during stimulation. **(15)**

(c) Suppose you are assigned to design a rehabilitation device, and for this particular application, researchers suggest operating in the anodic region. Demonstrate the pulse train you need for this application. Also, mention the electrode material you will select to avoid possible negative consequences. **(10)**

8. (a) Show that the measurement of only leads 1 and aVF is sufficient to reconstruct the full 6 lead frontal electrocardiogram. Write the reconstructed leads II, III, aVR, and aVL in terms of the measured leads I and aVF. Also, explain why is it useful to the cardiologist to have all 6 frontal leads when only 2 of them are sufficient to completely characterize the cardiac vector in the frontal plane. **(15)**

(b) Suppose you are tasked with developing a nerve stimulator that will be used to stimulate radial nerve endings. As a biomedical engineering, you know that the stimulator can be either a constant current or constant voltage type. Explain logically which type of stimulator you should design for your nerve stimulator. **(10)**

(c) Answer the following questions in brief- **(10)**

(i) There is a significant difference between the shape of action potential generated in cardiac contractile cell and autorhythmic cell. What causes this major difference?

(ii) What are the important considerations for selecting the material of an electrode for functional electrical stimulation application?

(iii) Why one raw EMG recording burst cannot be precisely reproduced in exact shape?

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-3/T-1 B. Sc. Engineering Examinations 2021-2022

Sub : **BME 303** (Biomedical Instrumentation and Measurements)

Full Marks : 210 Time : 3 Hours

The figures in the margin indicate full marks.

The symbols have their usual meanings.

USE SEPARATE SCRIPTS FOR EACH SECTION

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE**.

1. (a) With necessary explanations, construct the formula of measuring blood flow using the rapid-injection indicator dilution method. What are the limitations of indicator dilution test and how does the rapid-injection thermodilution method address those limitations? **(15)**

Suppose a patient is undergoing a rapid-injection thermodilution test. The following data are obtained during the test. Using the data, deermine the cardiac output of the patient

$V_i = 10$ ml, $\Delta T_i = -30$K

$\rho_i = 1005$ kg/m^3, $c_i = 4170$ J/(kg.K)

$\rho_b = 1060$ kg/m^3, $c_b = 3640$ J/(kg.K)

$$\int_0^{t_1} \Delta T_b dt = -5.0\ s.K$$

Here, subscripts *i* and *b* correspond to injectant and blood, respectively.

(b) Suppose a Doppler effect flow meter is used to measure blood velocity in a vessel with 5 mm diameter. The Doppler transducer is oriented at $\theta r = \theta s = 45°$ angle with respect to the vessel and transmits a 3 MHz ultrasonic signal from the source. The frequency of ultrasonic waves detected at the receiver is 200 KHz lower. Assuming that the blood velocity is uniform throughout the vessel (ignoring viscosity at the vessel walls), and according for ultrasonic wave propagation at 1,500 m/s in tissue and blood, estimate the volumetric flow rate of blood in the vessel. **(15)**

(c) Explain the basic principles of ultrasonic determination of blood pressure with necessary diagrams. **(5)**

2. (a) Consider the strain transducer shown below in Figure 2(a), with constant supply voltage, V_s = 1 V, and four strain gauges R_1, R_2, R_3 and R_4 all with identical nominal resistance R_{nom} = 100 kΩ, and gauge factor G = 100. The transducer produces a differential output voltage V_0 in response to positive strain ϵ applied to two of the strain gauges R_1 and R_4, and exact opposite negative strain $-\epsilon$ applied to the other two strain gauges R_2 and R_3. **(10)**

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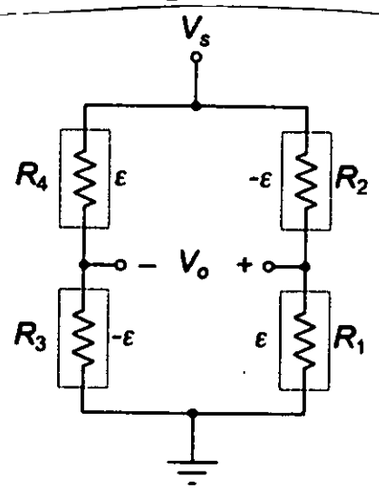
BME 303

Contd ... Q. No. 2(a)



$$R_1 = R_4 = R_{nom}(1 + G\epsilon)$$
$$R_2 = R_3 = R_{nom}(1 - G\epsilon)$$

Figure 2(a)

(i) Determine the output voltage V_0 as a function of strain ϵ. Explain if the response is linear.

(ii) Determine the sensitivity and offset of the strain transducer.

(iii) Now consider that the gauge factors of both R_1 and R_2 are 10% smaller than expected, whereas the gauge factors of both R_3 and R_4 are 10% larger than expected. Evaluate the sensitivity and offset of the strain transducer, and compare with (ii). Explain your observation.

(b) Design an ion-sensitive field effect transistor (ISFET) mentioning the basic structure and fabrication steps. **(15)**

(c) Explain how ultrasound transducers achieve beam focusing and beam steering without any moving parts. **(10)**

3. (a) One of the major problems during dialysis after bleeding out is the introduction of air bubbles as those can lead to embolism, which can result in cardiac arrest depending on where the embolism lodges. A safety check within the machine is to incorporate a bubble detector to warn clinicians or staff if bubbles have formed. As an engineer testing such a detection system, you receive the following signals from the system driven with a signal generator to mechanically stimulate test samples under two conditions: with and without bubbles. In each case the mechanical actuation by the signal generator couples to a membrane with compliance $C_d = 0.001\ Pa^{-1}$ in fluidic contact with the test sample. **(10)**

(i) Assuming that the amplitude of the signal generator voltage is kept the same in both tests with and without bubbles, and the signal generator is tuned to operate at the natural frequency in each case, determine which of the signals A and B of figure 3(a) correspond to the test with or without bubbles respectively. Explain why.

BME 303

Contd ... Q. No. 3(a)

(ii) Determine the compliance of bubbles (C_b) with the parameters from the given plot in figure 3(a). Remember that $\frac{V_{out}}{V_{source}} = \frac{1}{2\zeta}$.

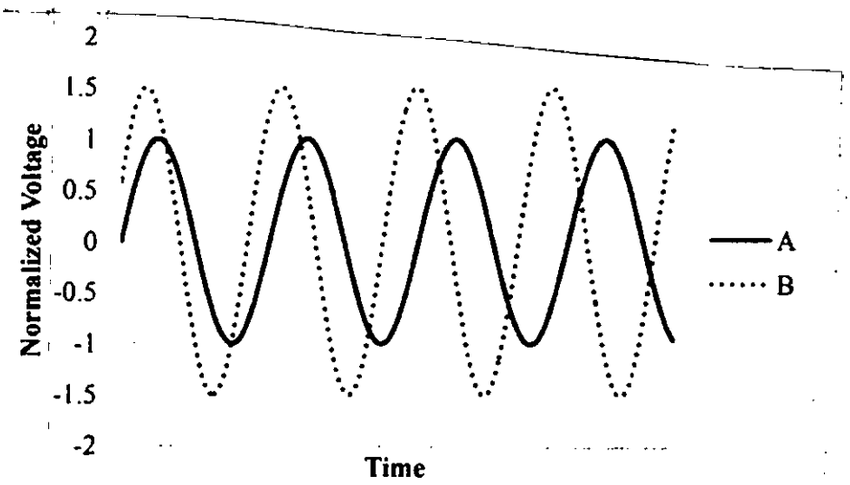


Figure 3(a)

(b) With suitable illustrations, explain why microshocks are more hazardous than macroshocks for the human body. List some clinical devices that can make patients susceptible to microshocks in a clinical environment. **(10)**

(c) With necessary diagrams, explain the nitrogen washout estimate process of lung volume. Also, discuss the subject of accuracy of measurement, especially of flow rate, by a single instrument over the wide range required for the nitrogen washout measurement process. **(15)**

4. (a) For the potentiometer shown below in figure 4(a), determine the ratio of the output voltage v_0 to the input voltage v_i as a function of the displacement ratio x_i/x_t. Approximately plot v_0/v_i in your answer script as a function of x_i/x_t in an ideal case where R_m/R_p should be very large. Show the minimum and maximum possible values in your graph. Also, show that maximum errors occurs in the neighborhood of $x_i/x_t = 0.67$. **(18)**

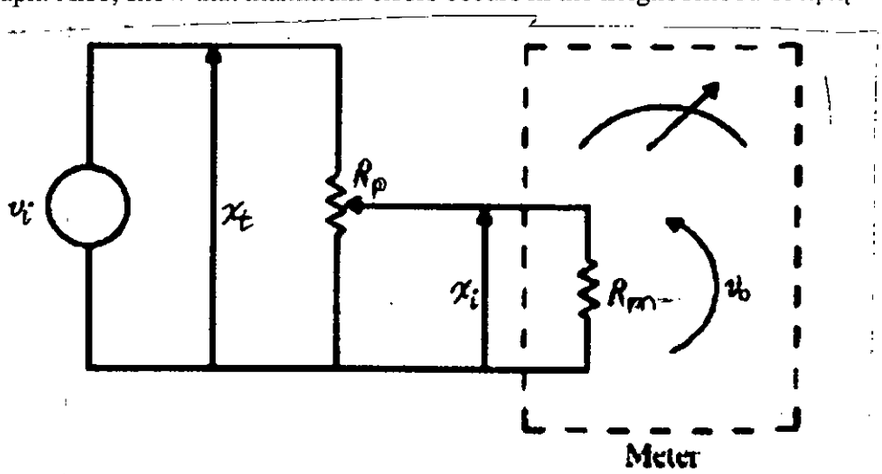


Figure 4(a)

BME 303

Contd ... Q. No. 4

(b) Sketch the arrangement of a P_{CO_2} electrode, and briefly explain how it works. Also, mention what affect the response time of the CO_2 electrode. **(10)**

(c) On a common timescale, illustrate and label the waveforms of magnet current, flow signal, and transformer voltage that will occur in a magnetic flowmeter for a gated sine wave, and a trapezoidal wave. Indicate the best time for sampling each flow signal. **(7)**

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

5. (a) An asynchronous cardiac pacemaker operates at a rate of 70 pulse/min. These pulses are of 2 msec. duration and have an amplitude 5 V when driving a 500 Ω load. **(20)**

(i) What is the total energy supplied to this load over a 10-year period?

(ii) Suppose that 35% of the energy from the power supply goes into the output pulses. What must be the capabilities of the power supply to operate the pacemaker for 10 years?

(iii) Assume that the power supply is three 2.8 V lithium cells. What must the milliampere-hour capacity of each cell be to operate this pacemaker for 10 years?

(iv) Even though a pacemaker such as this would have a 10-year capacity in its power supply, it is found that when it is implanted, the power supply becomes exhausted in a little over 5 years. Can you suggest some of the reasons why this theoretical calculation disagrees with actual practice?

(v) Describe a technique that you can use as a biomedical engineer to determine the status of the battery of this implanted pacemaker wirelessly as it cannot be directly contacted with electric probes connected to test instruments.

(b) What is an Arrhythmia Monitor, and how does it works? Illustrate the working principle of a basic arrhythmia monitoring system with a block diagram. **(15)**

6. (a) A simplified form of defibrillator consists of a dc voltage source that charges a capacitor through a series resistor R_s to a voltage sufficiently high to store enough energy to defibrillate a patient through chest electrodes using an energy of 300 J. Assume that the effective resistance between the electrodes on the patient's chest is 100 Ω and that 90% of the energy of the capacitor will be delivered to the patient within 8 msec. **(15)**

(i) What sized capacitor should be used?

(ii) At what voltage should the capacitor be initially charged?

(b) Why isn't a capacitive discharge defibrillator (CDD) recommended for patients with atrial arrhythmia? What alternative device can be used instead, and how does it address the issues with CDD? **(10)**

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BME 303

Contd ... Q. No. 6

(c) A differential amplifier has a differential gain of 220. Its CMRR vs Frequency curve is shown in Fig, 6(c). Determine the output voltage for the input voltages 45μV and 0.3 mV with a frequency of 100 Hz. **(10)**

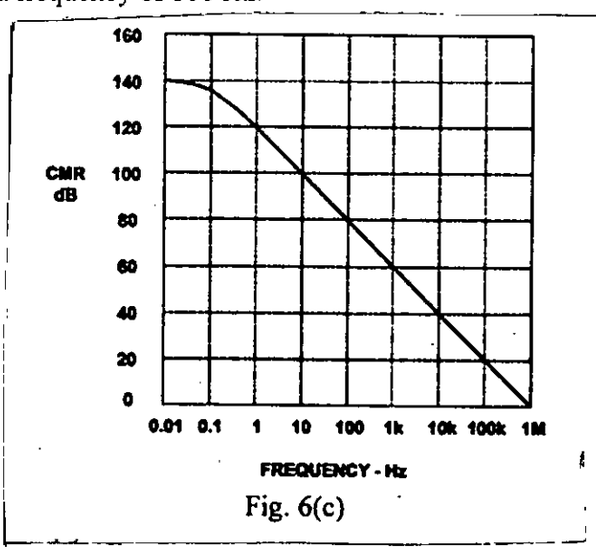

Fig. 6(c)

7. (a) A pulse oximeter is widely used for non-invasive measurement of oxygen saturation in the blood. A similar instrument can be used to measure carbon dioxide saturation. Show how to obtain S_{CO_2} from measurement of total absorbances $A(\lambda_1)$ and $A(\lambda_2)$ at two optical wavelengths λ_1 and λ_2, and from knowledge of specific absorptivity $\alpha_0(\lambda)$ and $\alpha_r(\lambda)$ for carbonated and reduced hemoglobin, respectively, as a function of wavelength. You may assume the measurement is performed in the veins rather than the arteries, so blood oxygenation is negligible. **(15)**

(b) Draw the equivalent circuit model of the electrode-skin interface and find the expression for the impedance of the circuit (i) when the subject is not sweating, (ii) when the subject is sweating. Also, discuss the effects of skin preparation using this model. **(10)**

(c) Consider the following circuit (shown in Fig. 7(c)) is being used for apnea detection using thermometer: **(10)**

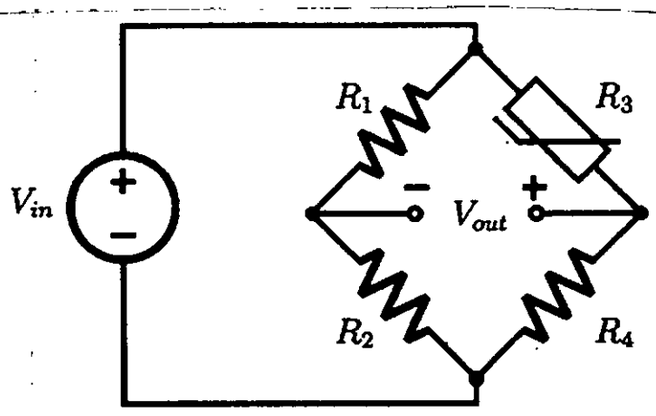

Fig. 7(c)

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BME 303

Contd ... Q. No. 7(c)

R3 represents a thermistor with a transfer function $R_3(t) = r_\infty e^{\beta T}$, here β and r_∞ constants, and T is temperature in Kelvin.

(i) Write the voltage output V_{out} of the system as a function of temperature T. Pay attention to the polarity of V_{out}.

(ii) Considering R_1 = 1K, R_2 = 2K, R_4 = 5K, r_∞ = 5E-15 and β = 0.1, plot the Sensitivity vs Temperature curve. Assume that the temperature varies between 20°C to 60°C.

8. (a) The Fig. 8(a) shows a bio-instrumentation amplifier using three OPAMPs that is being used to record bio-signals. **(15)**

(i) Derive the gain expression of this instrumentation amplifier.

(ii) Propose values for the circuit components such that this instrumentation amplifier has a gain of 30 dB.

(iii) What is the importance of the body reference electrode, E3?

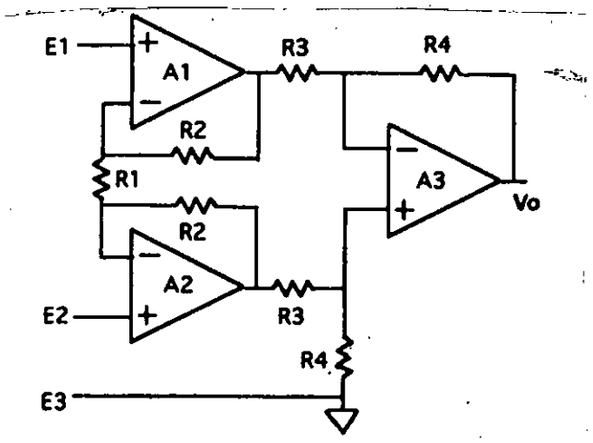

Fig. 8(a)

(b) The Fig. 8(b) shows a band pass filter circuit that is being used to record bio-signals. **(15)**

(i) Derive the gain and the lower and upper cut-off frequency expressions of this circuit.

(ii) Propose values for the circuit components such that the filter has a pass-band frequency appropriate for EMG signal acquisition.

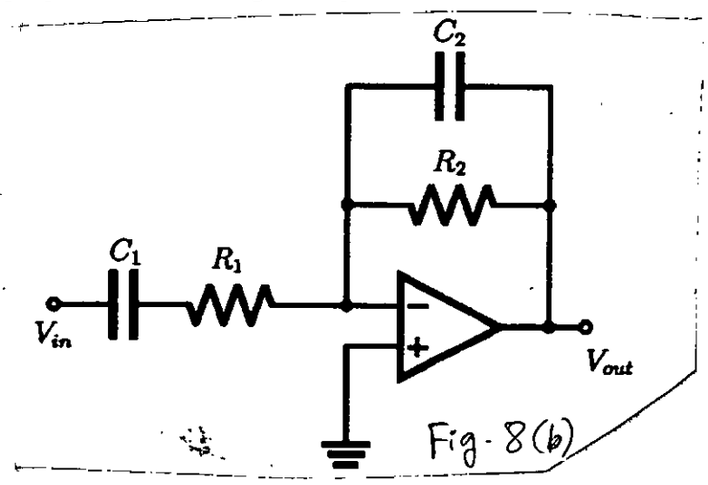

Fig. 8(b)

(c) What is diabetic retinopathy (DR)? Which eye signal we can use for detecting or analyzing the DR? **(5)**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-3/T-1 B. Sc. Engineering Examinations 2021-2022

Sub: **BME 311** (Biomedical Signals and System)

Full Marks: 210 Time: 3 Hours

USE SEPARATE SCRIPTS FOR EACH SECTION

The figures in the margin indicate full marks

SECTION – A

There are **FOUR** questions in this section.

1. (a) A cardiac defibrillator uses the following biphasic waveform. For this signal, perform a trigonometric Fourier series analysis in the compact form within the time window $[0, 2\pi]$ draw the frequency and phase spectrum. **(25)**

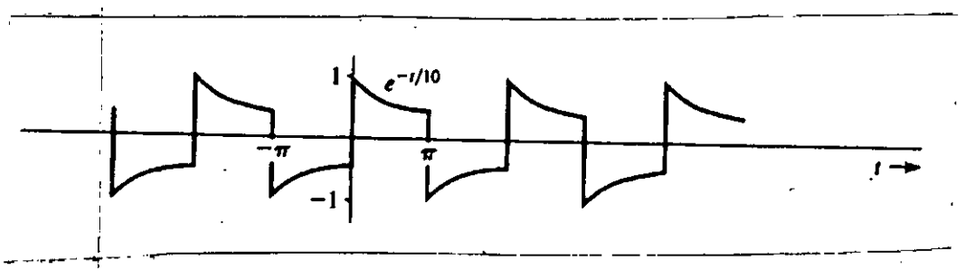

Figure for Question 1(a)

(b) Under what conditions does the Fourier series of a biomedical signal exist? Explain the limitations of analyzing a short burst of EMG signal using Fourier series. **(10)**

2. (a) Sleep study researchers frequently analyze the EEG signals through brainwaves of different frequency ranges as defined below. Studies show that as someone transitions into a deeper stage of sleep (from a shallow stage), the brainwave switch from theta waves to delta waves. You are required to select appropriate filter parameters to determine if a subject is in the deeper sleep stage. **(20)**

(i) Specify the parameters of an ideal filter $H(\omega)$ that can be used to extract the appropriate brainwaves for your task. Show its magnitude and phases spectrum.

(ii) Calculate the impulse response $h(t)$ of the filter designed in part (i).

(iii) Modify the filter designed in part (i) so that it is a practical filter considering a distortion less transmission. You may make any suitable assumptions about the filter's impulse response.

Note: The bandwidth is provided in Hz, but the Fourier spectrum should be shown in angular frequency (ω).

Contd P/2

BME 311
Contd... Q. No. 4

Name	Bandwidth
Alpha wave	8-12 Hz
Beta wave	13-30 Hz
Gamma wave	> 30 Hz
Theta wave	4-8 Hz
Delta	< 4 Hz

Table for Question 2(a)

(b) Prove the time differentiation and integration property of the Fourier transform. **(15)**

3. (a) Derive the equations of Fourier transform for an aperiodic biomedical signal. Explain in qualitative terms what the Fourier transform signifies. **(20)**

(b) The Fourier transform of a voltage signal $f(t)$ is given by $F(\omega)$. Answer the questions below in this regard. You may explain your answers using arbitrary waveforms of $f(t)$ and $F(\omega)$. **(15)**

(i) Considering that the Fourier transform $F(\omega)$ consists of a summation of sinusoids that results in $f(t)$ explain how you will calculate the magnitude of the sinusoidal component of the exact frequency 1Hz?

(ii) Following-up on (i), explain how will you calculate the energy of the sinusoids that exists between the frequency ranges 1-2Hz?

(iii) If a DC component of 5V is added to the signal $f(t)$ how will it affect the function $F(\omega)$?

4. (a) Find the inverse Laplace transform of: **(10)**

$$F(s)=\frac{(s+2)e^{-3s}}{s(s+1)^2}$$

(b) State the initial and final value theorem for Laplace transform. Prove the initial value theorem. **(10)**

(c) A simplified circuit model for a physiological system is shown in the Figure 4(c) (shown in page 6). Analyze the system using Laplace transform to find the zero-state response $y(t)$ if the input $x(t) = te^{-t}u(t)$. Also, determine the transfer function relating the output $y(t)$ and input $x(t)$. **(15)**

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

5. (a) The force applied to a touch receptor is $f(t)$. **(15)**

Contd P/3

BME 311

Contd... Q. No. 5(a)

(i) Write the analytical form of $f(t)$ in terms of unit step and ramp functions.

(ii) If the firing rate of an afferent nerve is given by the function, $y(t) = f(2t - 1)$, sketch $y(t)$.

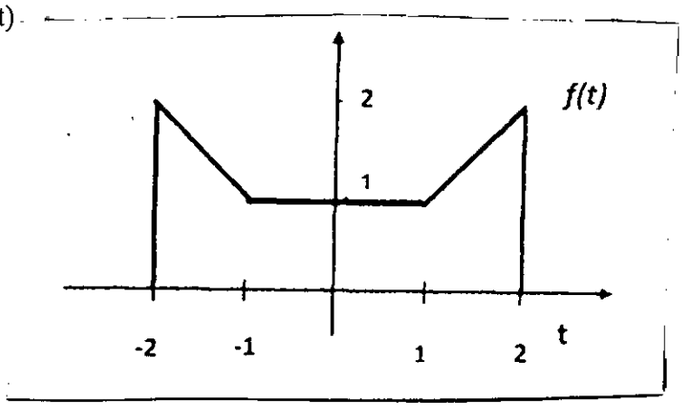

Figure for Question 5(a)

(b) Derive the odd and even parts of the following functions: **(8)**

i) $x(t) = e^{-2t}u(t)$

ii) $x(t) = u(t) - u(t-2)$

(c) The signal shown in Figure: Question 5(c), $x_1(t)$ (a pulse of duration 0.1) is input to a LT1 system and the signal $y_1(t)$ is observed at the output. **(12)**

i) If the signal $x_2(t)$ (a sequence of, 4 pulses 0.5 apart) is input, what will be the output? Explain in brief.

ii) Draw the output signal $y_2(t)$.

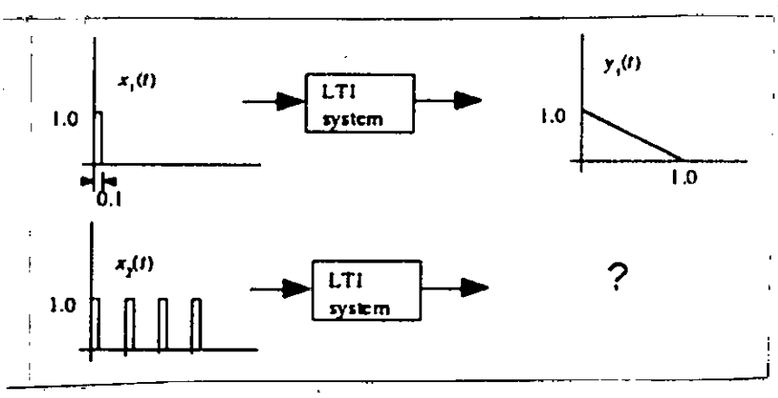

Figure for Question 5(c)

6. (a) A simplistic model of the intrafusal muscle fiber may be expressed by the following differential equation: **(14)**

$$I_a''(t) + 3I_a'(t) + 2I_a(t) = v''(t) - 2v'(t) + v(t)$$

Where, $I_a(t)$ and $v(t)$ are the output current and step change in the muscle fiber, respectively. Deduce the direct Form-I and Direct Form-II realizations of the system.

Contd P/4

BME 311

Contd... Q. No. 6

(b) **(16)**

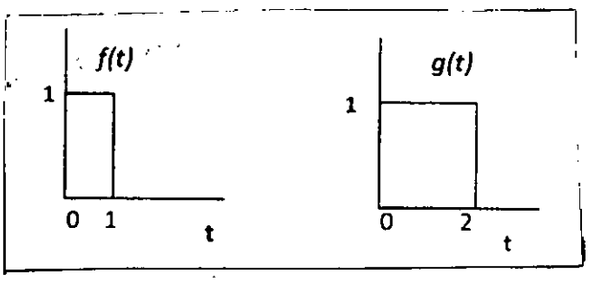

Figure for Question 6(b)

Perform graphical convolution of $f(t)$ and g(t) showed in Figure: Question 6(b).

(c) Determine the values of k for which the feedback system, $y(t)$ is stable. **(5)**

$$y(t) = (k^2 - 3k - 4) \log (t) + \sin (t)$$

7. (a) Determine the impulse response for the linear elastic muscular system governed by the differential equation: **(15)**

$$\frac{d^2y(t)}{dt^2} + 4\frac{dy(t)}{dt} + 3y(t) = x(t)$$

With the initial condition $y(0^-) = 4$.

(b) **(20)**

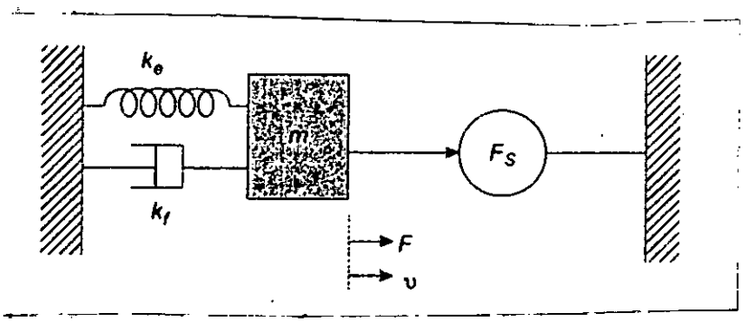

Figure: Question 7(b)

Figure: Question 7(b) shows the mechanical model of a block of skeletal muscle, where

$k_f = 8$ dyn s/cm, $k_e = 12$ dyn/cm, m = 2g, $F_s(t) = 10\cos(2t)$ dyn.

i) Develop the electrical analog circuit of this model.

ii) Find the length of the spring when. t = 010 s.

iii) What must be the value of k_f to limit the maximum velocity to ± 1 cm/s?

BME 311

8. (a)

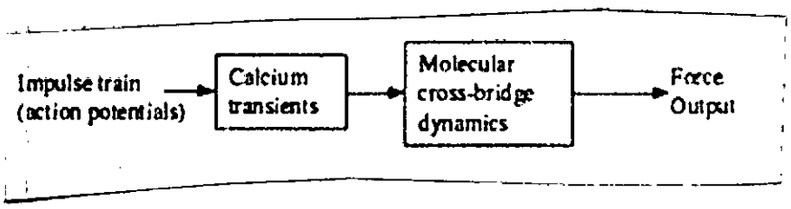

Figure: Question 8(a)

Skeletal muscle can be represented by a linear model showed in Figure: Question 8(a). The input to this overall system is a sequence of impulses which represent the action potential excitation. The first block called the active state has an impulse response, $h_1(t) = e^{-2t}u(t)$ and second block which represent the dynamic of molecular interactions between the myosin and actin molecules has an impulse response, $h_2(t) = e^{-0.5t}u(t)$. Calculate the function describing the muscle twitch force (output).

(b) **(25)**

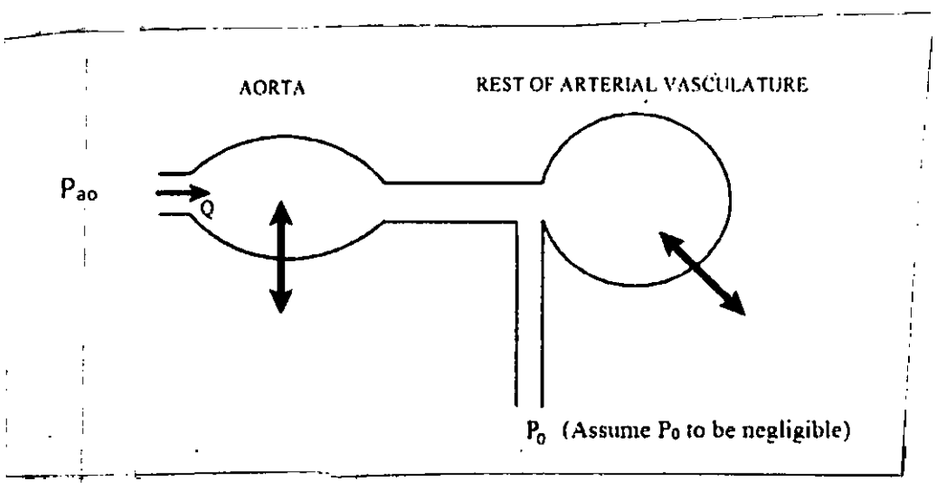

Figure: Question 8(b)

Figure: Question 8(b) shows a schematic diagram of the five-element Windkessel model that has been used to approximate the hemodynamic properties of the arterial tree. The model consists of a distensible (as illustrated by the two-ended arrows) aorta and a lumped representation of the rest of the arterial vasculature. The latter is modeled as a simple parallel combination of peripheral resistance. R_P, and periopheral compliance, C_P. The mechanical parameters pertinent to the aortic portion are: the compliance of the aortic wall. C_{ao}, the viscous resistance of the aortic wall, R_{ao}; and the inertance to flow through the aorta, L_{ao}, (Note that resistance to flow in the aorta is considered negligible compared to R_P).

i) Construct the electrical analog of this model.

ii) Derive the equivalent state-spate model relating aortic pressure, $\mathbf{P_{ao}}$ to the aortic flow, **Q**.

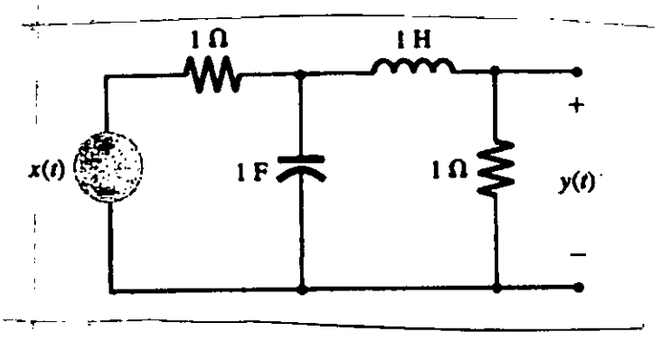

Figure. 4(c)

L-3/T-1/BME **Date: 13/04/2023**

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-3/T-3 B. Sc. Engineering Examinations 2021-2022

Sub: **MATH 313** (Probability and Statistics)

Full Marks: 210 Time: 3 Hours

USE SEPARATE SCRIPTS FOR EACH SECTION

The figures in the margin indicate full marks

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE** questions.
Symbols have their usual meanings.

1. (a) The median and mode of the following wage distribution are Tk. 33.5 and Tk. 34 respectively. However there frequencies are missing. Determine their values: **(17)**

Wage:	0-10	10-20	20-30	30-40	40-50	50-60	60-70	Total
Frequencies:	4	16	?	?	?	6	4	230

(b) The breaking strength of 80 test pieces of a certain alloy is given in the following table, the unit being given to the nearest pounds per square inch. **(18)**

Breaking strength:	44-46	46-48	48-50	50-52	52-54
No of Pieces:	3	24	27	21	5

Calculate the average breaking strength of the alloy and standard deviation. Also find the percentage of observations lying between mean $\pm 2\sigma$.

2. (a) Explain how moments help in describing the characteristics of a frequency distribution. Using moments calculate the coefficients of Skewness and Kurtosis from the following distribution and comment on the results obtained. **(17)**

Profits (in taka):	10-20	20-30	30-40	40-50	50-60
No. of companies:	18	20	30	22	10

(b) A study is made on the amount of converted sugar in a certain process at various temperatures. The data are coded and recorded as follows: **(18)**

Temperature X:	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2
Converted Y	8.1	7.8	8.5	9.8	9.5	8.9	8.6	10.2	9.3	9.2	10.5

(i) Find the equations both regression lines.

(ii) Estimate the amount of converted sugar produced when the coded temperature is 1.75.

(iii) Find the value of correlation coefficient.

3. (a) State central limit theorem. An electronics company manufactures resistors that have a mean resistance of 100 ohms and a standard deviation of 10 ohms. The distribution of resistance is normal. Find the probability that a random sample of 25 resistors will have an average resistance less than 95 ohms. **(17)**

Contd P/2

MATH 313/BME
Contd... Q. No. 3

(b) In an effort to estimate the mean amount spent per customer for dinner at a major Atlanta restaurant, data were collected for a sample of 49 customers over a three- week period. Assume a population deviation of $2.50. If the sample mean is $22.6, what is the 95% confidence interval for the population mean? Show the error in estimating μ by $\bar{x}$ in a figure. **(18)**

4. (a) A steel manufacturing company wishes to know whether the tensile strength of the steel wire has an overall average of 120 pounds. A random sample of 25 units of steel wire produced by the company yields a mean strength of 110 pounds and standard deviation of 12 pounds. Should the company conclude that the strength is not 120 pounds with 5 percent level of significance. **(17)**

(b) Two different types of drugs A and B tried on a certain patient for increasing weight, 5 persons were given drug A and 7 persons were given drug B. The increase in weight (in pounds) is given below: **(18)**

Drug A	8	12	13	9	3		
Drug B	10	8	12	15	6	8	11

Do the two drugs differ significantly with regard to their effect in increasing weights, using 5 percent level of significance? (Table is attached for the question No. 4)

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

5. (a) The probability that automobile being filled with gasoline will also need an oil change is 0.25; the probability that it needs a new oil filter is 0.40; and the probability that both the oil and filter need changing is 0.14. **(17)**

(i) If the oil had to be changed, what is the probability that a new oil filter is needed?

(ii) If a new oil filter is needed, what is the probability that the oil has to be changed?

(b) In a senior year of high school graduating class of 100 students, 42 studied mathematics, 68 studied psychology, 54 studied history, 22 studied both mathematics and history, 25 studied both mathematics and psychology, 7 studied history but neither mathematics nor psychology, 10 studied all three subjects, and 8 did not take any of the three. If a student is selected at random, find the probability that **(18)**

(i) a person enrolled in psychology takes all three subjects

(ii) a person not taking psychology is taking both history and mathematics.

Contd P/3

MATH 313/BME

6. (a) Pairs of pants are being produced by a particular outlet facility. The pants are "checked" by a group of 10 workers. The workers inspect pairs of pants taken randomly from the production line. Each inspector is assigned a number from 1 through 10. A buyer selects a pair of pants for purchase. Let the random variable X be the inspector number. **(17)**

(i) Give a reasonable probability mass function for X.

(ii) Plot the cumulative distribution function for X.

(b) From a sack of fruit containing 3 oranges, 2 apples and 3 bananas, a random sample of 4 pieces of fruit is selected. If X is the number of oranges and Y is the number of apples in the sample, find **(18)**

(i) the joint probability distribution of X and Y

(ii) $p[(X, Y) \in A]$, where A is the region that is given $\{(x, y) | x+y \leq 2\}$

(iii) σ_{XY}

7. (a) Statistics released by the National Highway Traffic Safety Administration and National Safety Council show that on an average weekend night, 1 out of every 10 drivers on the road is drunk. If 400 drivers and randomly checked on a Saturday night, what is the probability that the number of drunk drivers will be **(18)**

(i) less than 32?

(ii) more than 49?

(iii) at least 35 but less than 47?

(b) Suppose that the time, in hours, taken to repair a heat pump is a random variable X having a gamma distribution with parameters $\alpha = 2$, $\beta = 1/2$. What is the probability that the next service call will require **(17)**

(i) at most 1 hour to repair the heat pump?

(ii) at most 2 hours to repair the heat pump?

8. (a) Discuss random sampling and stratified sampling. The weight of 3000 male student at a university are normally distributed with mean of 66 kg and standard deviation of 3 kg. If 80 random samples consisting of 25 students are obtained, what would be the expected mean and standard deviation of sampling distribution of means of the sampling are those done **(17)**

(i) with replacement and

(ii) without replacement.

Contd P/4

MATH 313/BME
Contd... Q. No. 8

(b) In the study an evaluation of the Removal Method for estimating Benthic Populations and Diversity conducted by Virginia Tech on the Jackson River, 5 different sampling producers are used to determine the species counts. Twenty sampes are selected at random, and each of the 5 sampling procedures is repeated 4 times. The species counts are recorded as follows: **(18)**

Sampling Procedures				
Depletion	Modified Hess	Surber	Substrate Removal Kicknet	Kicknet
85	75	31	43	17
55	45	20	21	10
40	35	9	15	8
77	67	37	27	15

(i) Is there a significant difference in the average species counts for the different sampling procedures? Use a P-value in your conclusion.

(ii) Use Tukey's test with $\alpha = 0.05$ to find which sampling procedures differ. Use the following table.

Table Upper Percentage Points of the Studentized Range Distribution: Values of $q(0.05; k, v)$

Degrees of Freedom, v	Number of Treatments k								
	2	3	4	5	6	7	8	9	10
1	18.0	27.0	32.8	37.2	40.5	43.1	15.1	47.1	49.1
2	6.09	5.33	9.80	10.89	11.73	12.43	13.03	13.54	13.99
3	4.50	5.91	6.83	7.51	8.04	8.47	8.85	9.18	9.46
4	3.93	5.04	5.76	6.29	6.71	7.06	7.35	7.60	7.83
5	3.64	4.60	5.22	5.67	6.03	6.33	6.58	6.80	6.99
6	3.46	4.34	4.90	5.31	5.63	5.89	6.12	6.32	6.49
7	3.34	4.16	4.68	5.06	5.35	5.59	5.80	5.99	6.15
8	3.26	4.04	4.53	4.89	5.17	5.40	5.60	5.77	5.92
9	3.20	3.95	4.42	4.76	5.02	5.24	5.43	5.60	5.74
10	3.15	3.88	4.33	4.66	4.91	5.12	5.30	5.46	5.60
11	3.11	3.82	4.26	4.58	4.82	5.03	5.20	5.35	5.49
12	3.08	3.77	4.20	4.51	4.75	4.95	5.12	5.27	5.40
13	3.06	3.73	4.15	4.46	4.69	4.88	5.05	5.19	5.32
14	3.03	3.70	4.11	4.41	4.65	4.83	4.99	5.13	5.25
15	3.01	3.67	4.08	4.37	4.59	4.78	4.94	5.08	5.20
16	3.00	3.65	4.05	4.34	4.56	4.74	4.90	5.03	5.05
17	2.98	3.62	4.02	4.31	4.52	4.70	4.86	4.99	5.11
18	2.97	3.61	4.00	4.28	4.49	4.67	4.83	4.96	5.07
19	2.96	3.59	3.98	4.26	4.47	4.64	4.79	4.92	5.04
20	2.95	3.58	3.96	4.24	4.45	4.62	4.77	4.90	5.01
24	2.92	3.53	3.90	4.17	4.37	4.54	4.68	4.81	4.92
30	2.89	3.48	3.84	4.11	4.30	4.46	4.60	4.72	4.83
40	2.86	3.44	3.79	4.04	4.23	4.39	4.52	4.63	4.74
60	2.83	3.40	3.74	3.98	4.16	4.31	4.44	4.55	4.65
120	2.80	3.36	3.69	3.92	4.10	4.24	4.36	4.47	4.56
∞	2.77	3.32	3.63	3.86	4.03	4.17	4.29	4.39	4.47

page-05

For question No. 4

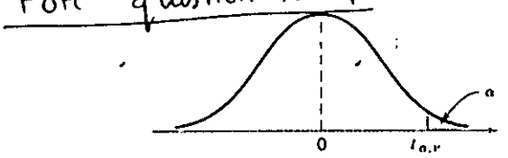

TABLE • V Percentage Points $t_{\alpha,\nu}$ of the t Distribution

ν \ α	.40	.25	.10	.05	.025	.01	.005	.0025	.001	.0005
1	.325	1.000	3.078	6.314	12.706	31.821	63.657	127.32	318.31	636.62
2	.289	.816	1.886	2.920	4.303	6.965	9.925	14.089	23.326	31.598
3	.277	.765	1.638	2.353	3.182	4.541	5.841	7.453	10.213	12.924
4	.271	.741	1.533	2.132	2.776	3.747	4.604	5.598	7.173	8.610
5	.267	.727	1.476	2.015	2.571	3.365	4.032	4.773	5.893	6.869
6	.265	.718	1.440	1.943	2.447	3.143	3.707	4.317	5.208	5.959
7	.263	.711	1.415	1.895	2.365	2.998	3.499	4.029	4.785	5.408
8	.262	.706	1.397	1.860	2.306	2.896	3.355	3.833	4.501	5.041
9	.261	.703	1.383	1.833	2.262	2.821	3.250	3.690	4.297	4.781
10	.260	.700	1.372	1.812	2.228	2.764	3.169	3.581	4.144	4.587
11	.260	.697	1.363	1.796	2.201	2.718	3.106	3.497	4.025	4.437
12	.259	.695	1.356	1.782	2.179	2.681	3.055	3.428	3.930	4.318
13	.259	.694	1.350	1.771	2.160	2.650	3.012	3.372	3.852	4.221
14	.258	.692	1.345	1.761	2.145	2.624	2.977	3.326	3.787	4.140
15	.258	.691	1.341	1.753	2.131	2.602	2.947	3.286	3.733	4.073
16	.258	.690	1.337	1.746	2.120	2.583	2.921	3.252	3.686	4.015
17	.257	.689	1.333	1.740	2.110	2.567	2.898	3.222	3.646	3.965
18	.257	.688	1.330	1.734	2.101	2.552	2.878	3.197	3.610	3.922
19	.257	.688	1.328	1.729	2.093	2.539	2.861	3.174	3.579	3.883
20	.257	.687	1.325	1.725	2.086	2.528	2.845	3.153	3.552	3.850
21	.257	.686	1.323	1.721	2.080	2.518	2.831	3.135	3.527	3.819
22	.256	.686	1.321	1.717	2.074	2.508	2.819	3.119	3.505	3.792
23	.256	.685	1.319	1.714	2.069	2.500	2.807	3.104	3.485	3.767
24	.256	.685	1.318	1.711	2.064	2.492	2.797	3.091	3.467	3.745
25	.256	.684	1.316	1.708	2.060	2.485	2.787	3.078	3.450	3.725
26	.256	.684	1.315	1.706	2.056	2.479	2.779	3.067	3.435	3.707
27	.256	.684	1.314	1.703	2.052	2.473	2.771	3.057	3.421	3.690
28	.256	.683	1.313	1.701	2.048	2.467	2.763	3.047	3.408	3.674
29	.256	.683	1.311	1.699	2.045	2.462	2.756	3.038	3.396	3.659
30	.256	.683	1.310	1.697	2.042	2.457	2.750	3.030	3.385	3.646
40	.255	.681	1.303	1.684	2.021	2.423	2.704	2.971	3.307	3.551
60	.254	.679	1.296	1.671	2.000	2.390	2.660	2.915	3.232	3.460
120	.254	.677	1.289	1.658	1.980	2.358	2.617	2.860	3.160	3.373
∞	.253	.674	1.282	1.645	1.960	2.326	2.576	2.807	3.090	3.291

ν = degrees of freedom.

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY, DHAKA

L-3/T-1 B. Sc. Engineering Examinations 2021-2022

Sub: **CSE 391** (Embedded System and Interfacing)

Full Marks: 210 Time: 3 Hours

USE SEPARATE SCRIPTS FOR EACH SECTION

The necessary diagrams can be found at the end of the question paper.

The figures in the margin indicate full marks

SECTION – A

There are **FOUR** questions in this section. Answer any **THREE** question.

1. Your little brother was going to connect an LED directly to a pin of an ATmega32. However, as you already know the risks, you told him to follow the recommended procedure. In the LED datasheet, he found that the absolute maximum rating for the forward voltage is 1.75 V and the absolute maximum rating for the forward current is 17.5 mA. **(10+10+15=35)**

   (a) What are the different types of memory in ATmega32? Write their names along with their use-cases.

   (b) What are the most widely used system architectures? What are the main differences among them? Which one is used in ATmega32?

   (c) Which device should you use to prevent the risks? Can you calculate the appropriate value for that device?

2. The pins of Raspberry Pi are a bit confusing. Most of them are multi-functional. They are numbered in a zigzag way. You remember a case when one of your friends connected a potentiometer to pin number 17 after your team was instructed to use GPIO17 for controlling the speed of a 3.3V small DC motor. **(13+12+10=35)**

   (a) Draw a schematic diagram of the above mentioned scenario. Mention the required pins only.

   (b) What are the types of PWM in Raspberry Pi? Order them based on accuracy. How is the timing of pulse achieved in each of the cases? Which ones are suitable for jitter free servo motor control?

   (c) Mention the steps you should follow to execute a program at startup in Raspberry Pi. What is the purpose of the '&' character in this regard?

3. (a) Wireless communication is an appealing feature in modern devices. Though it can be achieved through internet connection, there are other cheap alternatives as well. One of such alternatives is to use the NRF24 module. What are the restrictions regarding the address assignment of pipes? Address of which pipe is considered the address of the transmitter? **(20)**

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CSE 391/BME
Contd... Q. No. 3

(b) To develop a robot, you need to communicate with three peripheral devices. The communication should be full duplex. You friend told you that it can be achieved using the very same protocol that is used for interfacing SD cards with Arduino. Can you really connect more than one peripheral device using this protocol? Draw a high level diagram if it is possible. All the devices should be controlled with different pins. **(15)**

4. (a) How many wires are needed in I2C protocol? Write their names. Mention whether the protocol is synchronous. Is there any drawback of this protocol? **(10)**

(b) Can we get rid of button bouncing through hardware? Draw a high level schematic diagram. **(15)**

(c) Draw a layer-wise composition diagram of a Printed Circuit Board (PCB). **(10)**

SECTION – B

There are **FOUR** questions in this section. Answer any **THREE**.

5. ATmega32 is a RISC based microcontroller. It is cheap and can be used for various purposes. An ATmega32 chip has 40 pins in total, but not all of them can be used for I/O. Some pins have an ADC feature that enables the chip to get data from analog sensors.

(a) Which registers do you need to configure to develop a system so that whenever a push button connected to the INT1 pin is pressed, an external interrupt is sent to the processor? The interrupt should be generated in the rising edge. Draw each of the required registers along with their required values. **(15)**

(b) You want to read values from an LM35 using ATmega32. Which pins can be used for this purpose? You want a 2.5 V external source as reference and highest accuracy. You may use any of the valid odd numbered pins. Which registers do you need to configure? Draw each of the required registers along with their required values. **(20)**

6. (a) How many bits are there in the data and address bus of 8086? What is the largest amount of memory the processor can handle where each byte has a different address? **(10)**

(b) If the values of CS and IP are AB00H and CDFEH at some point then which memory address is read for execution? **(10)**

(c) Draw a segment diagram of the 8086 processor if the values of CS, DS, ES and SS are 4000H, 8000H, A000H and E000H in order. **(15)**

Contd P/3

CSE 391/BME

7. AC explosions are a cause of major fatalities in Dhaka right now. Experts find two major causes for this - refrigerant leak and overheat due to blockages. You want to develop a system that can help prevent such accidents. You have two sensors - one for detecting refrigerants, other for determining temperature. The refrigerant detector is a three terminal voltage based sensor while the temperature dector is resistance based. After a lot of trials you found threshold values for the sensors. You are going to detect leakage if the voltage is greater than 1V. The temperature is alarming if the resistance of the detector goes lower than 1kΩ. You want to develop the system using Arduino UNO. The system should also contain a buzzer and a relay. The buzzer whistles when leakage or high temperature is detected. The relay is then turned off. You may consider the relay just like a transistor. It has three terminals, say A, B & C. If the C terminal gets HIGH voltage, then it shorts A and B. If the voltage is LOW in C, then A and B are disconnected.

   (a) Draw a schematic diagram of the system mentioning the required pins, sensors, buzzer, relay and other necessary components. **(20)**

   (b) Write a program for the system. **(15)**

8. DC motors can be controlled using transistor as a switch. The current and voltage ratings of a DC motor are 0.25 A and 20 V respectively. Absolute maximum rating of collector current and collector-emitter voltage for the transistor are 0.95 A and 37 V respectively. In the saturation region, the transistor has a h_{FE} value of 12.5 and V_{BE} follows the following table.

I_c (A)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
V_{BE} (V)	0.5	0.6	0.68	0.75	0.80	0.84	0.87	0.88	0.887	0.89

   (a) Which pins are used to simulate analog outputs in Arduino UNO? Say, the motor is needed to rotate at 70% of its maximum speed. What value should you pass to the motor? Show the calculations. **(15)**

   (b) The only resistors that are available are of 50, 100, 200, 500, 1000 and 10000 ohms. How can you achieve necessary base resistance for controlling the motor using these available resistors? **(20)**

APPENDIX A: ATmega32 basic registers

Register Name	bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0
GICR	INT1	INT0	INT2	–	–	–	IVSEL	IVCE
GIFR	INTF1	INTF0	INTF2	–	–	–	–	–
MCUCR	SE	SM2	SM1	SM0	ISC11	ISC10	ISC01	ISC00
MCUCSR	JTD	ISC2	–	JTRF	WDRF	BORF	EXTRF	PORF
SFIOR	ADTS2	ADTS1	ADTS0	–	ACME	PUD	PSR2	PSR10
ADMUX	REFS1	REFS0	ADLAR	MUX4	MUX3	MUX2	MUX1	MUX0
ADCSRA	ADEN	ADSC	ADATE	ADIF	ADIE	ADPS2	ADPS1	ADPS0

APPENDIX B: ATmega32 pin diagram

1	PB0	(ADC0) PA0	40
2	PB1	(ADC1) PA1	39
3	PB2 (INT2)	(ADC2) PA2	38
4	PB3	(ADC3) PA3	37
5	PB4	(ADC4) PA4	36
6	PB5	(ADC5) PA5	35
7	PB6	(ADC6) PA6	34
8	PB7	(ADC7) PA7	33
9	RESET	AREF	32
10	VCC	GND	31
11	GND	AVCC	30
12	XTAL2	PC7	29
13	XTAL1	PC6	28
14	PD0	PC5	27
15	PD1	PC4	26
16	PD2 (INT0)	PC3	25
17	PD3 (INT1)	PC2	24
18	PD4	PC1	23
19	PD5	PC0	22
20	PD6	PD7	21

APPENDIX C: Arduino UNO pin diagram

		SCL
		SDA
		AREF
		GND
NC		D13 (SCK)
IOREF		D12 (CIPO)
RESET		~ D11 (COPI)
3V3		~ D10 (SS)
5V		~ D9
GND		D8
GND		
VIN		D7
		~ D6
A0		~ D5
A1		D4
A2		~ D3 (INT1)
A3		D2 (INT0)
A4 (SDA)		D1 (TX)
A5 (SCL)		D0 (RX)

APPENDIX D: Raspberry Pi pin diagram

1	3V3-power	5V-power	2
3	GPIO2/WP8/I2C1-SDA	5V-power	4
5	GPIO3/WP9/I2C1-SCL	GND	6
7	GPIO4/WP7/GPCLK0/1-WIRE-DATA	UART-TX/WP15/GPIO14	8
9	GND	UART-RX/WP16/GPIO15	10
11	GPIO17/WP0/SPI1CE1	PCM-CLK/PWM0/SPI1-CE0/WP1/GPIO18	12
13	GPIO27/WP2/SDIO-DAT3	GND	14
15	GPIO22/WP3/SDIO-CLK	SDIO-CMD/WP4/GPIO23	16
17	3V3-power	SDIO-DAT0/WP5/GPIO24	18
19	GPIO10/WP12/SPI0-MOSI	GND	20
21	GPIO9/WP13/SPI0-MISO	SDIO-DAT1/WP6/GPIO25	22
23	GPIO11/WP14/SPI0-SCLK	SPI0-CE0/WP10/GPIO8	24
25	GND	SPI0-CE1/WP11/GPIO7	26
27	GPIO0/WP30/EEPROM-SDA	EEPROM-SCL/WP31/GPIO1	28
29	GPIO5/WP21/GPCLK1	GND	30
31	GPIO6/WP22/GPCLK2	PWM0/WP26/GPIO12	32
33	GPIO13/WP23/PWM1	GND	34
35	GPIO19/WP24/SPI1-MISO/PWM1/PCM-FS	SPI1-CE2/WP27/GPIO16	36
37	GPIO26/WP25/SDIO-DAT2	PCM-DIN/SPI1-MOSI/WP28/GPIO20	38
39	GND	PCM-DOUT/SPI1-SCLK/WP29/GPIO21	40