Question #1

a) Compare the electrical activities in the *heart, stomach, and small intestine* in terms of features, organization, and function.
b) Describe the *ionic transport mechanisms* in cellular membranes.
c) Describe the transmission of bioelectricity in a chemical synapse. Compare excitatory and inhibitory synapses in terms of structural features and function. [30 Marks]

Question #2

Derive mathematical expressions for the *chemical, electrical, electrochemical, and Nernst* potentials. [20 Marks]

Question #3

Derive the delta rule for *error correction learning* in an artificial neural network represented by a *fully connected feed forward* network with **two** hidden neural units, and **two** output neural units. The hidden neural units receive the set of inputs $\{x_i \mid i = 0, ..., p\}$, and all neural units have *sigmoidal* activation functions. How can such learning be accelerated? [15 Marks]

Question #4

Consider a neuron whose dendritic tree is represented by a cable with a length of 300 μm, diameter of 10 μm, and a space constant of 0.25 cm. There are two synapses at the terminus of the cable. Synapse #1 has a reversal potential $E_{s1} = -50\ mV$ and each presynaptic action potential gives rise to a synaptic conductance $g_{s1} = 0.55\ mS/cm^2$, whereas the post-synaptic dendritic membrane has conductances ($g_{Na} = 0.01\ mS/cm^2$, $g_K = 0.367\ mS/cm^2$) and Nernst potentials ($E_{Na} = 54.2\ mV$, $E_K = -74.7\ mV$) for sodium and potassium, respectively. For synapse #2, each presynaptic action potential generates a postsynaptic potential v_s described by $v_s(t) = 50\pi\ sin(100\pi t)$ for $0 \leq t \leq 0.01$, otherwise $v_s(t) = 0$, where v_s is in mV, and t is in sec. The **latency & refractory** properties of the axo-somatic junction *(the axon hillock)*, which is located at the origin ($x = 0$), are described by $S = 200\ t_l^{-0.7}$ & $S = \frac{10}{t_r - 5}$, where S is the somatic potential in mV, t_l is latency in $msec$, and t_r is the refractory period in $msec$. The threshold for action potential firing is 5 mV.

Whenever the excitation threshold is reached, the soma fires an action potential described by $v_m(t) = 20\ t\ e^{[1-t]}$ where v_m is the transmembrane voltage in mV and t is time in $msec$. The action potential travels as a *right-moving wave* along the axonal cable (*length* = 10 mm & *diameter* = 0.4 mm) with a uniform propagation velocity of 1 $mm/msec$. The intracellular and extracellular conductivities of the axon are 0.01 & 0.05 S/cm, respectively.

Compute the following:

(a) The magnitudes of the postsynaptic and the somatic potentials due to a presynaptic action potential at synapse #1.

(b) The magnitudes of the postsynaptic and the somatic potentials, and the *frequency* of the action potentials in the *axon hillock*, if presynaptic action potentials having a *frequency* of 10Hz are applied to synapse #2.

(c) The axonal maximum longitudinal intracellular current, maximum transmembrane current per unit length, and the maximum extracellular potential 5 mm above the axon, at t = 5 $msec$, for $S \geq 5\ mV$. **[35 Marks]**