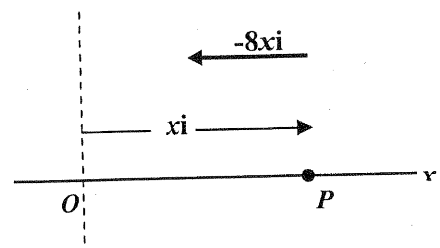
Student code:__________

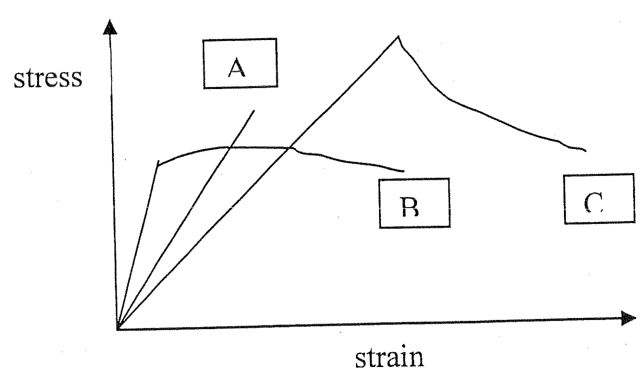
MORNING QUESTIONS (1-18) to choose 12 from:

Question 1. An ion channel is known to be permeable to Na^+, K^+, and Ca^{2+}. The outside $[Na^+]$, $[K^+]$, and $[Ca^{2+}]$ are 120, 9, 2 mM, respectively; whereas the inside concentration of these ions are 12, 90, and 0.002 mM, respectively. Please draw the equivalent circuit of the membrane that contains this channel.

Question 2. A particle P of mass 2 moves along the x axis attracted toward origin o by a force whose magnitude is numerically equal to $8x$. If it is initially at rest at $x = 20$, find (a) the differential equation and initial conditions describing the motion, (b) the position of the particle at any time, (c) the speed and velocity of the particle at any time, and (d) the amplitude, period and frequency of the vibration.



Question 3. You are working in a material-testing lab to evaluate the mechanical properties of novel polymers. You measured the stress-strain relationships of three different biomaterials--A, B and C as shown below:

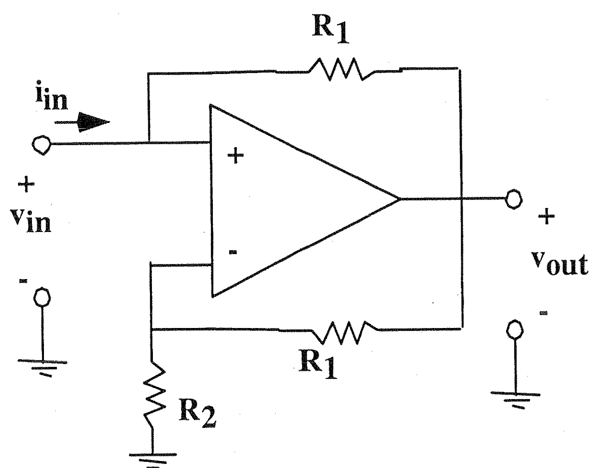


Student code:__________

Based on the above stress-strain curves, compare the following material properties in Table 1. Within each category, rank the material from the highest values to the lowest. Using illustrations to provide a schematic explanation of how each parameter is obtained from the stress-strain curve. The material stiffness was used as an example.

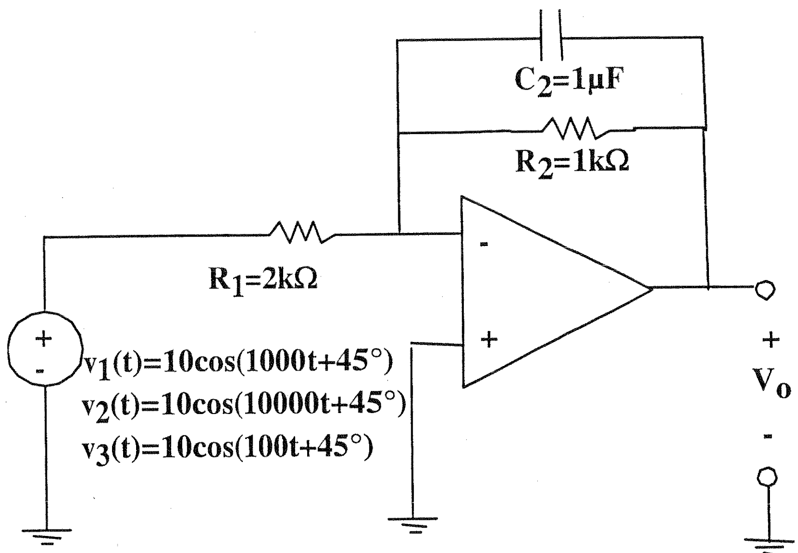
Properties	**Ranking**
Stiffness	B>A>C (example)
Resilience	
Yield strength	
Fracture strength	
Tensile strength	
Toughness	

Question 4. The circuit shown below is used to generate a negative resistance. Show using circuit theory that the input resistance is equal to $-R_2$. A negative resistance implies that this circuit is delivering power. Explain how this is possible.



Student code:_________

Question 5. For the circuit shown below calculate the steady state sinusoidal output voltage, $v_o(t)$, when the input is equal to one of each of the three input voltages. Each of the inputs is independent and only 1 input is on at a time, thus you will obtain 3 answers for the output voltage, one for each of the 3 different input voltages. What kind of filter is this and what is the cut-off frequency?



Question 6 (this question has 3 parts). a) Sketch the impulse response h(t) corresponding to the following linear system:

b) Is this system stable or unstable? How can you tell?

c) You add a negative feedback loop with a static transfer function with gain A. Determine a numerical value of A that produces an overall transfer function of:

$$\frac{Y(s)}{X(s)} = \frac{1}{s+10}$$

Student code:_________

Question 7. Consider the illustrated mechanical system, which depicts the human elbow and two of its flexor muscles.

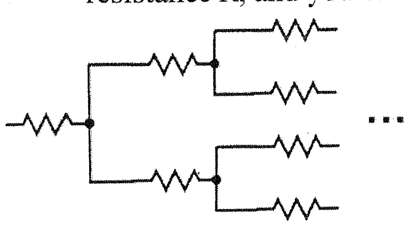
Two muscles (Muscle1 and Muscle2) must balance a mass M located a distance "c" from the pivot point of the hinge joint. Muscle1 attaches to the lower arm a distance "a" from the pivot point, while Muscle2 attaches at a distance of "b".

Assume that a=0.01 m
b=0.02 m
c=0.3 m
M= 5.0968 kg

Find the combination of muscle forces f_1 and f_2 that balance the mass M while minimizing the following function:

$$S = \left(\frac{f_1}{f_{1\max}}\right)^2 + \left(\frac{f_2}{f_{2\max}}\right)^2, \text{ where } f_{1max} = 1500 \text{ N and } f_{2max} = 500\text{N}$$

Question 8. Find an input resistance of the following infinite circuit. Each resistor has a resistance R, and you can assume that the circuit is grounded at infinity.



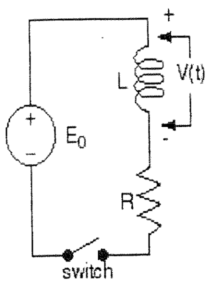
Question 9.

Proteins are defined structurally by different levels of structure: primary, secondary, tertiary and quaternary. Explain each of the four levels of structure.

Circular dichroism, X-ray diffraction, atomic force microscopy, and transmission electron microscopy, are techniques that are useful for obtaining structural information on proteins. State what structural information is obtained from each technique.

Student code:__________

Question 10. Consider the following circuit:



where E_0 (the voltage of the voltage source), L, and R are all known constants. At t=0, the switch is turned on. Find an expression for the voltage V(t) across the inductor L as a function of time for t>0.

Question 11. Suppose we are applying the backward Euler method to solve the following pair of differential equations:

$$\frac{dV}{dt} = W$$
$$\frac{dW}{dt} = -V$$

[Reminder: the backward Euler method for a general equation of the form

$$\frac{d\mathbf{y}}{dt} = \mathbf{f}(\mathbf{y}, t)$$

is given by,

$$\mathbf{y}_{n+1} = \mathbf{y}_n + \Delta t\,\mathbf{f}(\mathbf{y}_{n+1}, t_{n+1})$$

where n is the timestep index and Δt is the timestep size.]

(a) Find **explicit** expressions for V_{n+1} and W_{n+1} in terms of V_n and W_n. Note: this means that your expressions for V_{n+1} and W_{n+1} should **not** be defined in terms V_{n+1} and W_{n+1}.

(b) Show that the method is stable for this pair of equations for any size timestep by demonstrating that $V_{n+1}^2 + W_{n+1}^2$ is always less than or equal to $V_n^2 + W_n^2$.

Question 12.

If a sodium channel passes 1 pA of current, how many channels per square micrometer are necessary to change the membrane potential by 100 mV in 1 msec ?

The sodium channel opens by undergoing a configuration change when the electric field that it senses changes. What is the field change across the the cell membrane if the potential changes by 100 mV?

Student code:__________

Question 13. Hormone-receptor binding.

(a) Hormone H binds reversibly with receptor R:

$$H + R \leftrightarrow HR$$

(b) Complex HR reacts reversibly with itself to form a diimer HRRH:

$$HR + HR \leftrightarrow HRRH$$

(c) Protein G reacts reversibly with the dimer to produce an effector E:

$$HRRH + G \leftrightarrow E$$

Complete the following kinetic equations:

d[H]/dt = ?, d[R]/dt = ?, d[HR]/dt = ?,

d[HRRH]/dt = ?, d[G]/dt = ?, d[E]/dt = ?,

where [ ] indicates the initial concentration.

Why are some of these differential equations redundant?

How can reactants of redundant (non-independent) equations be related?

Question 14. Respiratory mass balances. The steady-state molar balances for an inert chemical species in the lungs are as follows:

$$Q_A[C_I - C_A] = [Q - Q_s][C_c - C_v]$$

$$QC_a = [Q - Q_s]C_c + Q_sC_v$$

$$C_c = \lambda C_A + [C_v - \lambda C_A]\varepsilon$$

The variables of this model are C_A, C_c, and C_a. All other symbols represent constants. Express these equations in the matrix form **Ax=b**, where the variables are given in terms of a vector of ratios:

$$\mathbf{x} = [C_A/C_v \quad C_c/C_v \quad C_a/C_v]^T$$

Obtain the matrix **A** and the vector **b**.

Question 15. Based on frequency content of action potentials and frequency response of two types of microelectrodes explain why

A. Metal microelectrode is a good sensor for axon action potential but poor sensor for cardiac action potential

B. Glass microelectrode is good sensor for both axon and cardiac action potentials. How to improve frequency response of glass microelectrode?

Question 16: The rate of sinus node pacemaker activity, and hence the heart rate, is modulated by neural inputs. If you were to block all neural inputs to the heart, would the heart rate decrease, increase , or remain unchanged? - explain

Student code:_________

Question 17. Reduction of iron oxide by carbon monoxide is of the following form:

$$Fe_2O_3(s) + CO(g) = Fe(s) + CO_2(g)$$

Balance this equation, and then, calculate how much carbon monoxide is required for reducing 5.3 tons of iron oxide. Determine first the weight of the CO needed and then, its approximate volume in m^3 at room temperature (about 20 °C) and normal atmospheric pressure.

Question 18. Find the value of sin 46° by approximating it with the first 3 terms of the appropriate Taylor series. Comment on the difference between the estimate and the true value.