1. Please check to ensure that you have a complete exam booklet. There are 22 numbered problems. Note that Problem 2 occupies 2 pages, Problem 3 occupies 2 pages, Problem 10 occupies 2 pages, Problem 22 occupies 6 pages. Including the cover sheet, you should have 31 pages. There should be no blank pages in the booklet.

2. The examination is closed book and closed notes. No reference material is allowed at your desk. A calculator is permitted.

3. All wireless devices must be turned off for the entire duration of the exam.

4. You may work a problem directly on the problem statement (if there is room) or on blank sheets of paper available from the exam proctor. Do not write on the back side of any sheet.

5. Your examination code number MUST APPEAR ON EVERY SHEET. This includes this cover sheet, the problem statement sheets, and any additional work sheets you turn in. DO NOT write your name on any of these sheets. Use the preprinted numbers whenever possible, or WRITE LEGIBLY!!

6. Under the rules of the examination, you must choose 8 problems to be handed in for grading. Each problem to be graded should be separated from the rest of the materials, stapled to the associated worksheets, and placed on the top of the appropriate envelope in the front of the exam room. DO NOT TURN IN ANY SHEETS FOR THE OTHER 17 PROBLEMS!!

7. The examination lasts 4 hours, from 9:30 AM to 1:30 PM EST.

8. When you hand in the exam:
   
   (a) Separate the 8 problems to be graded as explained above.

   (b) Check to see that your Code Number is in EVERY sheet you are turning in.

   (c) On the section at the bottom of this page, CIRCLE the problem numbers that you are turning in for grading.

   (d) Turn in this cover sheet (containing your code number) and the 8 problems to be graded.

   (e) All other material is to be placed in the discard box at the front of the room. You are not allowed to take any of the exam booklet pages from the room!

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Answer all the parts of the question.

a. (3pts) The following truth table describes the behavior of an encoder with an unusual priority. Based on the don't cares of the inputs, list the inputs from the highest priority to lowest.

<table>
<thead>
<tr>
<th>$IN_3$</th>
<th>$IN_2$</th>
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<th>$IN_0$</th>
<th>$OUT_1$</th>
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</table>

b. (5 points) Consider the circuits below. Here the nodes Q1, Q2, Q3 and Q4 are being observed. The timing diagrams for CLK and DATA are also given. Draw the timing diagram for the signals Q1, Q2, Q3 and Q4 in the space provided. Assume that the signals Q1, Q2 and Q3 are initially 0.

[Diagrams of the circuits are shown here.]

c. (2 points) Use 2's complement representation to perform the following computation. Use the minimum number of bits required to perform the computation.

i) -13-27
Problem 2 (Core: DSP-ECE2026)

The input to the above system is defined by

\[ x(t) = \sum_{k=-3}^{3} a_k e^{j100\pi kt}, \text{where } a_k = \begin{cases} \frac{1}{2\pi(4 + k^2)}, & k \neq 0 \\ \frac{1}{2}, & k = 0 \end{cases} \]

Assume that \( f_s = 400 \text{ Hz} \)

(a) Is \( x(t) \) periodic? If so, find the period \( T_0 \) in seconds. If not, explain why it is not periodic.

If periodic: \( T_0 = \)

If not periodic (explain):

(b) Plot the Discrete-Time Fourier Transform (DTFT) for \( x[n] \) (i.e., find \( X(e^{j\omega}) \)) (Label all complex amplitudes and the \( \omega \)-axis).
Problem 2 (Core: DSP-ECE2026)  

(c) The LTI system $h[n]$ is defined as:

$$h[n] = \delta[n - 1] + 2\delta[n - 4] + \delta[n - 9]$$

Find an expression for the magnitude and phase of the Discrete-Time Fourier Transform (DTFT) for $h[n]$ (i.e., find $|H(e^{j\omega})|e^{j\angle H(e^{j\omega})}$).

$$|H(e^{j\omega})| =$$

$$\angle H(e^{j\omega}) =$$

(d) For $x(t)$ given above, the output signal can be written as

$$y(t) = \sum_{k=0}^{3} B_k \cos(\omega_0 kt + \phi_k)$$

Determine the numerical values of the parameters:

$B_0$, $(B_1, \phi_1)$, $(B_2, \phi_2)$, $(B_3, \phi_3)$, and $\omega_0$.

$$B_0 =$$

$(B_2, \phi_2) =$

$(B_1, \phi_1) =$

$(B_3, \phi_3) =$

$\omega_0 =$
The attached C++ program compiles and executes without errors. In the table below, fill in the output lines produced by this C++ program in the table below. There may be extra spaces in the table.

<table>
<thead>
<tr>
<th>Output Line 1</th>
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<tbody>
<tr>
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<td>Output Line 31</td>
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5 of 31
// Program Code for ECE 2036 C++ Problem
#include <iostream>
using namespace std;
class test
{
public:
    test(int x);
    ~test()
    {
        cout << "Dest" << endl;
    }
    void x(test &y);
    int w;
};
test::test(int x)
: w(x+1)
{
    cout << "Cons" << endl;
}
void test::x(test &y)
{
    cout << y.w << endl;
    if (y.w>0) y.w = -y.w;
}
int main()
{
    test A(1);
    test B(0);
    A.x(A);
    B = A;
    cout << B.w << endl;
    int a[9]={0,1,2,3,4,5,6,7,8};
    int *aptr;
    aptr = &a[0];
    ++aptr;
    (*aptr)--;
    (*++aptr)++;
Problem 4 (Core: EDA-ECE2040)  

**Problem**

Analyze a circuit shown below.

![Circuit Diagram]

**PART I:** Assume that \( v_s(t) = 30 - 40e^{-5t}u(t) \).

(i) (2 points) Find the time constant of the natural response of \( i(t) \) in the units of second.

(ii) (4 points) Find the complete response for \( i(t) \).

**PART II:** Assume \( v_s(t) = 20\cos(\omega t) \) and the system is in the steady state.

(iii) (3 points) Find the network function \( H(\omega) \), defined by \( H(\omega) = \frac{V_o(\omega)}{V_s(\omega)} \).

(iv) (1 point) Find the corner frequency(-ies) of the network function.

No credits will be given for answers without the step-by-step work that is legibly written on the answer sheets.
Problem 5  (Core: CSS-ECE3020)  

A builder is constructing four houses on a street, as shown in the diagram to the right. Each house has two “adjacent” houses and one “opposite” house. (For example, houses B and D are adjacent to house A and house C is opposite house A.)

Assume there are six distinct possible house colors, one of which is green.

Calculate each of the following values. Clearly label each part and draw a box around your final numerical answer for each question. Additionally, to receive full credit, you MUST provide appropriate equations/calculations and a brief description of the rationale or logic for each answer.

For parts (A) – (D), assume that each house may be painted any of the six colors.

(A)  1 point – How many distinct arrangements of houses and colors are possible?

(B)  1 point – How many arrangements have each house painted a different color?

(C)  2 points – How many arrangements have at most two houses painted in each color?

(D)  3 points – Assume all color choices are equally likely. What is the probability that exactly two houses are painted green and are located adjacent to each other? What is the probability that exactly two houses are painted green and are located opposite of each other?

(E)  3 points – Assume that no house may be painted the same color as either of the adjacent houses and that all allowable color choices are equally likely. What is the probability that a house is painted the same color as the house located opposite it?
Problem 6 (Core: E&M-ECE3025)  

A time domain reflectometer (TDR) is connected to a transmission line system as shown below. The voltage V is recorded by the TDR with the source pulse shown below. Determine the transit times $\tau_1$ and $\tau_2$ and the impedances $Z_1$, $Z_2$, and $Z_3$. 

![Diagram of TDR and transmission line system](image-url)
Problem 7 (Core: E&M-ECE3030)

Assume that you have to budget for power needed for the following memory unit to operate properly: The cache operates at 1 GHz, the supply voltage is $V_{dd} = 2$V and L1 Instruction Cache has capacitance of 1.1 pF and activity factor of 0.9, L1 Data Cache has capacitance of 0.6 pF and activity factor of 0.3, L2 cache has $C=20$ nF and activity factor of 0.05.

(a) What is the power consumption of this system?

(b) One DRAM cell in L1 Cache has a storage capacitance equal to 1.5 fF. Its bit line is a poly-wire of size $0.5\mu m \times 250\mu m$ with length of 1mm and the copper resistivity is $15 \times 10^{-9} \, \Omega m$. What is the 50% delay of this DRAM cell?
Problem 8 (Core: Microsystems-ECE3040)  Code Number: __________

**Problem**

The following parameters of Si at 300 K may be useful:

\[ E_g = 1.12 \text{ eV}; \quad m^* = 1.09 \, m_0; \quad m^* = 1.15 \, m_0; \quad n_i = 1 \times 10 \, \text{cm}^{-3}; \quad N_C = 2.86 \times 10^{19} \, \text{cm}^{-3}; \quad N_V = 3.10 \times 10^{19} \, \text{cm}^{-3}; \quad \varepsilon_e = 11.8; \quad k = 8.62 \times 10^{-5} \, \text{eV} / \text{K} \]

The band-edge diagram along the vertical (x) direction of a Si n-channel MOSFET at 300 K is described by:

\[ E_C(x) = 1.02 \, \text{eV}, \quad x < 0 \, \text{cm} \]
\[ E_C(x) = 1.02 - (0.9e8)x^2 \, \text{eV}, \quad 0 \, \text{cm} < x < 1 \times 10^{-4} \, \text{cm} \]
\[ E_F(x) = 0 \, \text{eV}, \quad \text{for all } x \]

where \( x \) is in cm. This band edge diagram is sketched below.

(a) Calculate \( n \) and \( p \) in \( \text{cm}^{-3} \) at \( x = 0 \, \text{cm} \).

(b) Suggest possible values for the donor and acceptor densities \( N_A \) and \( N_D \) at \( x = 0 \, \text{cm} \). There is more than one set of possible values, but you are only expected to provide one set.

(c) Derive an expression for the electric field \( E(x) \) for \( x < 0 \, \text{cm} \) and \( 0 \, \text{cm} < x < 1 \times 10^{-4} \, \text{cm} \).

(d) Answer each of the following with one of these three: “left”, “right”, or “zero magnitude”.

(i) Direction of the diffusion current at \( x = 5 \times 10^{-5} \, \text{cm} \):

(ii) Direction of the drift current at \( x = 5 \times 10^{-5} \, \text{cm} \):

(iii) Direction of the total current at \( x = 5 \times 10^{-5} \, \text{cm} \):
The minimum incident solar energy at the location of the PV system is 5 kWh/m²/day. A 4 kW PV system is to be designed with 16 percent efficient panels rated 200 W each and installed on the roof of the house. The load is to be served by the electrochemical batteries which are charged to full capacity during the day (with charge/discharge cycle efficiency of 80 percent). The batteries are allowed to discharge 80 percent of their full capacity while feeding the load. Calculate the power of the night-time load which needs to be supplied from the batteries for 6 hours each night. NOTE: please assume that the battery capacity is chosen so as to receive the full daily energy produced by the system.
Problem 10 (Core: DSP-ECE3077)  

PROBLEM

In this problem, $X$ and $Y$ are independent and identically distributed random variables that are uniformly distributed on the interval $[0, 1]$. The probability density functions (pdfs) for $X$ and $Y$ are

$$f_X(x) = \begin{cases} 
1, & 0 \leq x \leq 1 \\
0, & \text{otherwise,}
\end{cases} \quad f_Y(y) = \begin{cases} 
1, & 0 \leq y \leq 1 \\
0, & \text{otherwise.}
\end{cases}$$

a. Calculate $P(X^2 \leq Y)$, the probability that $X^2$ is less than or equal to $Y$.

b. Let $Z$ be another random variable which is the maximum of $X$ and $Y$, $Z = \max(X, Y)$. Find the probability density function for $Z$. 
c. Now set $Z = X^2$. Find the probability density function of $Z$. 
Problem 11 (Core: S&C-ECE3084)  Code Number: __________

**PROBLEM**

**Part a**

Given the function

\[ f_n(t) = n^2 \left[ u\left(t + \frac{1}{n}\right) - u(t) \right] - n^2 \left[ u(t) - u\left(t - \frac{1}{n}\right) \right] \]

Plot the convolution \( g_n(t) = f_n(t) * u(t) \). What is the limit of \( g_n \) as \( n \to \infty \)?

**Part b**

Consider the functions \( f_n(t) = \delta(t) \sin(t)^n, n = 1, 2, \ldots \). Plot the second derivative of \( f_n(t) \) for \( n = 1, 2, \ldots \).
Problem 12 (Core: VLSI-ECE3150)

1. Design a 2-to-4 decoder using inverters, NANDs with up to four inputs, and NORs with up to four inputs. Your goal is to use as few gates as possible. Assume that inputs are available in both complemented and uncomplemented forms. Recall that a 2-to-4 takes in two bits and outputs four bits with a one-hot encoding, e.g., input 00 results in output 0001 while input 01 results in output 0010. Clearly label all inputs and outputs. In your design, use ______ for NAND, ______ for NOR and ______ for an inverter.

2. Assuming that the mobility of electrons is four times as high as that of holes, design in CMOS a 4-input NAND gate with equal rise and fall times. Use symbol $w$ to indicate the width of a minimum-size nFET, use symbol $\uparrow$ for a pFET and use symbol $\downarrow$ to designate an nFET.
PROBLEM

A 9 kVA, 208 V (L-L), 1200 rpm, 3-phase Y connected stator, synchronous generator has a stator resistance of 0.3 ohm per phase, and a synchronous reactance of 5 ohm per phase. The rotational mechanical loss is 500 W. No saturation. Field winding resistance equals 4.5 ohm. When the generator produces an output of rated kVA at rated voltage, and 0.8 pf lagging, the field current is 5 amp, determine

a) The voltage regulation
b) The efficiency
The common source amplifier shown below is driven by a source with an internal resistance of 1 kΩ. Assuming that the amplifier is unloaded and that the DC voltage at the output is 2.5 V, compute:

- The low-frequency voltage gain of the amplifier
- The upper 3dB frequency of the voltage gain using the method of open-circuit time constants.

You may make the following simplifying assumptions:

- Neglect the effect of $\lambda$ in the DC analysis (i.e. assume $\lambda = 0$).
- Neglect the body effect both in DC and in small-signal analysis.
- Assume that the gates of M1 and M2 are a small-signal ground.

Recall that for a MOSFET in saturation $I_D = (K'/2)(W/L)(V_{GS} - V_T)^2$ and the small-signal parameters are:

\[
\begin{align*}
g_m &= \sqrt{2K'(W/L)I_D} \\
C_{GD} &= C'_{OL}W \\
C_{DB} &= \frac{C_{db0}}{(1 + |V_{DB}|/\phi_{jd})^{m_{jd}}} \\
r_o &= 1/(\lambda I_D) \\
C_{GS} &= C'_{OL}W + (2/3)C'_{ox}WL \\
C_{SB} &= \frac{C_{sb0}}{(1 + |V_{SB}|/\phi_{js})^{m_{js}}}
\end{align*}
\]

Use the following MOSFET parameter values: n-channel: $K'_n = 25 \mu A/V^2$, $V_{TN} = 0.75 \text{ V}$, $\lambda_n = 0.01 \text{ V}^{-1}$, $C'_{ox} = 830 \mu F/m^2$, $C_{db0} = C_{sb0} = 160 F$, $\phi_{jd} = \phi_{js} = 0.7 \text{ V}$, $m_{jd} = m_{js} = 0.33$, $C_{OL} = 100 \text{ pF/m}$; p-channel: $K'_p = 10 \mu A/V^2$, $V_{TP} = -0.75 \text{ V}$, $\lambda_p = 0.02 \text{ V}^{-1}$, $C'_{ox} = 830 \mu F/m^2$, $C_{db0} = C_{sb0} = 770 F$, $\phi_{jd} = \phi_{js} = 0.7 \text{ V}$, $m_{jd} = m_{js} = 0.33$, $C'_{OL} = 150 \text{ pF/m}$.
Problem 15 (Core: S&C-ECE3550)  

**PROBLEM**

i) Let \( p(\cdot) \) and \( q(\cdot) \) be Hurwitz polynomials with real coefficients of degree \( n \) with all their roots on the real axis, and no roots in common. Prove that the root locus for the open loop transfer function \( H(s) = \frac{p(s^2)}{sq(s^2)} \) cannot cross the imaginary axis, for nonzero values of the gain.

ii) Let \( 0 < z_1 < z_2 < \ldots < z_n \). Show, using root locus techniques, that the polynomial

\[
r(s; \lambda) = \lambda s q_\lambda(s^2) + (1 - \lambda) p(s^2)
\]

is Hurwitz for all \( 0 < \lambda < 1 \), where

\[
p(s) = \prod_{i=1}^{n} (s + z_i), \quad q_\lambda(s) = \prod_{i=2}^{n} (s + \lambda z_i + (1 - \lambda) z_{i-1}).
\]
PROBLEM

When you PC needs to find out the IP address of www.cnn.com, the resolver software send a DNS lookup request (query) to a Local DNS Server. What are the three types of DNS servers (in order) that the Local DNS Server will send queries to find the answer (assuming its cache is empty)?

1. 

2. 

3. 

Identify the following parts of the URL "http://www.ece.gatech.edu/academics/index.html"

4. "gatech.edu" 

5. "www" 

6. "http" 

How does TCP know that a receiving computer has received each segment of a message stream?

7. 

What is the advantage of UDP relative to TCP for services such as DNS and NTP?

8. 

How does a CDN (like Akami) improve the delivery of Web content for its customers (like CNN)?

9. 

A "cellular" network gets its name because the area it covers is

10. 

20 of 31
Consider an air-filled parallel-plate waveguide shown below. It is possible to construct the mode electric field solution as a superposition of plane waves of equal amplitude, whose wavevectors, \( \mathbf{k}_u \) and \( \mathbf{k}_d \), are also shown. The wavevector magnitudes are identical (\(|\mathbf{k}_u| = |\mathbf{k}_d| = k = \omega / c\)).

![Diagram](image)

TE modes are considered, in which the electric field vector points in the \( y \) direction (normal to the page). The two wavevectors will have identical \( x \) and \( z \) components, and can be written in terms of these as:

\[
\mathbf{k}_u = k_x \mathbf{a}_x + \beta \mathbf{a}_z \quad \text{and} \quad \mathbf{k}_d = -k_x \mathbf{a}_x + \beta \mathbf{a}_z
\]

The total \( y \)-directed electric field in the guide can now be written in phasor form as the sum of the two waves as:

\[
E_y(r) = E_u + E_d = E_0 e^{-jk_u z} + E_0 e^{-jk_d z} e^{j\phi}
\]

where \( E_0 \) is the constant amplitude of each wave, and where the position vector is \( r = za_x + za_z \). \( \phi \) is the reflective phase shift at either boundary, which for the metal guide is equal to \( \pi \) radians.

a) Carry out the scalar products in the exponents and thus write the total field phasor in terms of \( z \) and \( \phi \). Simplify your result by using the Euler identity \( \sin(x) = (1/2j)(e^{jx} - e^{-jx}) \).

b) Express your above result in real instantaneous form by multiplying by \( e^{j\omega t} \) and taking the real part. Your answer should be in the form of the product of a standing wave in \( x \) and and traveling wave in \( z \).

c) Find the expression for \( k_x \) (in terms of known parameters) that will enable \( E_y \) to have the required value of zero at the guide boundaries (\( z = 0, d \)).

d) Knowing that \( k \), \( k_x \), and \( \beta \) form the sides of a right triangle, write an expression for \( \beta \) and from this, find an expression that will give the minimum required radian frequency \( \omega_{\text{min}} \) that will yield a propagating wave.
Problem 18 (Specialized: Optics-ECE4500)  Code Number: _________

Problem

Fabry–Pérot Interferometer for Refractive Index Measurement

The surfaces of a slab of homogeneus material of unknown refractive index $n$ are coated with semi-reflective films to form a Fabry–Pérot interferometer. The slab has a thickness of $d = 10 \text{ mm}$, and is placed in front of a convex lens with focal length $f = 300 \text{ mm}$. Interference results are observed on a screen placed at the focal plane of the lens.

(1) If the slab is illuminated with a plane wave of free-space wavelength $\lambda$ at normal incidence (along the optical axis of the system), find the relation between $n$ and $\lambda$ for constructive interference (bright spot) to occur on the screen.

(2) If the slab is illuminated with a plane wave of free-space wavelength $\lambda$ at a small incident angle $\theta$ with respect to the optical axis of the system, find the relation between $n$, $\lambda$ and $\theta$ for constructive interference to occur on the screen.

(3) Now the slab is illuminated with a sodium lamp which emits yellow light ($\lambda = 589.3 \text{ nm}$) along all directions. A bright spot is formed at the screen center, and the diameter of the first bright ring is 6 mm. Determine the refractive index $n$ of the slab material.
Consider the optical data link shown below, in which the total span length is \( L = L_1 + L_2 = 150 \text{ km} \). The optical transmitter provides average power \( P_t = 10 \text{ dBm} \) at carrier wavelength \( \lambda_m \); the receiver has sensitivity \( P_{rec} = -30 \text{ dBm} \), which yields a specified BER. Two single mode fibers make up the span, and these have loss and dispersion specifications as indicated. The second fiber is dispersion-compensating fiber (DCF); this fiber, while designed to have high negative dispersion, exhibits relatively high loss.

\[
\begin{align*}
\text{Tx} & \quad 10.0 \text{ dBm} & \quad D_1 = +6.0 \text{ ps/nm-km} & \quad L_1 & \quad \alpha_2 = 3.0 \text{ dB/km} & \quad \text{Rx} \\
& & \quad \alpha_1 = 0.2 \text{ dB/km} & \quad L_2 & & \quad -30.0 \text{ dBm}
\end{align*}
\]

To achieve an overall dispersion penalty for the link that is 1 dB (the dispersion limit) or less, the path average dispersion magnitude, \(|D_{avg}|\), must be less than or equal to 2.0 ps/nm-km, where

\[
D_{avg} = \frac{D_1 L_1 + D_2 L_2}{L_1 + L_2}
\]

a. Find the lengths, \( L_1 \) and \( L_2 \), such that the link exhibits the minimum loss within the dispersion limiting constraint as defined above.

b. Determine whether or not the link is viable from a loss standpoint, as a result of your part a computations. If not, specify the minimum required gain in dB of an optical amplifier that should be positioned in line to compensate loss.

c. With the link constructed as per your results, and with the amplifier (if needed) installed, will this link be dispersion-limited, or loss-limited, or both? Explain.

d. Suppose the optical carrier wavelength is shifted to a different value, and that loss is to first order invariant with wavelength. It is known, however, that dispersion in both fibers will vary significantly with wavelength. What must be true about the relation between fiber dispersions in this link so that your previous results will hold true at all wavelengths? You should display this requirement in a simple formula.
A uniform oxide layer of 0.4μm thickness is selectively etched to expose the bare silicon surface in some locations on a wafer (as shown below). Following the etch, a second oxidation of the wafer at 1000°C in H₂O grows 0.2μm on the bare silicon surface region.

a) [7 pts] Following the second oxide growth, how much new silicon dioxide grows in the region where 0.4μm silicon dioxide thickness already exists? Assume A=0.252 μm and B=0.316 μm²/hr.

b) [3 pts] Carefully re-sketch the wafer showing the location of the NEW oxide (due to second re-oxidation) relative to the OLD oxide (i.e., the initial 0.4μm oxide layer). No need to show dimensions.

![Diagram of wafer with oxide layers]
(3 pts) Cardiovascular Anatomy. Fill in the blanks with the best possible answer.

The heart has ______ chambers, named the __________ and the ___________.

The _______ side of the heart delivers blood to the lungs, and the _______ side to the rest of the body.

The heart fills during diastole, and ejects blood during _____________.

(4 pts) Draw a lumped electrical circuit model of the chamber which delivers the blood directly into the aorta, showing all of the following as circuit elements: (1) pressure filling the chamber, (2) pressure in the aorta, (3) compliance of the chamber, (4) the input valve to the chamber, and (5) the output valve from the chamber. Label your diagram completely.

(3 pts) Stroke volume is the volume of blood pumped by the heart in a single heartbeat, and is an important parameter to measure clinically. From one heartbeat to the next, stroke volume is not constant, and actually varies due to the dynamics of breathing.

Consider first the impact of breathing on the filling of the heart: do you expect the heart to receive more blood back from the veins during peak inspiration or peak expiration? Why? (Consider the pressures in the chest cavity, and how they change with respiration.)
1) The organism in question is a (hypothetical) squid living below the ice cap of Europa (also hypothetical that there would be water in liquid form there). He is an interplanetary friend of SpongeBob. He has a body temperature 3°C above the freezing point of water.

a) Calculate the Nernst potential for each of the following ions:

- $[K^+]_i = 150 \text{ mM}$ $[K^+]_e = 10 \text{ mM}$
- $[Na^+]_i = 12 \text{ mM}$ $[Na^+]_e = 150 \text{ mM}$
- $[Cl^-]_i = 25 \text{ mM}$ $[Cl^-]_e = 170 \text{ mM}$
- $[Ca^{2+}]_i = 180 \text{ mM}$ $[Ca^{2+}]_e = 20 \text{ mM}$

**Constants:**

- $R = 8.314 \ \frac{\text{J}}{\text{K} \cdot \text{mol}}$
- $F = 96485 \ \frac{\text{C}}{\text{mol}}$
- Avogadro’s Number $= 6.022 \times 10^{23} \ \frac{\text{atoms}}{\text{mol}}$
Problem 22 (Specialized: BioEng-ECE4784)    Code Number: _________

Through Hodgkin-Huxley type experiments it is determined that the membrane conductance for $\text{Cl}^-$ and $\text{Ca}^{2+}$ vary with time and voltage during the action potential. The conductances for $\text{K}^+$ and $\text{Na}^+$, however, are non-zero and do not change with time or voltage.

b) Sketch the full circuit model for the membrane, including all components. Explain the physiological origin of each of the components. What kind of protein channels must be present for each ion identified?
c) Write the differential equation for the total membrane current associated with the model.


d) For this organism, you find that the early part of the action potential is due to an influx of Cl^- and the latter part of the action potential is due to an efflux of Ca^{2+}. Speculate on the differences you would expect to find in the amino acid residue types in the voltage gated Ca^{2+} channels and the voltage-gated Cl^- channels.
2) Using the following resting channel conductance and density values for a mammalian axon, calculate the sodium and potassium membrane conductance of a section which has a diameter of 0.1 mm and a length of 1 mm.

- $\text{Na}^+$: channel conductance of 10 pS; channel density of 1000 per $\mu$m
- $\text{K}^+$: channel conductance of 5 pS; channel density of 300 per $\mu$m
3) Compare and contrast semiconductor pn junctions and electrically active membranes. Be thorough in your comparison, indicating what is remarkably similar and what is not. Also include a description of the physiological make-up of the plasma membrane, i.e. draw a picture.
4) Equation (1) is for Johnson noise. At a membrane voltage, $V_m$, of 70 mV and a Nernst potential of 20 mV for Na$^+$, what will be the membrane current through a single Na$^+$ channel. Also calculate the signal to noise ratio of that channel in dB.

$$i_n = \sqrt{\frac{4k_B T \Delta f}{R}}$$  \hspace{1cm} (1)

**Constants**

- $K_B = 1.380 \times 10^{23} \frac{J}{K}$