1. This is a closed book/closed notes exam.

2. A calculator, which may be a graphing calculator, or analytical software, such as MatLAB, on a computer may be used to perform the required calculations.

3. A computer may be used during the exam to download the test, to write answers on the exam electronically, to submit answers on Scholar, and to upload a file containing the work that you performed when calculating the answers to the problems.

4. Formatting answers:
   a. Use proper units and prefixes
   b. Use the passive sign convention
   c. Final answers should be expressed using three significant figures

5. Show all work.
   a. Full credit will not be given for correct answers without work that supports the answers.
   b. Partial credit will only be given if sufficient work is shown so that errors in calculations or conceptual errors can be traced.
1. In your own words, briefly explain (1-3 sentences each) the statements below. Where appropriate, mention any fundamental principles, laws, or equations that can be used to support your explanation.

   a. The sum of the powers in a circuit must be equal to zero.

      This is an outcome from the conservation of energy. The power generated in any circuit must be equal to the power dissipated.

   b. If \( I_1 = 1 \text{ mA} \cos(30t) \), the average current produced by the current source in the circuit to the right is equal to 0 mA, but the instantaneous current is usually not equal to 0 A.

      Since the integral of a sine or cosine function is equal to zero, the average value of that function is equal to zero. \( \int_0^n T 1 \text{mA} \cos\left(\frac{2\pi}{T}t\right) dt = 0 \) where \( T = \frac{2\pi}{30} \text{ s} \) and \( nT \) is an integral number of periods of the cosine function. However, the value of \( 1 \text{ mA} \cos(30t) \) is only zero when \( 30t \) is an odd multiple of 90°. A sketch of a cosine function would also be appropriate.

   c. The current sources in the circuit to the right cannot be connected in the manner shown.

      The current flowing through two components in series must be the same. A wire between the two current sources can’t store the excess 0.1 mA of current.

   d. The force required to move electrons through a metal resistor depends on the physical dimensions of the resistor as well as which metal is used to make the resistor.

      The force, \( F \), is equal to \( F = IR \). \( I \) is the movement of electrons per second and \( R = \frac{L}{A} \rho \). \( L/A \) is the ratio of the length to cross-sectional area of the resistor (the physical dimensions) and \( \rho \) contains the material properties of the material used to make the resistor.
2. The power generated or dissipated in each of the components below is the same: $P = -50 \text{ mW}$.

![Diagram of four components with voltages and currents]

a. Determine the magnitude of the missing parameter (the current or voltage) for each component, given the information provided in the image. All solutions are based upon $P = VI$, where the power is equal to -50 mW.

i. Value of missing parameter for component i:

$I = -50 \text{ mW}/6000 \text{ V} = -8.33 \mu\text{A}$ The answer may be +8.33 $\mu\text{A}$ if the direction of current is drawn in the opposite direction shown above.

ii. Value of missing parameter for component ii:

$V = -50 \text{ mW}/-2 \text{ mA} = 25 \text{ V}$

iii. Value of missing parameter for component iii:

$V = -50 \text{ mW}/90 \text{ A} = 0.556 \text{ mV} \text{ or } 556 \mu\text{V}$

iv. Value of missing parameter for component iv:

$I = -50 \text{ mW}/-3 \text{ V} = 16.7 \text{ mA}$

b. Label the image with the missing parameter to show either the direction of the current or the polarity of the voltage calculated.
3. For the circuit below:

\[ R_{eq} = R_1 + \frac{R_2 R_3}{R_2 + R_3} + R_4 \quad \text{or} \quad R_1 + \left( \frac{1}{R_2} + \frac{1}{R_3} \right)^{-1} + R_4 \]

b. Simplify the equation for \( R_{eq} \) if \( R_3 = 0 \) \( \Omega \).

\[ R_{eq} = R_1 + \frac{R_2(0\Omega)}{R_2 + (0\Omega)} + R_4 = R_1 + R_4 \]

c. Simplify the equation for \( R_{eq} \) if \( R_3 = \infty \) \( \Omega \).

\[ R_{eq} = R_1 + \frac{R_2(\infty \Omega)}{R_2 + (\infty \Omega)} + R_4 = R_1 + R_2 + R_4 \]

d. Calculate the value for \( R_3 \) when:

\[ R_{eq} = 9 \text{ k}\Omega \quad R_1 = 3 \text{ k}\Omega \quad R_2 = 12 \text{ k}\Omega \quad R_4 = 2 \text{ k}\Omega \]
4. For the circuit below:

a. Calculate the value of the voltage $V_{R3}$ and current $I_{R5}$.

There are several approaches that can be used to solve for the voltage and current. Voltage division is the most likely one to be used for $V_{R3}$. I have shown two of the ways that could be used to find $I_{R5}$.

\[ V_{R3} = \frac{3k\Omega}{3k\Omega + 2k\Omega} (6mV) = \frac{18}{5} mV = 3.60mV \text{ or } 3.6 \text{ mV} \]

\[ I_{R5} = \frac{6mV - V_{R3}}{4k\Omega} = 0.6 \mu A \text{ or } 600nA \]

or

\[ I_{req} = \frac{6mV}{2.5k\Omega} = 2.4 \mu A \]

\[ I_{R3} = 2.40 \mu A - \frac{6mV}{10k\Omega} = \frac{6mV}{10k\Omega} = 1.2 \mu A \]

\[ I_{R5} = \frac{R_4}{R_4 + R_5} I_{R3} = \frac{4k\Omega}{4k\Omega + 4k\Omega} (1.2mA) \]

\[ = 0.6 \mu A \text{ or } 600nA \]
b. Calculate the power for R3, R5, and V1.

\[ P_{R3} = I_{R3} V_{R3} = I_{R3}^2 R_{R3} = V_{R3}^2 / R_{R3} \]

\[ P_{R3} = 3.6mV(1.2\mu A) = +4.32nW \]

\[ P_{R5} = I_{R5} V_{R5} = I_{R5}^2 R_{R5} = V_{R5}^2 / R_{R5} \]

\[ P_{R5} = 2.4mV(0.6\mu A) = +1.44nW \]

\[ P_{V1} = I_{V1} V_{vi} = -2.4\mu A(6mV) = -14.4nW \]
5. For the circuit below, determine $V_{R4}$, $V_{R5}$, $I_{R4}$, and $I_{R5}$.

R5 is in parallel with V1 so $V_{R5} = 15\, V$.

$$I_{R5} = \frac{V_{R5}}{R5} = \frac{15\, V}{12\, k\Omega} = 1.25\, mA$$

Again, there are several ways that can be used to solve for $V_{R5}$ and $I_{R4}$.

One way is the solve for the equivalent resistance of $R1+R2 \parallel R3+R4$. The current flowing through the equivalent resistor is equal to $I_{R4}$. Then, voltage division can be used to find $V_{R4}$.

$$R_{eq} = R1 + \frac{R2R3}{R2 + R3} + R4 = 2k\Omega + \frac{2k\Omega(8k\Omega)}{2k\Omega + 8k\Omega} + 1k\Omega = 4.6k\Omega$$

$$I_{eq} = I_{R4} = \frac{15\, V}{4.6k\Omega} = 3.26\, mA$$

$$V_{R4} = \frac{R4}{R_{eq}} V1 = \frac{1k\Omega}{4.6k\Omega} 15\, V = 3.26\, V$$

or apply Ohm's Law $V_{R4} = I_{R4} R4 = 3.26\, mA(1k\Omega) = 3.26\, V$
6. For the circuit below, determine $V_{R3}$ and $I_{R3}$.

Again, there are multiple ways to solve the problem. A few approaches are shown below.

\[ R_{eq} = \frac{R_2 R_3}{R_2 + R_3} = 4 \Omega \]

\[ I_{R3} = \frac{R_2}{R_2 + R_3} (-4A) = \frac{6\Omega}{6\Omega + 12\Omega} (-4A) = -1.33A \]

or

\[ I_{R3} = \frac{R_{eq}}{R_3} (-4A) = \frac{4\Omega}{12\Omega} (-4A) = -1.33A \]

\[ V_{R3} = R_{eq} (-4A) = 4\Omega (-4A) = -16V \]

or

\[ V_{R_{total}} = (R_1 + R_{eq})(4A) = 28V \]

\[ V_{R3} = -28V \left( \frac{R_{eq}}{R_1 + R_{eq}} \right) = -16V \]
7. Nodal Analysis:
   a. Label the currents and voltages on the circuit below appropriately for nodal analysis.
   b. Write the **complete** set of equations that will be used to solve for the nodal voltages for the circuit below.

Partial credit will only be given if you label voltages and currents on the circuit.

![Circuit Diagram](image)

The specific equations written will depend on the choice of ground and selection of current direction. When they write the equations, they should recognize that there is current flowing through each of the voltage sources.

For the case shown:

**KCL equations:**
- Node A: \( I_1 = I_{V1} \)
- Node B: \( I_{V2} = IR_1 + IR_2 \)
- Node C: \( IR_2 + IR_4 + IR_6 = IR_3 + I_2 + IR_5 \)
- Node D: \( I_{V1} = IV_2 + IR_4 + IR_7 \)
- Node E: \( IR_7 = IR_6 \)

**Ohm’s Law**
- \( IR_1 = VB/R_1 \)
- \( IR_2 = (VB-VC)/R_2 \)
- \( IR_3 = VC/R_3 \)
- \( IR_4 = (VD-VC)/R_4 \)
- \( IR_5 = VC/R_5 \)
- \( IR_6 = (VE-VC)/R_6 \)
- \( IR_7 = (VD-VE)/R_7 \)

**Extra required equations:**
- \( V_1 = VA - VD \)
- \( V_2 = VD - VB \)