Problem 5.1: A semiconductor diode can be used as a variable attenuator:

\[ i_D = I_S \left( e^{\frac{qv_D}{kT}} - 1 \right). \]

(A) Derive an expression for the incremental conductance \( g \) of the diode. Assume that \( e^{\frac{qv_D}{kT}} \gg 1 \). That is, the current \( I \) is large enough so that the diode is well into the forward, or conducting, region.

(B) Show that \( g \) can be expressed as \( g = I \left( \frac{q}{kT} \right) \).

(C) Draw a complete incremental (small-signal) model for the circuit above. Explain why the current source does not appear in this model.

(D) Derive an expression for the attenuation of the circuit. That is, derive an expression for \( A \):

\[ A = \frac{v_d}{v_i} \]

where \( v_d \) is the incremental component of the diode voltage. Assume \( R \gg \frac{1}{g} \) and show that the attenuation is proportional to \( I \).

(E) If the magnitude of \( v_d \) is too large, this voltage will be distorted because the linear approximation implied in the definition of \( g \) becomes invalid. What is a reasonable upper bound for \( |v_d| ? \)  

\textbf{Hint:} Think Taylor series expansion of \( i_D = f(v_D) \).
Problem 5.2: The Gizmo whose circuit symbol is shown below is an electronic valve. The output characteristic of the Gizmo is shown as well.

The Gizmo functions as an amplifier in the circuit shown below:

(A) When no signal is present, i.e., when \( v_{IN} = V_{IN} \), the circuit is to have a current at \( P \) of \( i_P = 3 \text{mA} \). That is, the quiescent or operating-point current is to be \( I_P = 3 \text{mA} \).

Specify the operating-point value of \( V_{IN} \) that will produce the desired operating point.

Hint: Think load line.

(B) What is the value of \( V_{PC} \) at the operating point?
(C) An incremental model for the Gizmo at any operating point in the output characteristics is shown below.

\[ r_p \text{ and } \mu \text{ are constants which can be derived directly from the output characteristics above.} \]

(D) Assume \( r_p = 1.5k\Omega \) and \( \mu = 15 \).

(These are not the correct values corresponding to the output characteristics above, but will do for this part of the problem)

Draw a complete incremental model for the amplifier circuit shown above. Label all component values.

(E) Calculate the incremental voltage gain of this amplifier:

\[ A_v = \frac{v_{out}}{v_{in}} \]

Where \( v_{in} \) and \( v_{out} \) are the incremental components of the input and output voltages respectively.

(F) For extra credit, determine the approximate correct values of \( r_p \) and \( \mu \) from the output characteristics.

**Problem 5.3:** A FET is used as the control valve in the amplifier circuit shown below.

(A) Draw and label the complete incremental model of this amplifier.

(B) Derive an expression for the incremental voltage gain \( A_v = \frac{v_o}{v_i} \) in terms of \( R_S, R_L \), and the transconductance \( g_m \).
(C) Assume now that the source of the supply voltage $V$ has been damaged and produces in addition to $V$ a noise source $v_n$. The defective supply can be modeled as:

![Diagram of a noisy voltage source](image)

Draw and label an incremental model for the amplifier which takes into account this noisy voltage source.

(D) Using that model, determine the component of $v_o$ that results from $v_n$.

**Hint:** Think superposition.