NAME:

Specs: All resistors are 0.25 W and 5%. All semiconductors are made of silicon with the exception of the LEDs which have a forward bias voltage of 1.7 V and need about 10 mA of current to be brightly lit. All transistors have $\beta = 200$. The zener diode has a zener voltage of 5.7 V.

Problem 1. Consider the power supply circuit below. $V_{in}$ is supplied by a 9 V commercial battery. Depending on the battery life time and the current drawn from it, $V_{in}$ ranges from 7.5 to 9.5 V. The current $I_L$ is well within the range for this circuit to operate as a regulator.

a) What is $V_L$
b) Show that the BJT is always in the active-linear region. (10pts)

1) The zener diode is in the zener region because it is reversed biased by $V_{in}$ and $V_{in} > 5.7$ V. Thus, $V_D = -5.7$ V.
2) BJT is not in cut-off because $I_E = I_L > 0$. Thus $V_{BE} = 0.7$ V.

a) From KVL: $V_D + V_{BE} + V_L = 0 \rightarrow V_L = -V_D - V_{BE} = 5.7 - 0.7 = 5$ V.

b) By KVL: $-V_{in} + V_{CE} + V_L = 0 \rightarrow V_{CE} = V_{in} - V_L = V_{in} - 5$

But, $7.5 < V_{in} < 9.5 \rightarrow 7.5 - V_L < V_{in} - V_L < 9.5 - V_L$

Substituting for $V_L = 5$ V, we get $2.5 < V_{CE} < 4.5$ V

Since, $V_{CE} > V_\gamma = 0.7$V, BJT has to be in active-linear state.
Problem 2. Consider the circuit below. a) What is the current in LED when \( V_{in} = 0 \), b) What is the current in LED when \( V_{in} = 5 \), c) For what range of \( V_{in} \) LED will be ON, d) Modify the circuit such that LED will switch ON (or OFF) at \( V_{in} = 2.5 \) V (20pts).

From the circuit, we note that the current in LED is \( I_C \) and the voltage across resistor \( R_2 \) is \( V_{BE} \). Thus:

Ohm’s Law: \( I_1 = (V_{in} - V_{BE})/10k \)

Ohm’s Law: \( I_2 = V_{BE}/10k \)

KCL: \( I_1 = I_2 + I_B \)

a) \( V_{in} = 0 \).

Assume that BJT is in cut-off: \( I_B = 0 \), \( V_{BE} < 0.7 \) V.

Using \( I_B = 0 \) in KCL above, we have \( I_1 = I_2 \) and substituting for \( I_1 \) and \( I_2 \) from Ohm’s Law above we get:

\( (V_{in} - V_{BE})/10k = V_{BE}/10k \rightarrow V_{BE} = 0.5V_{in} = 0 \).

Since \( V_{BE} = 0 \), BJT is in cut-off, \( I_B = 0 \) and \( I_C = 0 \) and LED is OFF.

b) \( V_{in} = 5 \). Assume that BJT is NOT in cut-off (either active-linear or saturation):

\( V_{BE} = 0.7 \) V, \( I_B > 0 \). Then:

\( I_1 = (V_{in} - V_{BE})/10k = 4.3/10k = 0.43 \) mA

\( I_2 = V_{BE}/10k = 0.7/10k = 0.07 \) mA

\( I_B = I_1 - I_2 = 0.36 \) mA.

Since \( I_B > 0 \), our assumption of BJT NOT in cut-off is justified.

To find, \( I_C \), we assume that BJT is in saturation: \( V_{CE} = 0.2 \) V, \( I_C/I_B < \beta \)

Writing KVL in CE circuit gives:

\( 5 = 330I_C + V_{LED} + V_{CE} \rightarrow 330I_C = 5 - 1.7 - 0.2 = 3.1 \rightarrow I_C = 9.4 \) mA

Since \( I_C/I_B = 9.4/0.36 = 26 < 200 \) our assumption of BJT in saturation is justified. Thus, LED current is \( I_C = 9.4 \) mA and LED is ON.

c) LED will turn on at a certain “threshold” \( V_{in} \) such that BE junction is forward biased, \( V_{BE} = 0.7 \) V and \( I_B > 0 \), but \( I_B \) can be very small (the threshold is when \( V_{BE} = 0.7 \) V and \( I_B \approx 0 \)). From KCL and Ohm’s Law equations above, we have:

\( I_2 = V_{BE}/10k = 0.7/10k = 0.07 \) mA \( \rightarrow I_1 = I_2 + I_B \approx 0.07 \) mA

\( I_1 = (V_{in} - V_{BE})/10k = 0.07 \) mA \( \rightarrow V_{in} = 0.7 + 0.7 = 1.4 \) V.

So, LED is ON for \( 1.4 \leq V_{IN} \leq 5 \) V.

d) At the “threshold” value of \( V_{in} \) that switches the LED ON (or OFF), we have \( V_{BE} = 0.7 \) V and \( I_B \approx 0 \). Then, from KCL above \( I_1 = I_2 \) and Ohm’s Law across \( R_1 \) & \( R_2 \) gives:

\( (V_{in} - V_{BE})/R_1 = V_{BE}/R_2 \rightarrow V_{in} = V_{BE}[1 + R_1/R_2] \)

For \( V_{in} = 2.5 \) V and \( V_{BE} = 0.7 \) V, we get: \( R_1/R_2 = 2.57 \). Thus, we should modify the above circuit by either:

1) Keep \( R_1 = 10 \) kΩ and change \( R_2 = 10/2.57 = 3.9 \) kΩ

2) Keep \( R_2 = 10 \) kΩ and change \( R_1 = 10 \times 2.57 \approx 26 \) kΩ.