Name: ______________________________

Problem	**Points**	**Score**
1	10	
2	10	
3a	10	
3b	10	
4	10	
5	10	
6a	10	
6b	10	
6c	10	
6d	10	
Total	**100**	

Notes:

1. The exam is closed book / closed notes. You are allowed a copy sheet — only **one** side of **one** standard US-size (8.5” x 11”) sheet of paper — on which you can write relevant information such as equations.

2. Please show **all** work. Incorrect answers with no supporting explanations or work will be given no partial credit.

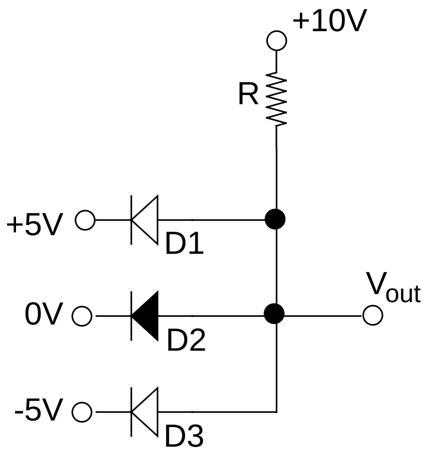
3. If I cannot read or follow your solution, it is wrong; and no partial credit will be given —**PLEASE BE NEAT**!

4. Please indicate clearly your answer to every problem.

5. There is sufficient space after each problem to write your solution. In case you need extra paper please see the instructor.

6. Assume an offset diode model with $V_\gamma = 0.7\text{V}$ unless specified otherwise. Assume $V_{BE} = 0.7\text{V}$ for a transistor in active region unless specified otherwise.

Problem No. 1:



Determine which diodes are forward biased and which are reverse biased in the adjacent circuit, and find the output voltage V_{out}.

Note that D2 is an ideal diode, while D1 and D3 are offset diodes.

If the current through the resistor cannot exceed 10 mA, what is the smallest possible value of the resistor R?

Solution:

Assume that all three diodes are reverse biased. Then all three act like open circuit, and therefore no current flows in the circuit. As a result $V_{out} = 10V$.

This will create a voltage drop of

$10V - 5V = 5V > 0.7V$ across D1, making it forward biased;

$10V - 0V = 10V > 0$ across D2, making it forward biased; and

$10V - (-5)V = 10V + 5V = 15V > 0.7V$ across D3, making it forward biased.

Thus our assumption is wrong, at least one of the diodes has to be forward biased. Since D3 has the largest voltage drop across it in the above calculation, it is most likely to be forward biased.

So let D1 and D2 be reverse biased and D3 be forward biased. This causes a drop of $0.7V$ across D3, and therefore

$$V_{out} = -5V + 0.7V = -4.3V.$$

This causes a voltage drop of

$-4.3V - 5V = -9.3V < 0.7V$ across D1, making it reverse biased; and

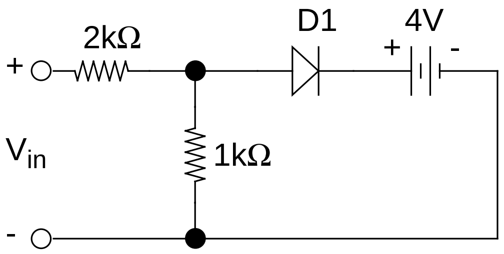
$-4.3V - 0V = -4.3V < 0$ across D2, making it reverse biased;

which agrees with our new assumption.

The minimum resistance can now be found using KVL and Ohm's law —

$$R_{min} = \frac{10V - V_{out}}{I_{max}} = \frac{10 - (-4.3)V}{10mA} = 1.43k\Omega$$

Problem No. 2:



In the adjacent circuit find the range of V_{in} for which the diode D1 is forward biased.

Solution:

The voltage across the 1kW resistor can be obtained using the voltage divider equation as —

$$V_{1k\Omega} = \frac{1k\Omega}{2k\Omega + 1k\Omega}V_{in} = \frac{1}{3}V_{in}$$

For forward bias, this voltage should be larger than the diode offset and the battery cell voltage. i.e. using KVL

$$V_{1k\Omega} = \frac{1}{3}V_{in} > 0.7V + 4.0V = 4.7V$$

Therefore

$$V_{in} > 3 \times 4.7V = 14.1V$$

Thus D1 is forward biased for $V_{in} > 14.1V$.

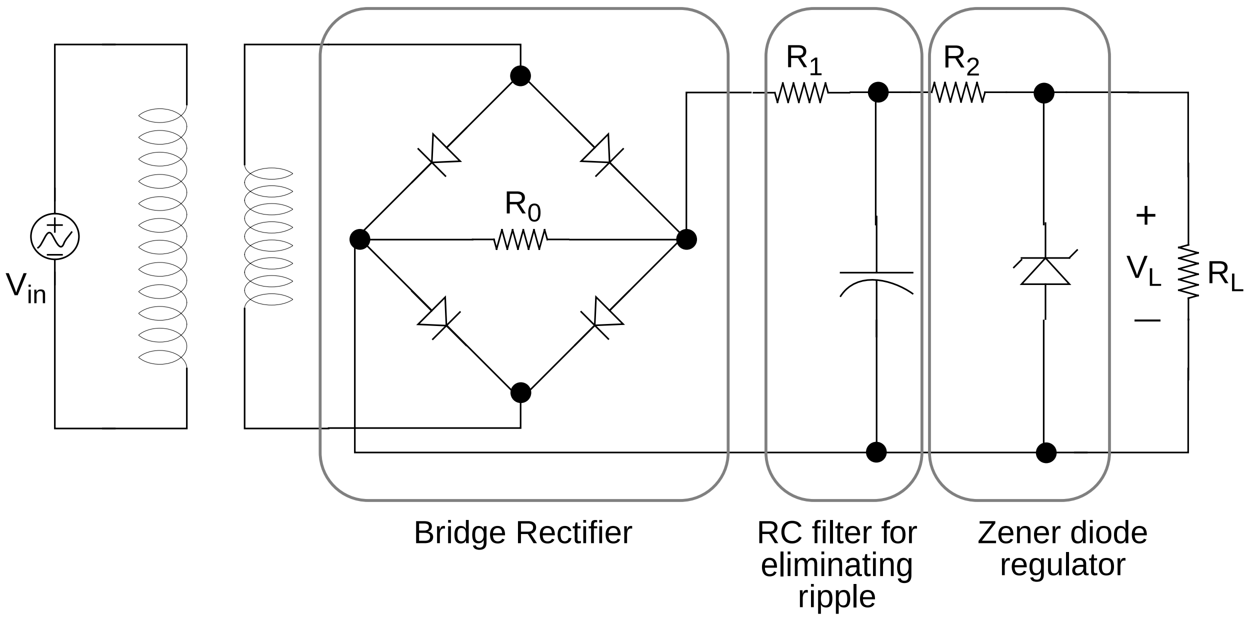
Problem No. 3:

An electric drill machine requires a constant 9V DC power supply. Design an adapter circuit to convert the 110V AC supply voltage into DC.

a) Draw a circuit diagram for the adapter with all its component devices (no need to calculate any values here) such as a full wave bridge rectifier, ripple elimination filter and Zener regulator. What should be the Zener breakdown voltage V_Z of the Zener diode in the regulator?

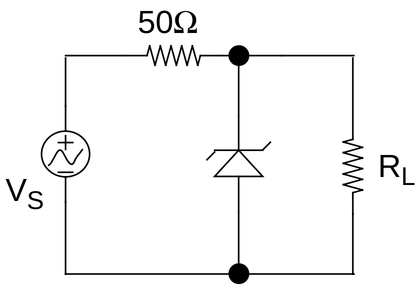
Solution:

The adapter circuit is as follows —



Since the regulated voltage value is 9V, the Zener diode reverse breakdown voltage (or Zener voltage) is $V_Z = -9V$.

b)



If the adjacent circuit is used for Zener regulation for the above power supply, where V_S is the rectified and filtered voltage, find the maximum acceptable load resistance R_L for the drill machine.

Assume a power rating of 4.5W on the Zener diode and V_S = 64V.

Solution:

The maximum current through the zener diode is given by

$$I_Z = \frac{P_Z}{V_Z} = \frac{4.5W}{9V} = 0.5A$$

The total current through the 50Ω resistance is given by

$$I_S = \frac{V_S - V_Z}{50\Omega} = \frac{64V - 9V}{50\Omega} = 1.1A$$

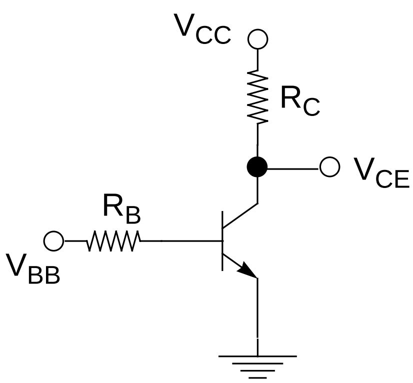
Thus the minimum current through the load resistance R_L to maintain regulation is

$$I_L = I_S - I_Z = 1.1A - 0.5A = 0.6A$$

Therefore the largest possible load resistance is

$$R_L = \frac{V_Z}{I_L} = \frac{9V}{0.6A} = 15\Omega$$

Problem No. 4:



The transistor in the adjacent circuit is considered to be in saturation if $V_{CE} < 0.4$V. Find the smallest possible value of R_B for which the transistor stays biased in the active (linear) region.

Assume that

$$V_{CC} = +15\text{V} \qquad R_C = 250\Omega$$
$$V_{BB} = +10\text{V} \qquad \beta = 100$$

Solution:

For the transistor to be in active region, V_{CE} 0.4V Therefore we have

$$I_C = \frac{V_{CC} - V_{CE}}{R_C} \le \frac{15V - 0.4V}{250\Omega} = 58.4mA$$

Thus the base current

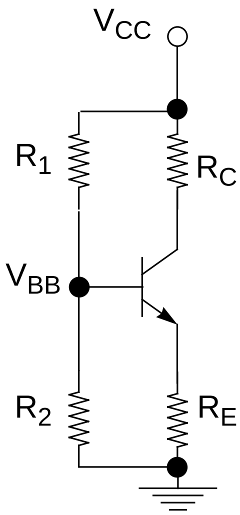
$$I_B = \frac{I_C}{\beta} \le \frac{58.4mA}{100} = 0.584mA$$

We have

$$R_B = \frac{V_{BB} - V_{BE}}{I_B} \ge \frac{10V - 0.7V}{0.584mA} = 15.92k\Omega$$

The smallest value for R_B is thus 15.92kΩ.

Problem No. 5:



Your electronics consultant — Back & Ward Solutions Inc. — has devised the adjacent DC self-bias circuit to measure the internal gain β of the transistor. The following values are used —

$$R_1 = 100k\Omega \qquad R_2 = 50k\Omega$$
$$R_C = 5k\Omega \qquad R_E = 3k\Omega$$
$$V_{CC} = 15V \qquad V_{BE} = 0.7V$$

The operating point of the transistor is measured to be at

$$I_{BQ} = 12.8\mu A \qquad V_{CEQ} = 4.72V$$

Find I_{CQ} and therefore calculate β for the transistor.

Solution:

There are two ways to solve this problem:

$$V_{BB} = V_{CC}\frac{R_2}{R_1 + R_2} = 5V \quad ; \quad R_B = R_1 \parallel R_2 = 33.33k\Omega$$

I]

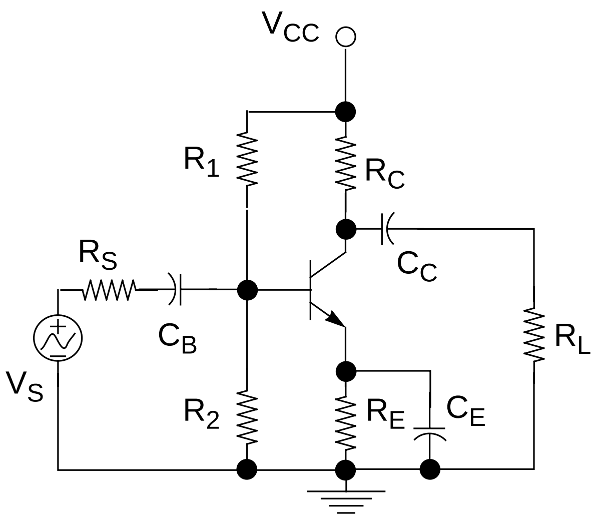
$$V_{BB} - V_{BE} - I_{BQ}R_B - I_{BQ}(1+\beta)R_E = 0$$
$$\therefore 1 + \beta = \frac{V_{BB} - V_{BE} - I_{BQ}R_B}{I_{BQ}R_E}$$
$$\therefore \beta = \frac{V_{BB} - V_{BE} - I_{BQ}R_B}{I_{BQ}R_E} - 1 = \frac{5V - 0.7V - 12.8\mu A \times 33.33k\Omega}{12.8\mu A \times 3k\Omega} = 100$$
$$\therefore I_{CQ} = \beta I_{BQ} = 1.28mA$$

II]

$$V_{CC} - I_{CQ}R_C - V_{CE} - I_{EQ}R_E = 0$$
$$\therefore V_{CC} - I_{CQ}R_C - V_{CE} - (I_{BQ} + I_{CQ})R_E = 0$$
$$\therefore V_{CC} - I_{CQ}(R_C + R_E) - V_{CE} - I_{BQ}R_E = 0$$
$$\therefore I_{CQ} = \frac{V_{CC} - V_{CE} - I_{BQ}R_E}{R_C + R_E} = \frac{15V - 4.72V - 12.8\mu A \times 3k\Omega}{5k\Omega + 3k\Omega} = 1.28mA$$
$$\therefore \beta = \frac{I_{CQ}}{I_{BQ}} = 100$$

Problem No. 6:

Auto Amplifiers Inc. is planning to introduce a new amplifier in the car stereo market for the year 2000 models. They have hired you as a design expert to analyze their latest common emitter amplifier. The circuit for this amplifier is shown below. The biasing values and the transistor hybrid parameters are as follows —



$$V_{CC} = 15V \qquad R_S = 100\Omega$$
$$R_1 = 40k\Omega \qquad R_2 = 10k\Omega$$
$$R_C = 5k\Omega \qquad R_E = 2k\Omega$$
$$\beta = 100 \qquad h_{fe} = \beta$$
$$h_{ie} = 1k\Omega \qquad h_{oe} = 10^{-8}S$$

a) In DC analysis of this circuit, what is the effective voltage V_{BB} at the base? What is the equivalent base resistance R_B? Draw the DC equivalent circuit.

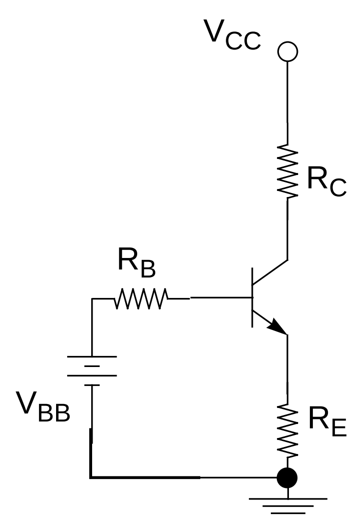
Solution:

The effective base voltage and the equivalent base resistance are given as follows —

$$V_{BB} = V_{CC}\frac{R_2}{R_1 + R_2} = 15V\frac{10k\Omega}{40k\Omega + 10k\Omega} = 3V$$

$$R_B = R_1 \parallel R_2 = \frac{R_1 R_2}{R_1 + R_2} = \frac{40k\Omega \times 10k\Omega}{40k\Omega + 10k\Omega} = 8k\Omega$$

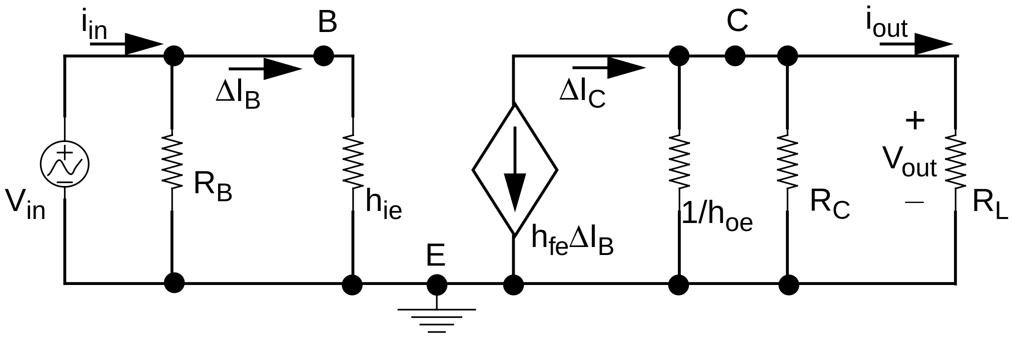
The corresponding DC equivalent circuit is shown here —



b) Draw the amplifier circuit for AC analysis with the appropriate small-signal transistor model. Calculate the transconductance g_m and the effective input resistance of the circuit r_i.

Solution:

The AC equivalent circuit with the small-signal transistor model is shown below.



Transconductance is given by

$$g_m = \frac{h_{fe}}{h_{ie}} = \frac{100}{1k\Omega} = 0.1S$$

The effective input resistance r_i is given by

$$r_i = R_B \| h_{ie} = \frac{R_B h_{ie}}{R_B + h_{ie}} = \frac{8k\Omega \times 1k\Omega}{8k\Omega + 1k\Omega} = 888.89\Omega$$

c) Calculate the output resistance r_o and the AC open circuit voltage gain μ of the amplifier. State explicitly any assumptions you make.

Solution:

The output resistance r_o is given by

$$r_o = R_C \| \frac{1}{h_{oe}} \approx R_C \;;$$

as h_{oe} is very small, and therefore $\frac{1}{h_{oe}}$ is very large.

Therefore

$$r_o = R_C = 5k\Omega$$

The AC open voltage gain is given by

$$\mu = -g_m R_C = -0.1S \times 5k\Omega = -500$$

d) For a load resistance of $R_L = 1k\Omega$, calculate the voltage gain A_V of the amplifier.

Solution:

In presence of load, the effective resistance at the output is $r_o \parallel R_L$.
Therefore the voltage gain is given by

$$\begin{aligned} A_V &= -g_m(r_o \parallel R_L) = -g_m(R_C \parallel R_L) \\ &= -0.1 \times (5k\Omega \parallel 1k\Omega) \\ &= -0.1 \times \frac{5k\Omega \times 1k\Omega}{5k\Omega + 1k\Omega} \\ &= -83.33 \end{aligned}$$