INDIAN INSTITUTE OF TECHNOLOGY BOMBAY
ELECTRICAL ENGINEERING DEPARTMENT

Solution to EE-Quiz-1
MS-101 Makerspace, 2023 Spring semester

Q–1 A voltage source was made using two 12 V batteries connected in series, each having an internal resistance of 5Ω.

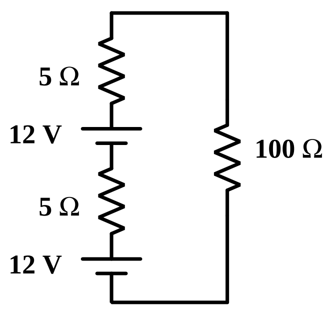
a) What's the no-load voltage of the voltage source? (No-load voltage is defined as the voltage across the terminals of the voltage source when no load is connected, i.e. the load resistance is infinite).

b) If a load resistance of 100Ω is connected across the terminals of the above voltage source, what will be the terminal voltage?

c) How much power in Watts will be dissipated in the 100Ω load resistor?

No marks without steps.

Answer 1)



When load resistor is infinite, no current flows through internal resistance. Therefore $\mathbf{V_{out} = 12 + 12 = 24\ V}$.

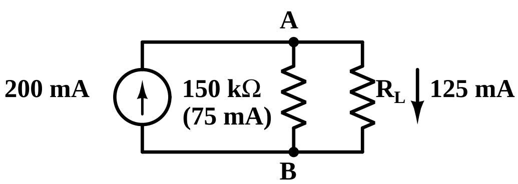
When load resistor = 100 Ω, current through the circuit is: $24/(5 + 5 + 100) = 218.18$ mA. Drop across internal resistors $= (5 + 5)\ \Omega \times 218.18$ mA $= 2.182$ V.
So the available voltage across the output load is:
$\mathbf{24 - 2.182 = 21.818\ V}$.

Power dissipation in the load resistor is:
$\mathbf{V^2/R = (21.818)^2/100 = 4.76\ W}$
or $\mathbf{I^2R = (0.21818)^2 \times 100 = 4.76\ W}$

Answer: $\boxed{\textbf{A): 24 V}}$ $\boxed{\textbf{B): 21.82 V}}$ $\boxed{\textbf{C): 4.76 W}}$ – **[Q1: 3 marks]**

Q–2 A practical current source is modelled as an ideal current source of 200 mA in parallel with a resistor of 150 kΩ. When a load resistance R_L was connected across this source, the current through R_L was found to be 125 mA. What is the value of R_L in kΩ?
No marks without steps.

Answer 2) KCL at A gives current through the 150 kΩ resistor = 200 − 125 = 75 mA.



So voltage across $R_S$is:
$V_{AB} = 150$ kΩ × 75 mA = 11250 V.

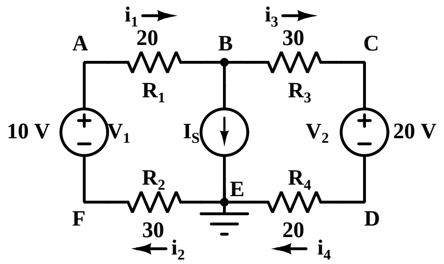
But V_{AB} is also the voltage across R_L.
Therefore, $R_L = 11250\ V/125$ mA $= 90$ kΩ.

$$\text{Alternately, } I_L = I_S\ \frac{R_S}{R_S + R_L} \quad \text{so } 125 = 200\ \frac{150}{150 + R_L}$$

$150 + R_L = (200 \times 150)/125$ Therefore $150 + R_L = 240$, $\quad R_L = 90$.

Answer: $\boxed{\mathbf{R_L = 90\ k\Omega}}$ – **[Q2: 2 marks]**

Q–3 In the circuit shown below, the component values are:



$V_1 = 10$ V, $V2 = 20$ V, $IS = 0.5$ A
$R1 = 20\Omega$, $R2 = 30\Omega$,
$R3 = 30\Omega$, $R4 = 20\Omega$.

Positive directions for currents are shown by arrows in the circuit diagram.

a) Find the values of i1, i2, i3 and i4, and report these values in the table on the right. Calculation steps are to be shown in the space below (Hint: use superposition method):

Answer 3-a) For $V_1 = 10, I_S = 0, V_2 = 0$, I_S is open circuited, while C and D are shorted. This gives i_1, i_2, i_3 and i_4 as $10/(20 + 30 + 20 + 30) = 100$ mA.

For $V_1 = 0, I_S = 0.5A, V_2 = 0$, A is shorted to F and C is shorted to D. Current splits equally to left and right because of equal total resistance. Thus $i_1 = 250$ mA, $i_2 = 250$ mA, $i_3 = -250$ mA and $i_4 = -250$ mA.

For $V_1 = 0, I_S = 0, V_2 = 20$, I_S is open circuited, while A and F are shorted. Current flows opposite to the direction of arrows and its magnitude is: $20/(30 + 20 + 30 + 20) = 200$ mA.

V_1 V	I_S mA	V_2 V	i_1 mA	i_2 mA	i_3 mA	i_4 mA
10	0	0	100	100	100	100
0	500	0	250	250	-250	-250
0	0	20	-200	-200	-200	-200
Total						
10	500	20	150	150	-350	-350

Answer:
Currents in mA

i_1	i_2	i_3	i_4
150	150	-350	-350

– [$\mathbf{1 \times 4 = 4}$]

b) Find the voltages at nodes A, B, and C in the circuit above and report these in the table on the right. Calculation steps are to be shown below.

Answer 3-b)

$V(A) = 0 - 0.15 \times 30 + 10 = -4.5 + 10 = 5.5$ V,
$V(B) = V(A) - 0.15 \times 20 = 5.5 - 3 = 2.5$ V,
$V(C) = V(B) - (-0.35) \times 30 = 2.5 + 10.5 = 13$ V

Answer:
Voltages at A, B and C

V(A)	V(B)	V(C)
5.5	2.5	13

– [$\mathbf{1 \times 3 = 3}$]

– [**Q3: 4 + 3 = 7 marks**]

Q–4 The current through a pn junction diode in the forward region can be approximated as: $I_d = I_S \exp(V/V_T)$, where V is the voltage across the diode, I_S is the reverse-saturation current and V_T is the thermal voltage. $V_T = 25$ mV, and $I_S = 10^{-14}$ A.

A resistor and the above pn junction diode are connected in series and then the series combination is connected across a battery of 5 V such that the diode is forward biased. If the voltage across the resistor is 4.3 V, calculate the diode current id in mA. Your current should be precise to the first decimal place.

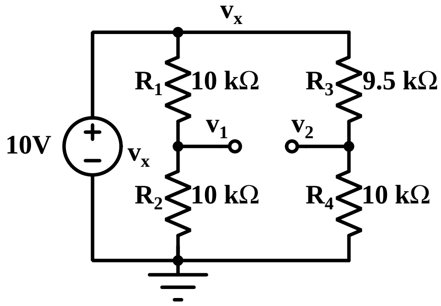
Answer 4)

Voltage across the diode $= 5 - 4.3 = 0.7$ V
$I_d = 10^{-14}\exp(0.7/0.025) = 14.46$ mA

Answer:
$\mathbf{I_d \approx 14.5\ mA}$

– **[Q4: 2 marks]**

Q–5 A Wheatstone bridge is shown below, where V_x is the bridge excitation voltage and v_1 and v_2 are the output terminal voltages.



Assume the differential-mode (DM) voltage of the bridge to be: $v_{id} = v_1 - v_2$.

Given: $v_x = 10$ V, $R_1 = R_2 = R_4 = 10$ kΩ, $R3 = 9.5$ kΩ:

a) What is the DM voltage of the above bridge in millivolts?

b) What is the common-mode (CM) voltage of the above bridge in volts?

c) If the output terminals v_1 and v_2 were connected to a differntial amplifier with a differential gain $A_d = 20$ and a common-mode gain $A_c = 0.01$, what would be the output voltage of the differntial amplifier?

No marks without steps.

Answer 5) **For all parts, half marks for steps, full marks for steps as well as values correct.**

$$v_1 = 10\ \frac{10}{10+10} = 5\text{ V}, \quad v_2 = 10\ \frac{10}{9.5+10} = 5.1282\text{ V}$$

$$v_{DM} = 5 - 5.1282 = -0.1282\text{ V}, \quad v_{CM} = \frac{5 + 5.1282}{2} = 5.0641\text{ V}$$

Answer: a) $\boxed{\mathbf{v_{DM} = -128.2\ mV}}$ – **[2]**

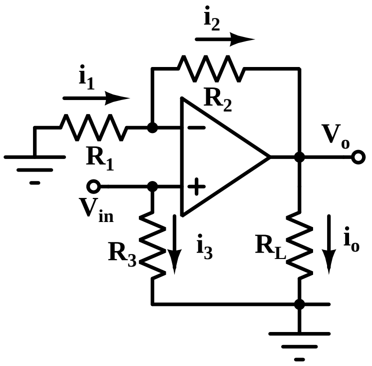
Answer: b) $\boxed{\mathbf{v_{CM} = 5.0641\ V}}$ – **[2]**

$$\begin{aligned} V_{out} &= A_{DM}v_{DM} + A_{CM}v_{CM} = 20 \times (-0.1282) + .01 \times 5.0641 \\ &= -2.5641 + 0.05064 = -2.5135\text{ V} \end{aligned}$$

Answer: c) $\boxed{\mathbf{v_{out} = -2.5135\ V}}$ – **[2]**

– **[Q5: 2 + 2 + 2 = 6 marks]**

Q–6 In the op-amp circuit shown in the figure below,



$R1 = 150$ kΩ, $R2 = 75$ kΩ

$R3 = 1$ MΩ, and $R_L = 1$ kΩ.

Find the voltage, current, and power gains.
Steps must be shown. No marks without steps.

Answer 6)

a) Voltage gain $A_v = v_o/v_{in}$
Steps: $v_o = (1 + R_2/R_1)v_{in}$
$A_v = v_o/v_{in} = 1 + 75/150 = 1.5$

b) Current gain $A_i = i_o/i_3$.
Steps: $i_3 = v_{in}/R_3$
$i_o = v_o/R_L = A_v v_i/R_L$
Current gain $A_i = A_v\ R_3/R_L$
$A_i = 1.5 \times 10^6/10^3 = 1500$

c) Power gain $A_p = (v_o i_o)/(v_i i_3) = A_v A_i$
So power gain $= 1.5 \times 1500 = 2250$.

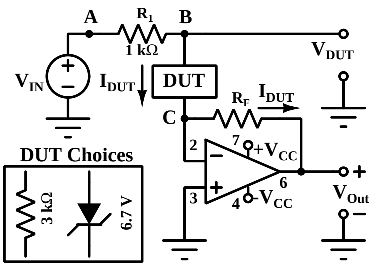
Answer: a)
Voltage gain $\boxed{\mathbf{A_v = v_o/v_{in} = 1.5}}$ – **[1.5]**

Answer: b)
Current gain $\boxed{\mathbf{A_i = i_o/i_3 = 1500}}$ – [2]

Answer: c)
Power gain $\boxed{\mathbf{A_p = A_v A_i = 2250.}}$ – **[1.5]**

– **[Q6: = 1.5 + 2 + 1.5 = 5 marks]**

Q–7 Circuit diagram of the op amp I to V converter used in Expt. 2 is shown below.



The device under test (DUT) is connected between terminals B and C. Assume that the op amp is ideal. Also assume that the maximum and minimum V_{Out} levels are $+V_{cc}$ and $-V_{cc}$ respectively.
$+V_{cc} = +12$ V, $-V_{cc} = -12$ V;
$R_1 = 1$ kΩ, $R_F = 2$ kΩ.

a) A 3 kΩ resistor is connected as the DUT.
If $V_{IN} = +6$ V, what will be the values of V_{DUT} and V_{Out}?

Answer 7-a) C is at virtual ground. $I_{DUT} = 6\ \text{V}/((1+3)\text{k}\Omega) = 1.5$ mA
$V_{DUT} = V_C + 3\ \text{k}\Omega \times 1.5\ \text{mA} = 0 + 4.5 = 4.5$ V
$V_{Out} = -R_F I_{DUT} = -2\ \text{k}\Omega \times 1.5\ \text{mA} = -3$ V
Answer: $\boxed{\mathbf{V_{DUT} = 4.5\ V}}$, $\boxed{\mathbf{V_{Out} = -3.0\ V}}$ – [2]

b) A Zener diode is connected as the DUT with its anode at terminal B and cathode at terminal C. The Zener voltage is $6.7V$, and the Zener I-V characteristic is linear in the Zener region (avalanche breakdown region) with a slope of 150Ω.
If $V_{IN} = -9$ V, what will be the values of V_{DUT} and I_{DUT}?

Answer 7-b) $I_{DUT} = -(9 - 6.7)/(1000 + 150) = -2$ mA,
$V_{DUT} = -9.0 + 1.0\ \text{k} \times 2\ \text{mA} = -7.0$ V.
Answer: $\boxed{\mathbf{V_{DUT} = -7\ V}}$ $\boxed{\mathbf{I_{DUT} = -2\ mA}}$ – [3]

– **[Q7: = 2 + 3 = 5 marks]**