Electrical Science-2 (15B11EC211)

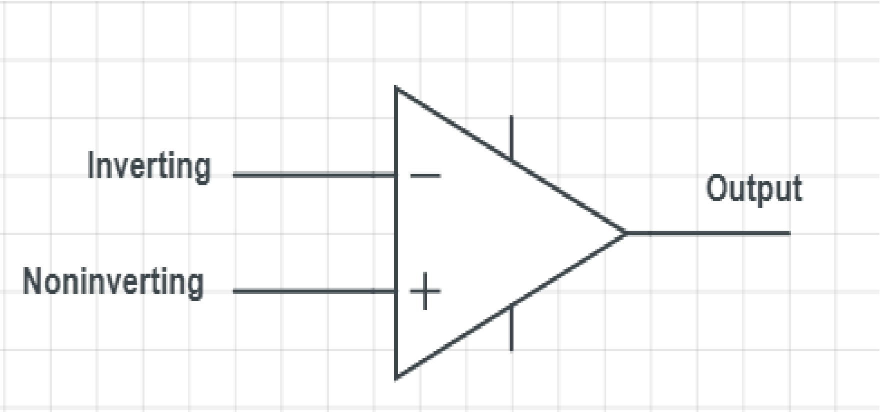
Unit-3
Operational Amplifier and Filters
Lecture-1

Contents

Operational Amplifier

- The op amp is an electronic unit that behaves like a voltage-controlled voltage source
- It is an active circuit element that designed to perform different mathematical operations like:

  - addition,
  - subtraction,
  - multiplication,
  - division,
  - Differentiation
  - integration.



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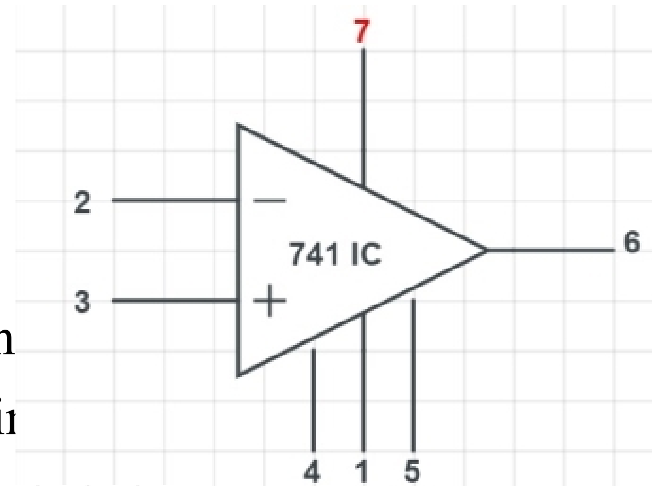
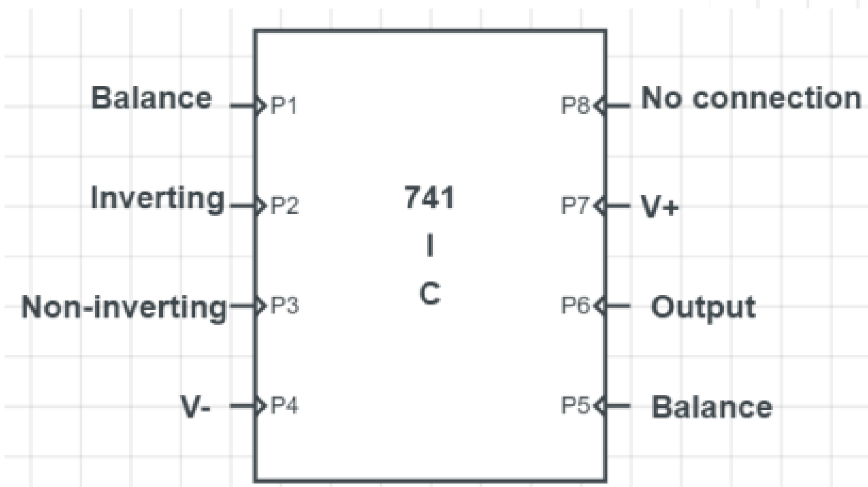
Circuit Symbol and Pin Identification

- An op amp is the eight-pin dual in-line package (DIP). The five important terminals are:
  1. The inverting input, pin 2.
  2. The noninverting input, pin 3.
  3. The output, pin 6.
  4. The positive power supply V^{+}, pin
  5. The negative power supply V^{-} , pi





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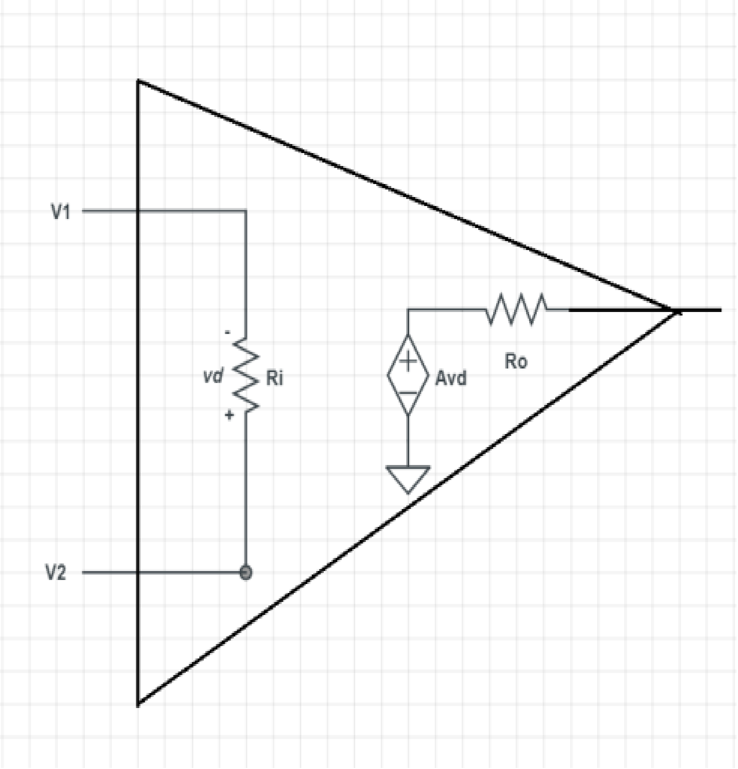
Equivalent circuit model

- The output section consists of a voltage-controlled source in series with the output resistance Ro.
- The input resistance Ri is the Thevenin equivalent resistance seen at the input terminals, while the output resistance Ro is the Thevenin equivalent resistance seen at the output.
- The differential input voltage vd and vo is given by $vd = v2 - v1$

$$vo = Avd = A(v2 - v1)$$

Where, A is open loop voltage gain



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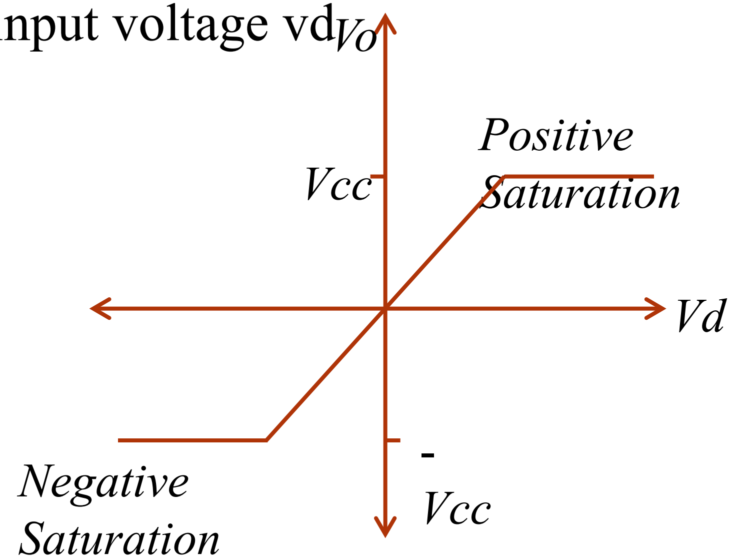
- A practical limitation of the op amp is that the magnitude of its output voltage cannot exceed |Vcc|.
- The op amp can operate in three modes, depending on the differential input voltage vd



1. $Positive\ saturation,\ vo = Vcc$
2. $Linear\ region,\ -Vcc \leq vo = Avd \leq Vcc$
3. $Negative\ saturation,\ vo = -Vcc$

Ideal op amp

- An ideal op amp is an amplifier with infinite open-loop gain, infinite input resistance, and zero output resistance.

- Open loop gain, A =infinity

- Input Resistance, Ri = infinity

- Output Resistance, Ro= zero

- Bandwidth =infinity

- Common Mode Gain =0

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Parameter	Typical range	Ideal values
Open loop gain, A	10^5 -10^8	∞
Input Resistance, Ri	10^5 -10^{13}Ω	∞ Ω
Output Resistance, Ro	10 to 100 Ω	0 Ω
Supply Voltage, Vcc	5 to 24 V	
Bandwidth	Attenuates and phases at high frequencies (depends on slew rate)	∞
Temperature	Bandwidth and gain	independent
Common Mode Gain	10^{-5}	0

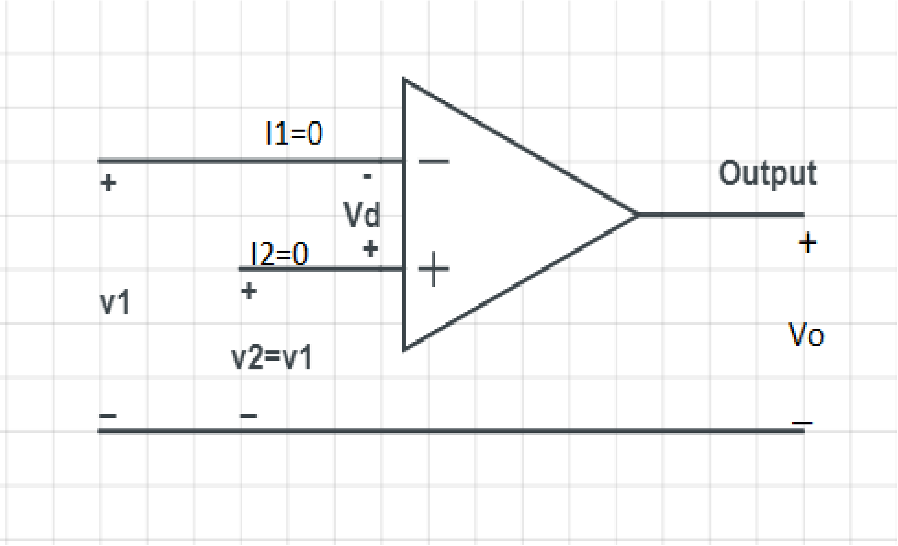
The Concept of the Virtual Short

- The currents into both input terminals are zero:.
- This is due to infinite input resistance. An infinite resistance between the input terminals implies that an open circuit exists there and current cannot enter the op amp

$$I1 = 0, \;\; I2 = 0$$

$$Vd = V2 - V1 = 0$$

$$V1 = V2$$



- Thus, an ideal op amp has zero current into its two input terminals and the voltage between the two input terminals is equal to zero.

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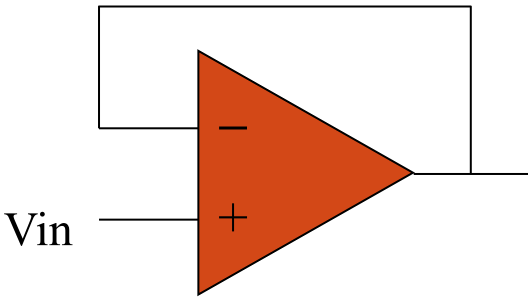
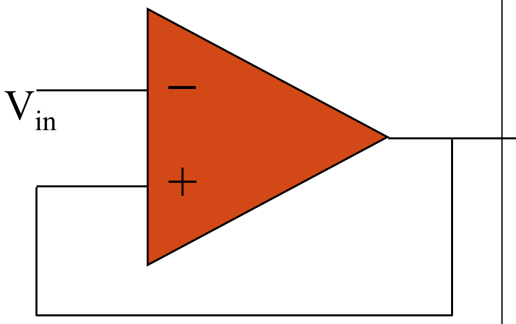
The op amp with feedback (Closed loop)

- Infinite Gain in negative feedback
- If the output is less than Vin, it shoots positive
- If the output is greater than Vin, it shoots negative



negative feedback loop

- If the + input is even a higher than Vin, the output goes way positive
- This makes the + terminal even more positive than Vin, making the situation worse
- This system will immediately “rail” at the supply voltage



positive feedback

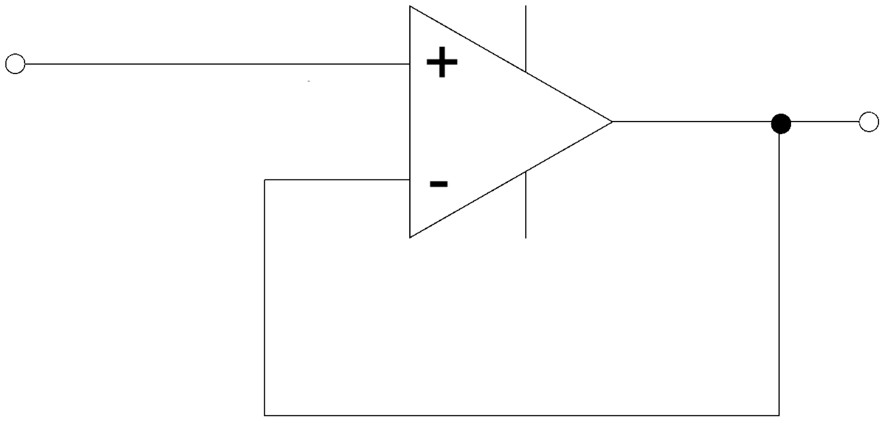
The op amp as a voltage follower

- Output is connected directly to negative input (negative feedback)

$$A_F = \frac{v_o}{v_i}$$

$$v_i = v_+ = v_- = v_o$$

$$A_F = \frac{v_o}{v_i} = 1$$



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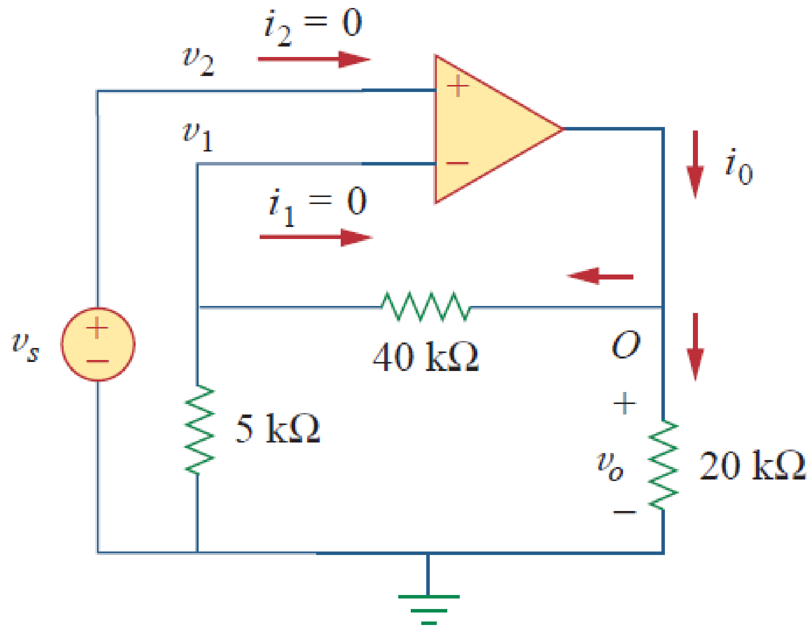
Problem

Q1. Find the closed-loop gain Vo/Vs of given figure. Determine current io when vs=1 V. Consider the op amp as an ideal.



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Sol: $$V2 = Vs \qquad 1$$

$$V1 = \frac{5}{5+40} Vo = \frac{Vo}{9} \qquad 2$$

$$V1 = V2 \qquad 3$$

Substituting Eqs. (1) and (2) into Eq. (3) yields the closed loop gain

$$Vs = \frac{Vo}{9}, \qquad \frac{Vo}{Vs} = 9$$

At node O,

$$io = \frac{Vo - Vs}{40} + \frac{Vo}{20}$$

When, Vs =1 V, Vo =9 V. Substituting for Vo =9 V

$$io = 0.2 + 0.45 = 0.65mA$$

Inverting Amplifier

- An inverting amplifier reverses the polarity of the input signal while amplifying it.

Applying KCL at node V1

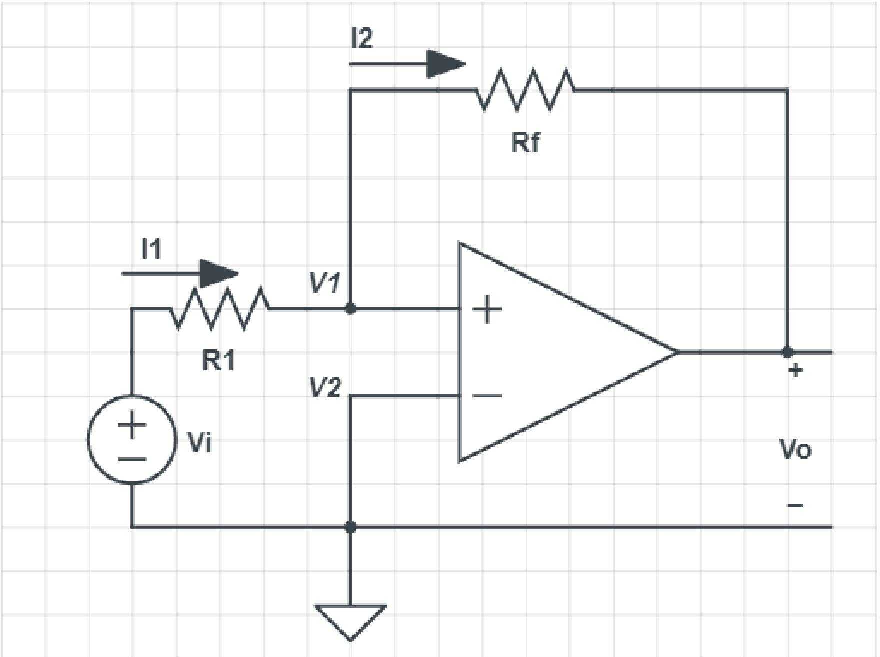
$$I1 = \ I2$$

$$\frac{Vi - V1}{R1} = \frac{Vi - Vo}{Rf} = 0$$

But V1 =V2= 0 for an ideal op amp, since the noninverting terminal is grounded. Hence,

$$\frac{Vi}{R1} = -\frac{Vo}{Rf}$$

$$Vo = -\frac{Rf}{R1}Vi$$



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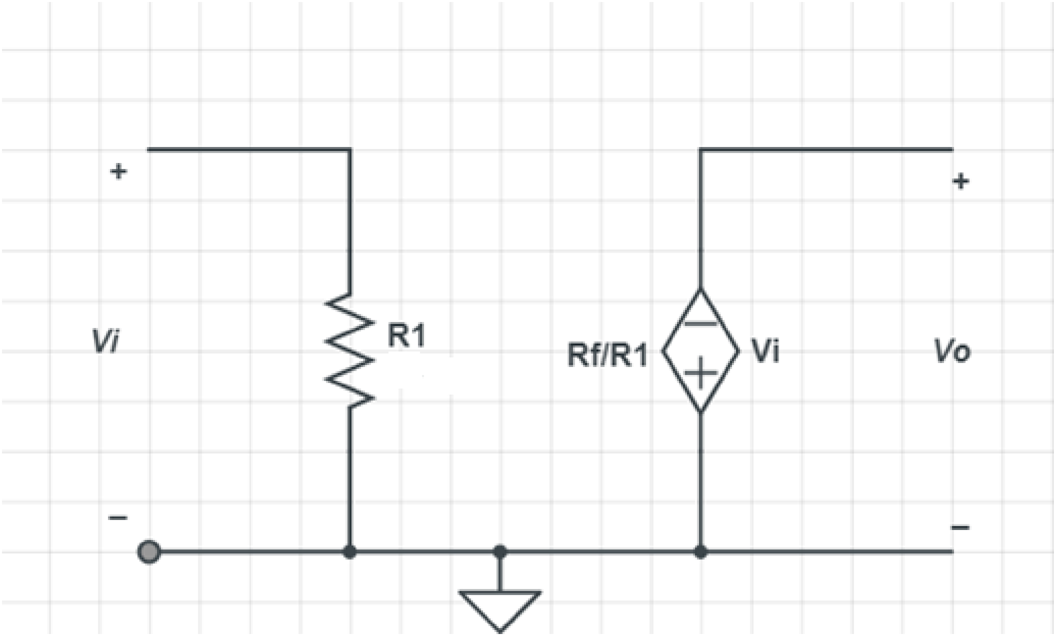
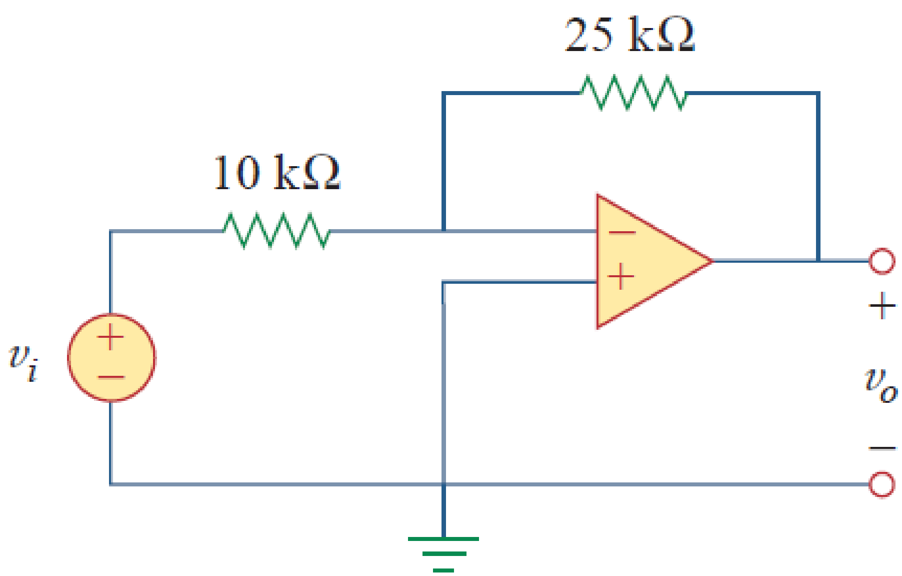
Equivalent circuit of an inverting amplifier

- An inverting amplifier reverses the polarity of the input signal while amplifying it.
- The gain is the feedback resistance divided by the input resistance which means that the gain depends only on the external elements connected to the op amp.



Problem

Q2. Refer to the op amp in given figure. If vi=0.5 V, calculate: (a) the output voltage vo, and (b) the current in the 10-kΩ resistor.



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Sol: (a)

$$Vo = -\frac{Rf}{R1}Vi$$

$$Vo = -2.5Vi$$

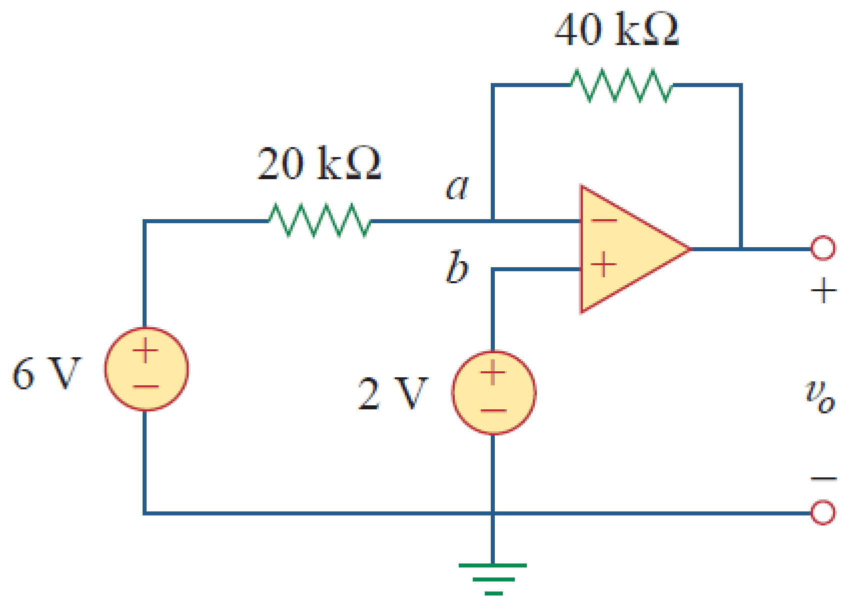
$$Vo = -2.5(0.5) = -1.25V$$

(b)

$$i = \frac{Vi - 0}{R1} = \frac{0.5 - 0}{10 \times 10^3} = 50\mu A$$

Problem

Q3. Determine vo in the op amp circuit shown in below Figure.



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Sol: Applying KCL at node 'a'

$$\frac{va - vo}{40} = \frac{6 - va}{20}$$

$$va - vo = 12 - va$$

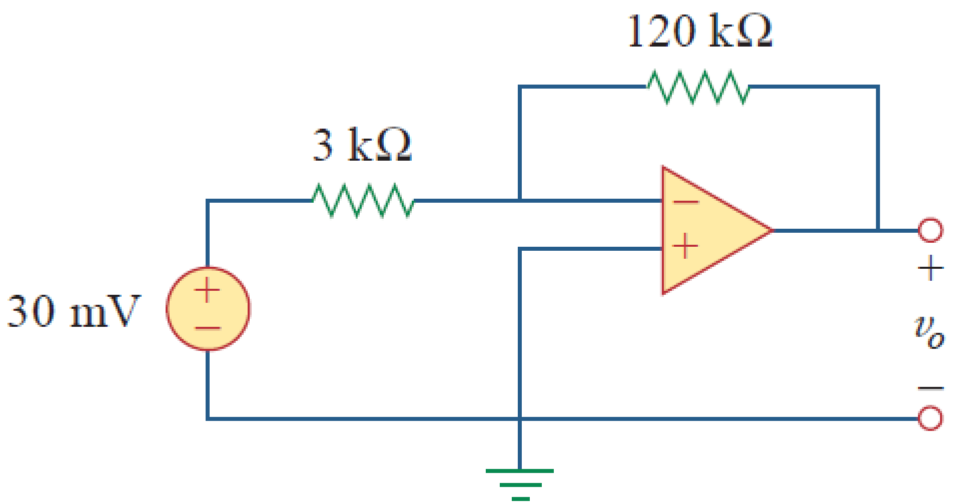
$$Vo = 3va - 12$$

because of the zero voltage drop across the input terminals of the op amp, $va = vb = 2V$

$$vo = 6 - 12 = -6V$$

Practice Problem

Q3. Find the output of the op amp circuit shown in below figure. Calculate the output voltage and current through the feedback resistor.



Answer: -1.2V, 10μA

Reference

1. Charles K. Alexander and Matthew N. O. Sadiku, "Fundamentals of Electric Circuits", Chapter 19, 4th ed, Mcgraw Hill, 2009