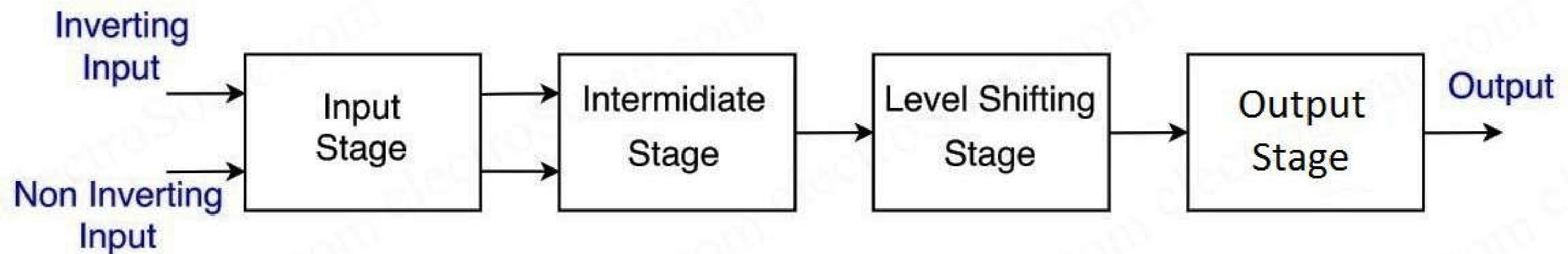
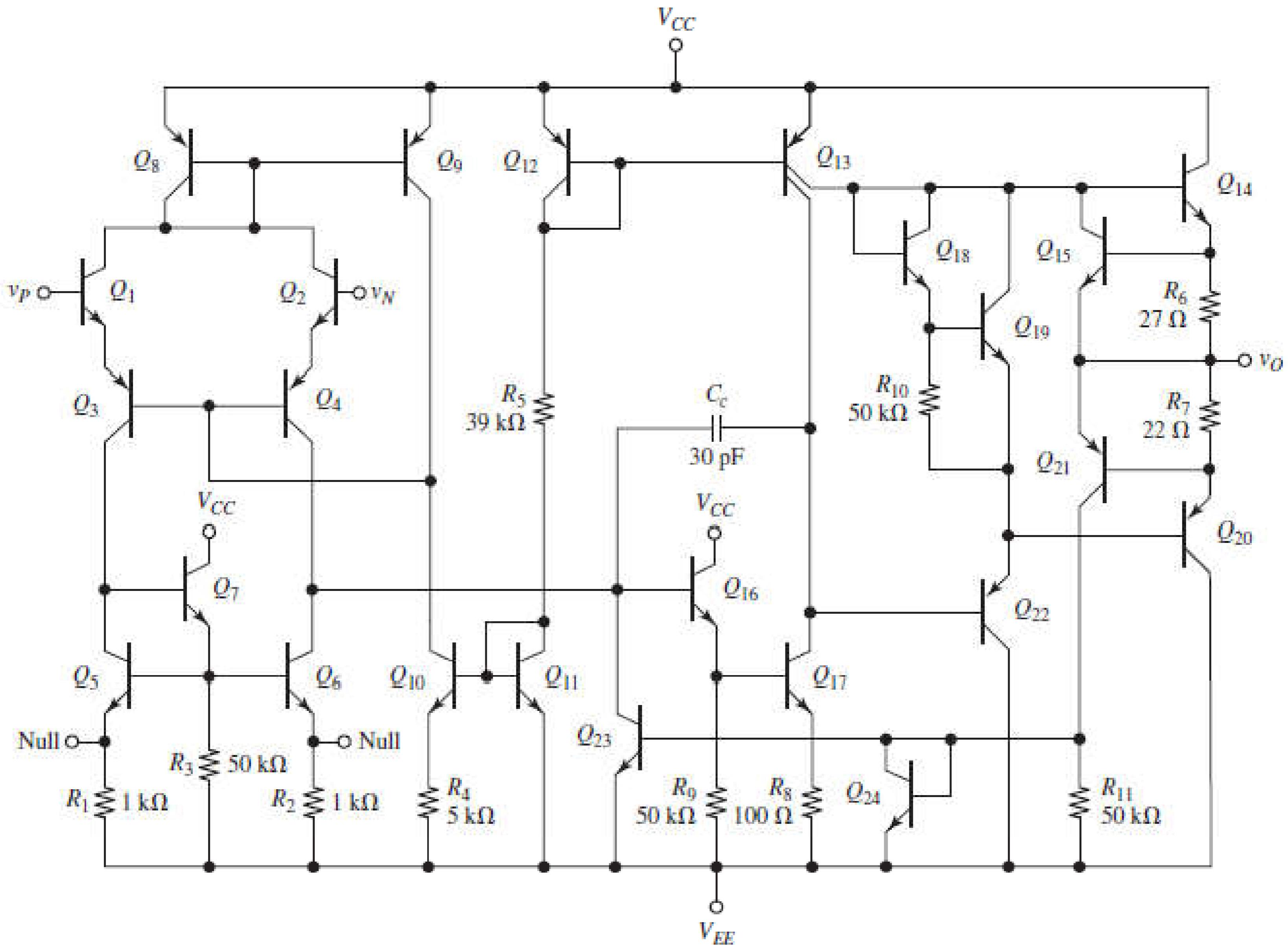


Opamp

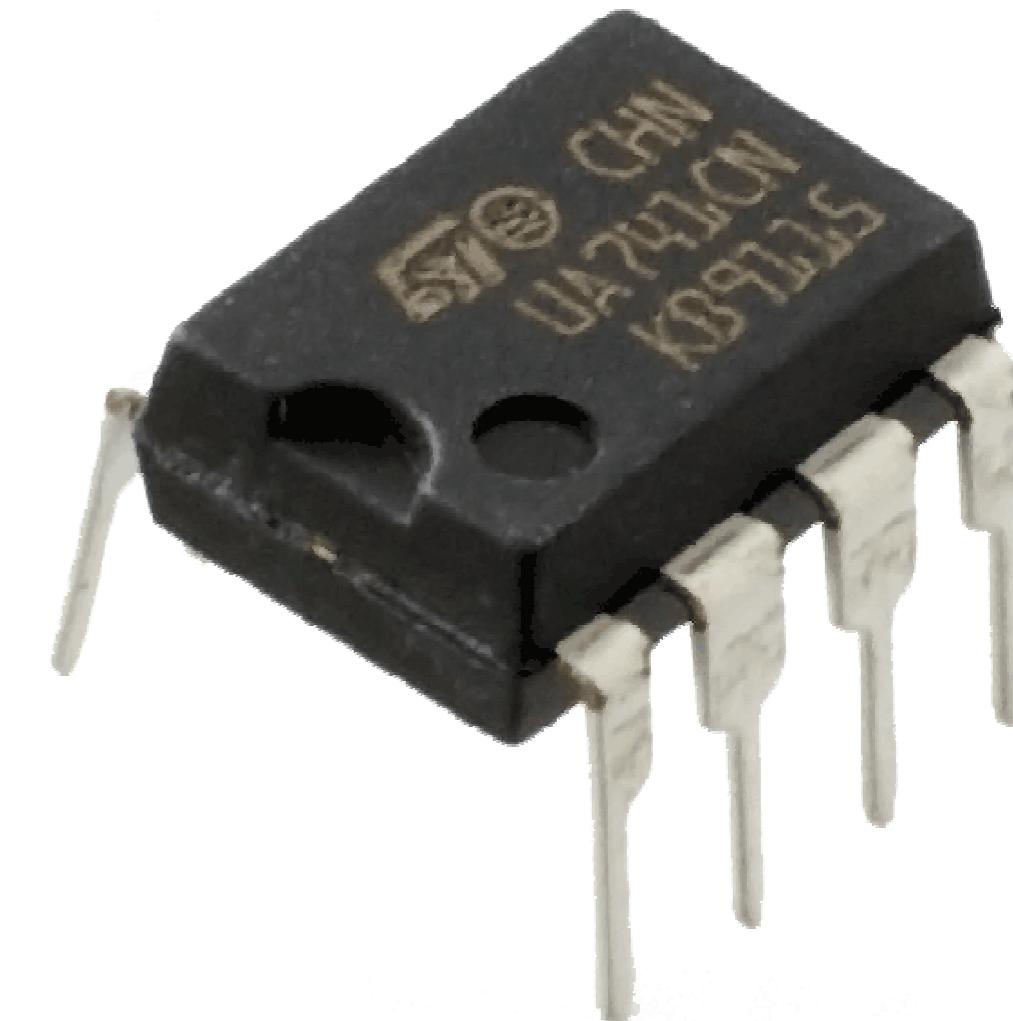
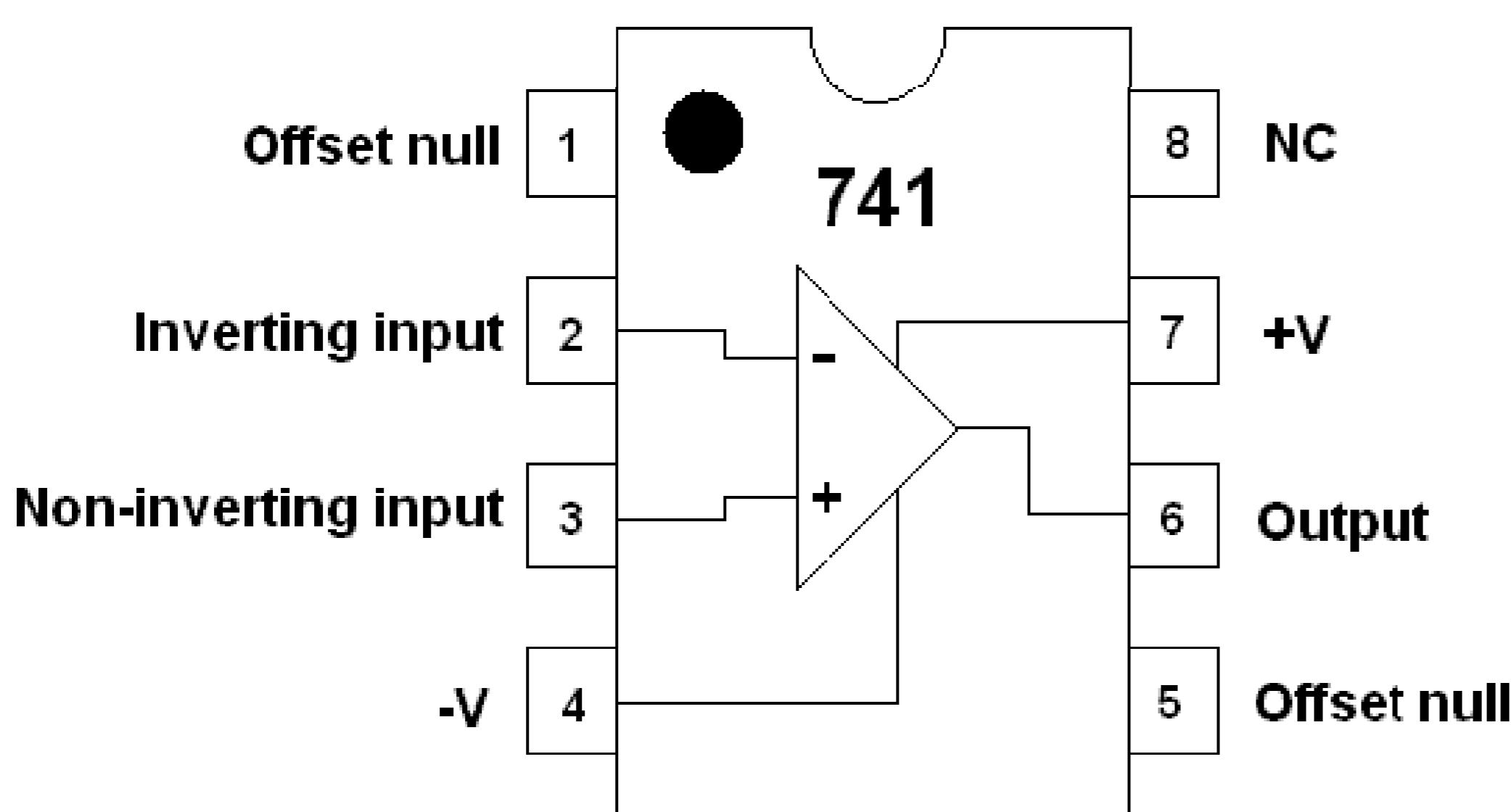
Opamp Block Diagram



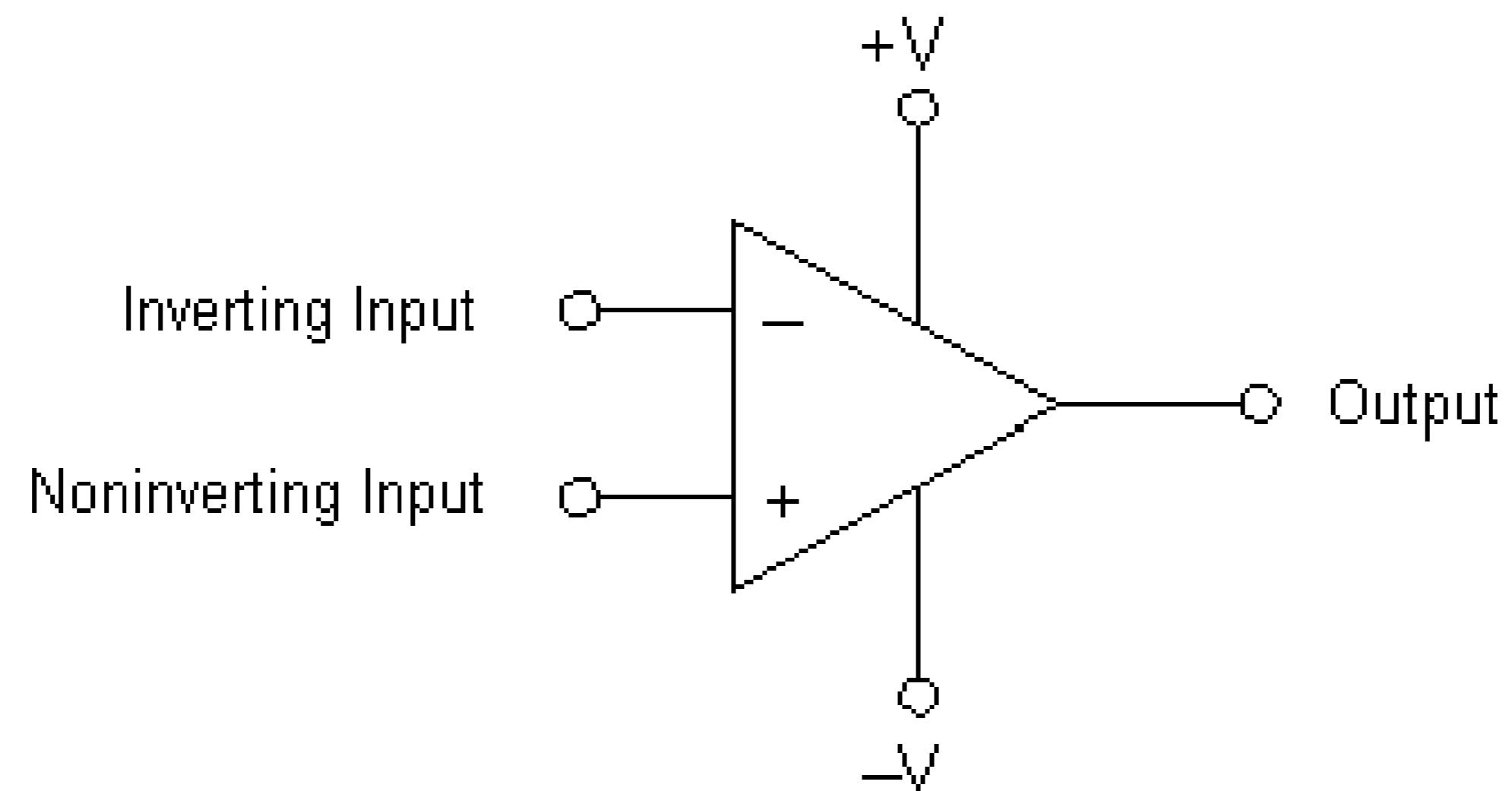
- An op amp is an active circuit element designed to perform mathematical operations of addition, subtraction, multiplication, division, differentiation, and integration, etc.



741 Package and Pin Details



Schematic Symbol



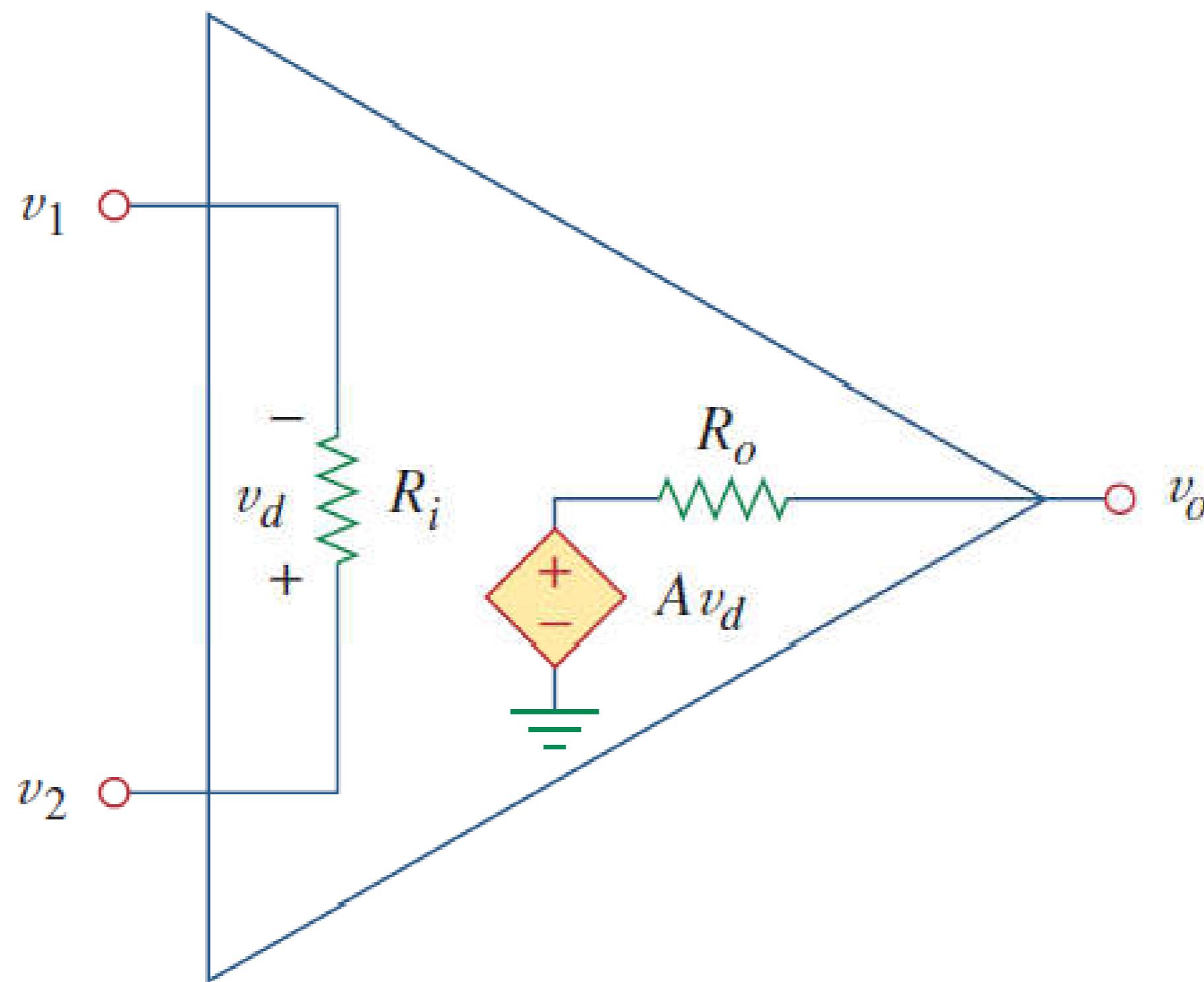
An Ideal Op-Amp

- Infinite open loop gain
- Infinite input impedance
- Zero output impedance
- Infinite bandwidth
- Infinite CMRR

Ideal versus Real Op-Amp

Parameter	Ideal Op-Amp	Real Op-Amp
Differential Voltage Gain	∞	$10^5 - 10^9$
Gain Bandwidth Product (Hz)	∞	1-20 MHz
Input Resistance (R)	∞	$10^6 - 10^{12} \Omega$
Output Resistance (R)	0	$100 - 1000 \Omega$

Equivalent Circuit Non – Ideal Opamp



Basics of an Op-Amp Circuit

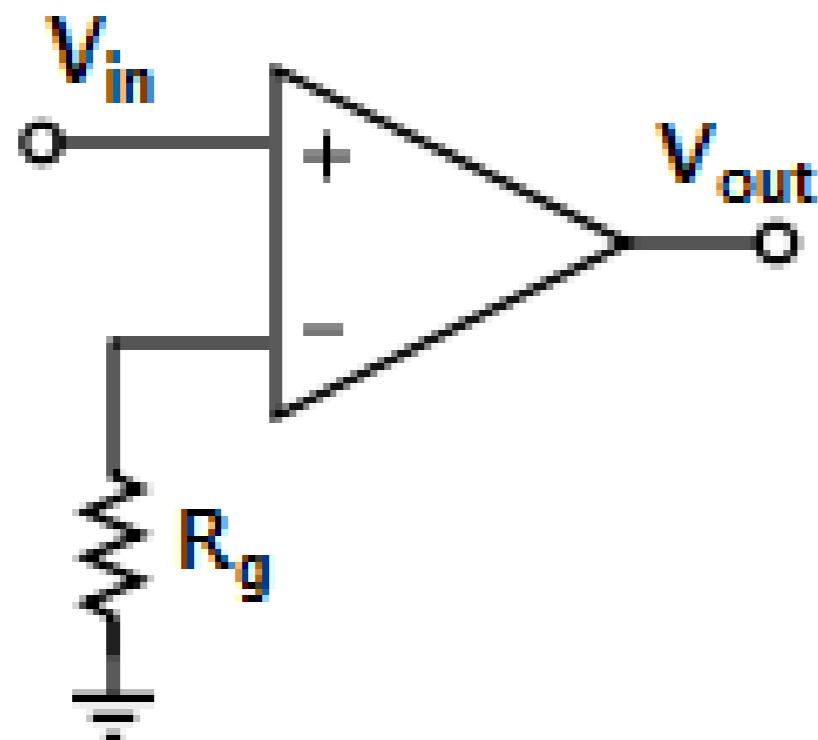
- An op-amp amplifies the difference of the inputs V_+ and V_- (known as the differential input voltage)
- This is the equation for an *open loop* gain amplifier:

$$V_{\text{out}} = A(V_+ - V_-)$$

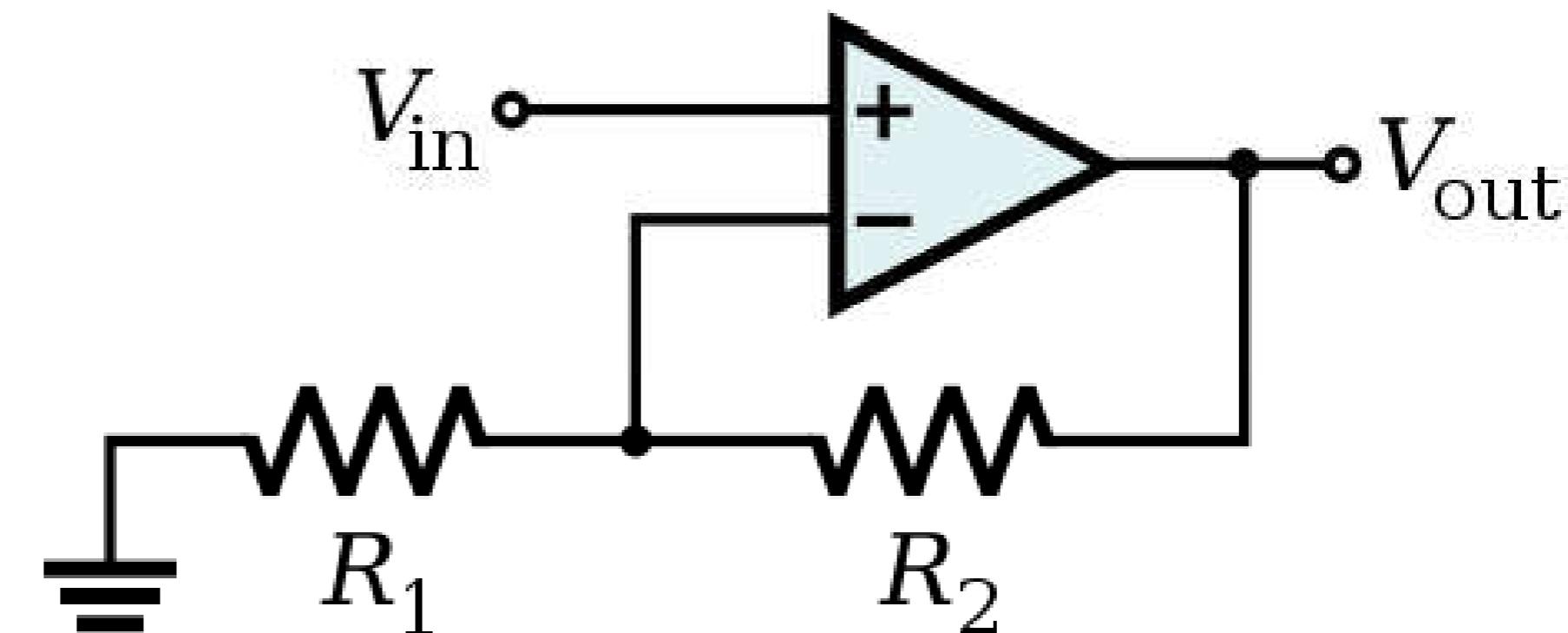
- K is typically very large – at around 10,000 or more for IC Op-Amps
- This equation is the basis for all the types of amps we will be discussing

Open Loop vs Closed Loop

- A closed loop op-amp has feedback from the output to the input, an open loop op-amp does not



Open Loop

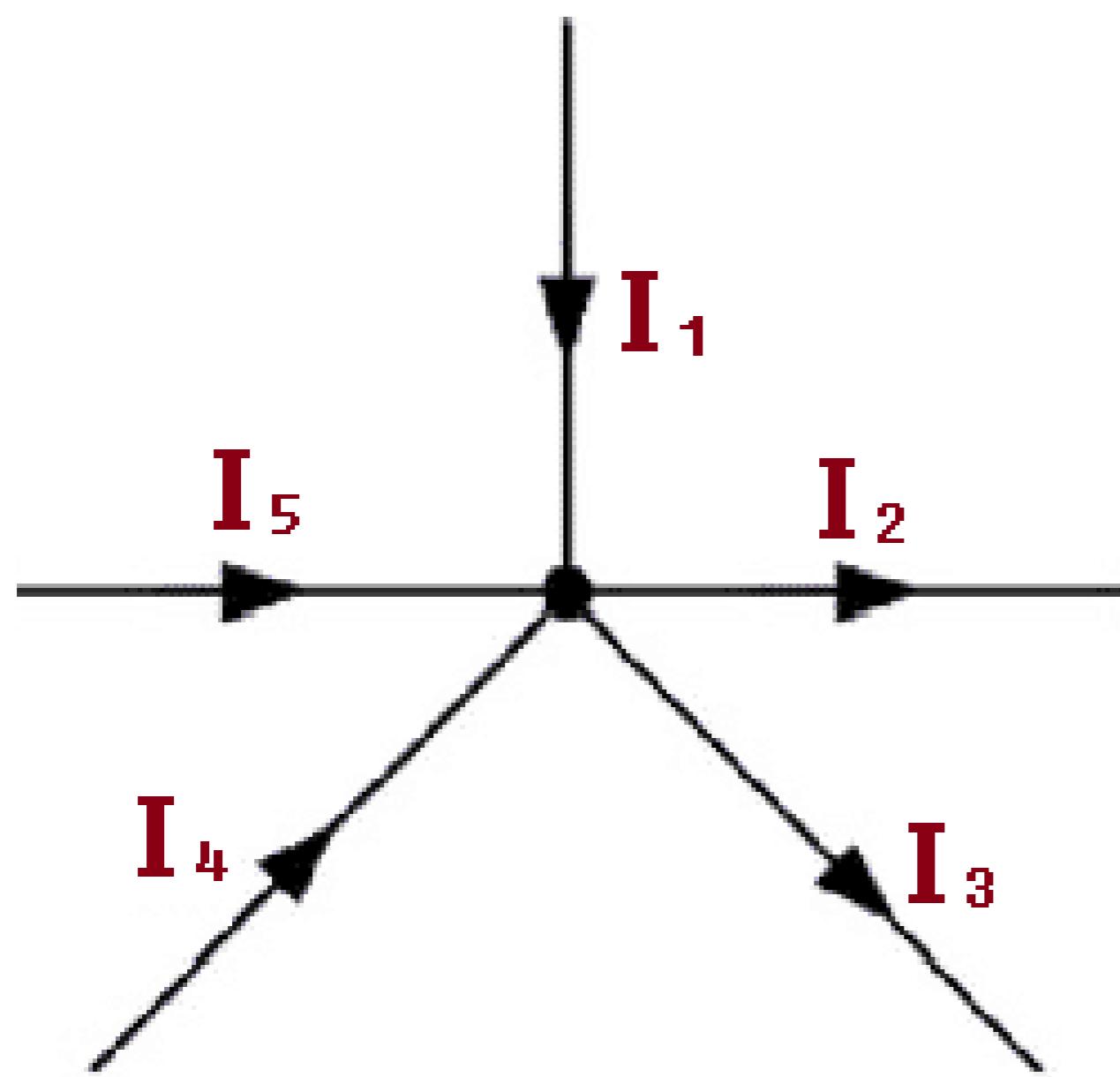


Closed Loop

Analysis Steps

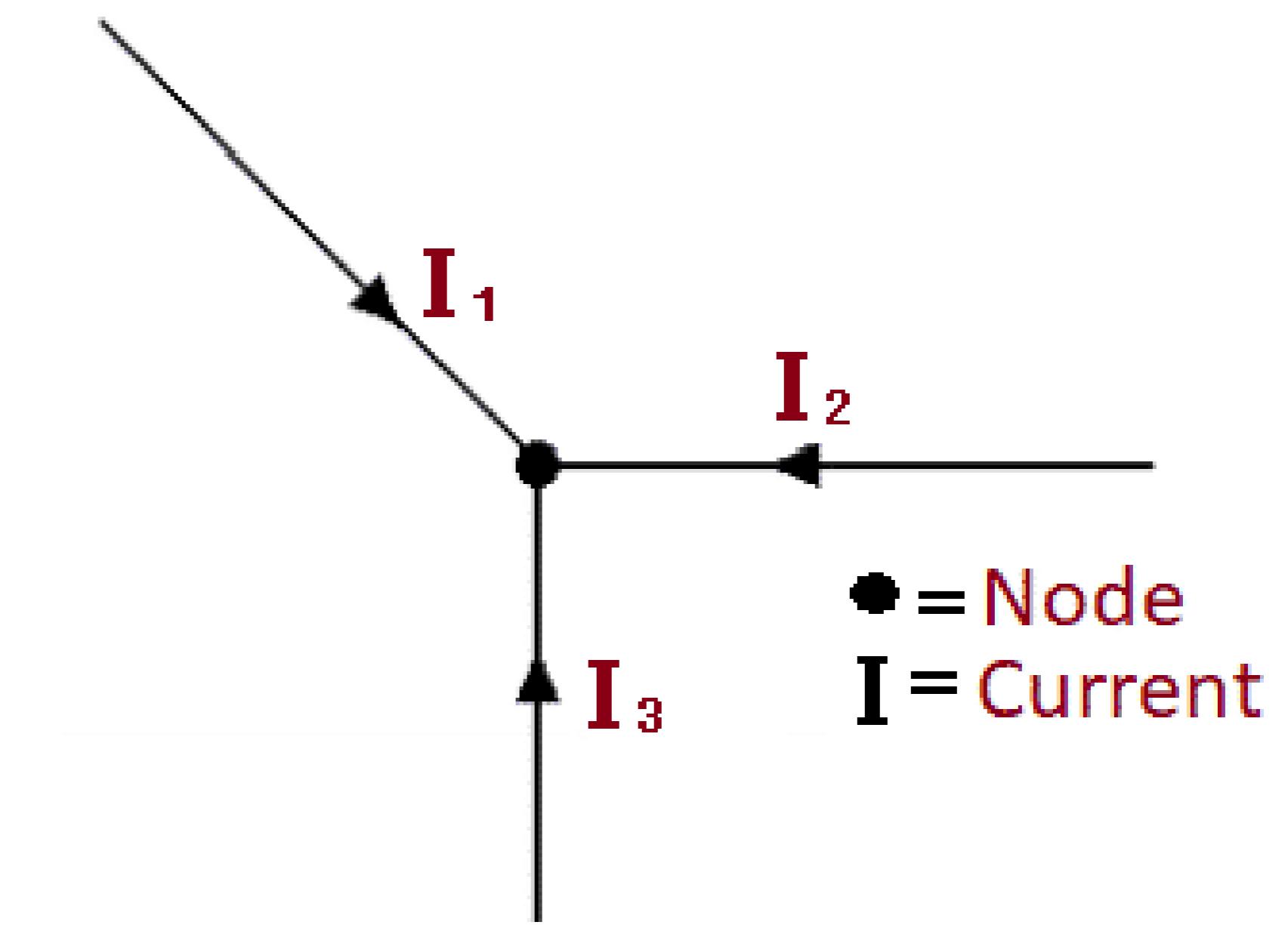
- Ideal Opamp
 - Opamp does not accept any input current
 - Voltage at inverting Terminal = Voltage at non-inverting terminal.
 - Apply KCL at the input nodes.
 - No KCL at the output nodes (Reason ?)

KCL



$$I_1 - I_2 - I_3 + I_4 + I_5 = 0$$

(a)

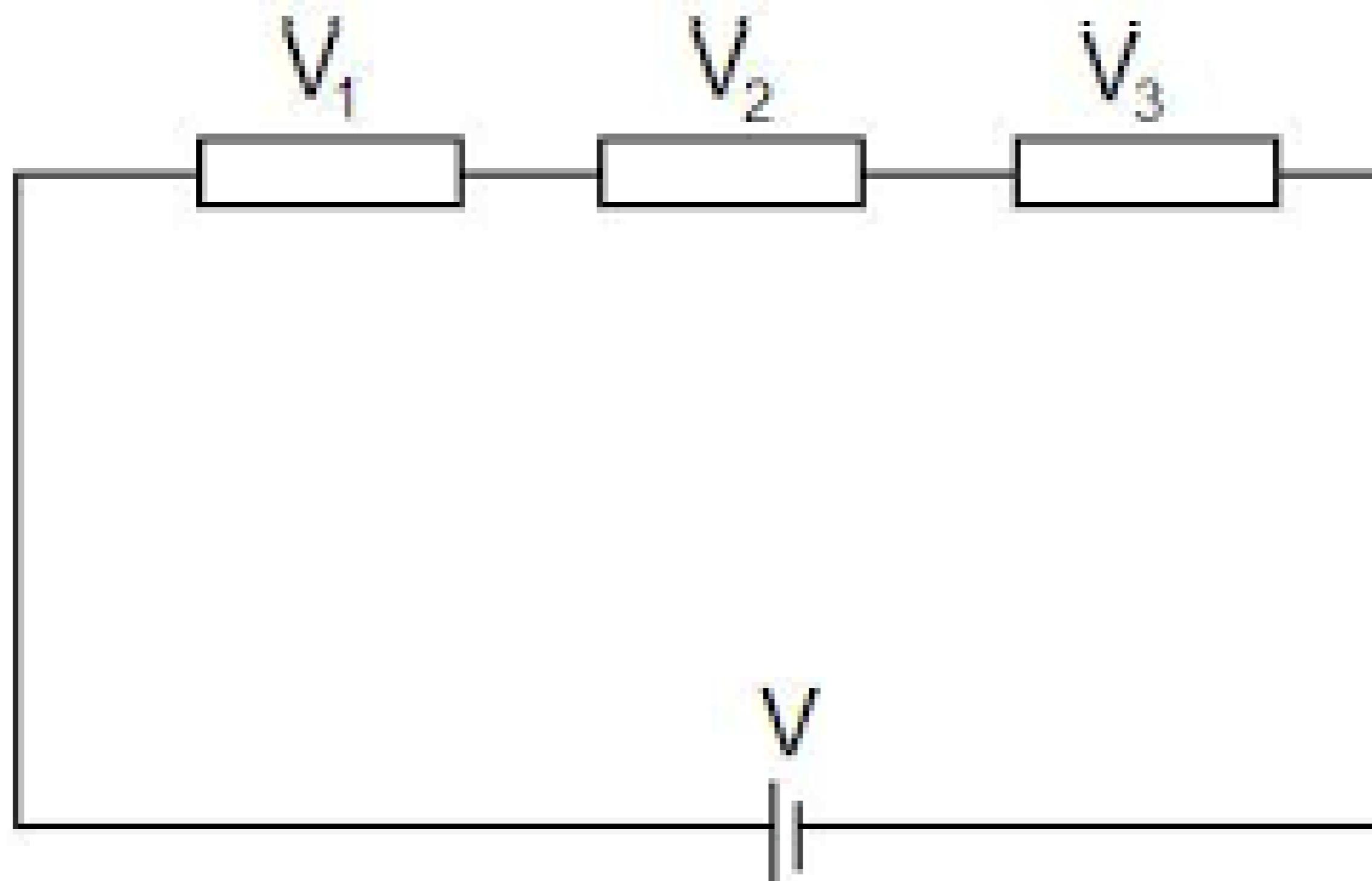


$$I_1 + I_2 + I_3 = 0$$

(b)

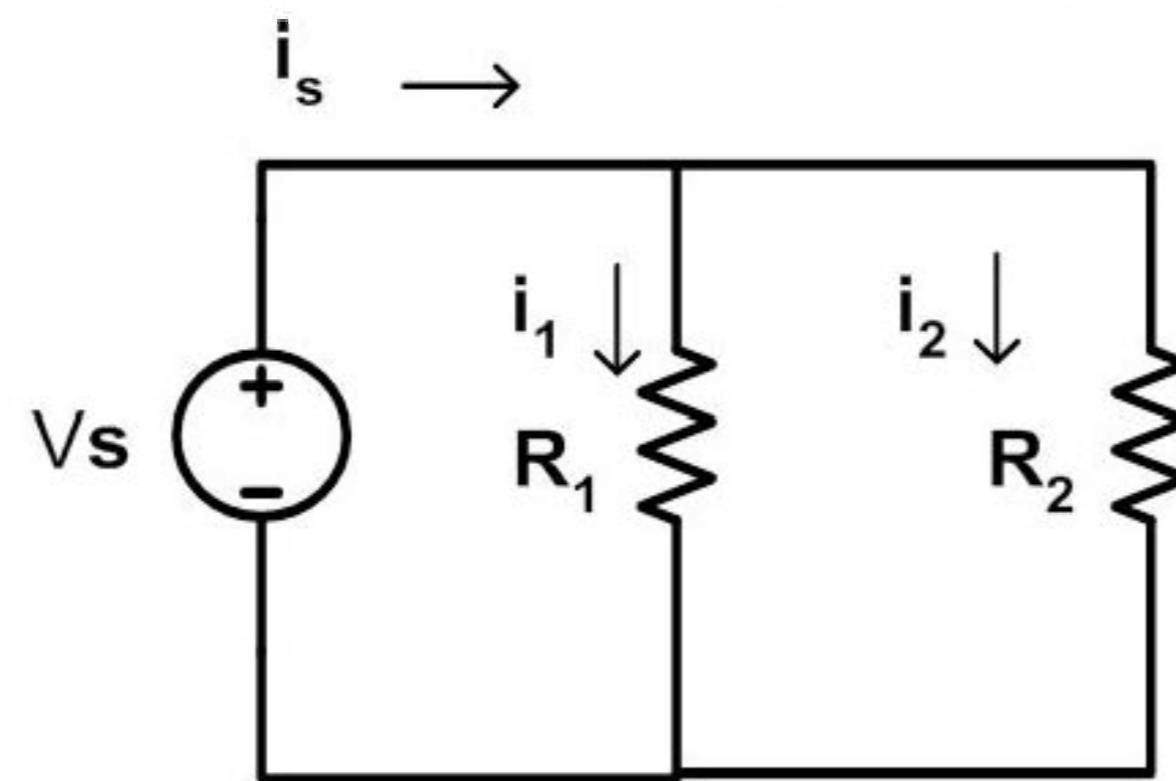
● = Node
I = Current

KVL



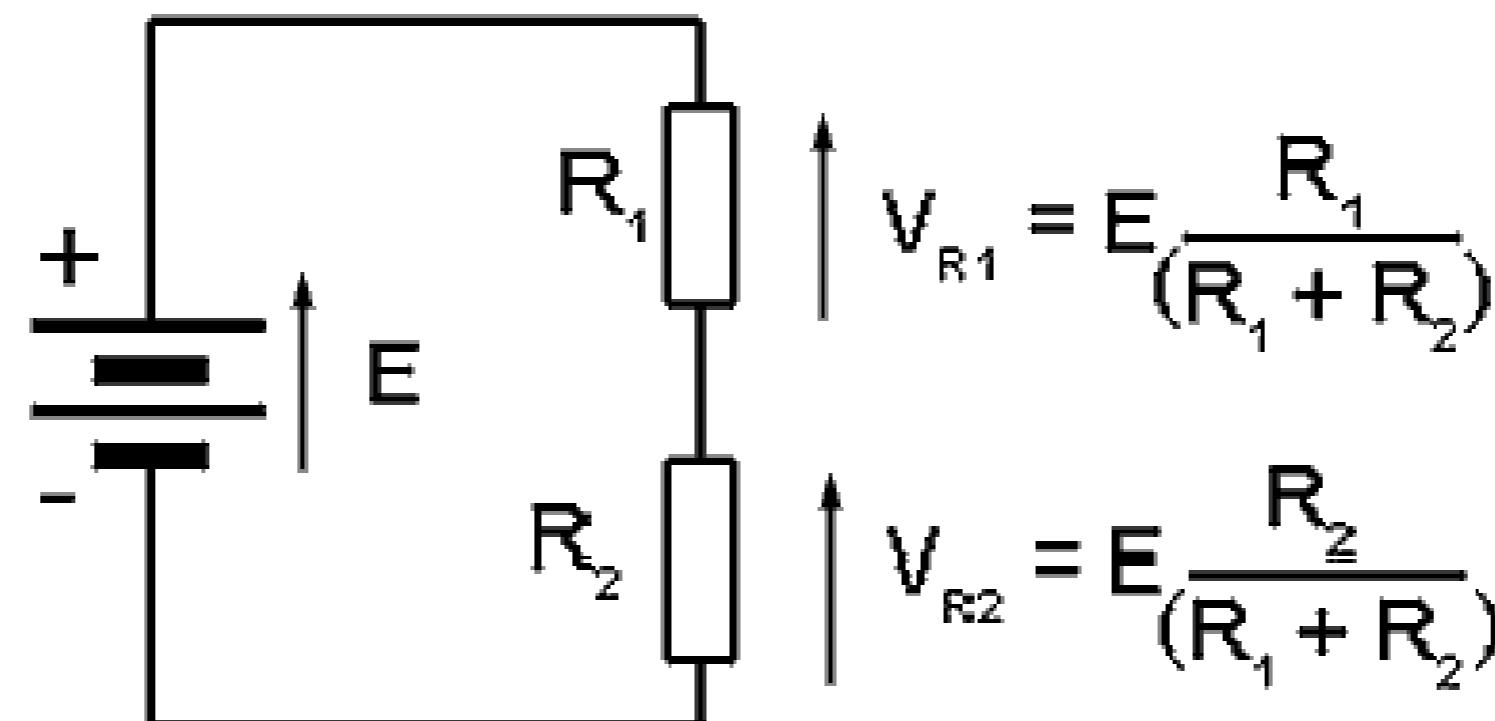
$$V = V_1 + V_2 + V_3$$

Current Division & Voltage Division



$$i_1 = \frac{R_2}{R_1 + R_2} i_s$$

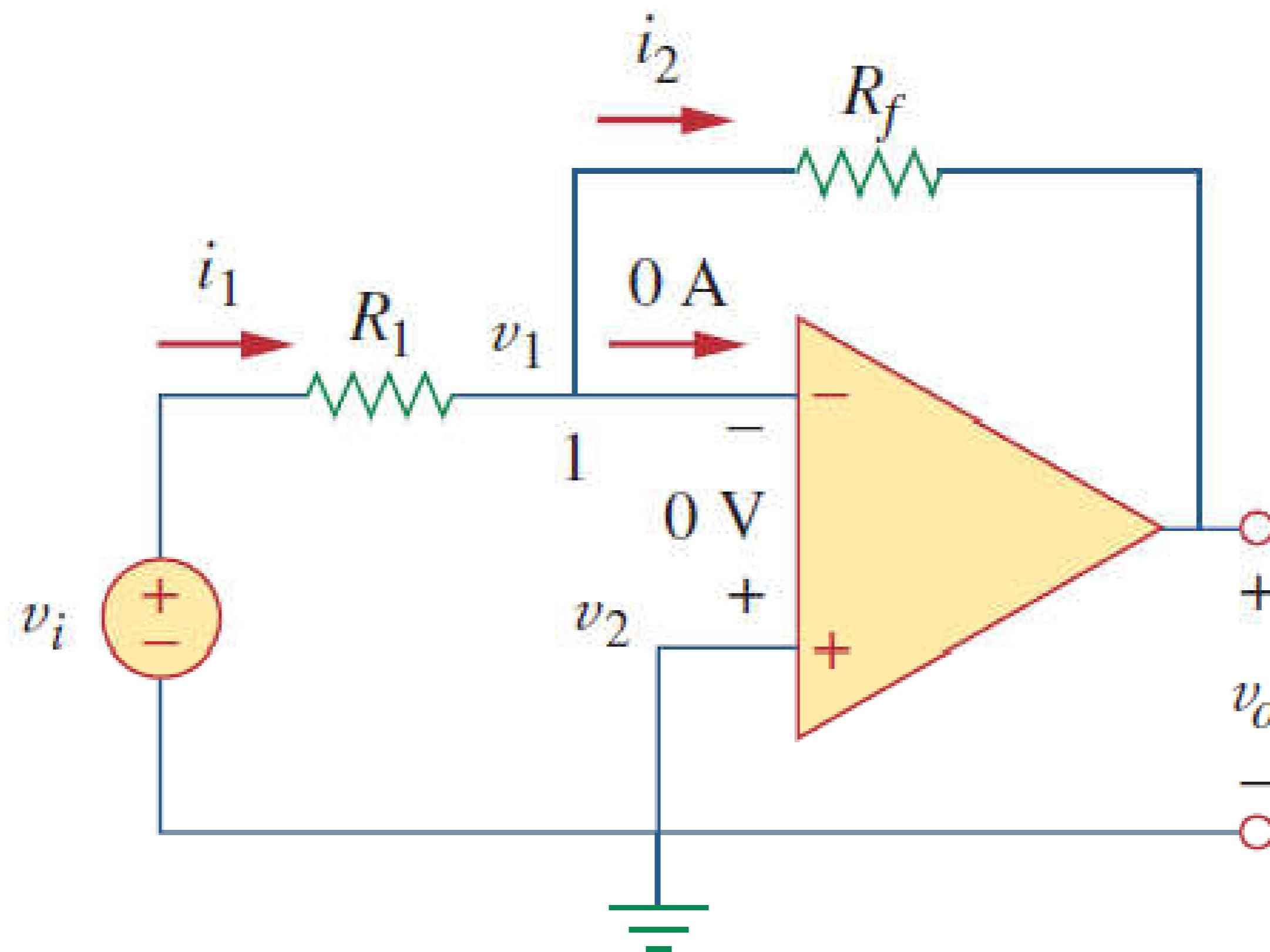
$$i_2 = \frac{R_1}{R_1 + R_2} i_s$$



$$V_{R1} = E \frac{R_1}{(R_1 + R_2)}$$

$$V_{R2} = E \frac{R_2}{(R_1 + R_2)}$$

Inverting Amplifier

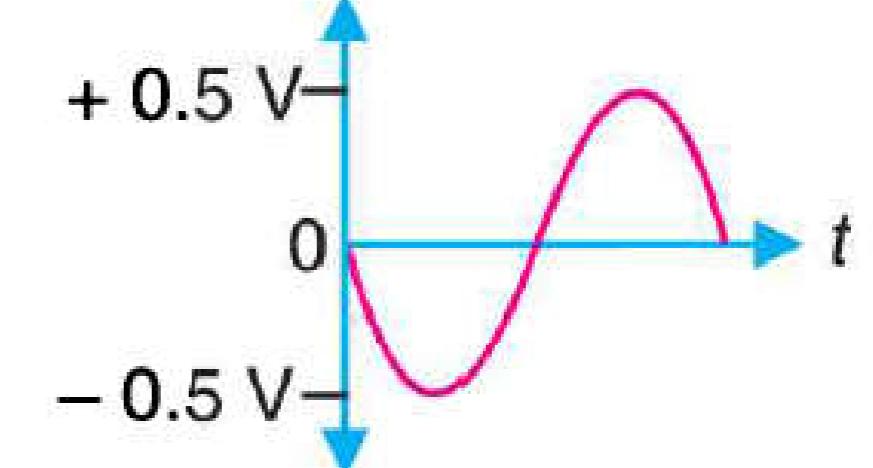
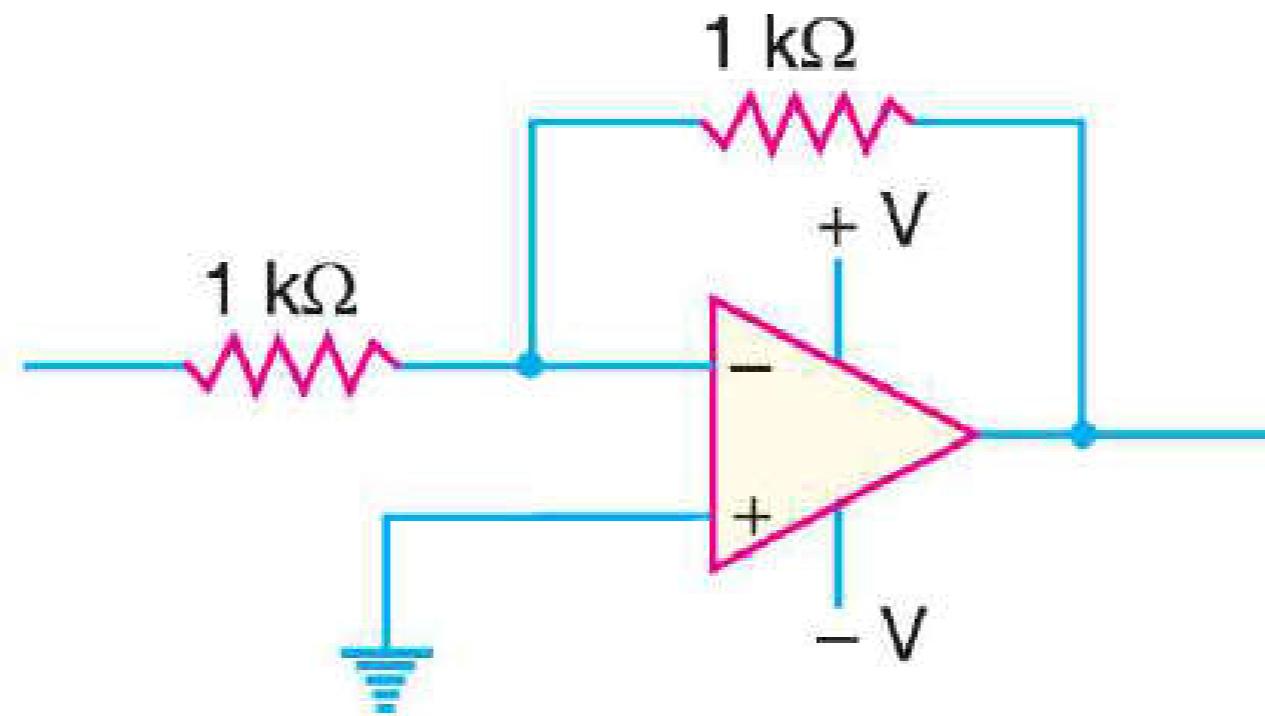
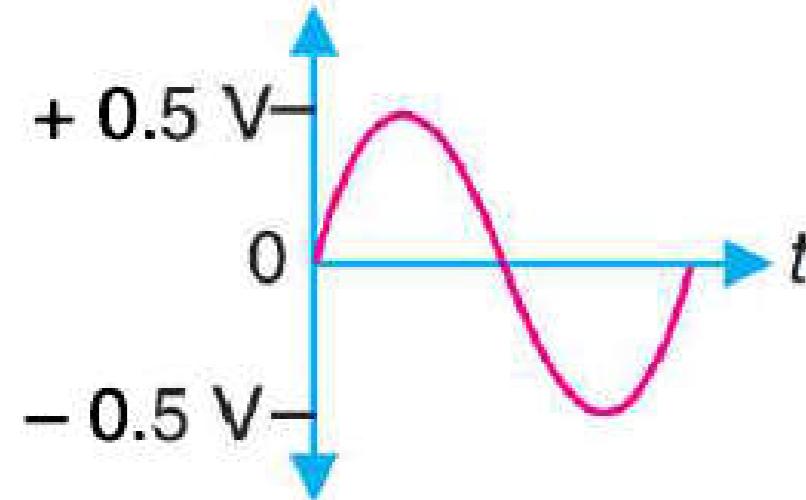


Gain Equation

$$i_1 = i_2 \Rightarrow \frac{v_i - v_1}{R_1} = \frac{v_1 - v_o}{R_f}$$

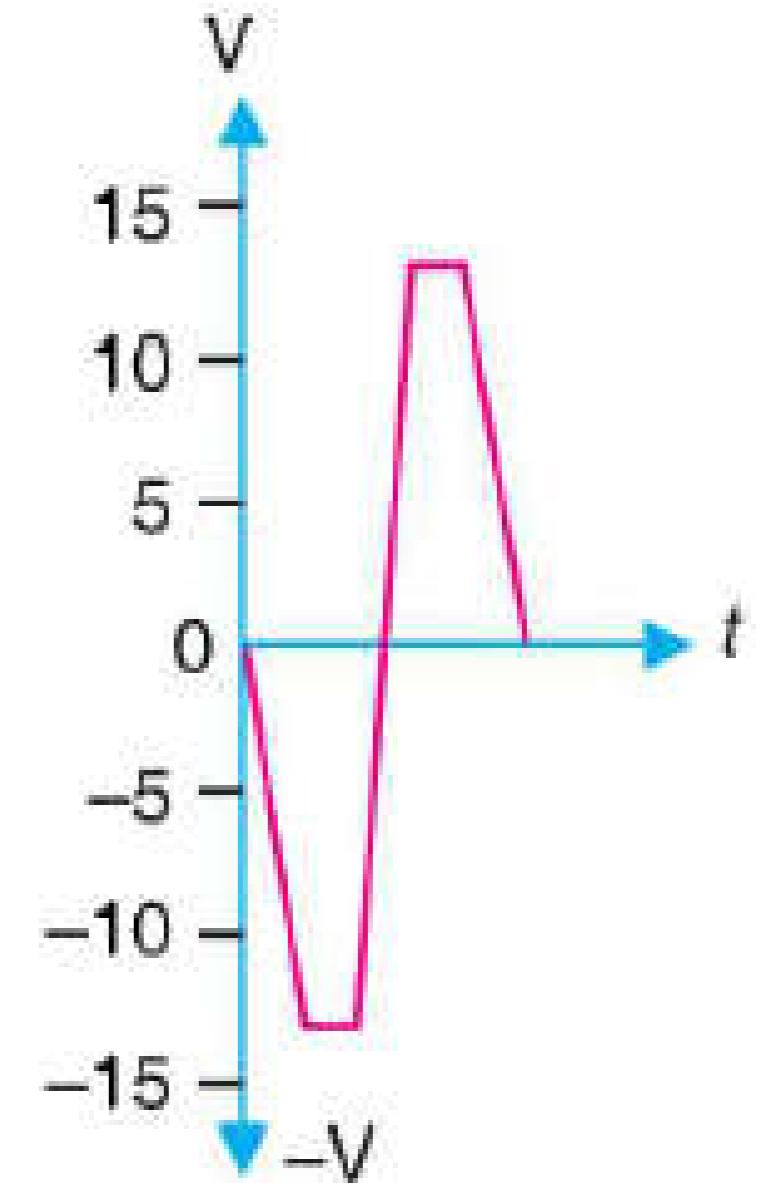
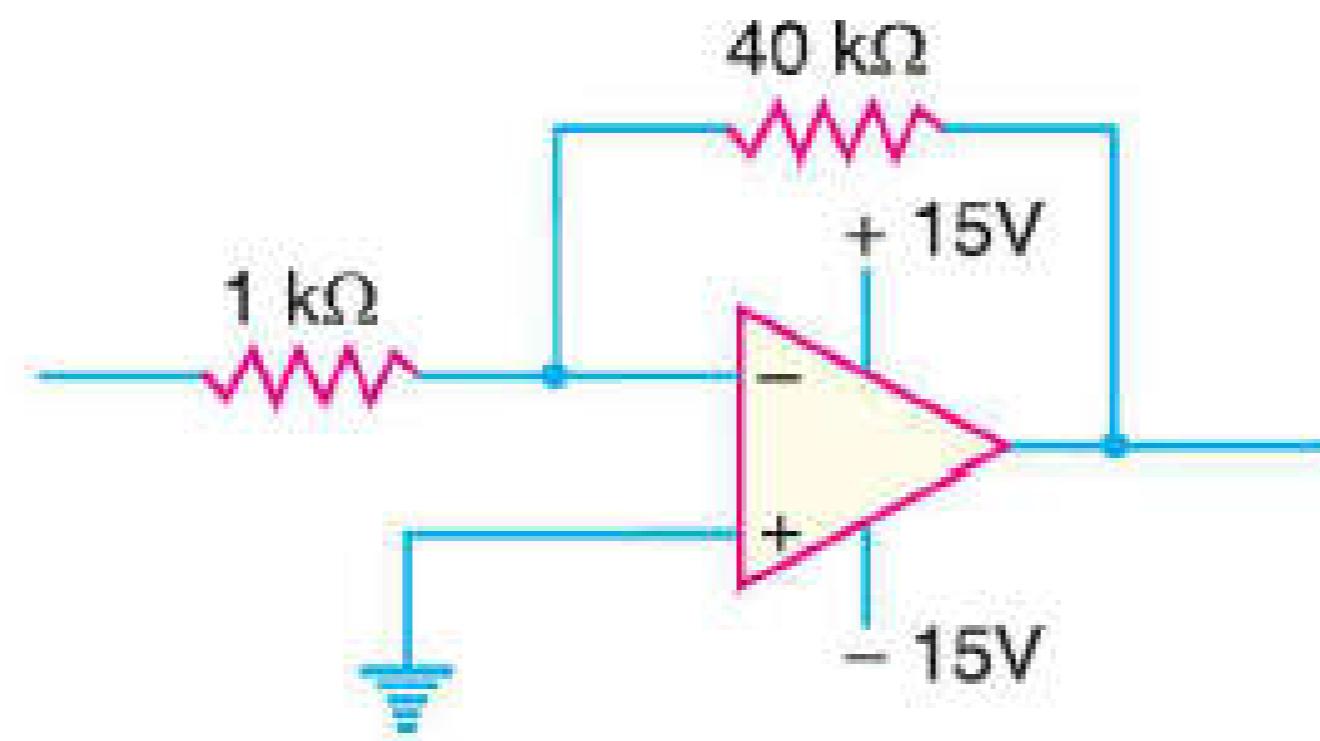
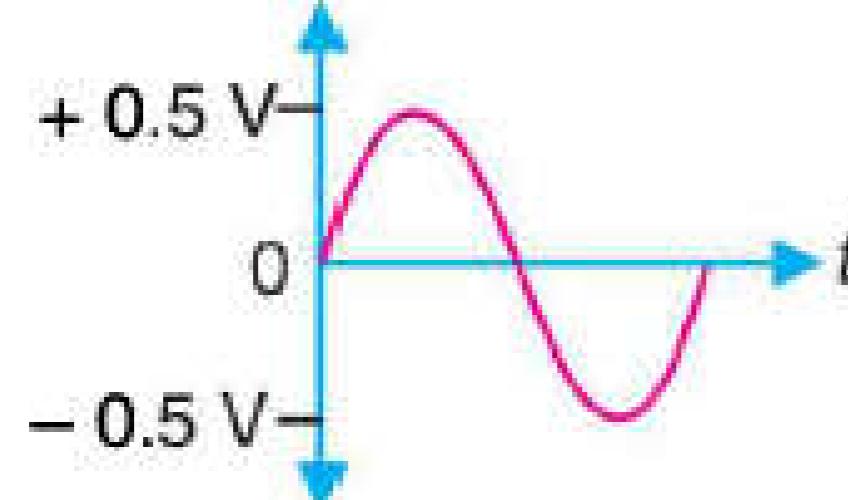
$$v_o = -\frac{R_f}{R_1} v_i$$

Example



$$\text{Voltage gain, } A_{CL} = -\frac{R_f}{R_i} = -\frac{1 \text{ k}\Omega}{1 \text{ k}\Omega} = -1$$

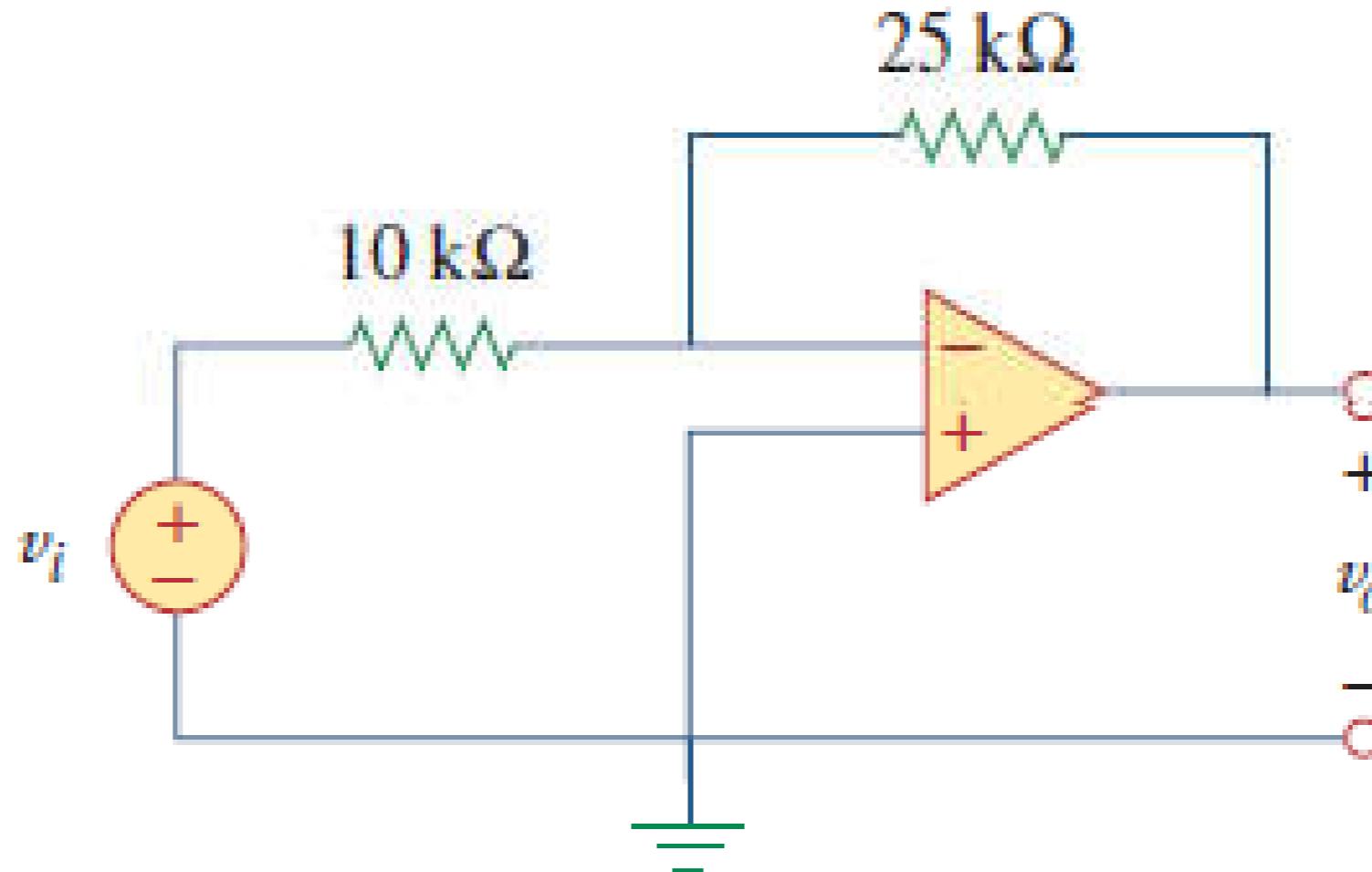
Example



$$\text{Voltage gain, } A_{CL} = -\frac{R_f}{R_i} = -\frac{40\text{ k}\Omega}{1\text{ k}\Omega} = -40$$

Question

- For the opamp in figure below. If v_i is 0.5 V, calculate: (a) the output voltage v_o , and (b) the current in the 10-k resistor.



Solution

(a) Using Eq. (5.9),

$$\frac{v_o}{v_i} = -\frac{R_f}{R_1} = -\frac{25}{10} = -2.5$$

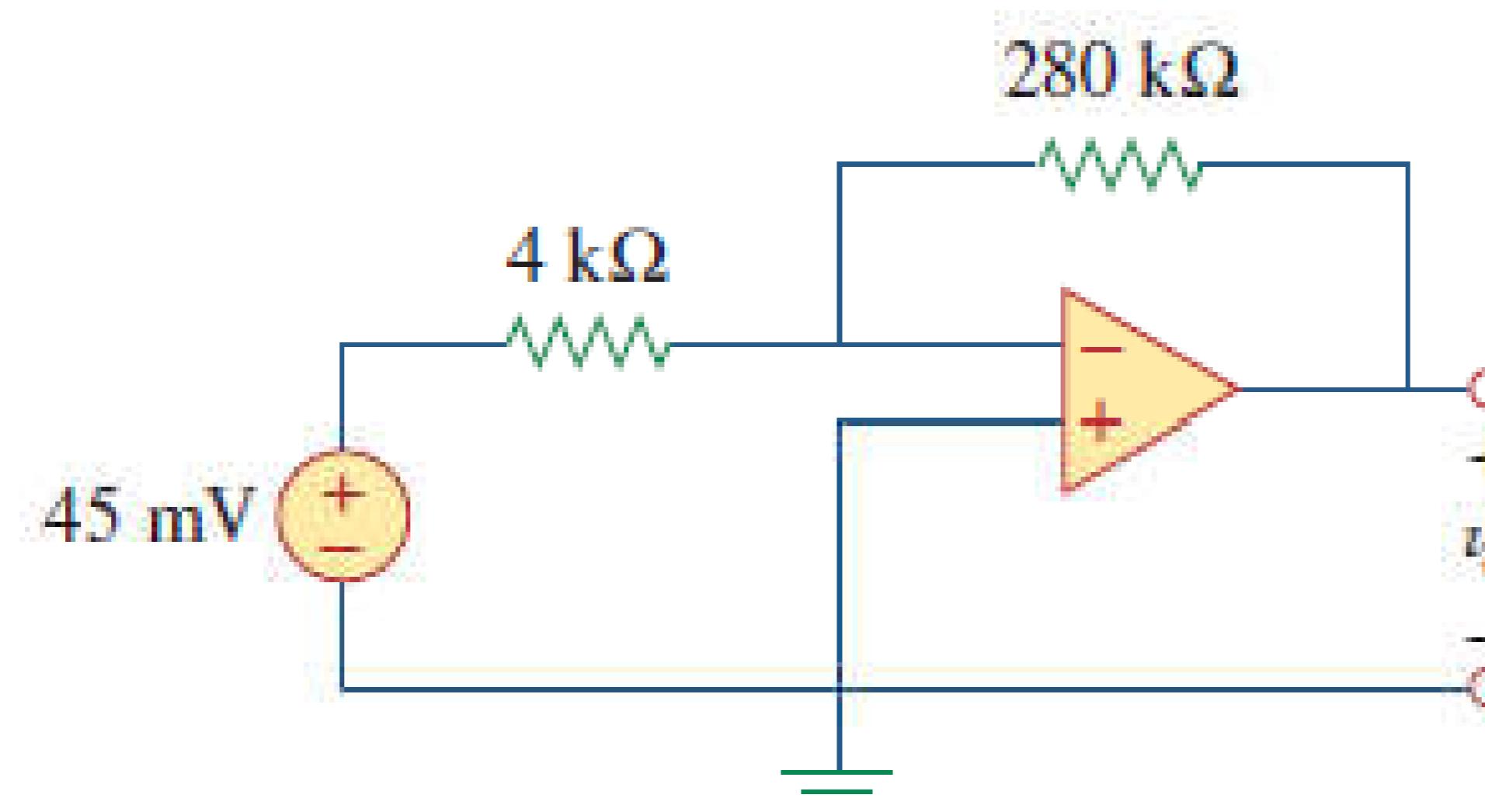
$$v_o = -2.5v_i = -2.5(0.5) = -1.25 \text{ V}$$

(b) The current through the $10\text{-k}\Omega$ resistor is

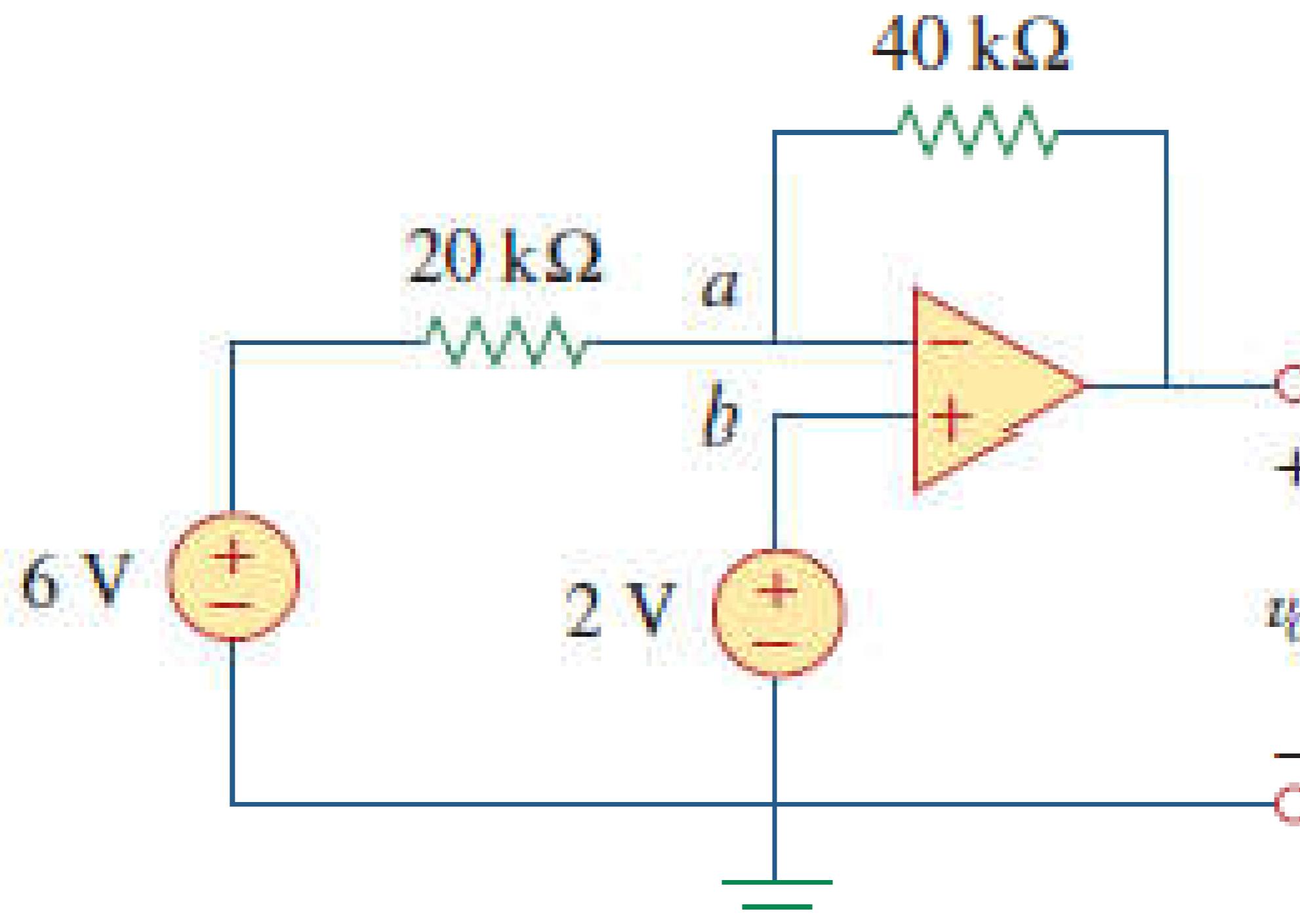
$$i = \frac{v_i - 0}{R_1} = \frac{0.5 - 0}{10 \times 10^3} = 50 \mu\text{A}$$

Question

- Find the output of the opamp circuit shown below. Calculate the current through the feedback resistor.



Determine V_o



Solution

Applying KCL at node a ,

$$\frac{v_a - v_o}{40 \text{ k}\Omega} = \frac{6 - v_a}{20 \text{ k}\Omega}$$

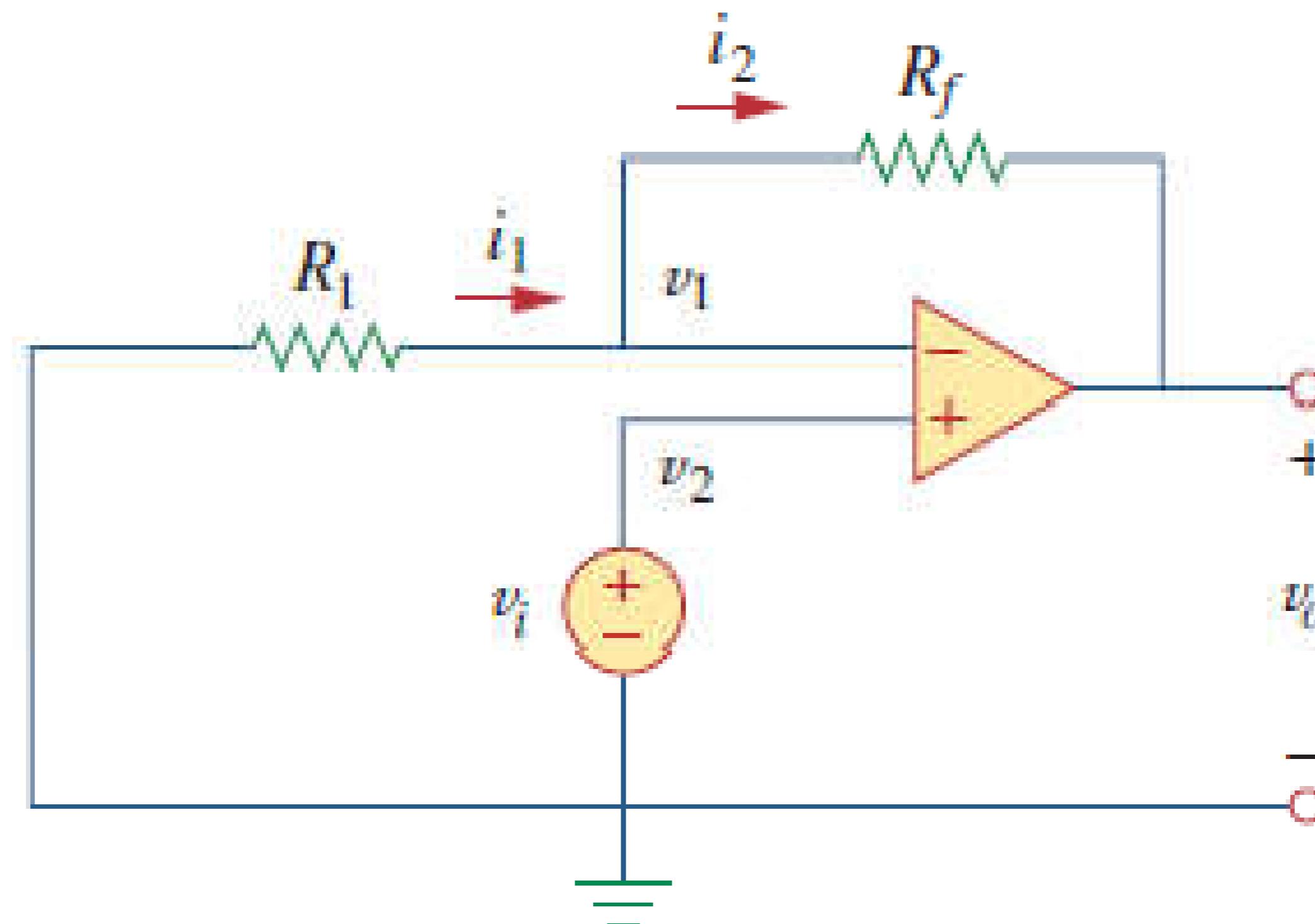
$$v_a - v_o = 12 - 2v_a \quad \Rightarrow \quad v_o = 3v_a - 12$$

But $v_a = v_b = 2 \text{ V}$ for an ideal op amp, because of the zero voltage drop across the input terminals of the op amp. Hence,

$$v_o = 6 - 12 = -6 \text{ V}$$

Notice that if $v_b = 0 = v_a$, then $v_o = -12$, as expected from Eq. (5.9).

Non-Inverting Amplifier



Gain Equation

$$\dot{i}_1 = \dot{i}_2 \Rightarrow \frac{0 - v_1}{R_1} = \frac{v_i - v_o}{R_f}$$

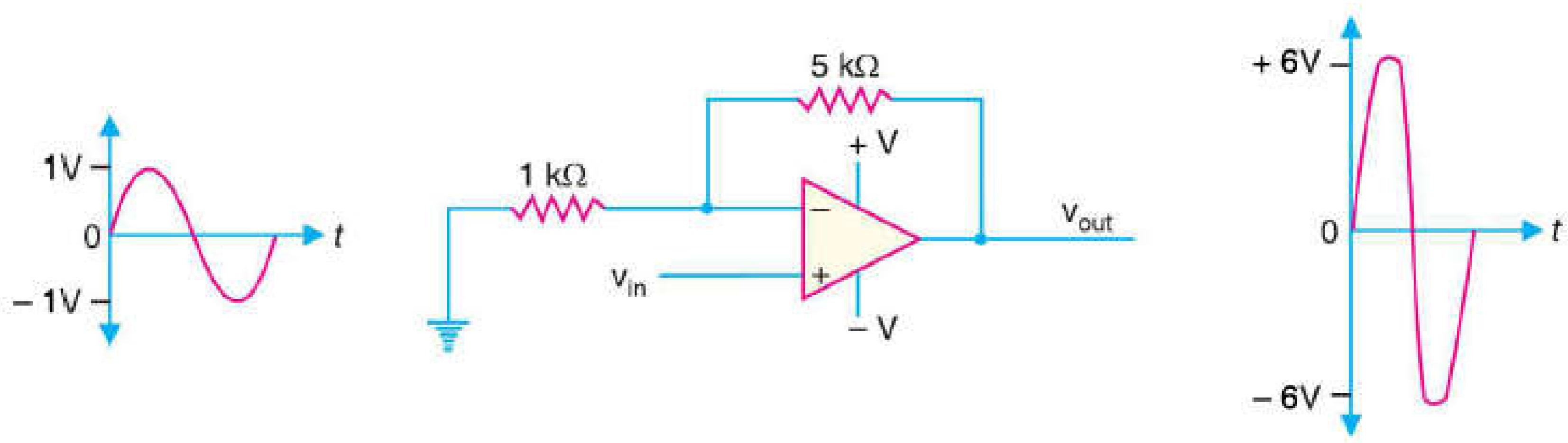
But $v_1 = v_2 = v_i$. Equation (5.10) becomes

$$\frac{-v_i}{R_1} = \frac{v_i - v_o}{R_f}$$

or

$$v_o = \left(1 + \frac{R_f}{R_1}\right)v_i$$

Example

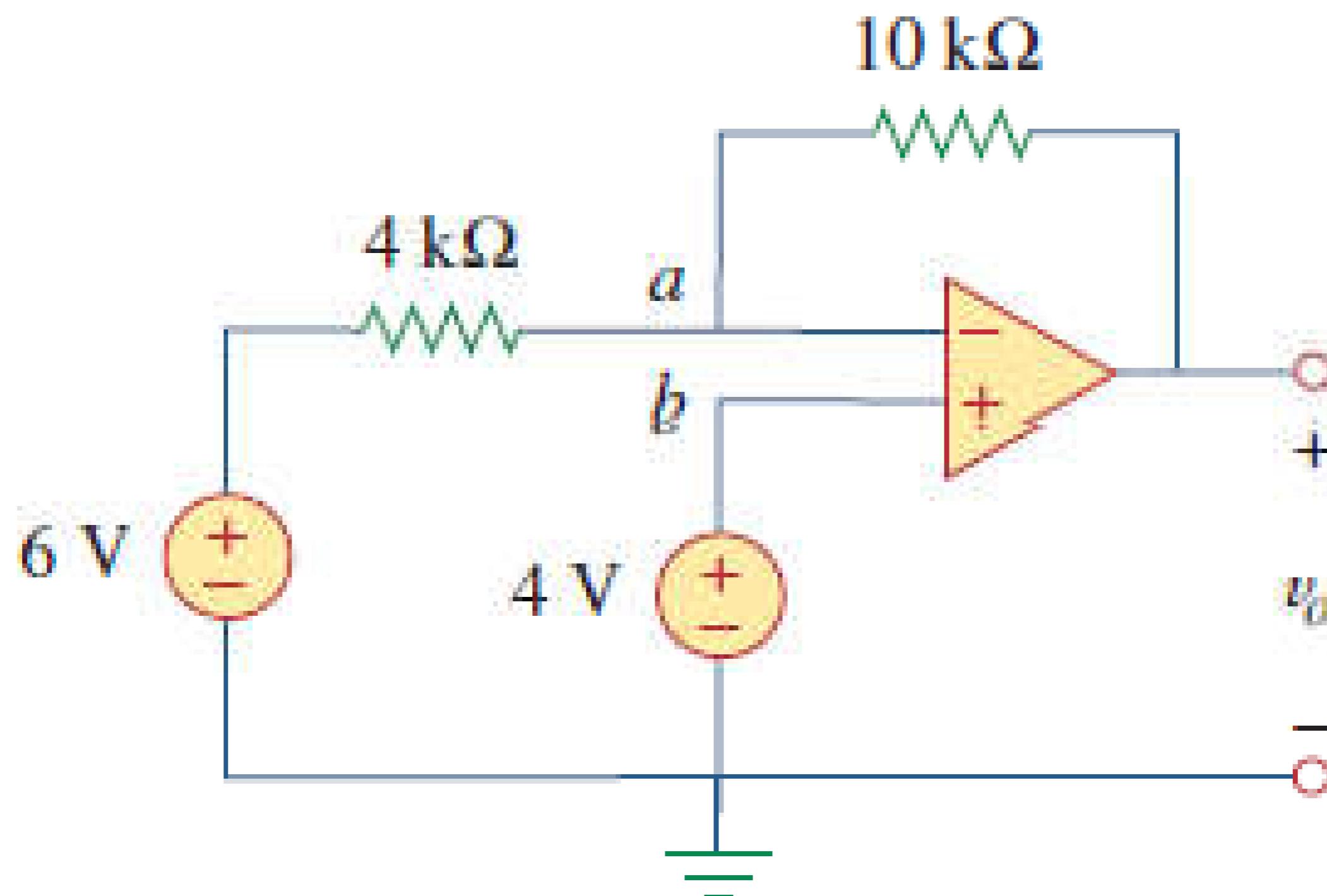


The input signal is 2 V peak-to-peak.

$$\text{Voltage gain, } A_{CL} = 1 + \frac{R_f}{R_i} = 1 + \frac{5 \text{ k}\Omega}{1 \text{ k}\Omega} = 1 + 5 = 6$$

$$\therefore \text{Peak-to-peak output voltage} = A_{CL} \times v_{inpp} = 6 \times 2 = 12 \text{ V}$$

Determin Vo



Solution

Applying KCL at node a ,

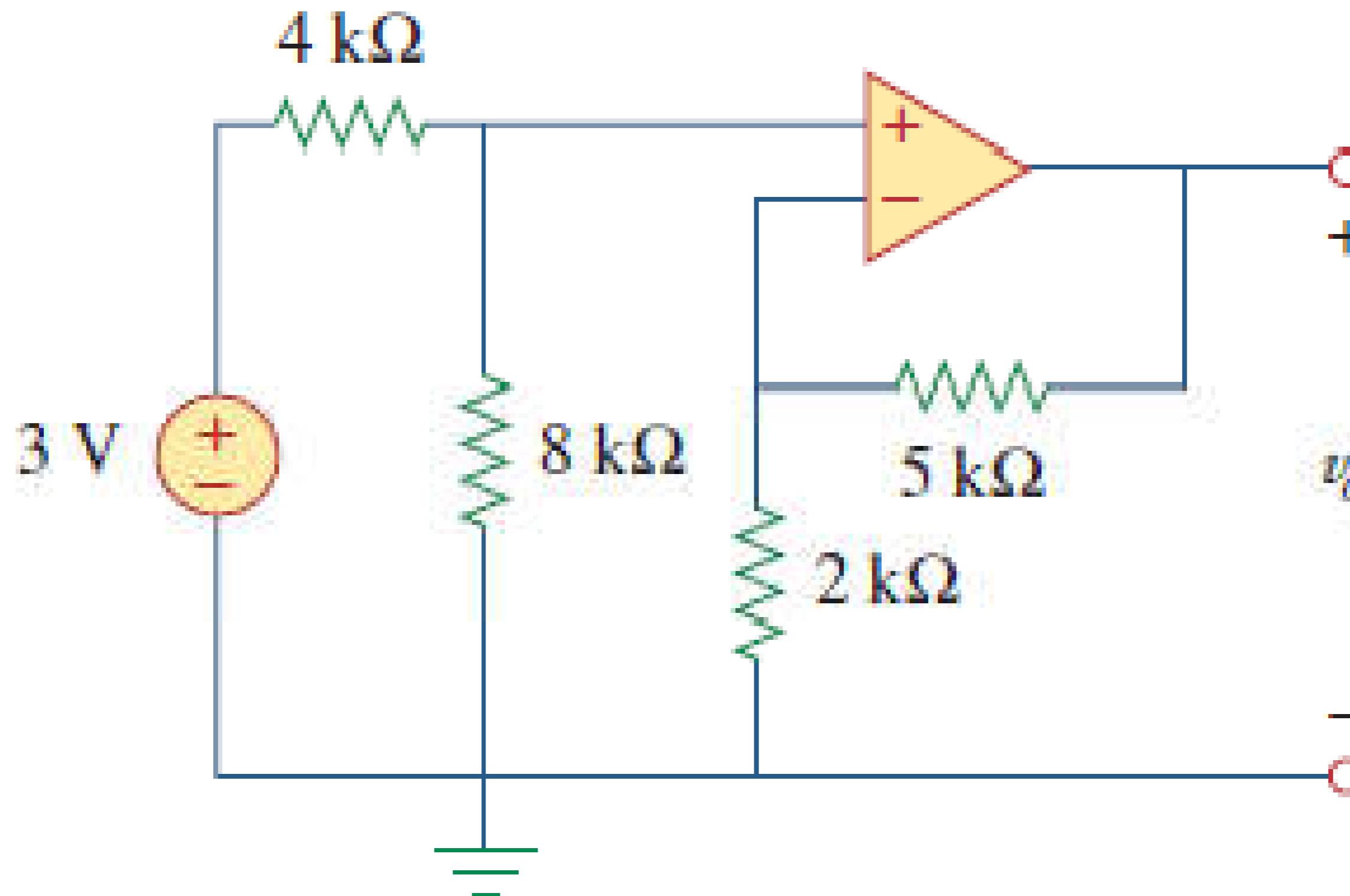
$$\frac{6 - v_a}{4} = \frac{v_a - v_o}{10}$$

But $v_a = v_b = 4$, and so

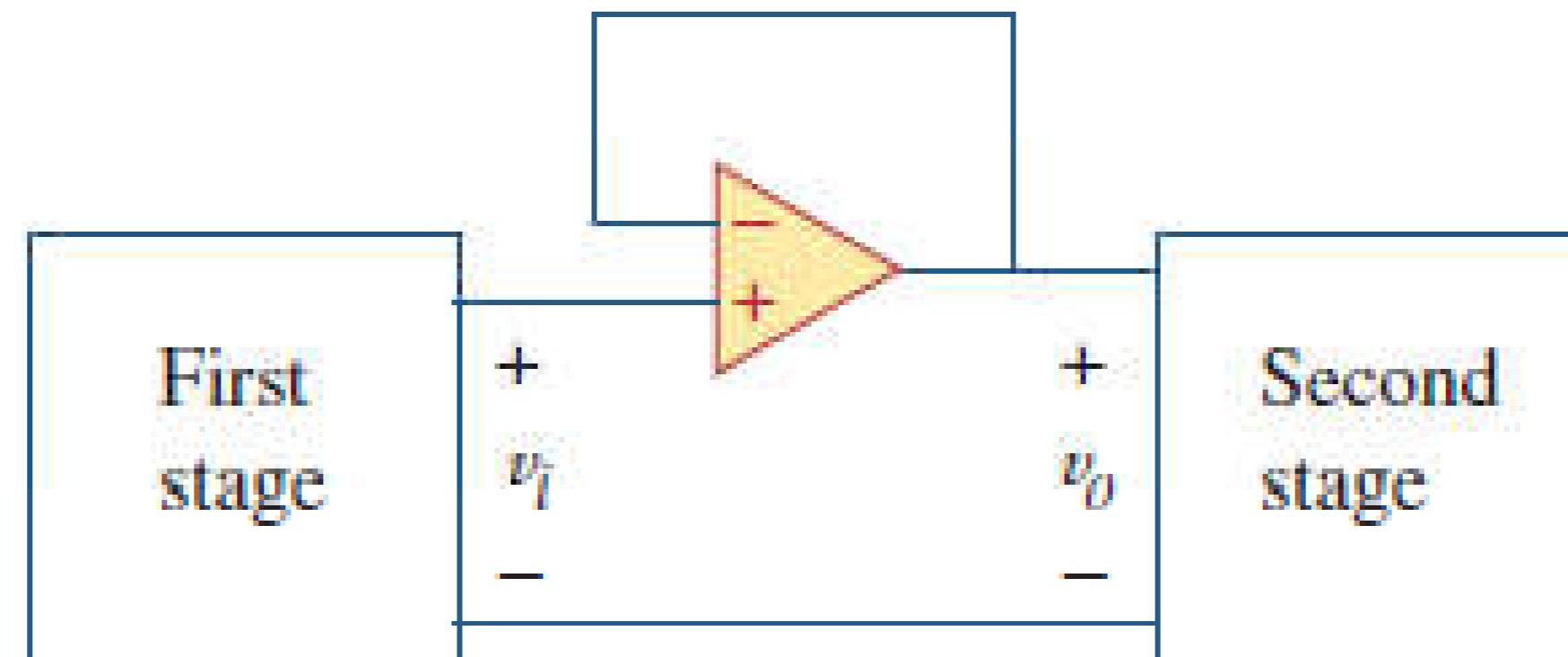
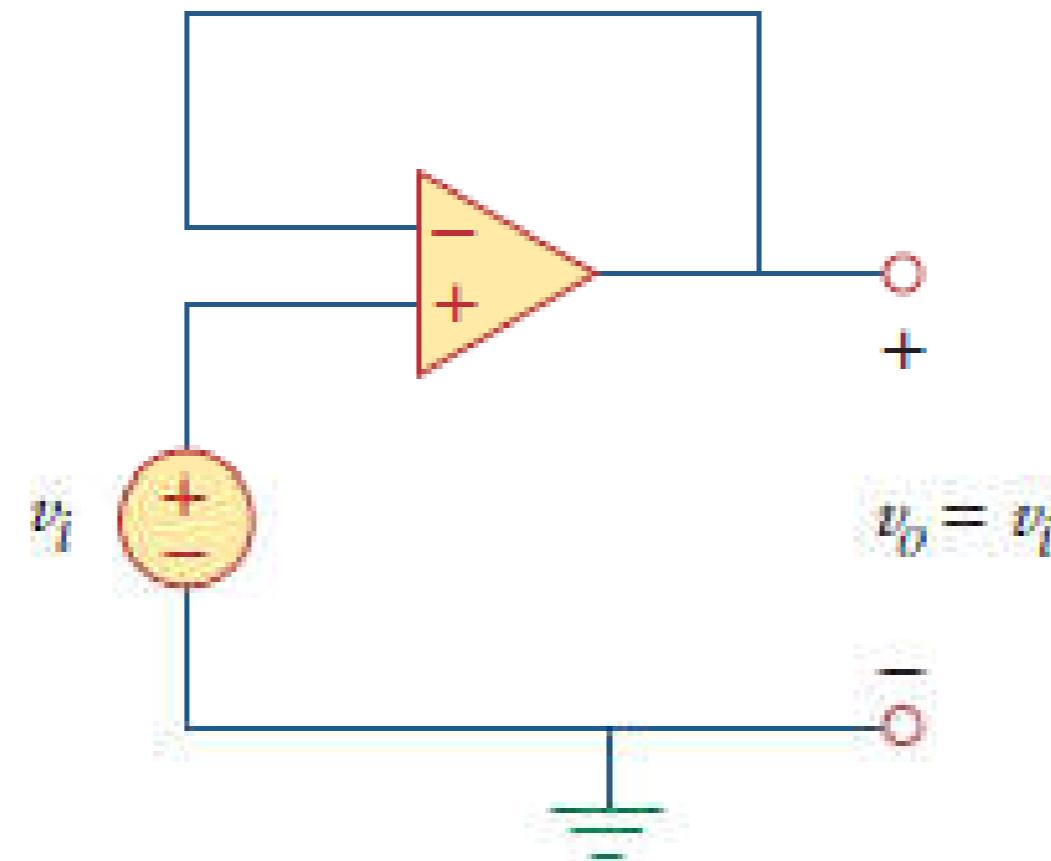
$$\frac{6 - 4}{4} = \frac{4 - v_o}{10} \quad \Rightarrow \quad 5 = 4 - v_o$$

or $v_o = -1$ V, as before.

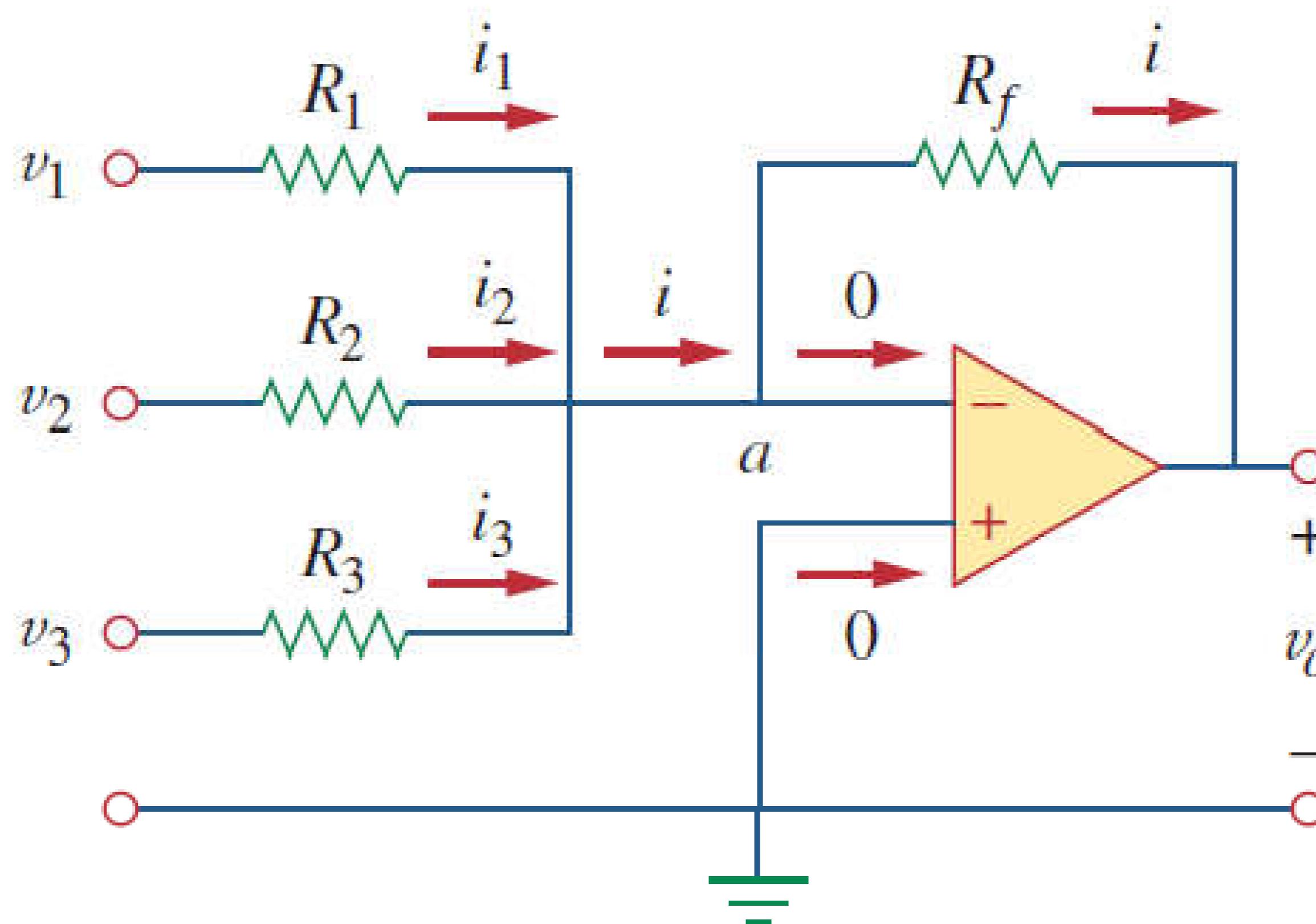
Determine V_o



Opamp as a Buffer



Summer



Derivation

Applying KCL at node a gives

$$i = i_1 + i_2 + i_3$$

But

$$i_1 = \frac{v_1 - v_a}{R_1}, \quad i_2 = \frac{v_2 - v_a}{R_2}$$

$$i_3 = \frac{v_3 - v_a}{R_3}, \quad i = \frac{v_a - v_o}{R_f}$$

We note that $v_a = 0$

$$v_o = -\left(\frac{R_f}{R_1}v_1 + \frac{R_f}{R_2}v_2 + \frac{R_f}{R_3}v_3\right)$$

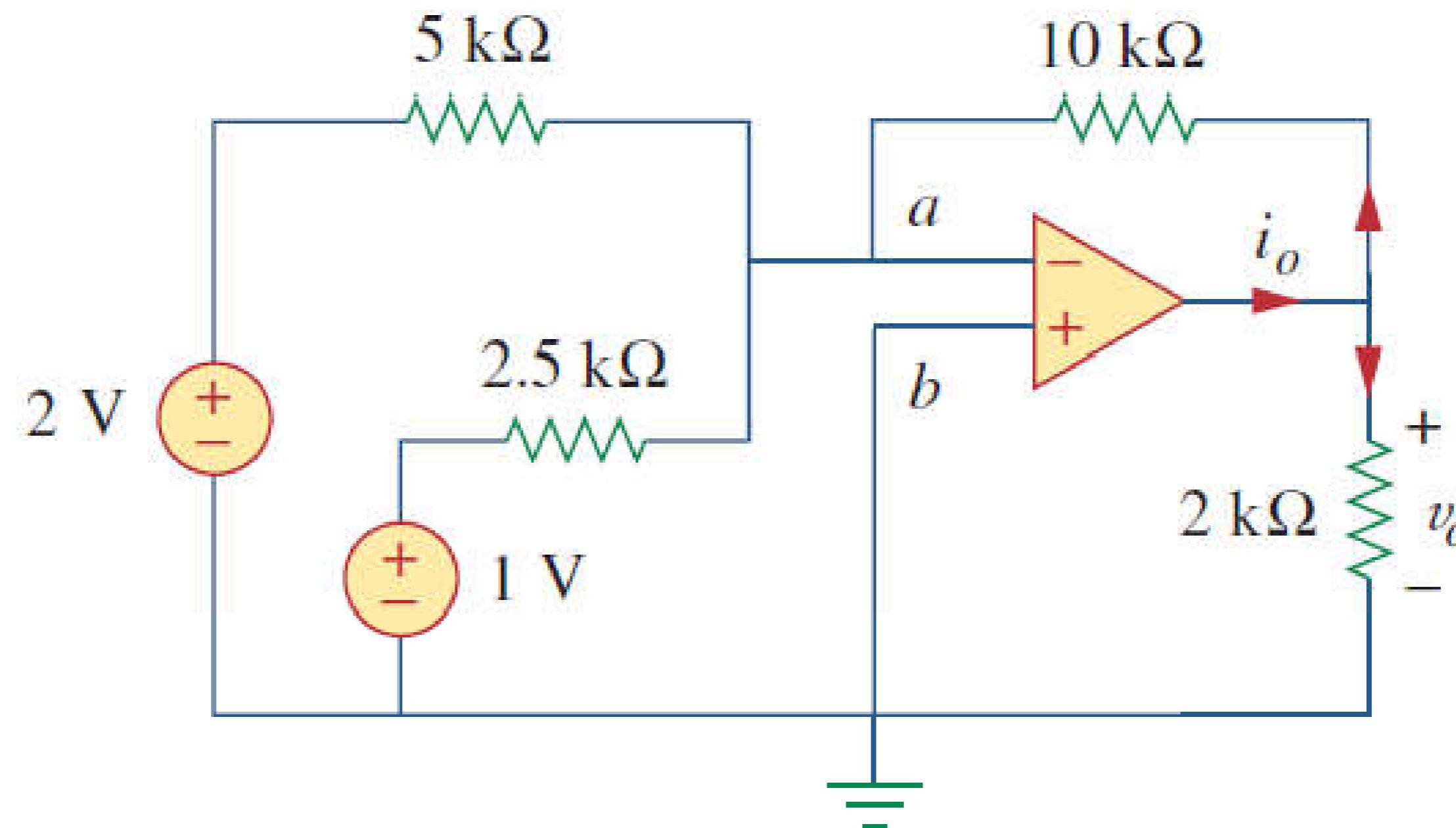
Averaging Amplifier

$$R_1 = R_2 = R_3$$

$$\frac{R_f}{R} = \frac{1}{n}$$

$$v_o = -\left(\frac{v_1 + v_2 + v_3}{3} \right)$$

Question



Solution

This is a summer with two inputs.

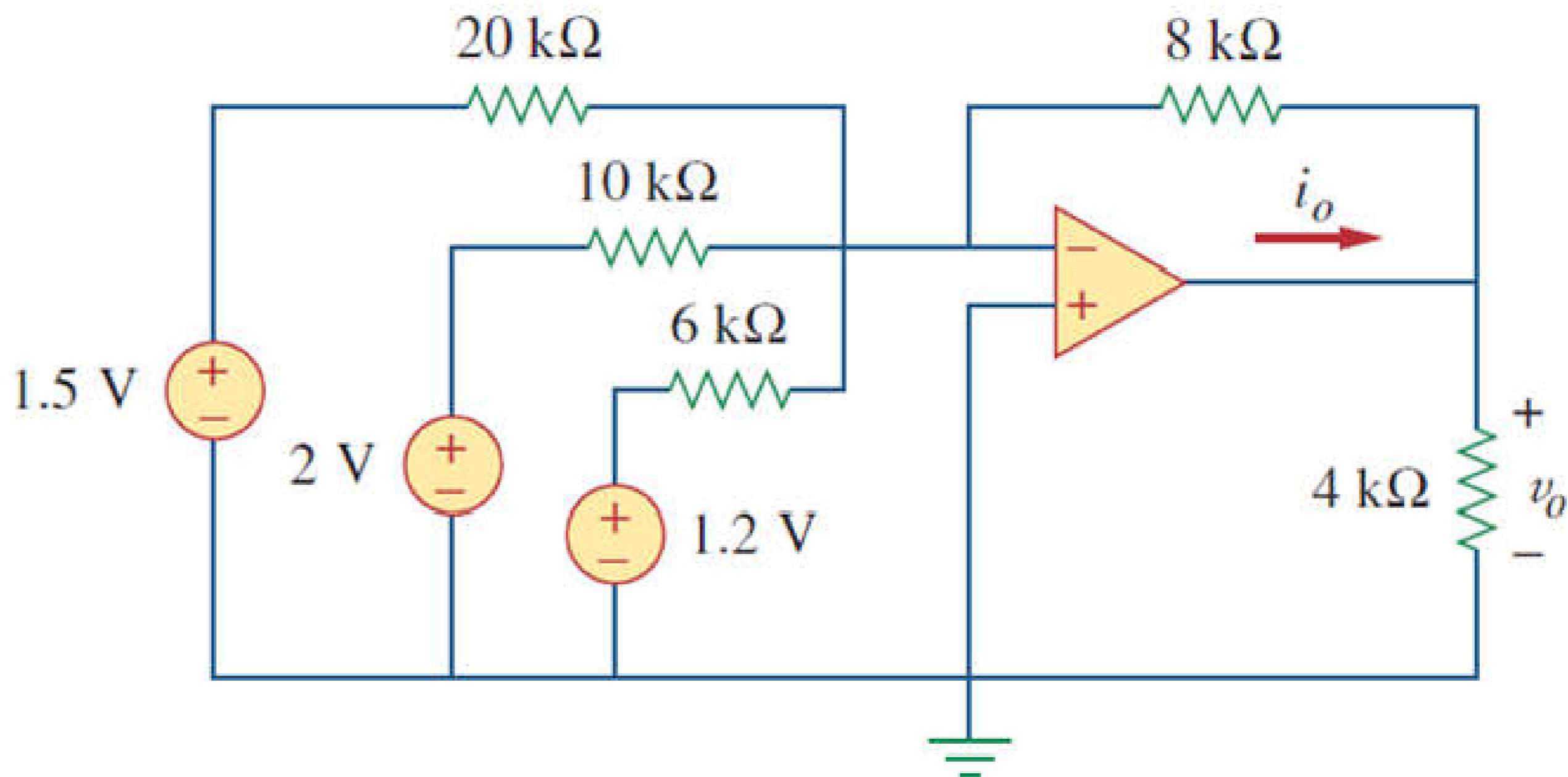
$$v_o = -\left[\frac{10}{5}(2) + \frac{10}{2.5}(1) \right] = -(4 + 4) = -8 \text{ V}$$

The current i_o is the sum of the currents through the $10\text{-k}\Omega$ and $2\text{-k}\Omega$ resistors. Both of these resistors have voltage $v_o = -8 \text{ V}$ across them, since $v_a = v_b = 0$. Hence,

$$i_o = \frac{v_o - 0}{10} + \frac{v_o - 0}{2} \text{ mA} = -0.8 - 4 = -4.8 \text{ mA}$$

Question

Find v_o and i_o in the op amp circuit shown

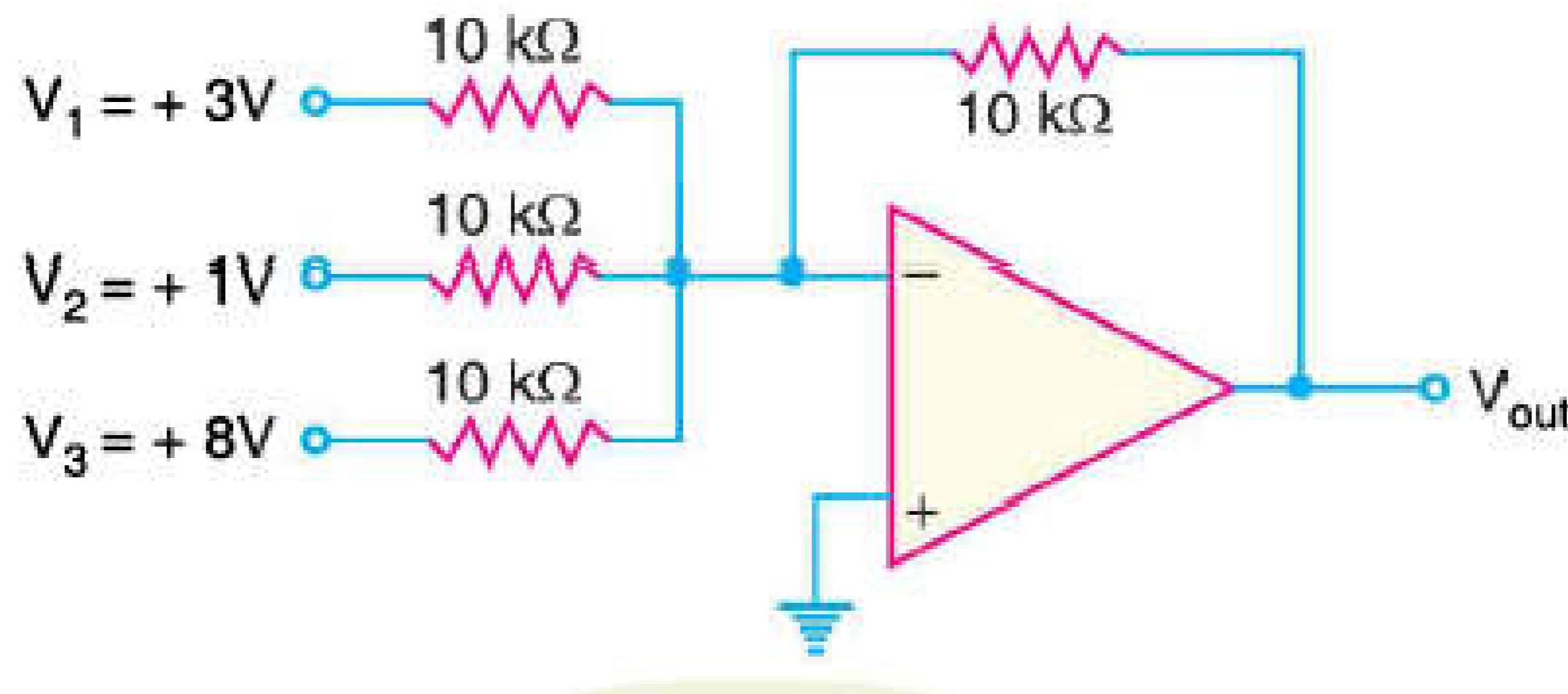


Answers

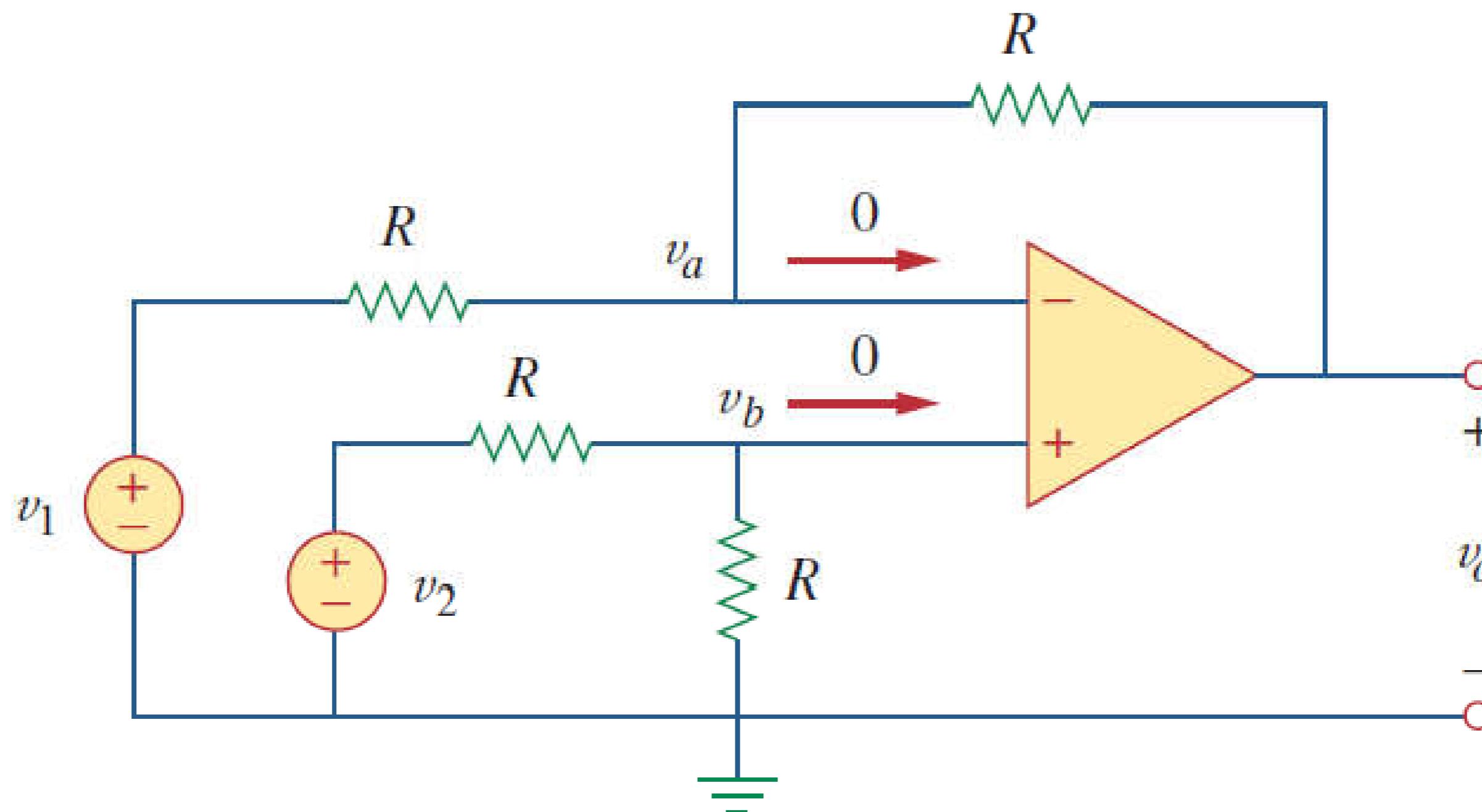
–3.8 V, –1.425 mA.

Design an op amp circuit with inputs v_1 and v_2 such that $v_o = -5v_1 + 3v_2$.

Question



Opamp as Subtractor



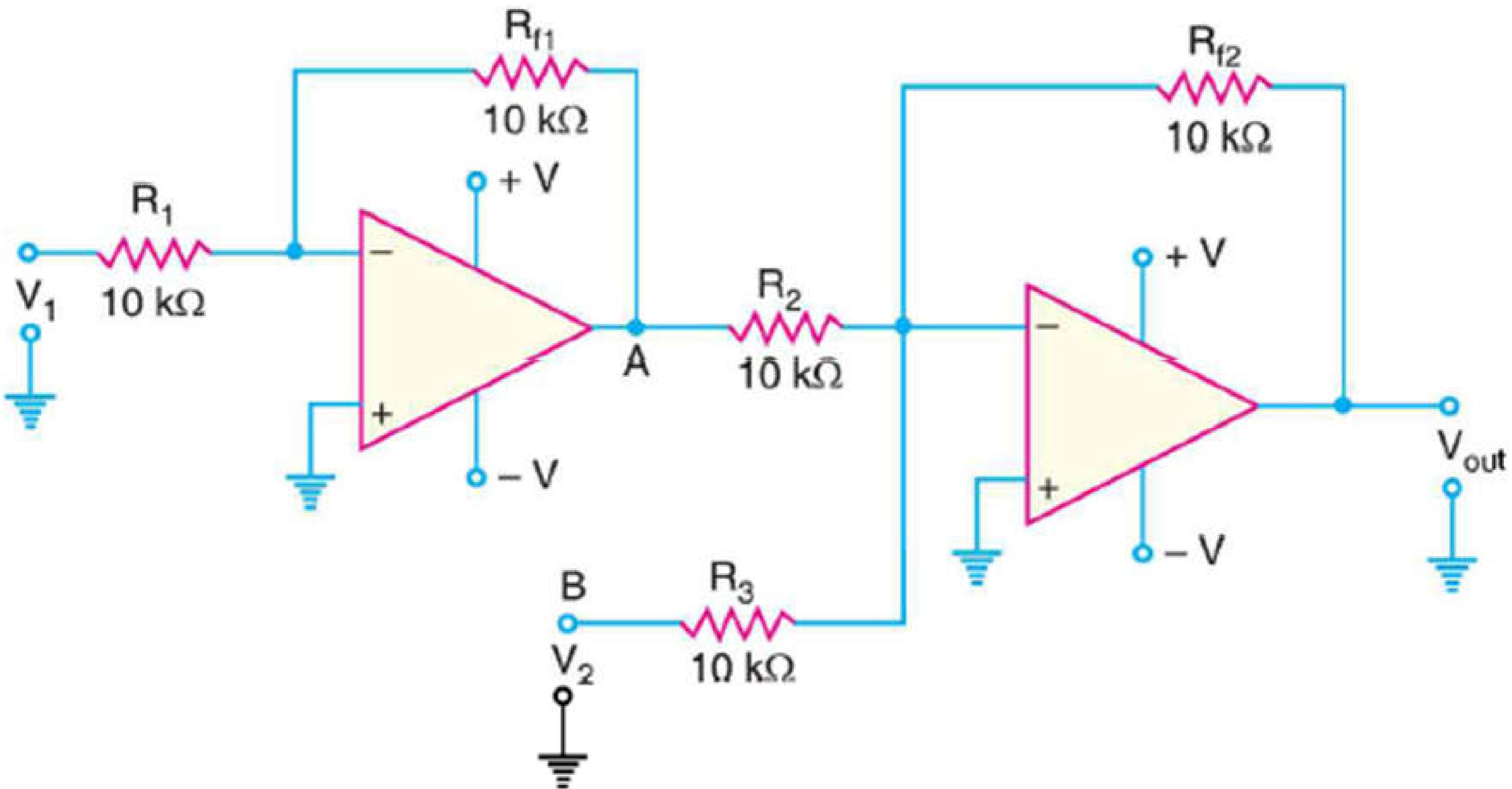
Derivation

$$v_o = -\frac{R}{R} v_1 + \left(1 + \frac{R}{R}\right) v_b$$

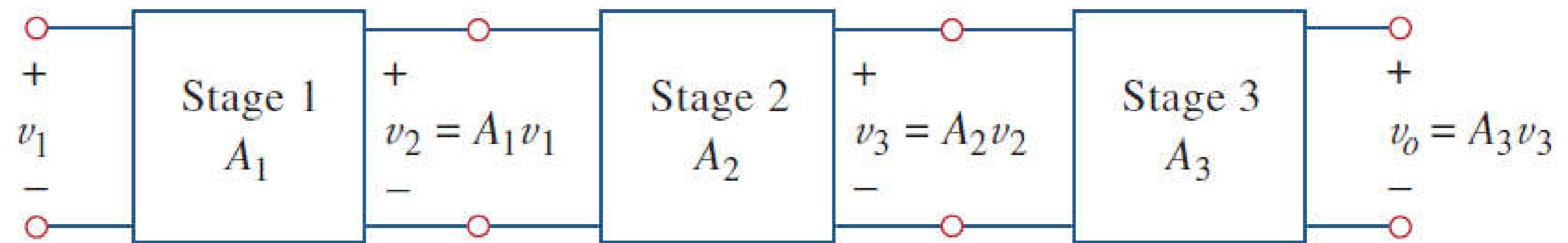
$$v_b = \frac{R}{R+R} v_2$$

$$v_o = v_2 - v_1$$

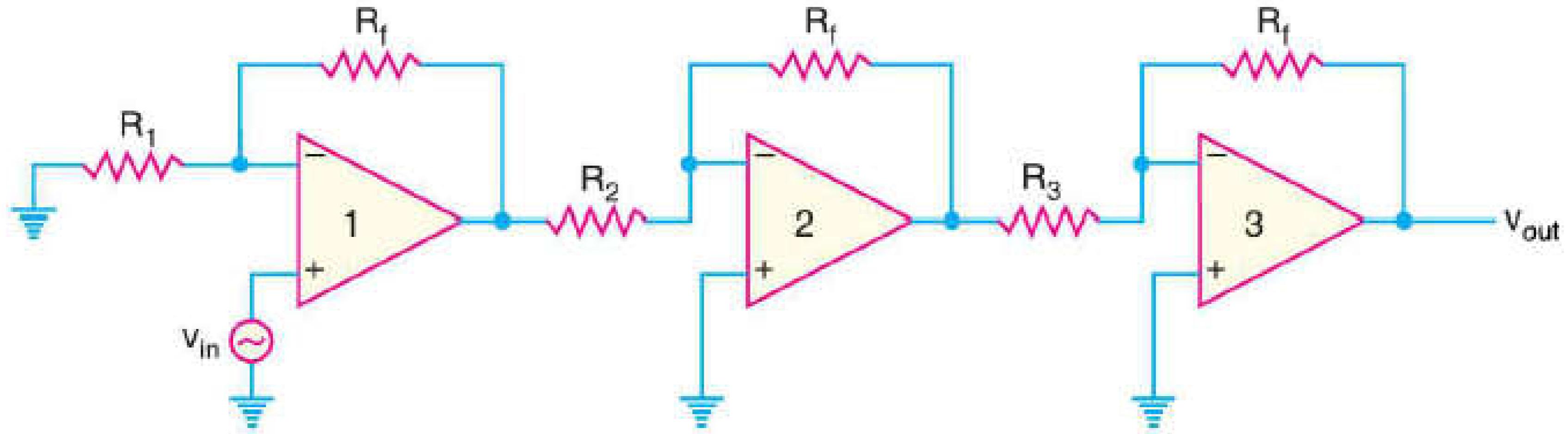
Example



Multistage Opamp Circuits



Example



The overall voltage gain A of this circuit is given by;

$$A = A_1 A_2 A_3$$

where A_1 = Voltage gain of first stage = $1 + (R_f/R_1)$

A_2 = Voltage gain of second stage = $-R_f/R_2$

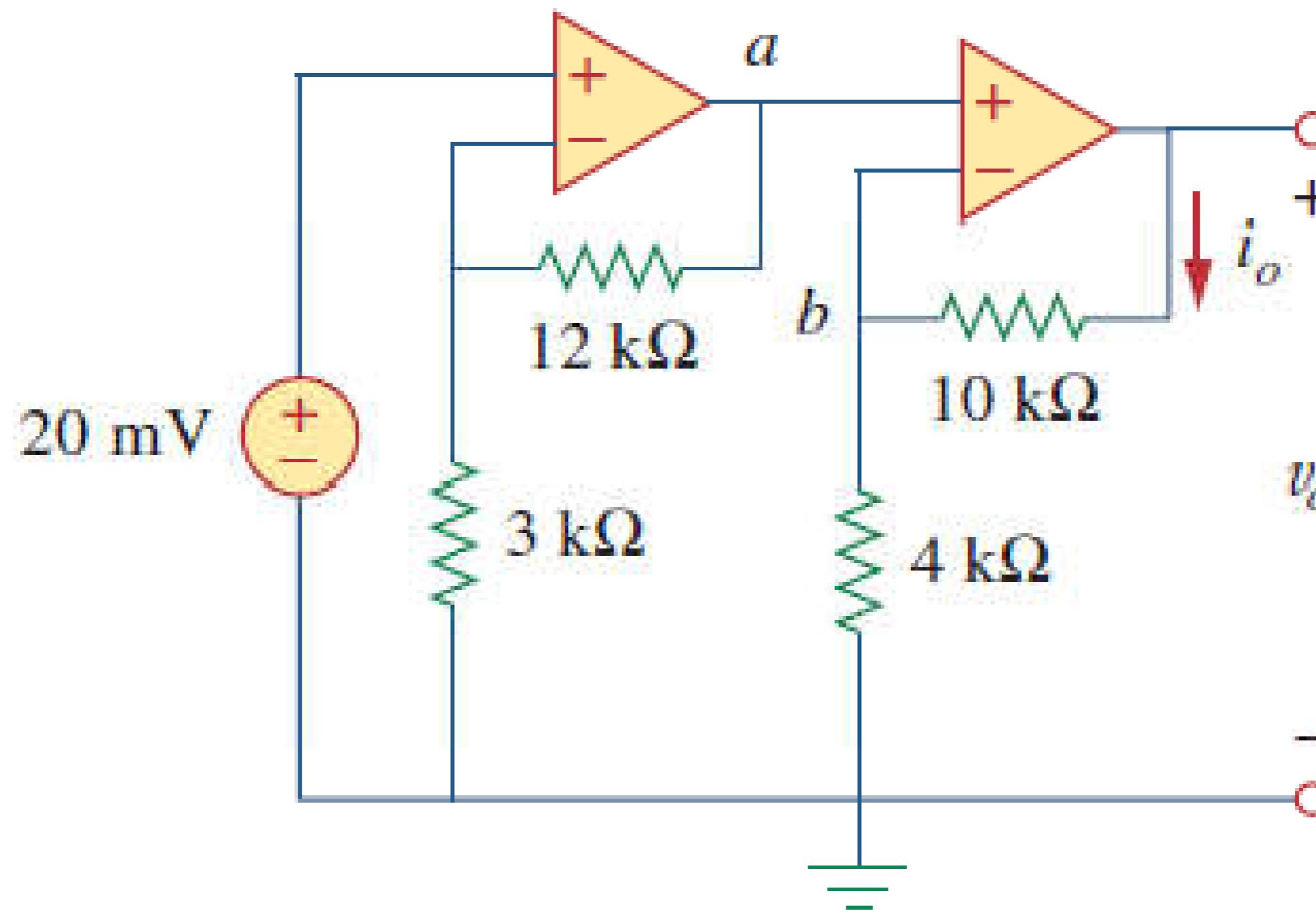
A_3 = Voltage gain of third stage = $-R_f/R_3$

Question

- In the previous circuit, if $R_f = 470\text{ k}$, $R_1=4.3\text{ k}$, $R_2=33\text{ k}$ and $R_3=33\text{ k}$. Determine the output voltage for an input voltage of 33 micro volts.

Question

Find v_o and i_o in the circuit



Solution

This circuit consists of two noninverting amplifiers cascaded. At the output of the first op amp,

$$v_a = \left(1 + \frac{12}{3}\right)(20) = 100 \text{ mV}$$

At the output of the second op amp,

$$v_o = \left(1 + \frac{10}{4}\right)v_a = (1 + 2.5)100 = 350 \text{ mV}$$

The required current i_o is the current through the $10\text{-k}\Omega$ resistor.

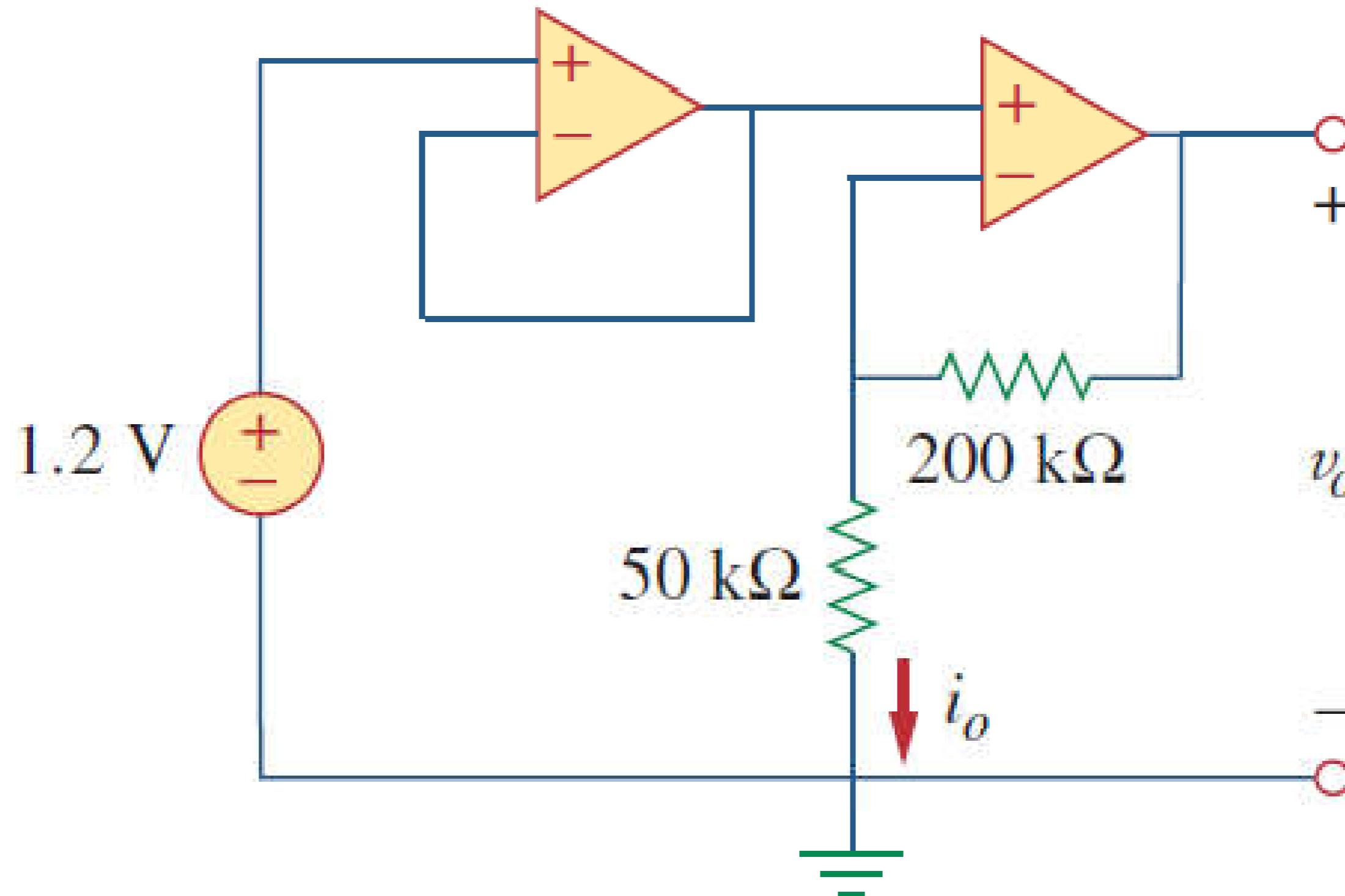
$$i_o = \frac{v_o - v_b}{10} \text{ mA}$$

But $v_b = v_a = 100 \text{ mV}$. Hence,

$$i_o = \frac{(350 - 100) \times 10^{-3}}{10 \times 10^3} = 25 \mu\text{A}$$

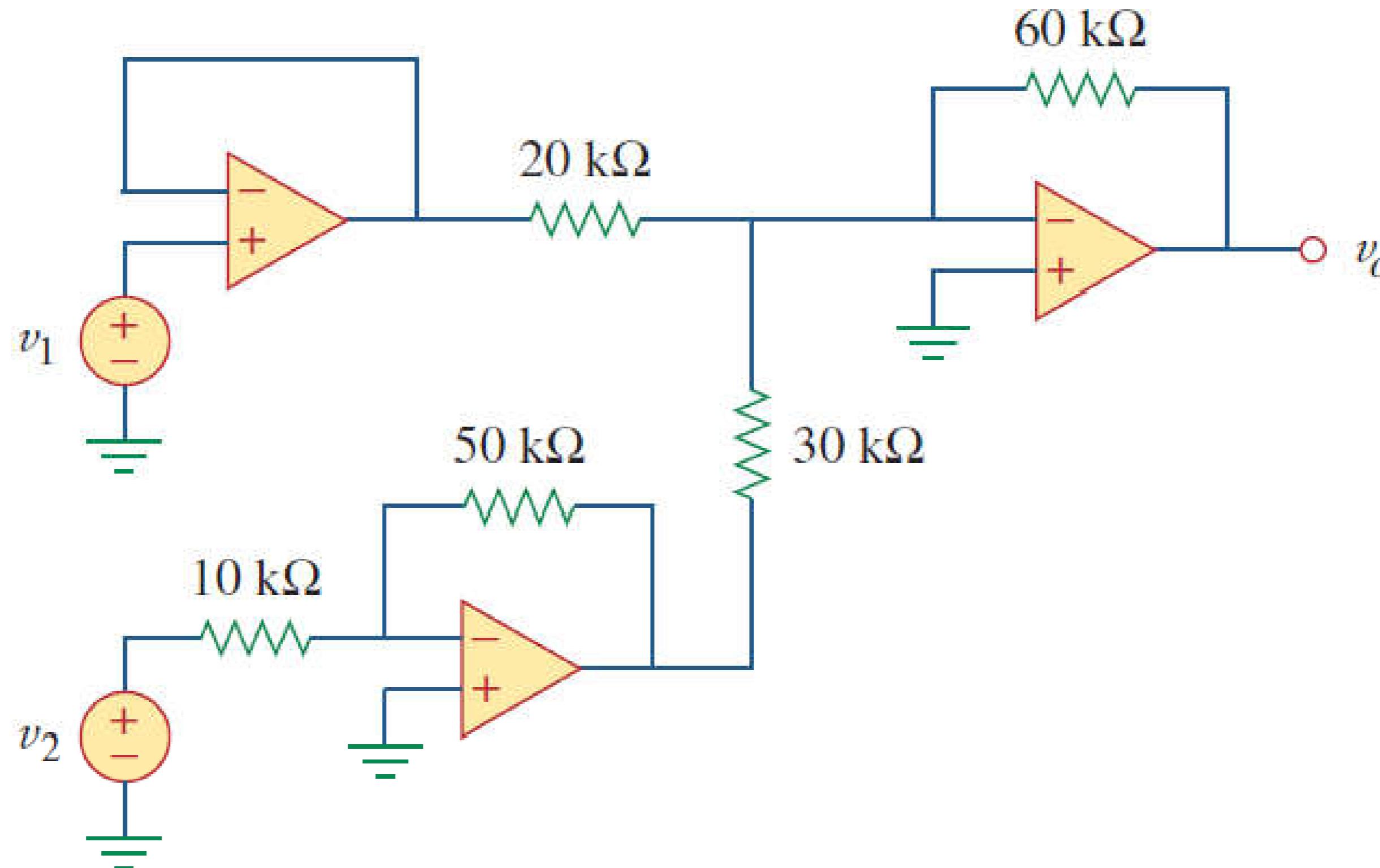
Question

Determine v_o and i_o in the op amp circuit



Question

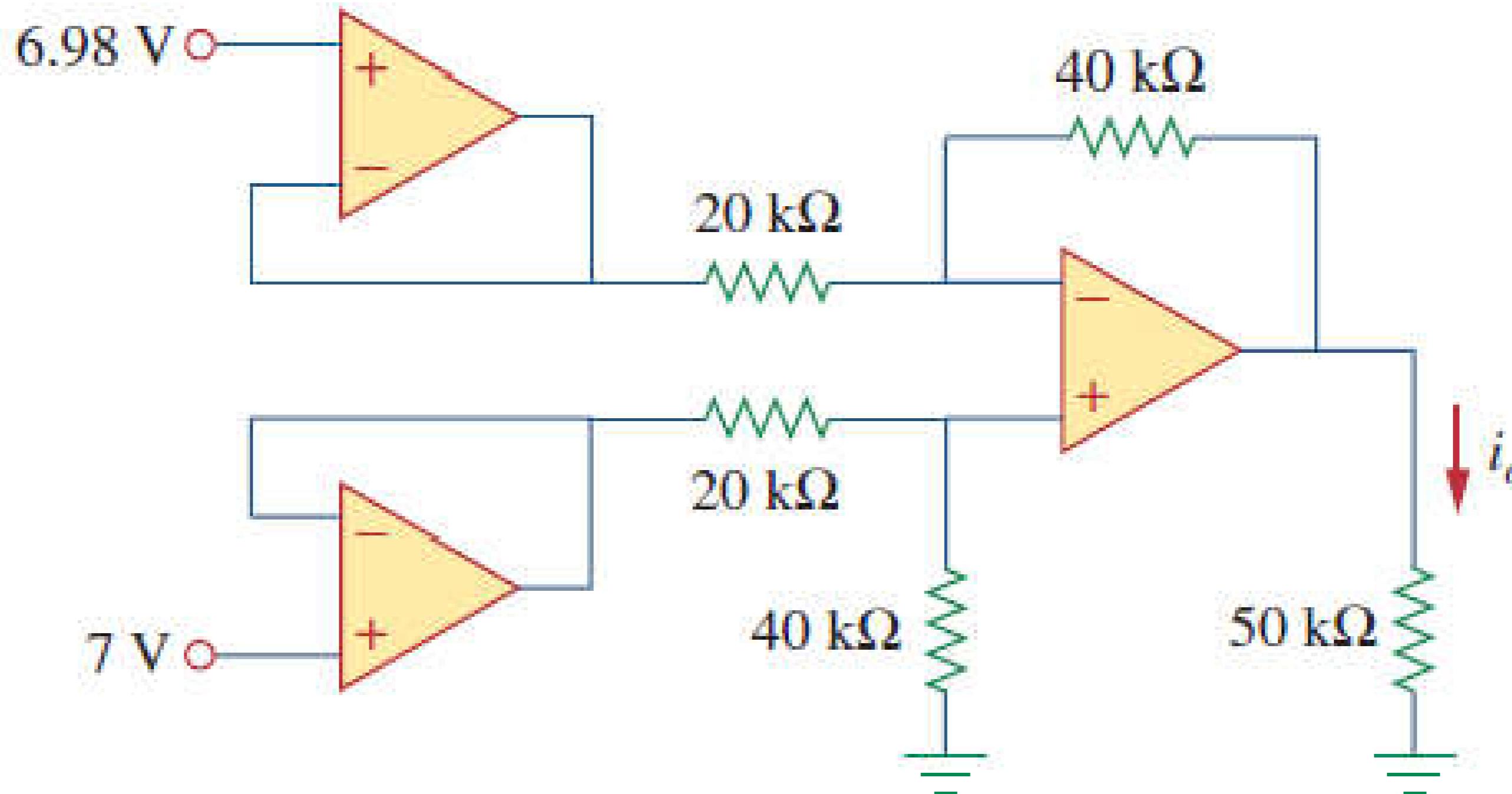
If $v_1 = 7$ V and $v_2 = 3.1$ V, find v_o in the op amp circuit



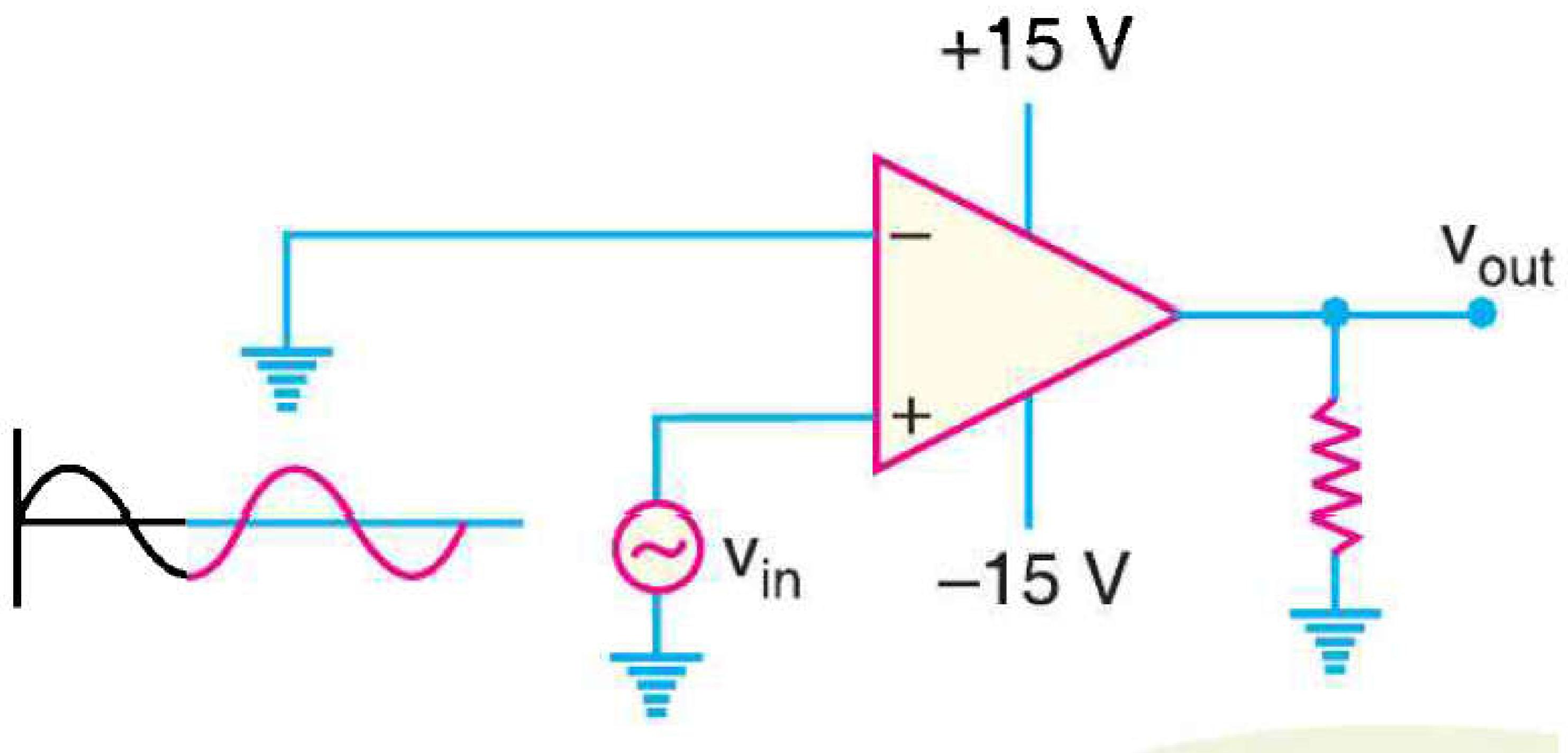
Question

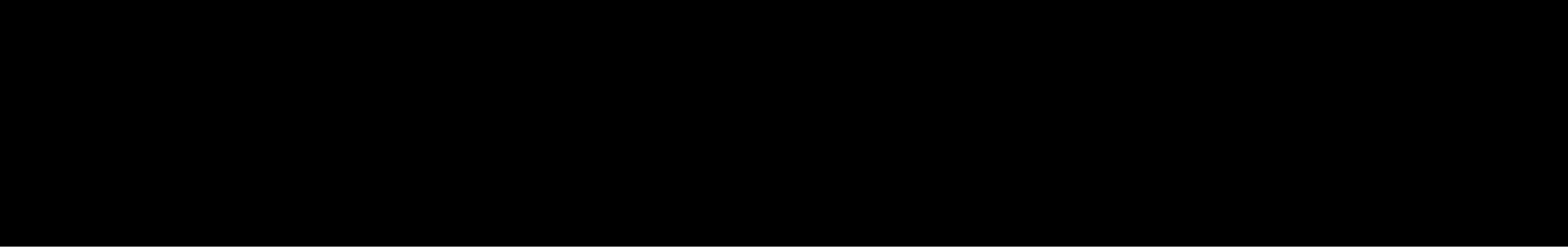
-800 μ A.

Obtain i_o



Concept Check





To Be Continued...