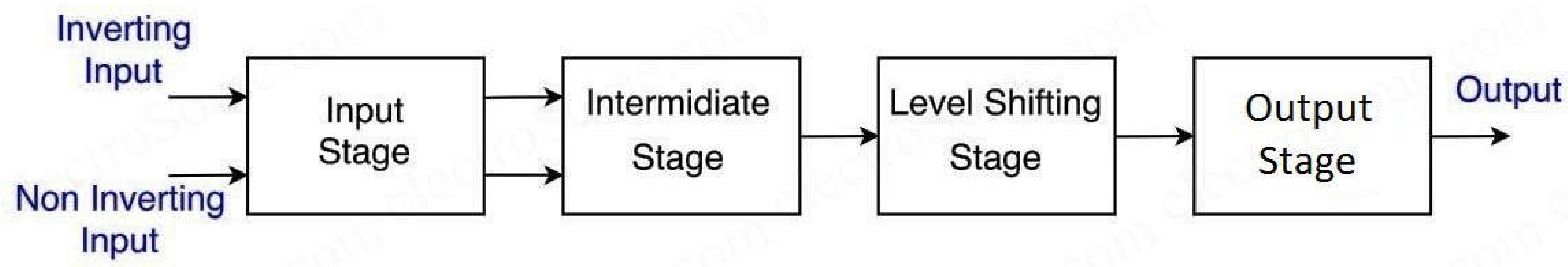
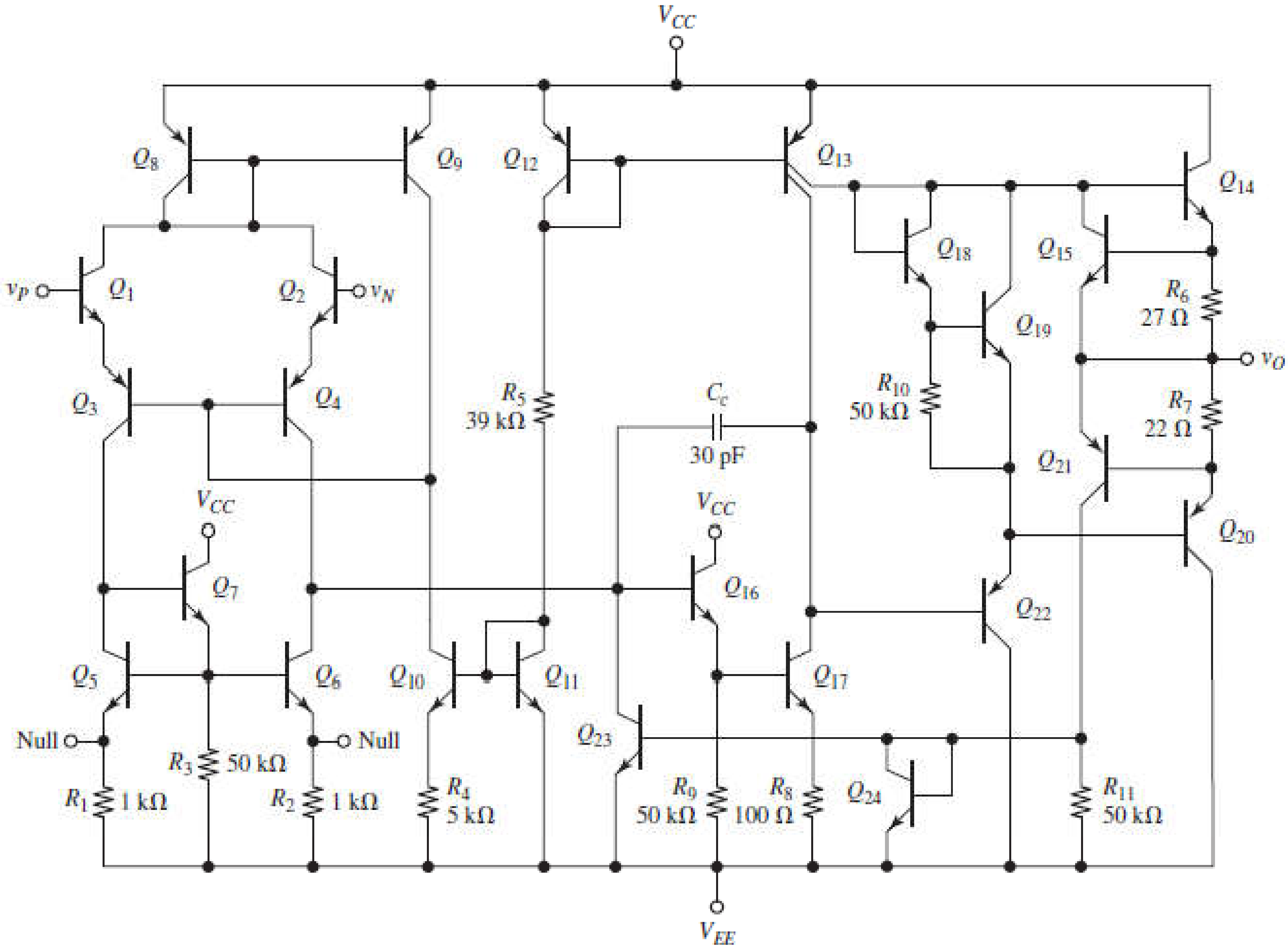
Opamp

Opamp Block Diagram

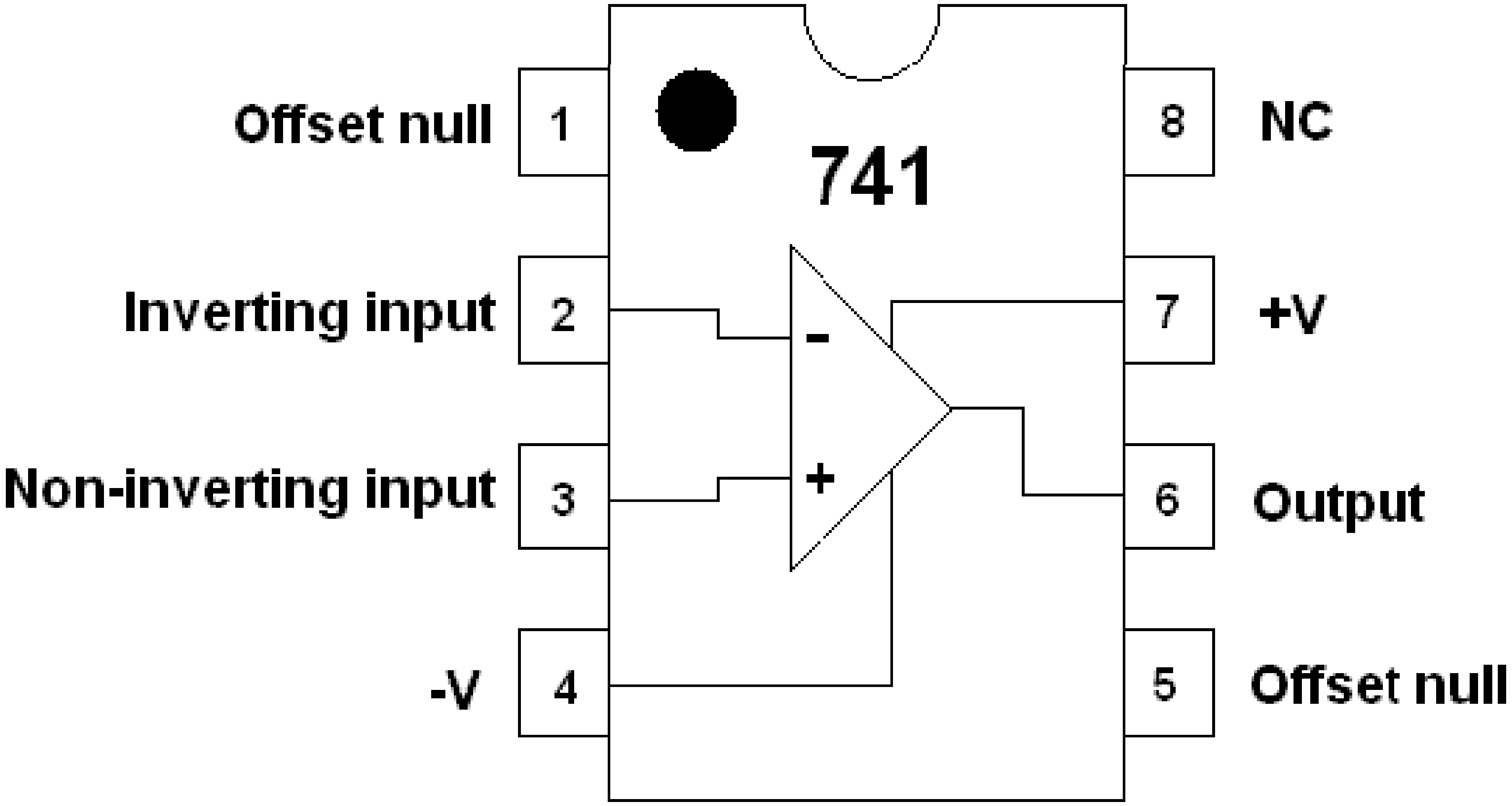


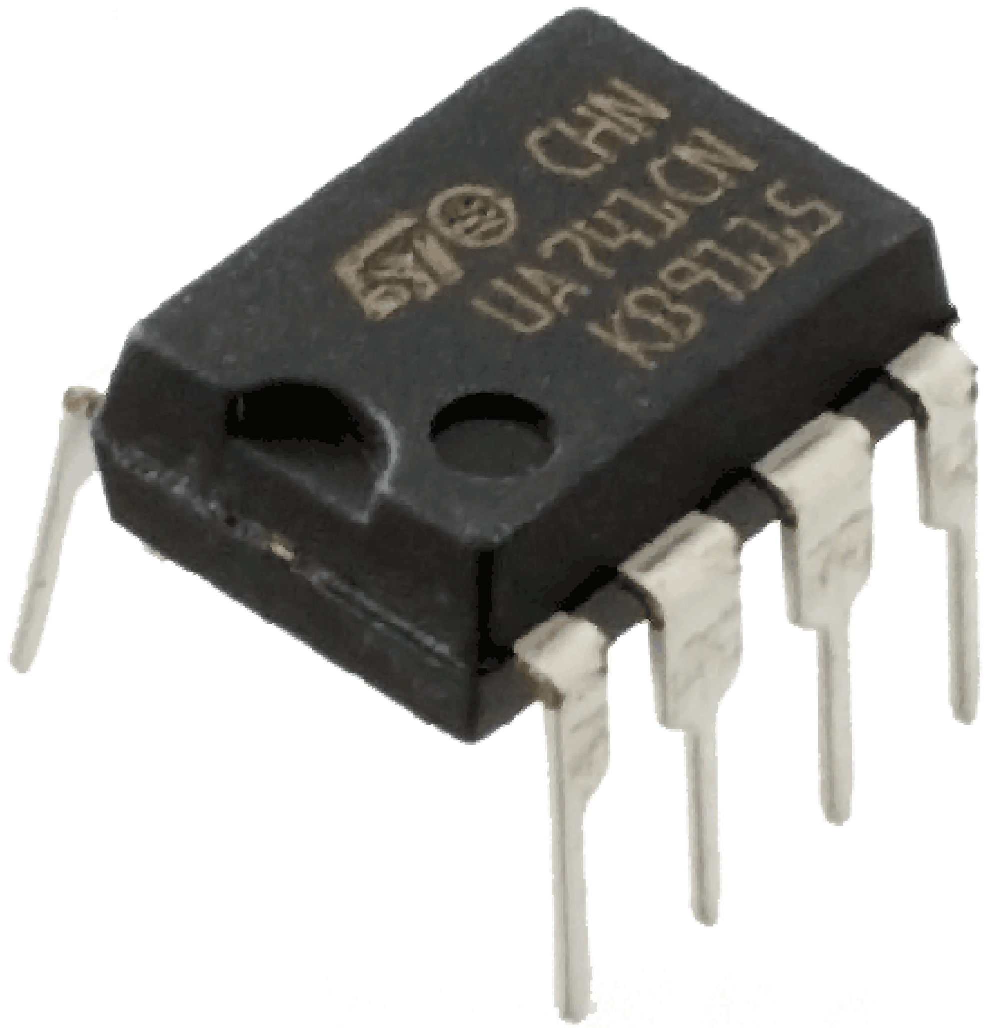
- An op amp is an active circuit element designed to perform mathematical operations of addition, subtraction, multiplication, division, differentiation, and integration, etc.



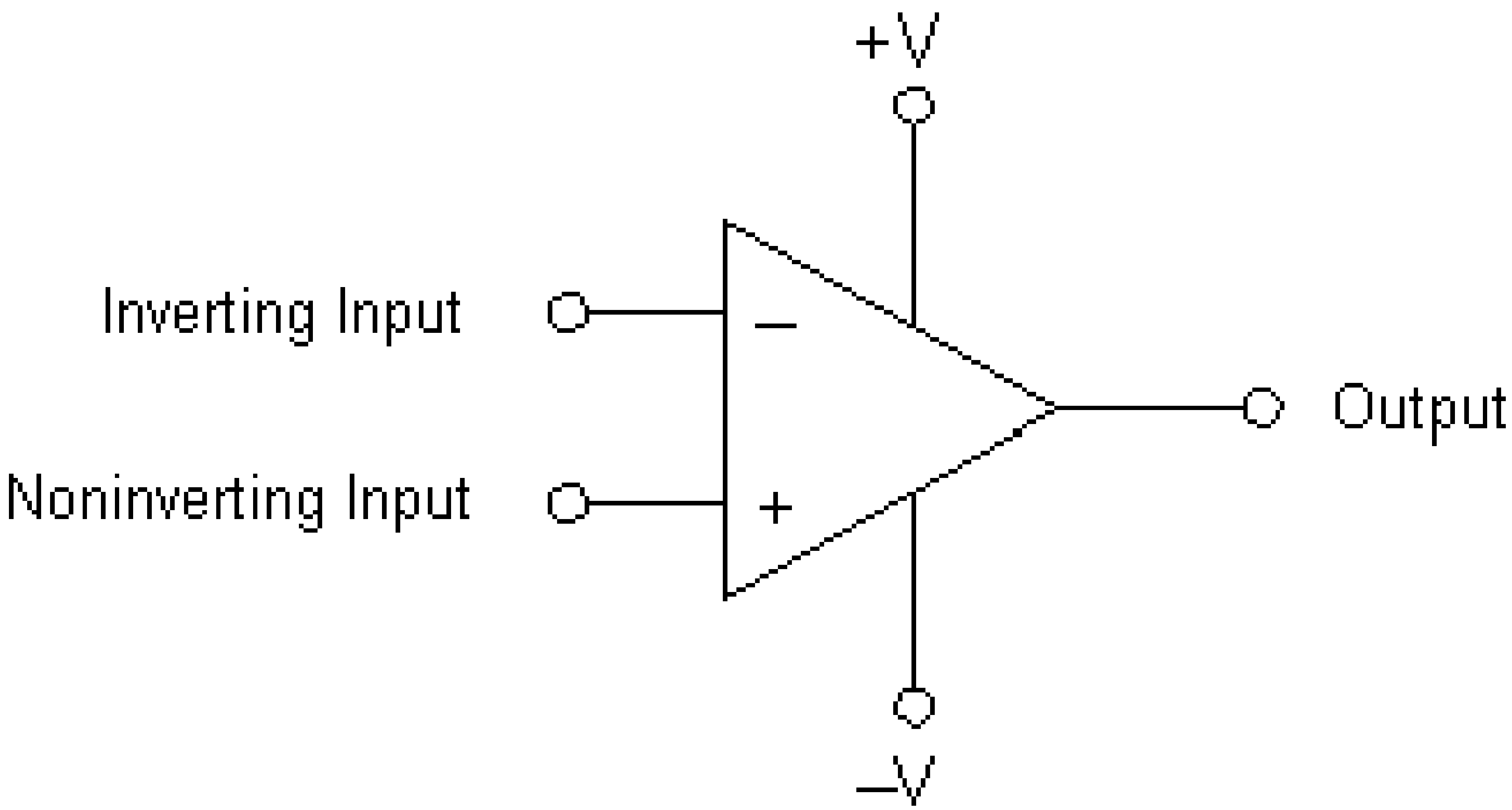
V_{CC}
Q_8
Q_9
Q_{12}
Q_{13}
Q_{14}
Q_{18}
Q_{15}
v_P
Q_1
Q_2
v_N
R_6
27 Ω
Q_{19}
v_O
R_5
39 kΩ
C_c
30 pF
R_{10}
50 kΩ
R_7
22 Ω
Q_3
Q_4
Q_{21}
V_{CC}
V_{CC}
Q_{20}
Q_7
Q_{16}
Q_{22}
Q_5
Q_6
Q_{10}
Q_{11}
Q_{17}
Null
Null
Q_{23}
R_3
50 kΩ
R_1
1 kΩ
R_2
1 kΩ
R_4
5 kΩ
R_9
50 kΩ
R_8
100 Ω
Q_{24}
R_{11}
50 kΩ
V_{EE}

741 Package and Pin Details





Schematic Symbol



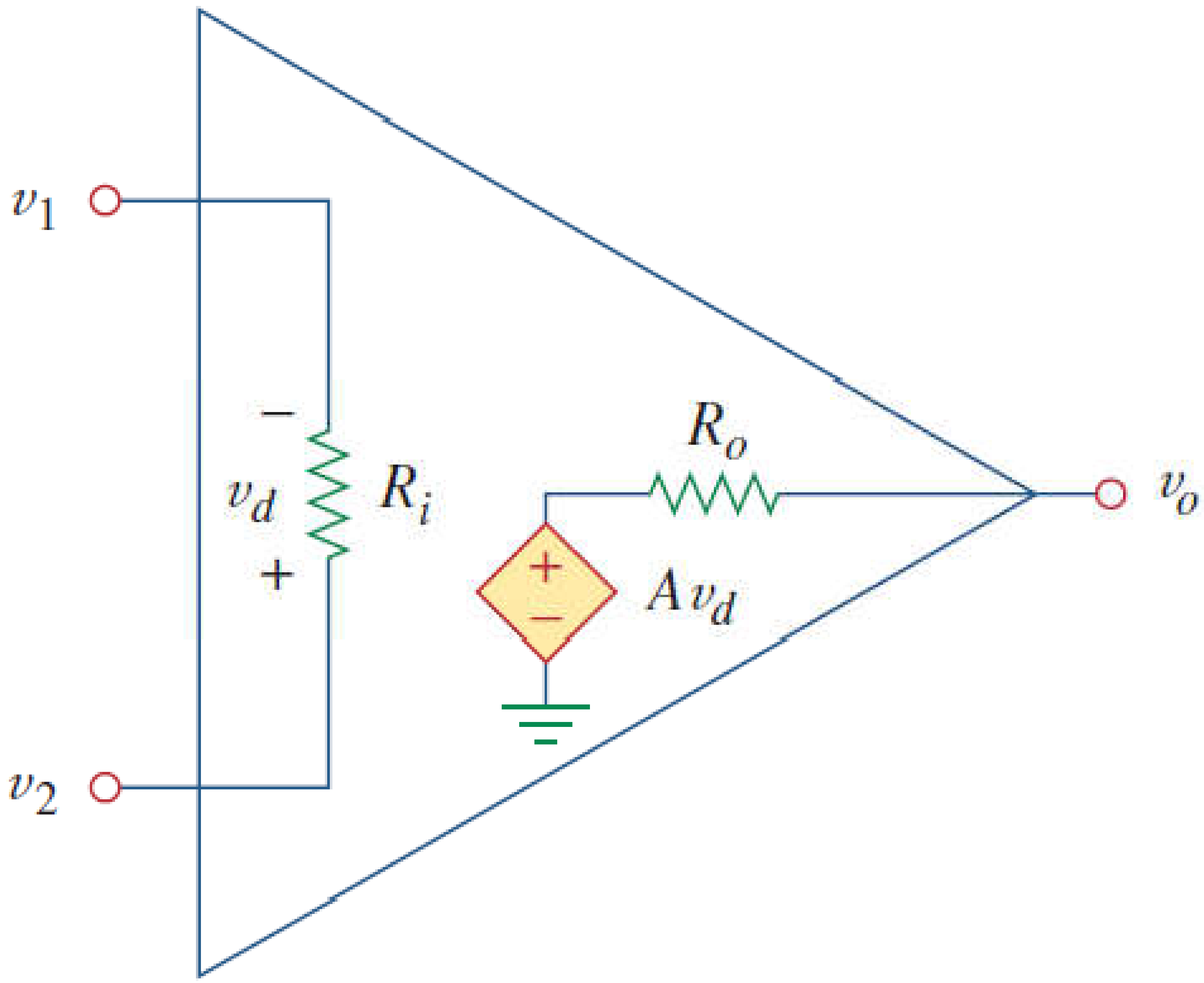
An Ideal Op-Amp

- 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} Ω
Output Resistance (R)	0	100 - 1000 Ω

Equivalent Circuit
Non – Ideal Opamp



Basics of an Op-Amp Circuit

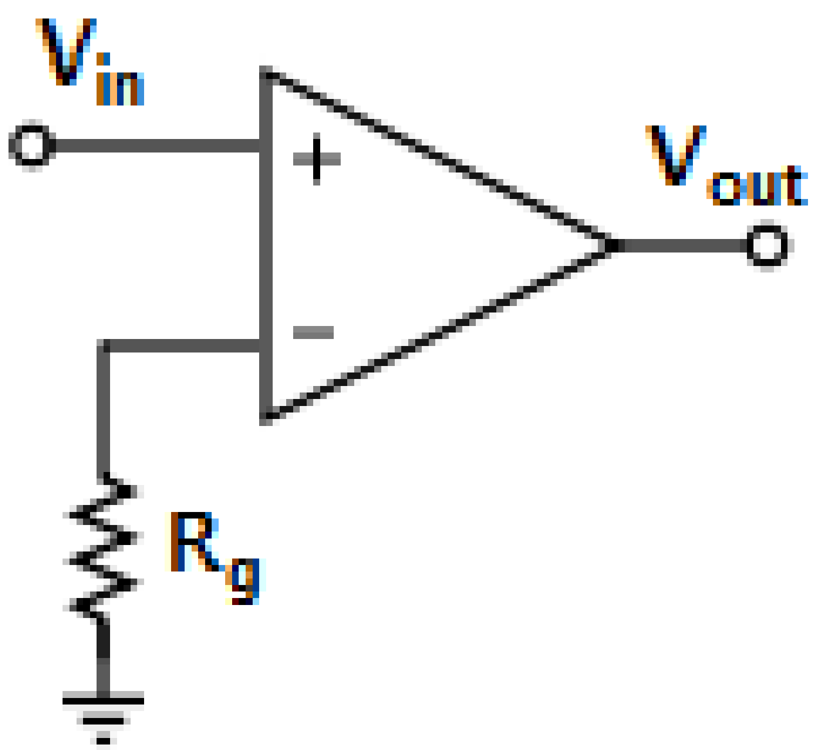
- An op-amp amplifies the difference of the inputs V_+ and V_- (known as the differential input voltage)
- This is the equation for an *open loop* gain amplifier:

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

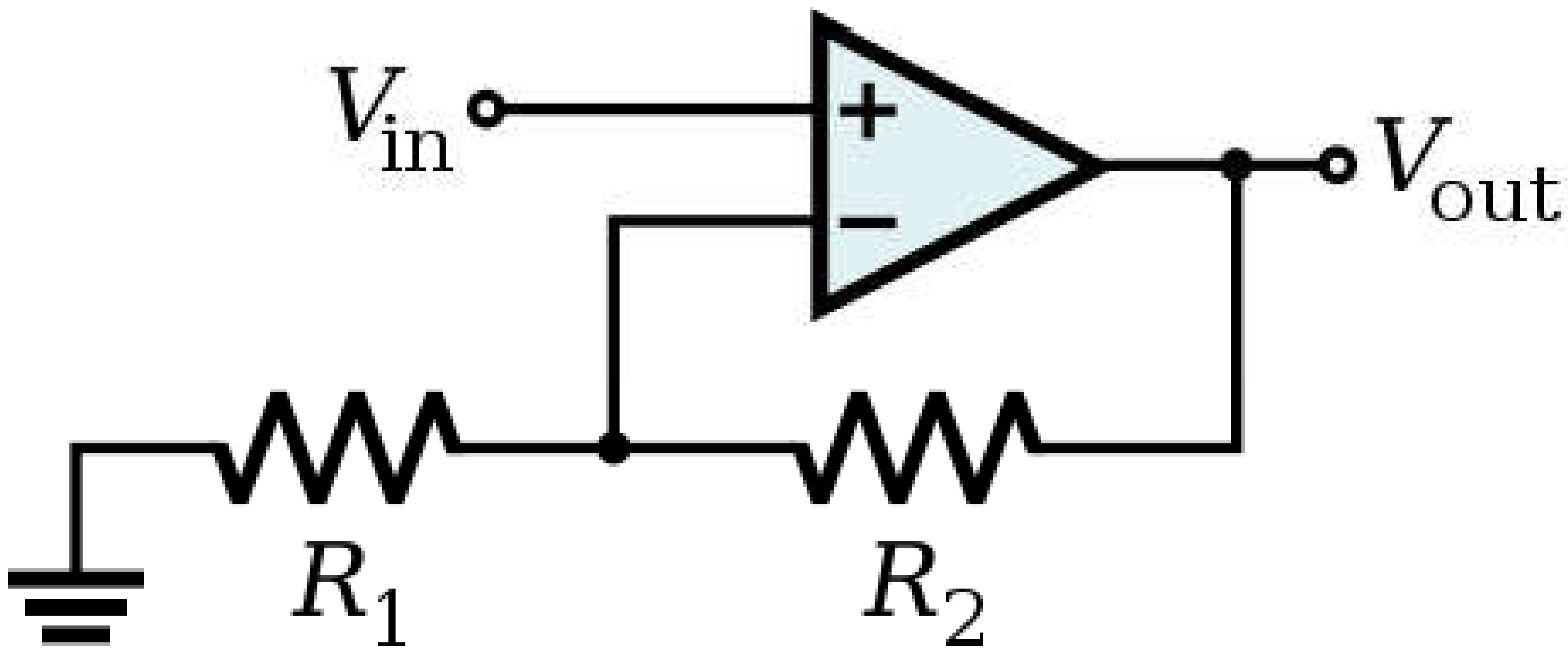
- K is typically very large – at around 10,000 or more for IC Op-Amps
- This equation is the basis for all the types of amps we will be discussing

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

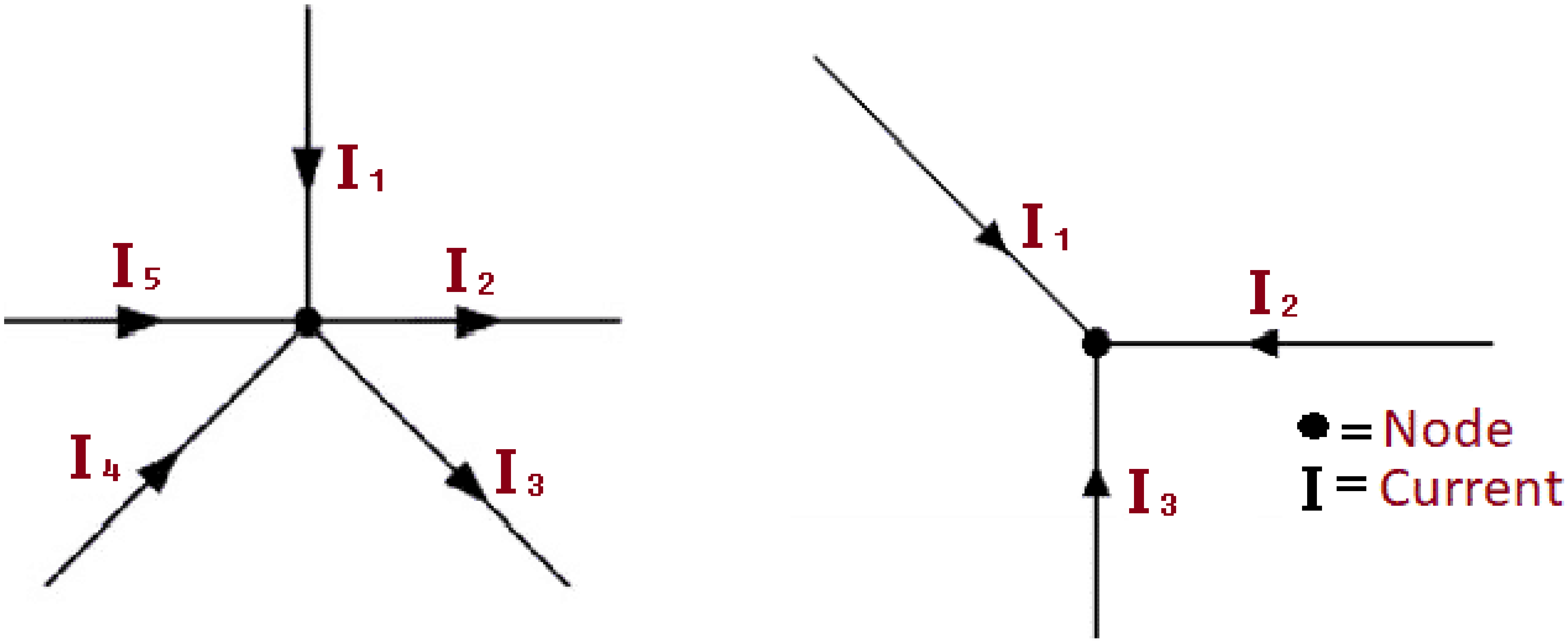


Closed Loop

Analysis Steps

- **Ideal Opamp**
  - Opamp does not accepts 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



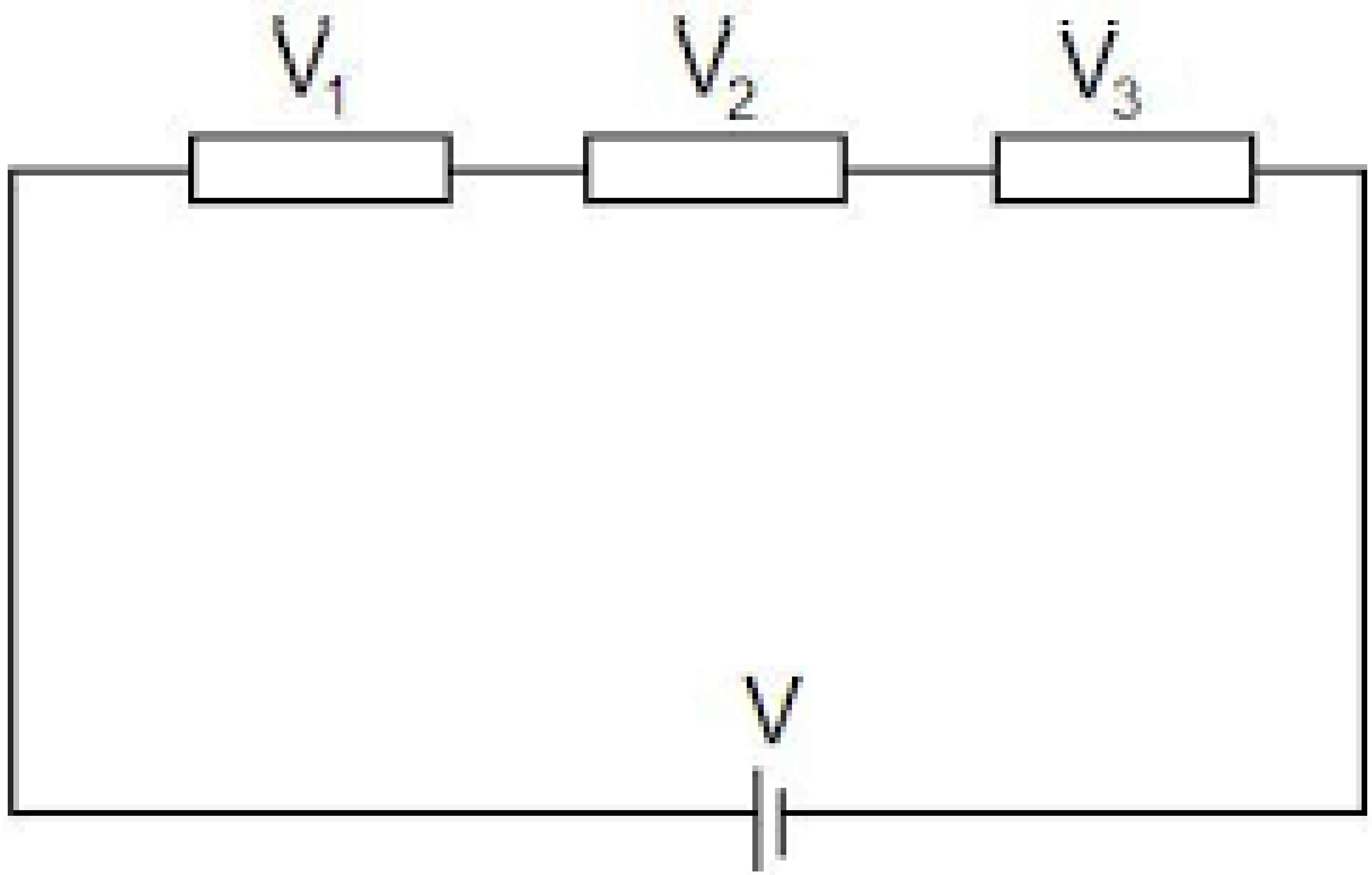
$I_1 - I_2 - I_3 + I_4 + I_5 = 0$

(a)

$I_1 + I_2 + I_3 = 0$

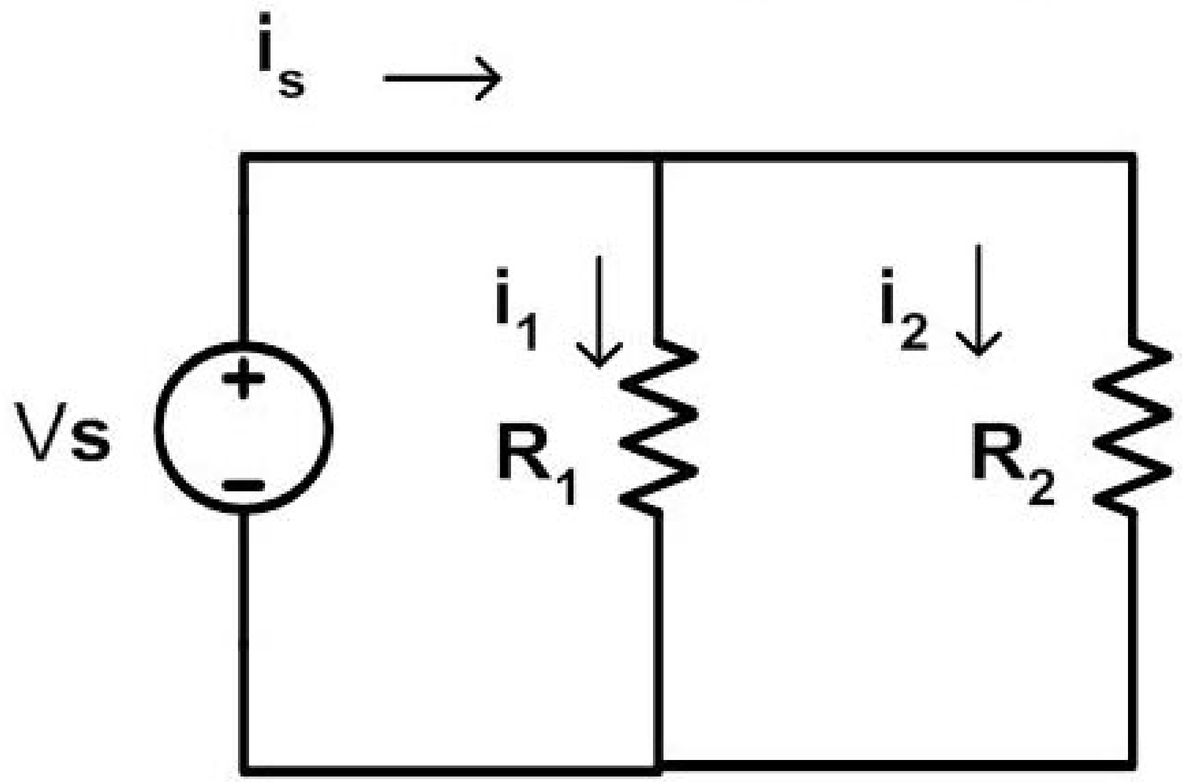
(b)

KVL



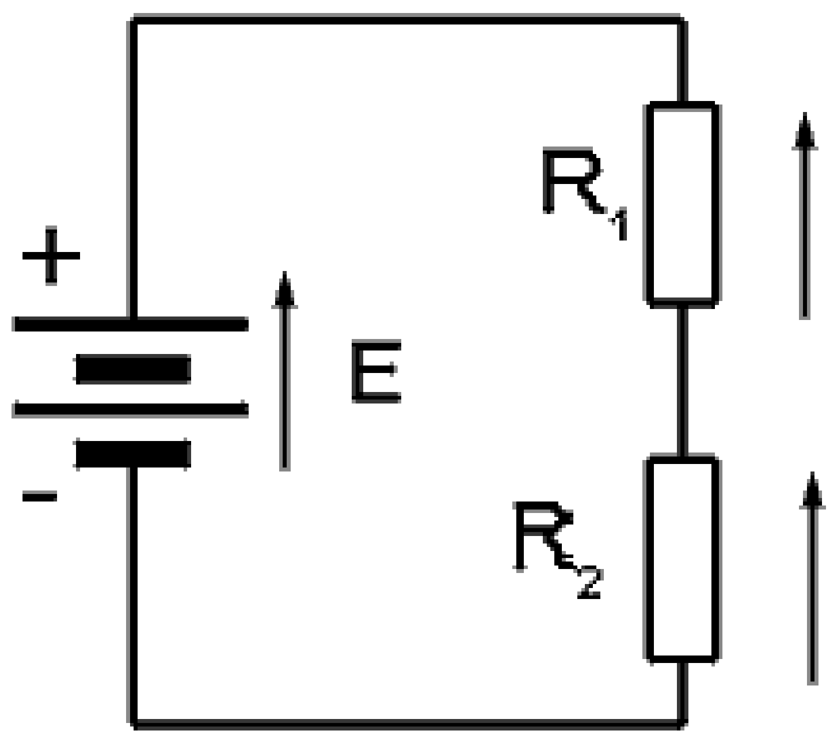
$$V = V_1 + V_2 + V_3$$

Current Division & Voltage Division



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

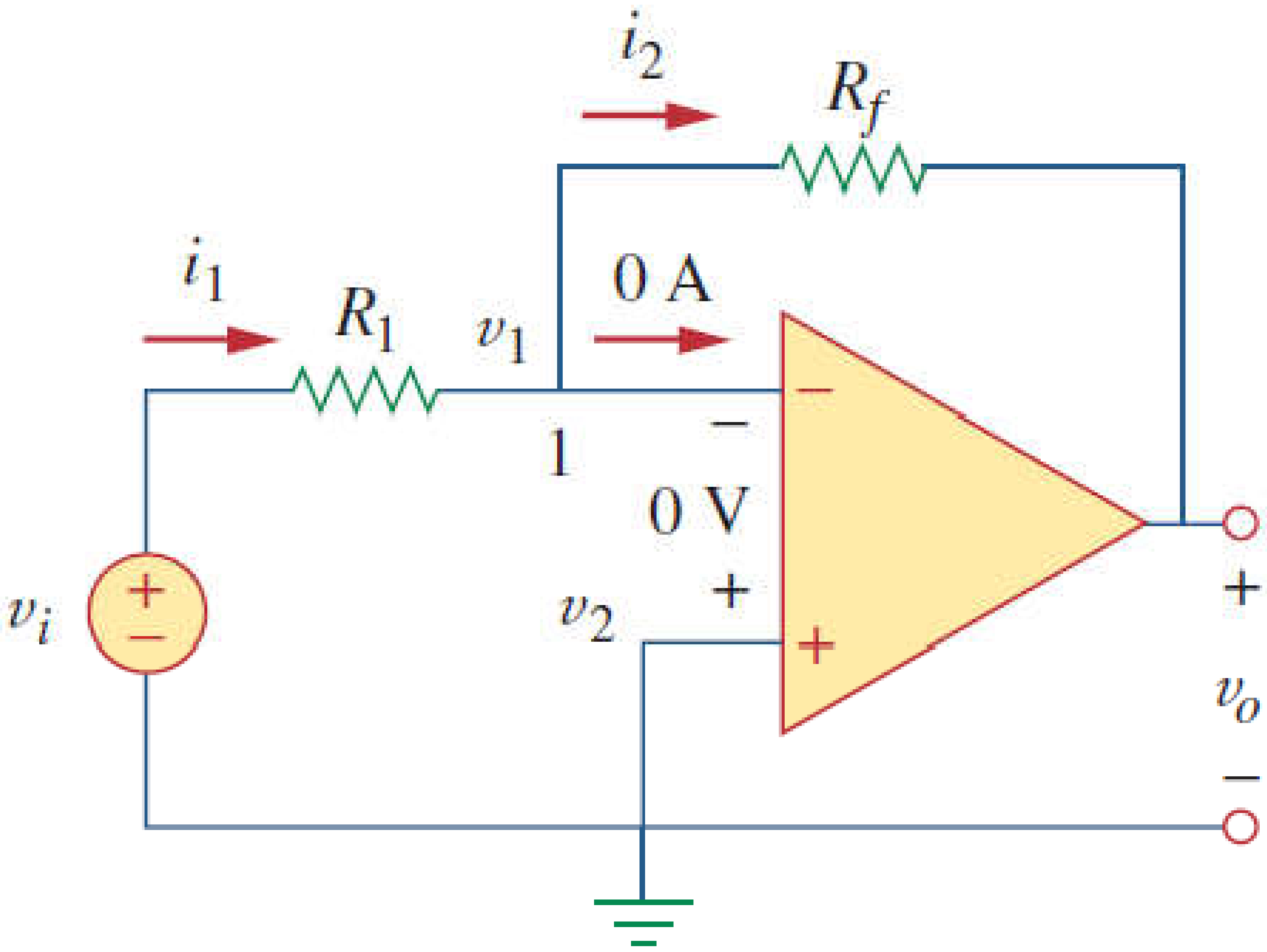
$$i_2 = \frac{R_1}{R_1 + R_2} i_s$$



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

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

Inverting Amplifier

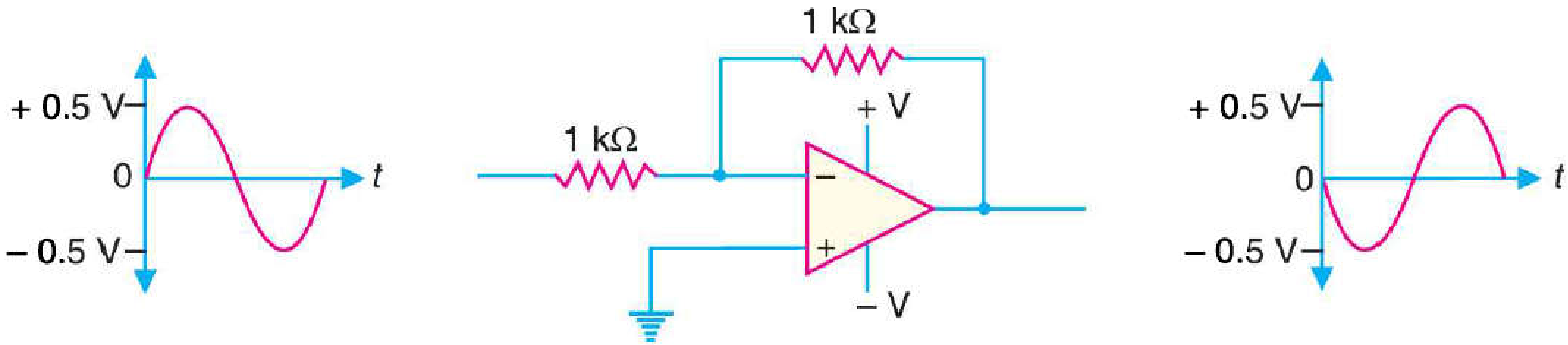


Gain Equation

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

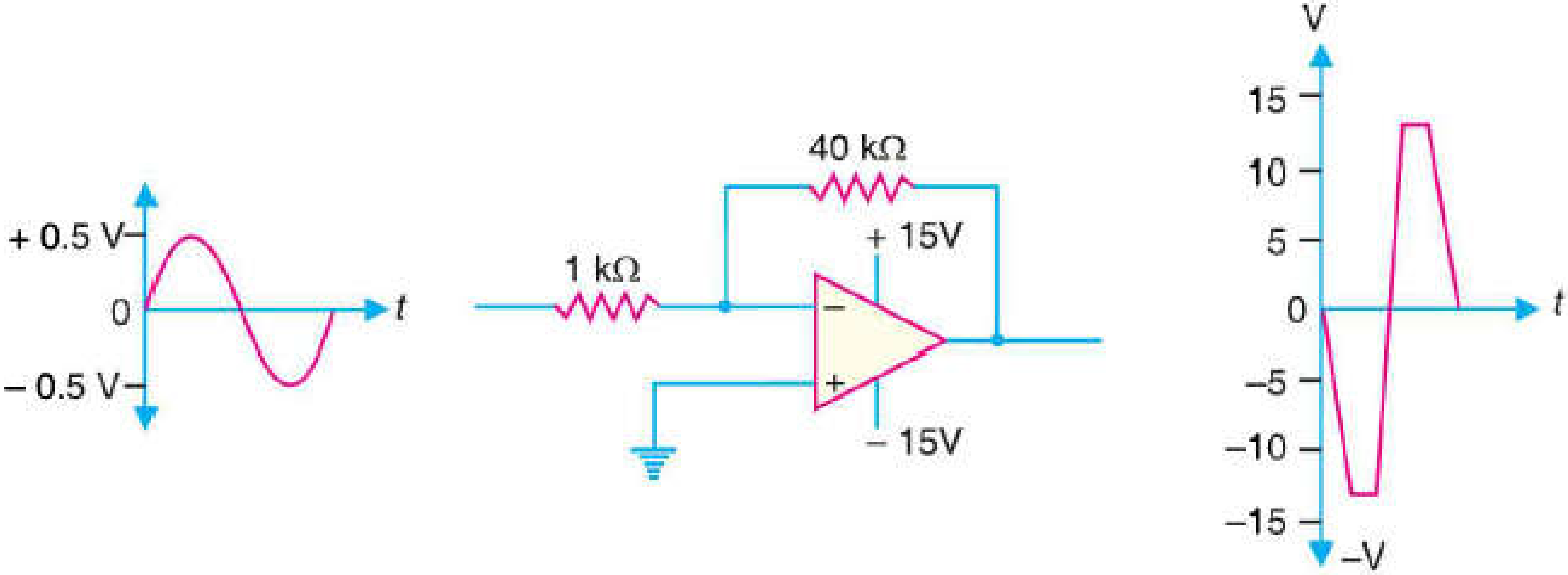
$$v_o = -\frac{R_f}{R_1} v_i$$

Example



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

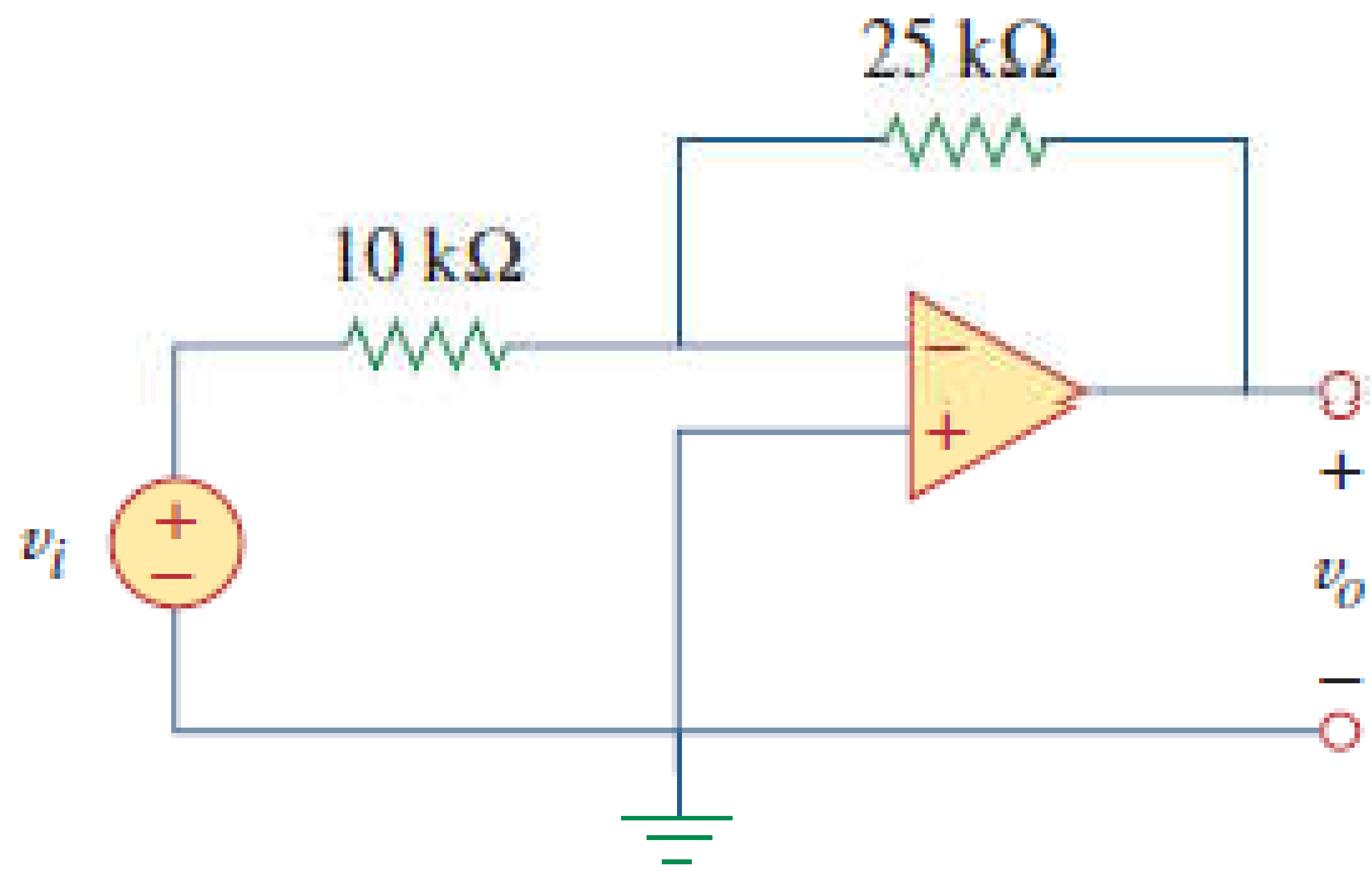
Example



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

Question

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



Solution

(a) Using Eq. (5.9),

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

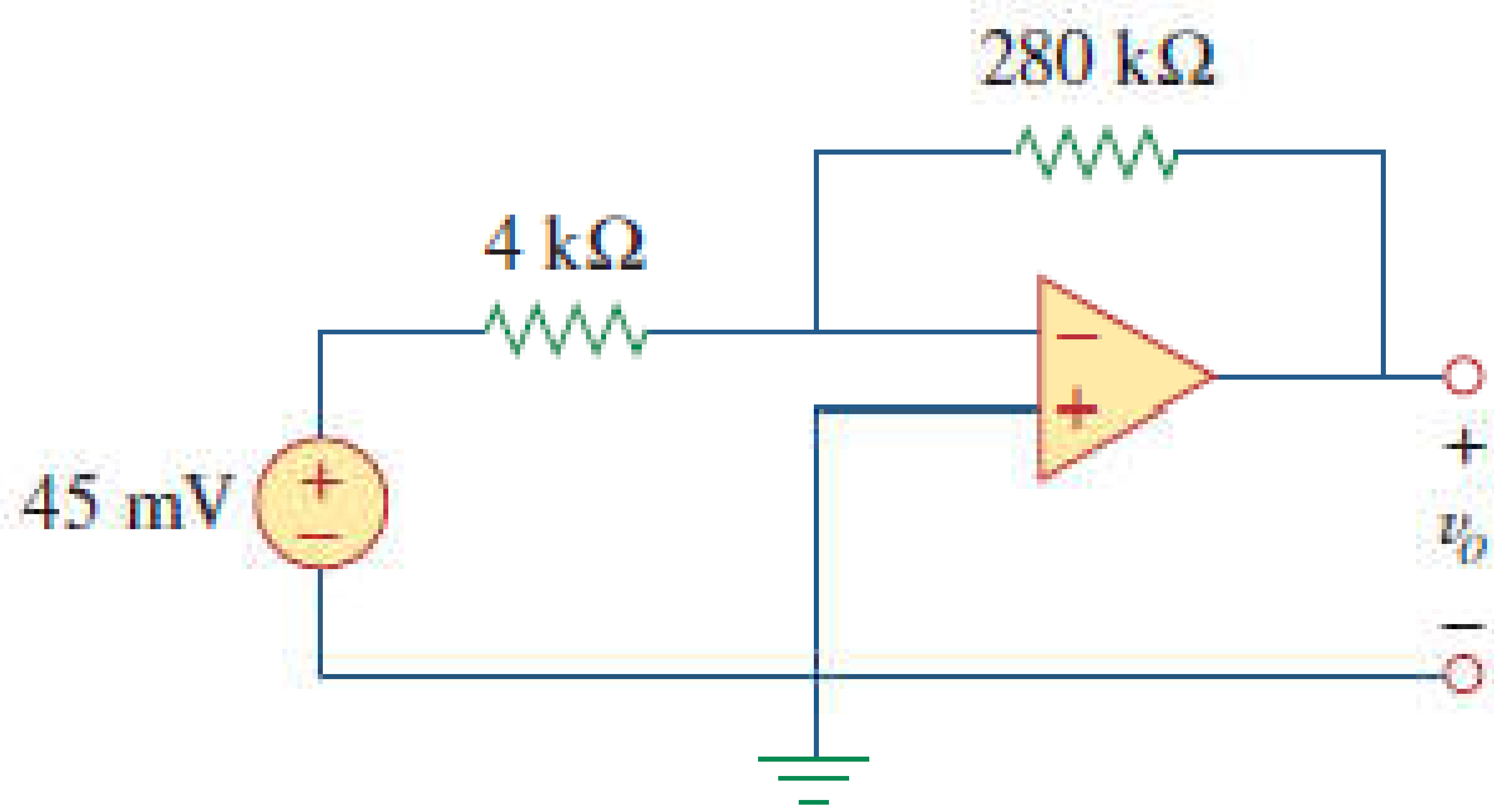
$$v_o = -2.5v_i = -2.5(0.5) = -1.25 \text{ V}$$

(b) The current through the 10-kΩ resistor is

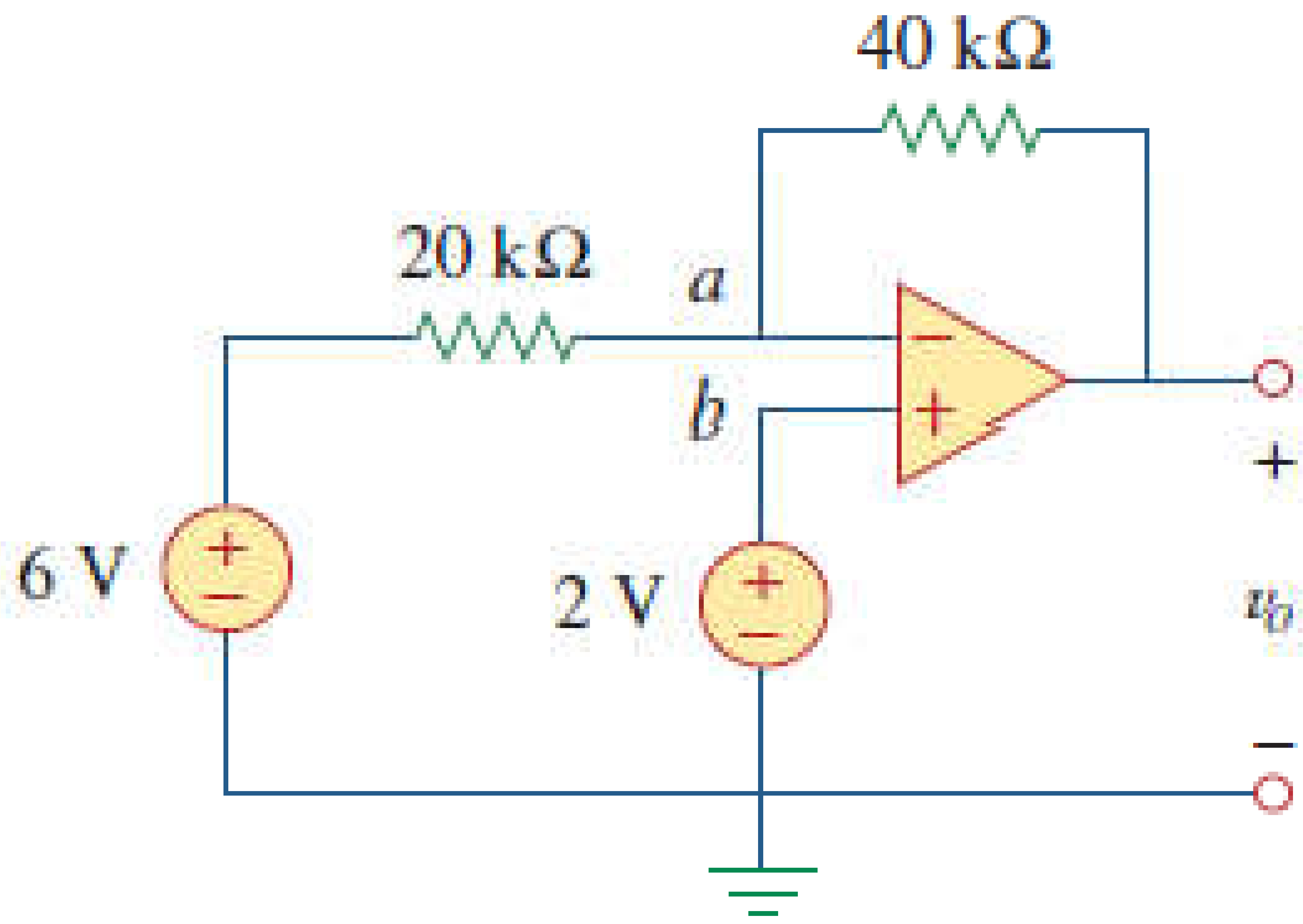
$$i = \frac{v_i - 0}{R_1} = \frac{0.5 - 0}{10 \times 10^3} = 50\ \mu\text{A}$$

Question

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



Determine Vo



Solution

Applying KCL at node a,

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

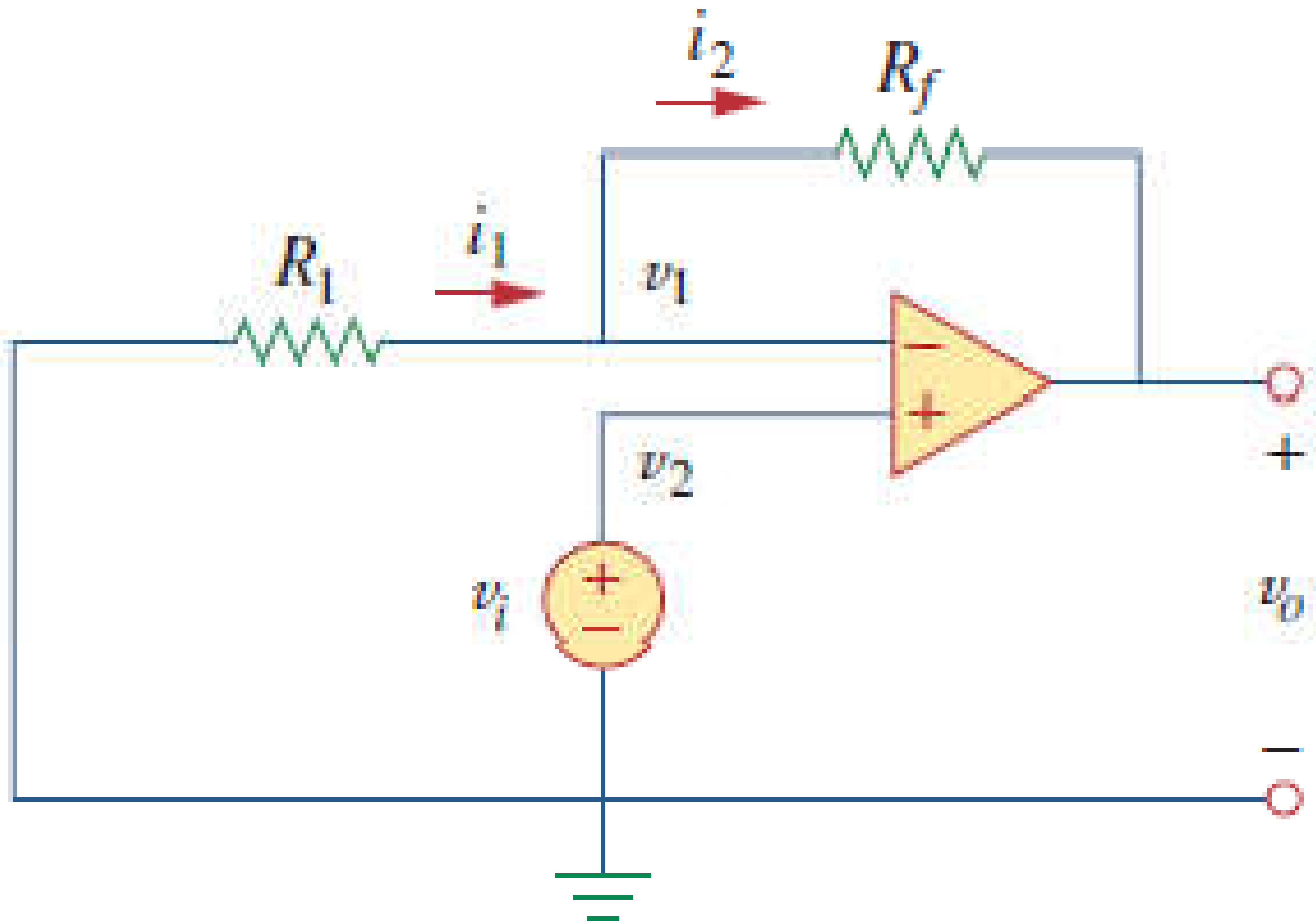
$$v_a - v_o = 12 - 2v_a \quad \Rightarrow \quad v_o = 3v_a - 12$$

But $v_a = v_b = 2$ 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

$$i_1 = i_2 \quad \Rightarrow \quad \frac{0 - v_1}{R_1} = \frac{v_1 - v_o}{R_f}$$

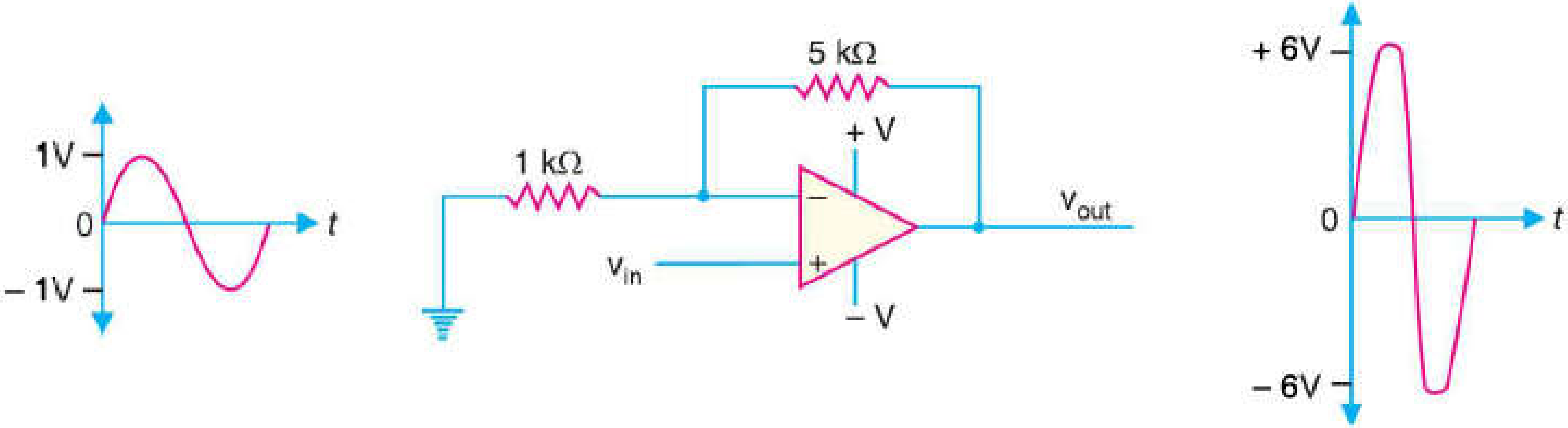
But $v_1 = v_2 = v_i$. Equation (5.10) becomes

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

or

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

Example

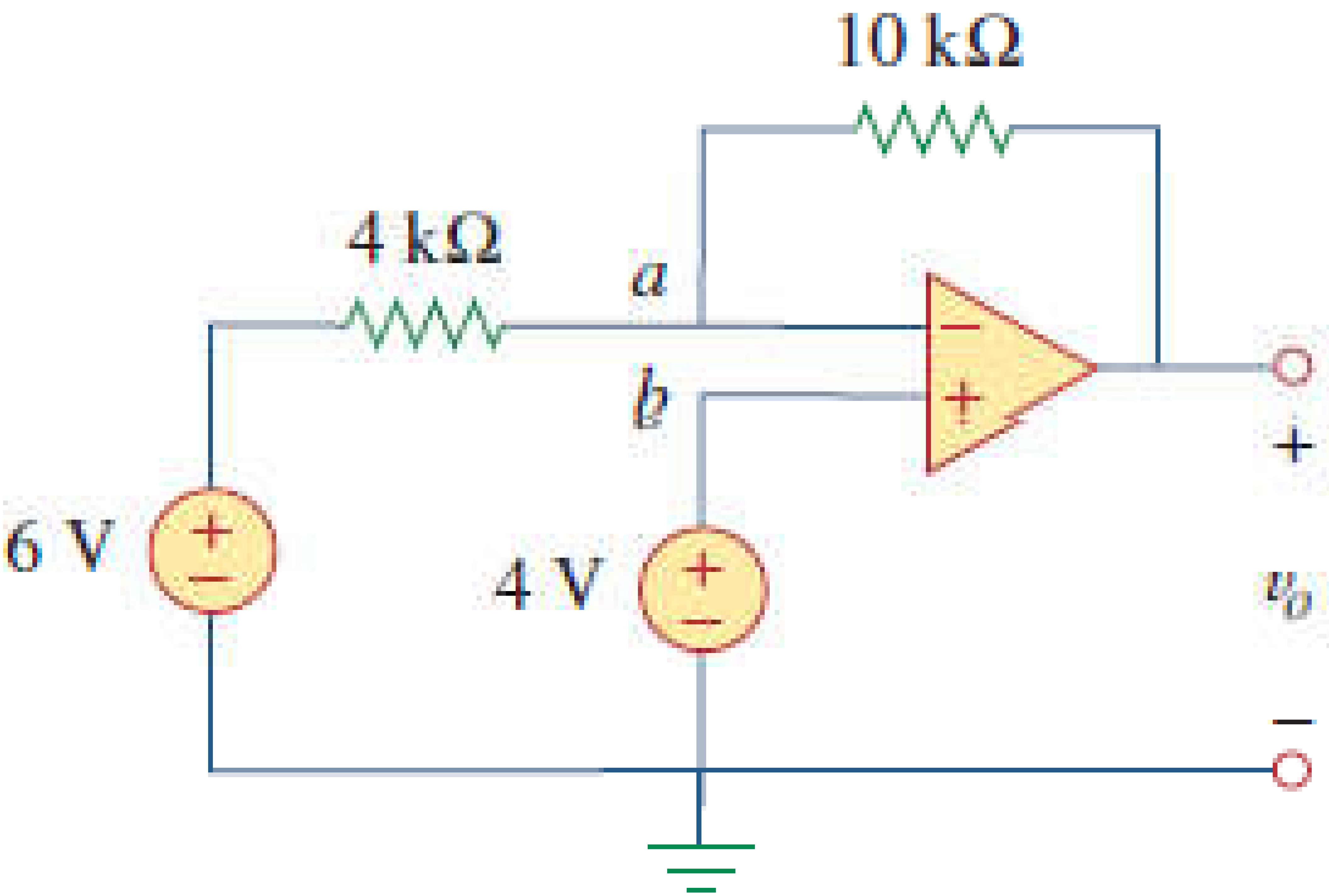


The input signal is 2 V peak-to-peak.

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

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

Determin Vo



Solution

Applying KCL at node a,

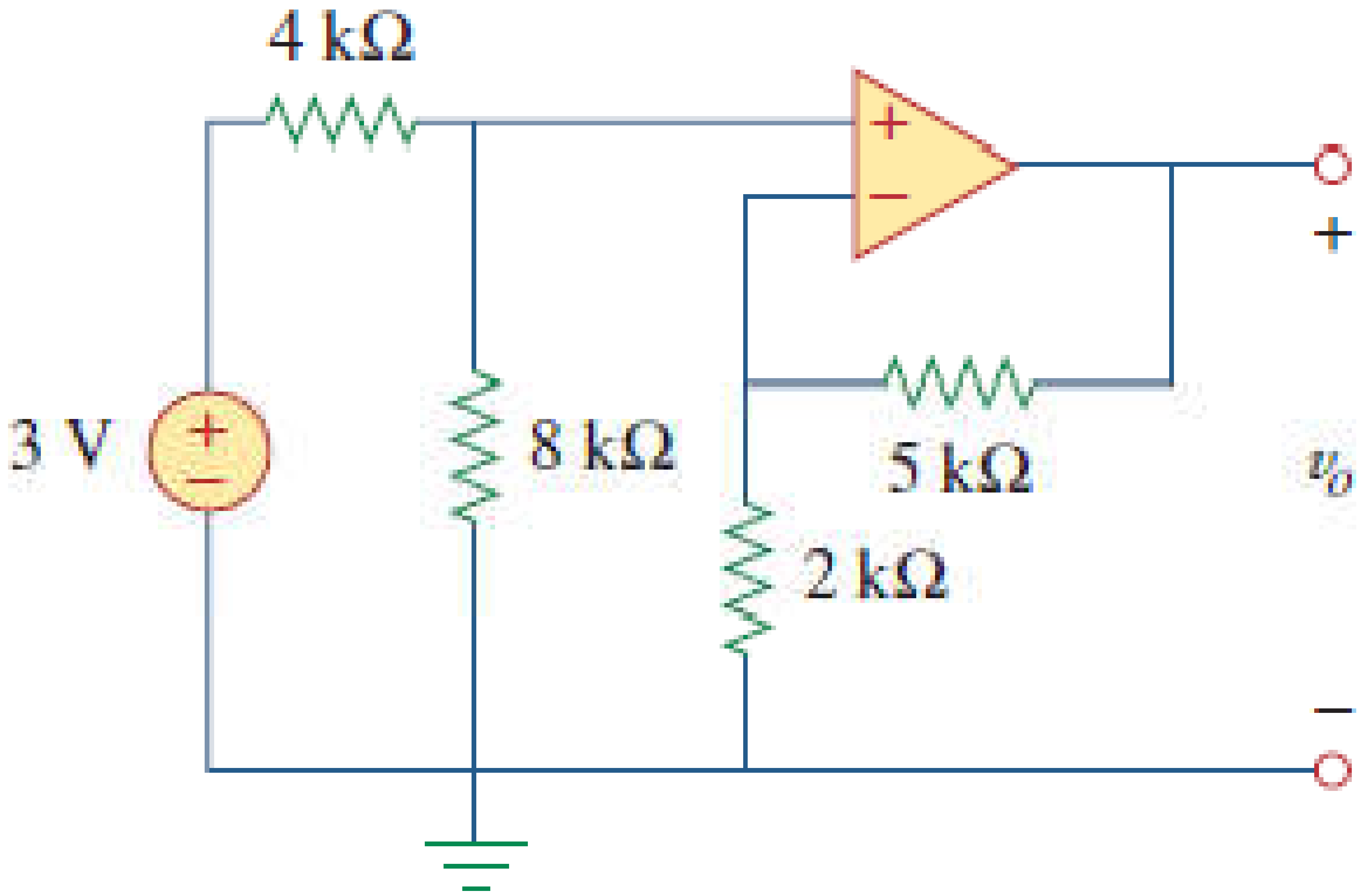
$$\frac{6 - v_a}{4} = \frac{v_a - v_o}{10}$$

But $v_a = v_b = 4$, and so

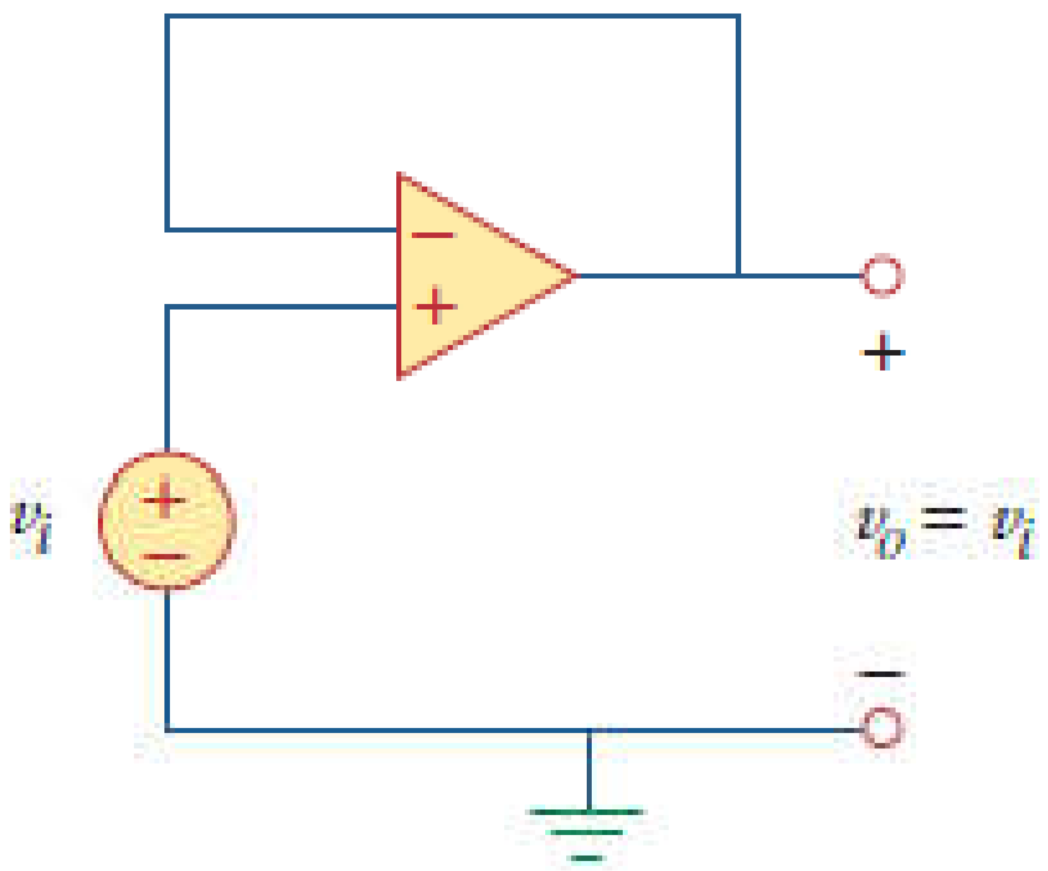
$$\frac{6-4}{4} = \frac{4 - v_o}{10} \qquad \Rightarrow \qquad 5 = 4 - v_o$$

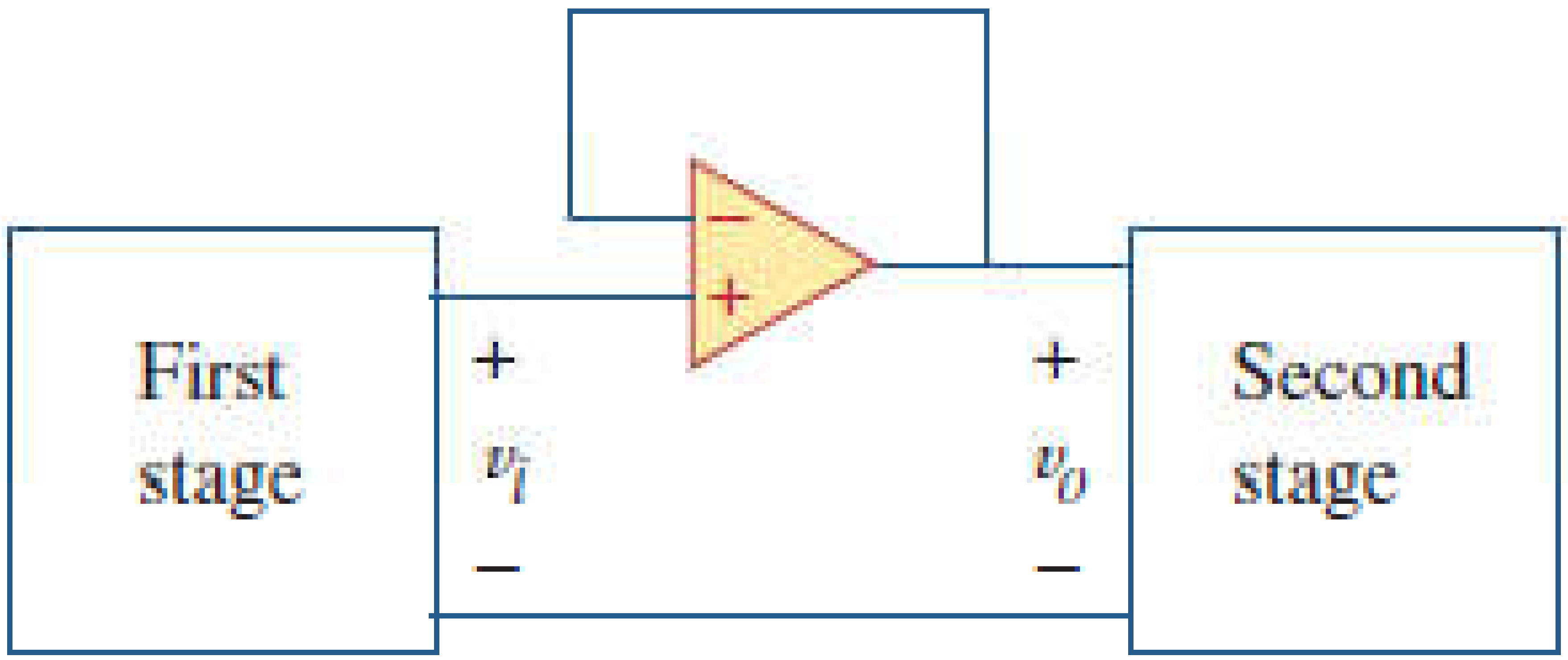
or $v_o = -1$ V, as before.

Determine Vo

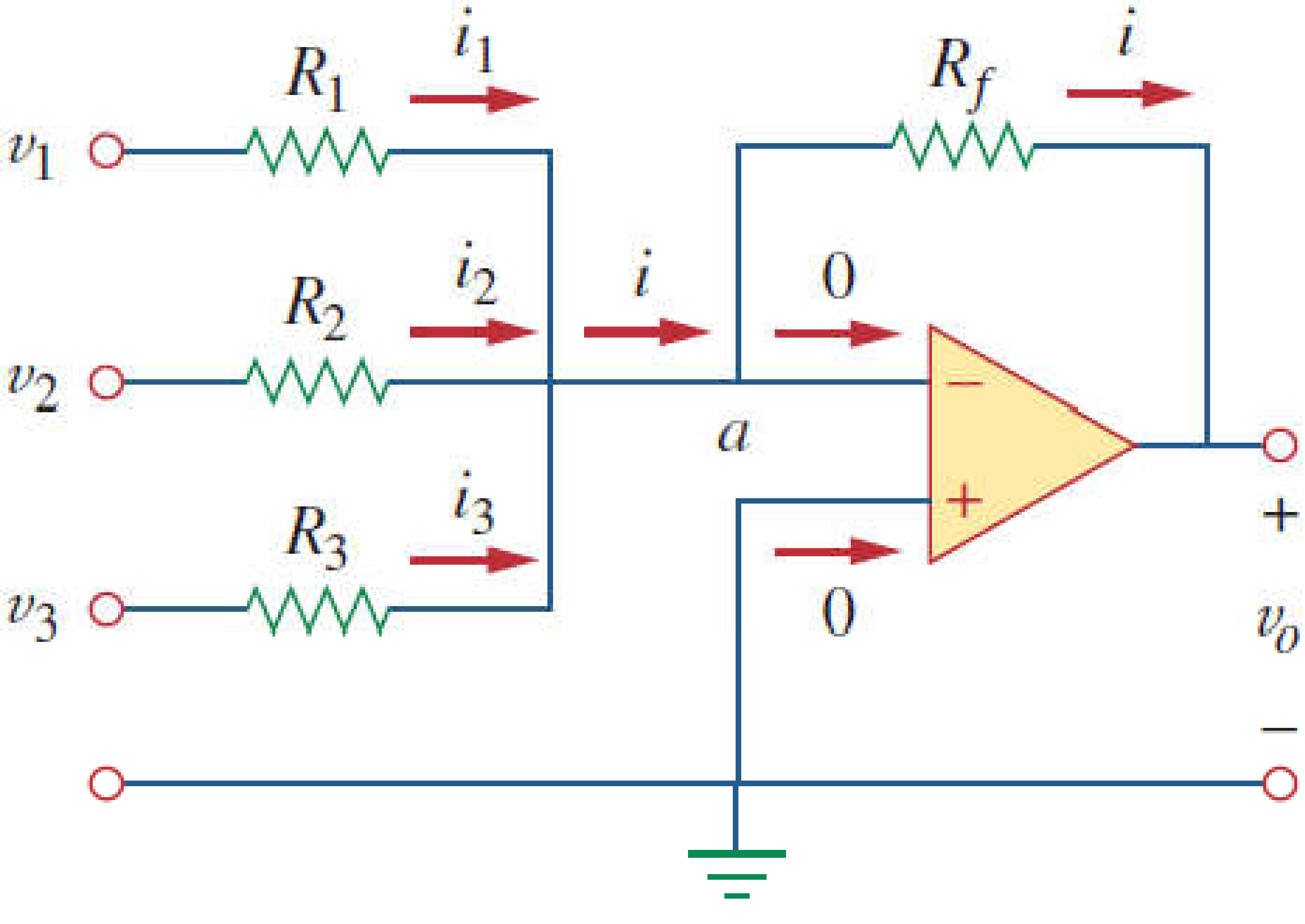


Opamp as a Buffer





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 $v_a = 0$

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

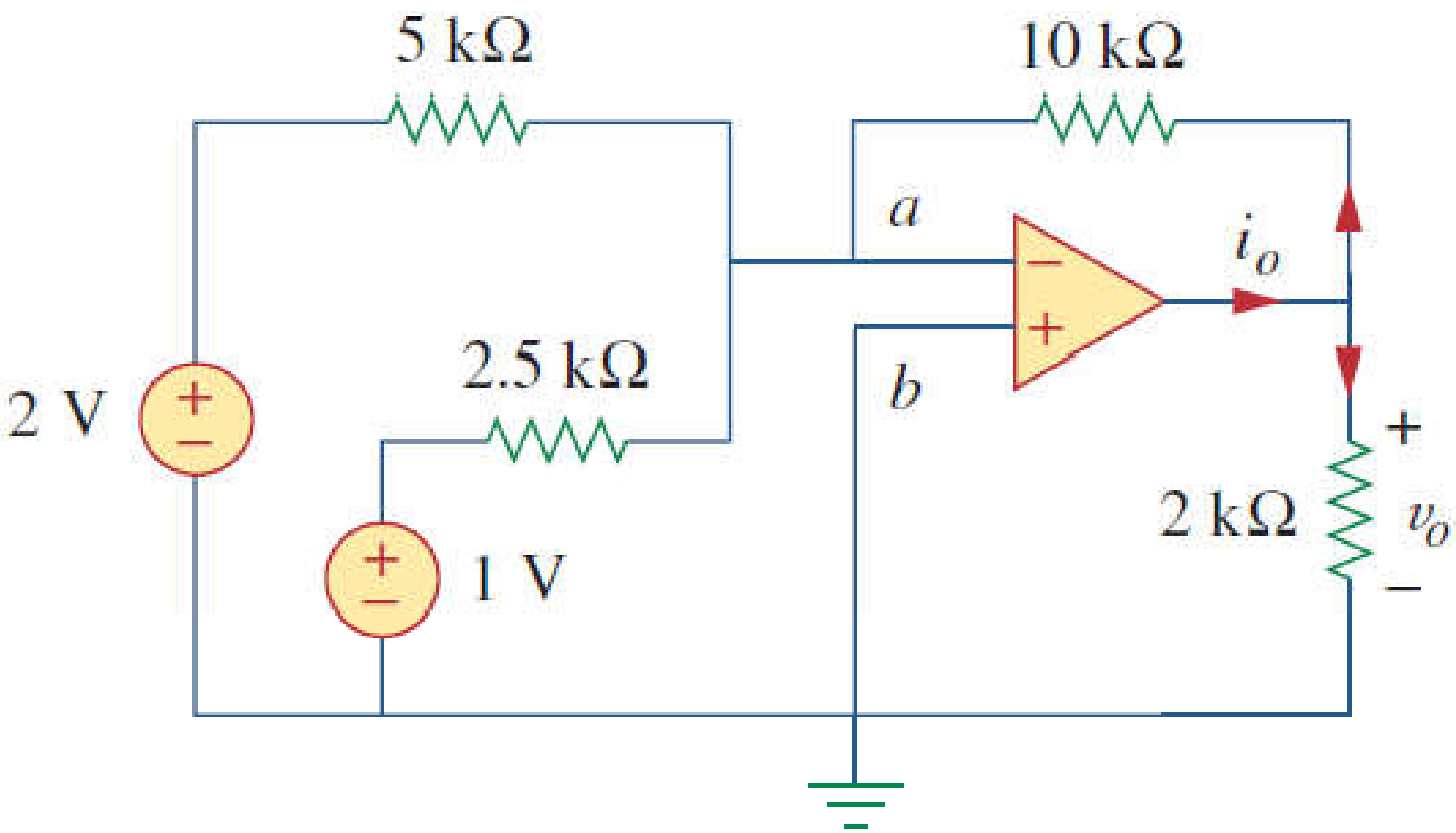
Averaging Amplifier

$$\boxed{R_1 = R_2 = R_3}$$

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

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

Question



Solution

This is a summer with two inputs.

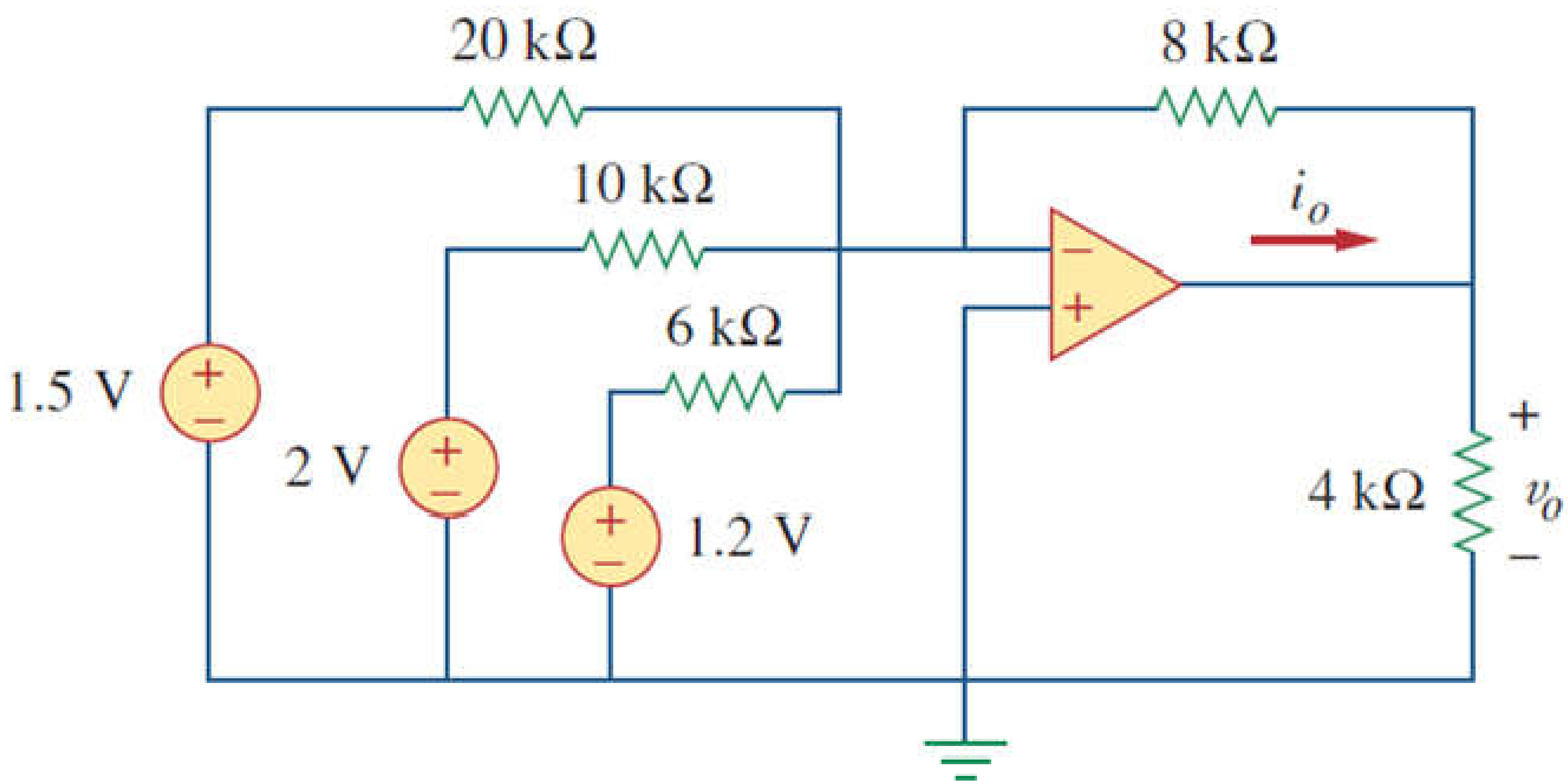
$$v_o = -\left[\frac{10}{5}(2) + \frac{10}{2.5}(1)\right] = -(4 + 4) = -8 \text{ V}$$

The current i_o is the sum of the currents through the 10-kΩ and 2-kΩ resistors. Both of these resistors have voltage $v_o = -8$ 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

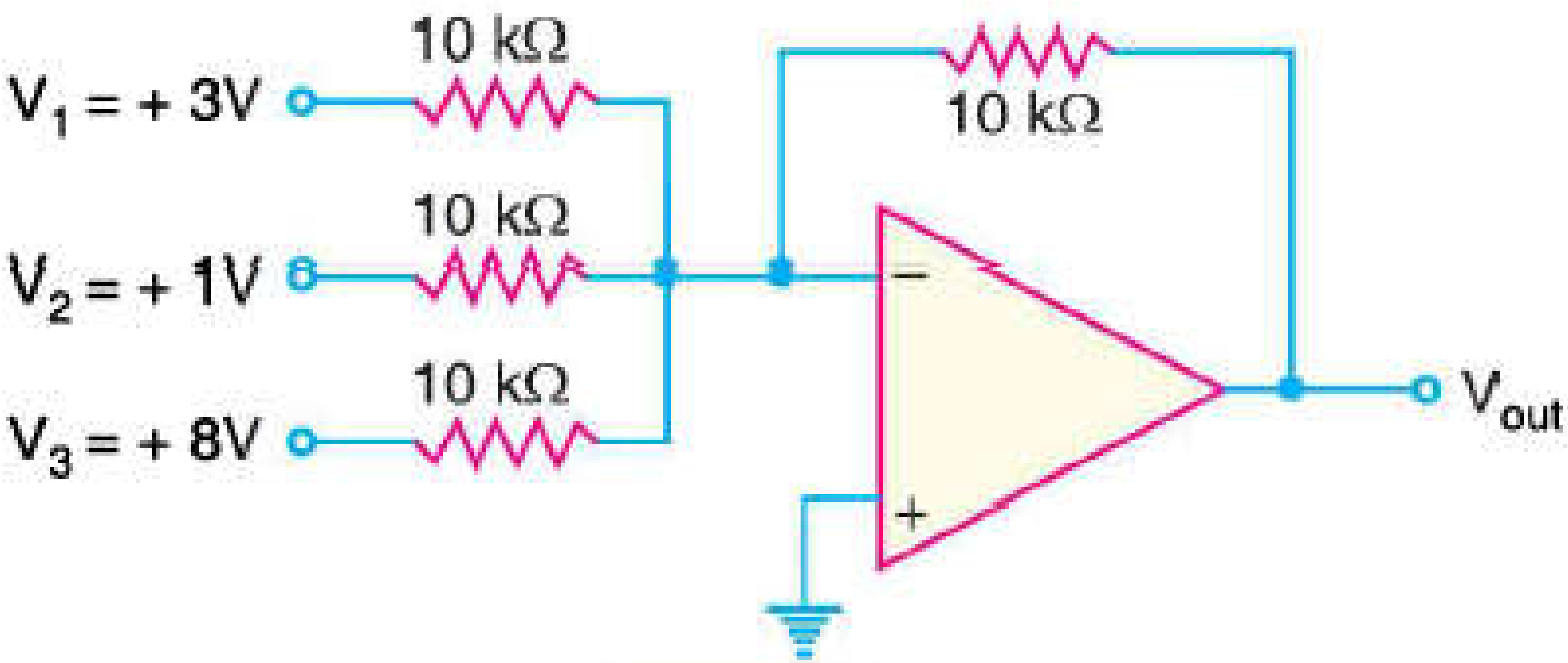


Answers

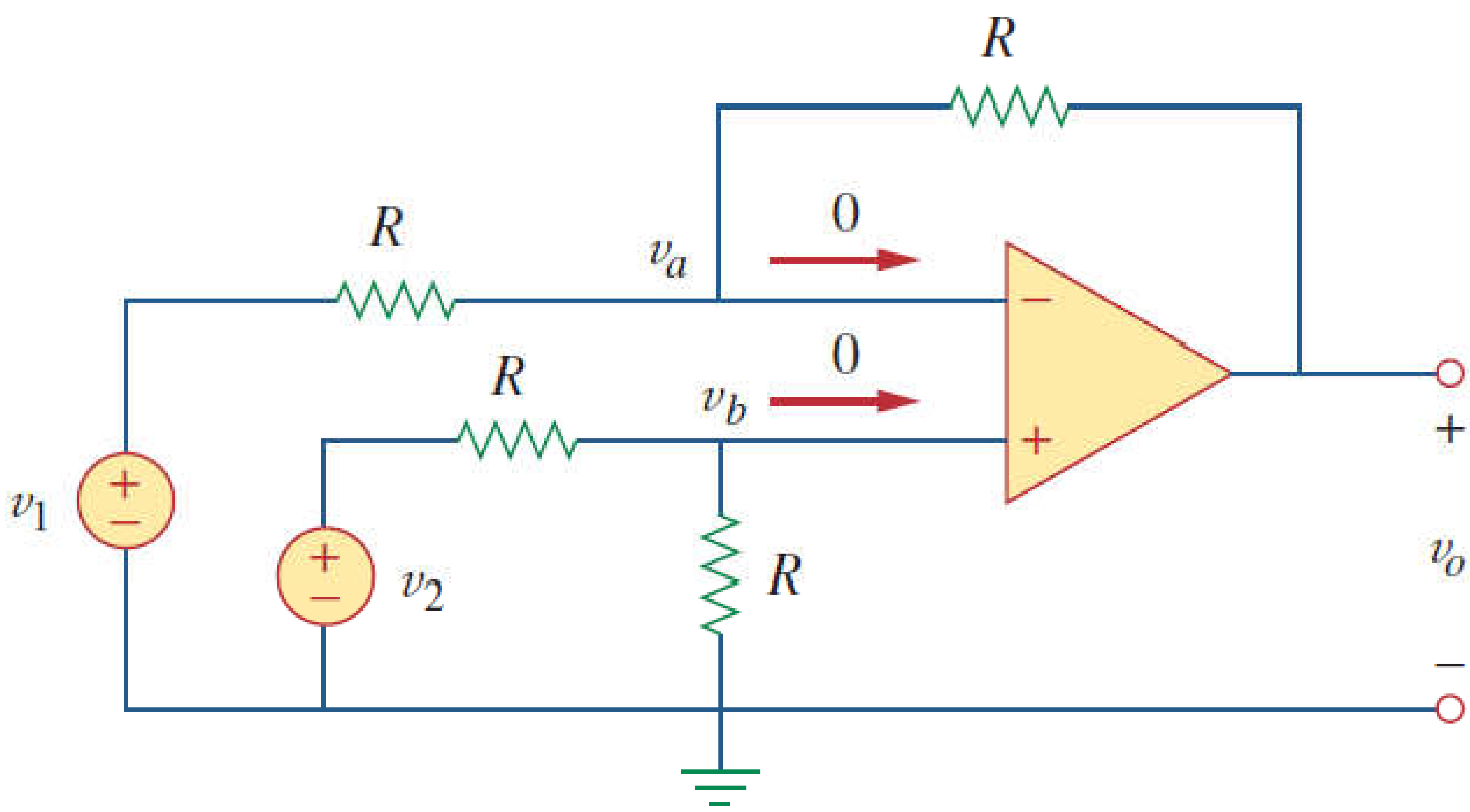
-3.8 V, -1.425 mA.

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

Question



Opamp as Subtractor



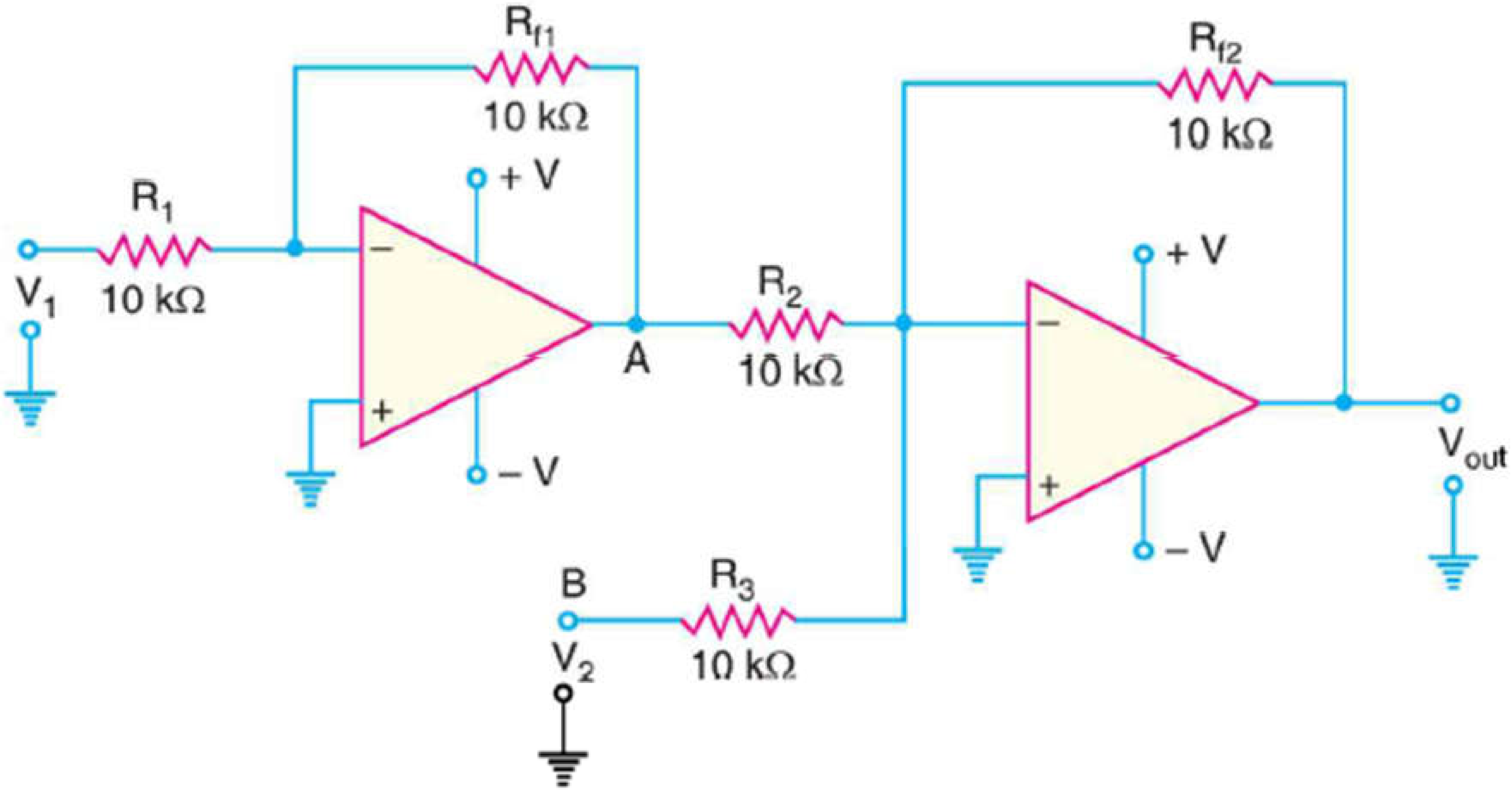
Derivation

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

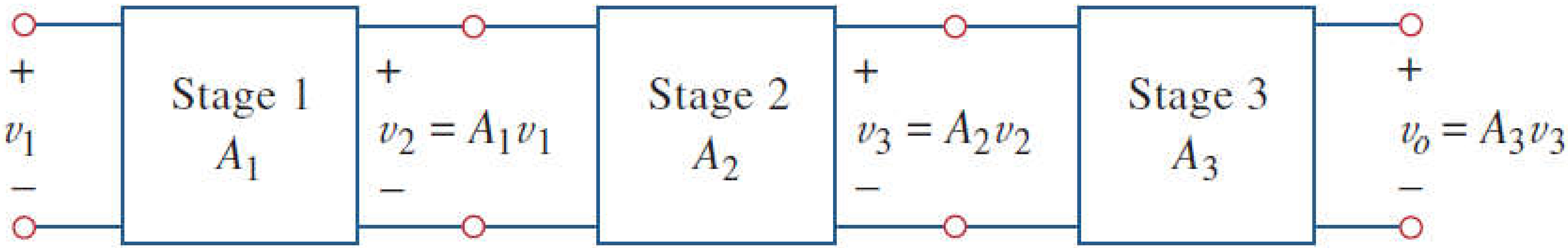
$$v_b = \frac{R}{R+R} v_2$$

$$\boxed{v_o = v_2 - v_1}$$

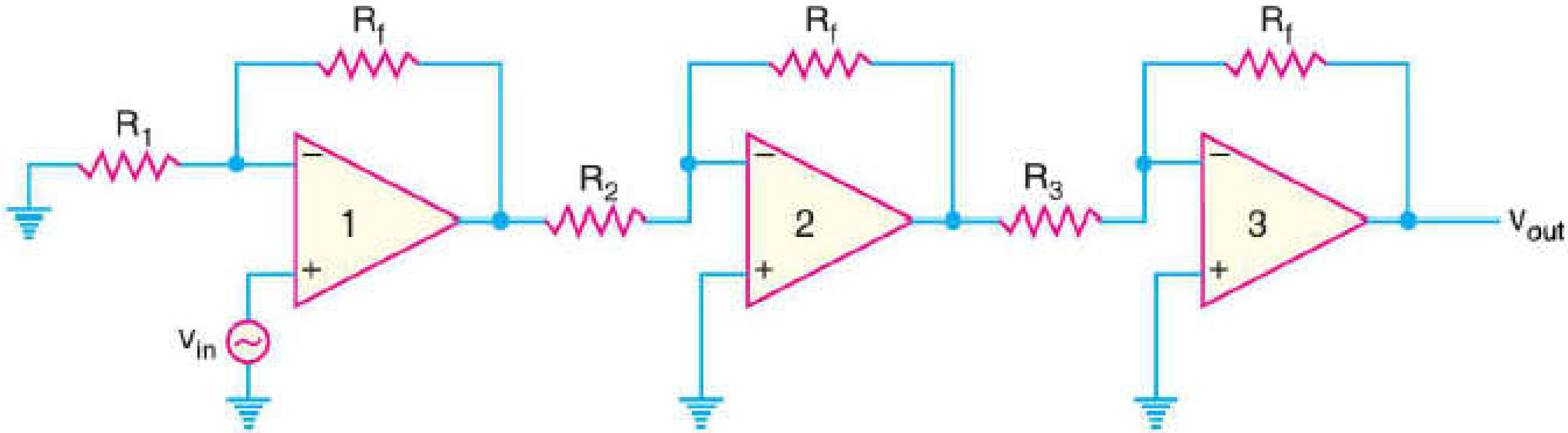
Example



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 = $-R_f/R_2$

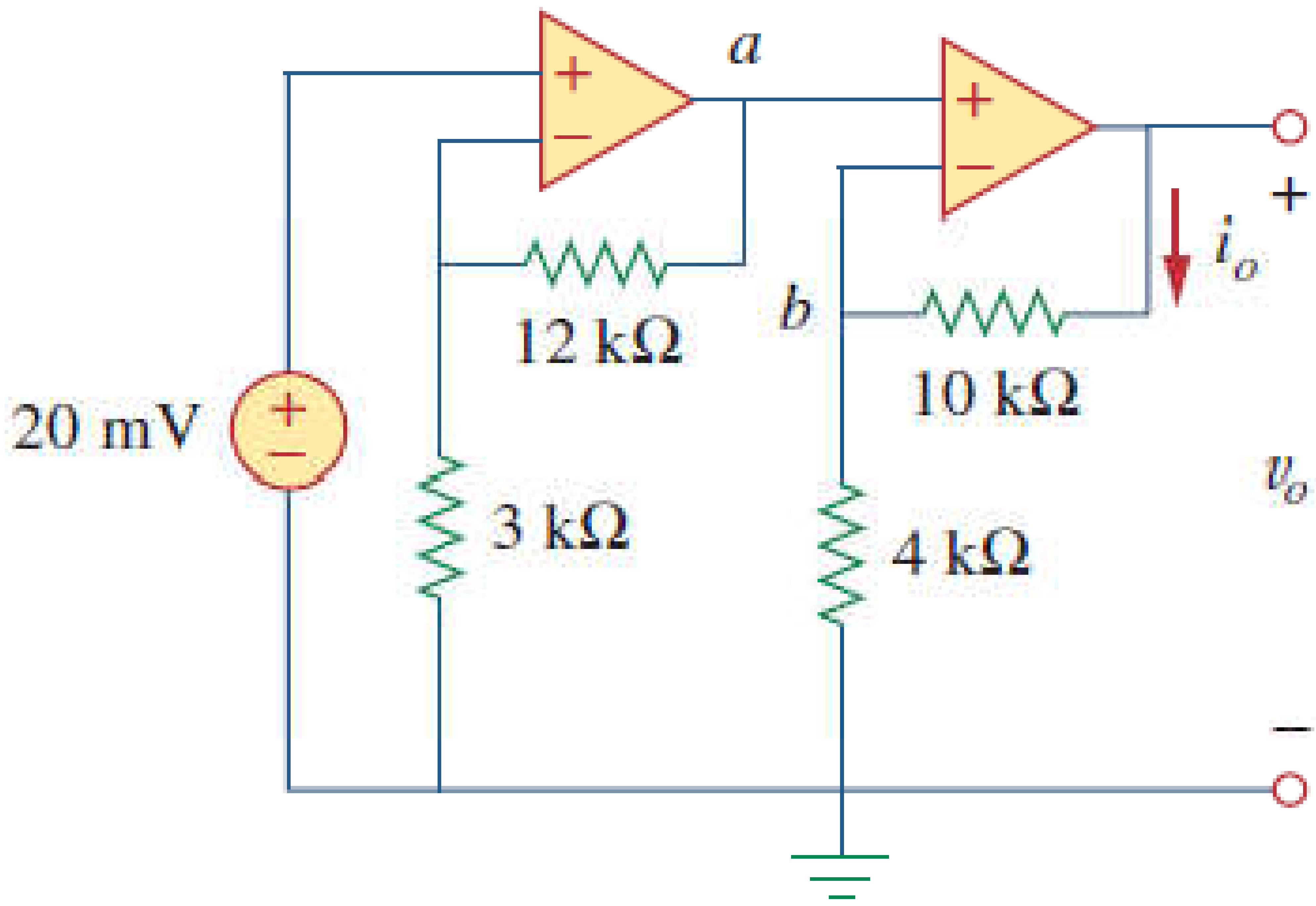
A_3 = Voltage gain of third stage = $-R_f/R_3$

Question

- In the previous circuit, if Rf = 470 k, R1=4.3 k, R2=33 k and R3=33 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-kΩ resistor.

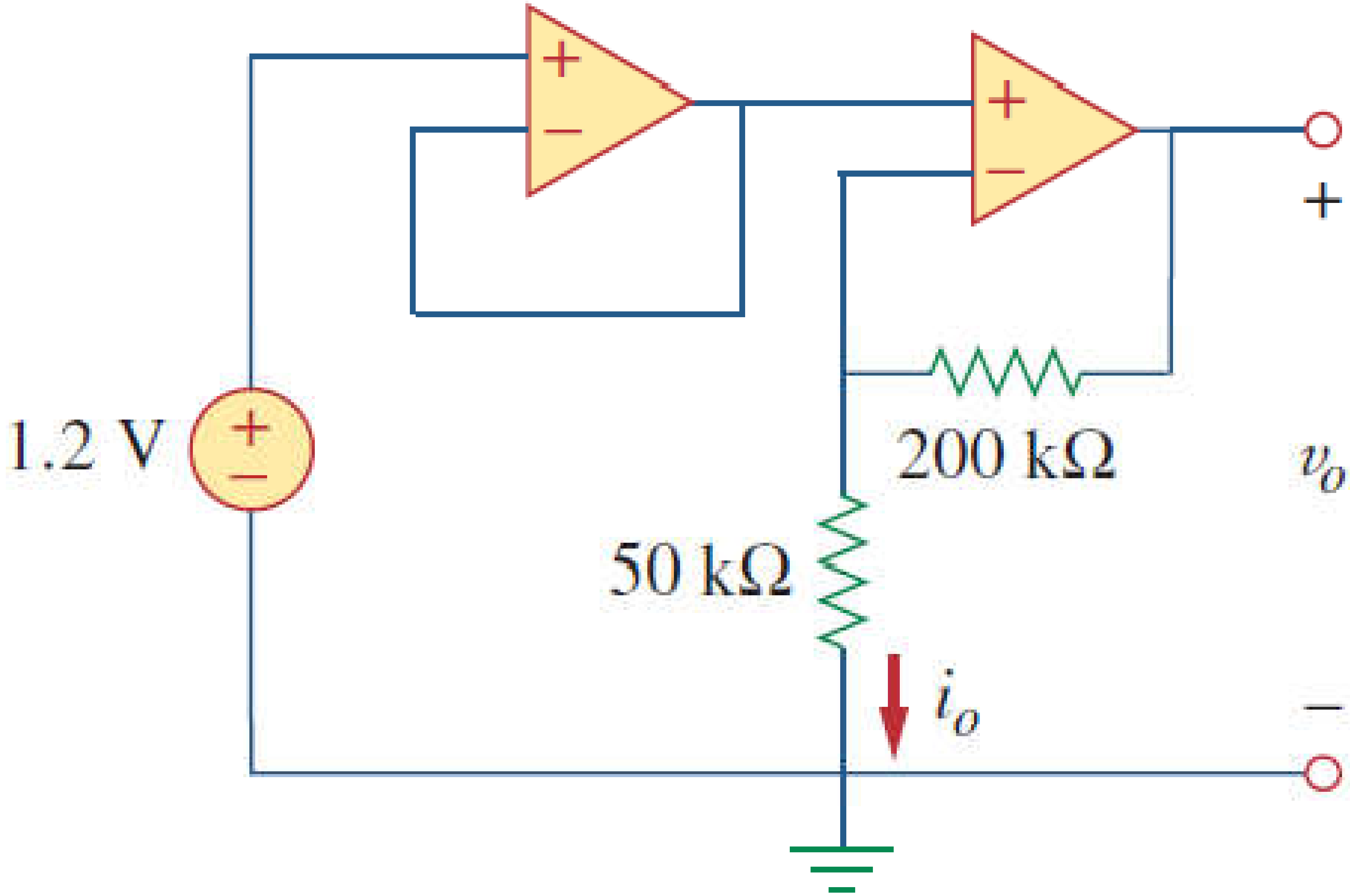
$$i_o = \frac{v_o - v_b}{10} \text{ mA}$$

But $v_b = v_a = 100$ mV. Hence,

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

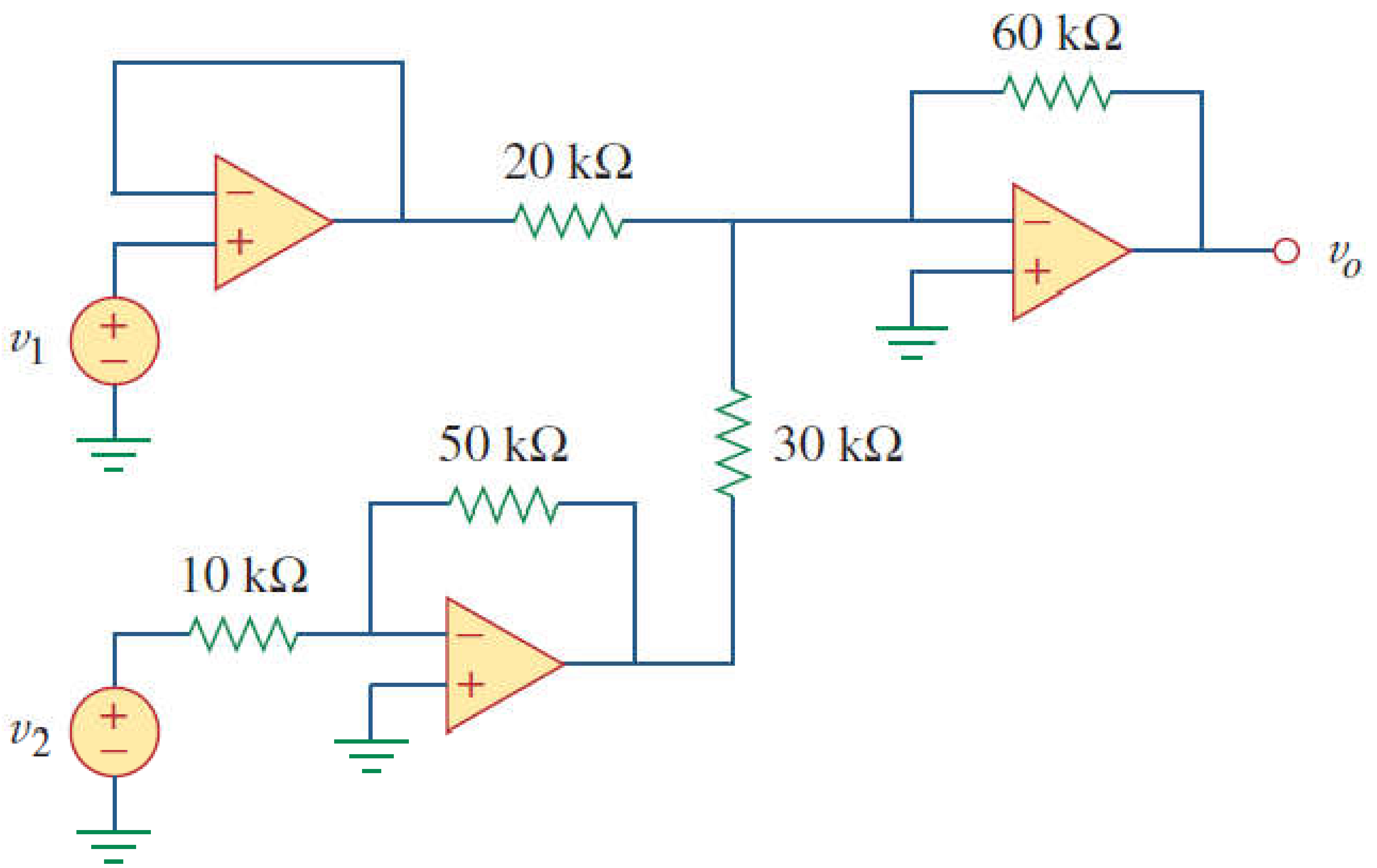
Question

Determine v_o and i_o in the op amp circuit



Question

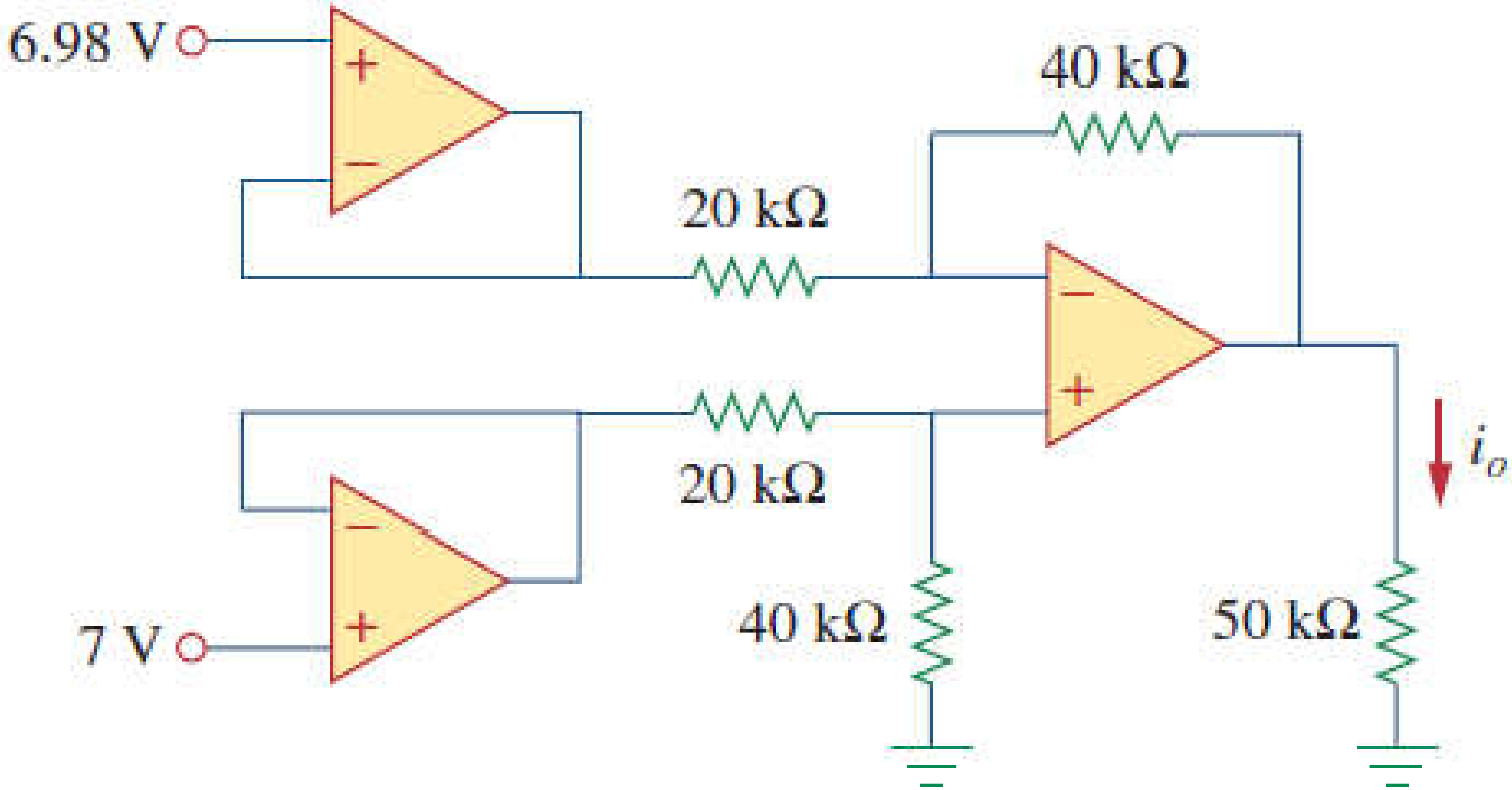
If $v_1 = 7$ V and $v_2 = 3.1$ V, find v_o in the op amp circuit



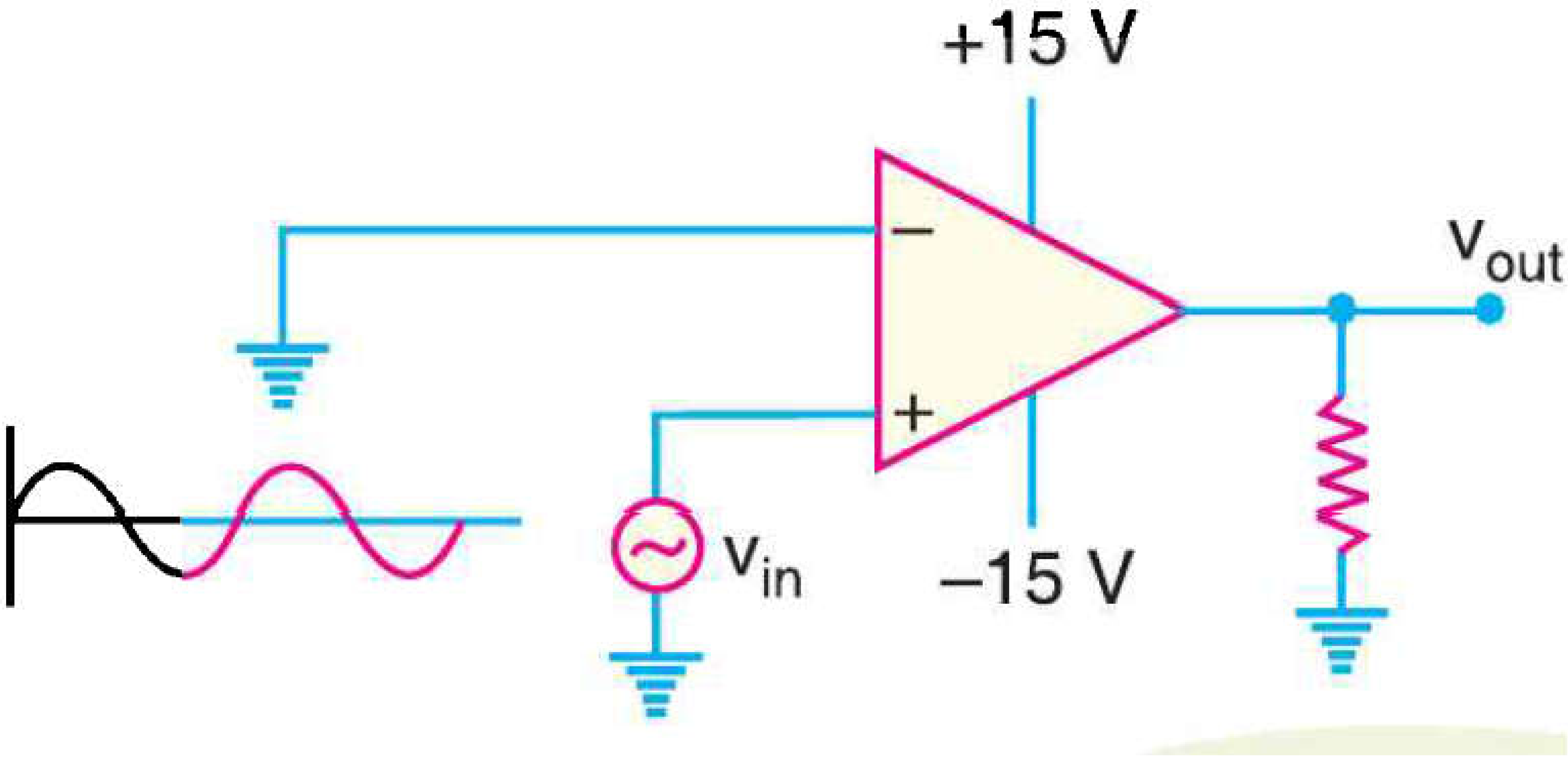
Question

$-800\ \mu A.$

Obtain i_o



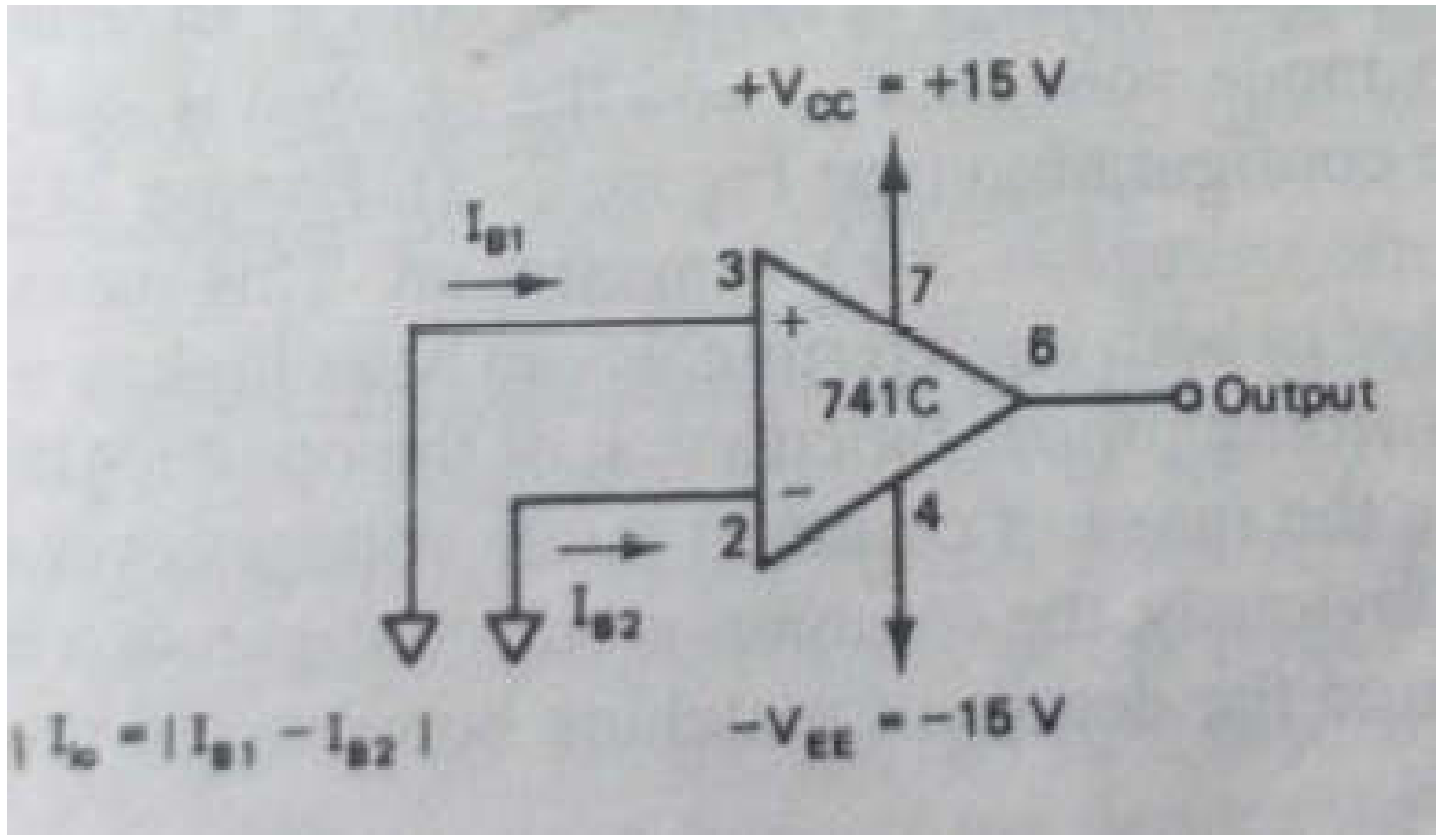
Concept Check



Input Offset Current

- Algebric difference between the currents entering the inverting and non-inverting terminals.

$$I_{io} = |I_{B1} - I_{B2}|$$



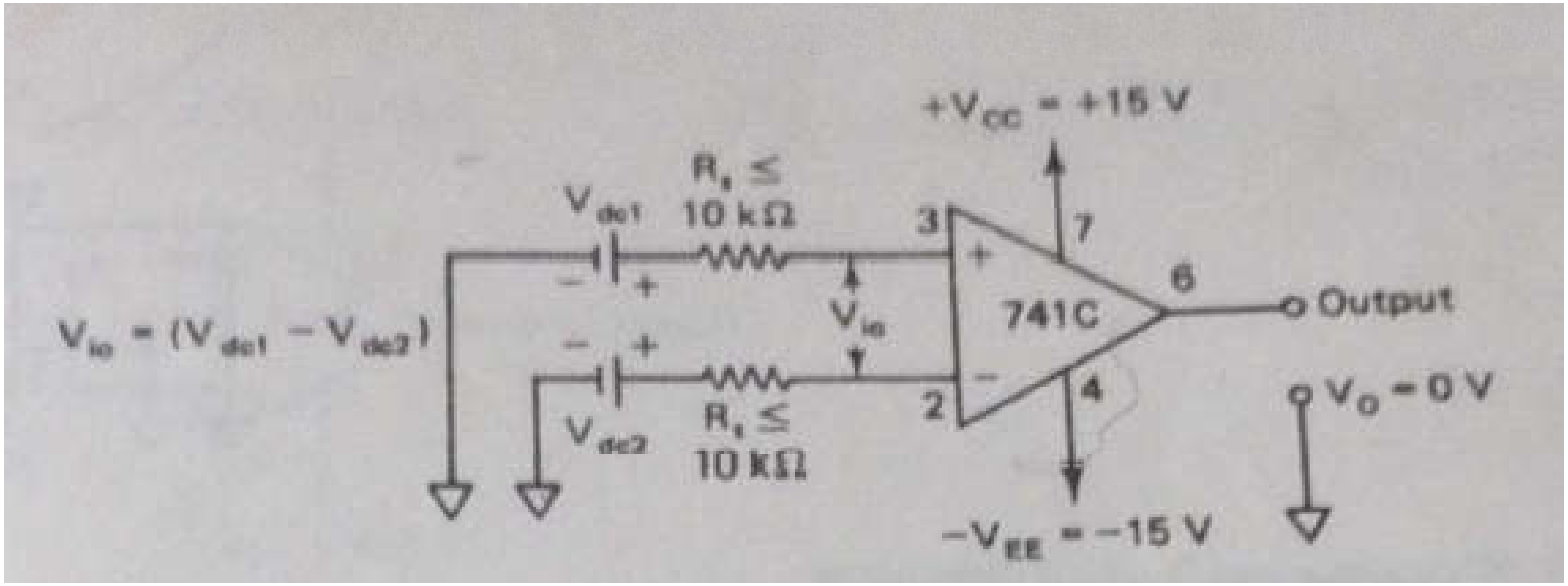
Input Bias Current

- Average of the currents that flow into the inverting an non-inverting terminals.

$$I_B = \frac{I_{B1} + I_{B2}}{2}$$

Input Offset Voltage

- It is the voltage that must be applied between the two input terminals of the opamp to nullify the output.



Common Mode Rejection Ratio

- It is defined as the ratio of Differential Mode Gain to Common Mode Gain.

$$CMRR = \frac{A_d}{A_{cm}}$$

Supply Voltage Rejection Ratio

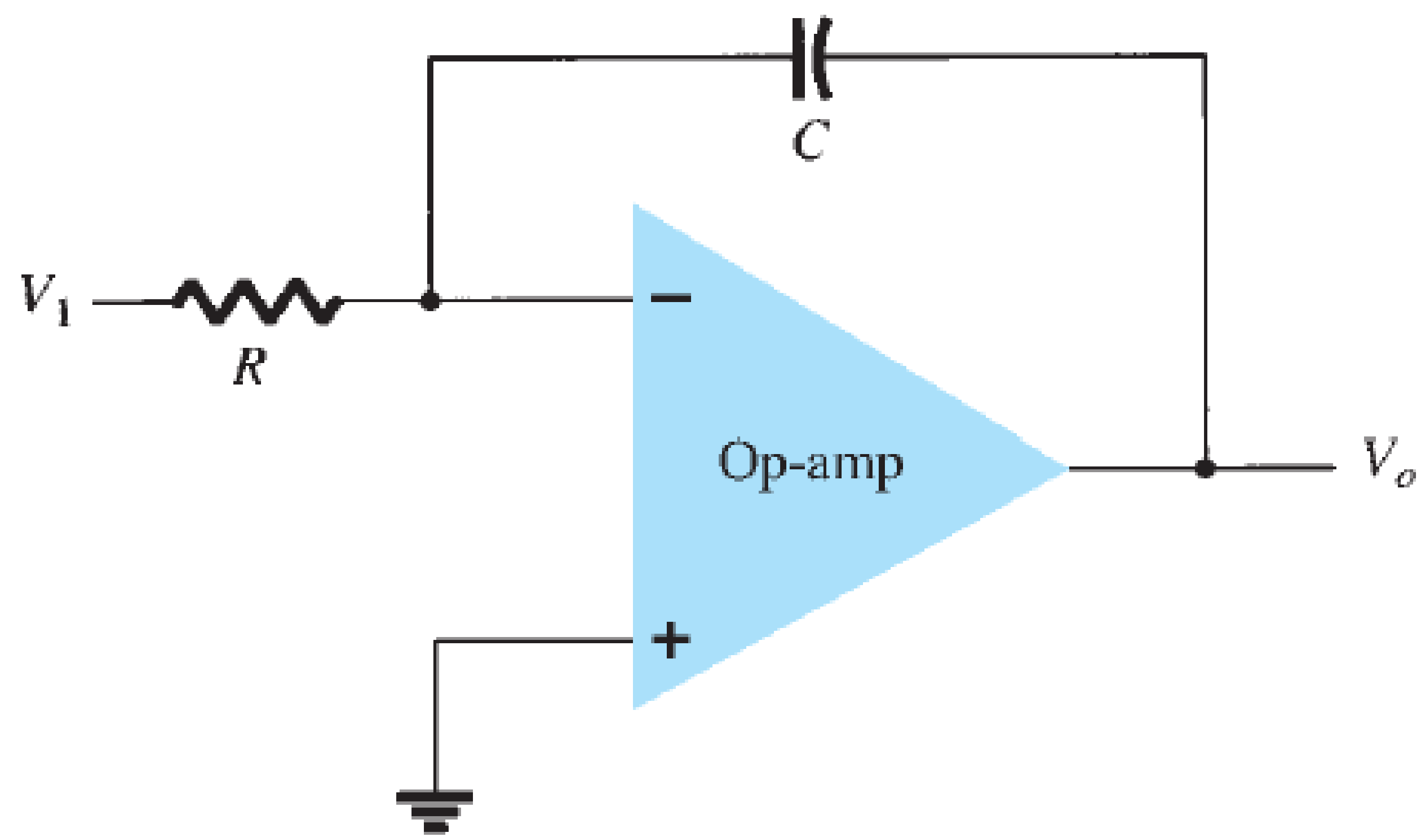
- Change in the opamp's input offset voltage, caused by variation in supply voltages. It is also known as PSRR. Lower the value, better the opamp's performance.

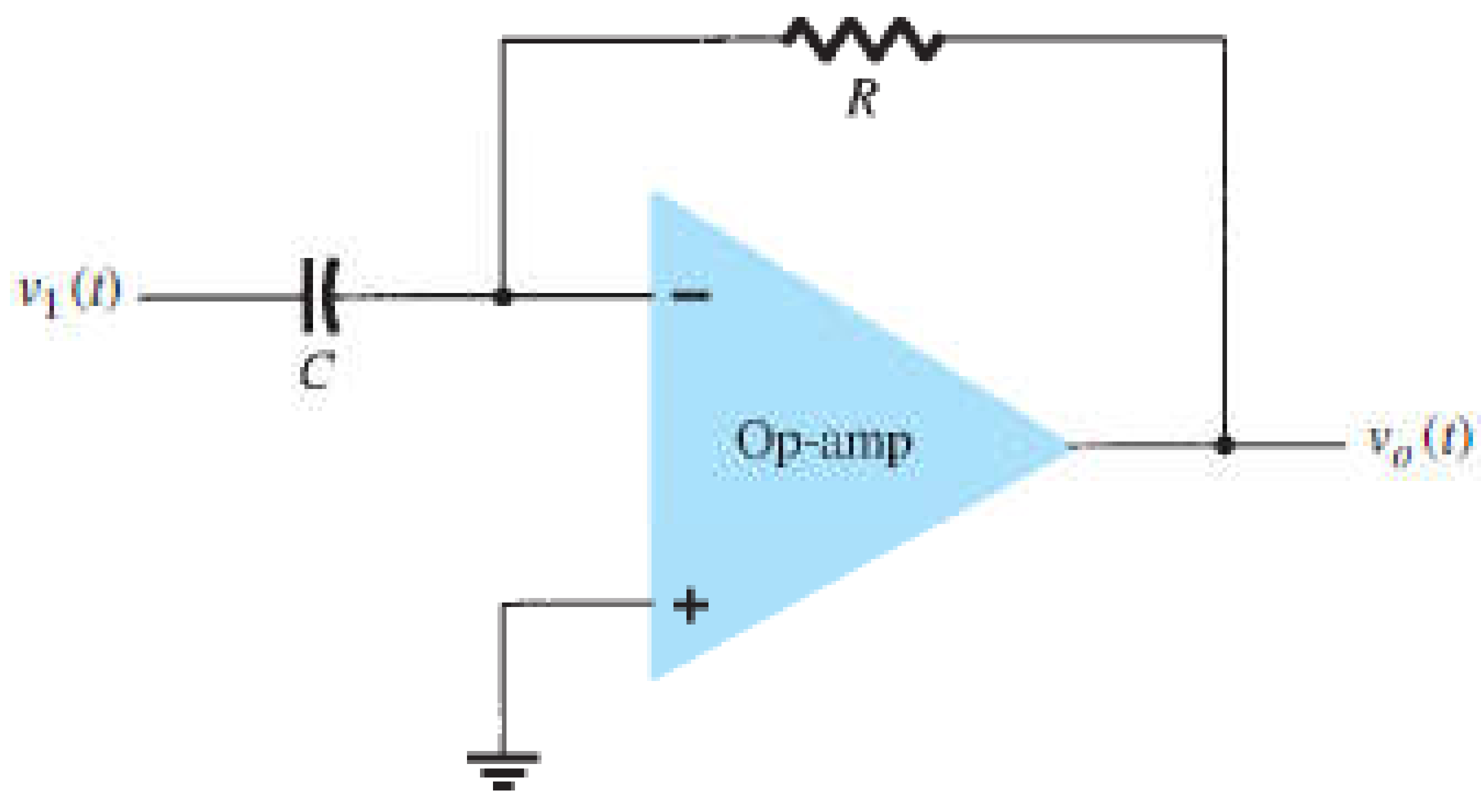
$$SVRR / PSRR = \frac{\Delta V_{io}}{\Delta V}$$

Slew Rate

- Maximum rate of change of output voltage per unit of time and is expressed in volts per microseconds.

$$SR = \left.\frac{dV_o}{dt}\right|_{\max} V/\mu s$$


C
V1
R
Op-amp
Vo


R
v1 (t)
C
Op-amp
vo (t)

[redacted]

$$\boxed{v_o(t) = -\frac{1}{RC}\int v_1(t)\,dt}$$

$$\boxed{v_o(t) = -RC\,\frac{dv_1(t)}{dt}}$$

End of Unit - 2