C5

Practice Problem 5.2

Repeat Example 5.1 using the ideal op amp model.

Answer: -2, 200 μA.

Example 5.1

A 741 op amp has an open-loop voltage gain of 2×10^5, input resistance of 2 MΩ, and output resistance of 50 Ω. The op amp is used in the circuit of Fig. 5.6(a). Find the closed-loop gain v_o/v_s. Determine current i when $v_s = 2$ V.

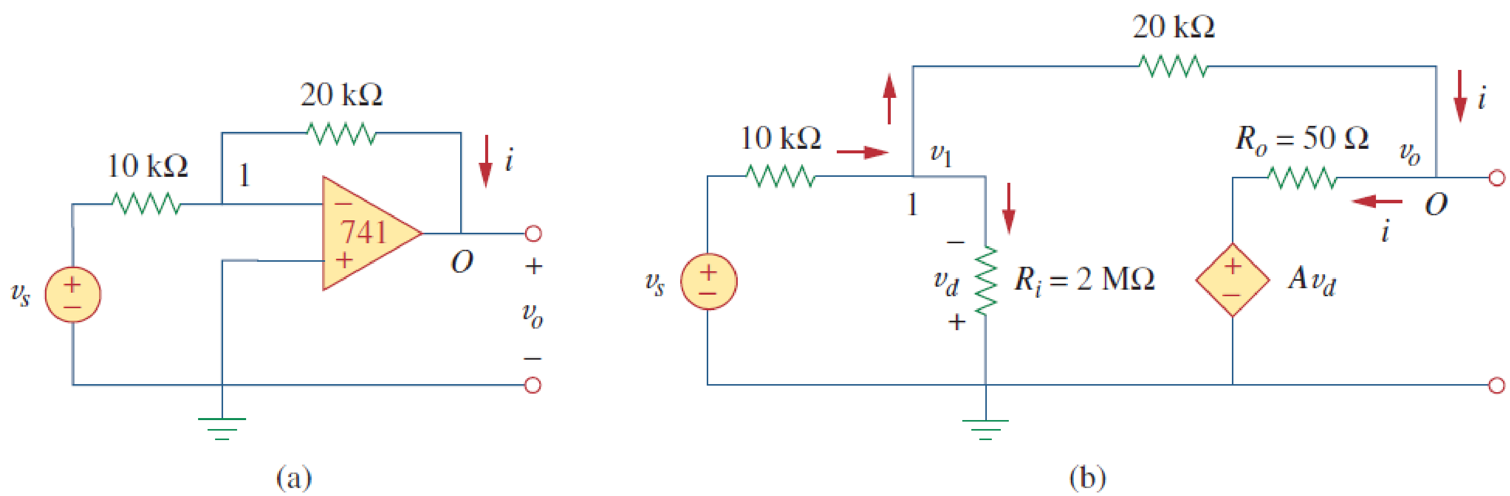


Figure 5.6
For Example 5.1: (a) original circuit, (b) the equivalent circuit.

Example 5.1

Example 5.1

A 741 op amp has an open-loop voltage gain of 2×10^5, input resistance of 2 MΩ, and output resistance of 50 Ω. The op amp is used in the circuit of Fig. 5.6(a). Find the closed-loop gain v_o/v_s. Determine current i when $v_s = 2$ V.

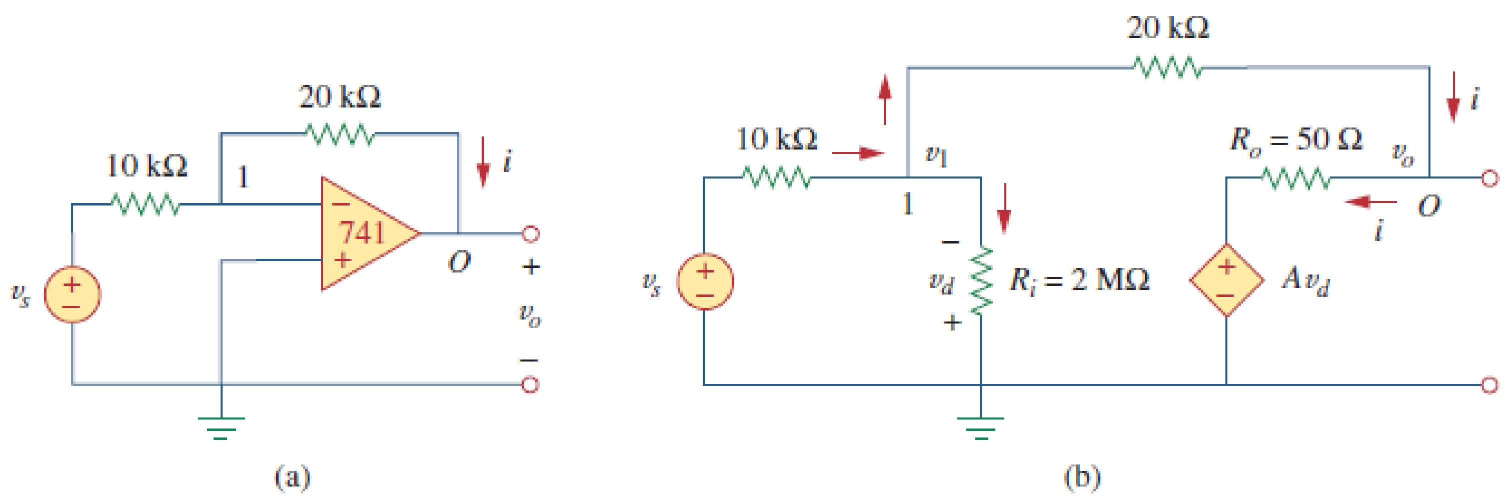
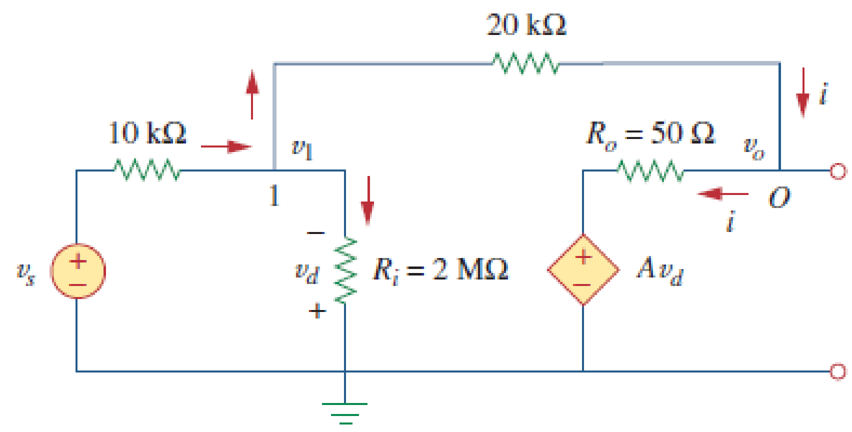


Figure 5.6
For Example 5.1: (a) original circuit, (b) the equivalent circuit.

A real op amp

- 1. The equivalent circuit



(b)

- 2. KCL@node 1

$$\frac{v_s - v_1}{10 \times 10^3} = \frac{v_1}{2000 \times 10^3} + \frac{v_1 - v_o}{20 \times 10^3}$$

$$200v_s = 301v_1 - 100v_o$$

$$2v_s \simeq 3v_1 - v_o \quad \Rightarrow \quad v_1 = \frac{2v_s + v_o}{3} \qquad \textbf{(5.1.1)}$$

- 3. KCL@node O

$$\frac{v_1 - v_o}{20 \times 10^3} = \frac{v_o - Av_d}{50}$$

$$v_d = -v_1 \text{ and } A = 200{,}000$$

$$v_1 - v_o = 400(v_o + 200{,}000v_1) \qquad \textbf{(5.1.2)}$$

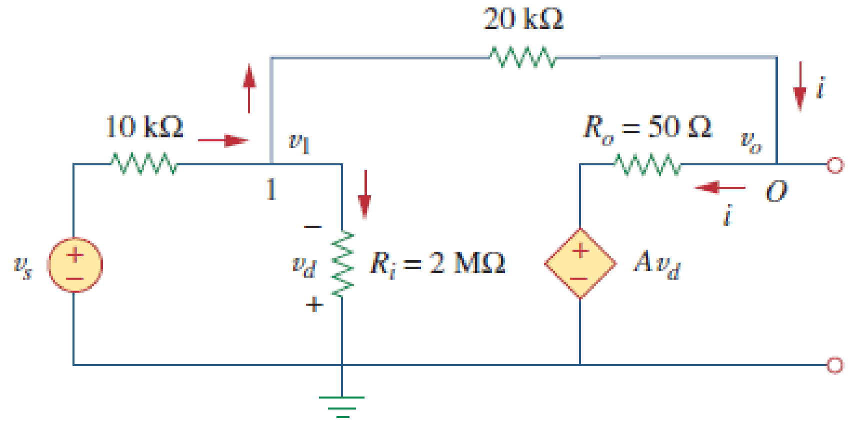
- 4.
  - 3 unknowns (v_s,v_1,v_o); need to get relation between v_s and v_o → eliminate v1
  - Substitute Eq. (5.1.2) into Eq. (5.1.1)

$$0 = 26{,}667{,}067 v_o + 53{,}333{,}333 v_s \quad \Rightarrow \quad \frac{v_o}{v_s} = -1.9999699$$

$\boxed{\text{This is closed-loop gain, because the 20-k feedback resistor closes the loop between the output and input terminals.}}$

- 5.
  - When v_s=2V, v_o=–3.9999398V.
  - From Eq. (5.1.1), we obtain v_1=20.066667 μV.
  - Thus, $i = \dfrac{v_1 - v_o}{20 \times 10^3} = 0.19999 \text{ mA}$

- Question: What if there is no feedback loop?



(b)

- <u>Answer</u>:
  - $v_1 = v_s \times (2/0.01+2)$
  - E.g., for v_s=2V, $v_1 \cong$2V,

    $|v_o| = |Av_d| >> |Vcc|$, in saturation region

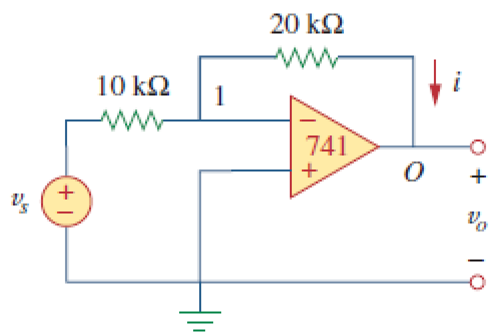
    $\boxed{\text{The feedback loop is helpful to operate an op amp in linear region.}}$

Problem 5.2

Repeat Example 5.1 using the ideal op amp model.

Practice Problem 5.2

Answer: -2, 200 μA.



(a)

V_1=0V

$(v_s-0)/10k=(0-Vo)/20k$

$V_o/V_s=-2$

For V_s=2V, V_o=-4V

$i=(0+4)/20k=200\mu A$

Comparisons

	Real op amp	Ideal op amp
Gain v_o/v_s	-1.9999699	-2
v_1	20.066667 μV	0 V
v_o	$-$3.9999398V μV	$-$4V
i	199.999 μA	200 μA
i_{Ro} (i through R_o)	199.999 μA	200 μA
v_d=0-v_1	$-$20.066667 μV	0V
Av_d	$-$4.0133 V	$v_o - i_{Ro} \times R_o = -4V \neq 0$ *

* cannot be calculated by $A \times v_d$ since $\infty \times 0$ is not defined.

Practice Problem 5.3

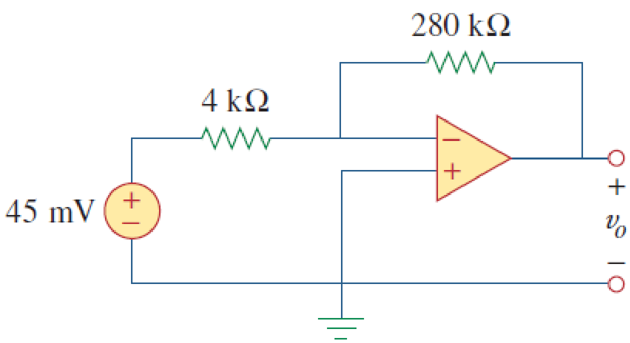


Figure 5.13
For Practice Prob. 5.3.

Find the output of the op amp circuit shown in Fig. 5.13. Calculate the current through the feedback resistor.

Answer: -3.15 V, $26.25\ \mu$A.

Practice Problem 5.5

Calculate v_o in the circuit of Fig. 5.20.

Answer: 7 V.

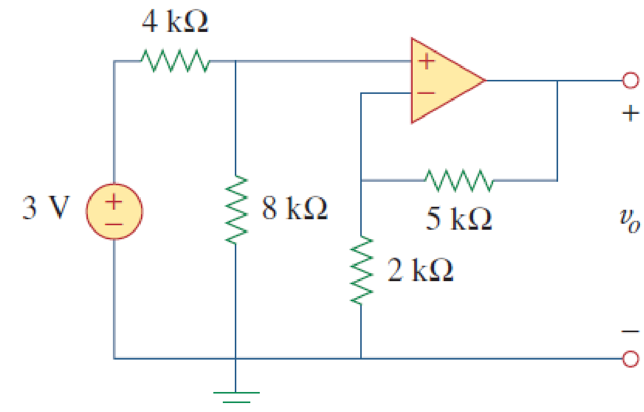


Figure 5.20
For Practice Prob. 5.5.

Find v_o and i_o in the op amp circuit shown in Fig. 5.23.

Practice Problem 5.6

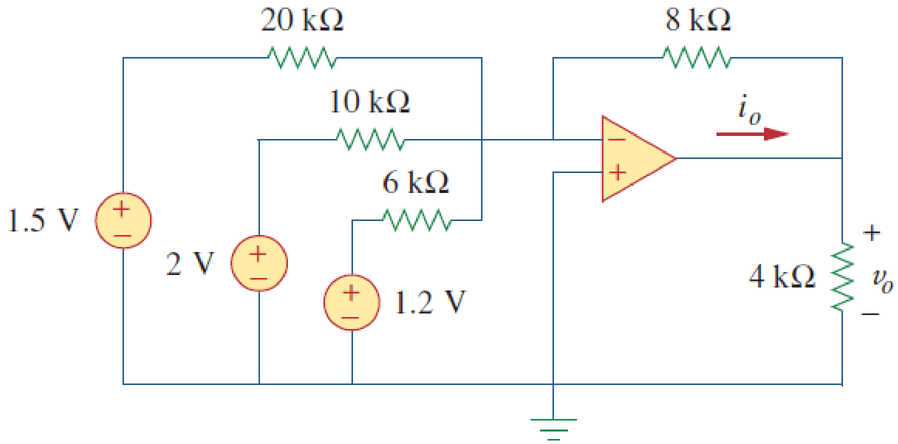


Figure 5.23
For Practice Prob. 5.6.

Answer: −3.8 V, −1.425 mA.

Practice Problem 5.7

Design a difference amplifier with gain 7.5.

Answer: Typical: $R_1 = R_3 = 20\text{k}\Omega$, $R_2 = R_4 = 150\ \text{k}\Omega$.

Practice Problem 5.8

Obtain i_o in the instrumentation amplifier circuit of Fig. 5.27.

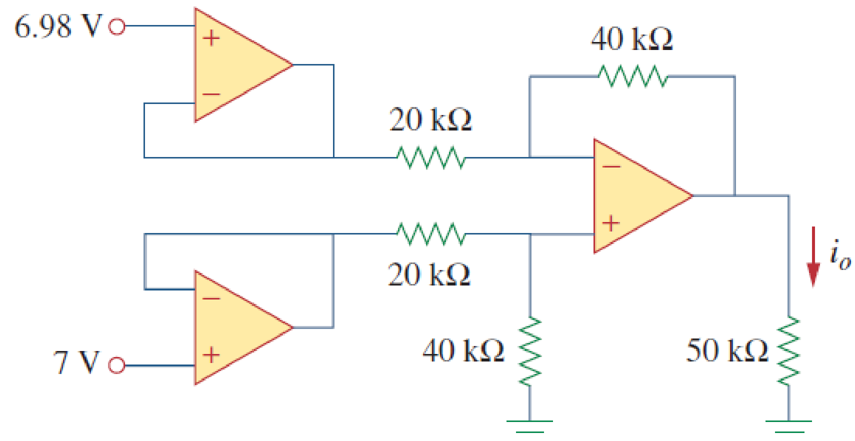


Figure 5.27
Instrumentation amplifier; for Practice Prob. 5.8.

Answer: $-800\ \mu A$.

Practice Problem 5.9

Determine v_o and i_o in the op amp circuit in Fig. 5.30.

Answer: 6 V, 24 μA.

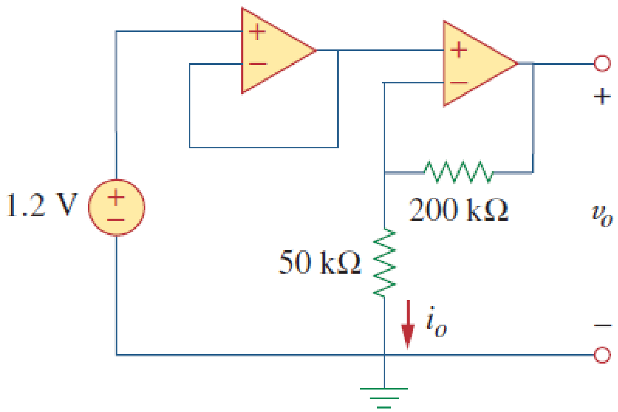


Figure 5.30
For Practice Prob. 5.9.

Practice Problem 5.10

If $v_1 = 7$ V and $v_2 = 3.1$ V, find v_o in the op amp circuit of Fig. 5.33.

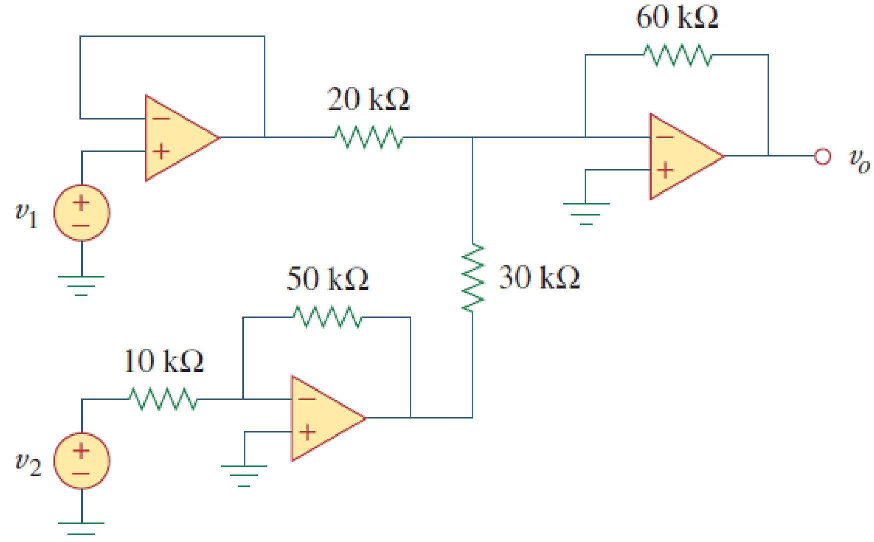


Figure 5.33
For Practice Prob. 5.10.

Answer: 10 V.

Practice Problem 5.12

A three-bit DAC is shown in Fig. 5.37.

(a) Determine $|V_o|$ for $[V_1V_2V_3] = [010]$.
(b) Find $|V_o|$ if $[V_1V_2V_3] = [110]$.
(c) If $|V_o| = 1.25$ V is desired, what should be $[V_1V_2V_3]$?
(d) To get $|V_o| = 1.75$ V, what should be $[V_1V_2V_3]$?

Answer: 0.5 V, 1.5 V, [101], [111].

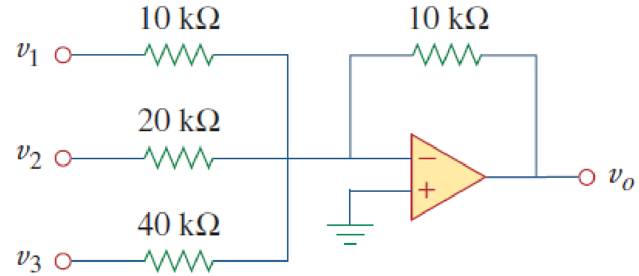


Figure 5.37
Three-bit DAC; for Practice Prob. 5.12.

Practice Problem 5.13

Determine the value of the external gain-setting resistor R_G required for the IA in Fig. 5.38 to produce a gain of 142 when $R = 25\ \text{k}\Omega$.

Answer: 354.6 Ω.

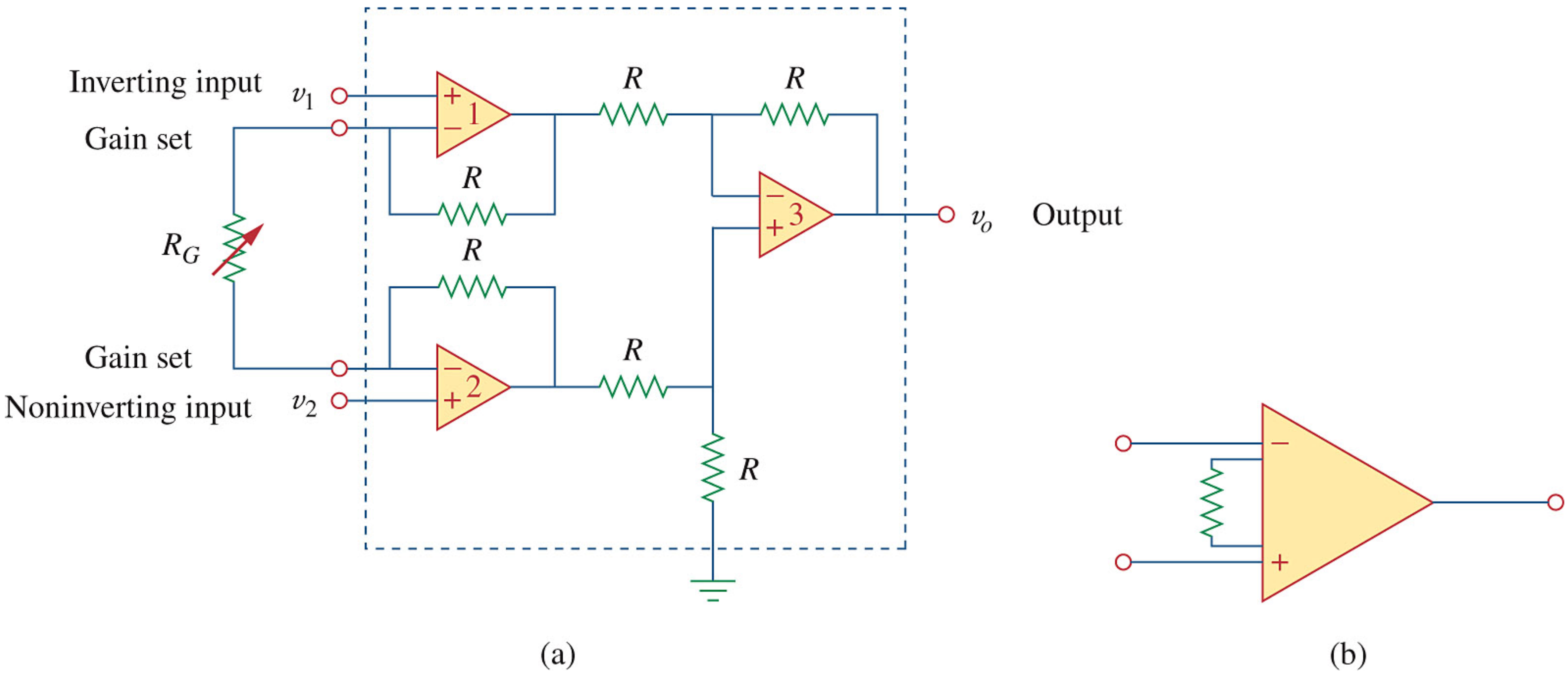


Figure 5.38 (a) The IA with an external resistance to adjust the gain, (b) schematic symbol.