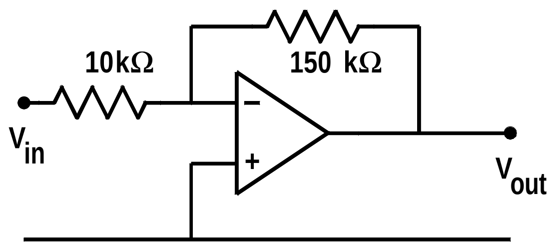
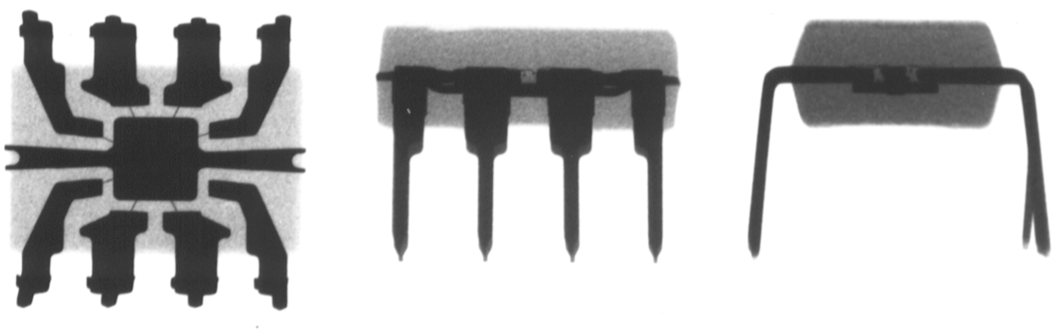
The following two rules are used to analyse the operation of op-amps in linear circuits:—

- When an op-amp is used in the linear region, the voltage difference between the inverting and noninverting inputs is approximately zero.
- No current flows into the input terminals of the op-amp.



The gain of an inverting amplifier is given by:—

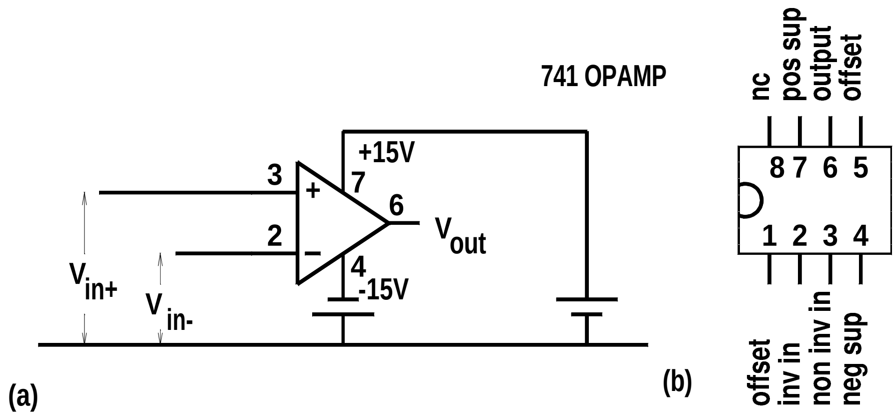
$$A_V = -\frac{R_f}{R_{in}}$$



Fine wires connecting the silicon chip mounted on the lead frame to the pins of the dil package

Silicon chip is mounted on the central square of the lead frame

But silicon is transparent to X-Rays due to the low atomic number of silicon.



An op-amp has two inputs,
an inverting input V_{in-}
a noninverting input V_{in+}.
Amplified difference voltage appears at the single output terminal.

$$V_{out} = A_o \left(V_{in+} - V_{in-} \right)$$

where A_o is called the open loop gain and $A_o \approx 10^5$ or 100dB.

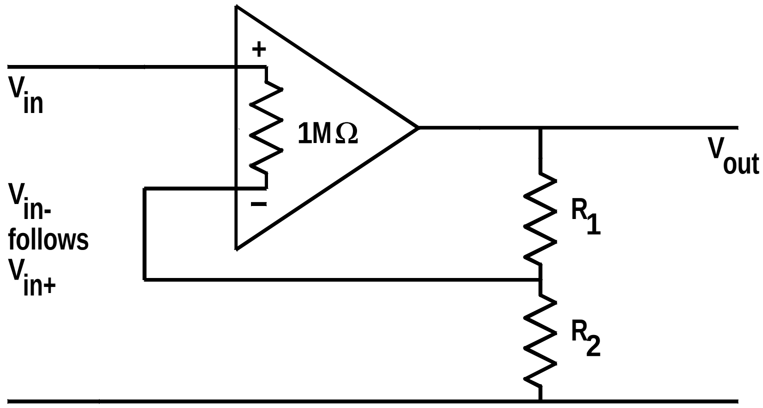
Linear region where output voltage remains within range $\pm 10V$,
Work backwards!

$$\left|V_{in+} - V_{in-}\right| = \frac{10V}{A_o} = \frac{10}{10^5} = 10^{-4}V = 100\mu V$$

which is small.

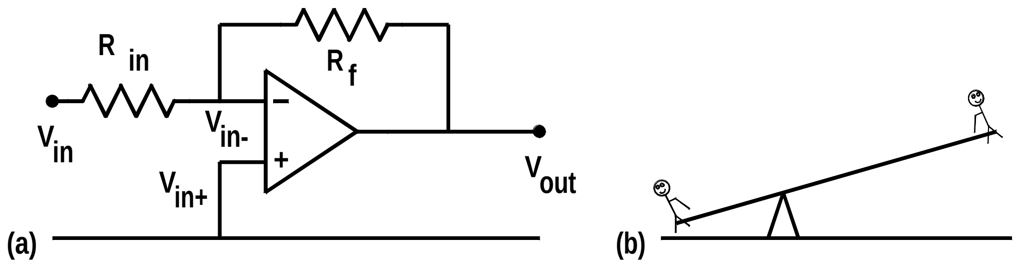
Then the voltage difference between the inverting and noninverting inputs is approximately zero.

Not exactly zero but negligible compared to the voltages normally applied to the amplifier circuit.
Distinction between op-amp and amplifier circuit with op-amp as component.



The op-amp has been designed to have an input resistance between the inverting and noninverting inputs of at least $1M\Omega$.

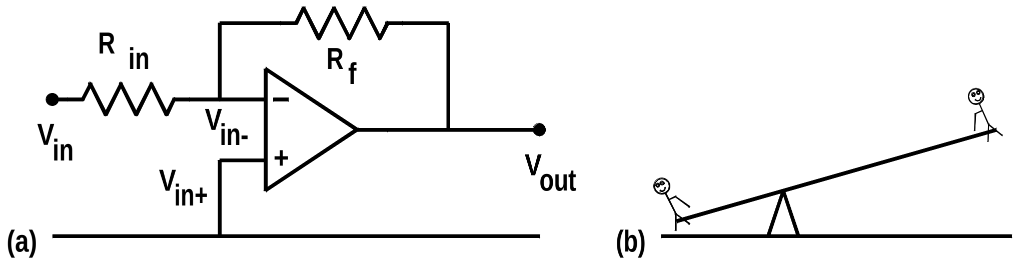
The typical voltages between the two input terminals is not greater than $100\mu V$
Current flowing into the input terminals is less than $\frac{100\mu V}{10^6\Omega} = 10^{-10}A$.
second approximation rule, *No current flows into the input terminals of the op-amp.*



Inverting amplifier circuit and model

Power supply connections not shown

Circuit can be drawn with either the inverting input (-) or the noninverting input (+) input at the top of the op-amp symbol



$$\text{Rule 1} \quad V_{in-} \approx V_{in+} = 0V$$

From Rule 2,

$$I_{in} = I_f$$

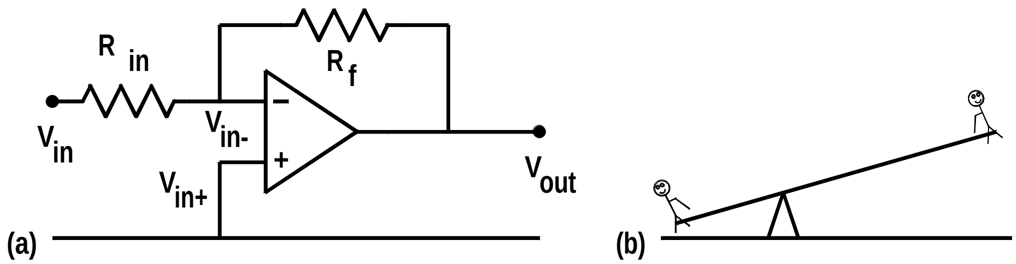
Use Ohm's Law to get

$$\frac{V_{in} - V_{in-}}{R_{in}} = \frac{V_{in} - 0V}{R_{in}} = I_{in}$$

$$\frac{V_{in-} - V_{out}}{R_f} = \frac{0V - V_{out}}{R_f} = I_f$$

$$\text{therefore} \quad \frac{V_{in}}{R_{in}} = -\frac{V_{out}}{R_f}$$

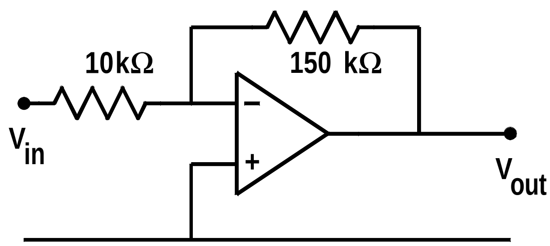
$$\text{or} \quad A_V = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$



$$\text{or} \quad A_V = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

Amplifier gain determined by the ratio of two resistors

The negative sign tells us that it is an inverting amplifier.



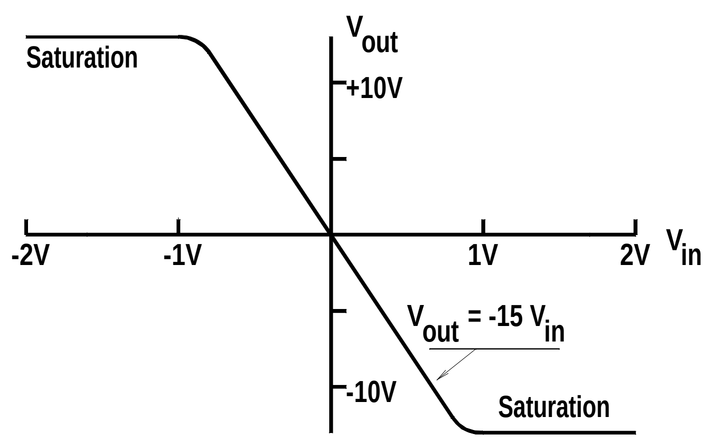
Dual $\pm 15V$ supply
$R_{in} = 10k\Omega$ and $R_f = 150k\Omega$.
Calculate the gain of the amplifier and plot a graph of the output voltage when V_{in} is varied from -2V to +2V.

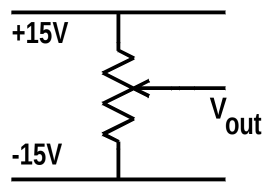
The gain of this circuit is

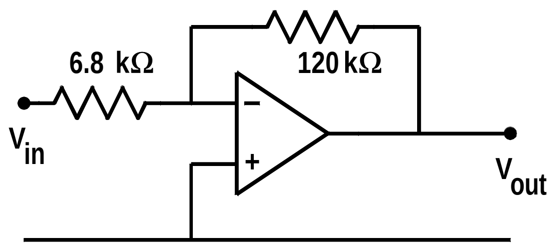
$$A_V = -\frac{150k\Omega}{10k\Omega} = -15$$

V_{in}	Calculated V_{out}	ActualV_{out}
-2V	+30V	+13V
-1V	+15V	+13V
-0.8V	+12V	+12V
-0.5V	+7.5V	+7.5V
0V	0V	0V
+0.5V	-7.5V	-7.5V
+0.8V	-12V	-12V
+1V	- 15V	-13V
+2V	-30V	- 13V

$$V_{out} = -15 \times V_{in}$$




+15V
-15V
V_{out}


6.8 kΩ
120 kΩ
−
+
V
in
V
out