Bioengineering First year

Electrical Engineering

Revision

of

Lectures 1 to 8

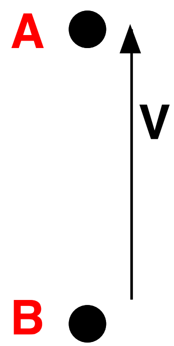
Voltages and Currents

Between two points in a circuit there will be a voltage. We have to discuss this voltage, so we give it a name:

V

But we additionally have to have some way of discriminating between a situation where A is more positive than B, and vice versa

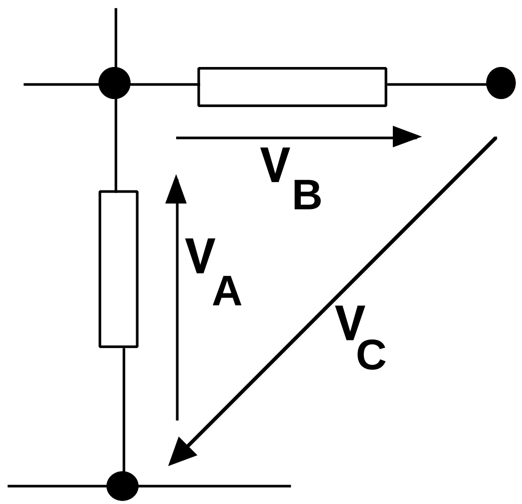
So we assign a reference direction to V as shown on the right. This direction is usually arbitrary, since we often do not know the polarity of the voltage. If we call the voltage VAB, it is usually understood that this is the voltage of A with respect to B



Voltages obey Kirchhoff's Voltage Law (KVL)

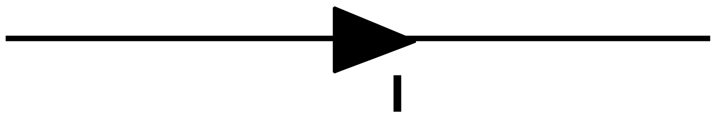
$$\sum_{\text{around loop}} V = 0$$

Note that the loop need not be "closed" by a component. Thus, in the circuit on the right, KVL can be written:



$$V_A + V_B + V_C = 0$$

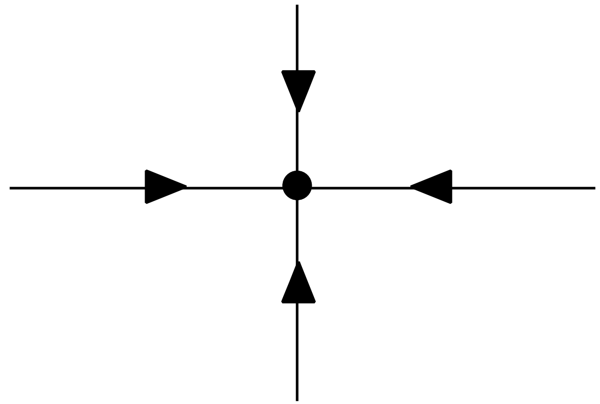
Voltages and Currents



Similarly we have to discuss the current flowing in a wire. Usually we do not know anything about that current, so we give it a name and a reference direction. The reference direction, indicated by the arrow, does not necessarily mean that the current flows in that direction. If it does, the value of I will be positive. If it doesn't, the value of I will be negative.

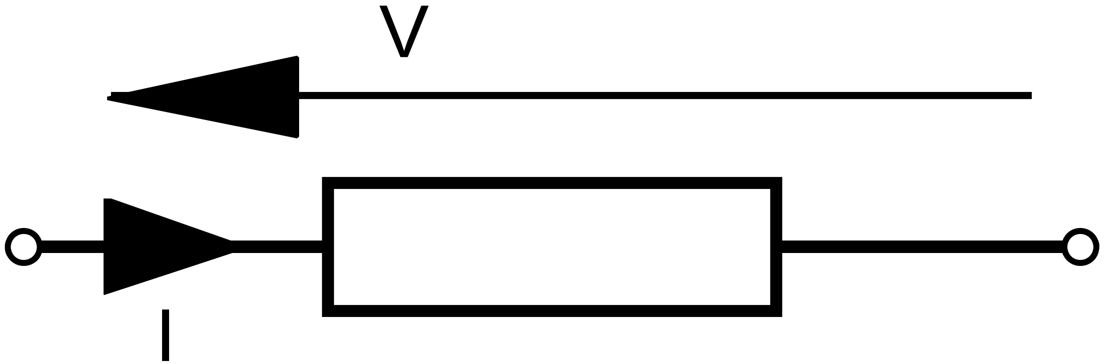
Currents obey Kirchhoff's Current Law (KCL)

$$\sum_{\text{at a node}} \mathbf{I} = \mathbf{0}$$



When writing down KCL for a node, it probably helps to note whether the reference currents are flowing into ("IN") or out of ("OUT") the node.

Ohms Law



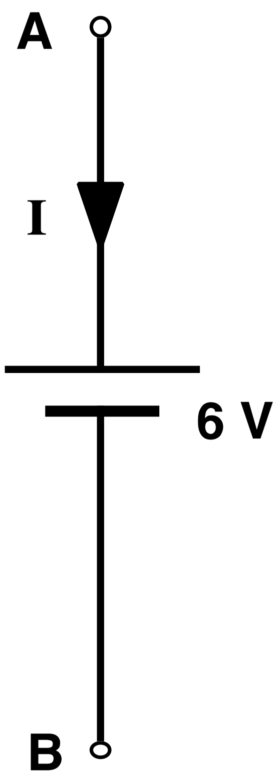
$$V = R \times I$$

. . . but only if reference directions are chosen as above !

Voltage source

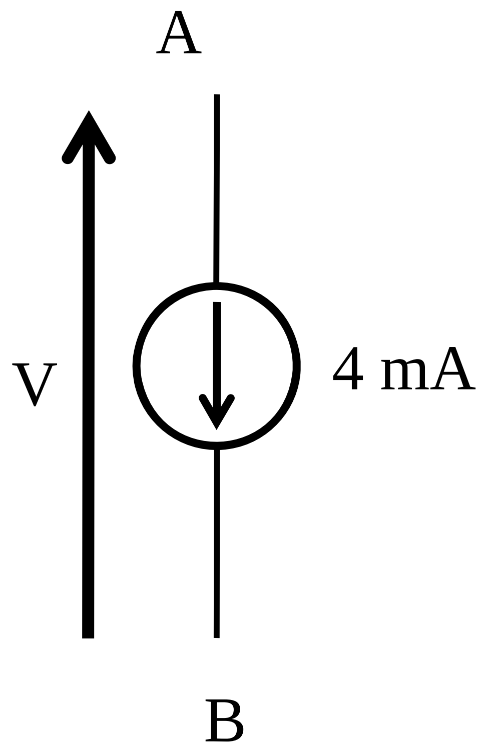
The symbol shown at right is a way of saying that the voltage between points A and B is 6 volts (with A more positive than B), *whatever the value or direction of the current I*

From the voltage source alone you cannot infer the value or direction of I. The current I is determined by what is connected to the voltage source.



Current source

The symbol shown at right is a way of saying that the current between points A and B is 4 mA in the direction indicated by the symbol, *whatever the value or direction of the voltage V.*

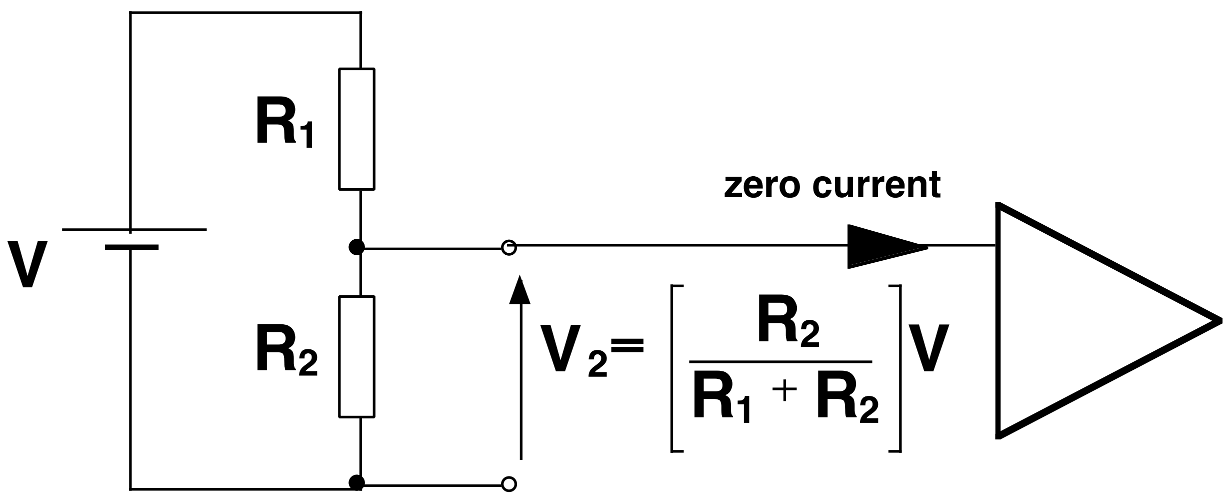


From the current source alone you cannot infer the value or direction of V. The voltage V is determined by what is connected to the current source.

Problem 3.1
and Test 1

I suggest you make sure you’re happy with the way those questions should be answered.

The voltage divider



Nodal analysis

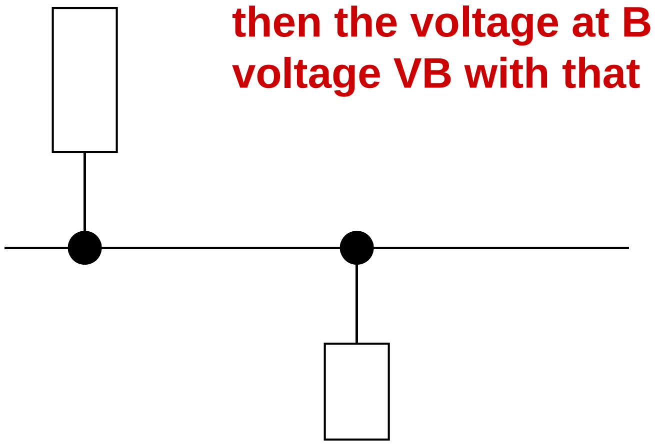
A method for finding all the voltages and currents in a circuit

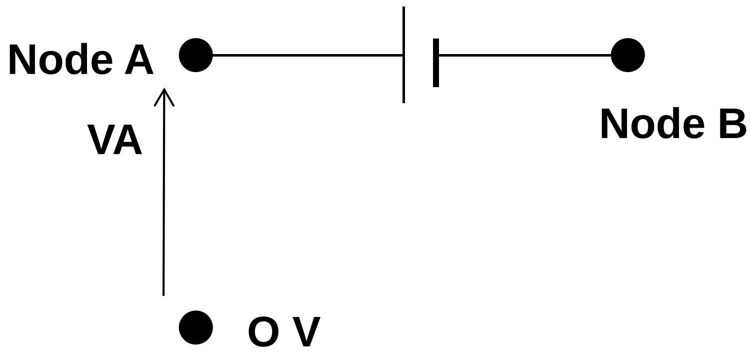
Apply it systematically, and don't make assumptions about the direction of any current or voltage

1. **Choose a reference node: indicate it with an 'earth' symbol or as 0 V (zero voltage).**

2. **Identify and label (e.g., 'A') those other nodes for which the voltage is unknown. Draw the corresponding voltage for each node**

Be careful! In the circuit below left, the 'blobs' are at the same voltage: don't assign different labels. Indeed, it might help to redraw the circuit. In the circuit below right, if VA is an unknown voltage, then the voltage at B is NOT unknown: don't associate an 'unknown' voltage VB with that node.





Nodal analysis - continued

3

Write down Kirchhoff's Current Law in turn for each node associated with an unknown voltage.

It is usually helpful to write, for each node:

KCL at A (IN) **followed by the equation**

as a reminder that you are summing the currents into that node.

In this way you will have as many equations as there are unknown voltages, so these nodal equations can be solved for the voltages.

Once the nodal voltages are known, all other voltages, and all currents, can be found.

Superposition Principle

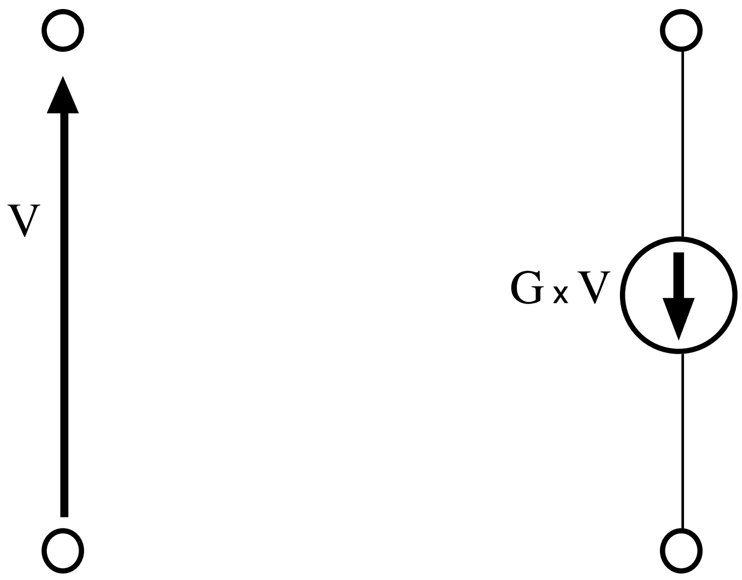
A method for analysing a circuit, especially when only one voltage or current is of interest

If the circuit contains N independent sources, create N new circuits each containing one of the original sources with the others set to zero (in other words, with voltage sources replaced by short circuits and current sources by open circuits)

Calculate the required current or voltage for each circuit, then add them to find the actual value.

Remember, if the circuit contains a controlled source (I.e., a dependent source) such as a VCCS, do not treat it as an independent source.

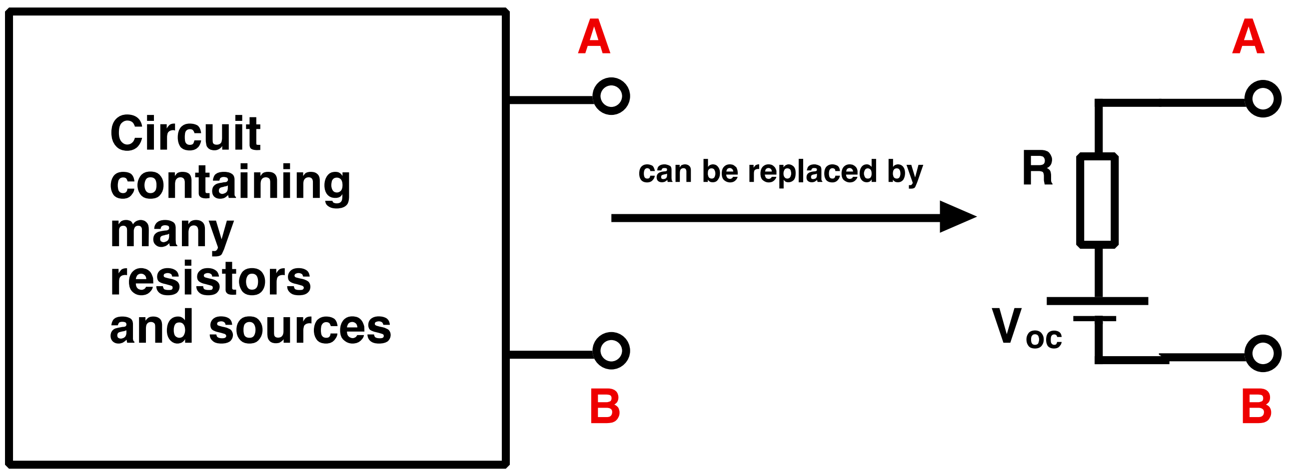
Voltage-controlled Current Source



Carry out your circuit analysis in the normal way. But remember, when analysing a circuit using the superposition principle, do not treat it as an independent source.

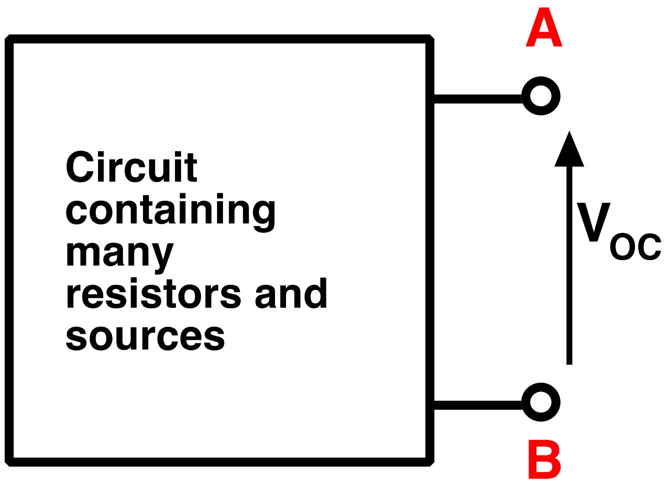
Thevenin's Theorem

Provides a way of replacing a complex circuit between two terminals with a much simpler circuit comprising a resistor and a voltage source.

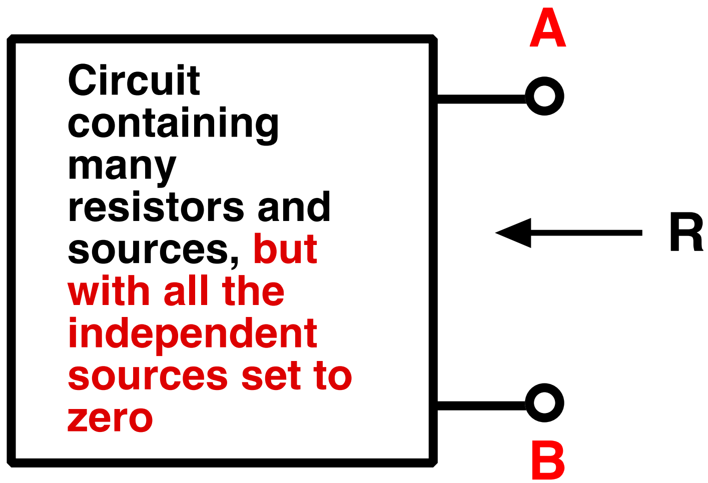


To find the values of R and V_{OC} , two circuits must be analysed

Thevenin’s Theorem - continued



Analysis of this circuit gives you the value of V_{OC}



The resistance between the terminals A and B is the value of R

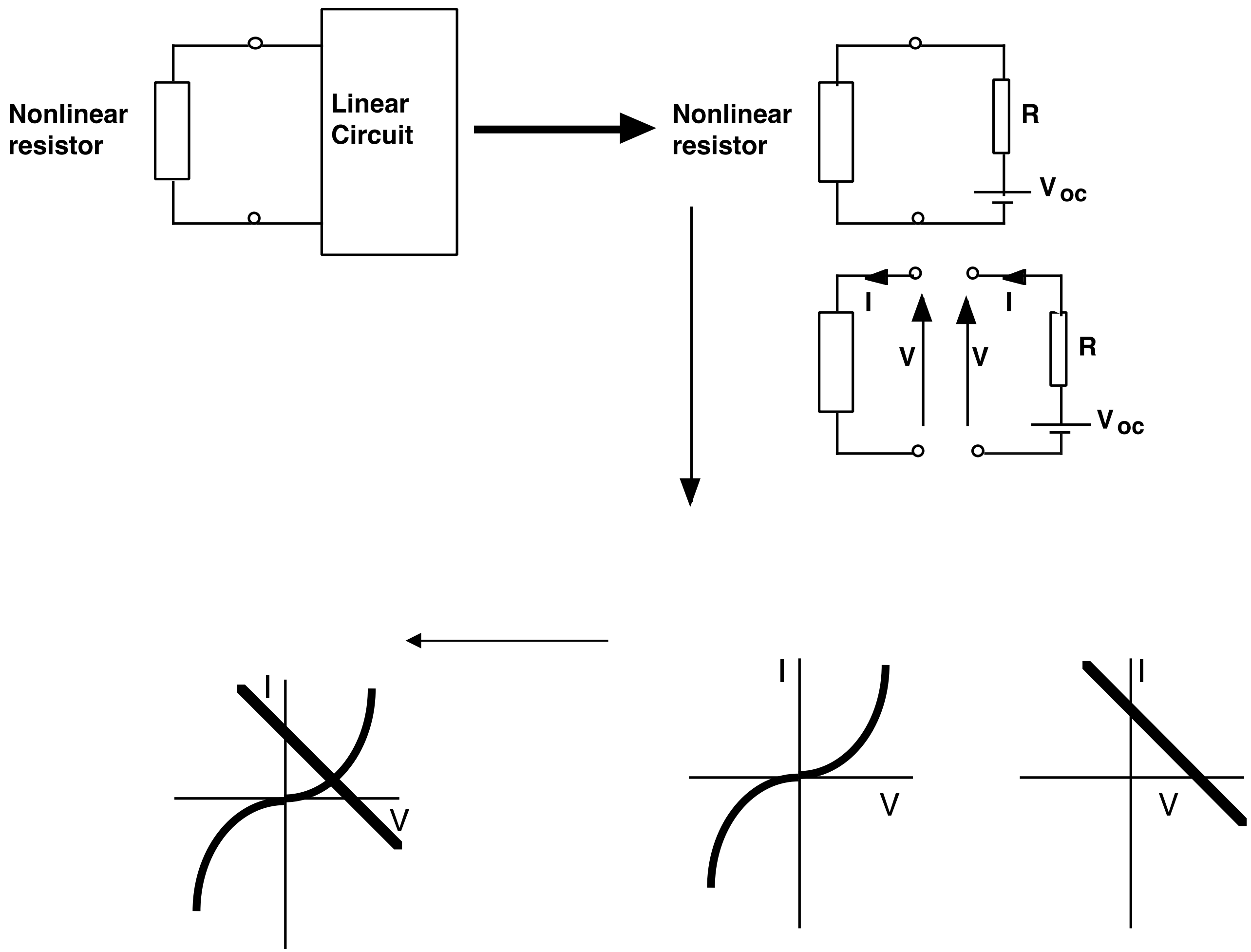
Be careful! If the circuit contains a voltage-controlled current source, DO NOT set its value to zero when calculating the value of R

One nonlinear resistor

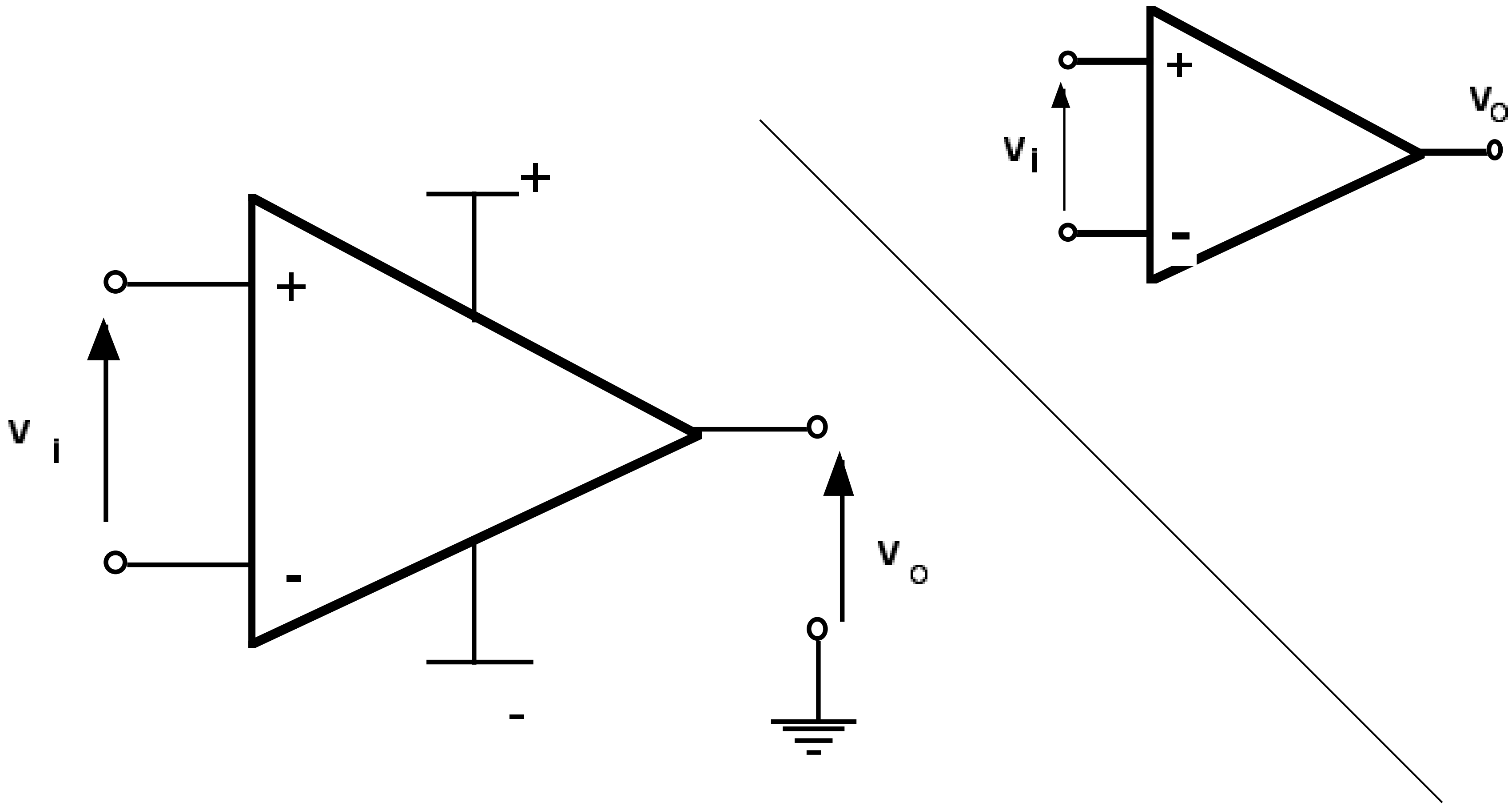
If a circuit contains one nonlinear resistor whose voltage-current characteristic is known, represent the rest of the circuit by a Thevenin Equivalent Circuit.

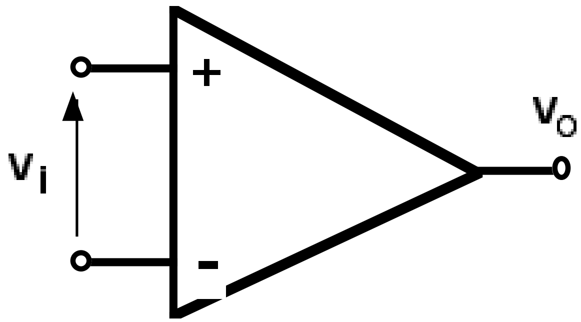
Split the circuit as shown

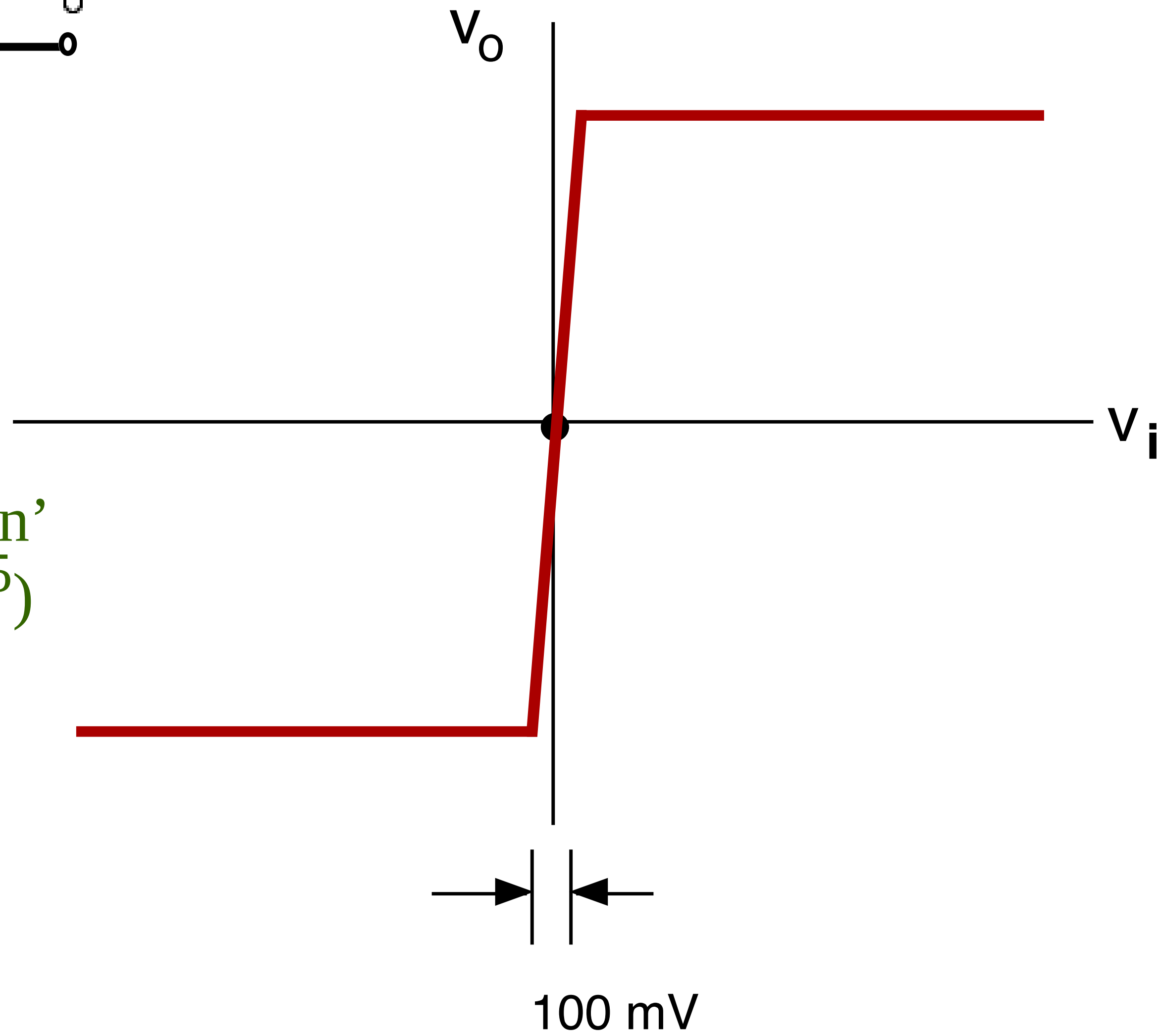
Then draw the voltage-current characteristic for each part on the same axes. The intersection identifies the state of the circuit.



The Operational Amplifier







Slope in ‘linear region’ is very high (e.g., 10^5)

Input currents are essentially zero

The Operational Amplifier

In general there are two modes of operation:

- Where operation is confined to the linear region.
  Often this is ensured by negative feedback

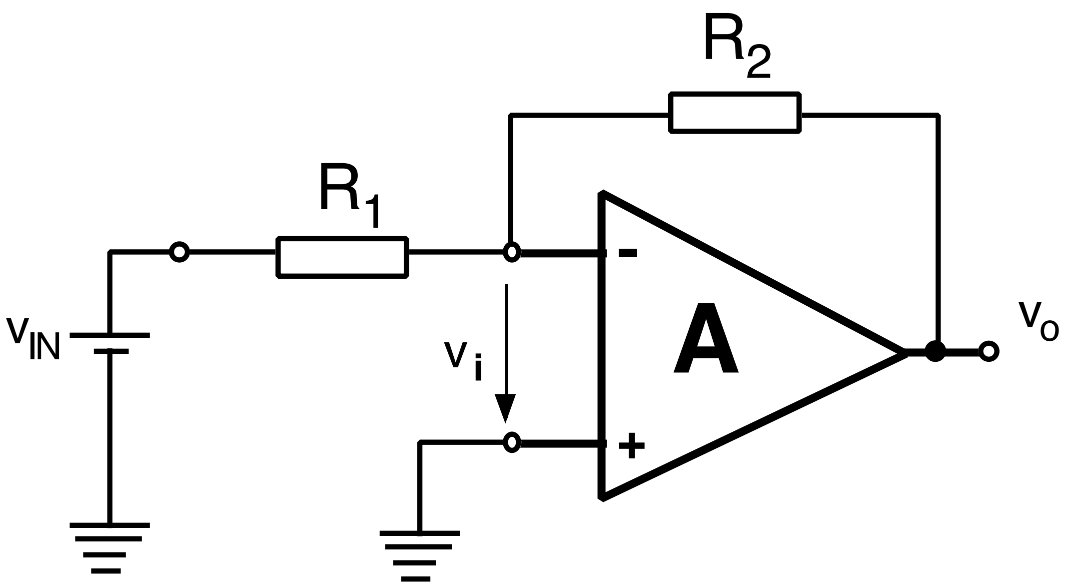
- Where operation is not confined to the linear region.
  Often this is ensured by positive feedback

Before attempting to analyse a circuit containing opamps,
decide which mode each opamp is in.

Linear operation

The Operational Amplifier: Linear operation

Example: the Inverter



Negative feedback ensures operation in the linear region

The Operational Amplifier: Linear operation

Example: the Inverter

$i = (v_{IN} + v_i)/R_1$

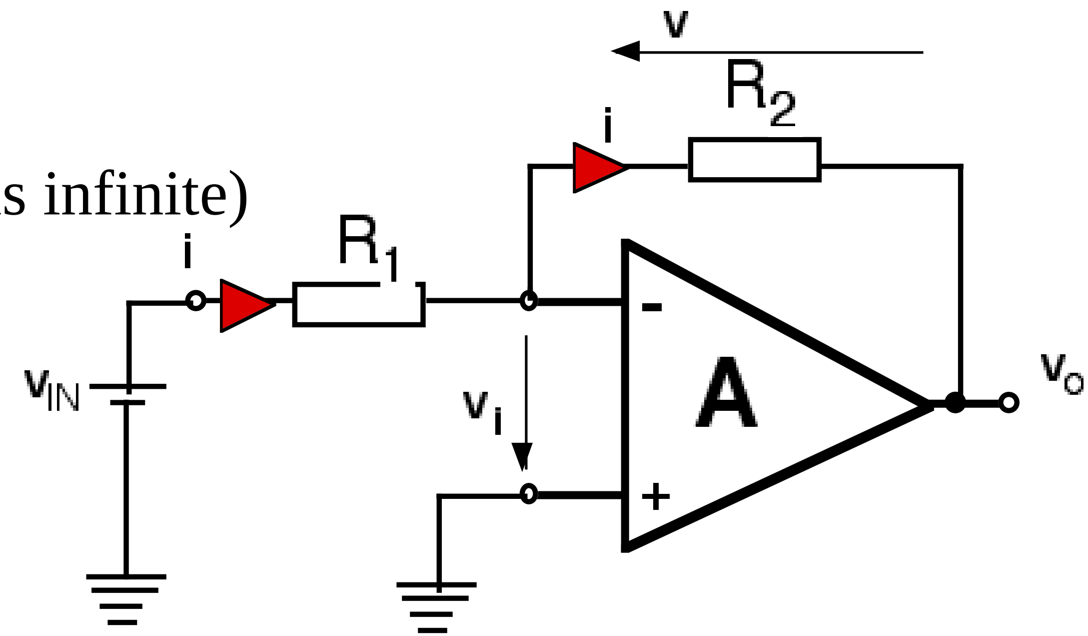
$v_i = 0$ (because A is infinite)

$v = i.R_2$

$v_o = - v$

Hence,

$v_o = - (R_2/R_1).v_{IN}$



Negative feedback ensures operation in the linear region

Where does the current flow after R_2? Into the opamp output.

Two independent properties of the opamp are used in the analysis:
(1) input currents are zero; (2) $v_i = 0$ (because A is very large)

Beware!

- Don’t apply KCL to the simple opamp model
- Be very careful with signs

The Operational Amplifier: Linear operation

Example: an integrator

$v_i = 0$ (because A is infinite)

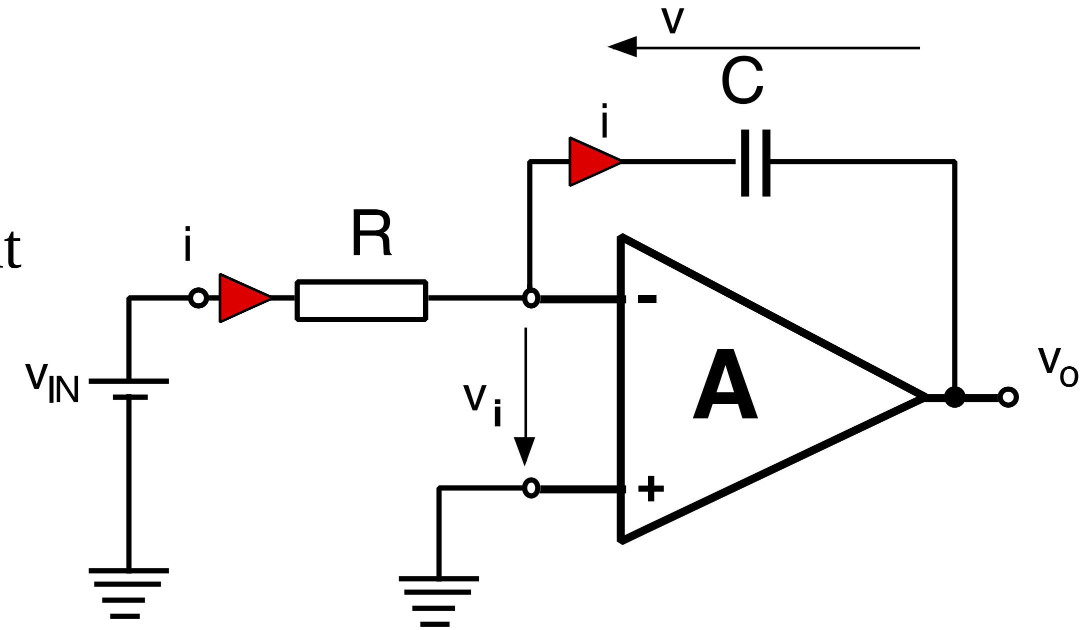
$i = (v_{IN} + v_i)/R$

$v = (1/C)\int i.dt$

$v_o = - v - v_i$

Hence,

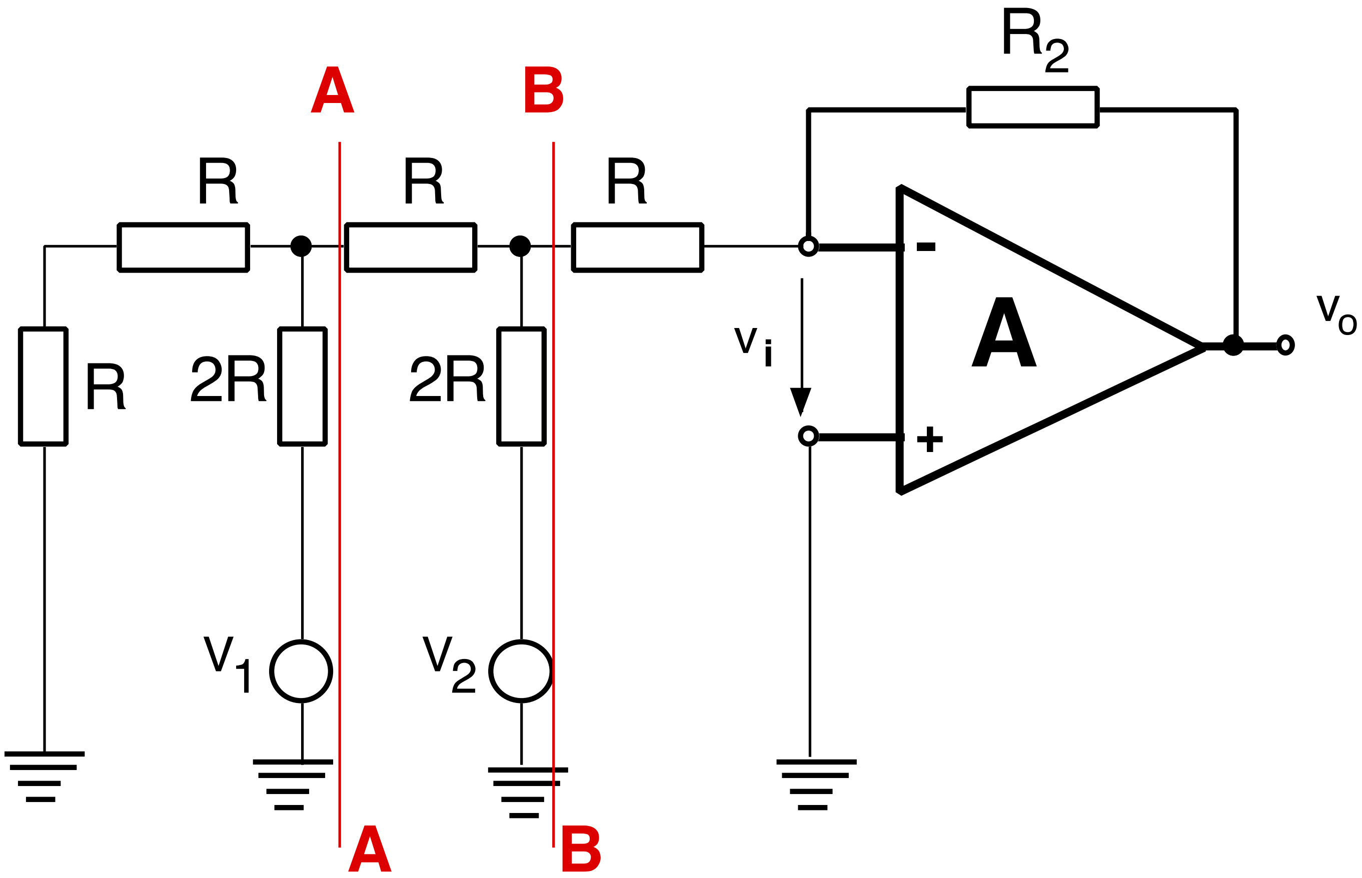
$v_o = - (1/CR)\int v_{IN}.dt$



The Operational Amplifier: Linear operation

Example: D/A converter

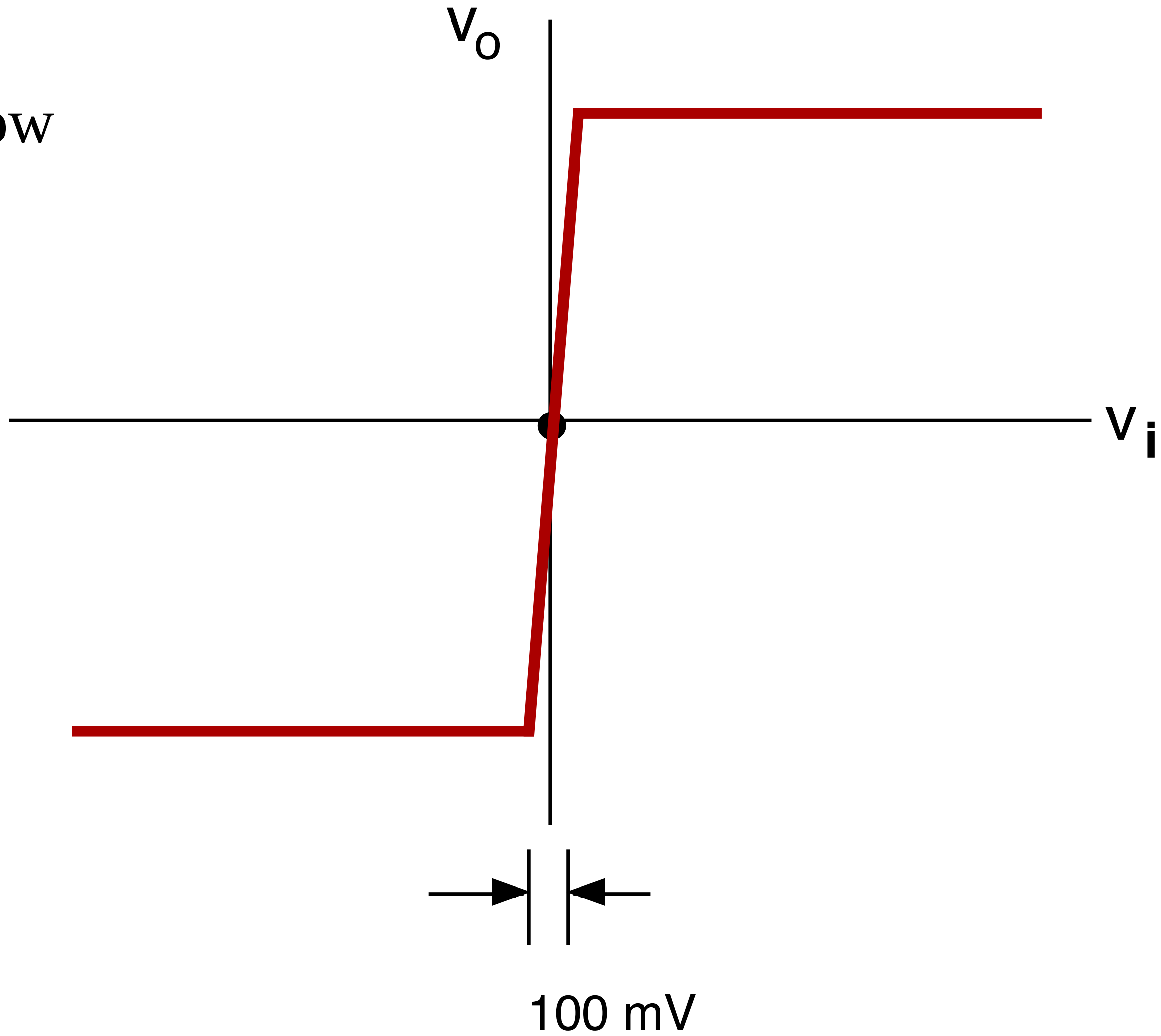
Simple approach: apply Thevenin's Theorem to the left of AA, then to the left of BB, etc, until an inverter circuit (see above) is obtained.



Nonlinear operation

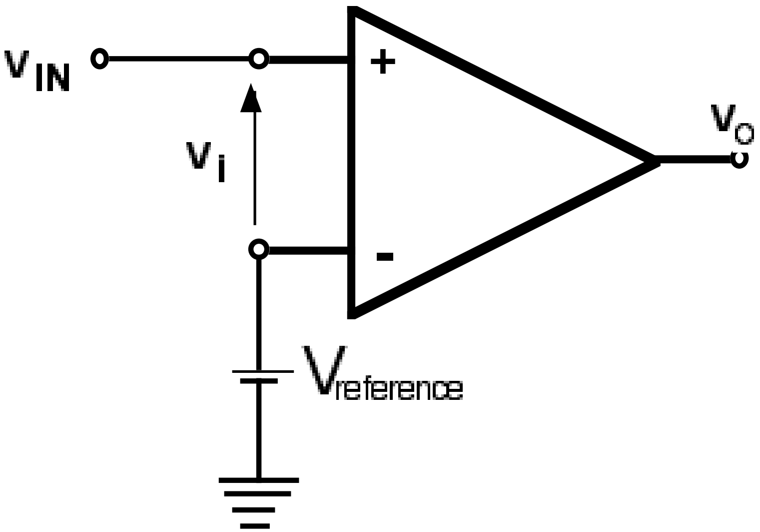
The Operational Amplifier: **Nonlinear** operation

Operation is not now restricted to the central, high slope region

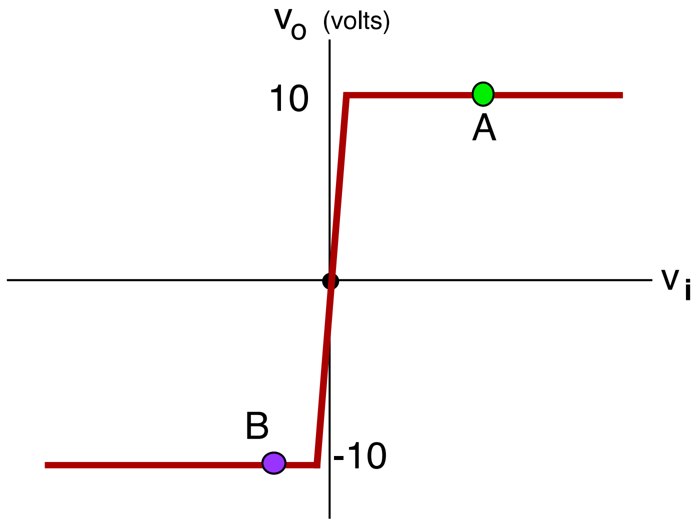


The Operational Amplifier: Nonlinear operation

Example: The Comparator



Assume v_o limits at +10 V and -10 V



When $v_{IN} > v_{reference}$, $v_i > 0$
And hence v_o = 10 V (e.g., point A)

When $v_{IN} < v_{reference}$, $v_i < 0$
And hence v_o = -10 V (e.g., point B)

The nonlinear operation may arise as a result of positive feedback

The Operational Amplifier: Nonlinear operation

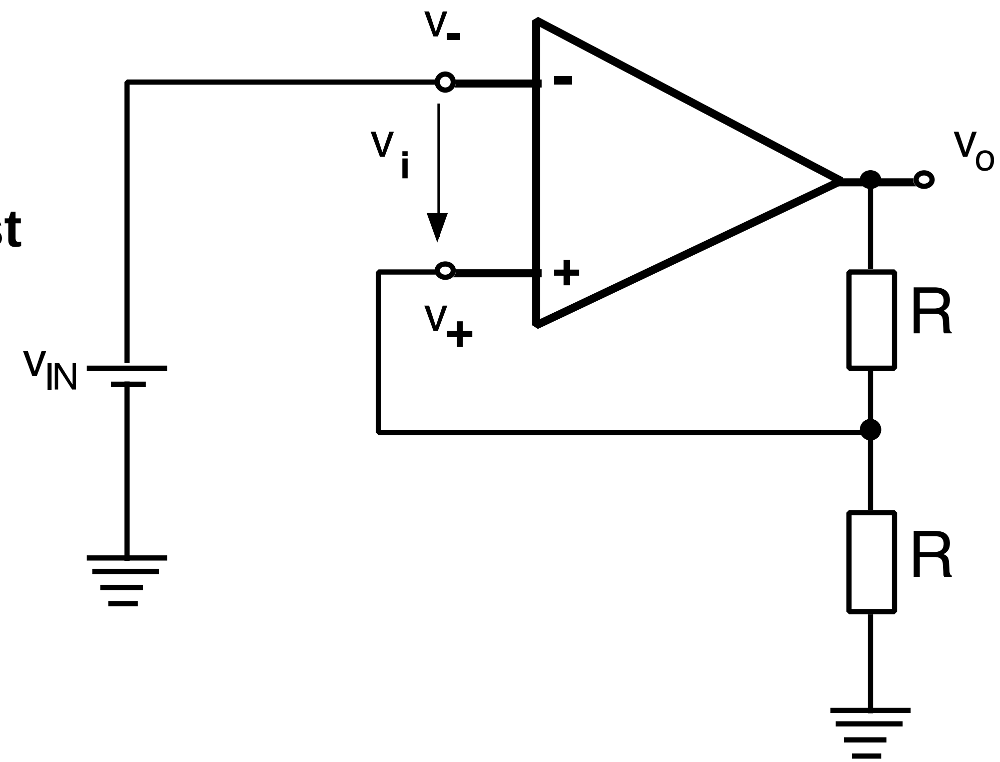
Example: Schmitt Trigger

There are only two possible states of this circuit:

The resistors need not have identical values

NOTE the polarity of v_i

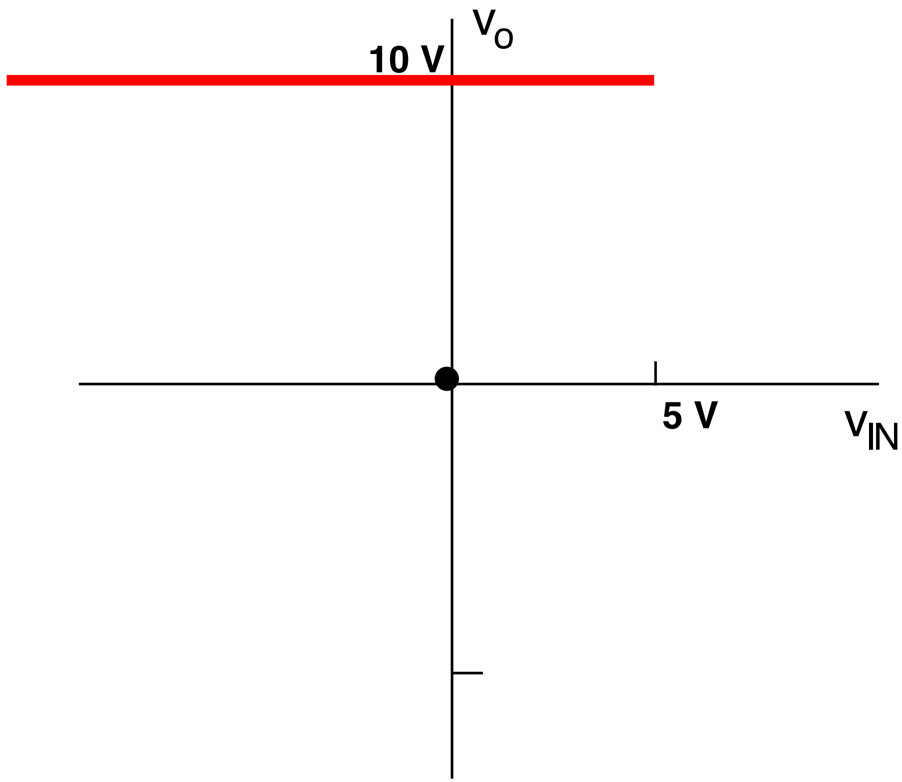
Assume v_o = 10 V
Then v_+ = 5 V
If v_o is positive, then v_i must be positive (see opamp characteristic).
If v_i is positive, v_{IN} < 5V
Thus
If v_o = 10 V, v_{IN} < 5V

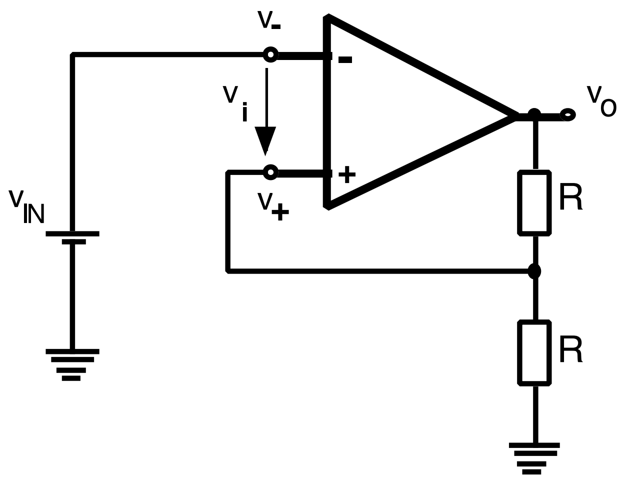


The Operational Amplifier: Nonlinear operation

Example: Schmitt Trigger

If v_O = 10 V, v_{IN} < 5V

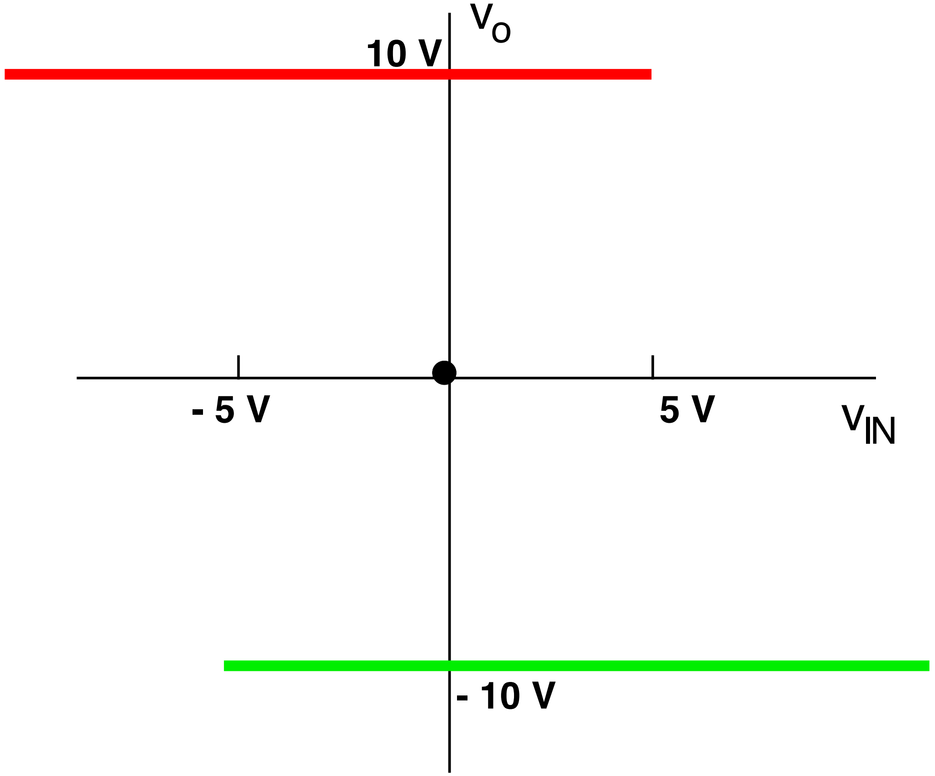


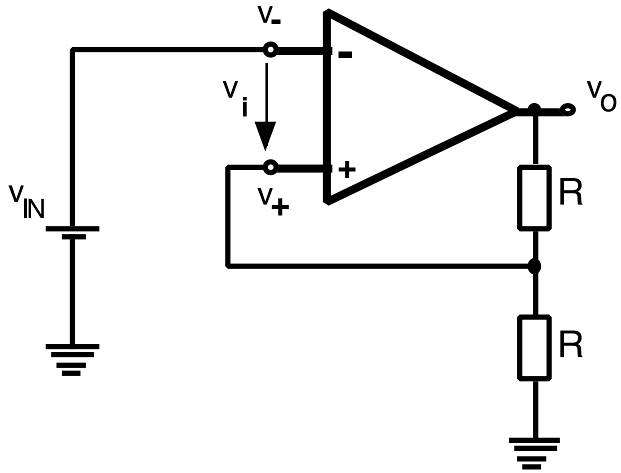


The Operational Amplifier: Nonlinear operation

Example: Schmitt Trigger

By a similar analysis, when $v_O = -10$ V, $v_{IN} > -5$ V (see green plot)

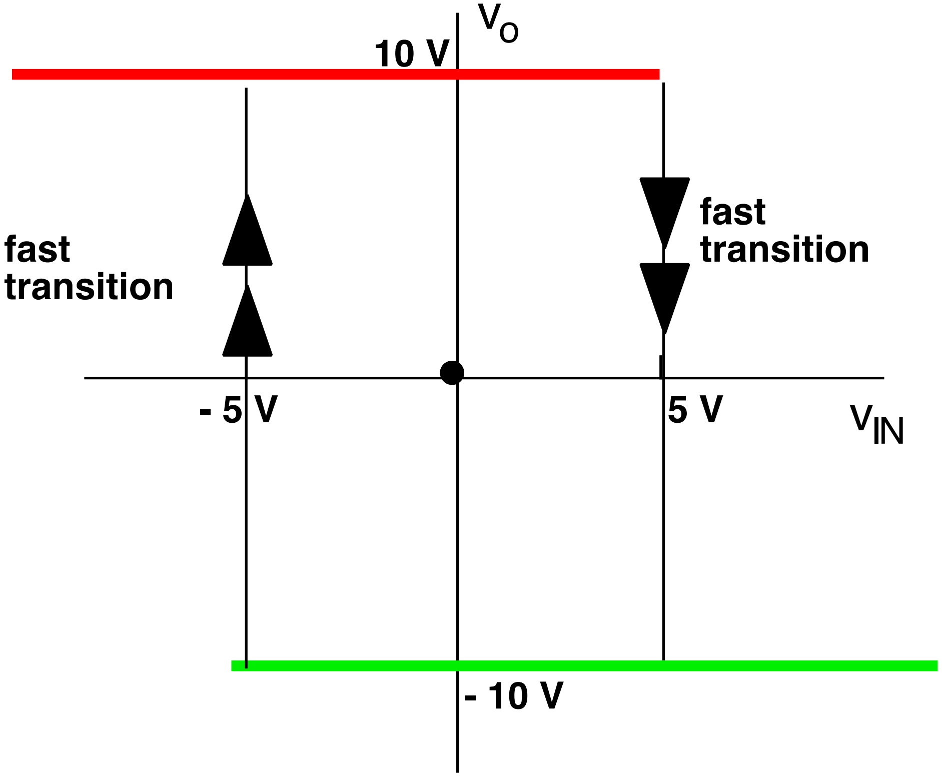


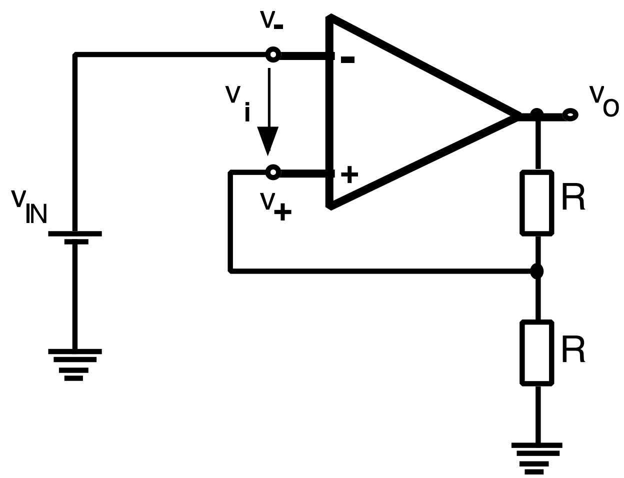


The Operational Amplifier: Nonlinear operation

Example: Schmitt Trigger

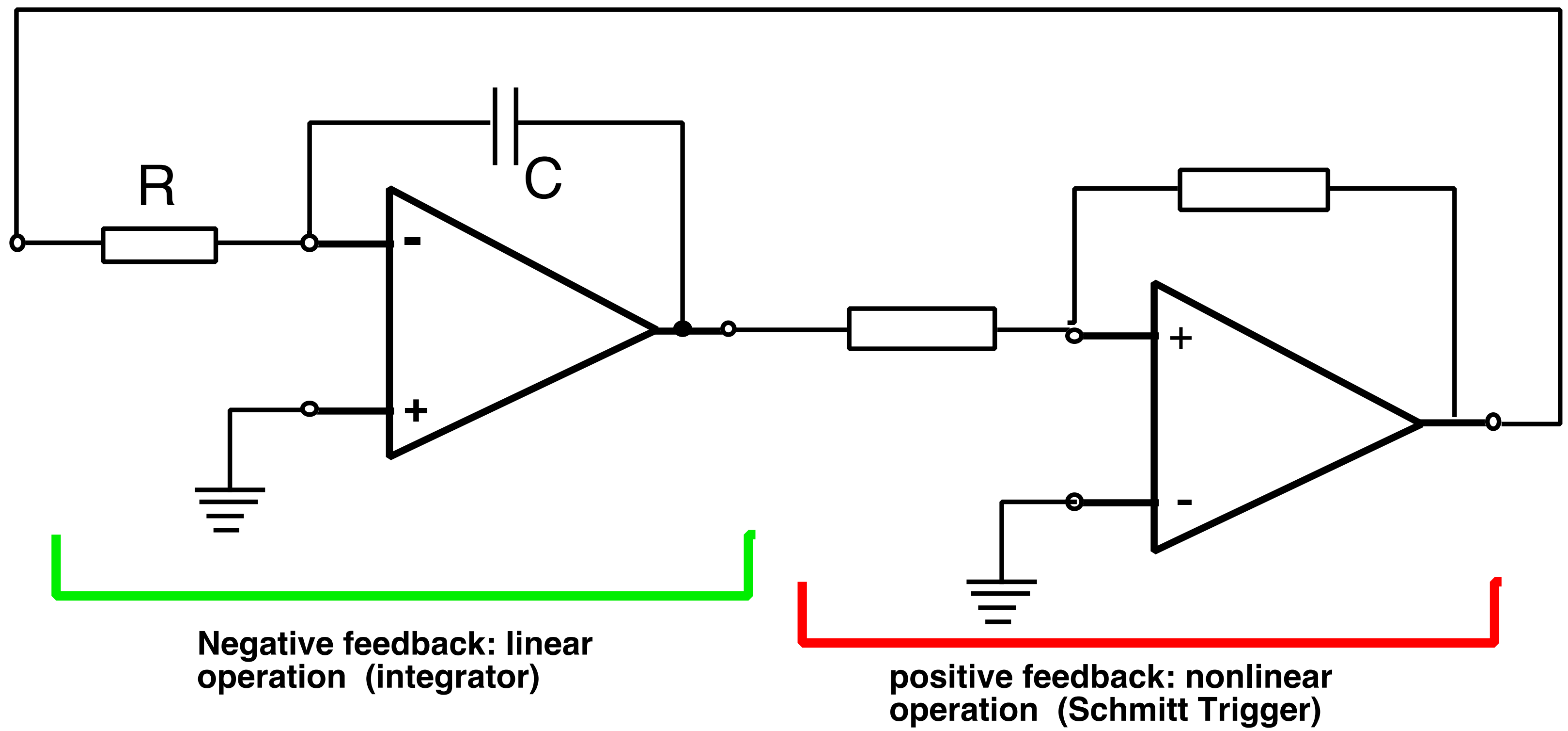
If, when v_O= +10 V (red line), v_{IN} exceeds 5 V, v_i becomes negative and there is a fast transition to a negative v_O, limiting at v_O = -10 V





The Operational Amplifier: Mixed operation

Example: circuit below



Before analysing a circuit such as this one identify, for each opamp, whether it is operating in a linear mode or has two states. Look at the feedback (positive or negative) and try to recognise the circuits and their function