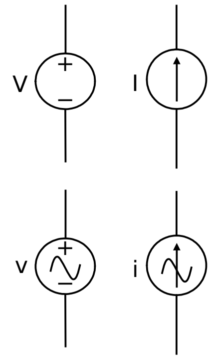
DC versus AC

Classification of Sources

Sources can be broadly classified as:

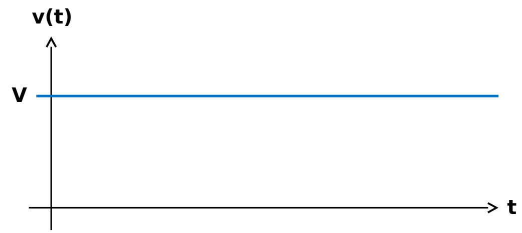
DC : direct current
- current flows in only one direction
- voltages do not change polarity

AC : alternating current
- current changes direction **periodically**
- voltages also periodically change polarity



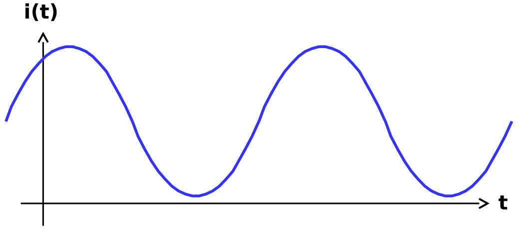
DC versus AC

DC or AC?



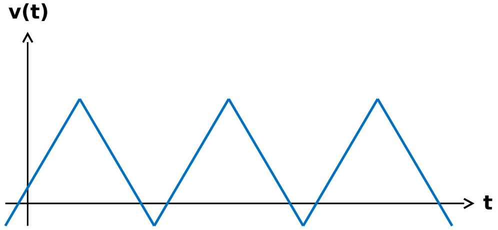
DC

DC or AC?



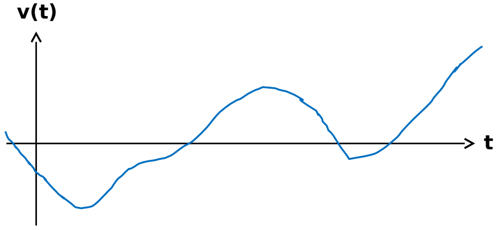
DC
current varies with time but doesn't change direction

DC or AC?



AC
voltage periodically changes polarity even if only momentarily

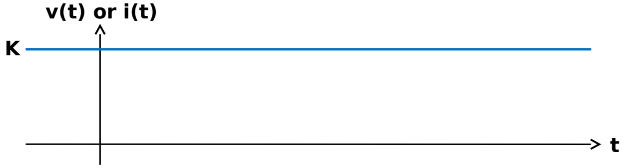
DC or AC?



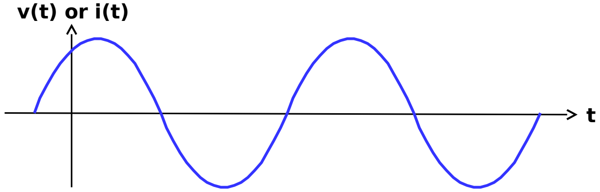
Neither
polarity changes but not periodically

When speaking in general …

DC implied to be time invariant



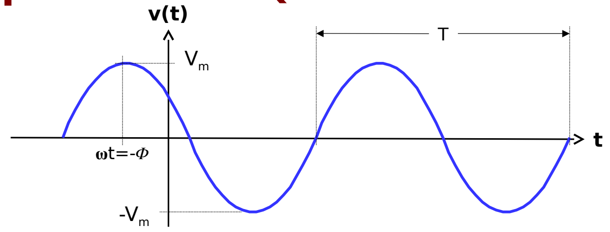
AC implied to be sinusoidal



History

- Late 1880's: "Battle" between proponents of DC and AC as the mode of distribution of electrical energy
  - Thomas Edison - main proponent of DC
  - Nikolai Tesla – main proponent of AC
- **DC**
  - easy to predict system behavior
  - transmitting DC over long distances resulted in large losses
- **AC**
  - more difficult to analyze and predict behavior
  - ability to step up and and step down AC voltages using transformers allowed electricity to be transmitted over long distances with less loss
- Tesla's concepts were eventually adopted by Westinghouse and General Electric and AC won over DC
- Presently, there is renewed interest in DC distribution because of advances in power electronics

Important AC Quantities



- AC - implied to be sinusoidal unless otherwise specified
- $v(t) = V_m \cos(\omega t + \Phi)$ volts where
  - V_m - amplitude
  - ω - angular frequency in radians per second
  - $\omega = 2\pi f$ where f is the frequency of the sinusoid in cycles per second or hertz
  - Φ - phase angle of the sinusoid or the angle by which the cosine wave is shifted left
- Household electricity in the Philippines is 60 Hz
  - $\omega \cong 377$ radians per second
  - T = period ≅ 16.67 milliseconds

Example

If electricity travels at the speed of light, what distance will electricity travel over one 60 Hz AC cycle?

Answer: 5,000 km

Effective Value of an AC Voltage

- The effective value of an AC voltage is its "DC equivalent" value. It is the DC voltage that delivers the same average power to a resistor as the AC voltage.
- If P_{ave} is the average power delivered by an AC voltage to a resistor R, its effective value is given by:

$$V_{eff} = \sqrt{(P_{ave})(R)}$$

- It can be shown that for sinusoidal voltages

$$V_{eff} = V_m / \sqrt{2}$$

- Household voltages are specified in terms of effective value. 220 volts is the effective value of the voltage coming out of household sockets in the Philippines.

Effective Value of an AC Current

- Concept of effective value applicable to current
- If P_{ave} is the average power delivered by an AC current to a resistor R, its effective value is given by: $I_{eff} = \sqrt{(P_{ave})/(R)}$
- It can be shown that for sinusoidal currents

$$I_{eff} = I_m / \sqrt{2}$$

Note:
The effective value of a waveform is also referred to as its rms value, i.e., $V_{eff} = V_{rms}$

Example

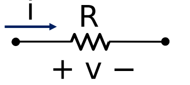
The average power delivered by a sinusoidal current source to a 5Ω resistor is 500 watts. What is the amplitude of the sinusoidal current?

Answer: 14.14 volts

Introduction to Non-Linear Elements

Definitions

A **linear element** is a passive element whose voltage-current relationship is described by a linear equation. Only one linear element is taken up in EEE 31 and that is the resistor where v=iR.

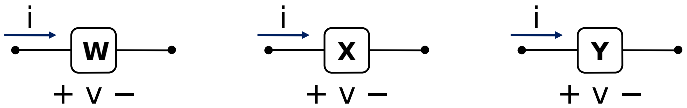


The voltage-current relationship in a **non-linear element** cannot be described by a linear equation. However, it can be described through other means such as:

- characteristic equation
- characteristic curve

Examples

The following are hypothetical non-linear elements described by characteristic equations:

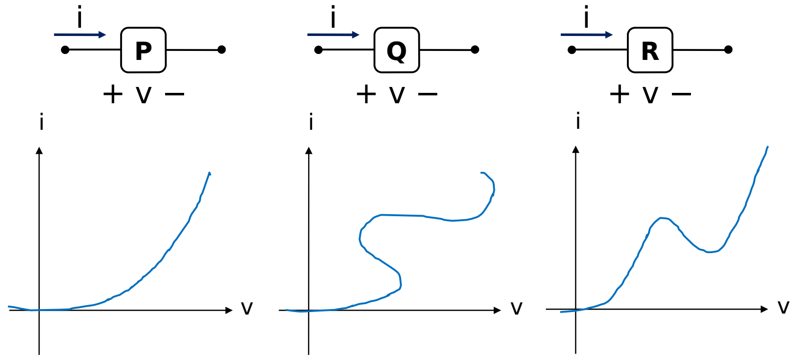


$i = k_1 v^2$ $i = k_2 v^{3/2}$ $i = I_o(e^{v/\eta V_T} - 1)$

Note: k_1, k_2, I_o, η and V_T are constants

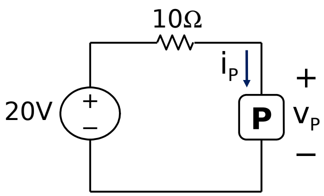
Examples

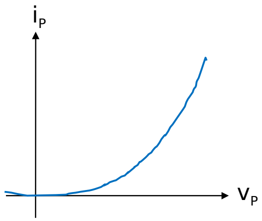
The following are hypothetical non-linear elements described by characteristic curves:



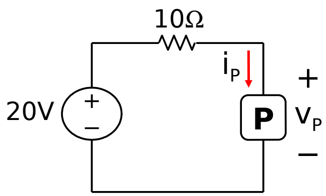
Example

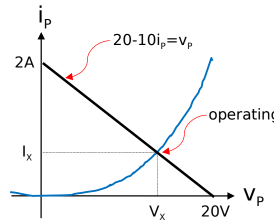
Element P with the characteristic curve shown is connected to a 20V voltage source through a 10Ω resistor as shown in the figure. At what voltage and current will element P be operating?





Solution





For the circuit shown, we can write the equation:

$$20 - 10i_P = v_P$$

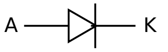
This is the equation of a straight line which can be plotted on top of the characteristic curve of the element P. The operating point of element P is where the 2 curves intersect. Thus, the voltage and current at which element P operates will be V_x and I_x correspondingly as shown in the graph.

Introduction to Diodes

Diode

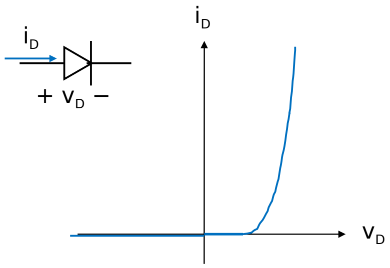
A **diode** is a non-linear passive element whose behavior depends in the way it is **biased**.

Circuit symbol:



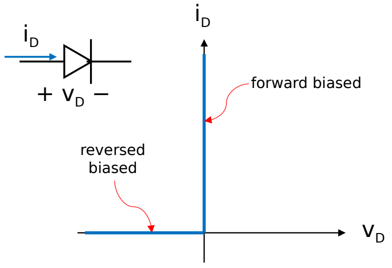
A - anode
K - cathode

Typical diode characteristic curve:



Ideal Diode

Characteristic curve approximated as follows:

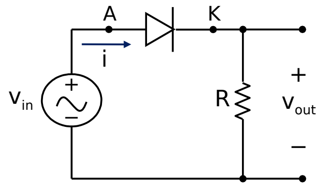


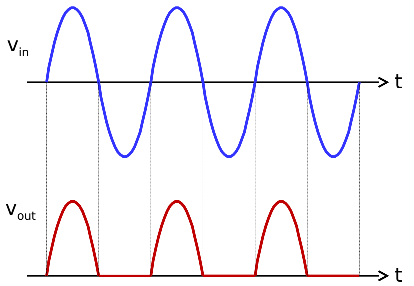
Forward biased – equivalent to a short circuit
Reverse biased – equivalent to an open circuit

Analyzing an Ideal Diode Circuit

1. Remove the diode and get the open circuit voltage across the terminals to which the diode was connected.
2. If the anode is positive with respect to the cathode, the diode is **forward-biased** and can be replaced by a short circuit.
3. If the anode is negative with respect to the cathode, the diode is **reverse-biased** and can be replaced by an open circuit.

Example: Half-Wave Rectifier





During positive half cycles:

- open circuit voltage across the diode terminals makes A positive wrt K
- diode is forward-biased and equivalent to a short circuit
- thus, $v_{out} = v_{in}$

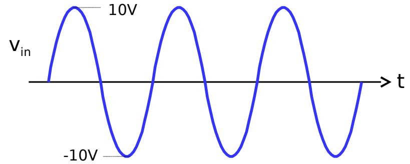
During negative half cycles:

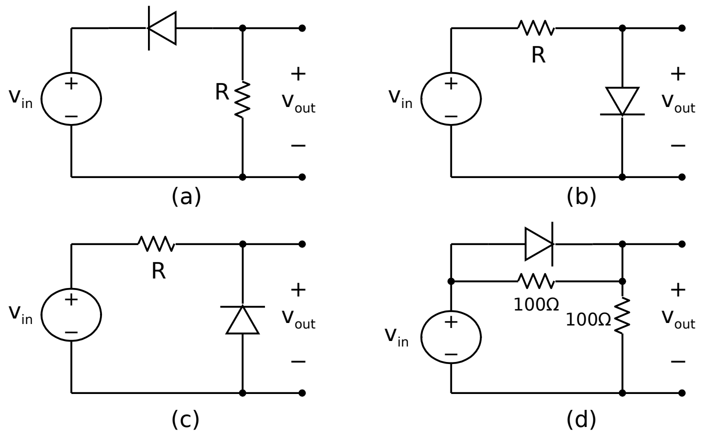
- open circuit voltage across the diode terminals makes A negative wrt K
- diode is reverse-biased and equivalent to an open circuit
- i=0 thus v_{out}=0

Note: A **RECTIFIER** is a circuit that converts AC to DC.

Exercises:

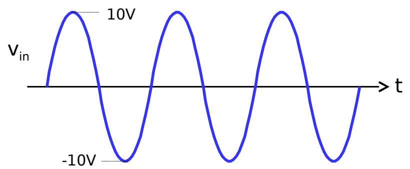
For the input voltage shown, determine the output voltage for each of the circuits shown below:

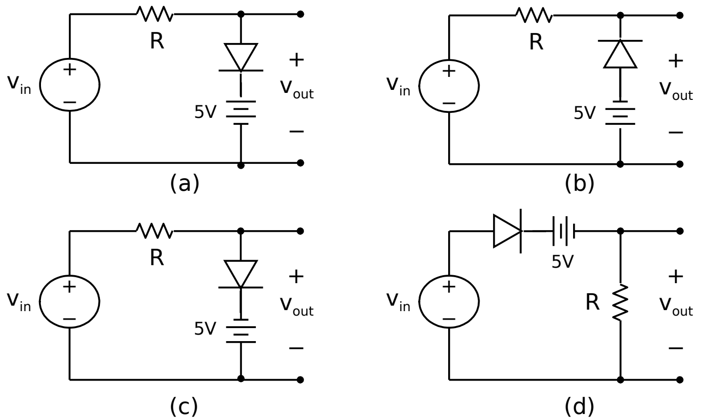




Exercises:

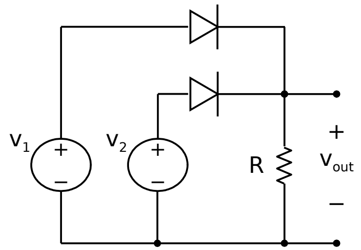
For the input voltage shown, determine the output voltage for each of the circuits shown below:





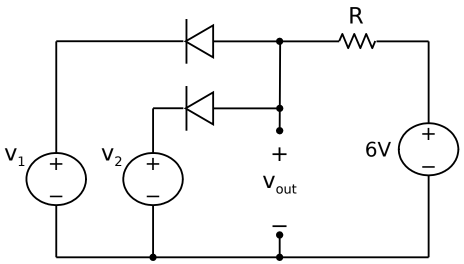
Diode Logic Gates

2-Input OR Gate



v_1	v_2	v_{out}
0 V	0 V	
0 V	5 V	
5 V	0 V	
5 V	5 V	

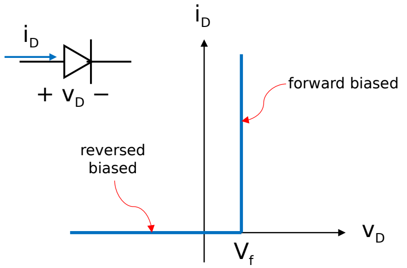
2-Input AND Gate



v_1	v_2	v_{out}
0 V	0 V	
0 V	5 V	
5 V	0 V	
5 V	5 V	

2nd Approximation of the Diode

Characteristic curve approximated as follows:



Forward biased – equivalent to a DC source whose value is V_f (diode forward voltage)

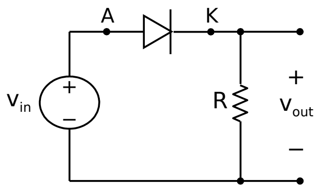
Reverse biased – equivalent to an open circuit

Note: For silicon diodes, $V_f \cong 0.7$ volts

Analyzing a Diode Circuit Using the 2nd Approximation

1. Remove the diode and get the open circuit voltage across the terminals to which the diode was connected.
2. If the open circuit voltage from A to K is greater than or equal to V_f, the diode is forward-biased and can be replaced by a voltage source V_f.
3. If the open circuit voltage from A to K is less than V_f, the diode is reverse-biased and can be replaced by an open circuit.

Example: Half-Wave Rectifier



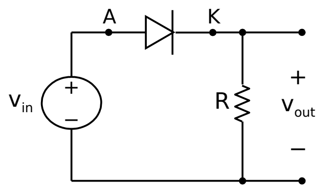
Diode is forward-biased when open circuit voltage from A to K is greater than or equal to V_f

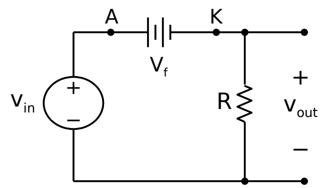
- this happens when $v_{in} \geqq V_f$
- diode can be replaced by voltage source V_f
- thus, $v_{out} = v_{in} - V_f$

Diode is reverse-biased when open circuit voltage from A to K is less than V_f

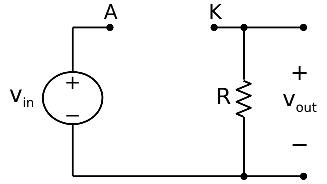
- this happens when $v_{in} < V_f$
- diode can be replaced by an open circuit
- thus, i=0 and $v_{out}=0$

Half-Wave Rectifier Equivalent Circuits





Equivalent circuit when $v_{in} \geqq V_f$



Equivalent circuit when $v_{in} < V_f$

Half-Wave Rectifier Output Using 2nd Approximation