Lecture 1: Ideal Diode

Up to this point in your career as an ECE student, you've been studying **linear** electrical components. For example, resistors (R), inductors (L), and capacitors (C) are ideally linear elements (and passive, of course).

Linear Circuit Elements

What do we mean that a component is "linear"? To answer this question, recall there are just two independent qualities of electricity in electrical circuits. These are voltage and current.

A linear circuit element is one that linearly relates the voltage across that element to the current through the element.

Linearity has a precise mathematical statement. If a quantity y is a function of another quantity x, as

$$y = f(x) \tag{1}$$

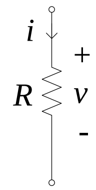
Then y is linearly dependent on x if

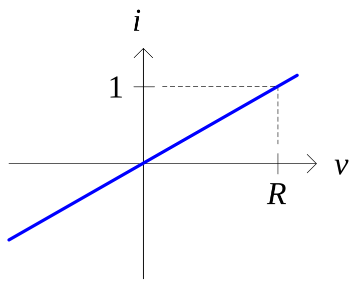
$$my = f(mx) \tag{2}$$

where m is a constant. In other words, f is a linear function if when quantity x is multiplied by some constant m results in the function simply being multiplied by m.

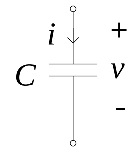
Here are a couple of examples of linear components in electrical circuits:

- Resistors: $v = Ri$.





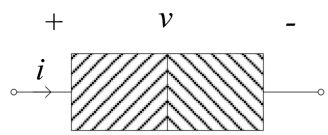
- Capacitors: $i = C\dfrac{dv}{dt}$.



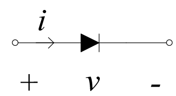
This is perhaps a bit tricker, but notice that differentiation is a linear operator: if *v* increases by a factor *m* then *i* does as well.

Ideal Diodes

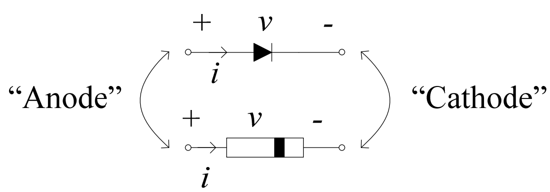
You will now learn about a new electrical circuit element, the diode. Diodes are made from two different types of semiconducting materials that come together to form a "junction":



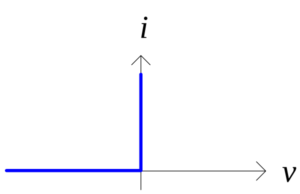
The circuit symbol is



which is related to the physical markings on a typical diode as



In stark contrast to resistors, inductors, and capacitors, the diode is a nonlinear element. For an **ideal diode**, the *i*-*v* characteristic curve is



It is apparent from this *i*-*v* characteristic curve that there are two distinct regions of operation of the ideal diode:

- $v < 0 \Rightarrow i = 0$. In this region, the diode is "off."
- $i > 0 \Rightarrow v = 0$. In this region, the diode is "on."

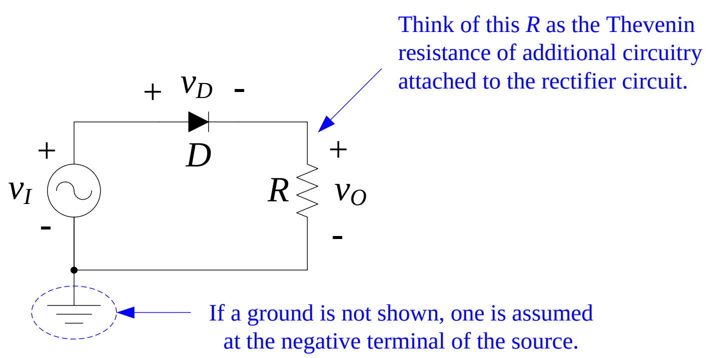
The ideal diode acts as an electronic "valve" allowing current in only one direction through the diode: in the direction of the arrow in the circuit symbol.

We will find this "valve" behavior very useful in some situations. For example, this is useful to prevent damage to an electronic device when the battery is inserted backwards, for example.

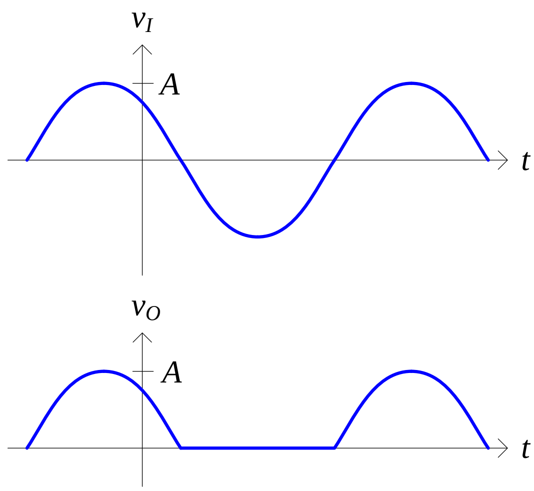
Applications of Diodes

Now we will briefly consider a couple of applications for diodes. We'll cover these in much more detail later.

- <u>Signal rectifier</u>.



When $v_I > 0$, current will flow into the anode of *D* and forward bias this device. With the ideal diode now "on," v_D is very small and $v_O \approx v_I$:

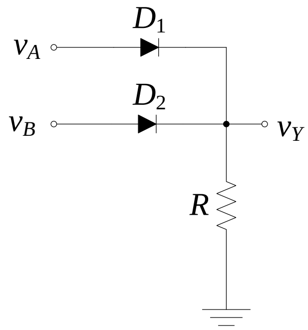


Conversely, when $v_I < 0$, the ideal diode is “off” and there is no current through *R*. Therefore, $v_O = 0$.

We have “rectified” the input voltage with this circuit.

This process of rectification will work for any type of input signal, whether it is periodic (as shown above) or not.

- Digital logic gate. Diodes and resistors together can be used to make rudimentary logic gates. For example:



Assuming the voltages are 0 V for “low” signals and 5 V for the “high” signals, then the circuit shown above is a two-input OR gate:

- If $v_A = 5$ V and $v_B = 0$ or 5 V, then $v_Y = 5$ V.
- If $v_B = 5$ V and $v_A = 0$ or 5 V, then $v_Y = 5$ V.

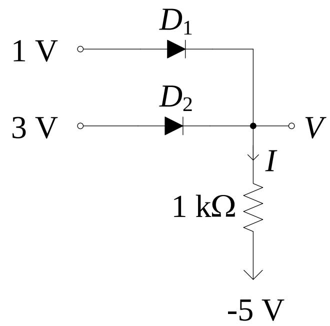
for ideal diodes. This is an OR function Y=A+B.

Why do we have the resistor in this circuit? It’s a “clamp down” resistor and forces the voltage $v_Y = 0$ when $v_A = v_B = 0$. (What if there was no R? Wouldn’t the voltage be zero in this case as well?)

One huge complication of diodes (or any nonlinear circuit element) in an electrical circuit is the use of superposition in the analysis is disallowed! (The exception to this is if the analysis has been linearized for only small amplitude signals. We’ll see this linearization throughout the course.)

Consequently, nonlinear circuit analysis is usually much more complicated than linear circuit analysis. One often needs numerical analysis for solution, such as that provided by circuit simulation software.

Example N1.1 Determine the voltage V and current I in the circuit below.



This is a nonlinear circuit, so a **completely different analysis procedure is required** than what you've used in the past for linear circuits.

One process you can use to solve this problem is to try (i.e. guess) different on/off combinations for the diodes D_1 and D_2 until you achieve a physically plausible and self consistent solution.

For example, if D_1 is "on" and D_2 is "on," then V = 1 V and 3 V. It is simply impossible to have two different voltages simultaneously at a node. Voltages must be single valued at all nodes. We conclude that D_1 and D_2 cannot both be "on" simultaneously.

Next, we try D_1 "off" and D_2 "on." This leads to

$$V = 3 \text{ V and } I = 8 \text{ mA.}$$

This result is physically realistic and self consistent since with V = 3 V then the voltage drop across D_1 requires that it be "off," which is what we have assumed.