EE101: Diode circuits

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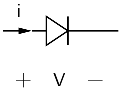
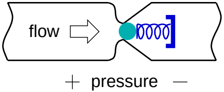
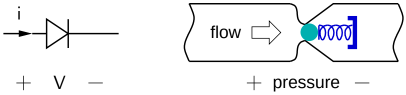
Diodes







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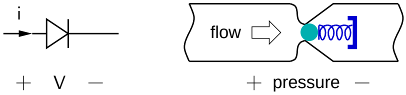
Diodes



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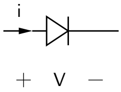

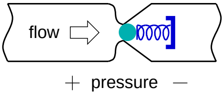

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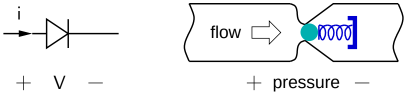

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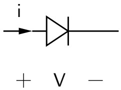

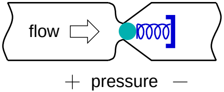

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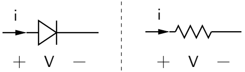
* In the forward direction, the diode resistance $R_D = V/i$ would be a function of V. However, it is often a good approximation to treat it as a constant (small) resistance.
* In the reverse direction, the diode resistance is much larger and may often be treated as infinite (i.e., the diode may be replaced by an open circuit).

Simple models: R_{on}/R_{off} model



$R = R_{on}$ if $V > 0$

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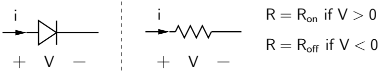

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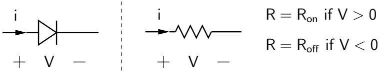

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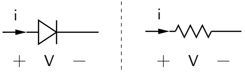

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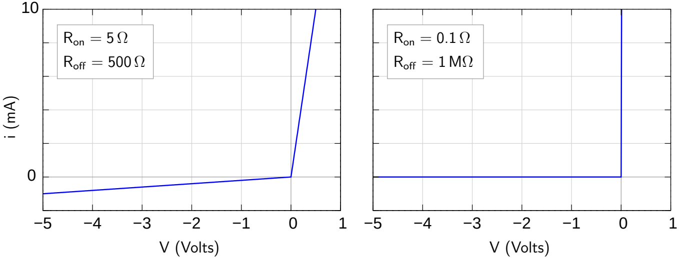
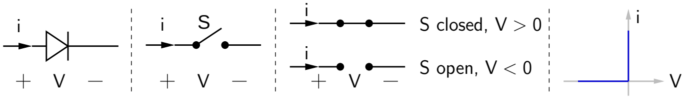
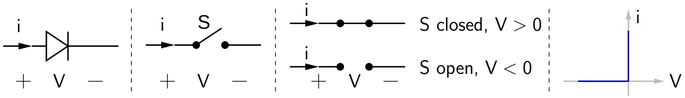


Simple models: ideal switch





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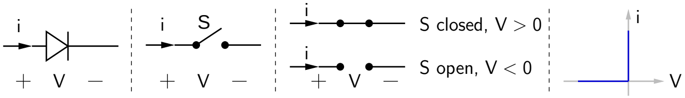

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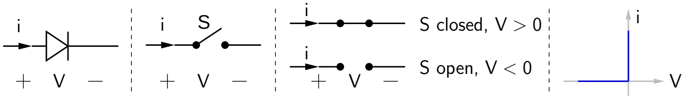

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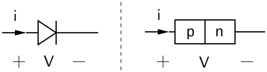
* The actual values of V and i for a diode in a circuit get determined by the i-V relationship of the diode *and* the constraints on V and i imposed by the circuit.

Shockley diode equation



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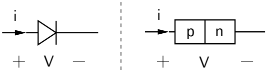

$$i = I_s \left[\exp\left(\frac{V}{V_T} \right) - 1 \right], \text{ where } V_T = k_B T/q\,.$$

k_B = Boltzmann's constant = 1.38×10^{-23} J/K.

q = electron charge = 1.602×10^{-19} Coul.

T = temperature in $^\circ K$.

$V_T \approx 25$ mV at room temperature (27 °C).

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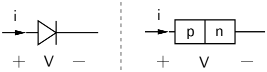

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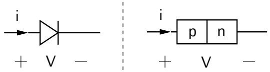

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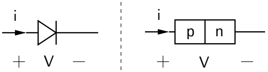

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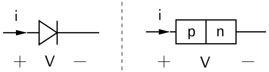

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* Although I_s is very small, it gets multiplied by a large exponential factor, giving a diode current of several mA for $V \approx 0.7\ V$.
* The "turn-on" voltage ($V_{\rm on}$) of a diode depends on the value of I_s. $V_{\rm on}$ may be defined as the voltage at which the diode starts carrying a substantial forward current (say, a few mA).
  For a silicon diode, $V_{\rm on} \approx 0.7\ V$.
  For a GaAs diode, $V_{\rm on} \approx 1.1\ V$.

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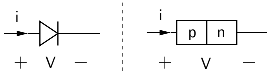

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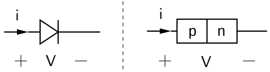

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V	$x = V/V_T$	e^x	i (Amp)
0.1	3.87	0.479×10^{2}	0.469×10^{-11}
0.2	7.74	0.229×10^{4}	0.229×10^{-9}
0.3	11.6	0.110×10^{6}	0.110×10^{-7}
0.4	15.5	0.525×10^{7}	0.525×10^{-6}
0.5	19.3	0.251×10^{9}	0.251×10^{-4}
0.6	23.2	0.120×10^{11}	0.120×10^{-2}
0.62	24.0	0.260×10^{11}	0.260×10^{-2}
0.64	24.8	0.565×10^{11}	0.565×10^{-2}
0.66	25.5	0.122×10^{12}	0.122×10^{-1}
0.68	26.3	0.265×10^{12}	0.265×10^{-1}
0.70	27.1	0.575×10^{12}	0.575×10^{-1}
0.72	27.8	0.125×10^{13}	0.125

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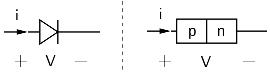

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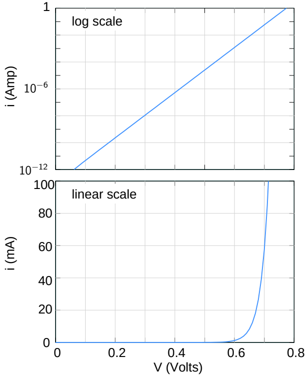
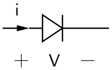
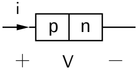


Shockley equation and simple models





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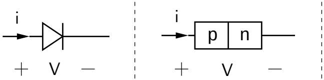

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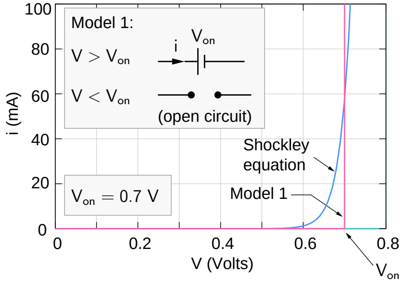

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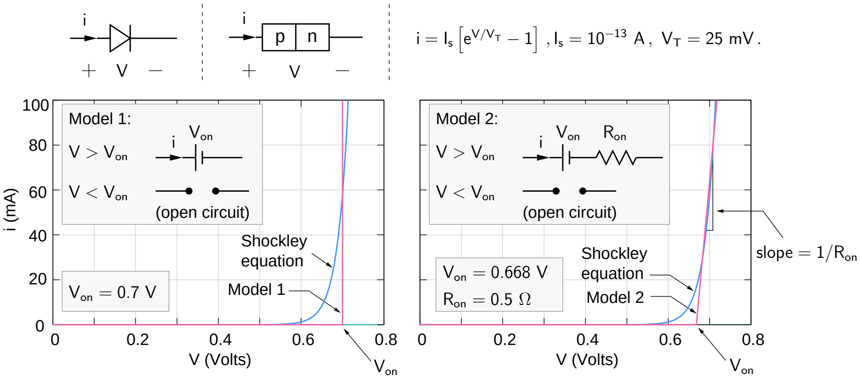

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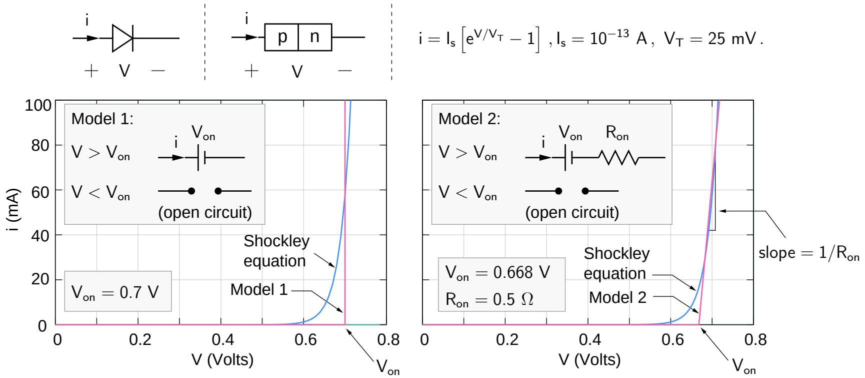

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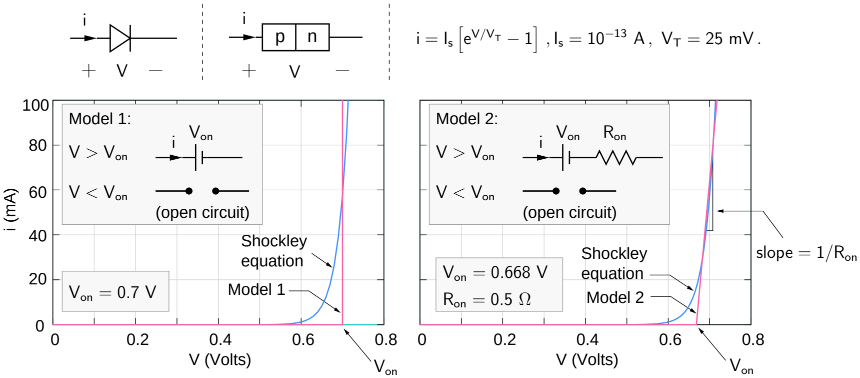

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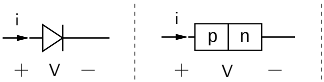

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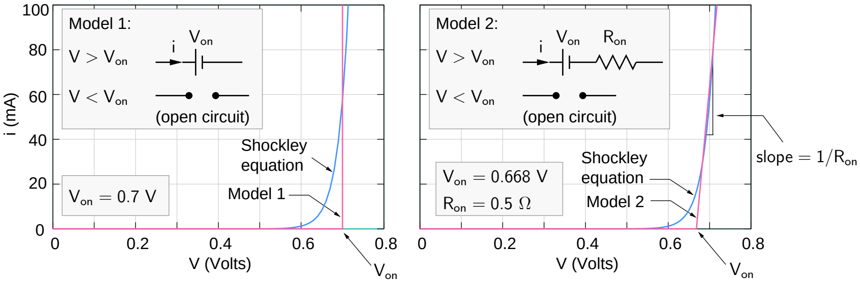

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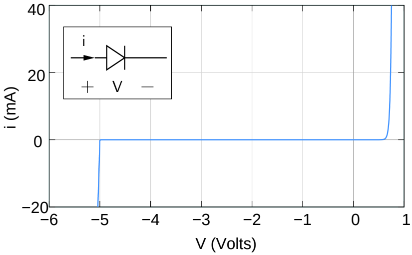
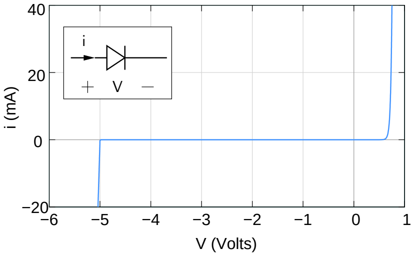
* Note that the “battery” shown in the above models is not a “source” of power! It can only absorb power (see the direction of the current), causing heat dissipation.

Reverse breakdown





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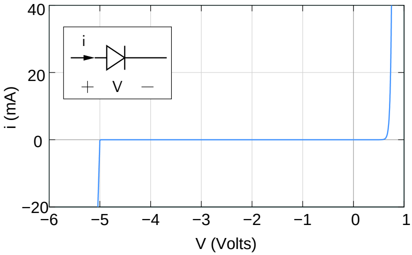

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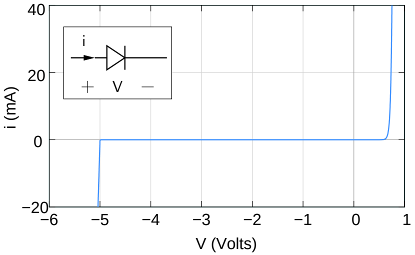

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* When the reverse bias $V_R > V_{BR}$, the diode allows a large amount of current. If the current is not constrained by the external circuit, the diode would get damaged.

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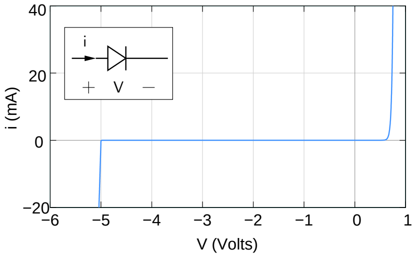
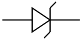
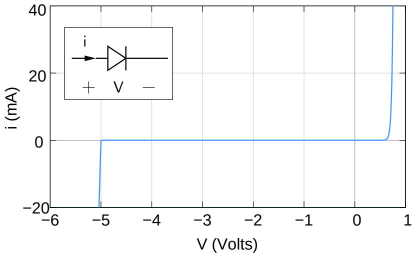
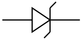




Symbol for a Zener diode





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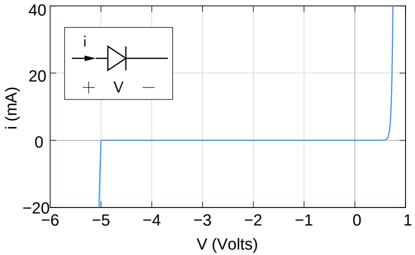

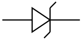

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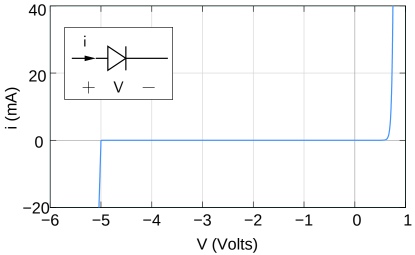
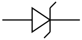
Reverse breakdown





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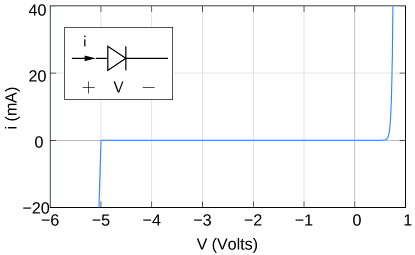

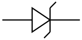

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* "Zener" diodes typically have V_{BR} of a few Volts, which is denoted by V_Z. They are often used to limit the voltage swing in electronic circuits.

Diode types

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* **Light-emitting diodes (LEDs)** emit light when a forward bias is applied. Typically, LEDs are made of III-V semiconductors.

  An LED emits light of a specific wavelength (e.g., red, green, yellow, blue).

  White LEDs combine individual LEDs that emit the three primary colors (red, green, blue) or use a phosphor material to convert monochromatic light from a blue or UV LED to broad-spectrum white light.

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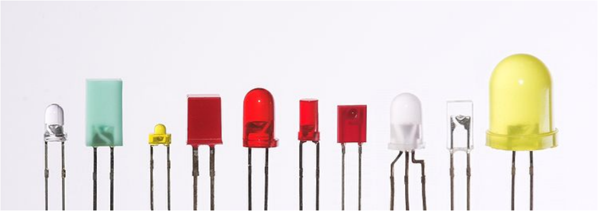

(source: wikipedia)

* **Solar cells** are generally silicon diodes designed to generate current efficiently when solar radiation is incident on the device. A "solar panel" has a large number of individual solar cells connected in series/parallel configuration.

  A solar cell can be modelled as a diode in parallel with a current source (representing the photocurrent). In addition, parasitic series and shunt resistances need to be considered.

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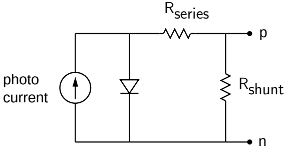

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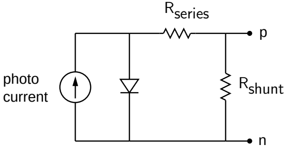

* **Photodiodes** are used to detect optical signals (DC or time-varying) and to convert them into electrical signals which can be subsequently processed by electronic circuits. They are used in fibre-optic communication systems, image processing, etc.

  A photodiode works on the same principle as a solar cell, i.e., it converts light into a current. However, its design is optimized for high-sensitivity, low-noise, or high-frequency operation, depending on the application.

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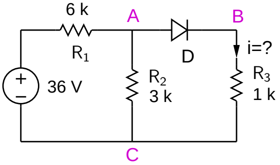
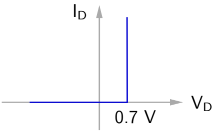
* Note that there are diode circuits in which the exponential nature of the diode I-V relationship is made use of. For these circuits, computer simulation would be required to solve the resulting non-linear equations.

Diode circuit example





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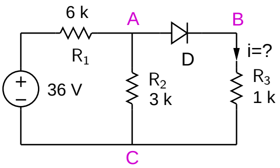
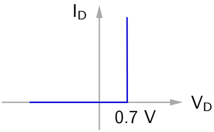
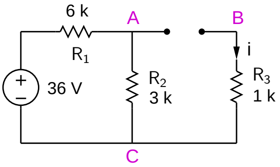
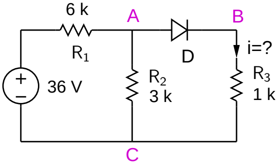
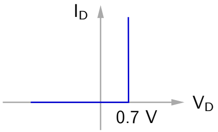




Case 1: D is off.







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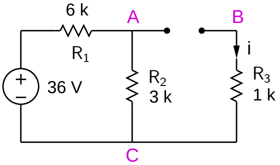

$$V_{AB} = V_{AC} = \frac{3}{9} \times 36 = 12\ \text{V},$$

which is not consistent with our assumption of D being off.

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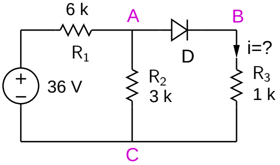

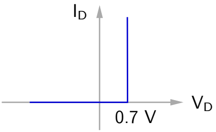

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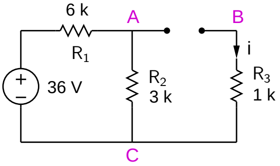

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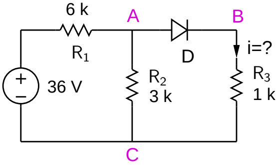

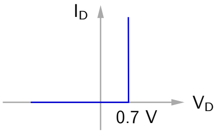

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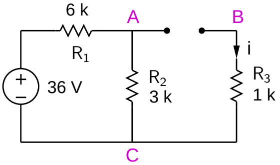

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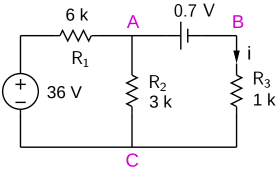

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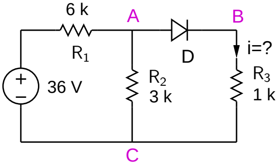

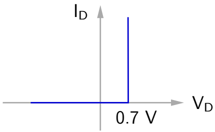

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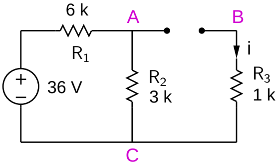

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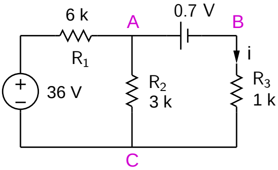

Taking $V_C = 0$ V,

$$\frac{V_A - 36}{6\text{ k}} + \frac{V_A}{3\text{ k}} + \frac{V_A - 0.7}{1\text{ k}} = 0,$$

$\rightarrow \; V_A = 4.47$ V, $i = 3.77$ mA.

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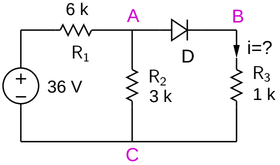

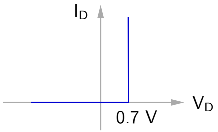

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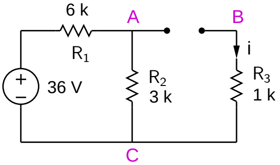

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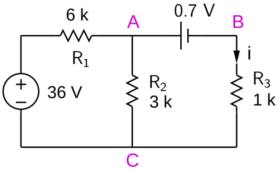

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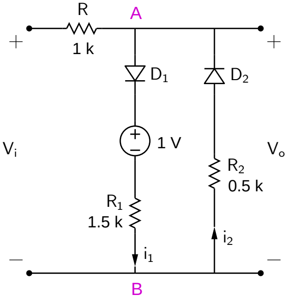
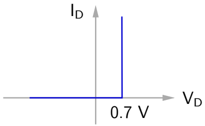
Remark: Often, we can figure out by inspection if a diode is on or off.

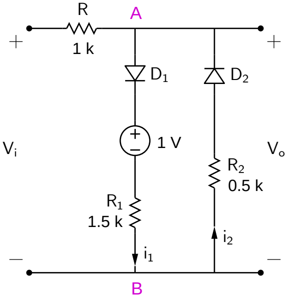


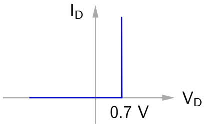


(a) Plot V_o versus V_i for -5 V $< V_i < 5$ V.

(b) Plot $V_o(t)$ for a triangular input:
-5 V to $+5$ V, 500 Hz.

Diode circuit example





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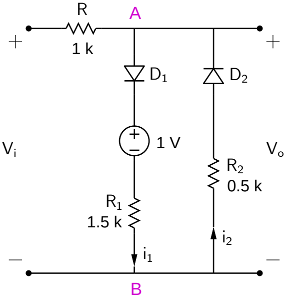

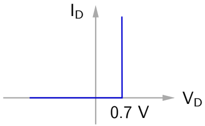

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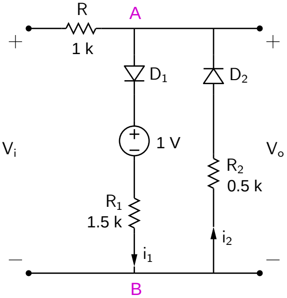
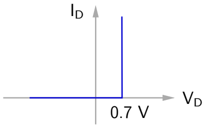
Consider D_1 to be on $\rightarrow$ $V_{AB} = 0.7 + 1 + i_1 R_1$.





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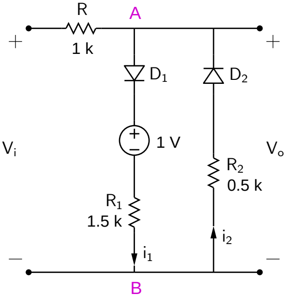
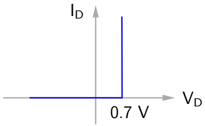
Note that $i_1 > 0$, since D_1 can only conduct in the forward direction.

$\Rightarrow V_{AB} > 1.7\ V \Rightarrow D_2$ cannot conduct.

Diode circuit example





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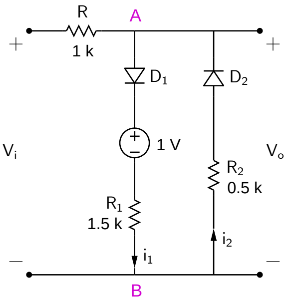

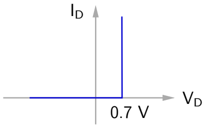

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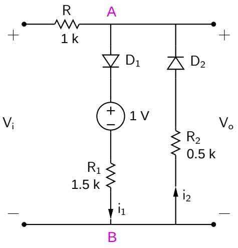
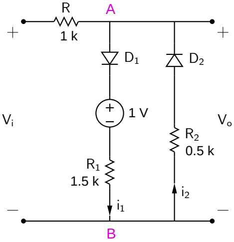
Clearly, D_1 on $\Rightarrow$ D_2 off, and D_2 on $\Rightarrow$ D_1 off.

* For $-0.7\ V < V_i < 1.7\ V$, both D_1 and D_2 are off.
  $\longrightarrow$ no drop across R, and $V_o = V_i$. (1)



Diode circuit example (continued)

* For $-0.7\ V < V_i < 1.7\ V$, both D_1 and D_2 are off.
  $\rightarrow$ no drop across R, and $V_o = V_i$. (1)
* For $V_i < -0.7\ V$, D_2 conducts. $\rightarrow V_o = -0.7 - i_2 R_2$.
  Use KVL to get i_2: $V_i + i_2 R_2 + 0.7 + R i_2 = 0$.
  $\rightarrow i_2 = -\dfrac{V_i + 0.7}{R + R_2}$, and
  $$V_o = -0.7 - R_2 i_2 = \frac{R_2}{R + R_2} V_i - 0.7 \frac{R}{R + R_2} . \qquad (2)$$



Diode circuit example (continued)

* For $-0.7\ V < V_i < 1.7\ V$, both D_1 and D_2 are off.
  $\rightarrow$ no drop across R, and $V_o = V_i$. (1)

* For $V_i < -0.7\ V$, D_2 conducts. $\rightarrow V_o = -0.7 - i_2 R_2$.
  Use KVL to get i_2: $V_i + i_2 R_2 + 0.7 + R i_2 = 0$.

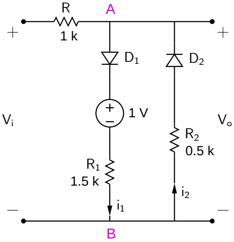
  $\rightarrow i_2 = -\dfrac{V_i + 0.7}{R + R_2}$, and

  $$V_o = -0.7 - R_2 i_2 = \frac{R_2}{R + R_2}\, V_i - 0.7\, \frac{R}{R + R_2} \,. \qquad (2)$$

* For $V_i > 1.7\ V$, D_1 conducts. $\rightarrow V_o = 0.7 + 1 + i_1 R_1$.
  Use KVL to get i_1: $-V_i + i_1 R + 0.7 + 1 + i_1 R_1 = 0$.

  $\rightarrow i_1 = \dfrac{V_i - 1.7}{R + R_1}$, and

  $$V_o = 1.7 + R_1 i_1 = \frac{R_1}{R + R_1}\, V_i + 1.7\, \frac{R}{R + R_1} \,. \qquad (3)$$

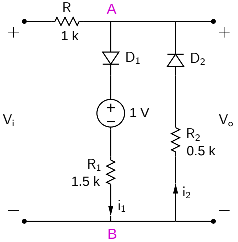


* For $-0.7\ V < V_i < 1.7\ V$, both D_1 and D_2 are off.
  $\rightarrow$ no drop across R, and $V_o = V_i$. (1)

* For $V_i < -0.7\ V$, D_2 conducts. $\rightarrow V_o = -0.7 - i_2 R_2$.
  Use KVL to get i_2: $V_i + i_2 R_2 + 0.7 + R i_2 = 0$.
  $\rightarrow i_2 = -\dfrac{V_i + 0.7}{R + R_2}$, and
  $$V_o = -0.7 - R_2 i_2 = \frac{R_2}{R + R_2} V_i - 0.7 \frac{R}{R + R_2} . \quad (2)$$

* For $V_i > 1.7\ V$, D_1 conducts. $\rightarrow V_o = 0.7 + 1 + i_1 R_1$.
  Use KVL to get i_1: $-V_i + i_1 R + 0.7 + 1 + i_1 R_1 = 0$.
  $\rightarrow i_1 = \dfrac{V_i - 1.7}{R + R_1}$, and
  $$V_o = 1.7 + R_1 i_1 = \frac{R_1}{R + R_1} V_i + 1.7 \frac{R}{R + R_1} . \quad (3)$$

* Using Eqs. (1)-(3), we plot V_o versus V_i.
  (SEQUEL file: `ee101_diode_circuit_1.sqproj`)

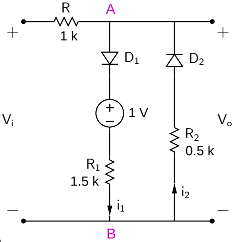


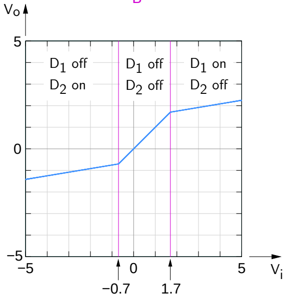
* For $-0.7\ V < V_i < 1.7\ V$, both D_1 and D_2 are off.
  $\rightarrow$ no drop across R, and $V_o = V_i$. (1)

* For $V_i < -0.7\ V$, D_2 conducts. $\rightarrow V_o = -0.7 - i_2 R_2$.
  Use KVL to get i_2: $V_i + i_2 R_2 + 0.7 + R i_2 = 0$.
  $\rightarrow i_2 = -\dfrac{V_i + 0.7}{R + R_2}$, and
  $$V_o = -0.7 - R_2 i_2 = \frac{R_2}{R + R_2}\, V_i - 0.7\, \frac{R}{R + R_2} \,. \qquad (2)$$

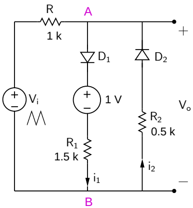
* For $V_i > 1.7\ V$, D_1 conducts. $\rightarrow V_o = 0.7 + 1 + i_1 R_1$.
  Use KVL to get i_1: $-V_i + i_1 R + 0.7 + 1 + i_1 R_1 = 0$.
  $\rightarrow i_1 = \dfrac{V_i - 1.7}{R + R_1}$, and
  $$V_o = 1.7 + R_1 i_1 = \frac{R_1}{R + R_1}\, V_i + 1.7\, \frac{R}{R + R_1} \,. \qquad (3)$$

* Using Eqs. (1)-(3), we plot V_o versus V_i.
  (SEQUEL file: `ee101_diode_circuit_1.sqproj`)



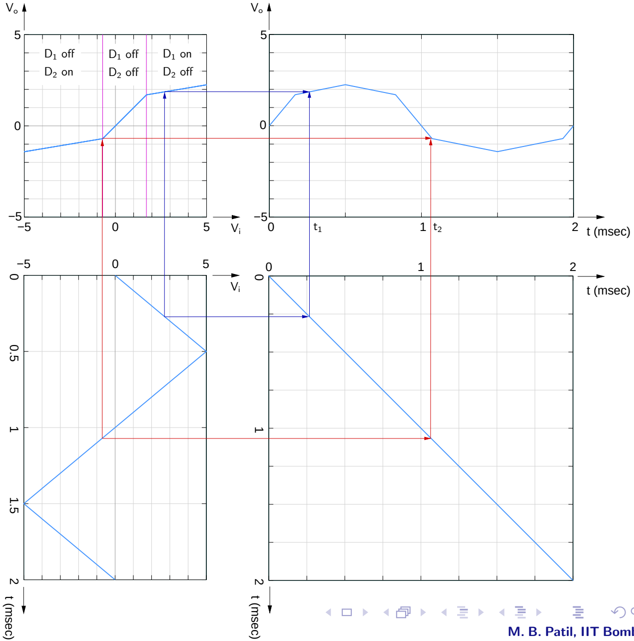


Diode circuit example (continued)

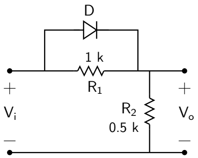


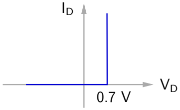
Point-by-point construction of V_o versus t:

Two time points, t_1 and t_2, are shown as examples.



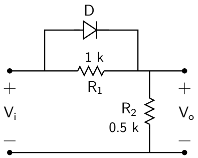
Diode circuit example

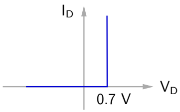




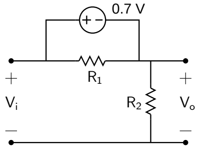
Plot V_o versus V_i for $-5\ \text{V} < V_i < 5\ \text{V}$.

Diode circuit example





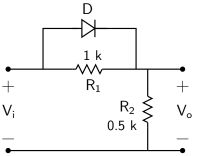
Plot V_o versus V_i for $-5\ V < V_i < 5\ V$.

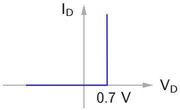


D on

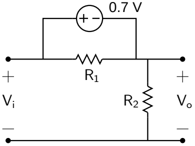
$V_o = V_i - 0.7$

Diode circuit example



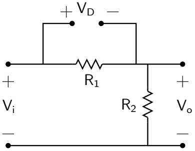


Plot V_o versus V_i for $-5\ V < V_i < 5\ V$.



D on

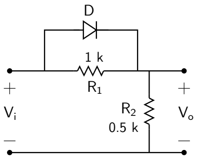
$$V_o = V_i - 0.7$$

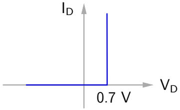


D off

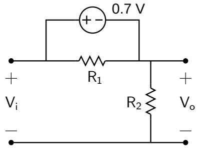
$$V_o = \frac{R_2}{R_1 + R_2} V_i$$

Diode circuit example



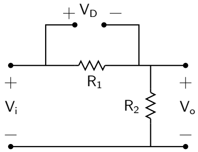


Plot V_o versus V_i for $-5\ \text{V} < V_i < 5\ \text{V}$.



D on

$V_o = V_i - 0.7$

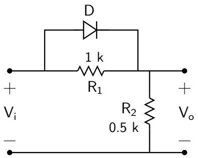


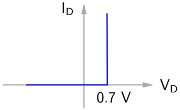
D off

$$V_o = \frac{R_2}{R_1 + R_2} V_i$$

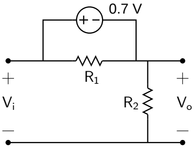
At what value of V_i will the diode turn on?

Diode circuit example



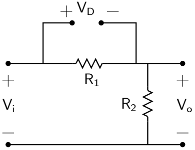


Plot V_o versus V_i for -5 V $< V_i < 5$ V .



D on

$V_o = V_i - 0.7$



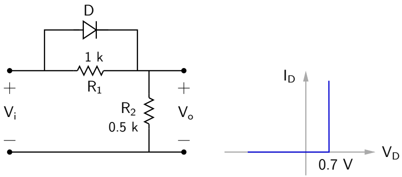
D off

$V_o = \dfrac{R_2}{R_1 + R_2} V_i$

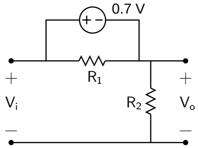
At what value of V_i will the diode turn on?

In the off state, $V_D = \dfrac{R_1}{R_1 + R_2}\, V_i$.

Diode circuit example

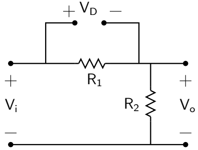


Plot V_o versus V_i for $-5\ \text{V} < V_i < 5\ \text{V}$.



D on

$V_o = V_i - 0.7$



D off

$$V_o = \frac{R_2}{R_1 + R_2} V_i$$

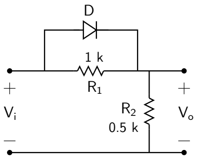
At what value of V_i will the diode turn on?

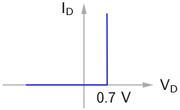
In the off state, $V_D = \dfrac{R_1}{R_1 + R_2}\, V_i$.

For D to change to the on state, $V_D =\ 0.7\ V$.

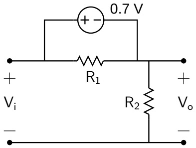
i.e., $V_i = \dfrac{R_1 + R_2}{R_1} \times 0.7 = 1.05\ V$.

Diode circuit example



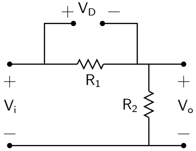


Plot V_o versus V_i for $-5\text{ V} < V_i < 5\text{ V}$.



D on

$V_o = V_i - 0.7$



D off

$$V_o = \frac{R_2}{R_1 + R_2} V_i$$

At what value of V_i will the diode turn on?

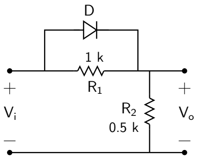
In the off state, $V_D = \dfrac{R_1}{R_1 + R_2} V_i$.

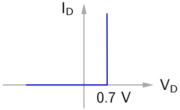
For D to change to the on state, $V_D = 0.7\ V$.

i.e., $V_i = \dfrac{R_1 + R_2}{R_1} \times 0.7 = 1.05\ V$.

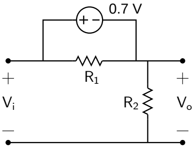
(SEQUEL file: `ee101_diode_circuit_2.sqproj`)

Diode circuit example



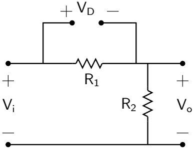


Plot V_o versus V_i for $-5\ V < V_i < 5\ V$.



D on

$V_o = V_i - 0.7$



D off

$$V_o = \frac{R_2}{R_1 + R_2} V_i$$

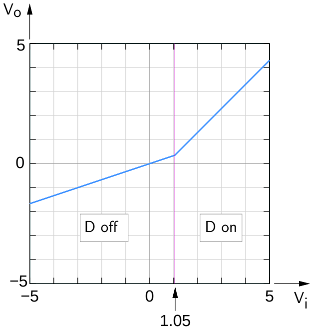
At what value of V_i will the diode turn on?

In the off state, $V_D = \dfrac{R_1}{R_1 + R_2} V_i$.

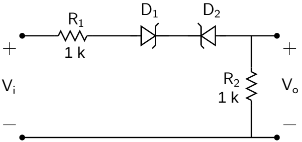
For D to change to the on state, $V_D = 0.7\ V$.

i.e., $V_i = \dfrac{R_1 + R_2}{R_1} \times 0.7 = 1.05\ V$.

(SEQUEL file: `ee101_diode_circuit_2.sqproj`)



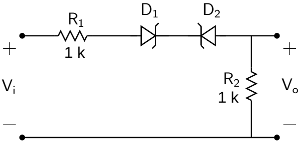
Diode circuit example



$V_{on} = 0.7$ V, $V_Z = 5$ V.

Plot V_o versus V_i.

Diode circuit example

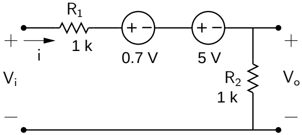


$V_{on} = 0.7$ V, $V_Z = 5$ V.

Plot V_o versus V_i.

For a current to flow, we have two possibilities:

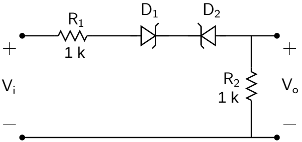
D_1 on (forward), D_2 in reverse breakdown



$$V_o = i\,R_2 = \frac{V_i - 5.7}{R_1 + R_2}\,R_2$$

Since $i > 0$, this can happen only when $V_i > 5.7$ V.

Diode circuit example

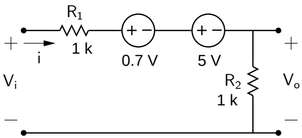


$V_{on} = 0.7$ V, $V_Z = 5$ V.

Plot V_o versus V_i.

For a current to flow, we have two possibilities:

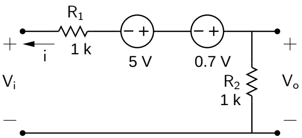
D_1 on (forward), D_2 in reverse breakdown



$$V_o = i\,R_2 = \frac{V_i - 5.7}{R_1 + R_2}\,R_2$$

Since $i > 0$, this can happen only when $V_i > 5.7$ V.

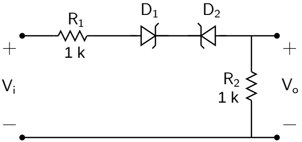
D_2 on (forward), D_1 in reverse breakdown



$$V_o = -i\,R_2 = \frac{V_i + 5.7}{R_1 + R_2}\,R_2$$

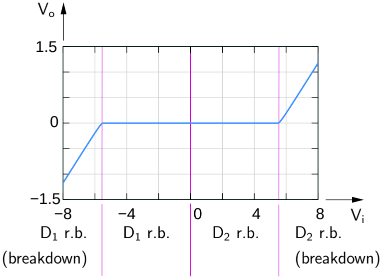
Since $i > 0$, this can happen only when $V_i <$ -5.7 V.

Diode circuit example



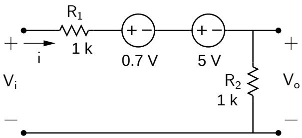
$V_{on} = 0.7$ V, $V_Z = 5$ V.

Plot V_o versus V_i.



For a current to flow, we have two possibilities:

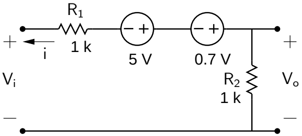
D_1 on (forward), D_2 in reverse breakdown



$$V_o = i\,R_2 = \frac{V_i - 5.7}{R_1 + R_2}\,R_2$$

Since $i > 0$, this can happen only when $V_i > 5.7$ V.

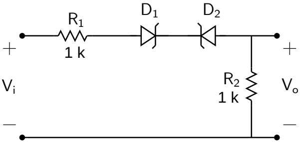
D_2 on (forward), D_1 in reverse breakdown



$$V_o = -i\,R_2 = \frac{V_i + 5.7}{R_1 + R_2}\,R_2$$

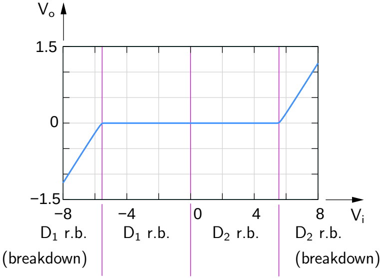
Since $i > 0$, this can happen only when $V_i <$ -5.7 V.

Diode circuit example



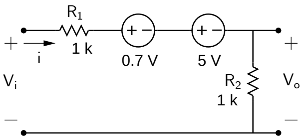
$V_{on} = 0.7$ V, $V_Z = 5$ V.

Plot V_o versus V_i.



For a current to flow, we have two possibilities:

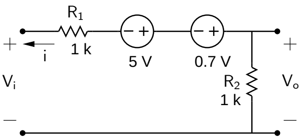
D_1 on (forward), D_2 in reverse breakdown



$$V_o = i\,R_2 = \frac{V_i - 5.7}{R_1 + R_2}\,R_2$$

Since $i > 0$, this can happen only when $V_i > 5.7$ V.

D_2 on (forward), D_1 in reverse breakdown

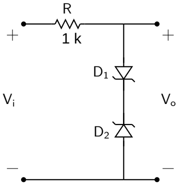


$$V_o = -i\,R_2 = \frac{V_i + 5.7}{R_1 + R_2}\,R_2$$

Since $i > 0$, this can happen only when $V_i <$ -5.7 V.

(SEQUEL file: ee101_diode_circuit_3.sqproj)

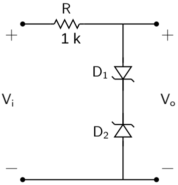
Diode circuit example (voltage limiter)



$V_{on} = 0.7$ V, $V_Z = 5$ V.

Plot V_o versus V_i.

Diode circuit example (voltage limiter)

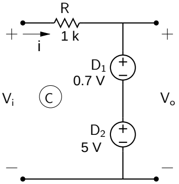


$V_{on} = 0.7$ V, $V_Z = 5$ V.

Plot V_o versus V_i.

For a current to flow, we have two possibilities:

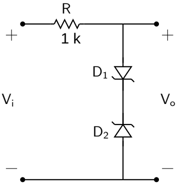
D_1 on (forward), D_2 in reverse breakdown



$V_o = 5.7$ V

$V_i > 5.7$ V

Diode circuit example (voltage limiter)

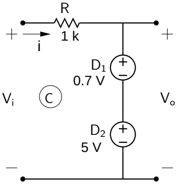


$V_{on} = 0.7$ V, $V_Z = 5$ V.

Plot V_o versus V_i.

For a current to flow, we have two possibilities:

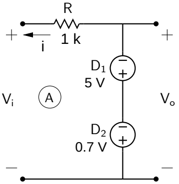
D_1 on (forward), D_2 in reverse breakdown



$V_o = 5.7$ V

$V_i > 5.7$ V

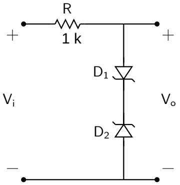
D_2 on (forward), D_1 in reverse breakdown



$V_o = -5.7$ V

$V_i < -5.7$ V

Diode circuit example (voltage limiter)

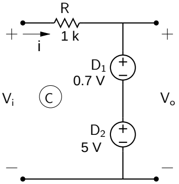


$V_{on} = 0.7$ V, $V_Z = 5$ V.

Plot V_o versus V_i.

For a current to flow, we have two possibilities:

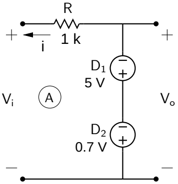
D_1 on (forward), D_2 in reverse breakdown



$V_o = 5.7$ V

$V_i > 5.7$ V

D_2 on (forward), D_1 in reverse breakdown

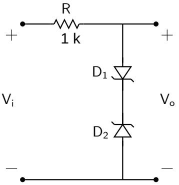


$V_o = -5.7$ V

$V_i < -5.7$ V

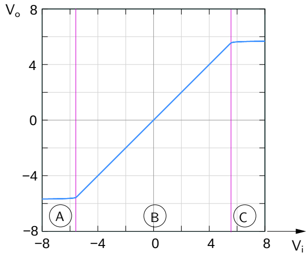
In the range, -5.7 V $< V_i < 5.7$ V, no current flows, and $V_o = V_i$. B

Diode circuit example (voltage limiter)



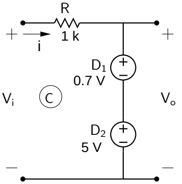
$V_{on} = 0.7$ V, $V_Z = 5$ V.

Plot V_o versus V_i.



For a current to flow, we have two possibilities:

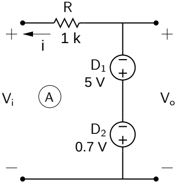
D_1 on (forward), D_2 in reverse breakdown



$V_o = 5.7$ V

$V_i > 5.7$ V

D_2 on (forward), D_1 in reverse breakdown

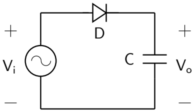


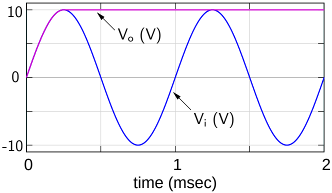
$V_o = -5.7$ V

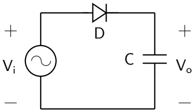
$V_i < -5.7$ V

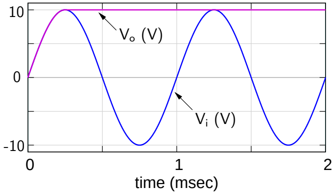
In the range, $-5.7\text{ V} < V_i < 5.7$ V, no current flows, and $V_o = V_i$. B

Peak detector

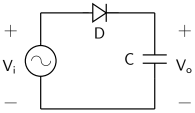


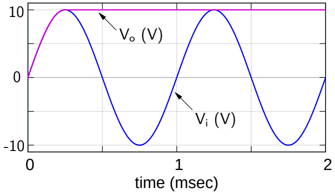






Let $V_o(t) = 0\ V$ at $t = 0$, and assume the diode to be ideal, with $V_{\mathrm{on}} = 0\ V$.

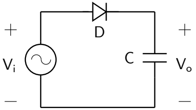


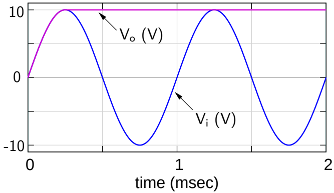


Let $V_o(t) = 0\ V$ at $t = 0$, and assume the diode to be ideal, with $V_{\text{on}} = 0\ V$.

For $0 < t < T/4$, V_i rises from 0 to V_m. As a result, the capacitor charges.

Peak detector

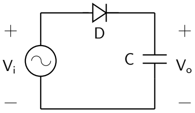


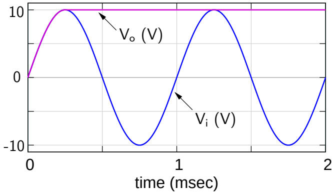


Let $V_o(t) = 0\ V$ at $t = 0$, and assume the diode to be ideal, with $V_{\text{on}} = 0\ V$.

For $0 < t < T/4$, V_i rises from 0 to V_m. As a result, the capacitor charges.

Since the on resistance of the diode is small, time constant $\tau \ll T/4$; therefore the charging process is instantaneous $\Rightarrow V_o(t) = V_i(t)$.





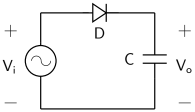
Let $V_o(t) = 0\ V$ at $t = 0$, and assume the diode to be ideal, with $V_{on} = 0\ V$.

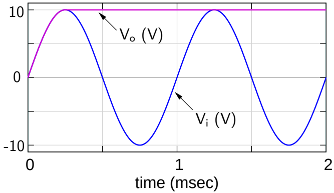
For $0 < t < T/4$, V_i rises from 0 to V_m. As a result, the capacitor charges.

Since the on resistance of the diode is small, time constant $\tau \ll T/4$; therefore the charging process is instantaneous $\Rightarrow V_o(t) = V_i(t)$.

For $t > T/4$, V_i starts falling. The capacitor holds the charge it had at $t = T/4$ since the diode prevents discharging.

Peak detector





Let $V_o(t) = 0\ V$ at $t = 0$, and assume the diode to be ideal, with $V_{\text{on}} = 0\ V$.

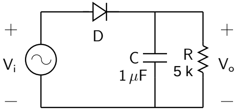
For $0 < t < T/4$, V_i rises from 0 to V_m. As a result, the capacitor charges.

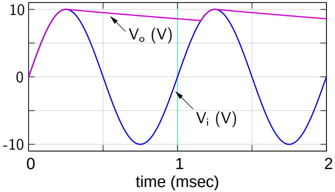
Since the on resistance of the diode is small, time constant $\tau \ll T/4$; therefore the charging process is instantaneous $\Rightarrow V_o(t) = V_i(t)$.

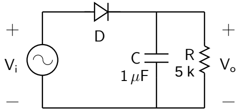
For $t > T/4$, V_i starts falling. The capacitor holds the charge it had at $t = T/4$ since the diode prevents discharging.

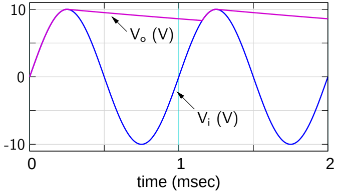
SEQUEL file: `ee101_diode_circuit_5.sqproj`

Peak detector (continued)



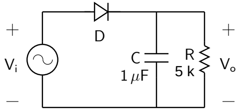


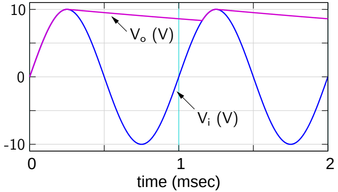




If a resistor is added in parallel, a discharging path is provided for the capacitor, and the capacitor voltage falls after reaching the peak.

Peak detector (continued)

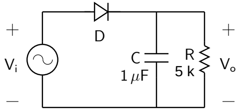


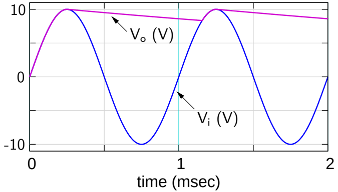


If a resistor is added in parallel, a discharging path is provided for the capacitor, and the capacitor voltage falls after reaching the peak.

When $V_i > V_o$, the capacitor charges again. The time constant for the charging process is $\tau = R_{\mathrm{Th}}C$, where $R_{\mathrm{Th}} = R \parallel R_{\mathrm{on}}$ is the Thevenin resistance seen by the capacitor, R_{on} being the on resistance of the diode.

Peak detector (continued)





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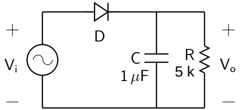
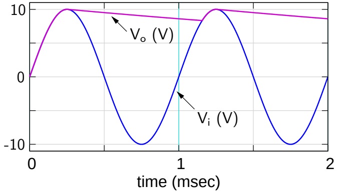
Since $\tau \ll T$, the charging process is instantaneous.





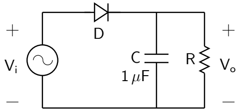
If a resistor is added in parallel, a discharging path is provided for the capacitor, and the capacitor voltage falls after reaching the peak.

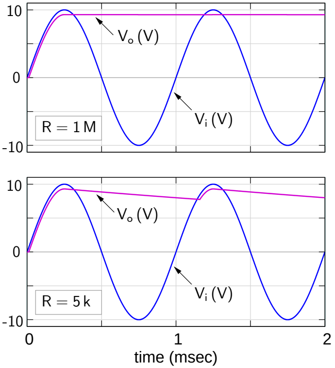
When $V_i > V_o$, the capacitor charges again. The time constant for the charging process is $\tau = R_{\rm Th}C$, where $R_{\rm Th} = R \parallel R_{\rm on}$ is the Thevenin resistance seen by the capacitor, $R_{\rm on}$ being the on resistance of the diode.

Since $\tau \ll T$, the charging process is instantaneous.

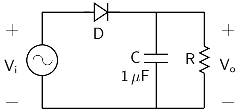
SEQUEL file: `ee101_diode_circuit_5a.sqproj`

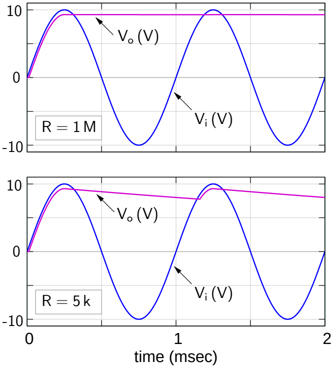
Peak detector (with $V_{on} = 0.7\ V$)





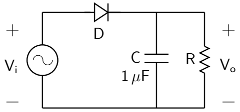
Peak detector (with $V_{on} = 0.7\ V$)

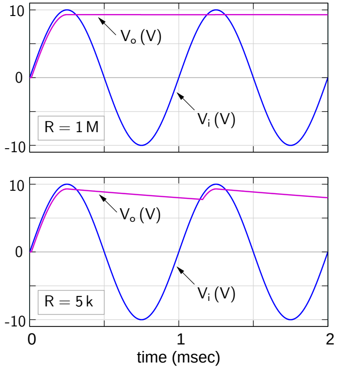




With $V_{on} = 0.7\ V$, the capacitor charges up to $(V_m - 0.7\ V)$.

Peak detector (with $V_{on} = 0.7\ V$)

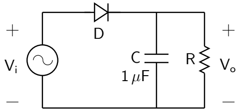


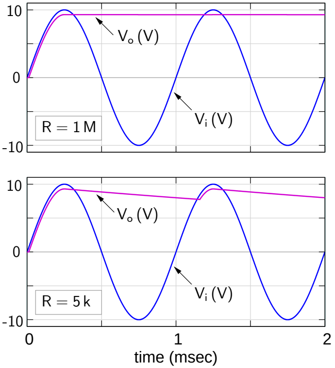


With $V_{on} = 0.7\ V$, the capacitor charges up to $(V_m - 0.7\ V)$.

Apart from that, the circuit operation is similar.

Peak detector (with $V_{on} = 0.7\ V$)

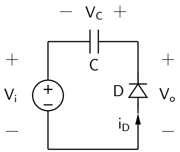


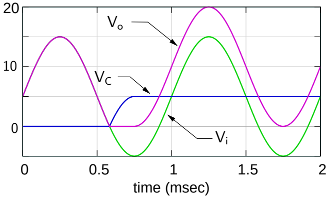


With $V_{on} = 0.7\ V$, the capacitor charges up to $(V_m - 0.7\ V)$.

Apart from that, the circuit operation is similar.

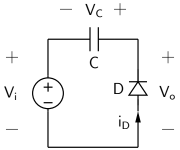
SEQUEL file: `ee101_diode_circuit_5a.sqproj`

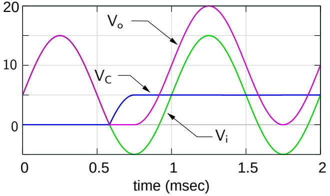




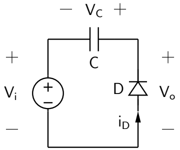
* Assume $V_{on} = 0\ V$ for the diode.
  When D conducts, $V_D = -V_o = 0 \Rightarrow V_C + V_i = 0$, i.e., $V_C = -V_i$.

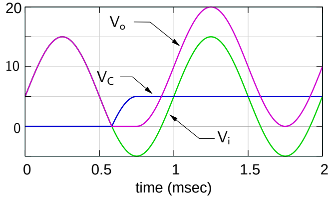
Clamped capacitor





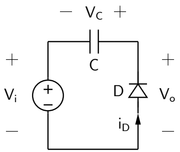
* Assume $V_{on} = 0\ V$ for the diode.
  When D conducts, $V_D = -V_o = 0 \Rightarrow V_C + V_i = 0$, i.e., $V_C = -V_i$.
* V_C can only increase with time (or remain constant) since i_D can only be positive.

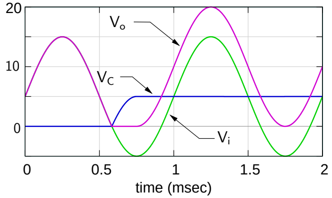




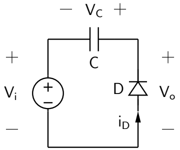
* Assume $V_{on} = 0\ V$ for the diode.
  When D conducts, $V_D = -V_o = 0 \Rightarrow V_C + V_i = 0$, i.e., $V_C = -V_i$.
* V_C can only increase with time (or remain constant) since i_D can only be positive.
* The net result is that the capacitor gets charged to a voltage $V_C = -V_i$, corresponding to the maxmimum negative value of V_i, and holds that voltage thereafter. Let us call this voltage V_C^0 (a constant).

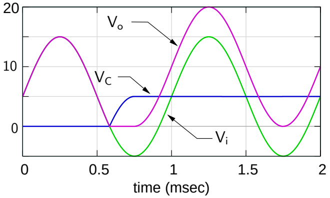
Clamped capacitor





- Assume $V_{on} = 0\ V$ for the diode.
  When D conducts, $V_D = -V_o = 0 \Rightarrow V_C + V_i = 0$, i.e., $V_C = -V_i$.
- V_C can only increase with time (or remain constant) since i_D can only be positive.
- The net result is that the capacitor gets charged to a voltage $V_C = -V_i$, corresponding to the maxmimum negative value of V_i, and holds that voltage thereafter. Let us call this voltage V_C^0 (a constant).
- $V_o(t) = V_C(t) + V_i(t) = V_C^0 + V_i(t)$, which is a "level-shifted" version of V_i.

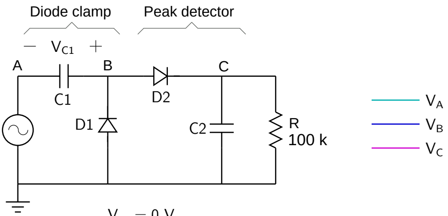


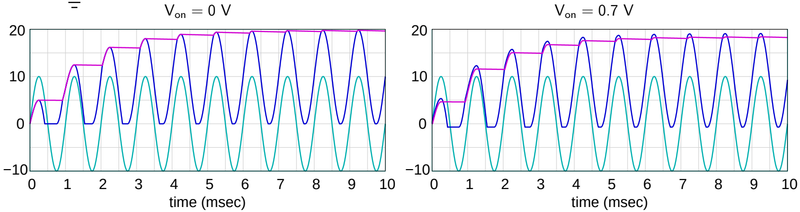


* Assume $V_{on} = 0\ V$ for the diode.
  When D conducts, $V_D = -V_o = 0 \Rightarrow V_C + V_i = 0$, i.e., $V_C = -V_i$.
* V_C can only increase with time (or remain constant) since i_D can only be positive.
* The net result is that the capacitor gets charged to a voltage $V_C = -V_i$, corresponding to the maxmimum negative value of V_i, and holds that voltage thereafter. Let us call this voltage V_C^0 (a constant).
* $V_o(t) = V_C(t) + V_i(t) = V_C^0 + V_i(t)$, which is a "level-shifted" version of V_i.

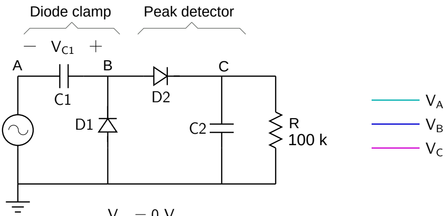
  (SEQUEL file: `ee101_diode_circuit_6.sqproj`)

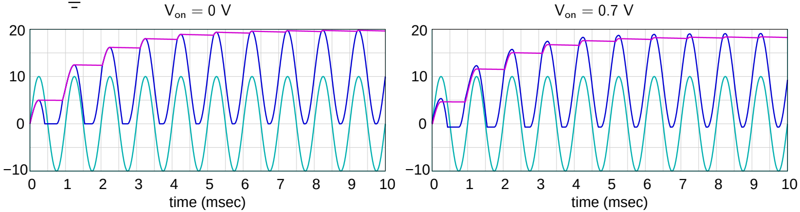
Voltage doubler





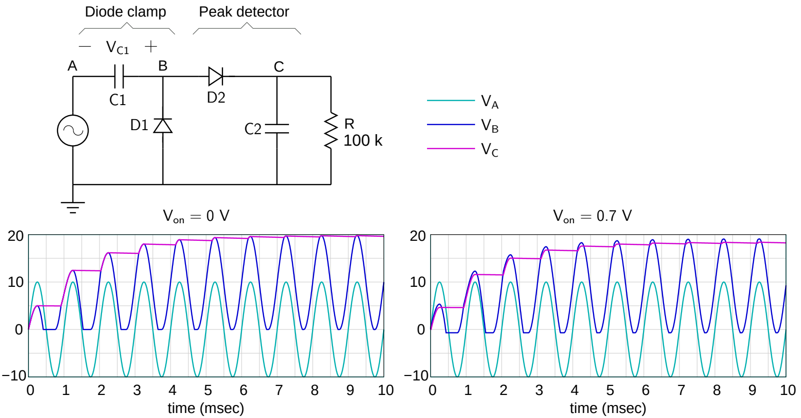
Voltage doubler





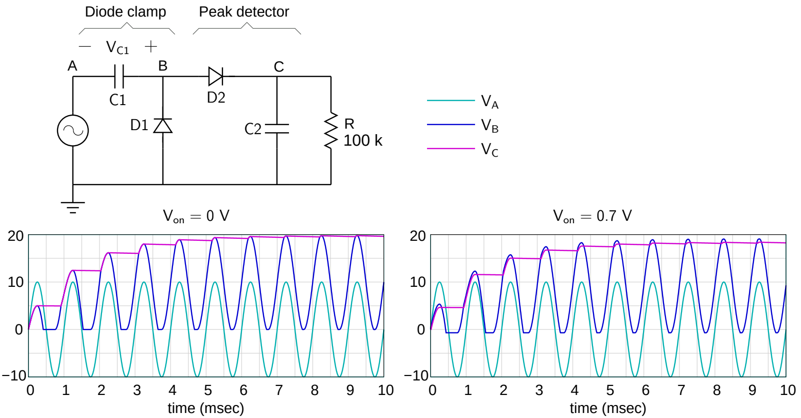
* The diode clamp shifts V_A up by V_m (the amplitude of the AC source), making V_B go from 0 to 2 V_m.

Voltage doubler



* The diode clamp shifts V_A up by V_m (the amplitude of the AC source), making V_B go from 0 to 2 V_m.
* The peak detector detects the peak of V_B (2 V_m w.r.t. ground), and holds it constant.

Voltage doubler



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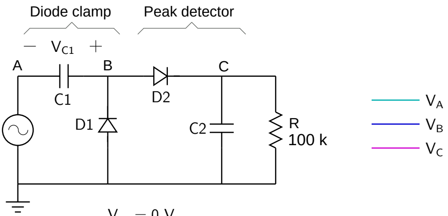
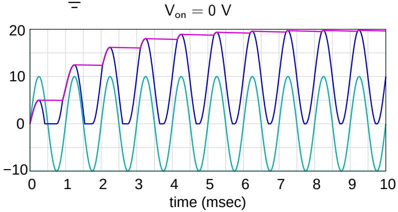
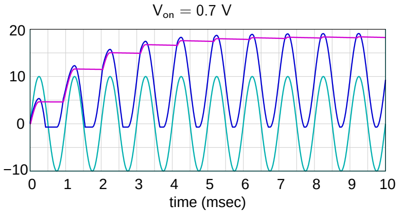
* The peak detector detects the peak of V_B (2 V_m w.r.t. ground), and holds it constant.
* Note that it takes a few cycles to reach steady state. Plot V_{C1}, i_{D1}, i_{D2} versus t and explain the initial behaviour of the circuit.







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* Note that it takes a few cycles to reach steady state. Plot V_{C1}, i_{D1}, i_{D2} versus t and explain the initial behaviour of the circuit.

  (SEQUEL file: `ee101_voltage_doubler.sqproj`)