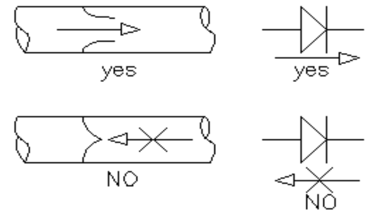
Diodes Notes

ECE 2210

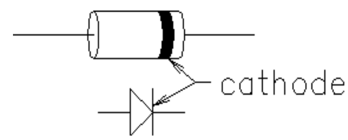
A. Stolp
4/8/03,
11/5/23

Diodes are basically electrical check valves. They allow current to flow freely in one direction, but not the other. Check valves require a small forward pressure to open the valve. Similarly, a diode requires a small forward voltage (bias) to "turn on". This is called the forward voltage drop. There are many different types of diodes, but the two that you are most likely to see are silicon diodes and light-emitting diodes (LEDs). These two have forward voltage drops of about 0.7V and 2V respectively.



Mechanical check valve   Diode

silicon diode   LED



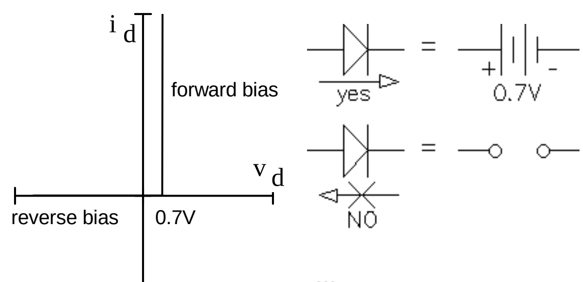
The electrical symbol for a diode looks like an arrow which shows the forward current direction and a small perpendicular line. The two sides of a diode are called the "anode" and the "cathode" (these names come from vacuum tubes). Most small diodes come in cylindrical packages with a band on one end that corresponds to the small perpendicular line, and shows the polarity, see the picture. Normal diodes are rated by the average forward current and the peak reverse voltage that they can handle. Diodes with significant current ratings are known as "rectifier" or "power" diodes. (Rectification is the process of making AC into DC.) Big power diodes come in a variety of packages designed to be attached to heat sinks. Small diodes are known as "signal" diodes because they're designed to handle small signals rather than power.

Diodes are nonlinear parts

So far in this class we've only worked with linear parts. The diode is definitely NOT linear, but it can be modeled as linear in its two regions of operation. If it's forward biased, it can be replaced by battery of 0.7V (2V for LEDs) which opposes the current flow. Otherwise it can be replaced by an open circuit. These are "models" of the actual diode. If you're not sure of the diode's state in a circuit, guess. Then replace it with the appropriate model and analyze the circuit. If you guessed the open, then the voltage across the diode model should come out less than +0.7V (2V for LEDs). If you guessed the battery, then the current through the diode model should come out in the direction of the diode's arrow. If your guess doesn't work out right, then you'll have to try the other option. In a circuit with multiple diodes (say "n" diodes), there will be 2^n possible states, all of which may have to be tried until you find the right one. Try to guess right the first time.

Constant-voltage-drop model

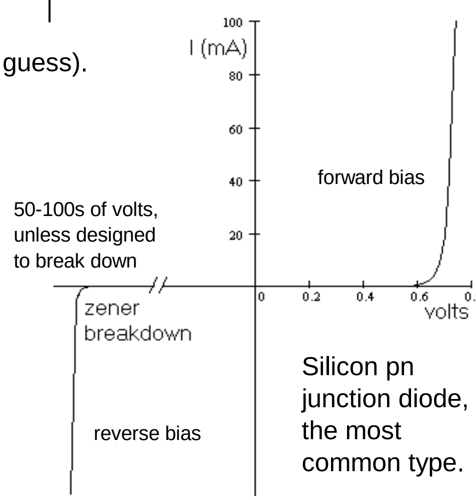
This is the most common diode model and is the only one we'll use in this class. It gives quite accurate results in most cases.



1. Assume the diode is operating in one of the linear regions (make an educated guess).
2. Analyze circuit with a linear model of the diode.
3. Check to see if the diode was really in the assumed region.
4. Repeat if necessary.

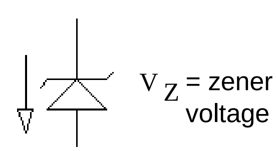
Actual diode curve

The characteristics of real diodes are actually more complicated than the constant-voltage-drop model. The forward voltage drop is not quite constant at any current and the diode "leaks" a little current when the voltage is in the reverse direction. If the reverse voltage is large enough, the diode will "breakdown" and let lots of current flow in the reverse direction. A mechanical check valve will show similar characteristics. Breakdown does not harm the diode as long as it isn't overheated.



Silicon pn junction diode, the most common type.

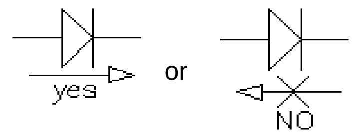
Zener diodes are special diodes designed to operate in the reverse breakdown region. Since the reverse breakdown voltage across a diode is very constant for a large range of current, it can be used as a voltage reference or regulator. Zener diodes are also used for over-voltage protection. In the forward direction zeners work the same as regular diodes.



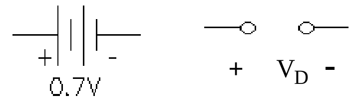
Basic Diode DC Circuit Analysis

1. Make an educated guess about each diode's state.

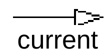
conducting / not conducting



2. Replace each diode with the appropriate model:



3. Redraw and analyze circuit.
4. Make sure that each diode is actually in the state you assumed:

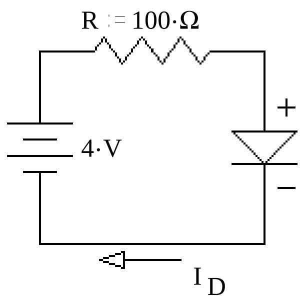


$V_D < 0.7V$ Check

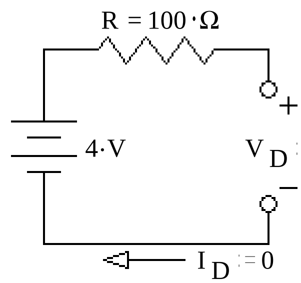
Note: 0.7V is for silicon junction diodes & is different for other types. (2V for LED)

5. If any of your guesses don't work out right, then you'll have to start over with new guesses. In a circuit with n diodes there will be 2^n possible states, all of which may have to be tried until you find the right one. Try to guess right the first time.

Ex. 1

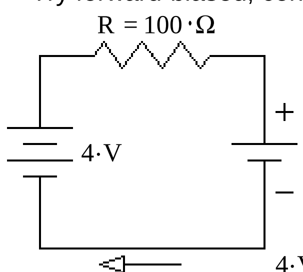


Try reverse-biased, nonconducting model
(Bad choice but done here to illustrate method)



$V_D := 4 \cdot V > 0.7V$ Doesn't work, diode must be forward biased.

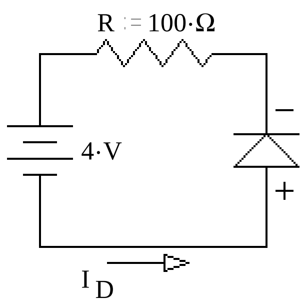
Try forward-biased, conducting model



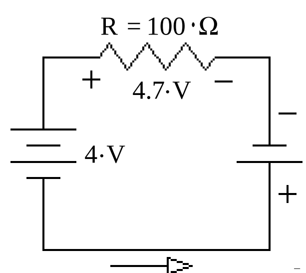
$V_D := 0.7 \cdot V$

$I_D = \frac{4 \cdot V - 0.7 \cdot V}{100 \cdot \Omega} = 33 \cdot mA > 0$ The current *is* in the forward direction, confirming the assumption.

Ex. 2



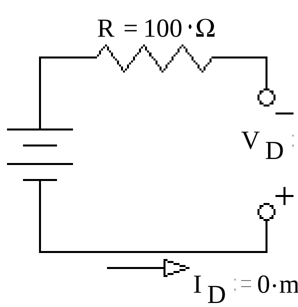
Try forward-biased, conducting model
(Bad choice but done here to illustrate method)



$V_D := 0.7 \cdot V$

$I_D = \frac{-4 \cdot V - 0.7 \cdot V}{1 \cdot k\Omega} = -4.7 \cdot mA < 0$ Doesn't work, diode must be reverse biased.

Try reverse-biased, nonconducting model

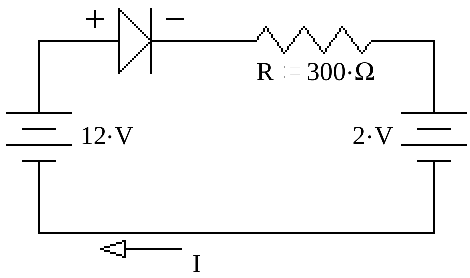


Check the diode voltage

$V_D := -4 \cdot V < 0.7V$ Confirms diode *is* reverse biased

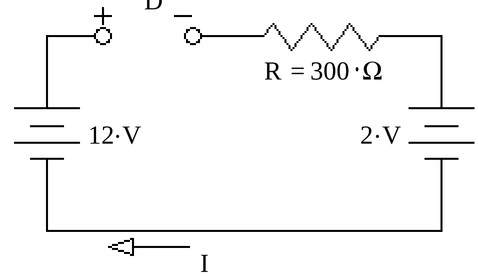
$I_D := 0 \cdot mA$

Ex. 3



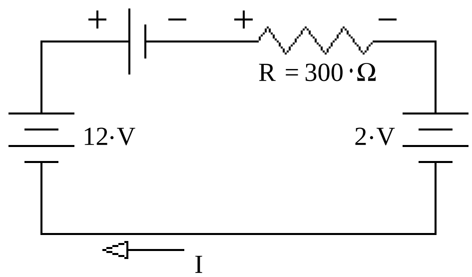
Try reverse-biased, nonconducting model

$V_D = 12\cdot V - 2\cdot V = 10\cdot V > 0.7\ V$ Doesn't work, diode must be forward biased.



Try forward-biased, conducting model

$V_D := 0.7\cdot V$ $\quad V_R = 12\cdot V - 2\cdot V - V_D = 9.3\cdot V$

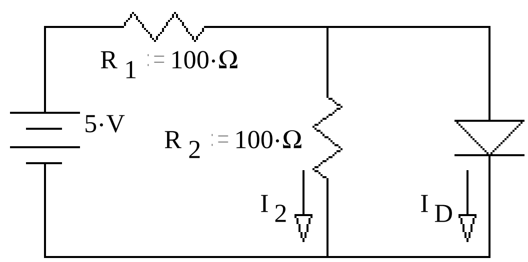


Check the diode current $\quad I = \dfrac{9.3\cdot V}{R} = 31\cdot mA \quad > 0$

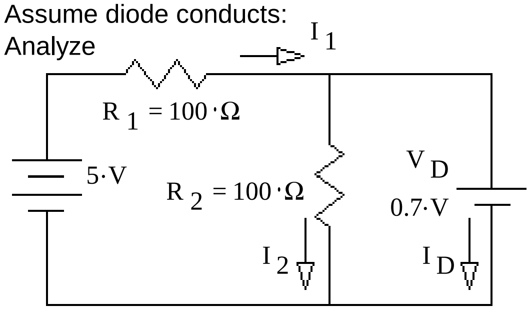
Confirms diode is forward biased

In each of these examples so far, my first guess was pretty stupid. I did that intentionally to show the process.
I suspect that you can make better guesses and thus save yourself some work.

Ex. 4



Assume diode conducts:
Analyze



$V_{R1} := 5\cdot V - V_D$

$V_{R1} = 4.3\cdot V$

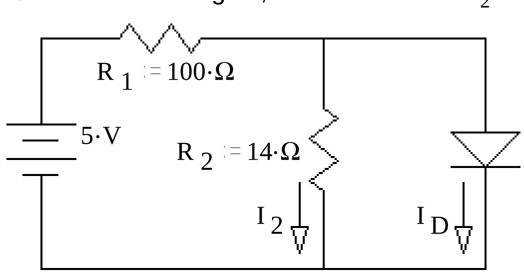
$I_1 := \dfrac{V_{R1}}{R_1}$

$I_1 = 43\cdot mA$

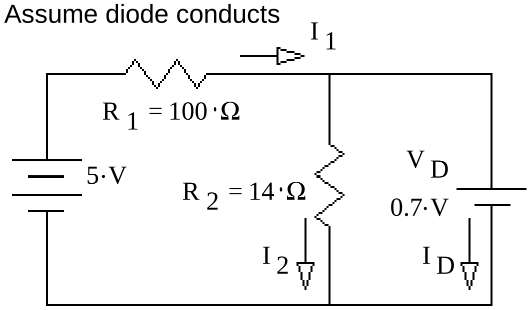
$V_{R2} := V_D \quad I_2 := \dfrac{V_{R2}}{R_2} \quad I_2 = 7\cdot mA$

We assumed conducting (assuming a voltage),
so check the current: $I_D = I_1 - I_2 = 36\cdot mA$ > 0, so assumption was correct

Ex. 5 Same circuit again, but with smaller R_2



Assume diode conducts



$V_{R1} := 5\cdot V - V_D$

$V_{R1} = 4.3\cdot V$

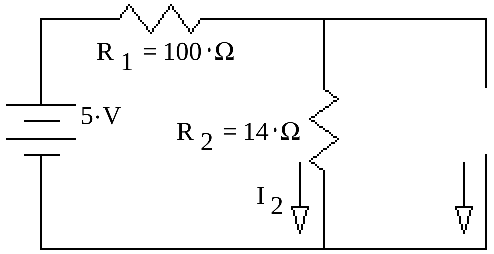
$I_1 := \dfrac{V_{R1}}{R_1}$

$I_1 = 43\cdot mA$

$V_{R2} := V_D \quad I_2 := \dfrac{V_{R2}}{R_2} \quad I_2 = 50\cdot mA$

$I_D = I_1 - I_2 = -7\cdot mA$ < 0, so assumption was **WRONG !**

Try again with diode not conducing

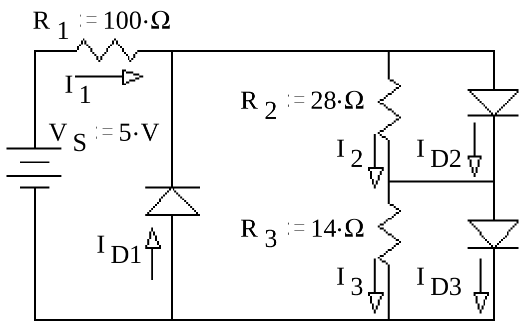


$I_D := 0 \cdot mA$ $\qquad I_2 := \dfrac{5 \cdot V}{R_1 + R_2}$

We assumed not conducting (assuming a current),
so check the voltage: $V_{R2} := I_2 \cdot R_2$ $\qquad V_{R2} = 0.614 \cdot V$ < 0.7 V, so assumption was correct.

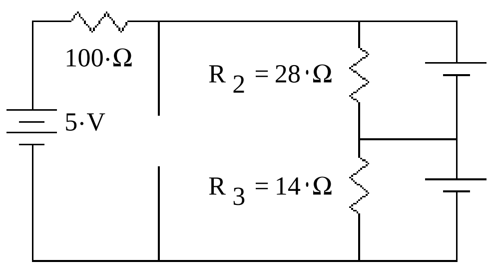
Actually, this final check isn't necessary, since first assumption didn't work, this one had to work.

Ex. 6



You can safety say that diode D_1 doesn't conduct without rechecking later because no supply is even trying to make current flow through that diode the right way.

Assume both D_2 and D_3 conduct.



$V_{D2} := 0.7 \cdot V$

$V_{D3} := 0.7 \cdot V$

Analyze $\quad V_{R1} := V_S - 0.7 \cdot V - 0.7 \cdot V$

$V_{R1} = 3.6 \cdot V$ $\qquad I_1 := \dfrac{V_{R1}}{R_1}$ $\qquad I_1 = 36 \cdot mA$

$I_2 := \dfrac{V_{D2}}{R_2}$ $\qquad I_2 = 25 \cdot mA$

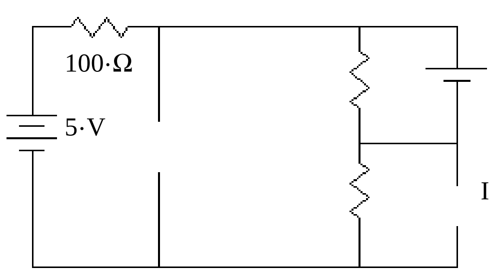
$I_3 := \dfrac{V_{D3}}{R_3}$ $\qquad I_3 = 50 \cdot mA$

We assumed D_1 & D_2 conduct (assumed a voltage),
so check currents:

$I_{D2} = I_1 - I_2 = 11 \cdot mA$ $\qquad > 0$, so assumption OK

$I_{D3} = I_1 - I_3 = -14 \cdot mA$ $\qquad < 0$, so assumption is **wrong**

Assume D_2 conducts and D_3 doesn't. Analyze



$V_{D2} := 0.7 \cdot V$ $\qquad I_2 := \dfrac{V_{D2}}{R_2}$ $\qquad I_2 = 25 \cdot mA$

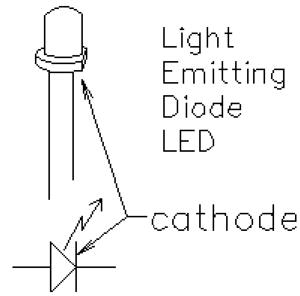
$I_{D3} := 0 \cdot mA$ $\qquad I_3 = I_1 := \dfrac{V_S - V_{D2}}{R_1 + R_3}$ $\qquad I_1 = 37.72 \cdot mA$

Assumed D_2 conducts, so check D_2 current: $\quad I_{D2} = I_1 - I_2 = 12.72 \cdot mA$ $\quad > 0$, so assumption OK

Assumed D_3 doesn't conduct, so check D_3 voltage: $\quad V_{R3} := I_1 \cdot R_3$ $\qquad V_{R3} = 0.528 \cdot V$ < 0.7 V, so OK

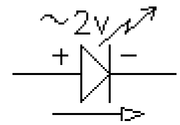
Once you find a case that works, you don't have to try any others.

LEDs (**L**ight - **E**mitting **D**iodes)

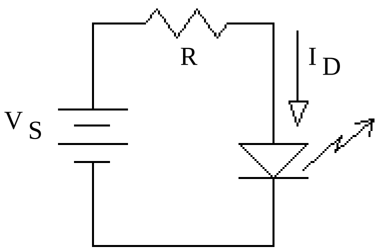


An LED has a higher voltage drop when forward biased, more like 2V for red, yellow or green LEDs, even more for blue or white (often well over 3V). In this class we'll assume 2V for all LEDs.

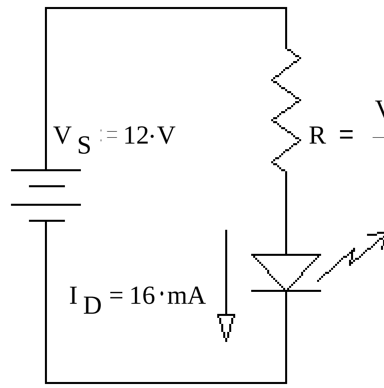
The symbol for an LED is like a regular diode but with one or more arrows that represent the light emission.



As a simple rule-of-thumb, you usually want between 10 and 20 mA of current for decent light.

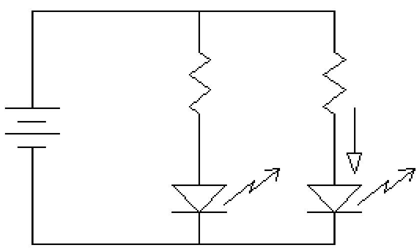


For example, in a car, you might design for: $I_D := 16 \cdot mA$

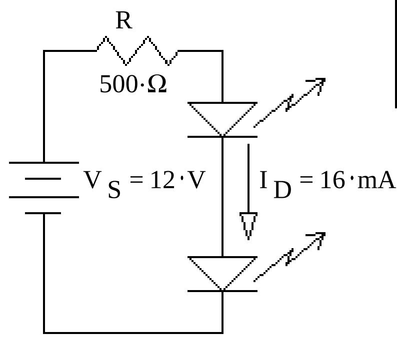


$$R = \frac{V_S - 2 \cdot V}{I_D} = 625 \cdot \Omega$$

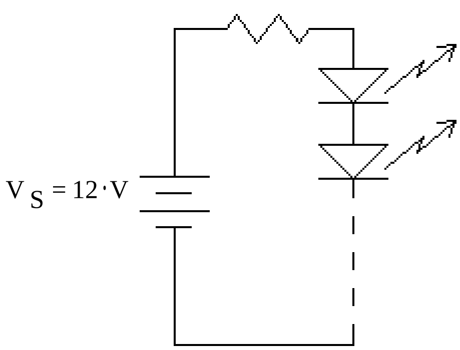
For more lights, you might do this:



OR:



$$R := \frac{V_S - 2 \cdot (2 \cdot V)}{I_D} \qquad R = 500 \cdot \Omega$$

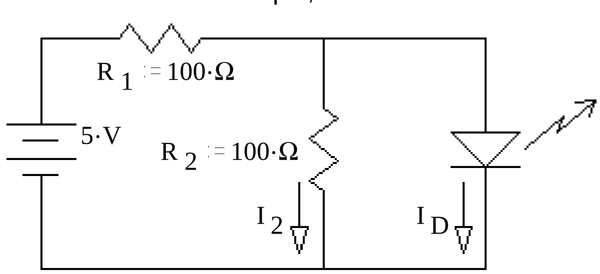


How many LEDs could you place in series?

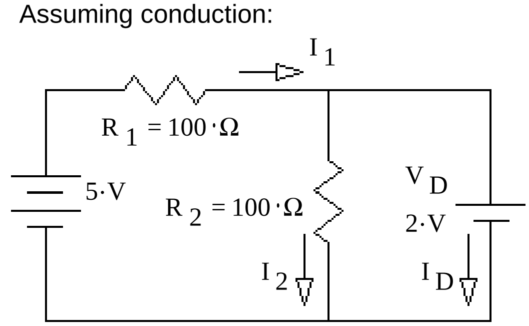
You may be tempted to say 6, but that would be unwise for two reasons:

1. 2V forward drop is not all that accurate and even a small difference in the voltage across a diode can make a huge difference in the current.
2. If the 12V is for a car, then it's not all that accurate either At times it could go as high as 14.5V .

Ex. Similar to earlier example, but now with an LED



Assuming conduction:



$V_{R1} := 5 \cdot V - 2 \cdot V$

$V_{R1} = 3 \cdot V$

$I_1 := \frac{V_{R1}}{R_1}$

$I_1 = 30 \cdot mA$

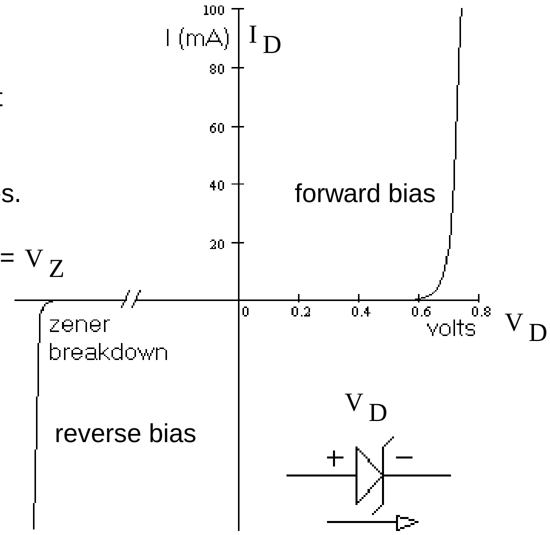
$V_{R2} := V_D \qquad I_2 := \frac{V_{R2}}{R_2} \qquad I_2 = 7 \cdot mA$

Check the current: $I_D = I_1 - I_2 = 23 \cdot mA$ > 0, so assumption was correct

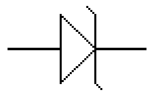
Zener Diodes

Zener diodes are special diodes designed to operate in the reverse breakdown region. Since the reverse breakdown voltage across the diode is very constant for a large range of current, it can be used as a voltage reference or regulator. Diodes are not harmed by operating in this region as long as their power rating isn't exceeded. In the forward direction zeners work the same as regular diodes.

zener breakdown voltage = V_Z

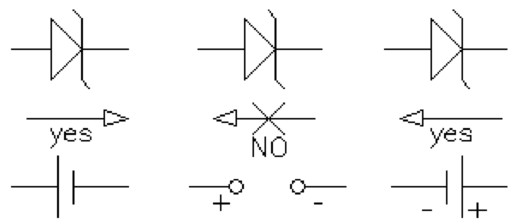


The symbol for a zener diode



note how the cathode line is modified to look a little like a "Z"

Same basic diode circuit analysis



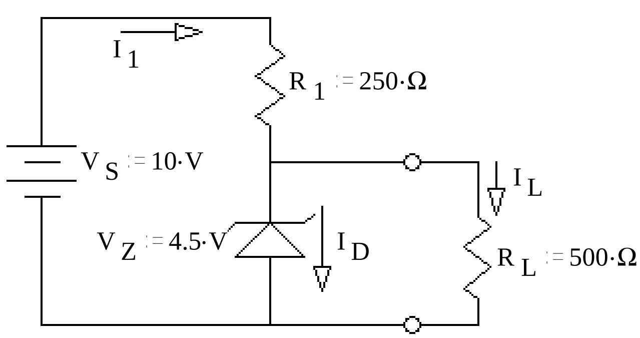
1. Make an educated guess about each diode's state.
2. Replace each diode with the appropriate model:
3. Redraw and analyze circuit.
4. Make sure that each diode is actually in the state you assumed: $V_D = 0.7\ V$ $0.7\ V > V_D > V_Z$ V_Z checks

Zener diodes are often used in voltage regulation circuits. The objective of a voltage regulator is to provide a constant voltage to a load even when the load changes or supply voltage changes. Real voltage regulators can only maintain regulation for a limited range of load current (or load resistance) and for a limited range of supply voltages.

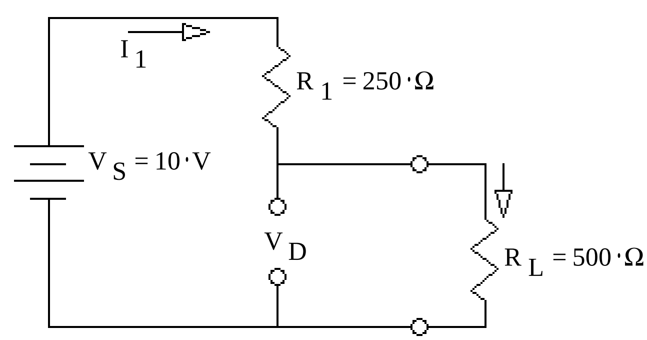
The simplest type of voltage regulator is the "shunt regulator", covered below. In more complicated regulator circuits the zener is only used as a reference voltage and is not directly connected to the load.

Zener Diode Circuit Examples

Ex. 1 Typical shunt regulator circuit:



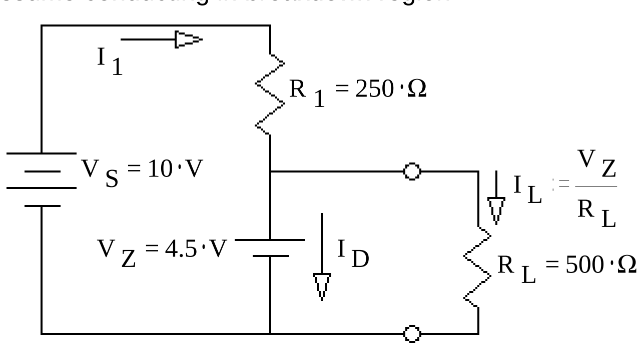
Assume not conducting



$$V_D = V_S \cdot \frac{R_L}{R_1 + R_L} = 6.67\cdot V > V_Z = 4.5\cdot V$$

so assumption is **wrong**

Assume conducting in breakdown region

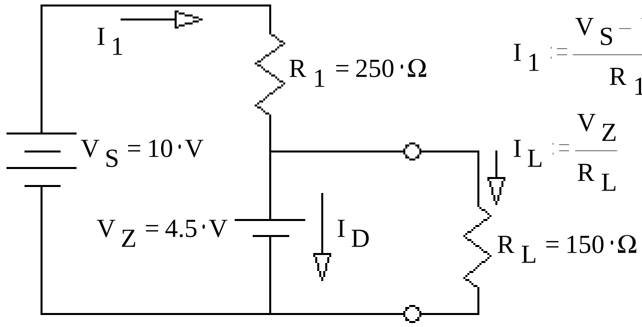


$I_L = 9\cdot mA$ $I_1 := \frac{V_S - V_Z}{R_1}$ $I_1 = 22\cdot mA$

Assumed a conducting region, so check the current to see if the current flows in the direction shown.

$I_D = I_1 - I_L = 13\cdot mA > 0$, so assumption OK

Ex. 2 What if R_L is smaller? $R_L := 150 \cdot \Omega$



$I_1 := \frac{V_S - V_Z}{R_1}$ $I_1 = 22 \cdot mA$

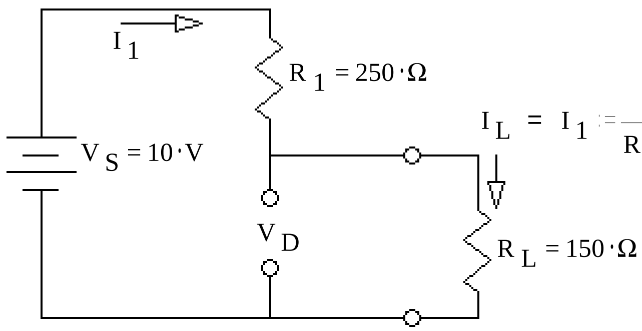
$I_L := \frac{V_Z}{R_L}$ $I_L = 30 \cdot mA$

Assumed a conducting region, so check the current to see if the current flows in the direction shown.

$I_D = I_1 - I_L = -8 \cdot mA < 0$, so assumption is **WRONG !**

Circuit "falls out" of regulation

Assume not conducting



$I_L = I_1 := \frac{V_S}{R_1 + R_L}$ $I_1 = 25 \cdot mA$

$V_D := \frac{R_L}{R_1 + R_L} \cdot V_S$

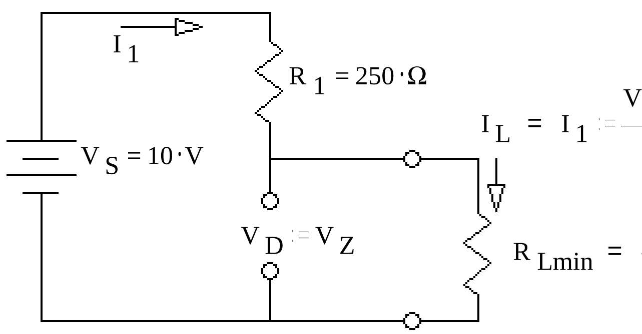
Assumed a nonconducting region, so check the voltage to see if it's in the right range.

$V_D = 3.75 \cdot V < V_Z = 4.5 \cdot V$

so this assumption is OK

How small can R_L be and still maintain regulation?

Assume both nonconducting AND $V_D = V_Z$ at the same time.

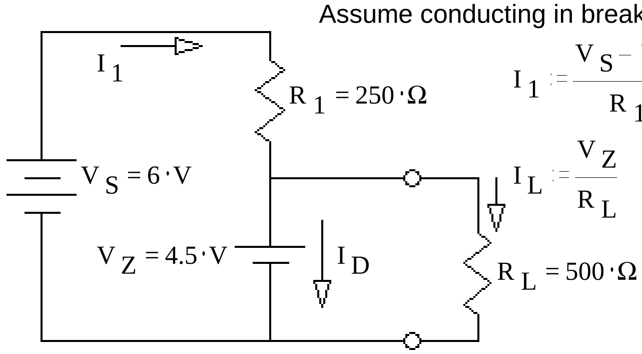


$I_L = I_1 := \frac{V_S - V_Z}{R_1}$ $I_1 = 22 \cdot mA$

$R_{Lmin} = \frac{V_Z}{I_1} = 204.5 \cdot \Omega$

Ex. 3 What if V_S is smaller instead of R_L? $V_S := 6 \cdot V$ $R_L := 500 \cdot \Omega$

Assume conducting in breakdown region



$I_1 := \frac{V_S - V_Z}{R_1}$ $I_1 = 6 \cdot mA$

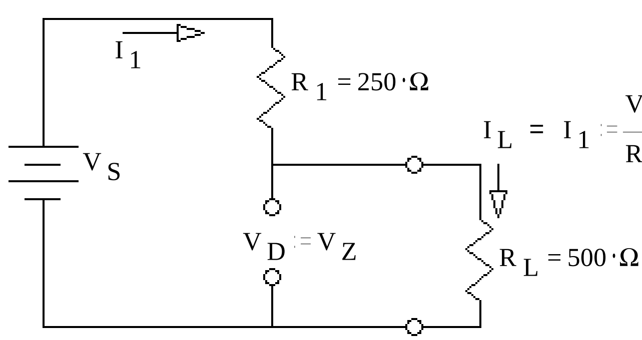
$I_L := \frac{V_Z}{R_L}$ $I_L = 9 \cdot mA$

Assumed a conducting region, so check the current to see if the current flows in the direction shown.

$I_D = I_1 - I_L = -3 \cdot mA < 0$, so assumption is **WRONG !**

How small can V_S be and still maintain regulation?

Assume both non-conduction AND $V_D = V_Z$ at the same time.



$I_L = I_1 := \frac{V_Z}{R_L}$ $I_1 = 9 \cdot mA$

$V_{R1} := I_1 \cdot R_1$ $V_{R1} = 2.25 \cdot V$

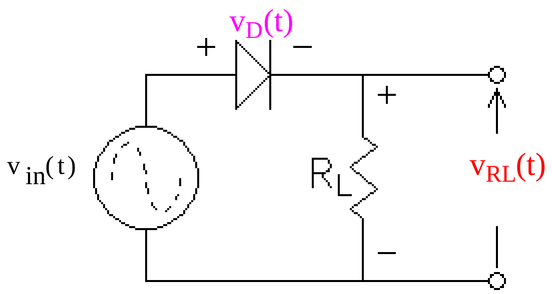
$V_{Smin} = V_Z + V_{R1} = 6.75 \cdot V$

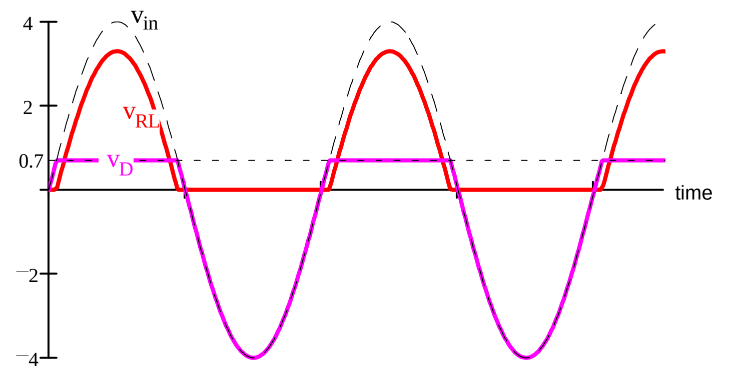
Rectifier Circuits & Power Supplies

Electronic circuits all work on DC power, yet we would often like to use AC power from an outlet to run them. A very common type of "power supply" is a device or circuit which converts AC input power to DC power, usually at a lower voltage. You are certainly familiar with power supplies for laptops and phones, but other devices, like audio amplifiers, monitors and TVs that plug directly into AC sockets, have built-in power supplies. Most modern power supplies are more complex than the ones I will show here, but still incorporate some of the same parts and concepts.

In the circuits below, I assume the input is sinusoidal AC and the desired output is DC. Where the DC output voltage is lower than the AC input, a transformer can be used on the AC side to first lower the AC voltage. Diodes are used as "rectifiers", allowing current to flow in only one direction and converting the AC to DC.

Half-wave rectification



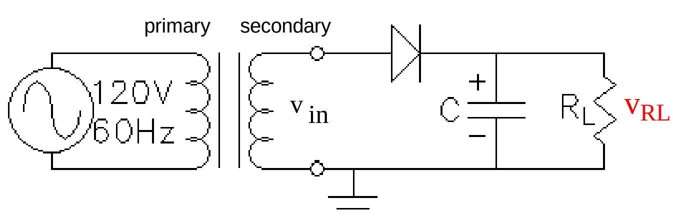


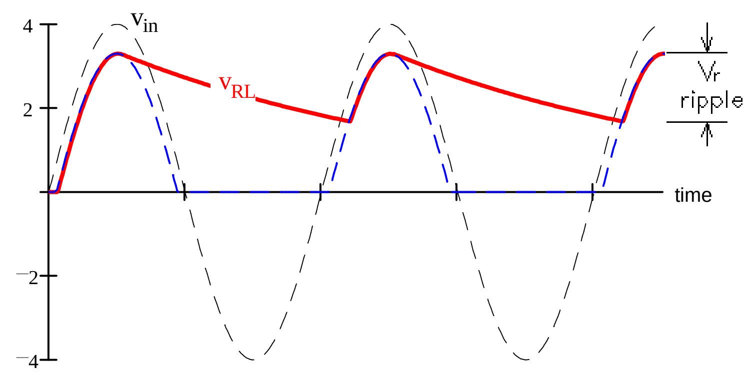
I show the input as a dashed line so it's easier to see the other waveforms.

R_L is the load and may actually be far more than just a resistor

V_{RL} is now DC, although a bit bumpy. Some things are better if they're bumpy, but not roads and not DC voltages.

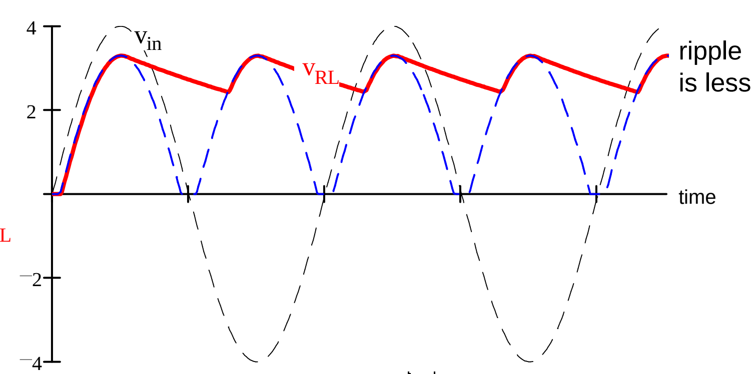
Usually the AC is derived from the AC wall outlet (often through a transformer) and a capacitors are used to smooth out the bumps.

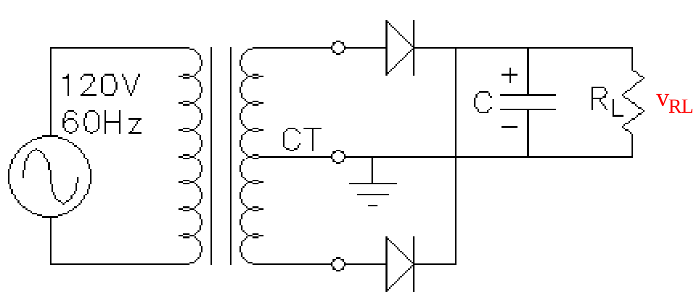




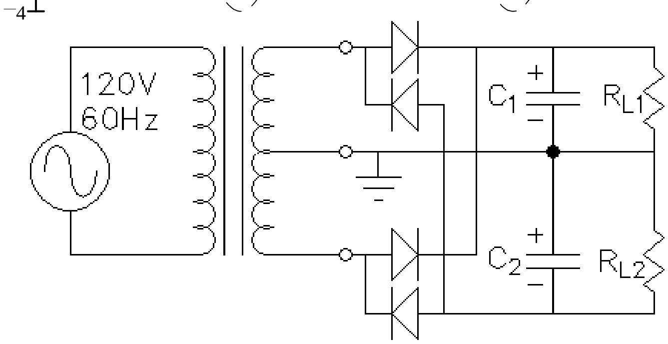
Full-wave rectification

If the negative half of the input is also used, then it's called "full-wave" rectification. The "center tap" in the secondary of this transformer makes it easy to get full-wave rectification.



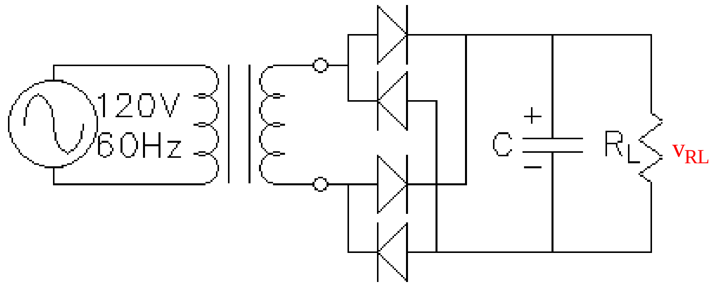


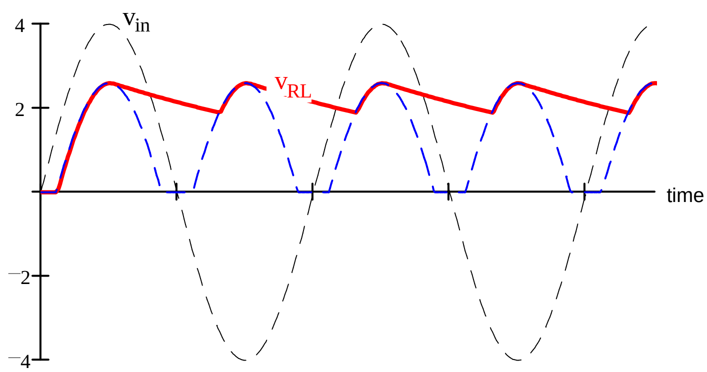
The center-tap transformer is also good for making ± supplies



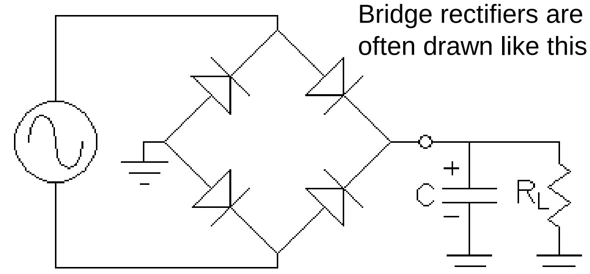
Bridge

A "bridge" circuit or "bridge rectifier" can give you full-wave rectification without a center-tap transformer, but now you loose another "diode drop"

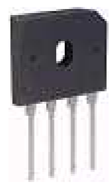


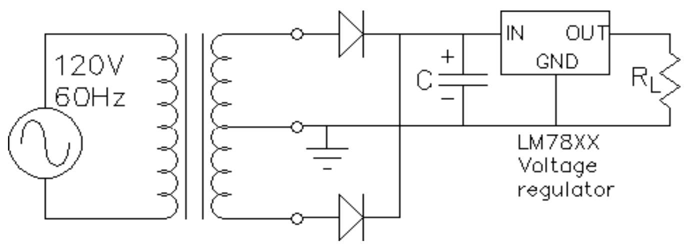


Bridge rectifiers are often drawn like this



The four diodes of a bridge rectifier are often packaged in a single package.

In all of these power supplies a three-terminal voltage regulator may be used to further regulate and smooth out the DC voltage.

So clearly, it is important to understand how diodes work in AC circuits.

Diode AC Circuit Analysis

1. Replace the diode with an open (nonconducting model) and redraw the circuit.
2. Determine the waveform across the open.
3. Compare that waveform to the conduction-region voltage of the diode (typically $0.7\mathrm{V}$) to determine time region(s) when the diode will conduct.
4. Draw the "output" waveform for non-conduction times using the circuit drawing made in step 1.
5. Draw the circuit with the conducting diode model and draw the "output" waveform for conduction times. Usually you start by determining the output when the input is at a peak value and then follow-up by filling in between there and the conducting waveform section(s) you've already drawn.

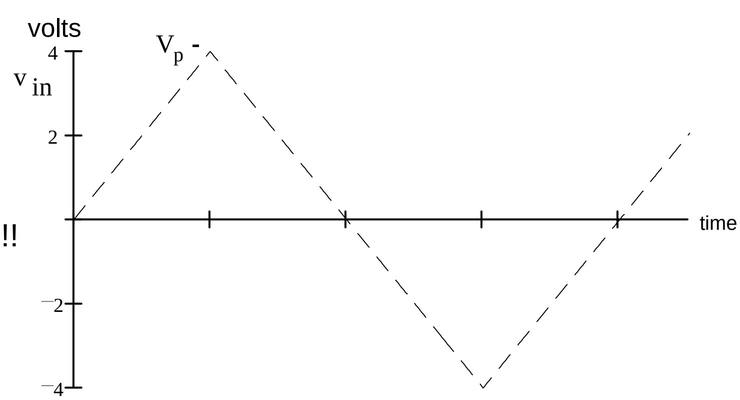
Triangular Waveforms

My examples and problems use input waveforms made of straight lines and triangular pieces. I do this to make the waveforms easier to draw. It also makes it easier to determine the times when important events occur.

Real waveforms are almost never triangular !!

It's just that many of us are not very good at drawing sine waves and partial sine waves.

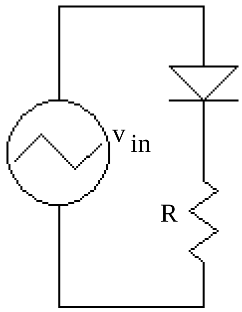
Input waveforms are drawn as dashed lines so that we can draw over them.



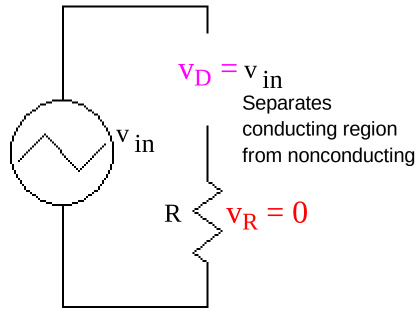
The input for the next 2 examples

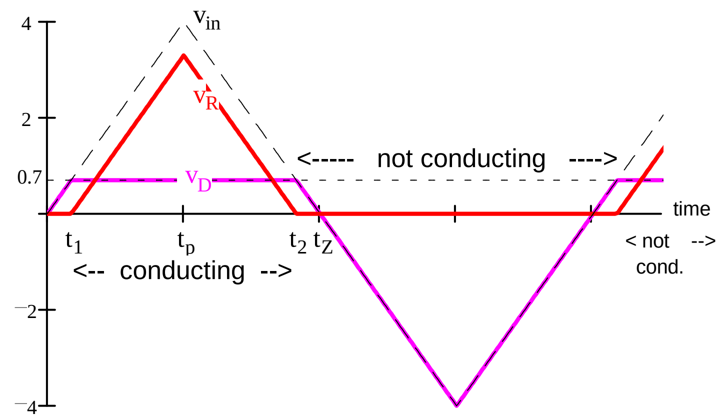
Ex. 1 The first example is very similar to the Half-wave rectifier you saw earlier, only the resulting waveforms are easier to draw because they consist of simple straight lines.

Diode doesn't conduct until v_{in} reaches 0.7V, so 0.7V is a dividing line between the two models of the diode.

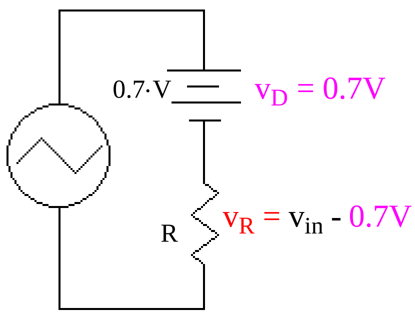


not conducting





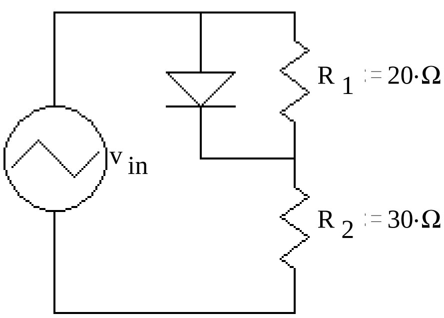
conducting



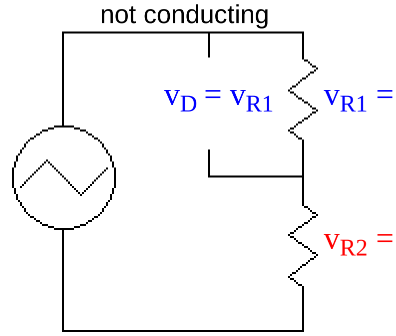
important times:

slope of $v_{in} = \dfrac{V_p}{t_p} = \dfrac{0.7 \cdot V}{t_1}$ $\qquad t_1 = \dfrac{0.7 \cdot V}{V_p} \cdot t_p \qquad t_2 = t_z - t_1$

Ex. 2



not conducting



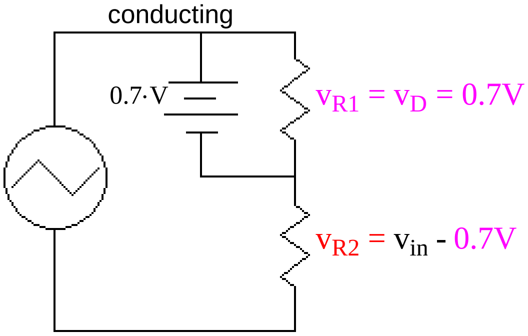
$v_{R1} = v_{in} \cdot \dfrac{R_1}{R_1 + R_2}$

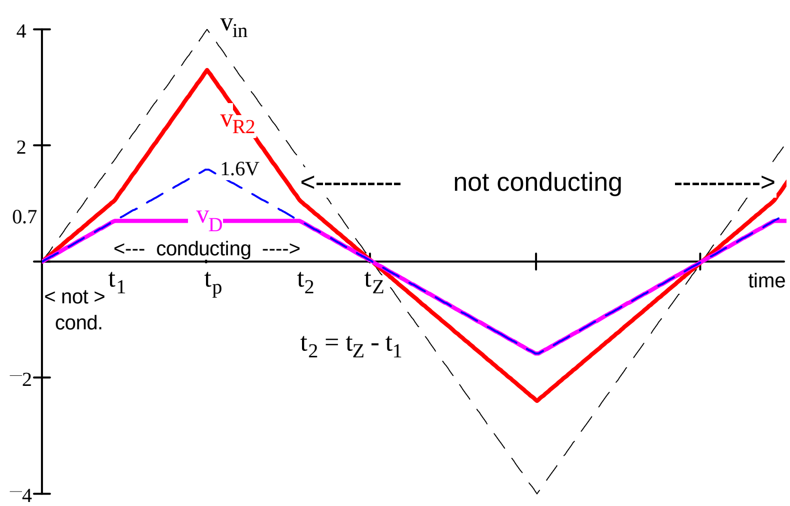
$v_{R2} = v_{in} \cdot \dfrac{R_2}{R_1 + R_2}$

dashed line below that peaks at:

$$4 \cdot V \cdot \frac{20 \cdot \Omega}{20 \cdot \Omega + 30 \cdot \Omega} = 1.6 \cdot V$$

conducting

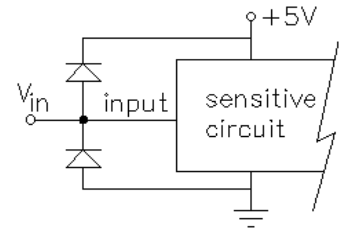




$$t_1 = \frac{0.7 \cdot V}{V_p \cdot \dfrac{R_1}{R_1 + R_2}} \cdot t_p$$

Other Useful Diode Circuits

Simple limiter circuits can be made with diodes.
A common input protection to protect circuit from excessive input voltages such as static electricity.



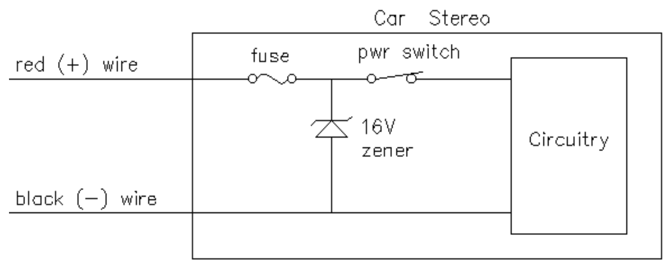
The input to the box marked "sensitive circuit" can't get higher than the positive supply + 0.7V or lower than the negative supply - 0.7V.

Put a fuse in the V_{in} line and the diodes can make it blow, providing what's known as "crowbar" protection.

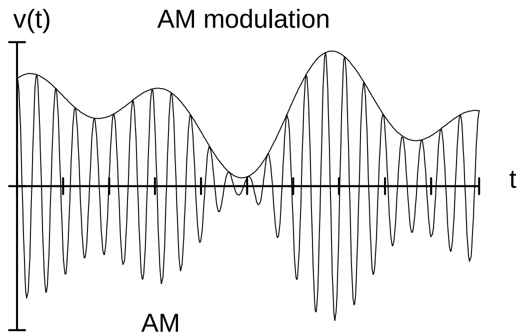
Another example of crowbar protection:

If the input voltage goes above 16 V. the fuse will blow, protecting the circuitry.

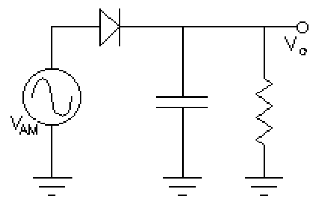
Or, If the input voltage is hooked up backwards the fuse will blow, protecting the circuitry.



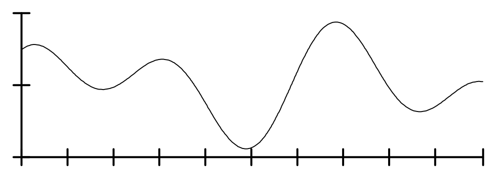
AM detector



A simple rectifier circuit



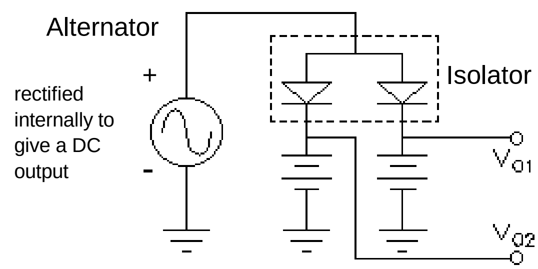
Returns the modulation signal



And a coupling capacitor can remove the DC

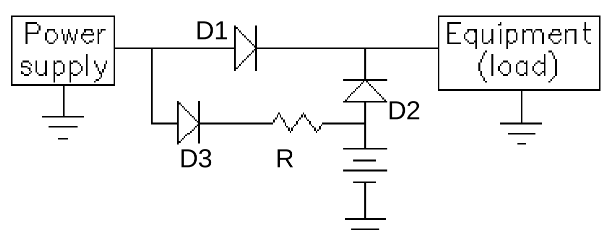
Battery Isolator

Like you might find in an RV. One alternator is used to charge two batteries. When the alternator is **not** charging, the batteries and the circuits they are hooked to should be isolated from one another. If not, then one battery might discharge through the second, especially if second is bad. Also, you wouldn't want the accessories in the RV to drain the starting battery, or your uncle George from South Dakota might never leave your driveway.



Battery Backup Power

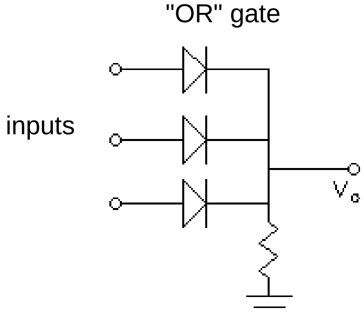
Normally the power supply powers the load through D1. However, if it fails, the load will remain powered by the battery through D2. Finally, D3 and R may be added to keep the battery charged when the power supply is working. These sorts of circuits are popular in hospitals.



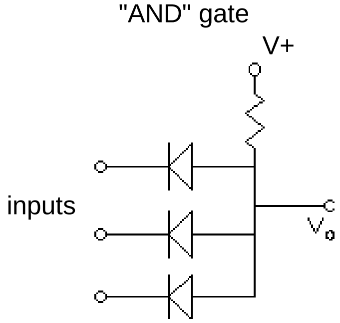
Diode Logic Circuits

Actually, both of the previous circuits are logic circuits as well.

"OR" gate

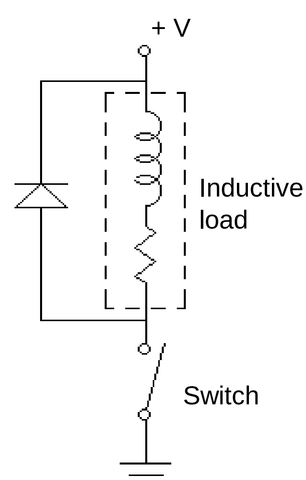


"AND" gate



"Flyback" Diode

Every time the switch opens the inductor current continues to flow through the diode for a moment. If the diode weren't there, then the current would arc across the switch.



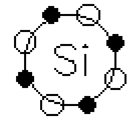
Diode Physics (The simple version)   EE 2210

A.Stolp 3/22/01, rev, 2/25/16

FYI Only, You don't need to know this

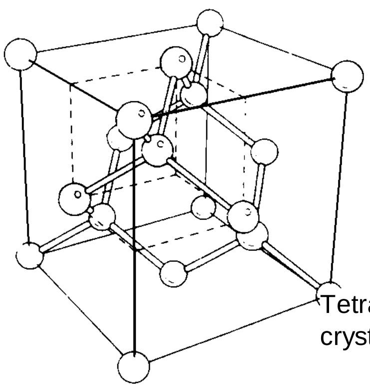
Silicon atoms

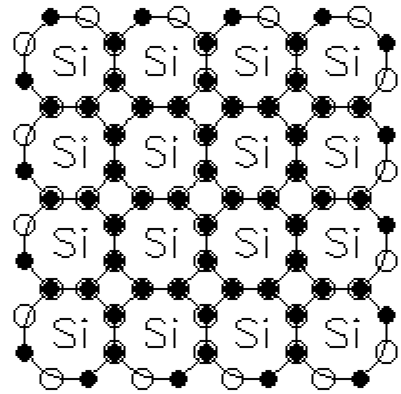
Silicon atoms each have 4 valence electrons (electrons in their outermost shell). That leaves 4 spaces in the outer shell of 8. This makes silicon a very reactive chemical, like carbon, which has the same valence configuration.



Silicon crystals

Each atom covalently bonds with four neighboring atoms to form a tetrahedral crystal, which we'll represent in 2D.

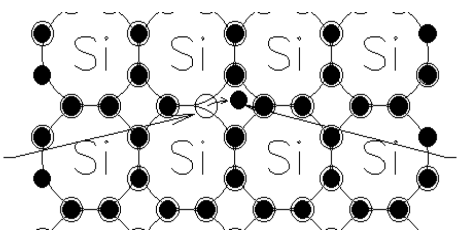


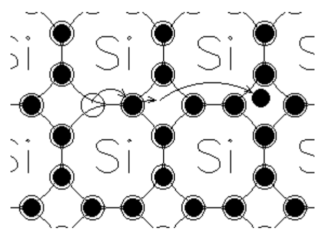


2-dimensional representation

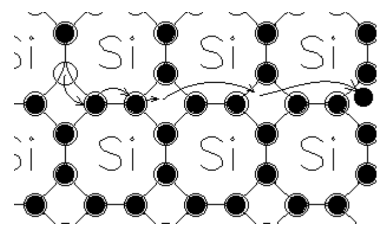
In the pure, "intrinsic" crystal, practically all the electrons are used in bonds and all the spaces are filled, which leaves almost no electrons free to move and thus no way to make current flow.

By the effects of heat, light and/or large electric fields, a few electrons do break free of the bonds and become "free" carriers. That is, they're free to move about crystal and "carry" an electrical current.





carrier movement



more carrier movement

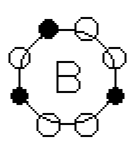
Interestingly, the space that was vacated by the electron also acts like a carrier. This pseudo-carrier is called a "hole" and it acts like a positively charged carrier.

Unless there's a lot of heat or light, the intrinsic silicon is still a very bad conductor.
Silicon is considered a semiconductor.

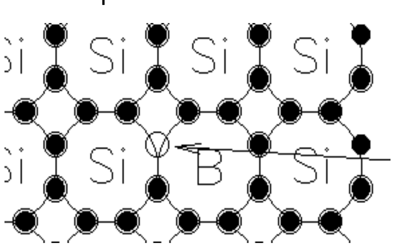
Doping

p-type

Some atoms, like boron and aluminum naturally have 3 valence electrons in their outer shells.

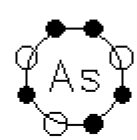


If you replace some of the silicon atoms in a crystal with boron there won't be quite enough electrons to fill the crystalline bond structure and unfilled spaces will act just like free holes. This "doped" silicon crystal is now called an p-type semiconductor. The p refers to the "extra" "positive" carriers.

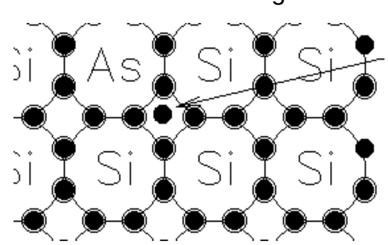


n-type

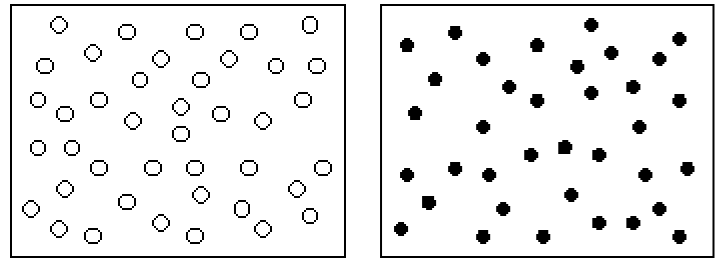
Some atoms, like arsenic and phosphorus naturally have 5 valence electrons in their outer shells.



If you replace some of the silicon atoms in a crystal with arsenic the 5th electron doesn't fit into the crystalline bond structure and is therefore free to roam about and be a carrier. This "doped" silicon crystal is now called an n-type semiconductor. The n refers to the "extra" negative carriers.



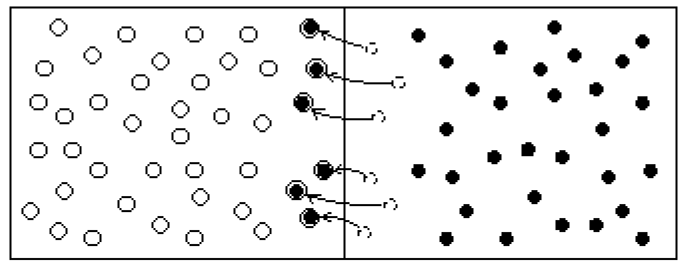
It turns out that the free carriers are the most important things in the semiconductor crystals, so we can simplify the drawings to show only these free carriers.



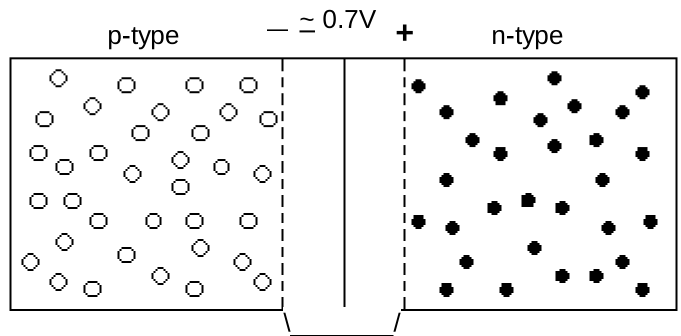
circles represent free holes   dots represent free electrons

PN Junction

When a p-type semiconductor is created next to an n-type, some of the free electrons from the n side will cross over and fill some of the free holes on the p side. This makes the p side negatively charged and leaves the n side positively charged. When the voltage across the junction reaches about 0.7 V the electrons find it too difficult to move against the charge and the process stops.



A region near the junction is now depleted of carriers and (surprise) is called the depletion region.



Reverse bias

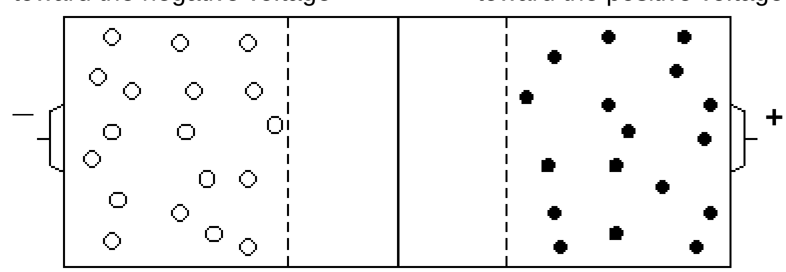
This pn junction is now a diode. If you place an external voltage across the diode in the reverse bias direction, the depletion region gets bigger and no current flows.

This reverse bias region can be used as a heat or light sensor since the only current flow should be due to a few carriers produced by these effects.

The reverse biased diode can also be used as a voltage variable capacitor since it is essentially an insulator (the depletion region) sandwiched between two conducting regions.

"positive" holes move toward the negative voltage

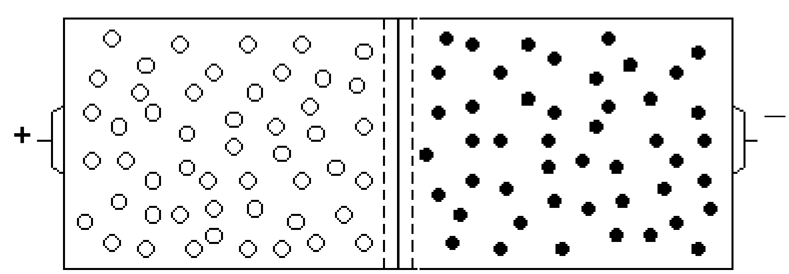
negative electrons move toward the positive voltage



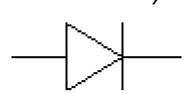
With reverse bias the depletion region gets bigger

Forward bias

If you place an external voltage across the diode in the forward bias direction, the depletion region shrinks until your external voltage reaches about 0.7V. After that the diode conducts freely..



With forward bias the depletion region gets smaller and eventually (at about 0.7V) conducts freely.

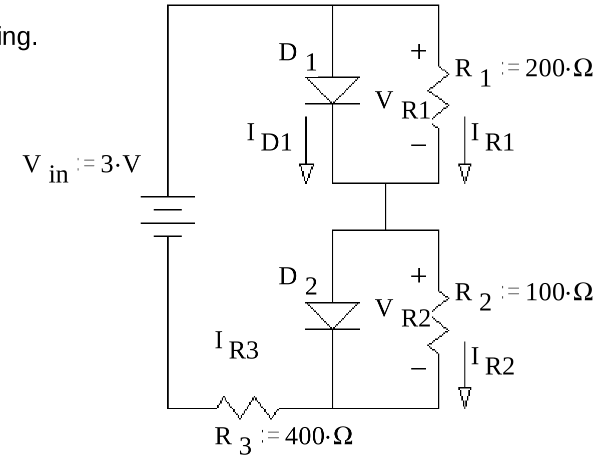


Diode

Diode Physics (The simple version) p.2

Exam-type Diode Circuit Examples

On an exam, I usually tell you what assumptions to make about the diodes, then you can show that you know how to analyze the circuit and test those assumptions. Since everyone starts with the same assumptions, everyone should do the same work.



Assume that diode D_1 is conducting and that diode D_2 is not conducting.

a) Find V_{R1}, I_{R1}, I_{R3}, I_{D1}, V_{R2} based on these assumptions.
   Do not recalculate if you find the assumptions are wrong.

V_{R1} = ________

I_{R1} = ________

I_{R3} = ________

I_{D1} = ________

V_{R2} = ________

Solution:

$V_{R1} := 0.7 \cdot V$

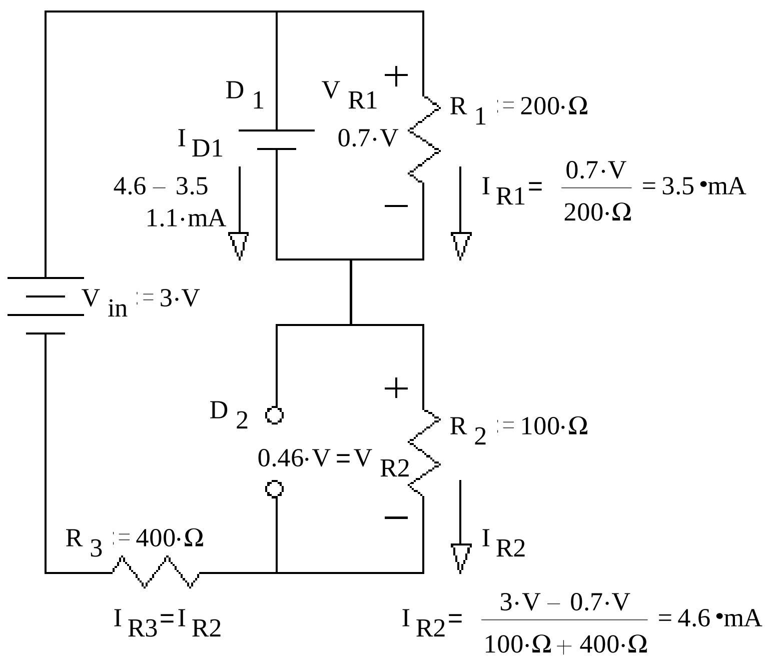
$I_{R1} := \frac{V_{R1}}{R_1}$ $\qquad I_{R1} = 3.5 \cdot mA$

$I_{R3} := \frac{V_{in} - 0.7 \cdot V}{R_2 + R_3}$ $\qquad I_{R3} = 4.6 \cdot mA$

$I_{D1} := I_{R3} - I_{R1}$ $\qquad I_{D1} = 1.1 \cdot mA$

$I_{R2} := I_{R3}$

$V_{R2} := I_{R2} \cdot R_2$ $\qquad V_{R2} = 0.46 \cdot V$



$V_{R2} = 4.6 \cdot mA \cdot 100 \cdot \Omega = 0.46 \cdot V$

(circle one)

b) Was the assumption about D_1 correct? yes no

How do you know? (Specifically show a value which is or is not within a correct range.)

yes $\quad I_{D1} = 1.1 \cdot mA > 0$

c) Was the assumption about D_2 correct? yes no

(circle one)

How do you know?

yes $\quad V_{D2} = V_{R2} = 0.46 \cdot V < 0.7V$

d) Based on your answers to b) and c), which (if any) of the following was not correctly calculated in part a.

V_{R1} $\qquad I_{R1}$ $\qquad I_{R3}$ $\qquad I_{D2}$ $\qquad V_{R2}$

(circle any number of answers)

Circle none in this case

ECE 2210 Diode Circuit Examples p2

Assume that diode D_1 does **NOT** conduct.

Assume that diodes D_2 and D_3 **DO conduct.**

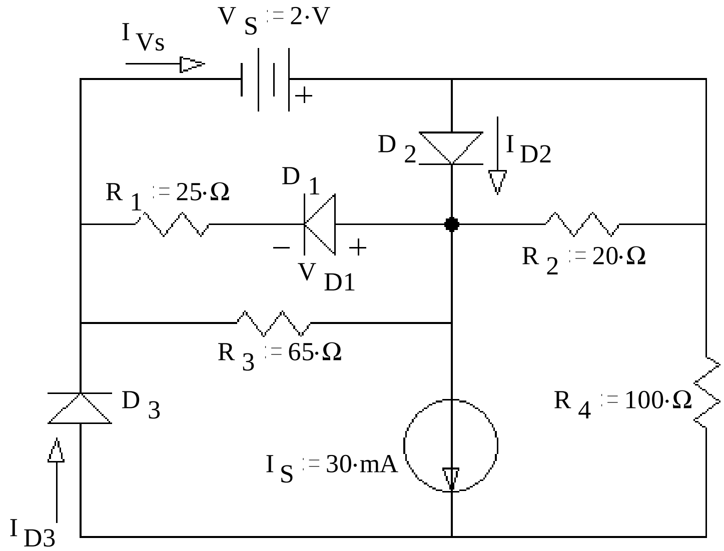
a) Stick with these assumptions even if your answers come out absurd.
Find the following:

V_{D1} = ____________

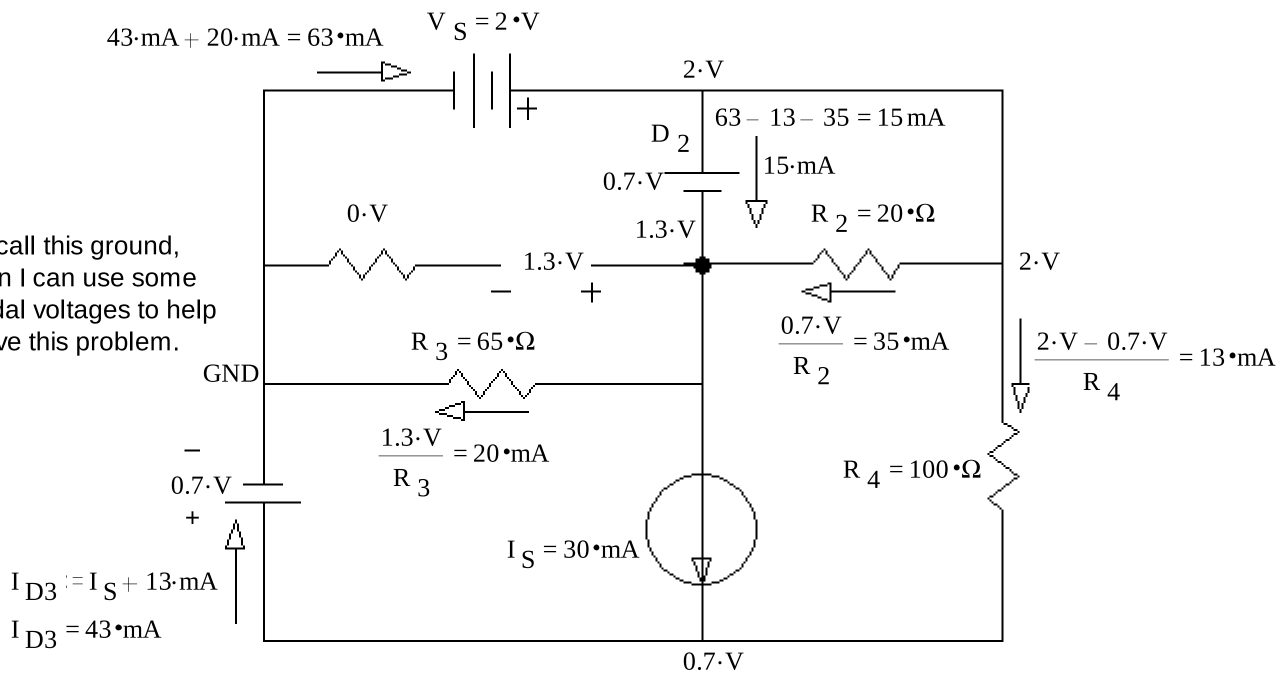
I_{D2} = ____________

I_{D3} = ____________

I_{Vs} = ____________



If I call this ground, then I can use some nodal voltages to help solve this problem.



Alternate way to find: $I_{D2} := 20 \cdot mA + I_S - \frac{0.7 \cdot V}{R_2}$ $\quad I_{D2} = 15 \cdot mA$

b) Based on the numbers above, was the assumption about D_1 correct? Circle one: yes no

How do you know? (Specifically show a value which is or is not within a correct range.) $V_{D1} = 1.3 > 0.7V$ no

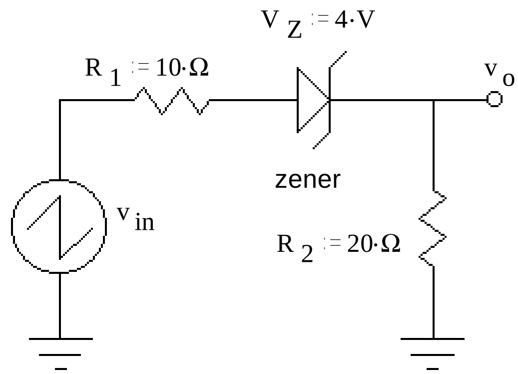
c) Based on the numbers above, was the assumption about D_2 correct? Circle one: yes no
How do you know? (Show a value & range.)

$I_{D2} = 15 \cdot mA > 0$ yes

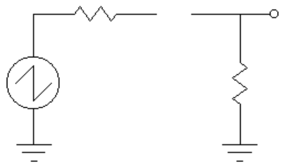
d) Based on the numbers above, was the assumption about D_3 correct? Circle one: yes no
How do you know? (Show a value & range.)

$I_{D3} = 43 \cdot mA > 0$ yes

A voltage waveform (dotted line) is applied to the circuit shown.
Accurately draw the output waveform (v_o) you expect to see.
Label important times **and** voltage levels.



If diode doesn't conduct:

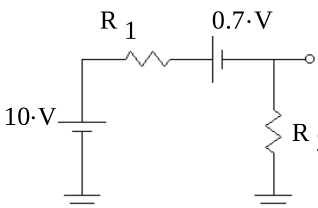


$v_o := 0$

Positive half

Diode conducts at: $0.7 \cdot V$ input at time: $\frac{0.7 \cdot V}{10 \cdot V} \cdot 10 \cdot ms = 0.7 \cdot ms$

Maximum:

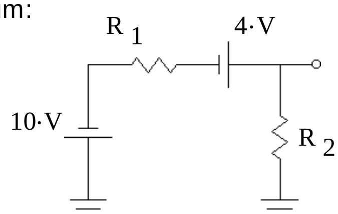


$v_o := (10 \cdot V - 0.7 \cdot V) \cdot \frac{R_2}{R_1 + R_2}$ $v_o = 6.2 \cdot V$

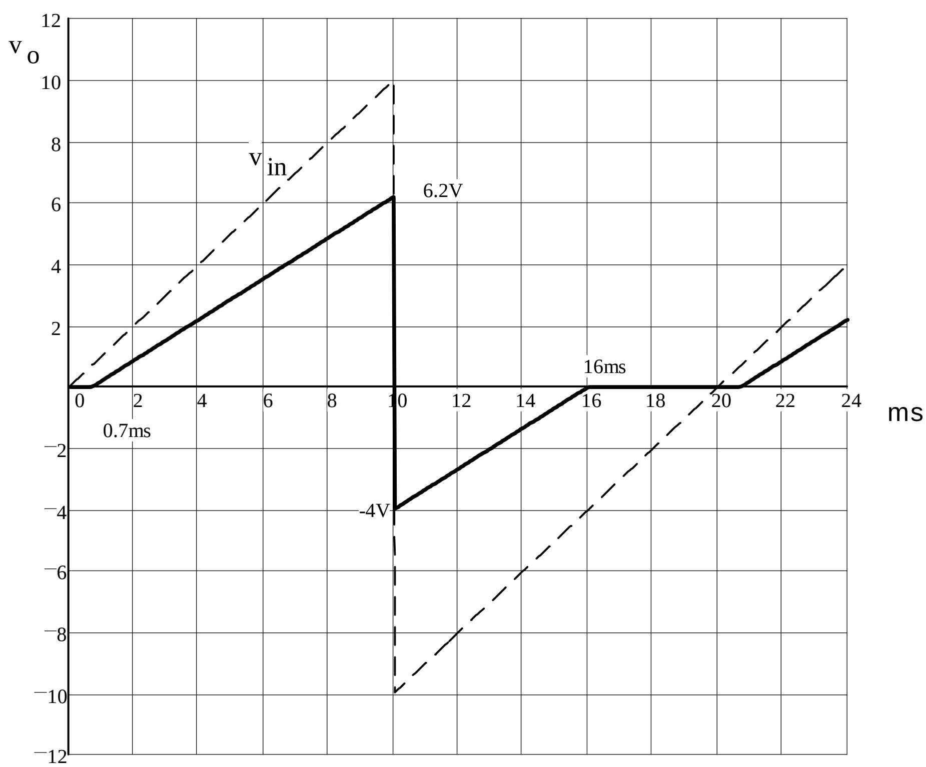
Negative half

Diode conducts at: $-4 \cdot V$ input at time: $20 \cdot ms - \frac{4 \cdot V}{10 \cdot V} \cdot 10 \cdot ms = 16 \cdot ms$

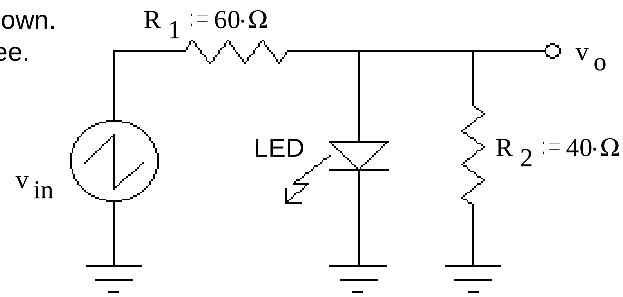
Maximum:



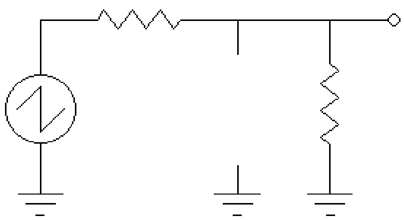
$v_o := -(10 \cdot V - 4 \cdot V) \cdot \frac{R_2}{R_1 + R_2}$ $v_o = -4 \cdot V$



A voltage waveform (dotted line) is applied to the circuit shown. Accurately draw the output waveform (v_o) you expect to see. Label important times **and** voltage levels.



If diode doesn't conduct:

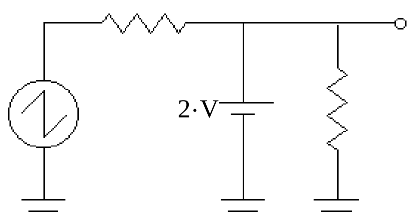


$$v_o = \frac{R_2}{R_1 + R_2} \cdot v_{in}$$

$$\frac{R_2}{R_1 + R_2} \cdot 10 \cdot V = 4 \cdot V$$

When: $v_{in} := \frac{R_1 + R_2}{R_2} \cdot 2 \cdot V$ $\quad v_{in} = 5 \cdot V$ $\quad$ at: $5 \cdot ms$ $\quad$ Diode begins to conduct

When diode conducts:



$v_o = 2 \cdot V$