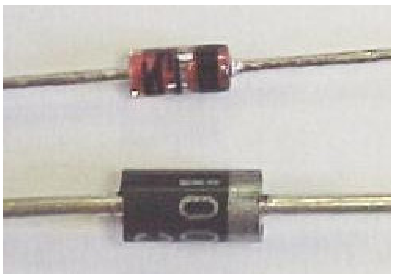
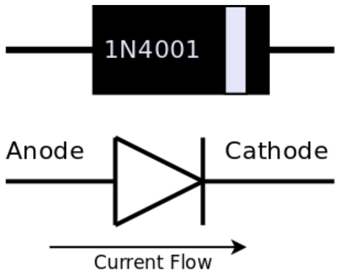
# Diodes, LEDS and Zener Diodes

## Diodes Overview

A diode is a semiconductor device that only allows current to flow in one direction. When current flows through a silicon diode there is a small potential difference across the diode of around 0.7V. A diode has a maximum current rating and a maximum reverse breakdown voltage rating - exceeding either of these will damage the diode.



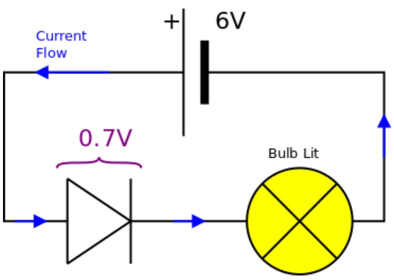



A diode has two leads called the anode and the cathode and current can only flow from the anode to the cathode.

Typical silicon diodes include the small 1N4148 signal diode which can take a current of around 200 mA and the slightly more robust 1N4001 which has a maximum current rating of 1 A and a reverse breakdown voltage of 50 V. In both cases the cathode is marked with a ring on the body of the diode.

## Forward Bias

When a diode is connected so that current can flow from the anode to the cathode it is forward biased as shown in the diagram.

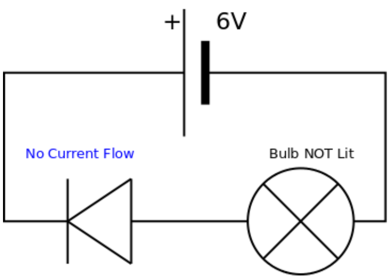



In this example the forward bias voltage across the diode is 0.7 V and the potential difference across the bulb is 5.3 V.

As current flows through the diode and there is a 0.7 V potential difference it will dissipate power and get warm. If too much current flows then the diode will be damaged. All diodes have a maximum forward bias current.

## Reverse Bias

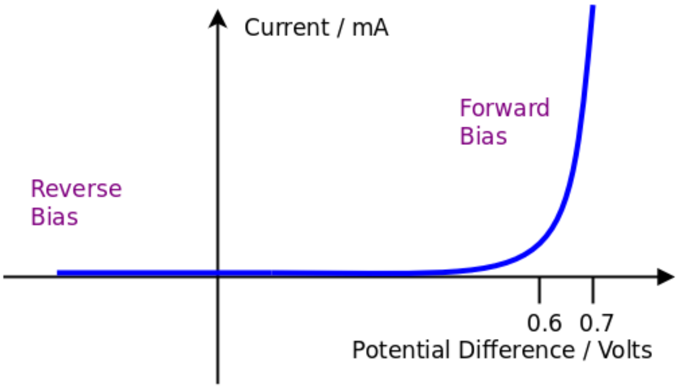
When a diode is connected so that no current can flow it is reverse biased as shown.




No current flows in the circuit and the potential difference across the bulb is 0 V. Therefore, the (reverse) potential difference across the diode is 6 V. If the reverse bias voltage is too high the diode will be damaged. All diodes have a maximum reverse bias voltage.

## Transfer Characteristics

The transfer characteristics of a device describe how the current changes as the potential difference changes.




In reverse bias the current remains zero even when the potential difference increases to several volts.

In forward bias the current is initially zero when the potential difference is less than 0.6V and then rapidly increases as the potential difference increases to 0.7V.

**Important Note** The forward bias potential difference does not exceed 0.7V, if current flows through the diode, the potential difference is around 0.7V. This means that a diode is almost always used in series with other components.

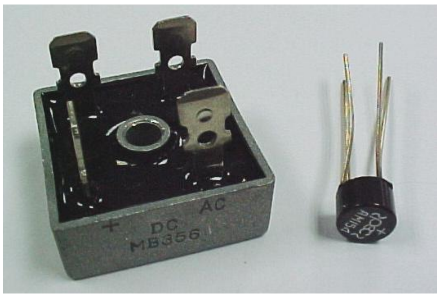
The diode is a non-ohmic component. It has a very high resistance when V < 0.6V. The resistance rapidly falls to a very low value when V > 0.6V, approximately 0Ω when V = 0.7V.

## Use as a Protection Diode

When any device containing a coil of wire, such as a relay, electric motor or solenoid, is turned OFF a very large reverse voltage is generated for a very short time. This voltage is called the back E.M.F. and can be several hundred volts from even small relays and motors used at low voltages. The back E.M.F. can easily damage logic gates, Op-Amps and transistors.

A diode placed in reverse bias across the device can protect the rest of the circuit. When the device is operating normally the diode is reverse biased and does not conduct (and therefore has no effect whatsoever). When the device is turned off the large back E.M.F. momentarily forward biases the diode, the diode conducts and limits the back E.M.F. to 0.7V above the power supply voltage. Instead of the control circuit being subject to hundreds of volts, it now only has to cope with 12.7V which is much more reasonable.

## Use in Rectification



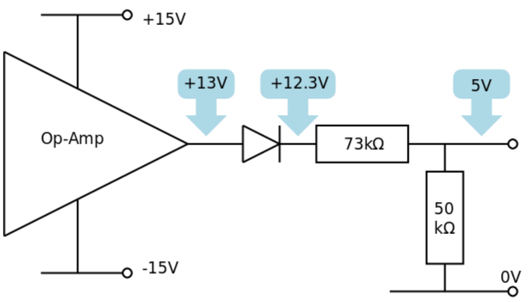

A diode, or several diodes, can be used to convert A.C. into D.C. by only allowing current to flow in one direction. Rectifier diodes can usually handle large forward bias currents and have a reverse breakdown voltage greater than the peak voltage of the A.C. being rectified.

# Use as a Reference Voltage

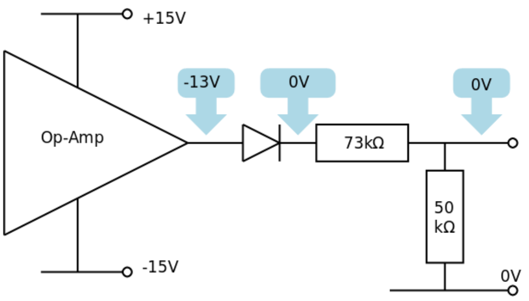
The fact that the potential difference across a diode is almost constant at 0.7V when a current flows means that it can make a useful voltage reference. In the diagram the output voltage is always 0.7V even when the input voltage varies. This could be used as the reference voltage in a comparator circuit.

# Used to make Logic Level signals

Consider a circuit where the ±13V output from a comparator circuit needs to be connected to a logic circuit working at 5V. The output of the comparator is ±13V but the input to the logic circuit needs to be either 5V or 0V.



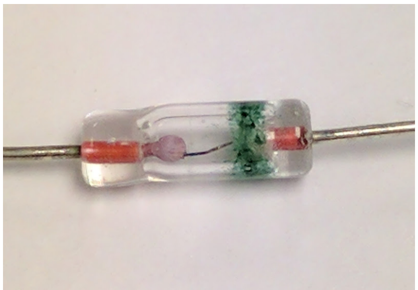

When the output from the comparator is +13V the diode is forward biased and conducts. The potential divider is used to create a 5V Logic signal (Logic 1). The voltage drop across the diode is 0.7V and so the potential divider must reduce 12.3V to 5V.




The potential difference across the two resistors are in the ratio 7.3:5 and therefore a 73kΩ and a 50kΩ resistor are used. In reality values from the E24 series such as 68kΩ and 47kΩ would be used.

When the output from the comparator is −13V the diode is in reverse bias. No current flows and the output voltage is 0V (Logic 0).

# Other Diodes

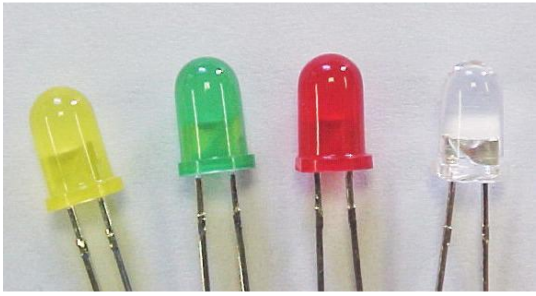


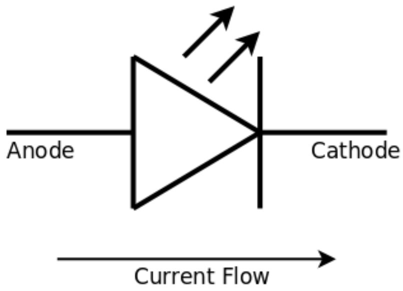
When we talk about a diode we are almost invariably talking about a silicon diode. Diodes are also made from a semiconductor called Germanium. A Germanium diode has a very low forward bias potential difference of around 0.1V making them ideal for use in very low voltage circuits.

A typical application of Germanium diodes is as the demodulator in a simple A.M. radio.

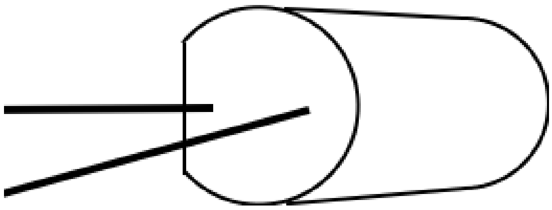
# Light Emitting Diodes Overview

Light Emitting Diodes (LEDs) are ubiquitous in electronics and are the focus of much current research and development. LED bulbs provide environmentally acceptable alternatives to traditional incandescent bulbs, LED lasers power the Internet and OLED displays have revolutionised smart phones and TVs.



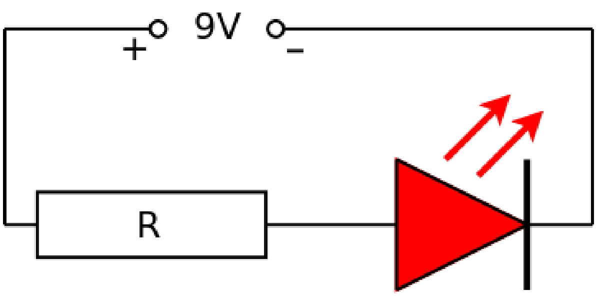



The humble LED used in school electronics comes in many shapes and sizes but, most commonly, they are circular with a diameter of 5 mm and come in a range of colours from Red to Blue.



Like a silicon diode, LEDs have an anode and a cathode. The cathode is marked by a flat side on the LED casing and by the shorter of the two legs. It is important to know which way round to connect an LED as they only allow current to flow in one direction which is from the anode to the cathode.

## Forward Bias



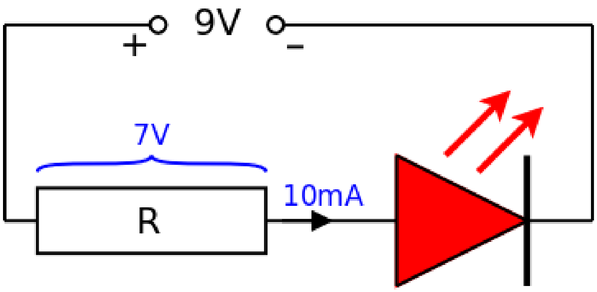

An LED is forward biased when current can flow from the anode to the cathode.

When current flows through the LED there is a potential difference across the LED of around 2V although this can depend on the type and colour of LED being used.

If the supply voltage is less than 2V no current will flow and the LED will not light.

In almost all cases LEDs are used with power supplies greater than 2V and a series resistor is essential to stop the LED being damaged. In this case the series resistor limits the current flowing through the LED.

## Series Resistor Calculation




All LEDs have a different forward bias voltage and a different optimal current.

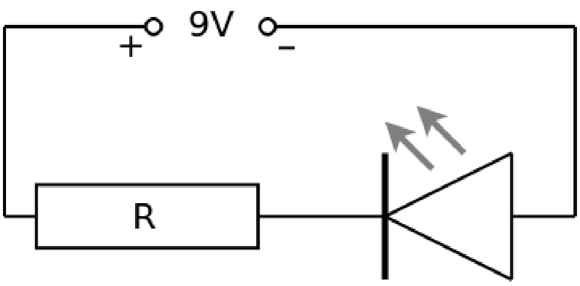
As a general rule, normal 5mm indicator LEDs have a forward bias voltage of about 2V and take a current of about 10mA to 20mA. This means they can easily be controlled directly by logic gates and Op-Amps.

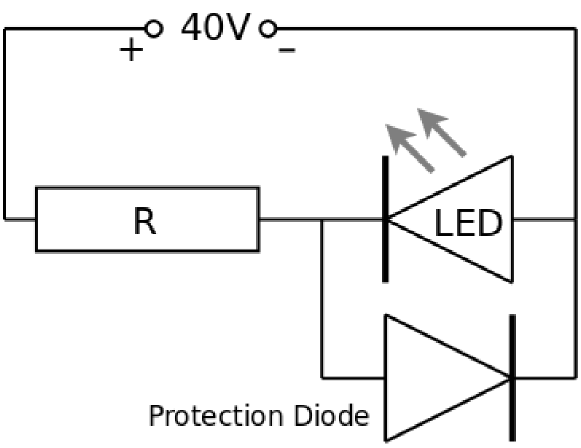
To calculate the value of the series resistor, calculate the potential difference across the resistor. In the example the supply voltage is 9V and the LED forward bias voltage is 2V therefore the voltage across the resistor is 7V. Knowing the desired current through the LED (and therefore through the resistor) use the resistor equation to calculate the value of the series resistor. In the example V = 7V and I = 10mA giving:

$$R = 7 \div 0.01 = 700\Omega$$

Choose the most appropriate resistor form the E24 series.

## Reverse Bias



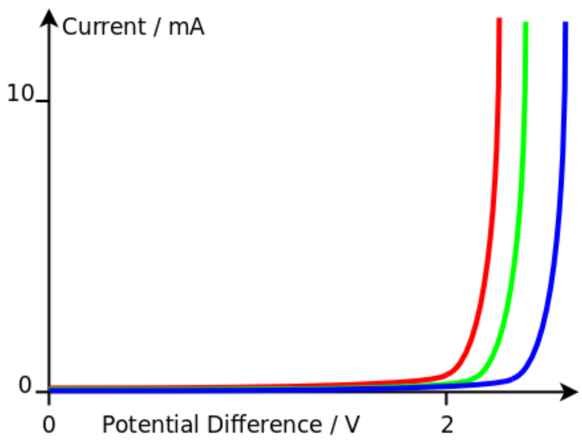

In reverse bias, current cannot flow from the cathode to the anode and the LED does not light.

If the reverse bias voltage across an LED is too great (> about 20V) then the LED can be damaged.

To avoid this a regular silicon protection diode can be connected in parallel with the LED but the other way round. When the LED is reverse biased, the diode is forward biased and will conduct through the LED's series resistor. As the diode is conducting, the potential difference across the diode, and hence across the LED, is limited to around 0.7V which is perfectly acceptable. When the LED is forward biased and hence lit, the protection diode is reverse biased and does not conduct.

## Transfer Characteristics

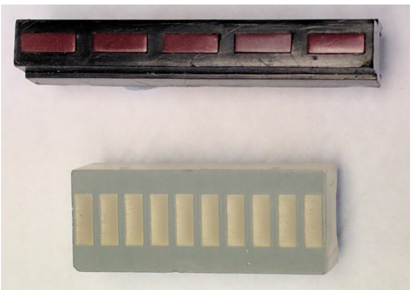
The transfer characteristics show how the current through the LED changes as the potential difference changes.




LEDs do not conduct when reverse biased and so the current in zero, the LED is not illuminated.

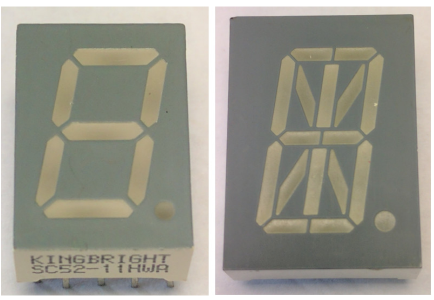
When forward biased, different colour LEDs start to conduct at different forward bias voltages. RED LEDs are turned on most easily requiring a little less than 2V whereas the BLUE LEDs require a higher forward bias voltage of closer to 3V. Note that in all cases LEDs require a greater forward bias voltage than regular silicon diodes which only require 0.7V.

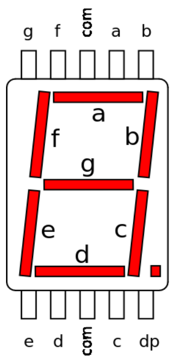
## LED Arrays



An LED array is simply a series of individual LEDs packaged together to make a single display unit. The LEDs are all electrically separate and each element of the array requires a series resistor. These are useful for bar graphs and VU meters as well as being used to make futuristic looking machines in old school Si-Fi movies.

## 7 Segment Displays




The 7 segment display is an arrangement of 7 LEDs and a separate LED for the decimal place. The display can form the digits 0-9 to display decimal numbers and can also form the letters A-F allowing Hexadecimal to be displayed. The more complex 16 segment display can be used to display all the letters of the alphabet.

In a 'Common Cathode' 7-segment display the cathodes of all eight LEDs are connected to a common pin which is connected to 0V. Each separate segment of the display should have its own series resistor. Each segment is connected to +Ve to illuminate the display. In a 'Common Anode' 7-seg display, all eight anodes are connected to a common pin which is connected to the +Ve supply. Each segment is connected separately to 0V via its own series resistor to illuminate the display.

## High Power LEDs

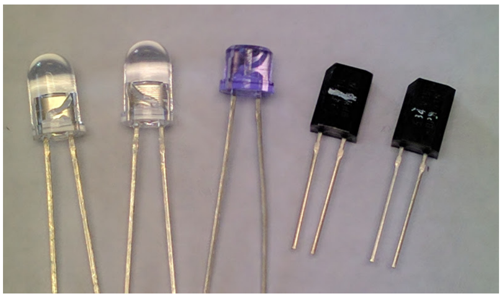
High power LEDs are just like regular LEDs except that they

(a) often require a heatsink

(b) take a LOT more current and so can not be easily controlled directly by logic gates

(c) are very bright so you need to take care not to damage your eyesight.

## Infrared LEDs

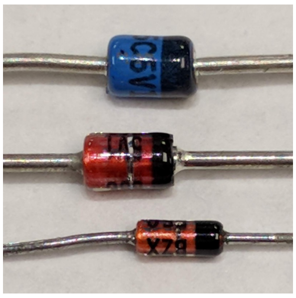


Infrared (IR) LEDs are exactly like regular LEDs except that they do not emit visible light. This makes them harder to test therefore a multimeter must be used.

IR LEDs are commonly used in remote control handsets for TVs etc or in IR security lighting.

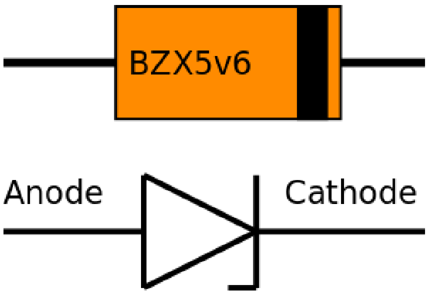
# Zener Diodes Overview

A zener diode is a type of diode that conducts in both directions. In forward bias a zener diode behaves exactly like a standard silicon diode. In reverse bias a zener diode will conduct and allow current to flow when the applied voltage is greater than the zener voltage.



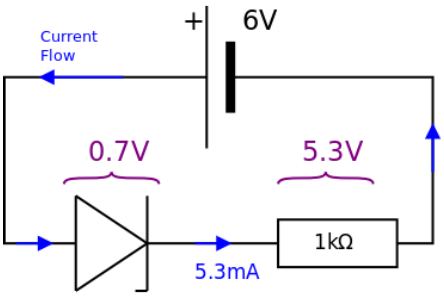
The zener voltage is a characteristic of a zener diode. Any given zener diode has a very specific fixed zener voltage. Zener diodes are available in many different zener voltages ranging from 1.8 V up to voltages in excess of 100 V.

The maximum power handling is an important characteristic of a zener diode. When current flows through a zener diode it dissipates energy and heats up. The power handling of a zener diode determines how much power can be dissipated without damaging the zener diode.




Zener diodes can be identified by the letter "Z" in the name or by having the zener voltage as part of the name. For example a 1N4148 is a regular silicon diode whereas a BZX85c5v6 is a zener diode with a zener voltage of 5.6 volts. In the image of zener diodes the blue and red examples are labelled 5v1 and the smaller orange one is labelled BZX.

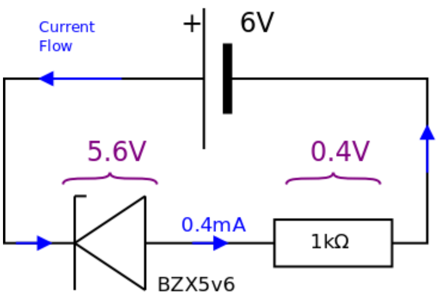
## Forward Bias




When the anode is connected to the battery positive the zener diode is forward biased and it behaves in the same way as a silicon diode.

The forward bias voltage across the zener diode is 0.7 V and the potential difference across the 1 kΩ resistor is 5.3 V so that a current of 5.3 mA flows in the circuit.

## Reverse Bias

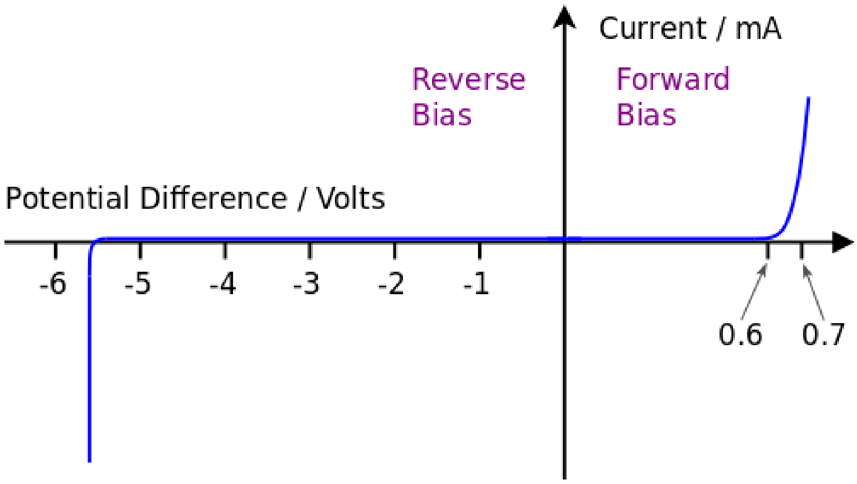



When the cathode is connected to the battery positive the zener diode is reverse biased. The battery voltage is greater than the zener voltage (5.6 V) and so the zener diode conducts. The voltage drop across the zener diode is maintained at 5.6 V and the potential difference across the 1 kΩ resistor is therefore 0.4 V leading to a circuit current of 0.4 mA.

In reverse bias, the power dissipated by the zener diode is 5.6 V × 0.4 mA = 2.2 mW.

## Transfer Characteristics

The transfer characteristics of a device describe how the current changes as the potential difference changes.




In forward bias the current is initially zero when the potential difference is less than 0.6V and then the current rapidly increases as the potential difference increases to from 0.6V to 0.7V. The forward bias potential difference does not exceed much more than 0.7V when current flows through the zener diode and therefore the zener diode is used in series with other components.

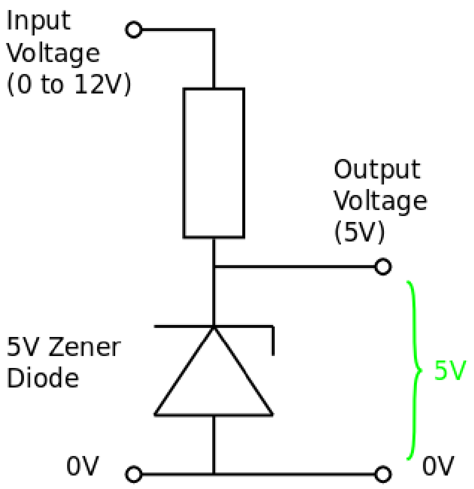
In reverse bias the current is initially zero when the potential difference is less than the zener voltage. When the potential difference exceeds the zener voltage the current rapidly increases. The reverse bias potential difference across the zener diode is almost constant once current flows and so the zener diode must be used in series with other components.

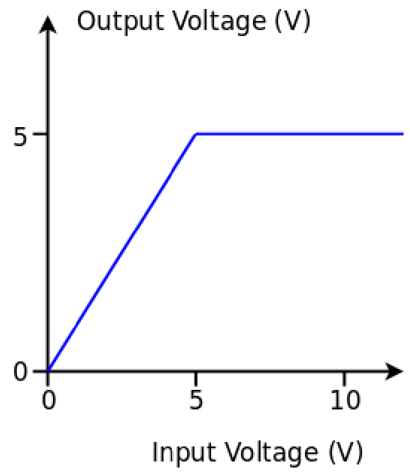
**Note:** There must be a few milliamps of current flowing through the zener diode before the reverse bias voltage remains constant as can be seen by the corner on the graph.

In both forward bias and reverse bias the zener diode is a non-ohmic component having a very high resistance when the potential difference is low but reducing to a very low resistance for greater potential differences.

## Use as a Regulator

In reverse bias a zener diode acts as a very basic voltage regulator. A variable input voltage will result in a (relatively) constant output voltage.



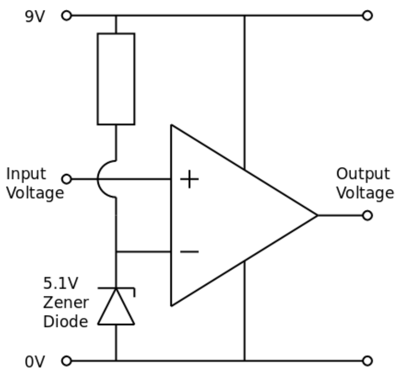




When the potential difference across the zener diode is less than the zener voltage no current flow through the zener diode. Assuming no current flows through the load, the potential difference across the resistor will be zero and the output voltage is the same as the input voltage. If current flows through the load, the output voltage will be less than the input voltage due to the potential difference across the resistor.

When the input voltage is greater than the zener voltage the zener diode conducts in reverse bias, current flows through the resistor to ensure the potential difference across the zener diode remains constant. Therefore the output voltage remains constant even when the input voltage changes.

## Use with a Comparator

A zener diode can be used as a reference voltage in a comparator circuit.



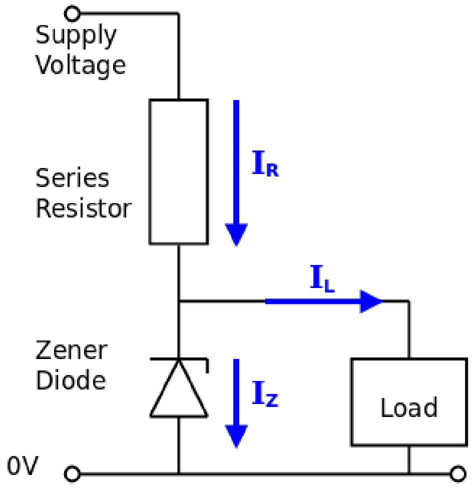

The zener diode in reverse bias and the series resistor provide a fixed voltage at the inverting input of the operational amplifier. In the diagram, this is 5.1V.

When the input voltage is less than 5.1V the output of the Op-Amp comparator is approximately 0V. When the input voltage is greater than 5.1V the output of the Op-Amp comparator is approximately 9V.

The advantage of using a zener diode to provide a reference voltage rather than a potential divider or potentiometer is that the reference voltage remains fixed even if the power supply voltage fluctuates. When a potential divider is used to provide a reference voltage, changes in the supply voltage result in changes in the reference voltage.

# Calculating Series Resistor Value

Used in reverse bias, a zener diode always needs a suitable series resistor. The resistor value must be low enough to allow adequate current to flow through the zener diode and the circuit (the load) connected in parallel with the zener diode. The resistor value must be high enough to avoid damaging the zener diode if too much power is dissipated.




There are two situations to consider:

Situation 1: Knowing the maximum power handling of the zener diode, calculate a suitable value for the series resistor and then calculate the maximum current that can flow through the load.

Situation 2: Knowing what current the load requires, calculate a suitable value for the series resistor and then choose a zener diode with a suitable power rating.

**Example 1:** A 5.6 V zener diode is rated at 500 mW. What series resistor is needed for use with a 12 V supply? How much current can be provided to the load if the zener diode requires a minimum reverse bias current of 4 mA?

From the diagram it can be seen that current in the resistor = current in zener diode + current in load. The maximum current will flow in the zener diode, and maximum power will be dissipated, when the load is disconnected and takes zero current.

Using I = P ÷ V gives $I_Z$ = 0.5 ÷ 5.6 = 0.089 A or 89 mA. Maximum current that can flow in zener diode must be limited to 89 mA

Potential difference across the resistor = 12 − 5.6 = 6.4 V

When the load takes no current, $I_R$ = $I_Z$ = 89 mA

Using R = V ÷ I gives R = 6.4 ÷ 0.089 = 71 Ω (so use 75 Ω from the E24 series)

With R = 75 Ω and V = 6.4 V, the current in the series resistor is I = 6.4 ÷ 75 = 85 mA, therefore the maximum current that can be provided to the load is 81 mA (85 mA flowing through the series resistor − 4 mA required by the zener diode)

**Example 2:** A load requires a steady voltage of 5.1 V and a current of 2 A. What value of series resistor must be used if the supply voltage is 12 V and the zener diode requires a reverse bias current of 20 mA? What must be the power rating of the zener diode?

The load requires a current of 2 A and the zener diode needs 20 mA (0.02 A) therefore the resistor current is 2.02 A

The potential difference across the resistor is 12 − 5.1 = 6.9 V

Using R = V ÷ I gives R = 6.9 ÷ 2.02 = 3.4 Ω so use the next lowest value (to ensure the minimum current is available) of 3.3 Ω from the E24 series.

Using R = 3.3 Ω gives a current of I = 6.9 ÷ 3.3 = 2.09 A

In the worst case scenario, when the load is disconnected ($I_L$ = 0), all of the current flowing through the resistor must flow through the zener diode.

The maximum power rating of the zener diode is given by P = V × I

and so P = 5.1 × 2.09 = 10.7 W

**Note:** The above example is a very poor way to derive a steady 5V from a 12V supply. There are much better methods but the example shows how the calculations should be done.

# Website

https://www.electronicsteaching.com/Electronics_Resources/DocumentIndex.html