CO2037 – Electrical Electronic Circuits

Diode and Its Applications

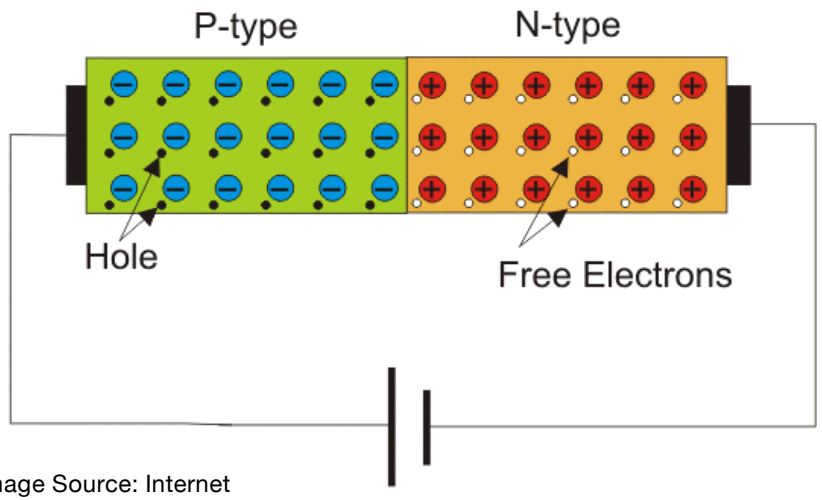
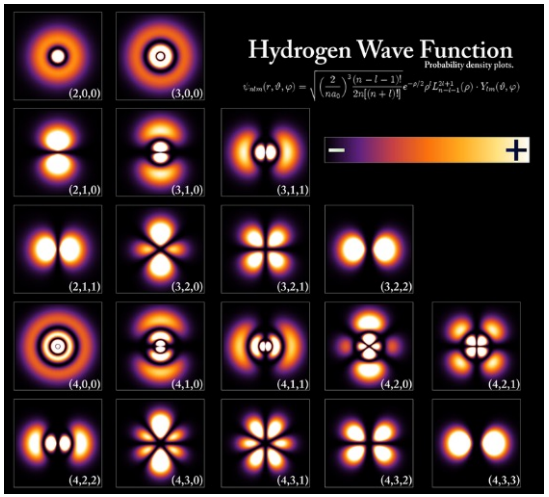
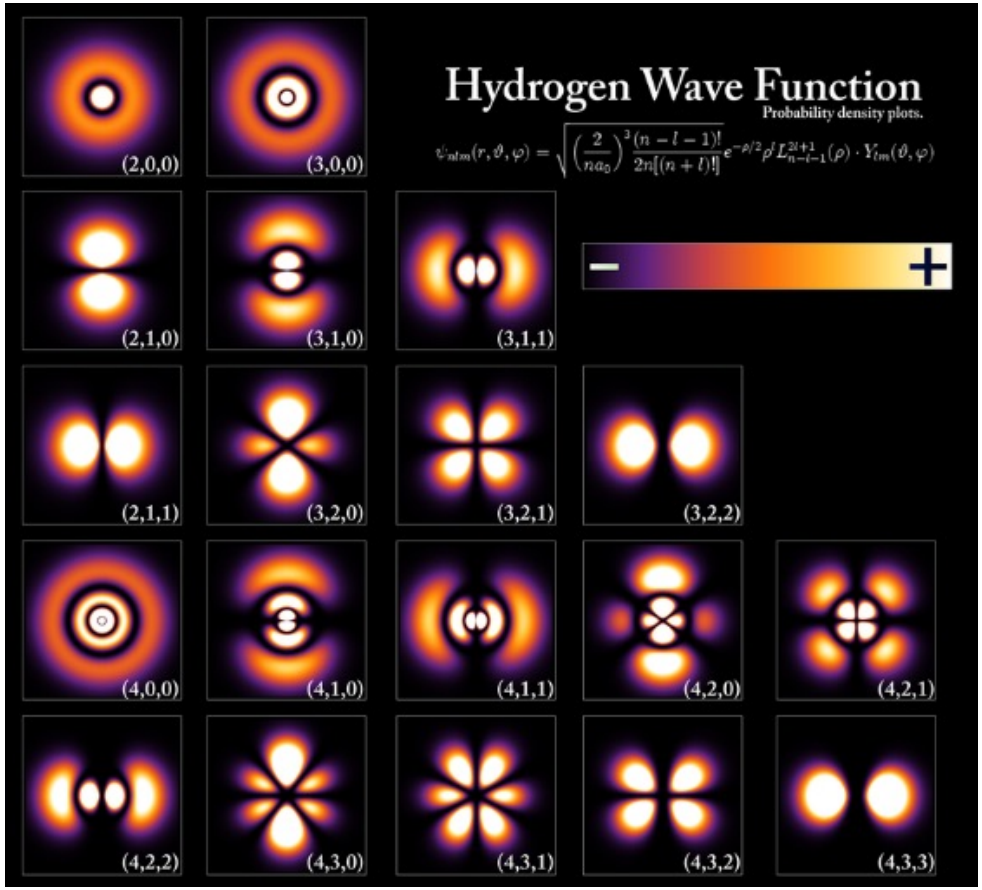


Image Source: Internet



Diode and Its Applications

- Introduction to semiconductor
- Diode
- Applications



Semiconductor

- Semiconductors are a special class of elements having a conductivity between that of a good conductor and that of an insulator.
- Two classes: **single-crystal** and **compound**
- The three semiconductors used most frequently in the construction of electronic devices are Ge, Si, and GaAs.

Germanium (Ge)

- The discovery of the diode in 1939 and the transistor in 1947 germanium was used almost exclusively

- Advantages
  - Easy to find
  - Fairly large quantities
  - Easy to refine to obtain very high levels of purity

- Disadvantage
  - Sensitivity to changes in temperature

Silicon (Si)

- 1954 the first silicon transistor was introduced

- Advantages
  - Less temperature sensitive
  - The most abundant materials on earth
  - High levels of purity

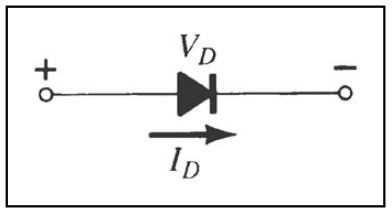
- Disadvantage
  - Sensitive to issues of speed.

Gallium Arsenide (GaAs)

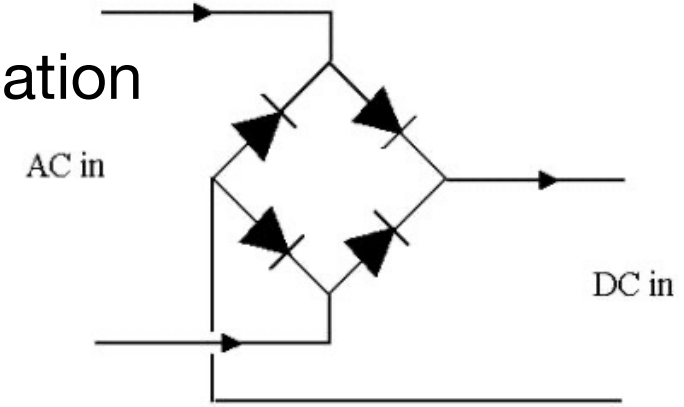
- The first GaAs transistor in the early 1970s.
- New transistor had speeds of operation up to five times that of Si.
- GaAs was more difficult to manufacture at high levels of purity, was more expensive.
- Today, it is often used as the base material for new high-speed, very large scale integrated (VLSI) circuit designs.

Diode

- The diode is the simples and most fundamental non-linear circuit element

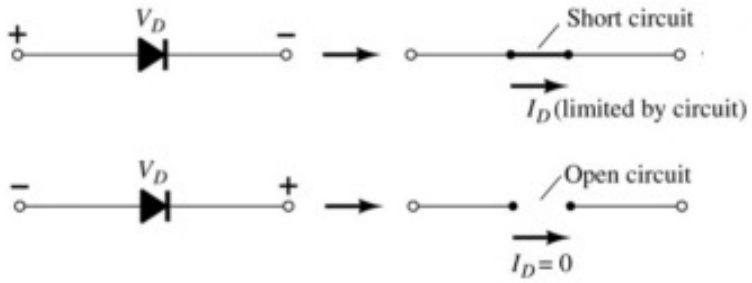


- Like a resistor, it has two terminals
- Unlike a resistor, it has a non-linear current-voltage characteristics.
- Its use in rectifiers is the most common application



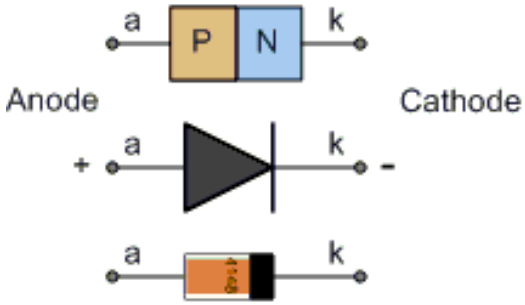
Diode

- Diode is an electric device which allows current to flow only in one direction.

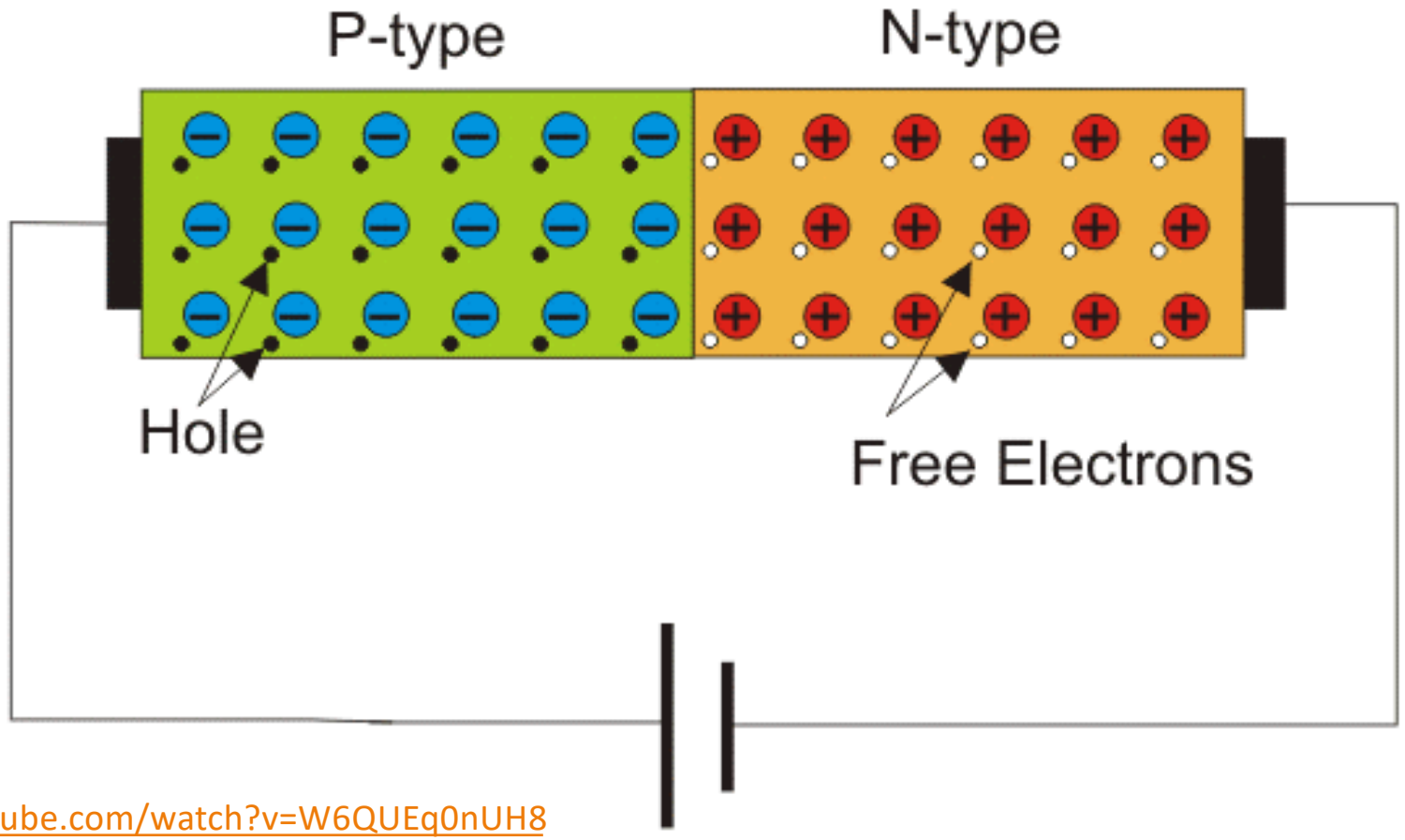


- The voltage applied to the semi conductor diode is referred to as bias voltage

- There are two types of bias voltage
  - Forward biased
  - Reversed biased

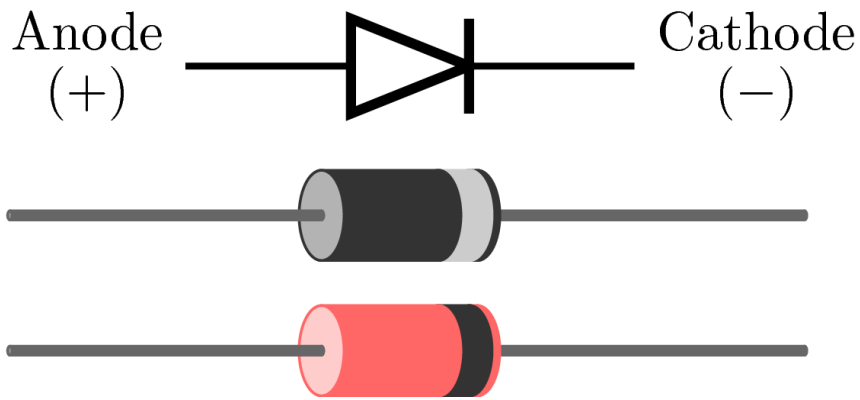


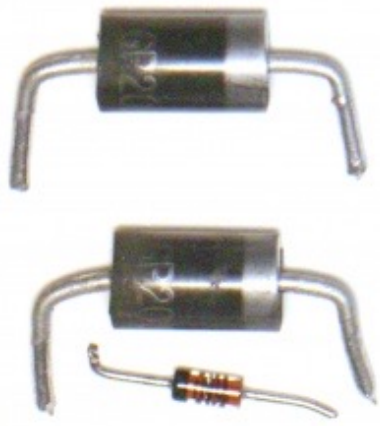
PN Junction and Diode (Video)



https://www.youtube.com/watch?v=W6QUEq0nUH8

Diodes

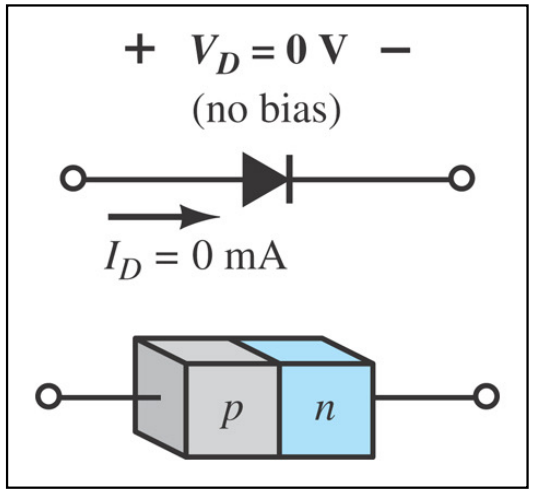




- Diode is composed of **P** and **N** semiconductors
- Diode is **ON** when $V_{AC} \geq 0.7V$
- Diode if **OFF** when $0 \geq V_{AC} \geq -1000V$
- Out of this range, diode is broken

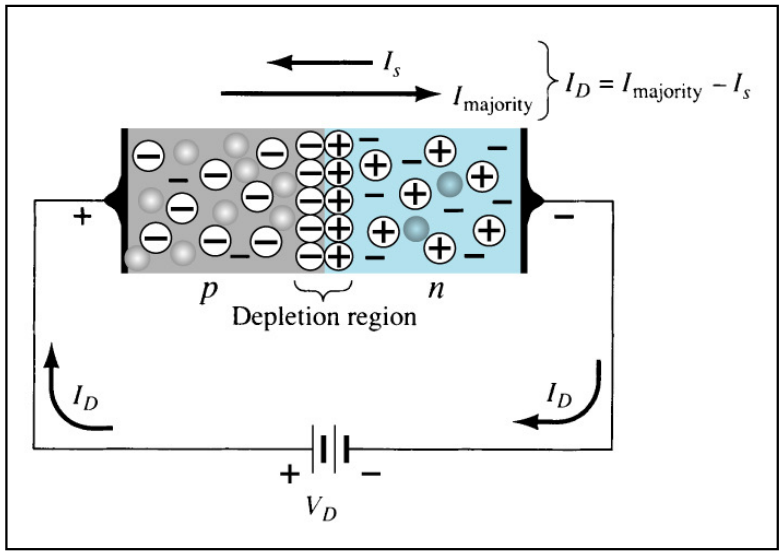
Diode – No Bias

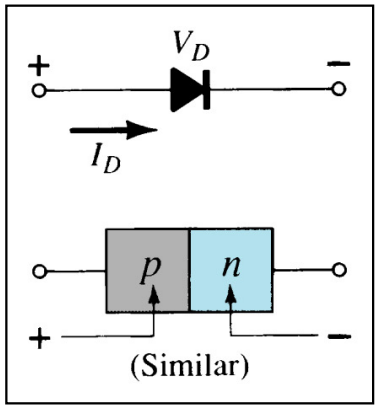
- No external voltage is applied: $V_D = 0$ V
- There is no diode current: $I_D = 0$ A
- Only a modest depletion region exists



Diode – Forward Bias

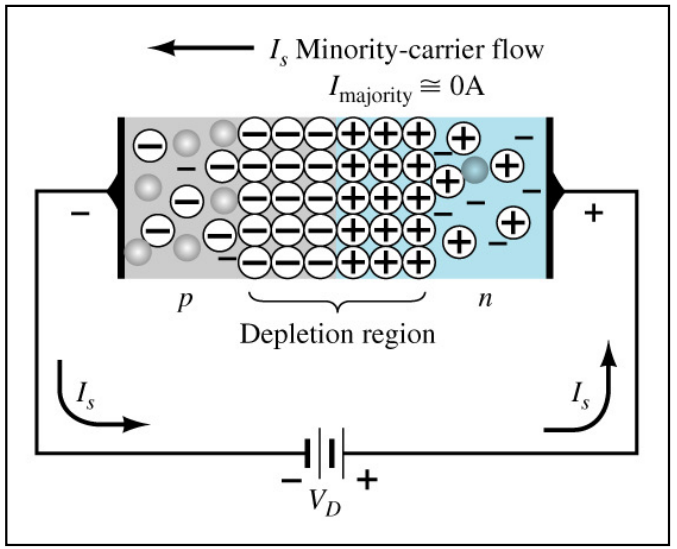
- External voltage is applied across the *p*-*n* junction in the same polarity as the *p*- and *n*-type materials.
- The forward voltage causes the depletion region to narrow.
- The electrons and holes are pushed toward the *p*-*n* junction.
- The electrons and holes have sufficient energy to cross the *p*-*n* junction

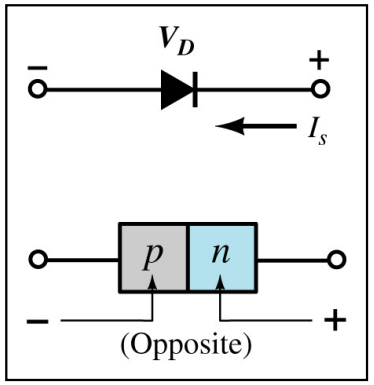




Diode – Reverse Bias

- External voltage is applied across the *p*-*n* junction in the opposite polarity of the *p*- and *n*-type materials.
- The reverse voltage causes the depletion region to widen.
- The electrons in the *n*-type material are attracted toward the positive terminal of the voltage source.
- The holes in the *p*-type material are attracted toward the negative terminal of the voltage source.





Diode Equivalent Circuit

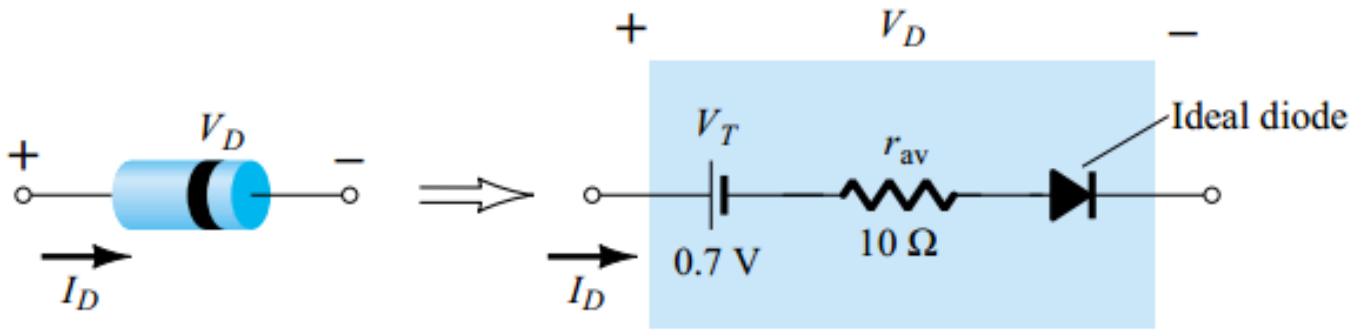
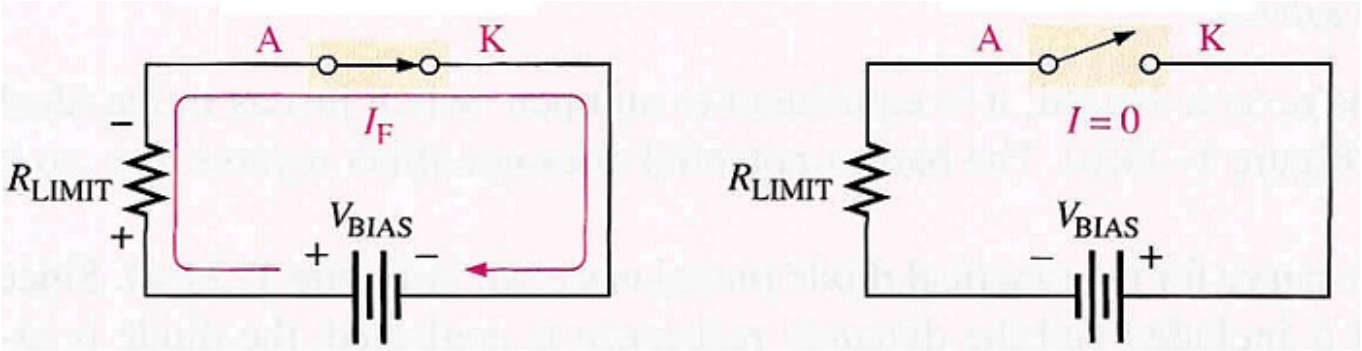


Figure 1.32 Components of the piecewise-linear equivalent circuit.

Ideal Diode Model

- Works as a switch
  - Forward bias (switch is close)
  - Reverse bias (switch is open)
- Threshold battery voltage and internal resistance are ignored.

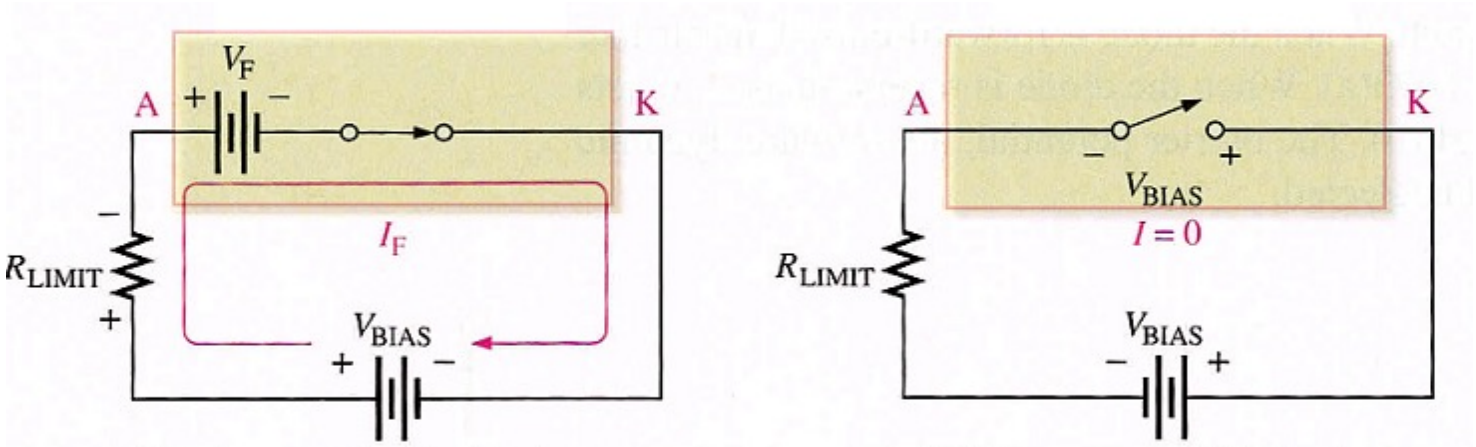


$$I_F = \frac{V_{BIAS}}{R_{LIMIT}}$$

Forward bias **Reverse bias**

Practical Diode Model

$$I_F = \frac{V_{BIAS} - V_F}{R_{LIMIT}}$$



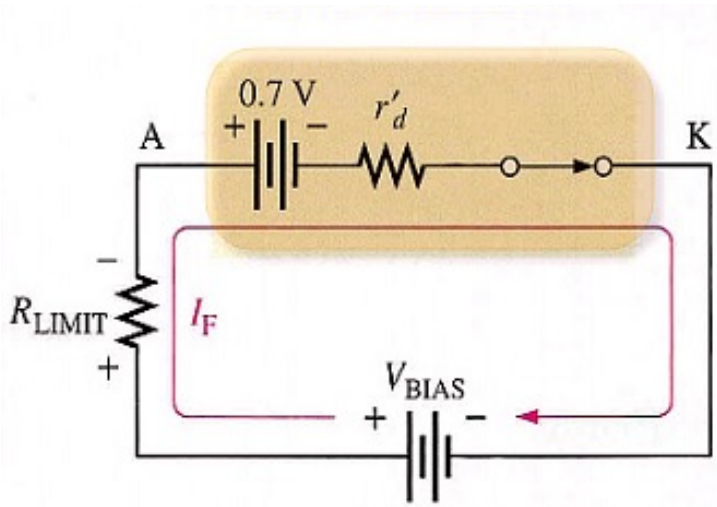
Forward bias **Reverse bias**

- **Constants**
  - Silicon Diode: $V_F = 0.7V$ ($V_F = V_{BIAS}$ if $V_{BIAS} < 0.7V$)
  - Germanium Diode: $V_F = 0.3V$ ($V_F = V_{BIAS}$ if $V_{BIAS} < 0.3V$)

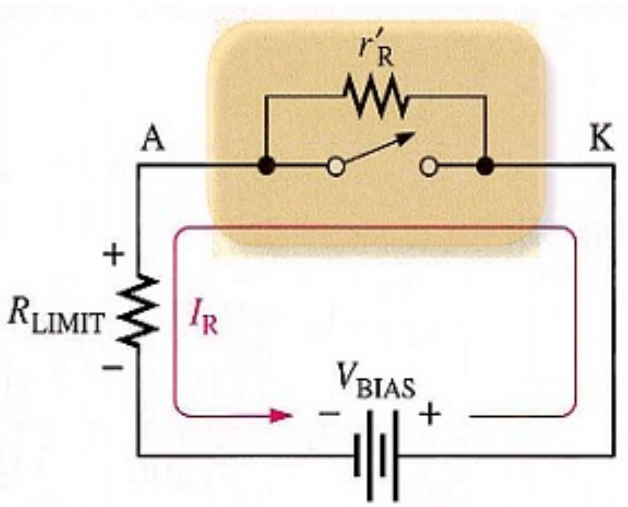
Complete Diode Model

$$I_F = \frac{V_{BIAS} - 0,7\,V}{R_{LIMIT} + r'_d}$$

$$I_R = \frac{V_{BIAS}}{R_{LIMIT} + r'_R}$$



Forward bias

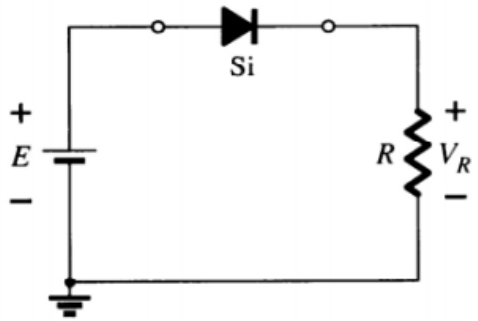


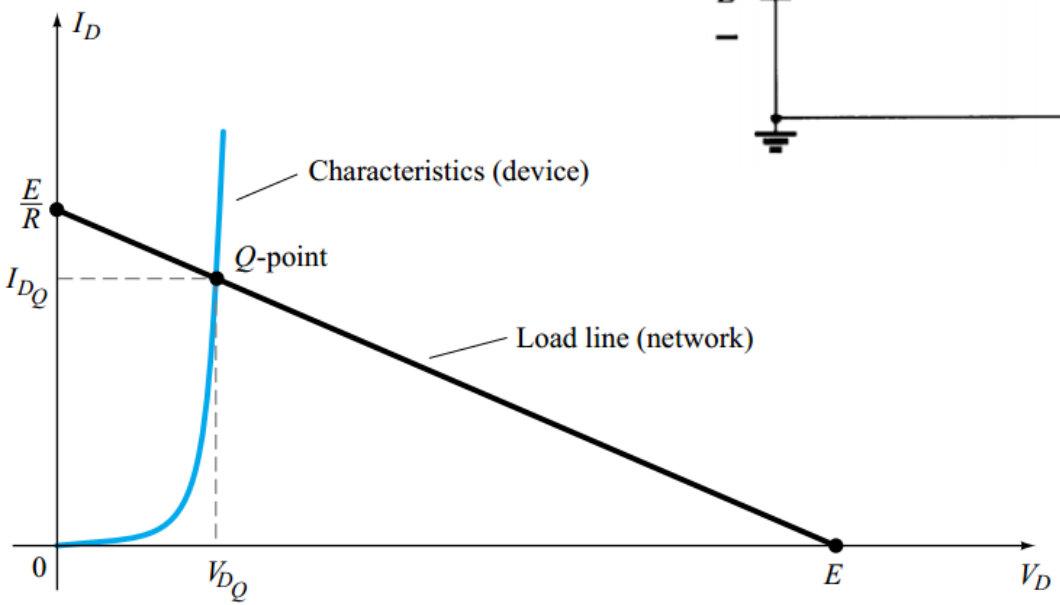
Reverse bias

Load-Line Analysis

The load line plots all possible combinations of diode current (I_D) and voltage (V_D) for a given circuit. The maximum I_D equals E/R, and the maximum V_D equals E.

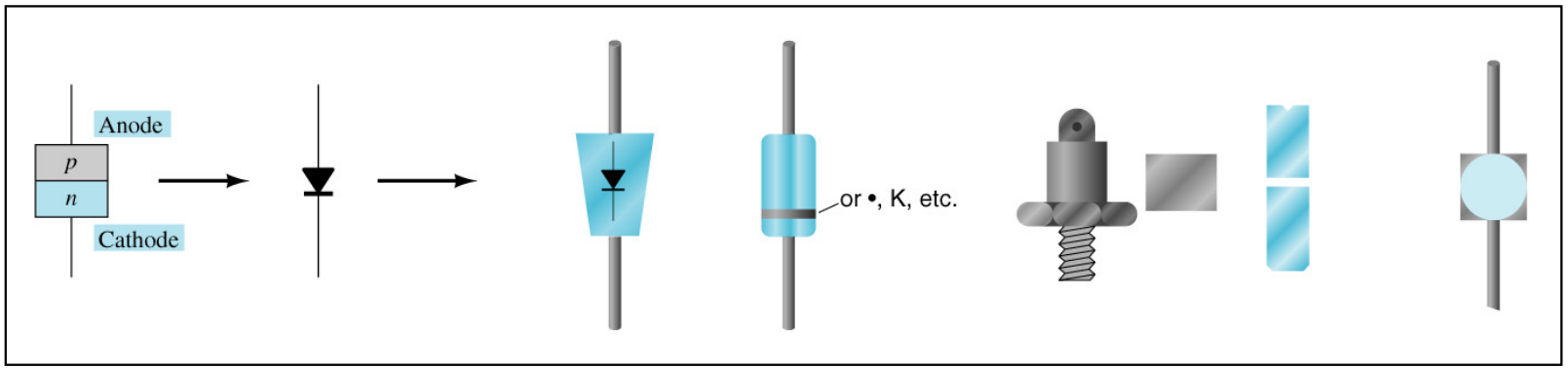
The point where the load line and the characteristic curve intersect is the Q-point, which identifies I_D and V_D for a particular diode in a given circuit.





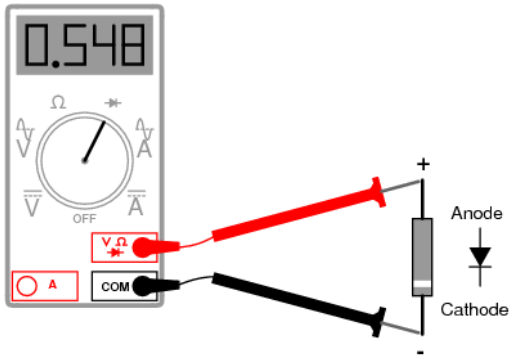
Diode Symbol and Packaging

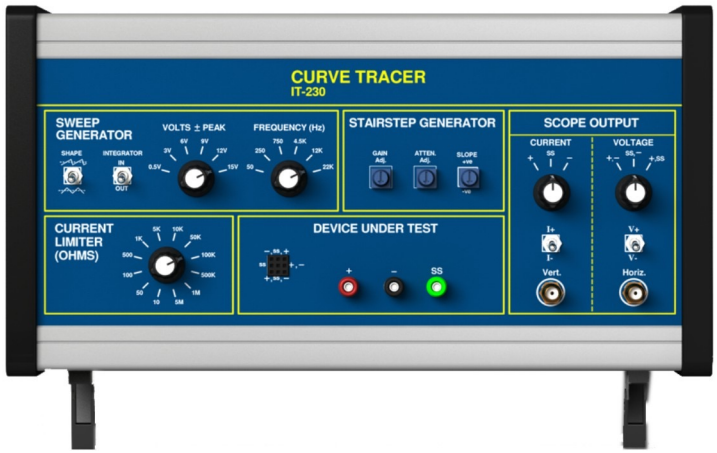
- The anode is abbreviated A
- The cathode is abbreviated K



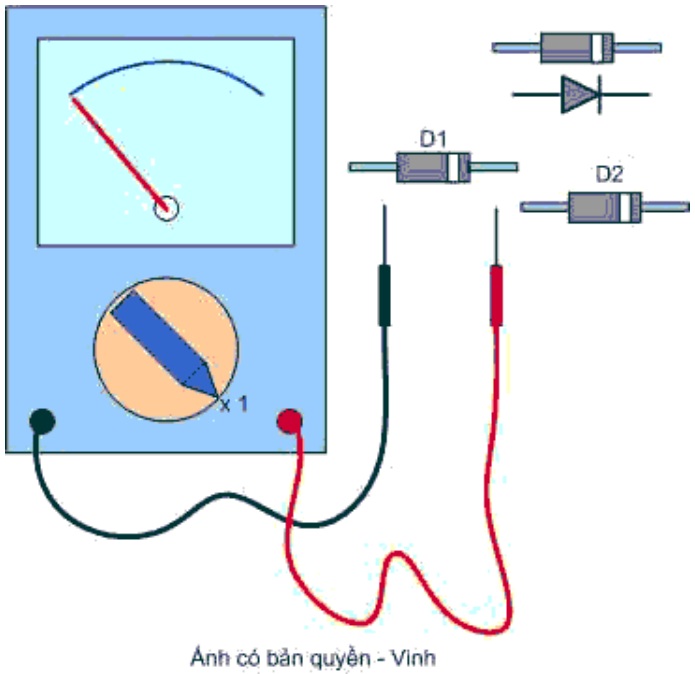
Diode Testing

- Diodes are commonly tested using one of these types of equipment:
  - Diode checker
  - Ohmmeter
  - Curve tracer





Diode Checking using OPAM

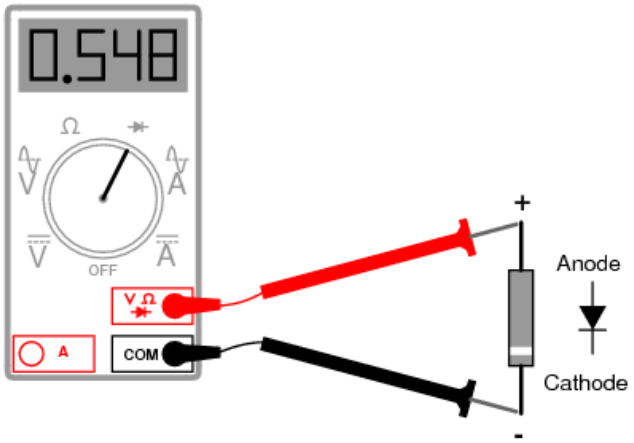


- Black – Anode (Red – Cathode): Cursor moves ON
- Reverse connection: Cursor stops

Diode Checker

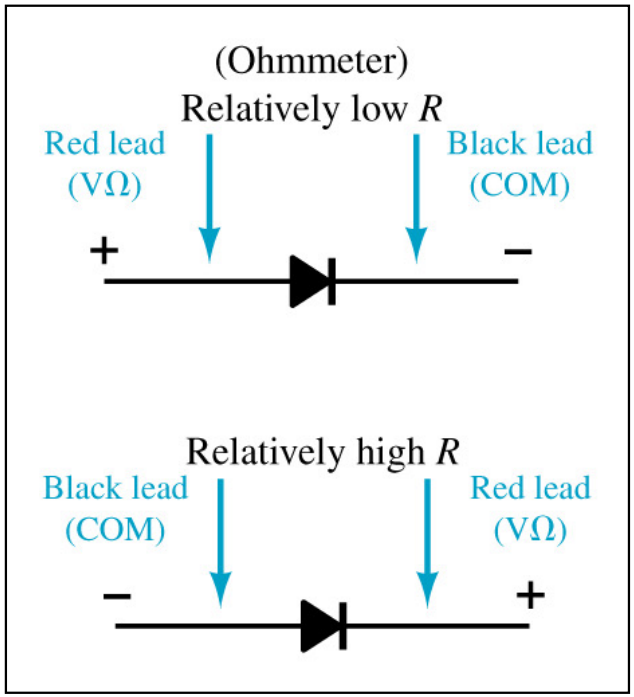
- Many digital multimeters have a diode checking function. The diode should be tested out of circuit.

- A normal diode exhibits its forward voltage:
  - Gallium arsenide ≈ 1.2 V
  - Silicon diode ≈ 0.7 V
  - Germanium diode ≈ 0.3 V



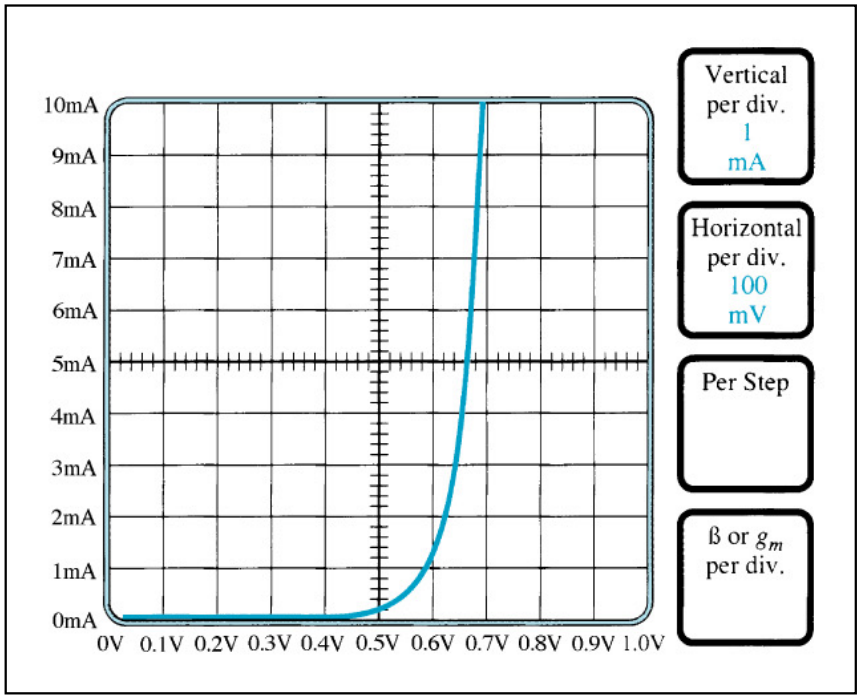
Ohmmeter

- An ohmmeter set on a low Ohms scale can be used to test a diode. The diode should be tested out of circuit.



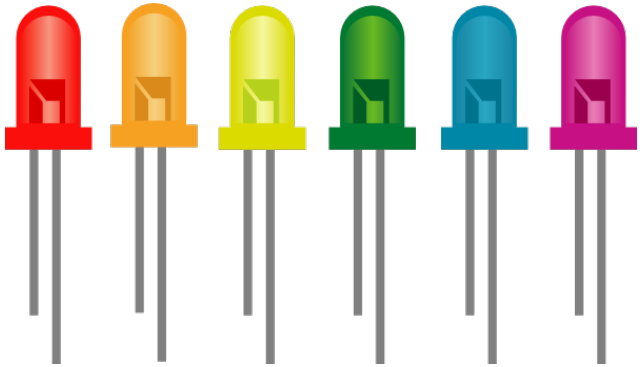
Curve Tracer

- A curve tracer displays the characteristic curve of a diode in the test circuit. This curve can be compared to the specifications of the diode from a data sheet.



Other Types of Diodes

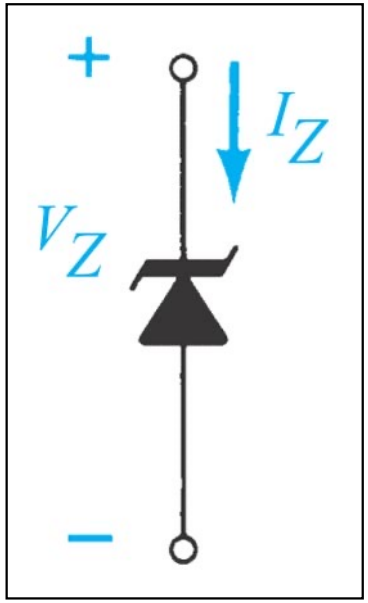
- There are several types of diodes besides the standard *p-n* junction diode. Three of the more common are:
  - Zener diodes
  - Light-emitting diodes
  - Diode arrays



Zener Diode

- A **Zener diode** is one that is designed to safely operate in its zener region; i.e., biased at the Zener voltage (VZ).

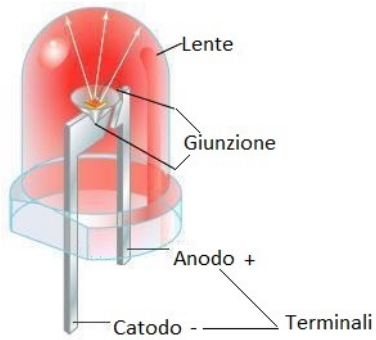
- Common zener diode voltage ratings are between 1.8 V and 200 V

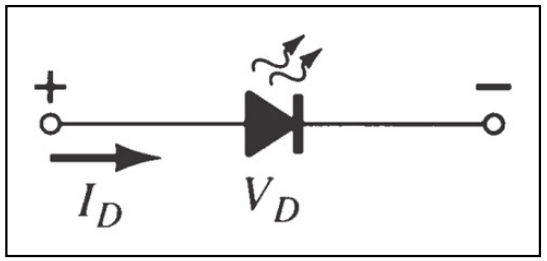


Light-Emitting Diode (LED)

- An **LED** emits light when it is forward biased, which can be in the infrared or visible spectrum.

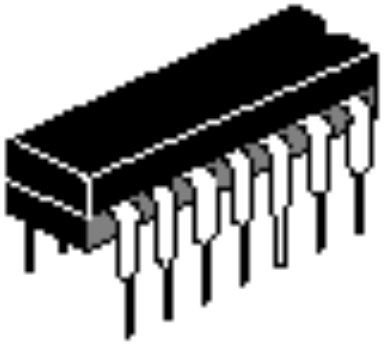
- The forward bias voltage is usually in the range of 2 V to 3 V.



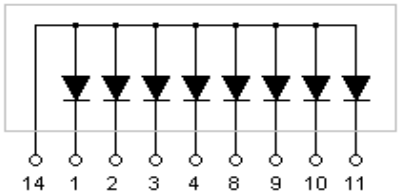


Diode Arrays

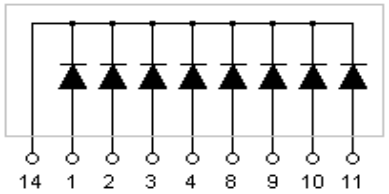
- Multiple diodes can be packaged together in an integrated circuit (IC).
- A variety of diode configurations are available.



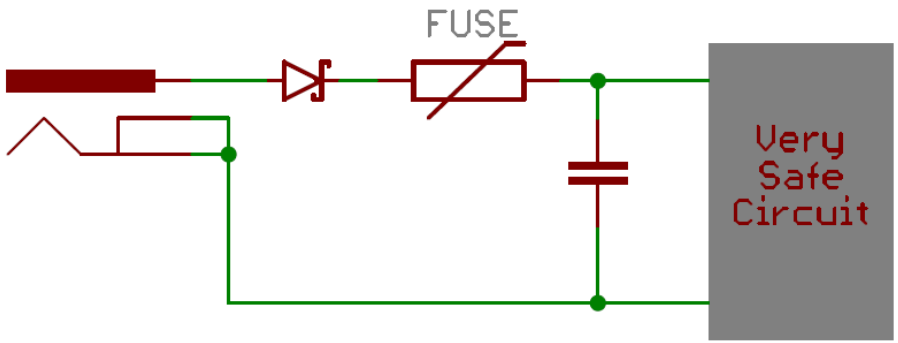
Common Anode



Common Cathode



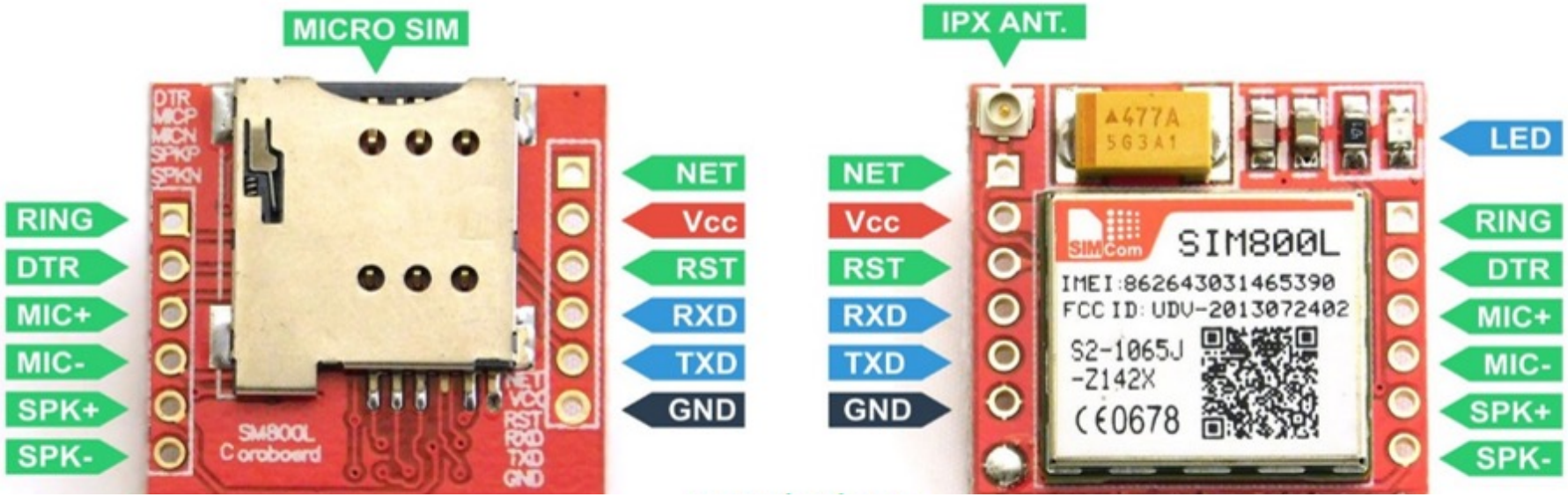
Diode Application - Reverse Current Protection



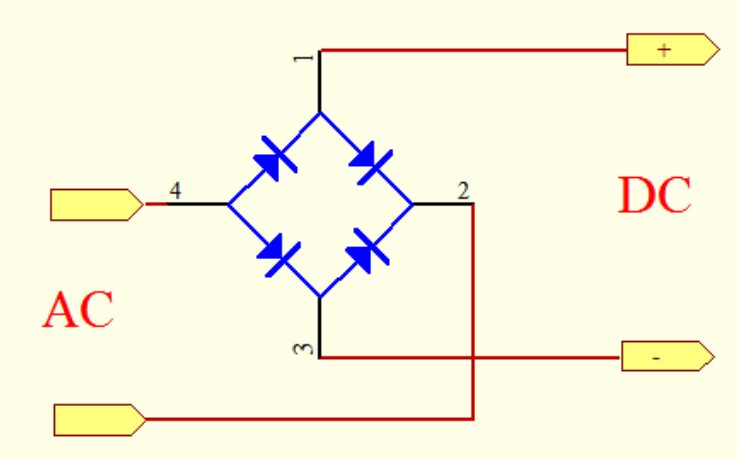
- **Mandatory design** for any system
- Drawback: around 0.7V loss because of the forward voltage drop.
  - **Schottky diodes** an excellent choice for reverse protection diodes.

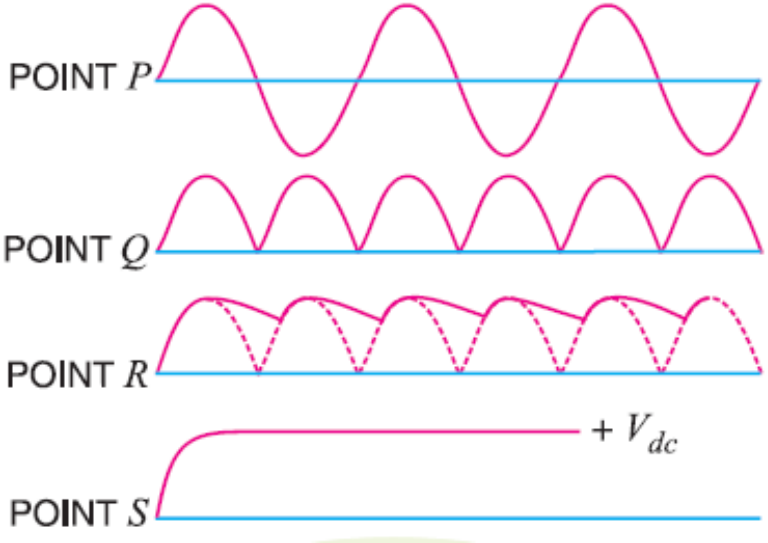
Diode Application – Reverse Current Protection

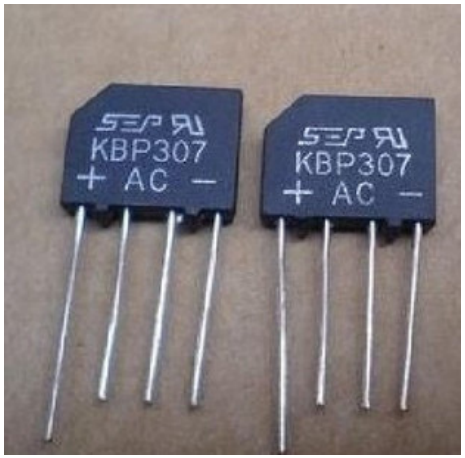
- SIM800L: 4.3V

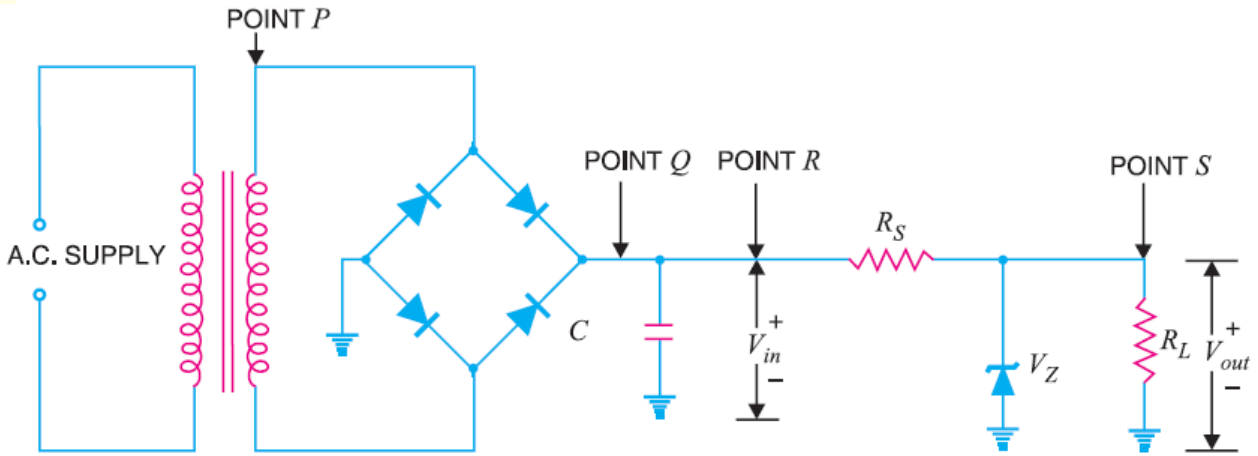


DC Adapter Circuits



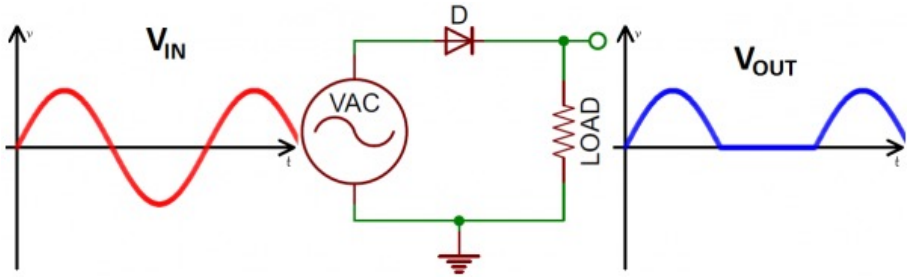


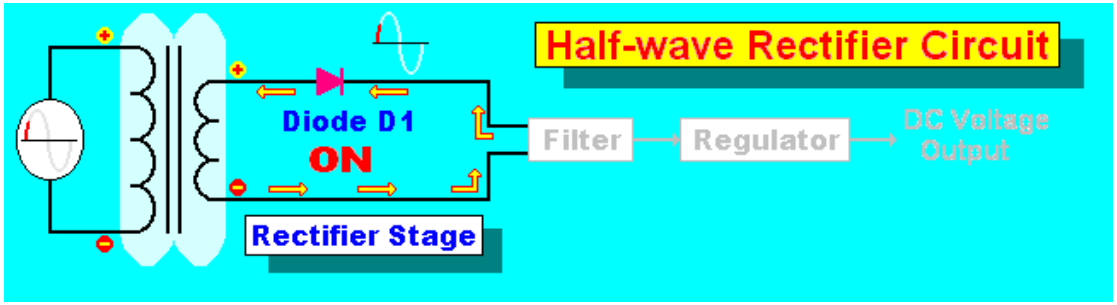




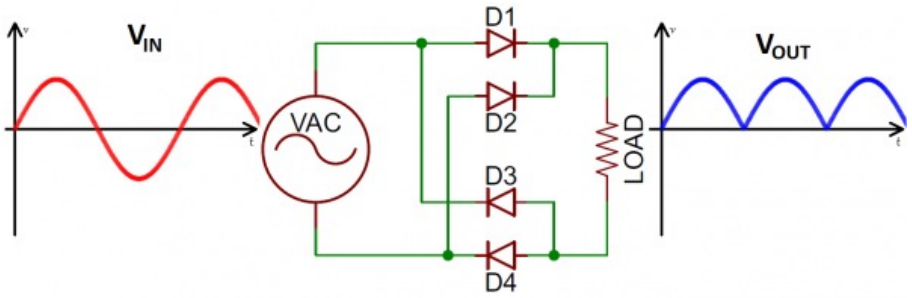
Diode Application – Rectifier

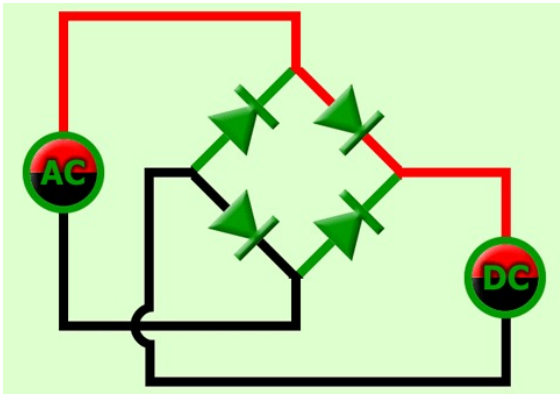
- Convert **Alternating Current** (AC) to **Direct Current** (DC)
  - Half wave rectifier



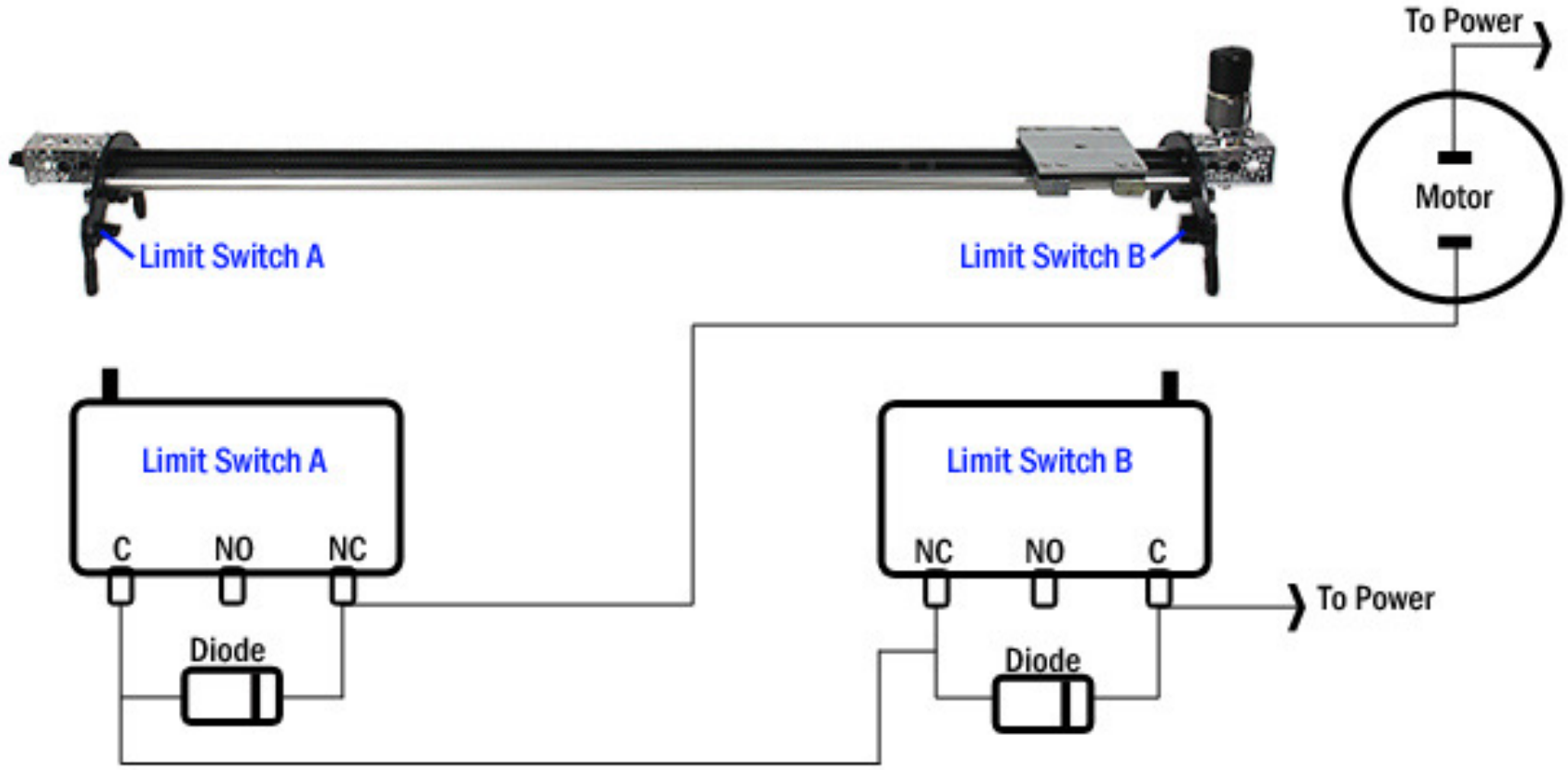


  - Full wave rectifier

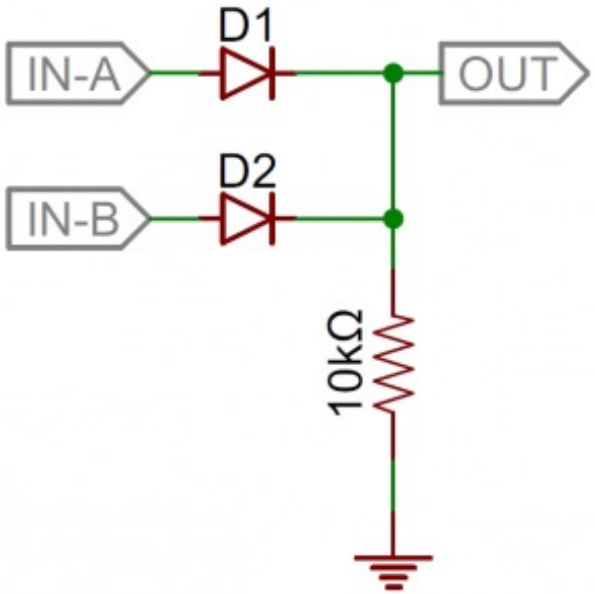




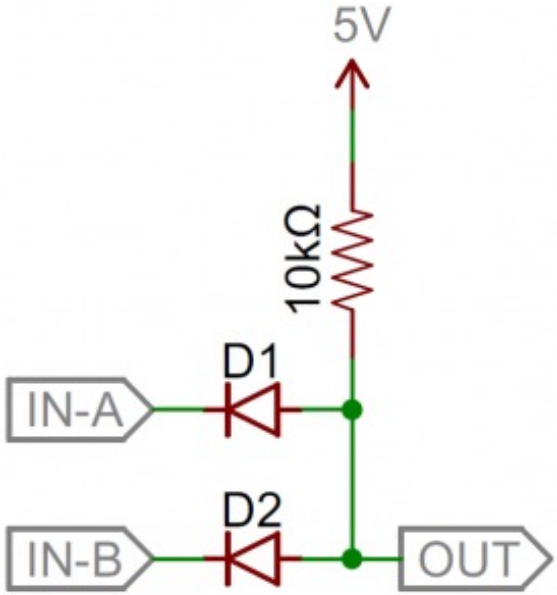
Diode Application - Limit Switch Application



Diode Application - Logic Gates



- OR

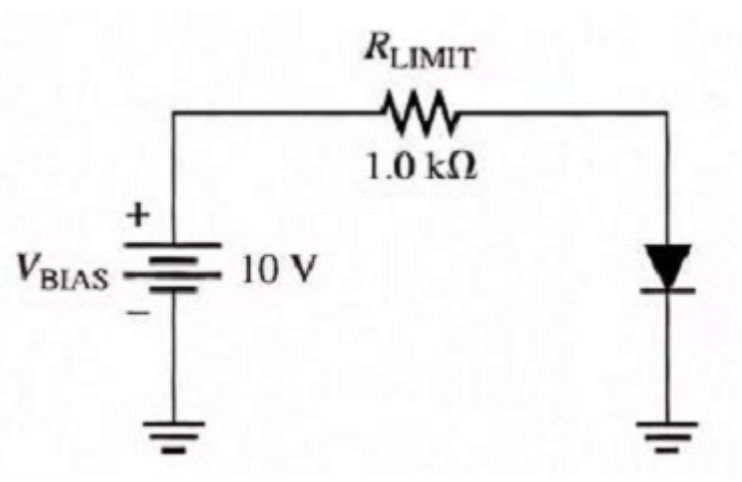


- AND

Exercise 1

- Given circuit
  - Forward bias voltage $V_F = 0.7V$
  - Internal resistance $r'_d = 10\Omega$

- Determine V_F, I_F and V_{RLIMIT} for three diode models
  - Ideal diode model
  - Practical diode model
  - Complete diode model



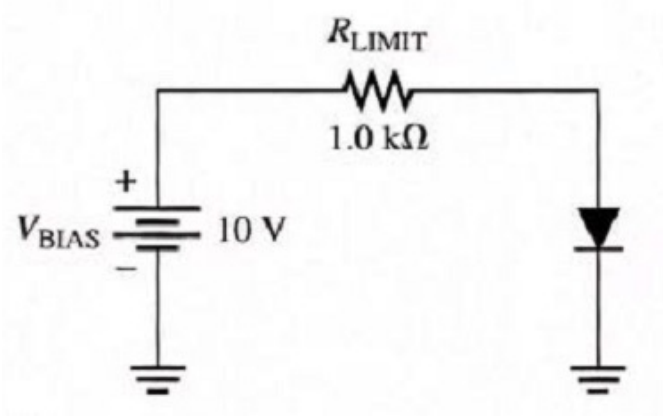
Solution

- Ideal diode model

$$V_F = 0\,V$$

$$I_F = \frac{V_{BIAS}}{R_{LIMIT}} = \frac{10\,V}{1k\Omega} = 10\,mA$$

$$V_{R_{LIMIT}} = I_F \bullet R_{LIMIT} = (10\,mA) \bullet (1k\Omega) = 10\,V$$



- Practical diode model

$$V_F = 0,7\,V$$

$$I_F = \frac{V_{BIAS} - V_R}{R_{LIMIT}} = \frac{10\,V - 0,7\,V}{1k\Omega} = 9,3\,mA$$

$$V_{R_{LIMIT}} = I_F \bullet R_{LIMIT} = (9,3\,mA) \bullet (1k\Omega) = 9,3\,V$$

- Complete diode model

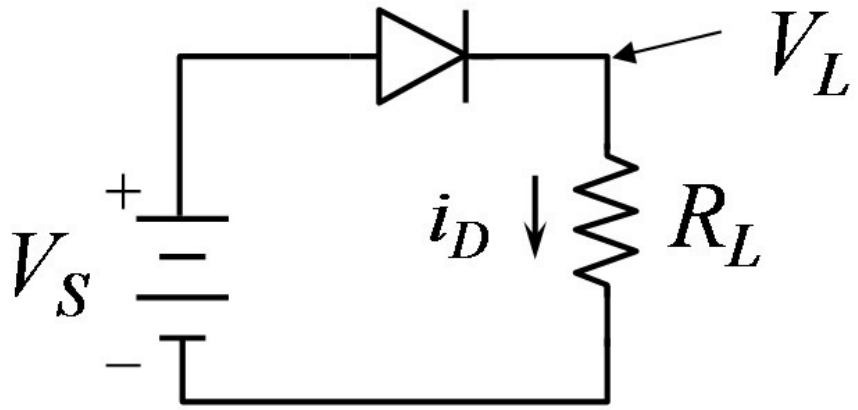
$$I_F = \frac{V_{BIAS} - 0,7}{R_{LIMIT} + r'_d} = \frac{10\,V - 0,7\,V}{1k\Omega + 10\,\Omega} = \frac{9,3\,V}{1010\,\Omega} = 0,00921\,A = 9,21\,mA$$

$$V_F = 0,7\,V + r'_d . I_F = 0,7\,V + (10\,\Omega) \bullet (9,21\,mA) = 792\,mV$$

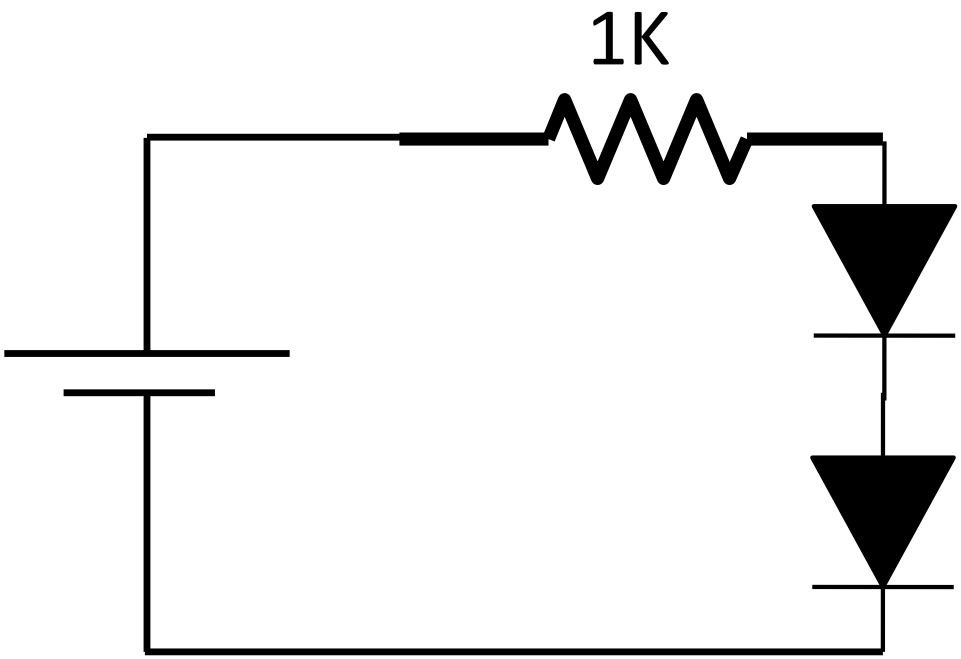
$$V_{R_{LIMIT}} = I_F \bullet R_{LIMIT} = (9,21\,mA) \bullet (1k\Omega) = 9,21\,V$$

Exercise 2

- Analyze the circuit by using the diode practical model.
- V_S = 5V and the current (I_D) in the circuit is 1mA.
- What is the value of R_L.
- The dropdown voltage of the diode is 0.7V



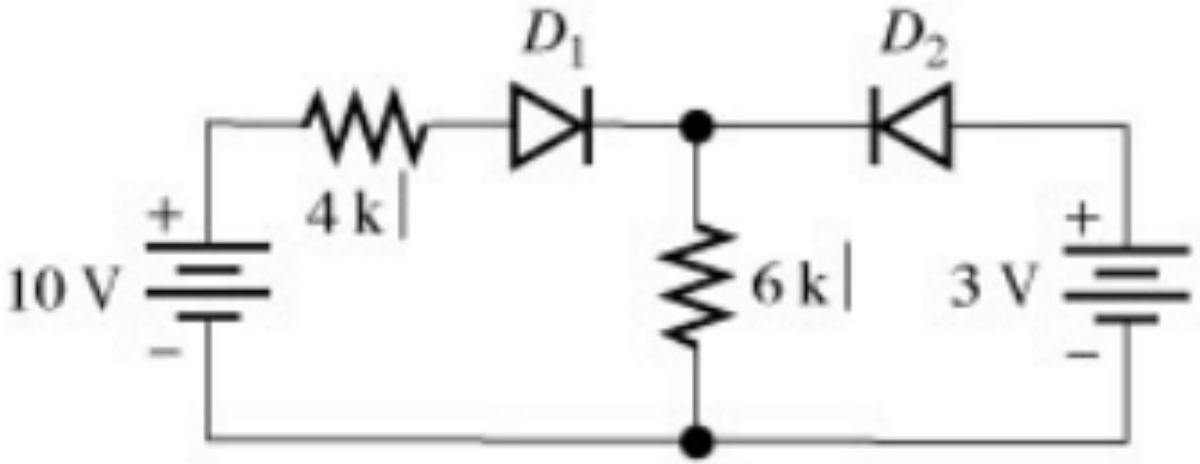
Exercise 3



- The voltage supply is 9V, the dropdown voltage of each diode is V_F=0.7V and r_d=10 ohm. Determine the current in the circuit.

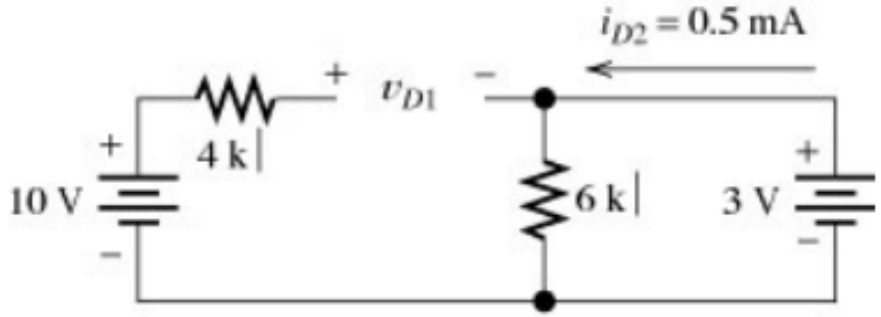
Exercise 4

- Analyze the circuit using ideal diode model

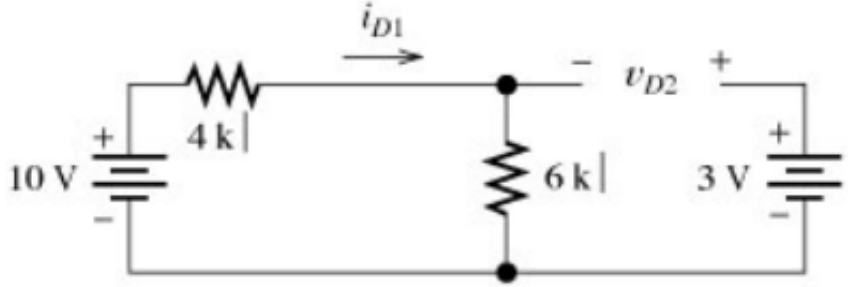


Solution (Ex. 4)

- Assume that D1 is OFF and D2 is ON

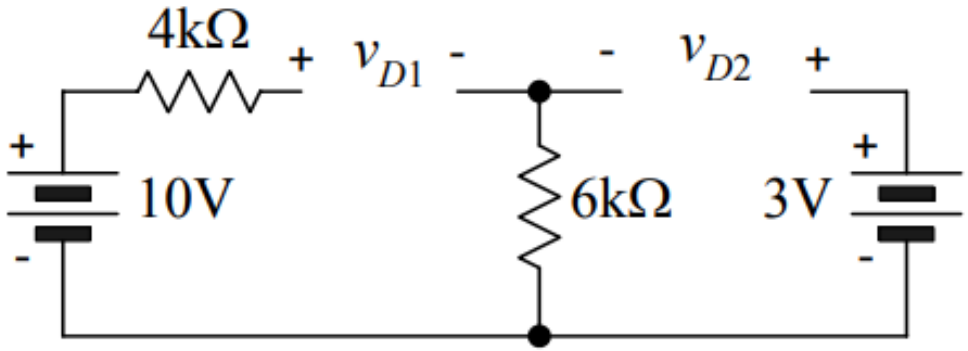


- Assume that D1 is ON and D2 is OFF



Solution (Ex. 4)

- Assume that both D1 and D2 are OFF

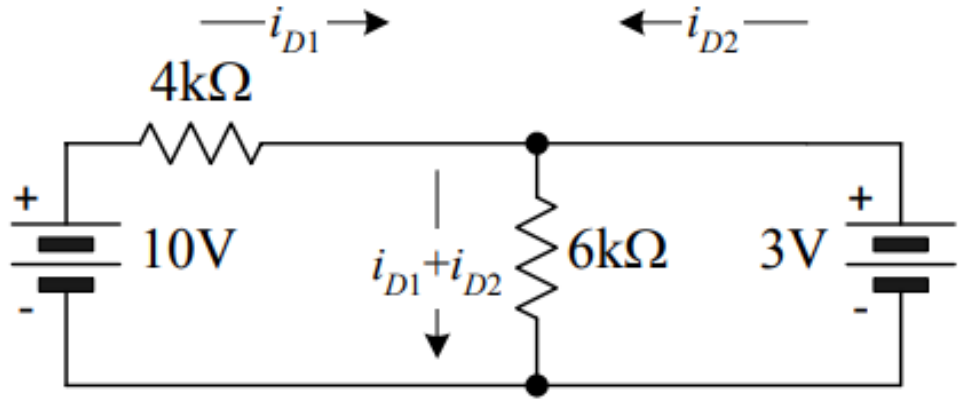


- Assume that both D1 and D2 are ON

$$i_{D1} + i_{D2} = \frac{3\text{V}}{6\text{k}\Omega} = 0.5\text{mA}$$

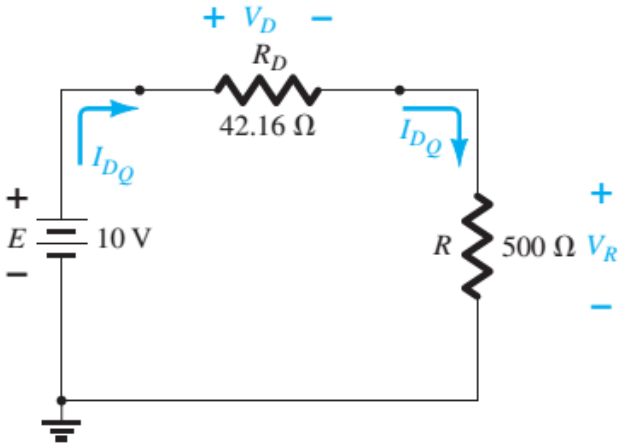
$$i_{D1} = \frac{10\text{V} - 3\text{V}}{4\text{k}\Omega} = 1.75\text{mA}$$

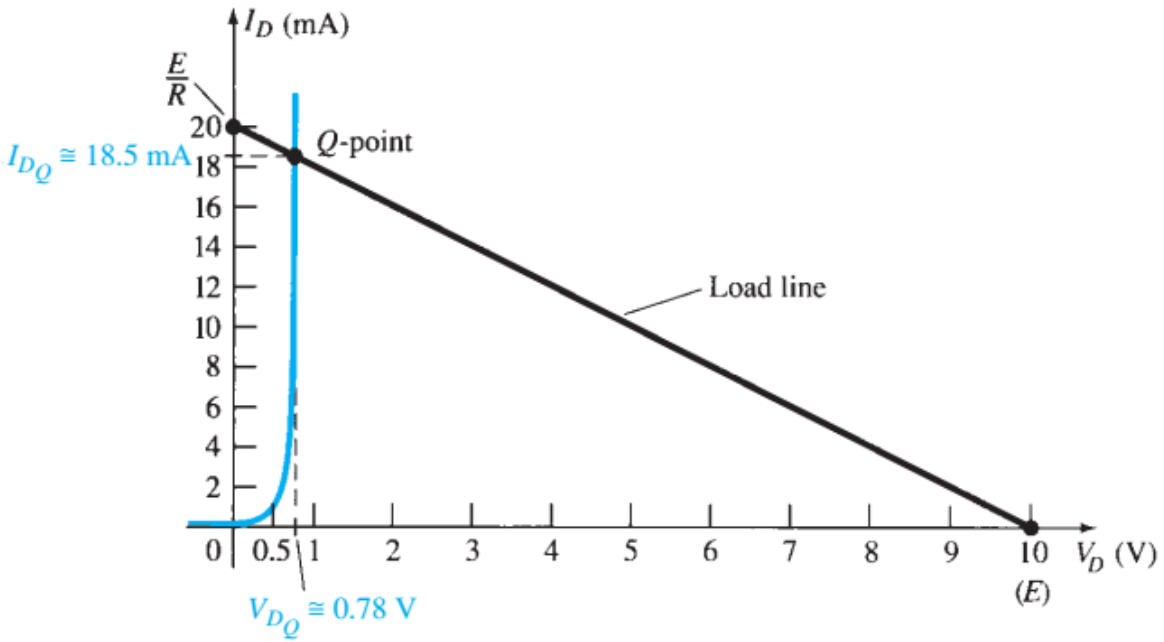
$$i_{D2} = (i_{D1} + i_{D2}) - i_{D1} = 0.5 - 1.75 = -1.25\text{mA}$$



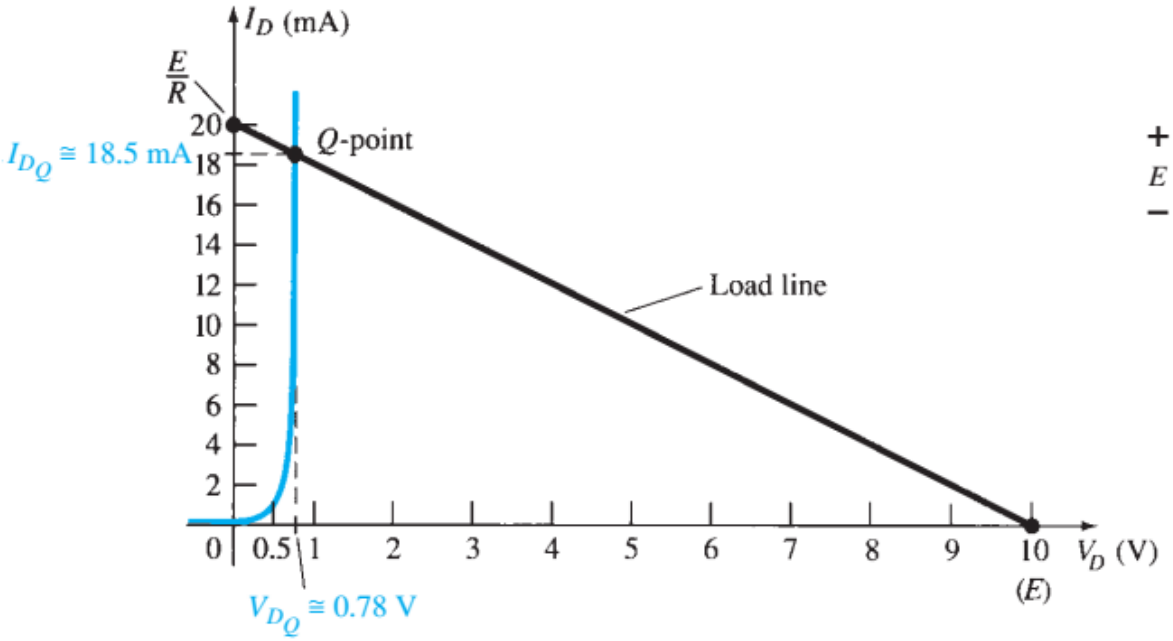
Exercise 5

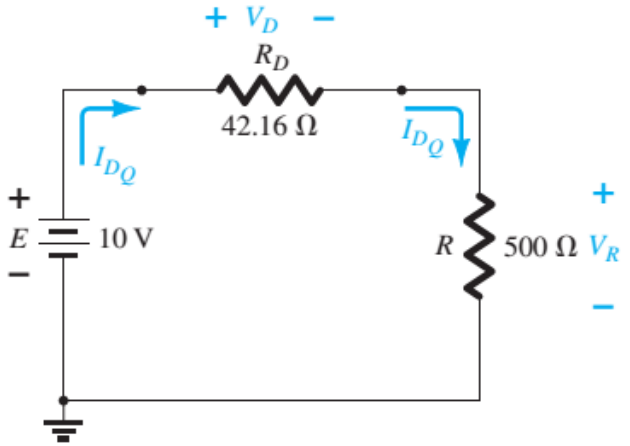
- Determine V_D, I_D and V_R based on the characteristic of the diode given in the following figure.





Solution (Ex. 5)



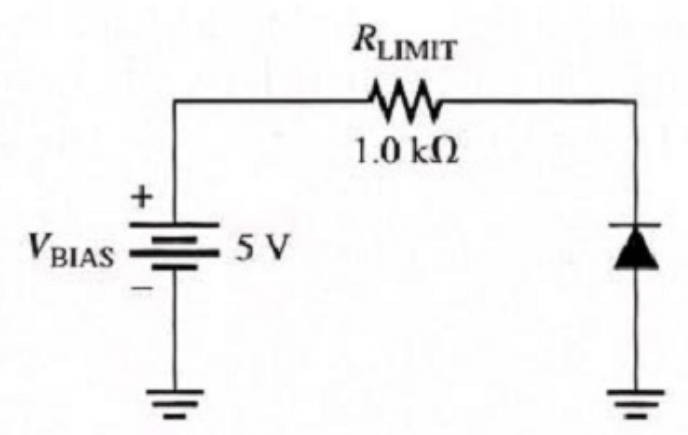


$$V_R = E - V_D = 10\,\text{V} - 0.78\,\text{V} = \mathbf{9.22\,V}$$

Exercise 6

- Given circuit
  - Reverse current $I_R = 1\ \mu A$

- Determine V_F, I_F and V_R for three diode model
  - Ideal diode model
  - Practical diode model
  - Complete diode model



Exercise 7

- Analyze and validate the value of the voltmeter in case of using ideal diode model ?