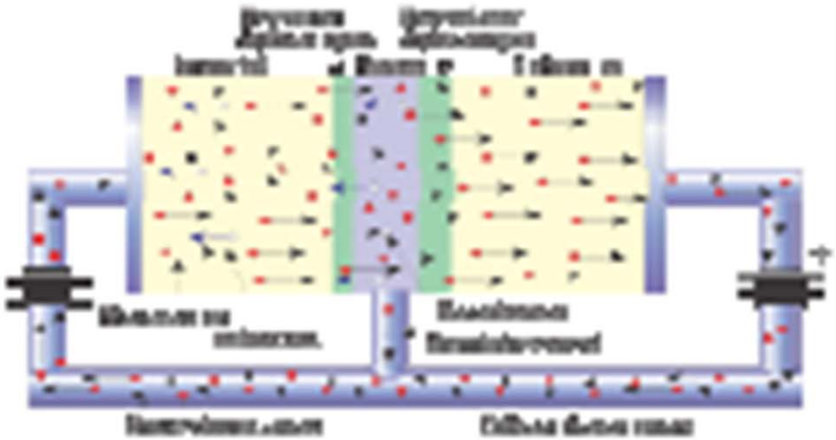
Electronic Devices

Ninth Edition

Floyd

Chapter 4: Bipolar Junction Transistors

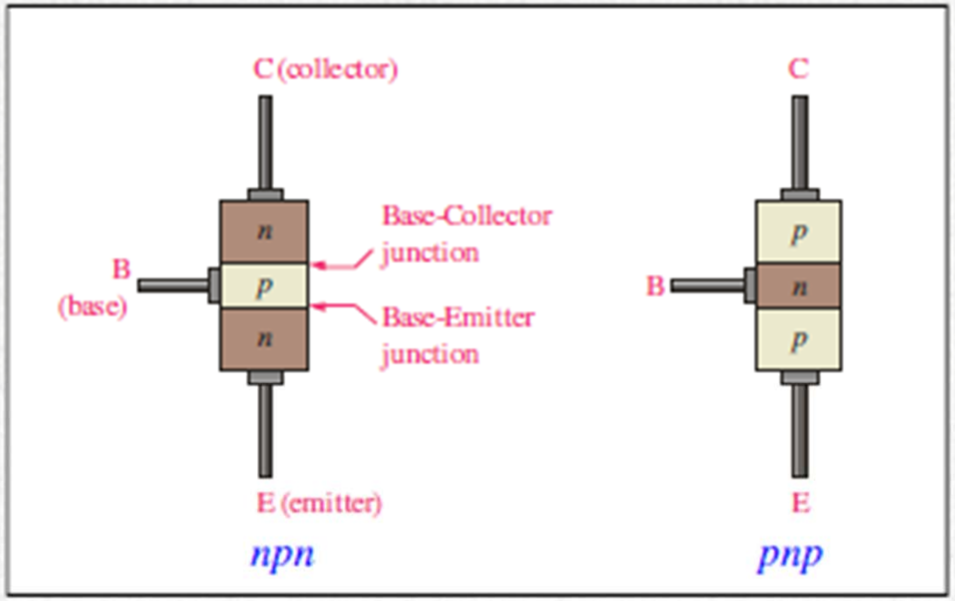


Summary

BJT Structure

The BJT has three regions called the emitter, base, and collector. Between the regions are junctions as indicated.

The base is a thin lightly doped region compared to the heavily doped emitter and moderately doped collector regions.



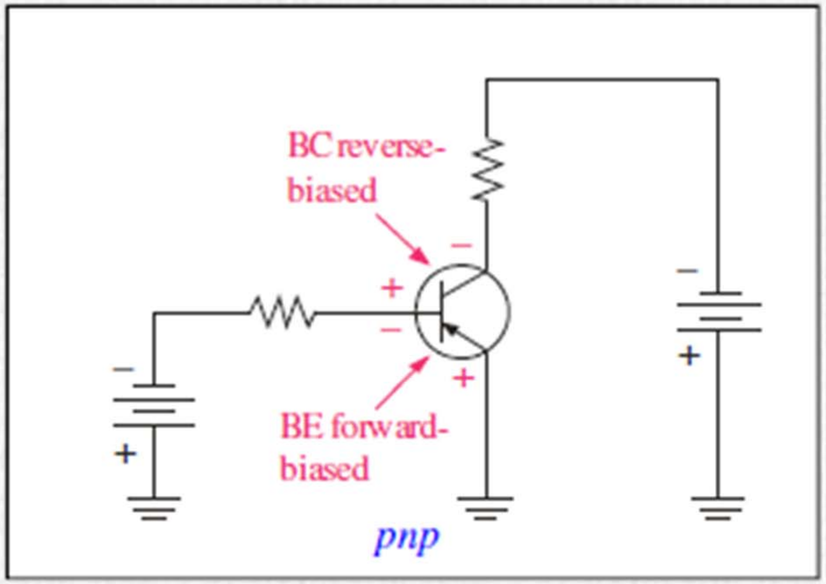
Summary

BJT Operation

In normal operation, the base-emitter is forward-biased and the base-collector is reverse-biased.

For the *npn* type shown, the collector is more positive than the base, which is more positive than the emitter.

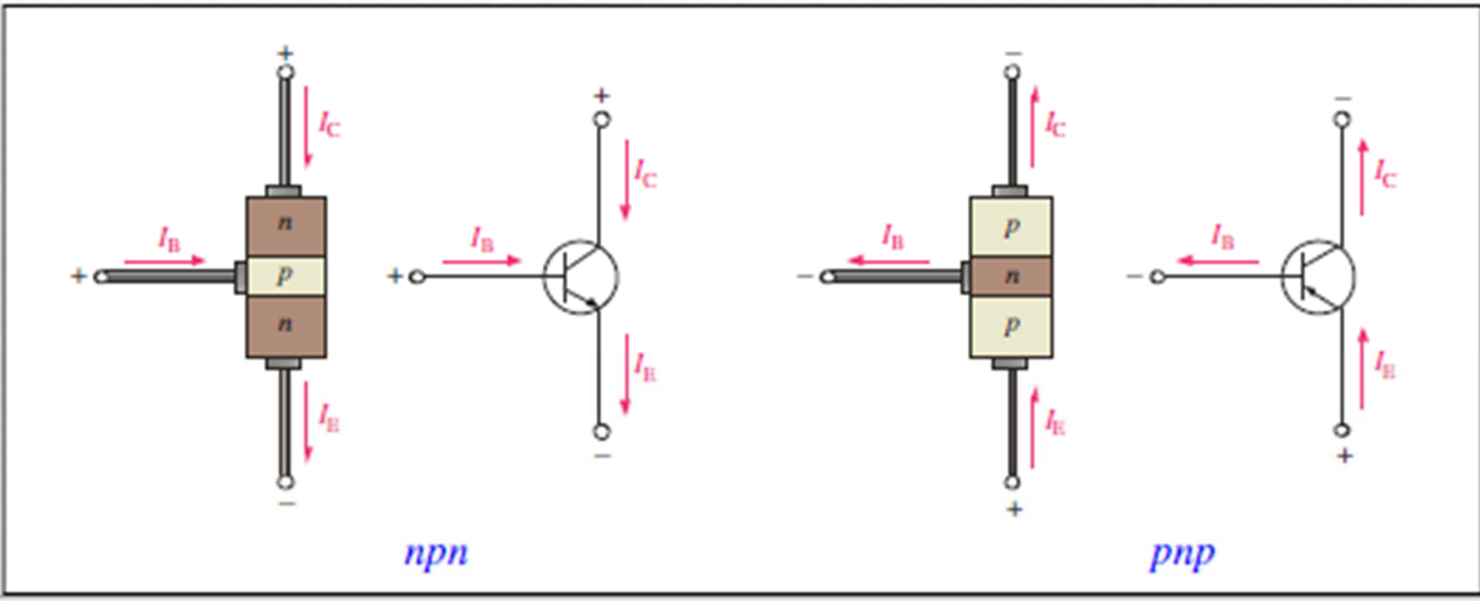
For the *pnp type*, the voltages are reversed to maintain the forward-reverse bias.



Summary

BJT Currents

The direction of conventional current is in the direction of the arrow on the emitter terminal. The emitter current is the sum of the collector current and the small base current. That is, $I_E = I_C + I_B$.



Summary

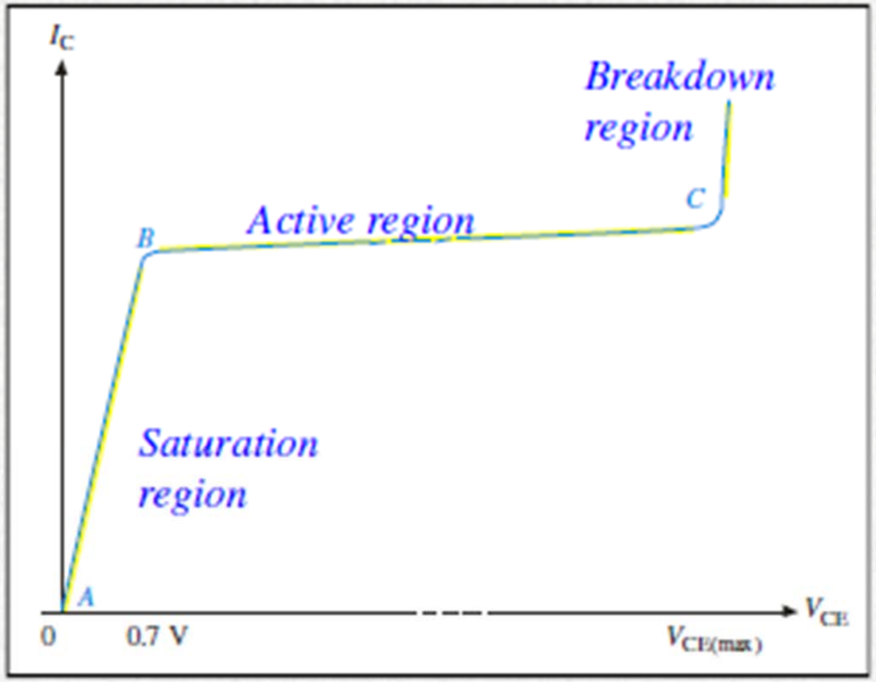
BJT Characteristics

The collector characteristic curves show the relationship of the three transistor currents.

The curve shown is for a fixed based current. The first region is the **saturation region.**

As V_{CE} is increased, I_C increases until *B*. Then it flattens in region between points *B* and *C*, which is the **active region.**

After *C*, is the **breakdown region.**



Summary

BJT Characteristics

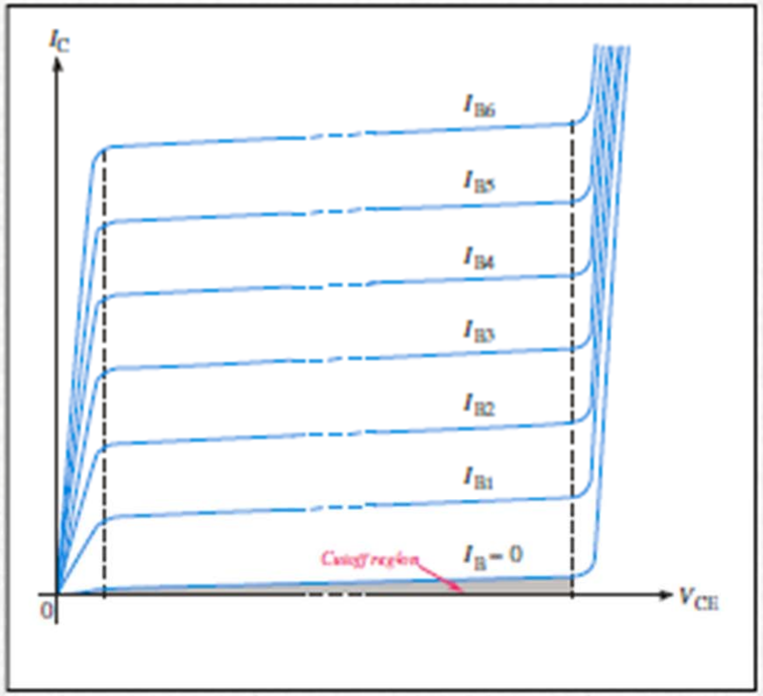
The collector characteristic curves illustrate the relationship of the three transistor currents.

By setting up other values of base current, a family of collector curves is developed.

β_{DC} is the ratio of collector current to base current.

$$\beta_{DC} = \frac{I_C}{I_B}$$

It can be read from the curves. The value of β_{DC} is nearly the same wherever it is read.



Summary

BJT Characteristics

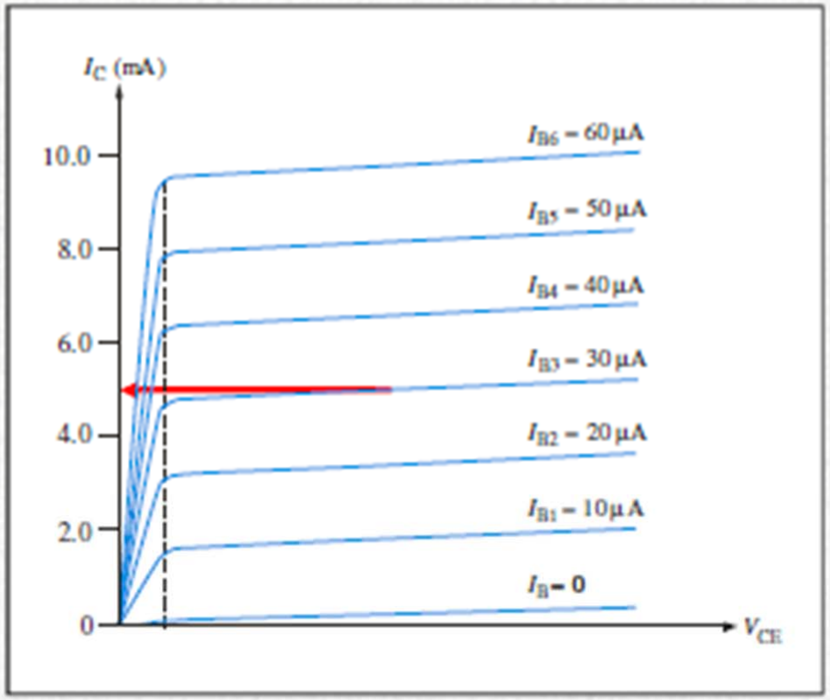
Example: What is the β_{DC} for the transistor shown?

Solution:

Choose a base current near the center of the range – in this case I_{B3} which is 30 µA.

Read the corresponding collector current – in this case, 5.0 mA. Calculate the ratio:

$$\beta_{DC} = \frac{I_C}{I_B} = \frac{5.0\text{ mA}}{30\ \mu\text{A}} = 167$$

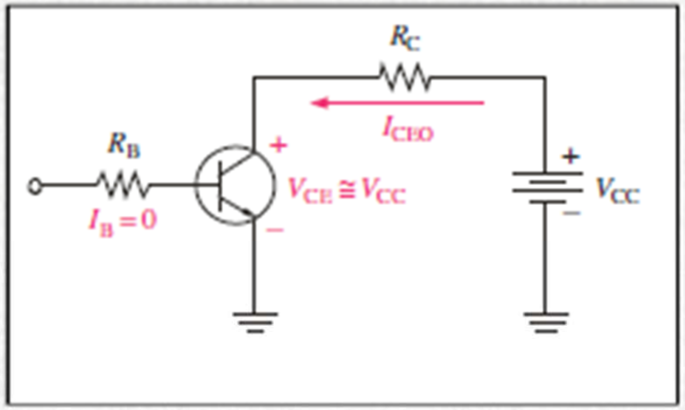


Summary

Cutoff

In a BJT, **cutoff** is the condition in which there is no base current, which results in only an extremely small leakage current (I_{CEO}) in the collector circuit. For practical work, this current is assumed to be zero.

In cutoff, neither the base-emitter junction, nor the base-collector junction are forward-biased.

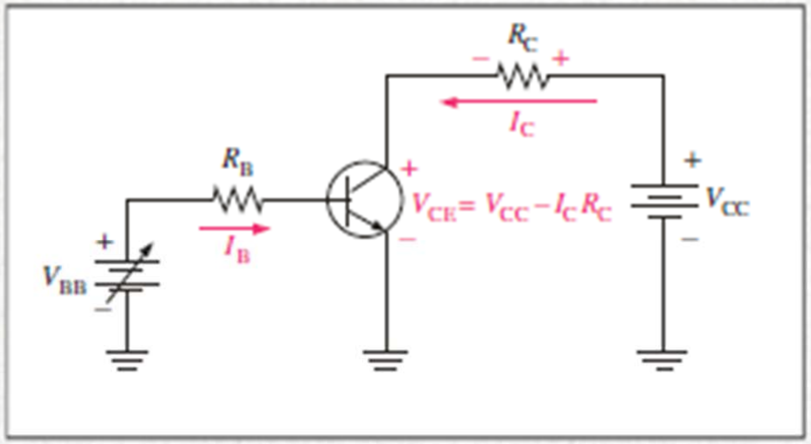


Summary

Saturation

In a BJT, **saturation** is the condition in which there is maximum collector current. The saturation current is determined by the external circuit (V_{CC} and R_C in this case) because the collector-emitter voltage is minimum (≈ 0.2 V)

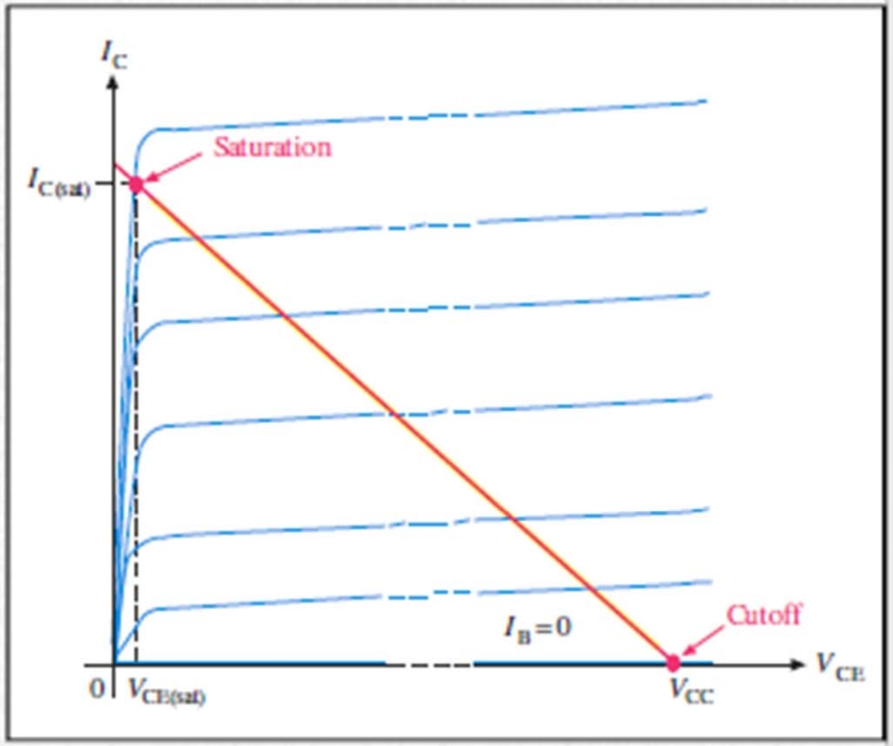
In saturation, an increase of base current has no effect on the collector circuit and the relation $I_C = \beta_{DC} I_B$ is no longer valid.



Summary

DC Load Line

The **DC load line** represents the circuit that is external to the transistor. It is drawn by connecting the saturation and cutoff points.



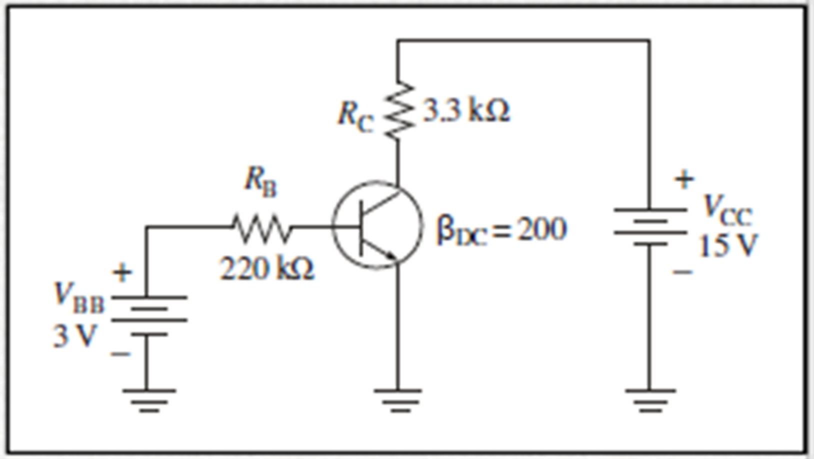
The transistor characteristic curves are shown superimposed on the load line. The region between the saturation and cutoff points is called the **active region.**

Summary

DC Load Line

Example:

What is the saturation current and the cutoff voltage for the circuit? Assume $V_{CE} = 0.2$ V in saturation.



Solution:

$$I_{SAT} = \frac{V_{CC} - 0.2\text{ V}}{R_C} = \frac{15\text{ V} - 0.2\text{ V}}{3.3\text{ k}\Omega} = 4.48\text{ mA} \qquad V_{CO} = V_{CC} = 15\text{ V}$$

Follow-up:

Is the transistor saturated? $I_B = \dfrac{3.0\text{ V} - 0.7\text{ V}}{220\text{ k}\Omega} = 10.45\ \mu\text{A}$

$I_C = \beta\, I_B = 200\,(10.45\ \mu\text{A}) = 2.09$ mA Since $I_C < I_{SAT}$, it is not saturated.

Summary

Data Sheets

Data sheets give manufacturer's specifications for maximum operating conditions, thermal, and electrical characteristics. For example, an electrical characteristic is β_{DC}, which is given as h_{FE}. The 2N3904 shows a range of β's on the data sheet from 100 to 300 for $I_C = 10$ mA.

Characteristic		Symbol	Min	Max	Unit
ON Characteristics					
DC current gain		h_{FE}			–
($I_C = 0.1$ mA dc, $V_{CE} = 1.0$ V dc)	2N3903		20	–	
	2N3904		40	–	
($I_C = 1.0$ mA dc, $V_{CE} = 1.0$ V dc)	2N3903		35	–	
	2N3904		70	–	
($I_C = 10$ mA dc, $V_{CE} = 1.0$ V dc)	2N3903		50	150	
	2N3904		100	300	
($I_C = 50$ mA dc, $V_{CE} = 1.0$ V dc)	2N3903		30	–	
	2N3904		60	–	
($I_C = 100$ mA dc, $V_{CE} = 1.0$ V dc)	2N3903		15	–	
	2N3904		30	–	

Summary

DC and AC Quantities

The text uses capital letters for both AC and DC currents and voltages with rms values assumed unless stated otherwise.

DC Quantities use upper case roman subscripts. Example: V_{CE}. (The second letter in the subscript indicates the reference point.)

AC Quantities and time varying signals use lower case italic subscripts. Example: V_{ce}.

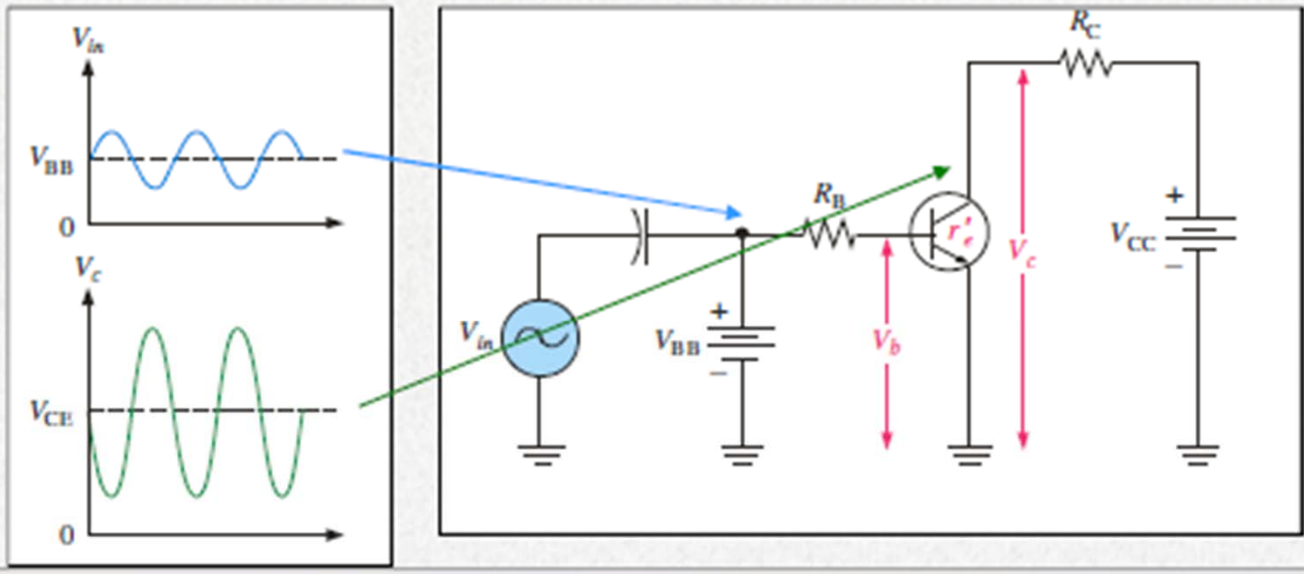
Internal transistor resistances are indicated as lower case quantities with a prime and an appropriate subscript. Example: r_e'.

External resistances are indicated as capital R with either a capital or lower case subscript depending on if it is a DC or ac resistance. Examples: R_C and R_c.

Summary

BJT Amplifiers

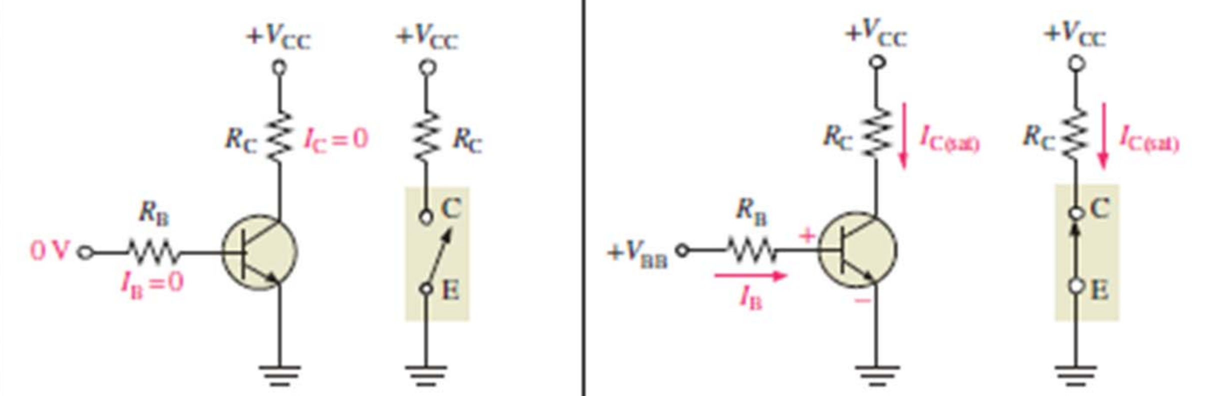
A BJT amplifies AC signals by converting some of the DC power from the power supplies to AC signal power. An ac signal at the input is superimposed in the dc bias by the capacitive coupling. The output ac signal is inverted and rides on a dc level of V_{CE}.



Summary

BJT Switches

A BJT can be used as a switching device in logic circuits to turn on or off current to a load. As a switch, the transistor is normally in either cutoff (load is OFF) or saturation (load is ON).



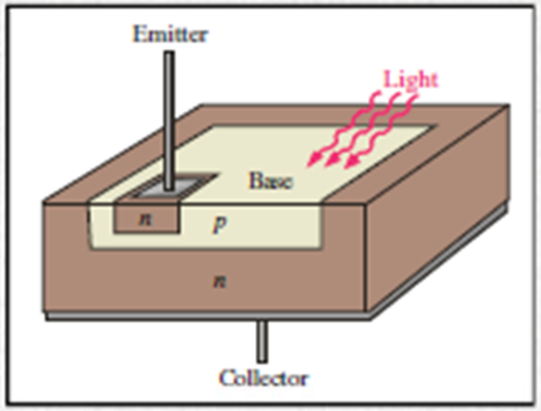
In cutoff, the transistor looks like an open switch.

In saturation, the transistor looks like a closed switch.

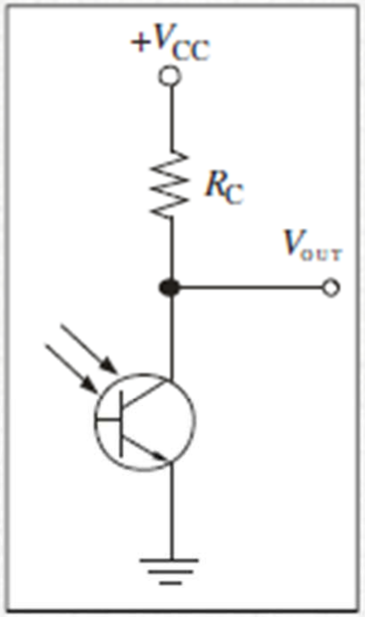
Summary

Phototransistors

A phototransistor produces base current when light strikes the exposed photosensitive base region, which is the active area. Phototransistors have high gain and are more sensitive to light than photodiodes.



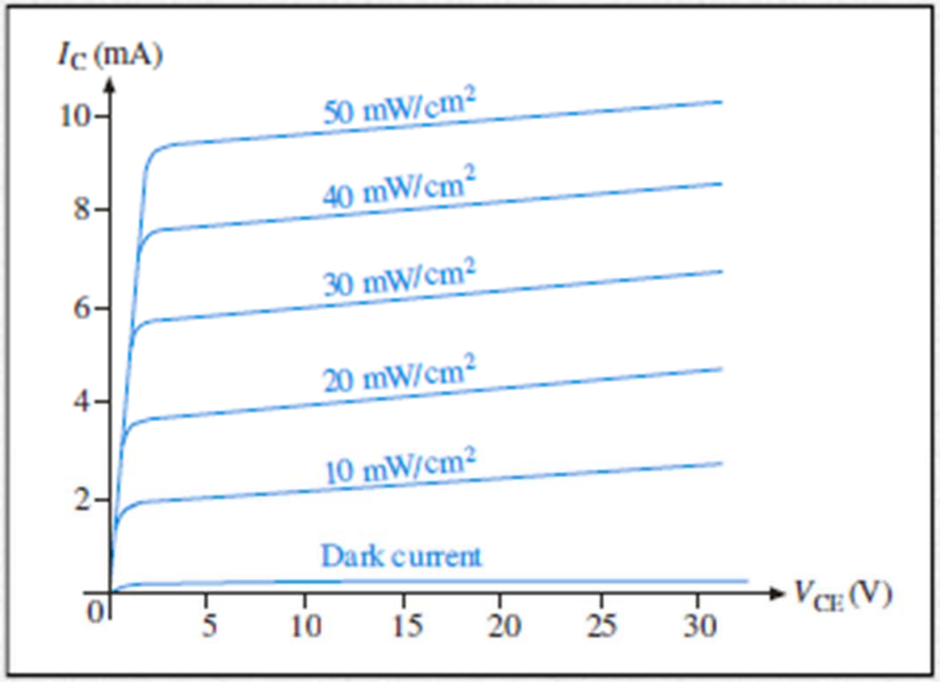
In a typical circuit the base lead is left open. In the circuit shown, the output voltage is maximum with no light and drops with increasing light.



Summary

Phototransistors

The characteristic curves for a phototransistor are based on light flux (mW/cm^2) to the base rather than base current in an ordinary transistor.



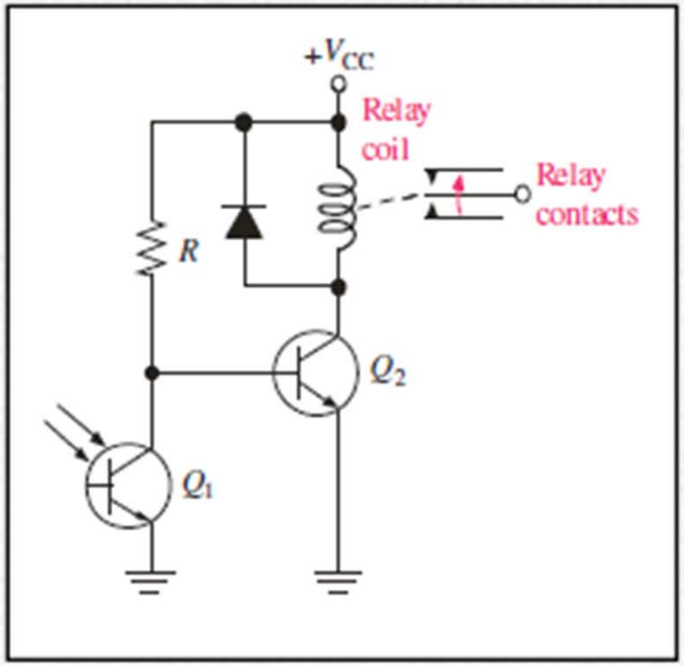
Summary

Phototransistors

The output from the phototransistor can be used to activate or deactivate a relay. In this case, the phototransistor is part of a switching circuit.

Question:

Is either transistor ON for the circuit when there is no incident light?



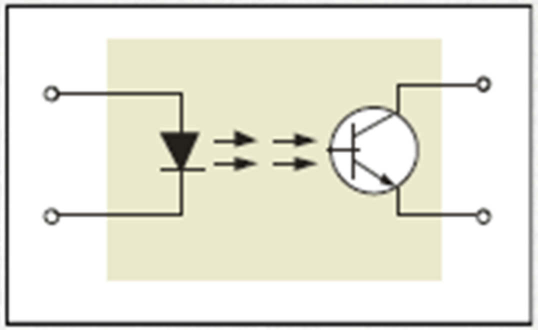
Answer:

With no incident light, Q_1 will be biased OFF. Q_2 will be forward-biased through R and is ON. Collector current in Q_2 causes the relay to be energized.

Summary

Optocouplers

An optocoupler is a single package containing an LED and a phototransistor. Optical couplers transfer a signal from one circuit to another while providing a high degree of isolation.



A key specification for optocouplers is the current transfer ratio or CTR, which is a measure of efficiency. The CTR is the ratio of output current to input current. Typically values are from 50% to 110% for standard optocouplers.

Summary

Applications for Optocouplers

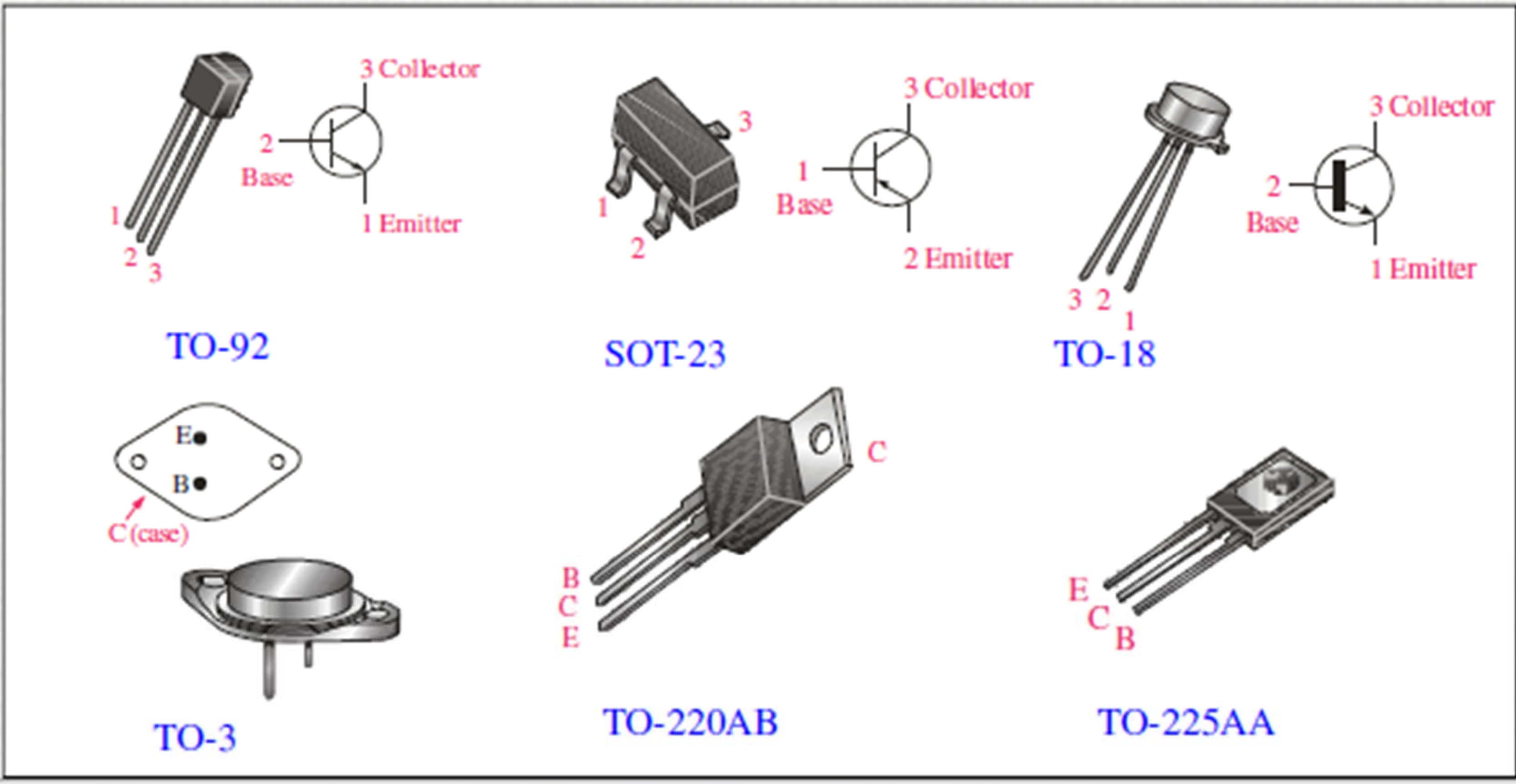
Optocouplers are used when data or signals need to be transferred from a control circuit to a power circuit without making electrical connections between the circuits. For example, the logic circuits in a traffic light controller need to be isolated from the lights themselves.

Another application for optocouplers is as a transducer to detect a light path such as a hole in a rotating disk. In this case, the LED and phototransistor are separated by a gap.

Optocouplers are also useful for isolating patients from the monitoring instruments.

Summary

A Sample of Common Transistor Packages



Summary

BJT Basic Test

A basic test for a BJT is to use the **Diode Test** function of your DMM.

To test the base-emitter junction of a BJT, connect the positive lead to the base and the negative lead to the emitter. You should see a voltage close to 0.7 V for an *npn* transistor.

Reversing the leads will show OL for “overload”.

The procedure is repeated to test the base-collector junction.

Selected Key Terms

BJT (bipolar junction transistor)	a transistor constructed with three doped semiconductor regions separated by two *pn* junctions.
Emitter	the most heavily doped of the three semiconductor regions of a BJT.
Base	one of the three semiconductor regions of a BJT. The base is thin and lightly doped compared to the other regions.
Collector	the largest of the three semiconductor regions of a BJT.

Selected Key Terms

Beta the ratio of dc collector current to the dc base current in a BJT; current gain from base to collector.

Saturation the state of a BJT in which the collector current has reached a maximum and is independent of the base current.

Cutoff the nonconducting state of a transistor.

Phototransistor a transistor in which base current is produced when like strikes the photosensitive semiconductor base region.

Quiz

1. The region on the characteristic curve in which the current changes only slightly with an increase in V_{CE} is called the

a. saturation region

b. cutoff region

c. breakdown region

d. active region

Quiz

2. β_{DC} is defined as the ratio of

a. collector current to base current

b. collector current to emitter current

c. emitter current to base current

d. emitter current to collector current

Quiz

3. When a BJT is in saturation, the

   a. collector current does not change with an increase in base current

   b. base current cannot increase

   c. collector to emitter voltage is maximum

   d. all of the above

Quiz

4. When a BJT is cutoff, the

   a. voltage from collector to emitter is near zero

   b. collector current is near zero

   c. base-emitter junction is forward-biased

   d. none of the above

Quiz

5. The lower end of the dc load line touches the *x*-axis at

a. saturation

b. cutoff

c. breakdown

d. 0.7 V

Quiz

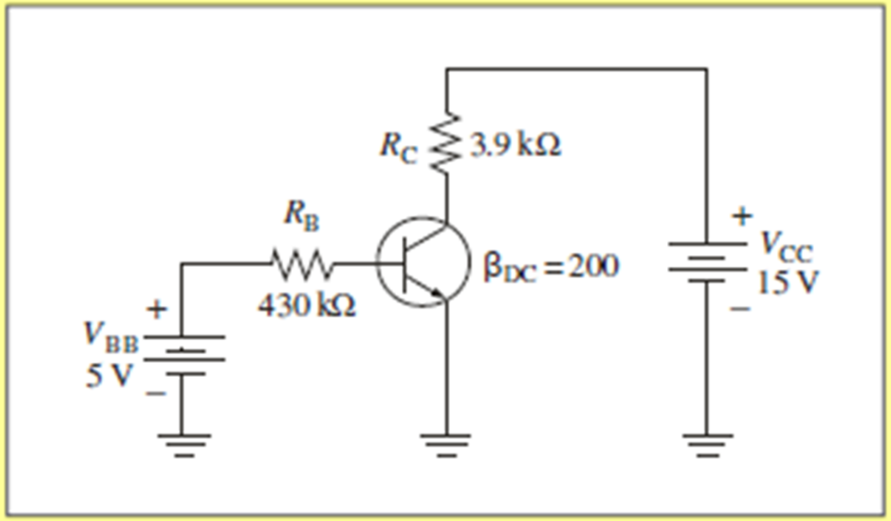
6. For the circuit shown, the base current is

a. 1.0 μA

b. 1.16 μA

c. 10 μA

d. 11.6 μA



Quiz

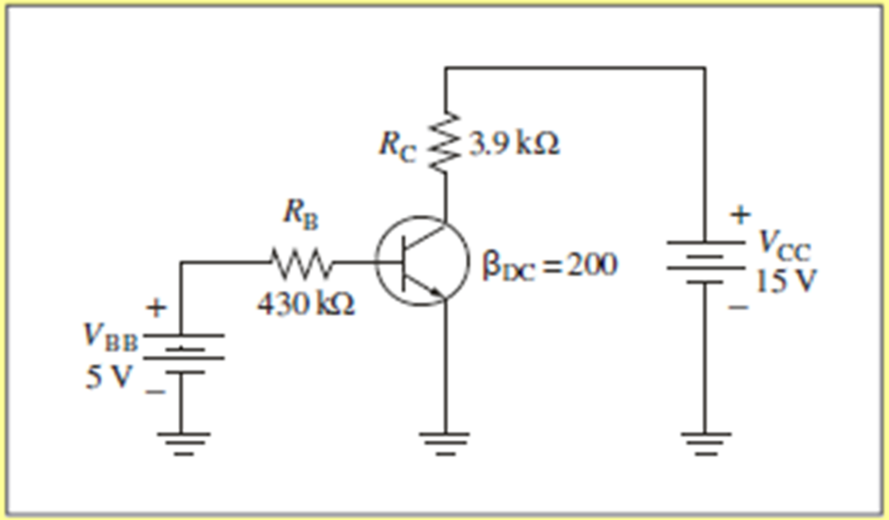
7. For the circuit shown, the saturation current is

a. 200 µA

b. 2.0 mA

c. 3.79 mA

d. 14.8 mA



Quiz

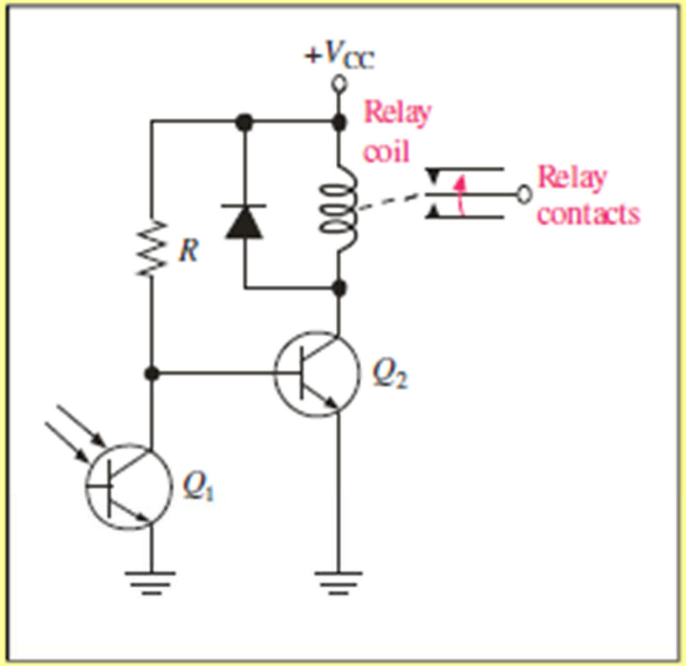
8. For the phototransistor circuit, assume there is sufficient light to saturate Q_1. In this condition,

a. Q_2 is also saturated

b. the diode is conducting

c. the relay is energized

d. none of the above



Quiz

9. An optocoupler is a single package containing

   a. two transistors

   b. an LED and a phototransistor

   c. a phototransistor and a relay

   d. an LED and a relay

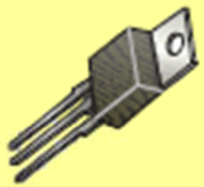
Quiz

10. The transistor package that is a TO-3 case is

a. 

b. 

c. 

d. 

Quiz

Answers:

1. d	6. c
2. a	7. c
3. a	8. d
4. d	9. b
5. b	10. c