5.1 BJT Device Structure and Physical Operation

Reading Assignment: *pp. 377-392*

Another kind of transistor is the **Bipolar Junction Transistor** (BJT).

BJTs are **analogous** to MOSFETs in many ways:

1.

2.

3.

4.

The two types of BJTs are *npn* and *pnp* (**analogous** to NMOS and PMOS).

A BJT is a "Silicon sandwich" –one type of Si sandwiched between two layers of the other.

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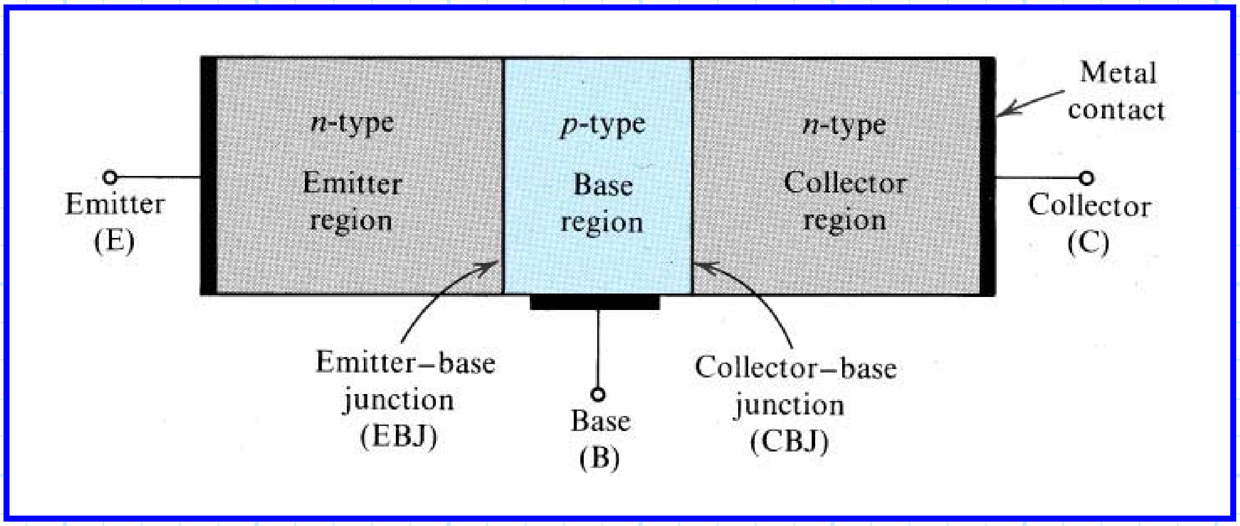
BJT Structure and Modes of Operation

First, let's start with the ***npn*** Bipolar Junction Transistor (BJT). As the **name** implies, the *npn* BJT is simply an hunk of *p*-type Silicon sandwiched between two slices of *n*-type material:



Each of the **three Silicon regions** has one terminal electrode connected to it, and thus the *npn* BJT is a **three terminal** device.

The three terminals are **named**:

1. *Collector*
2. *Base*
3. *Emitter*

Note that this *npn* BJT structure creates **two *p-n* junctions** !

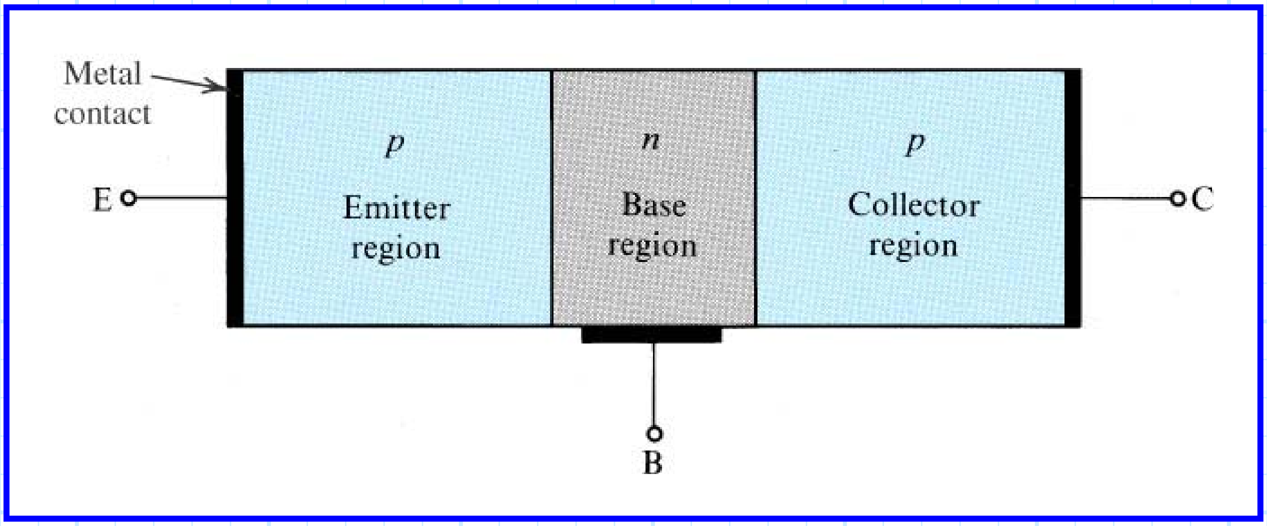
* The junction between the ***n*-type collector** and the ***p*-type base** is called the **Collector-Base Junction** (CBJ).

Note for the **CBJ**, the **anode** is the **base**, and the **cathode** is the **collector**.

* The junction between the ***n*-type emitter** and the ***p*-type base** is called the **Emitter-Base Junction** (EBJ).

Note for the **EBJ**, the **anode** is the base, and the **cathode** is the emitter.

Now, we find that the ***pnp*** BJT is simply the **complement** of the *npn* BJT—the *n*-type silicon becomes *p*-type, and vice versa:



Thus, the *pnp* BJT **likewise** has **three** terminals (with the same names as the *npn*), as well as **two** *p-n* junctions (the CBJ and the EBJ).

* For the *pnp* BJT, the **anode** of the **CBJ** is the **collector**, and the **cathode** of the **CBJ** is the **base**.

* Likewise, the **anode** of the **EBJ** is the **emitter**, and the **cathode** of the **EBJ** is the **base.**

Note that these results are precisely **opposite** that of ***npn*** BJT.

Now, we know that **each** *p-n* junction (for either *npn* or *pnp*) has **three** possible **modes**:

1. *forward biased*
2. *reverse biased*
3. *breakdown*

We find that **breakdown** is **not** generally a useful mode for transistor operation, and so we will **avoid** that mode.

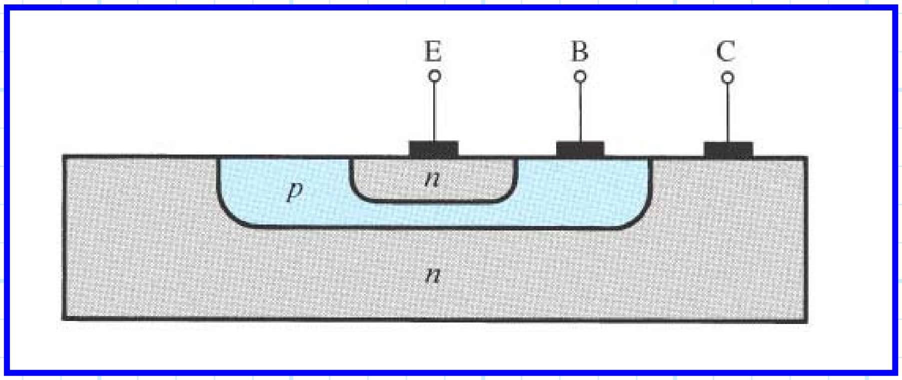
Given then that there are **two useful** *p-n* junction modes, and **two** *p-n* junctions for each BJT (i.e., CBJ and EBJ), a BJT can be in one of **four** modes!

MODE	EBJ	CBJ
1	Reverse	Reverse
2	Forward	Reverse
3	Reverse	Forward
4	Forward	Forward

Now, let's give each of these four BJT modes a **name**:

MODE	EBJ	CBJ
Cutoff	Reverse	Reverse
Active	Forward	Reverse
Reverse Active	Reverse	Forward
Saturation	Forward	Forward

We will find that the **Reverse Active** mode is of **limited** usefulness, and thus the **three basic operating modes** of a BJT are Cutoff, Active, and Saturation.

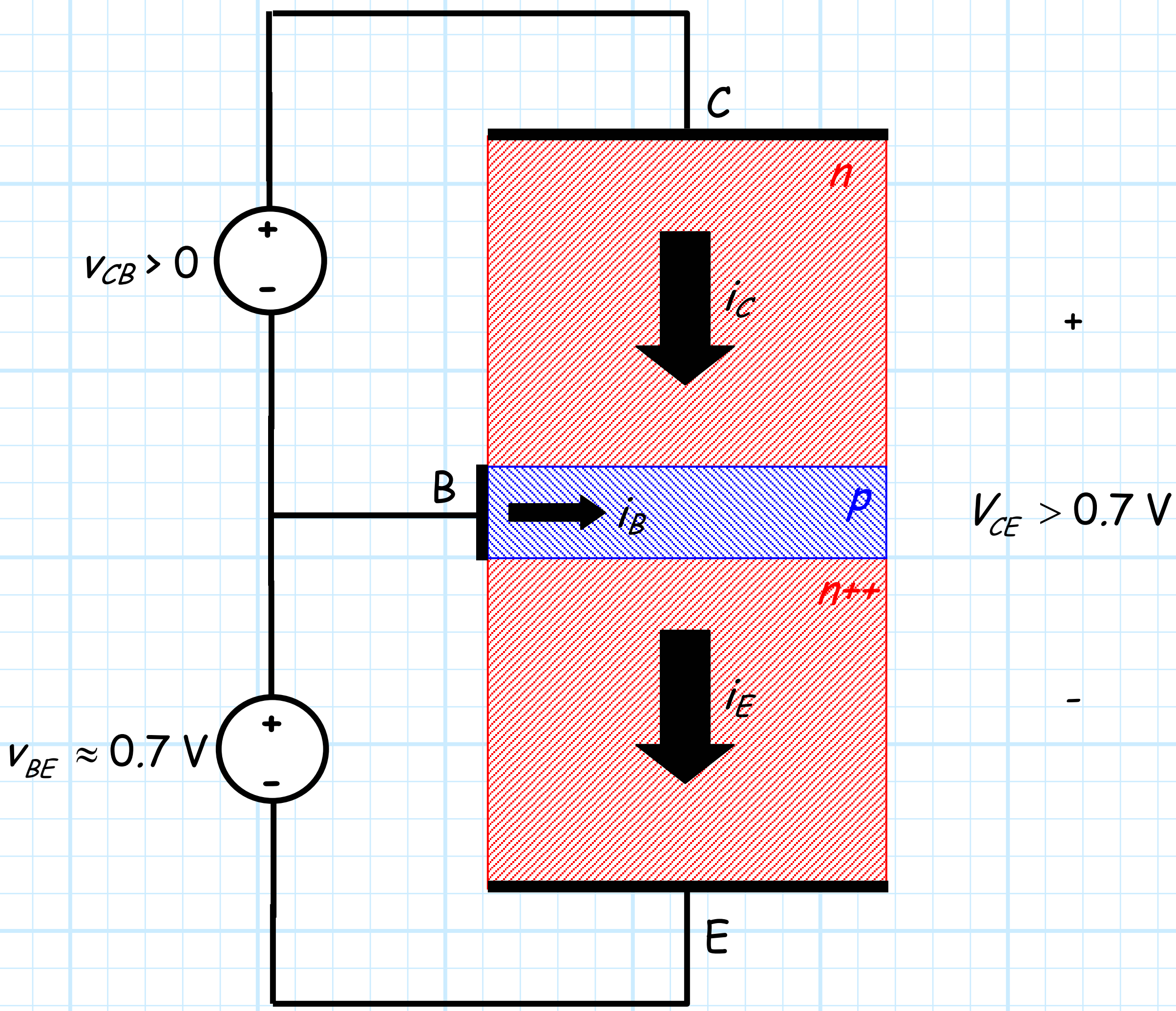


An Integrated Circuit BJT

The *npn* Transistor in the Active Operating Region

We know that the **base-emitter** junction of an *npn* BJT in the **active** region will be **forward** biased, while the **collector-base** junction will be **reversed** biased. In other words:

$$v_B - v_E \doteq v_{BE} \approx 0.7 \ V \quad and \quad v_C - v_B \doteq v_{CB} > \ 0 \ V$$



Q: *OK, if the collector-base junction is **reverse** biased, then **no** current will flow through the collector-base junction, meaning i_C **must be zero** and $i_B=i_E$, right ??*

A: NO ! A BJT is more **complex** in its operation than that. Recall the base is **very thin**. This causes something **unusual** to happen!

* Recall that if the **collector-base** junction is reversed biased, then the barrier voltage is **large** and the **diffusion** current will drop to **zero**.

* However, recall also that the **drift** current is **unaffected** by the barrier voltage, so drift current **does** flow across the collector base junction !

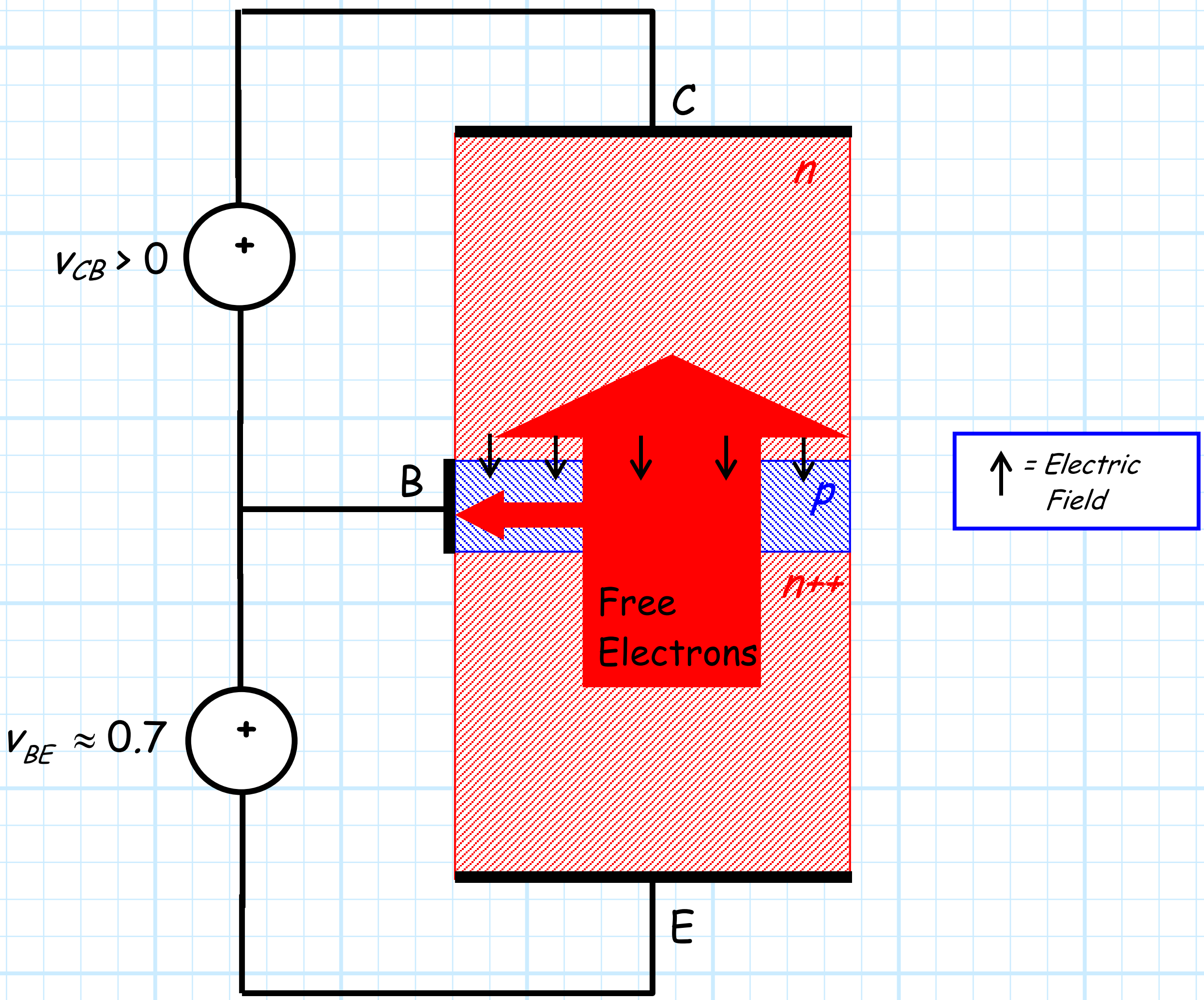
Q: *Pft! This diffusion current is really small, right? Like 10^{-12} A!?*

A: NO! Again, this is true for a junction diode, but **not** for a *npn* transistor.

* Recall that the **base-emitter** junction is forward biased, and therefore the **diffusion** current across this junction is **large**.

* The **emitter** region of an *npn* transistor is **heavily** doped (n++), so that the **diffusion** current primarily consists of **free electrons** moving from the emitter into the base.

* Normally, these free electrons would move to the **base electrode**, and some still do. But **most** get **swept across** the collector base junction by the **electric field** in the depletion region.



In other words, the large number free electrons in the emitter **diffuse** across the base-emitter junction into the base, then **drift** across the collector-base junction into the collector.

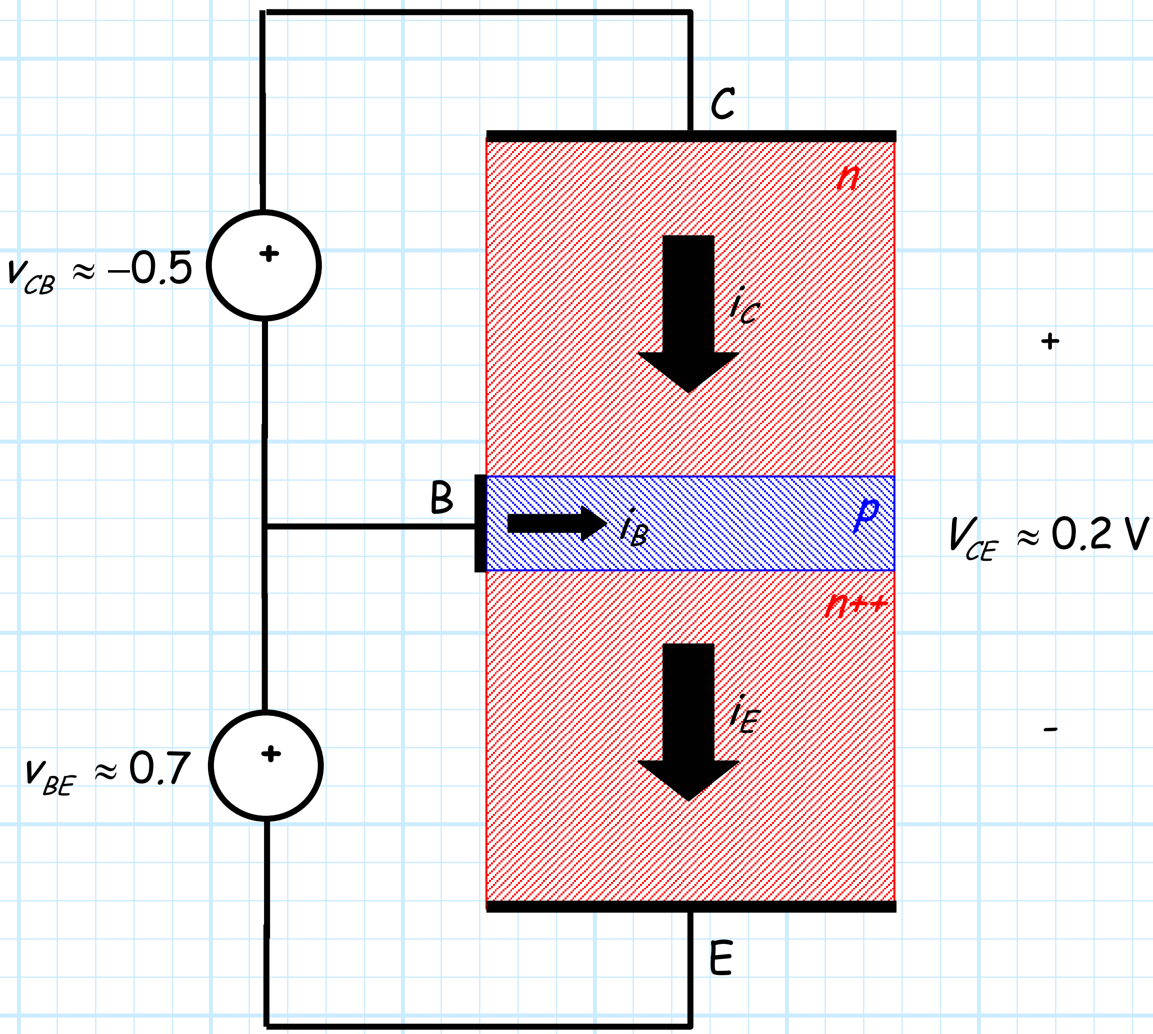
We say that emitter **emits** free electrons, and the collector **collects** them.

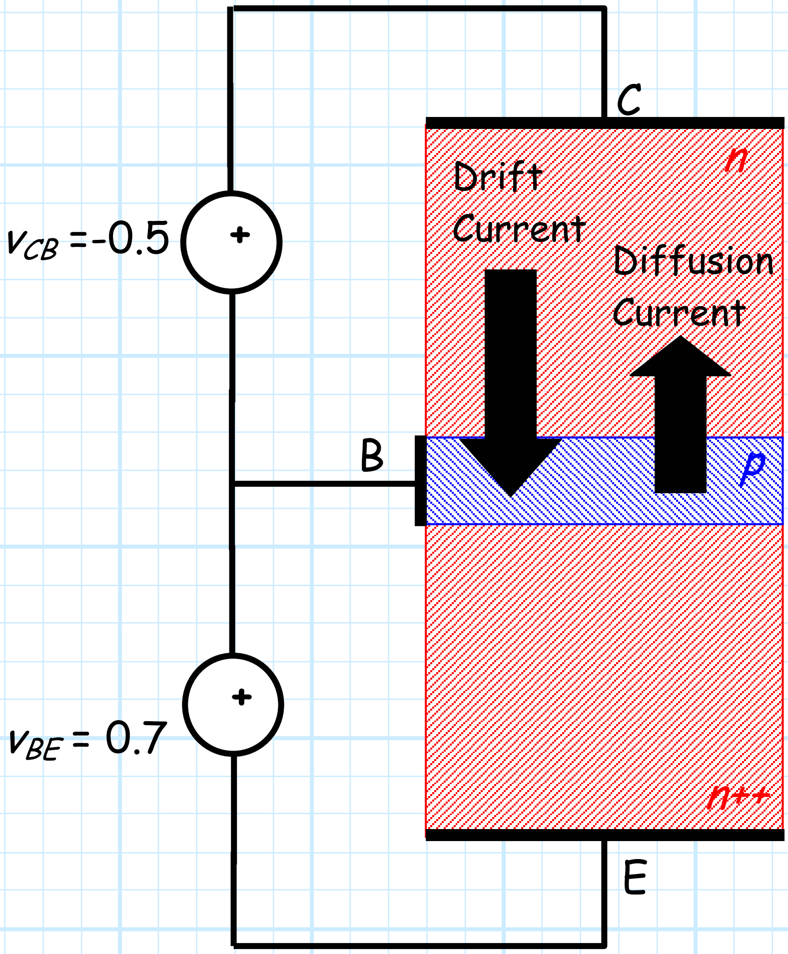
If the base is **thin**, then for every free electron that diffuses across the base-emitter junction, we find that **100 or more** are collected (i.e, drift across the CBJ) by the collector!

The *npn* Transistor in Saturation

We know that for an *npn* BJT in **saturation**, **both** the BEJ and CBJ will be **forward biased**. In other words:

$$v_B - v_E \doteq v_{BE} \approx 0.7 \ V \quad \text{and} \quad v_C - v_B \doteq v_{CB} \approx \ -0.5 \ V$$





* In **active** mode, the collector current consists mainly of free-electrons that **drift** from the emitter into the collector.

* Since in **active** mode the CBJ is **reverse biased**, there is **no diffusion** of free electrons and holes.

* But in **saturation**, the CBJ is **forward biased** therefore there is also a large amount **diffusion current**!

Recall that **diffusion** current flows in the **opposite** direction of **drift** current.

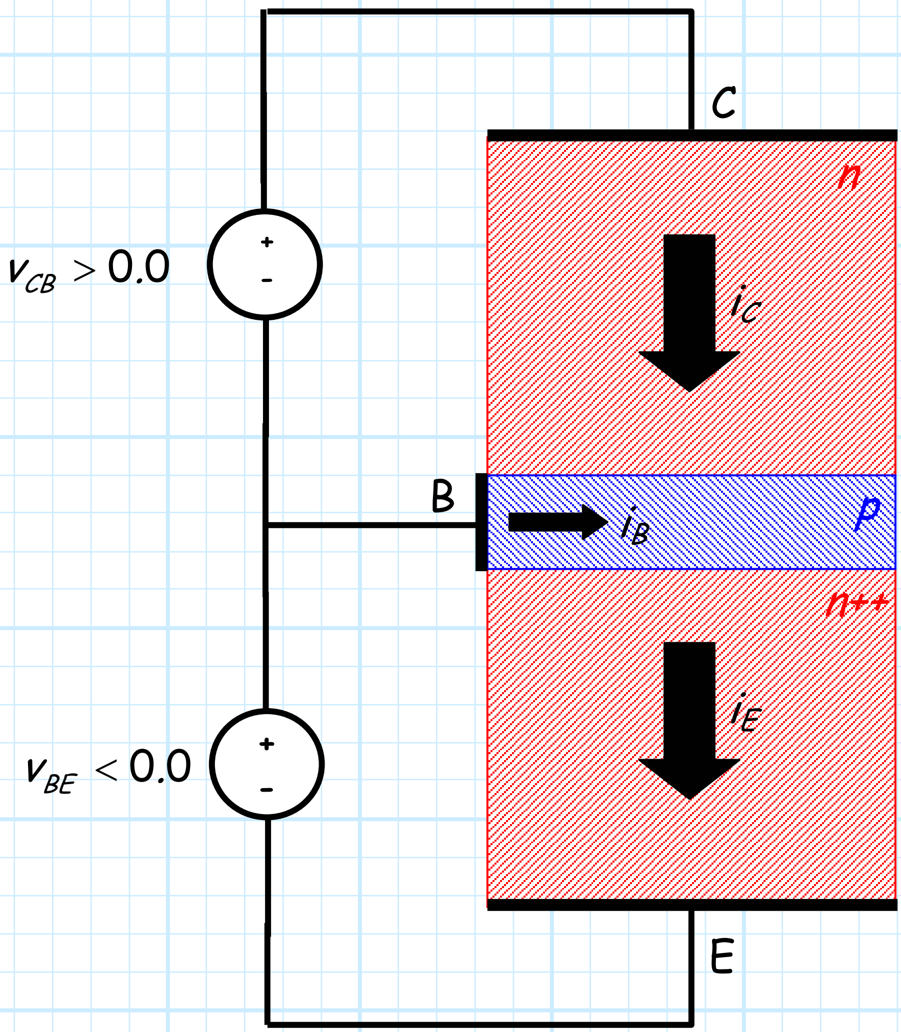
As a result, diffusion and drift current tend to **cancel** each other.

Therefore in **saturation**, the **total collector current** (i.e., drift **minus** diffusion) is **less** than that of drift alone.

The *npn* BJT in Cutoff

We know that for an *npn* BJT in **cutoff**, **both** the BEJ and CBJ will be **reverse biased**. In other words:

$$v_B - v_E \doteq v_{BE} < 0.0 \ V \quad \text{and} \quad v_C - v_B \doteq v_{CB} > 0.0 \ V$$



If both *p-n* junctions (CBJ and EBJ) are **reverse biased**, then **no current** will flow! I.E.:

$$i_B = i_C = i_E = 0.0 \text{ for a BJT in Cutoff}$$