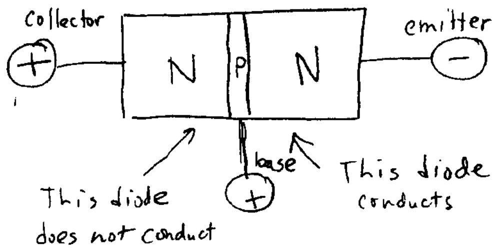
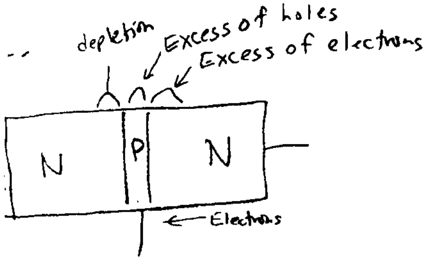
Bipolar Junction Transistors



(Very crude explanation)

But ....



The excess of holes in the p region is sufficient to overcome the depletion region, making it conduct.

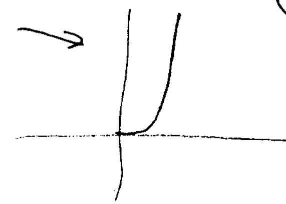
Electrons sweep through the base into the collector.

This conduction is controlled by the base current

→ more base current
= more conduction.

Amplification

Remember diode V/I characteristic →



Small change in voltage produces large change in current.

with no collector connection:

$$I_B = I_E = \text{same as a diode}$$

$$= I_{ES}\left(e^{\frac{V_{be}}{V_T}} - 1\right)$$

I_{ES} = emitter saturation current
$= 10^{-12} - 10^{-17}$

$V_T \approx 26\,mV$.

With positive voltage on collector

I_B = same as before,

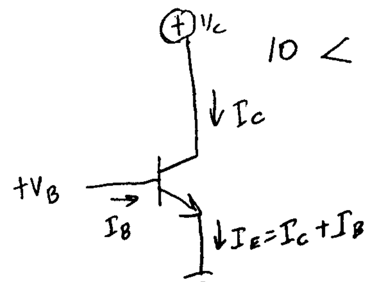
$I_E = I_C + I_B$

I_C = big compared with I_B

$$I_C = \beta I_B$$

↑
"beta" is a parameter that describes this.

$$\beta = \frac{I_C}{I_B}$$



$10 < \beta < 1000$ (usually)

Typical = 100

Other transistor parameters

$$\alpha = \frac{I_C}{I_E} = \frac{I_C}{I_C + I_B} = \frac{\beta I_B}{(\beta+1) I_B} = \frac{\beta}{\beta+1}$$

(really says the same as β, but looks different)

$.9 < \alpha < .999$ Typical = .99

or - - -

$$\alpha = \frac{\beta}{\beta+1}$$

$$(\beta+1)(\alpha) = \beta$$

$$\alpha\beta + \alpha = \beta$$

$$\alpha\beta - \beta = -\alpha$$

$$(\alpha-1)\beta = -\alpha$$

$$\beta = \frac{-\alpha}{\alpha-1} = \frac{\alpha}{1-\alpha}$$

$$I_B = I_{ES}\left(e^{\frac{V_{BE}}{V_T}} - 1\right)$$

$$I_C = \beta I_B$$

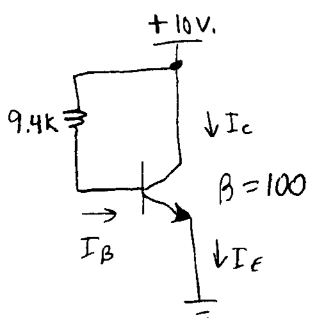
$$= \beta I_{ES}\left(e^{\frac{V_{BE}}{V_T}} - 1\right)$$

$$\approx \beta I_{ES}\left(e^{\frac{V_{BE}}{V_T}}\right)$$

$$\approx I_S\left(e^{\frac{V_{BE}}{V_T}}\right)$$

↖ "scale current"

Here's a circuit:



What is I_C, I_B, I_E.

Assume $V_{BE} = .6$ V.

$$I_B = \frac{V}{R} = \frac{9.4}{9.4K} = 1 \text{ ma}$$

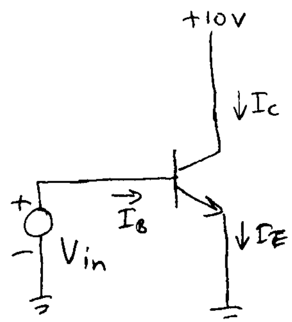
$$I_C = \beta I_B = 100 \text{ ma}$$

$$I_E = I_C + I_B = 101 \text{ ma}$$

Example 2: (more detail)

Transistor parameters: $\beta = 100 = 10^2$

$I_{ES} = 10^{-14}$



Calculate: $I_S = 10^{-12} = \beta I_{ES}$

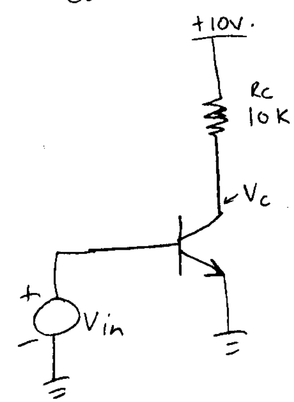
$$I_C = I_S e^{\frac{V_{BE}}{V_T}}$$

$$= 10^{-12} e^{\frac{V_{BE}}{V_T}}$$

Note Large current change →

V_{BE}	I_C
0	10^{-12}
.1	4.7×10^{-11}
.2	2.1×10^{-9}
.3	1×10^{-7}
.4	4.8×10^{-6}
.5	2.2×10^{-4}
.6	1×10^{-2}
.7	5×10^{-1}
.8	2.3×10^{1}
.9	1.1×10^{3}
1.0	5.0×10^{4}

Now, put a resistor in series with the collector:



Assume it doesn't change Ic.

What is Vc?

V_{BE}	V_{RC}	
0	1×10^{-8}	≈ 0
.1	4.7×10^{-7}	
.2	2.1×10^{-5}	
.3	1.0×10^{-3}	
.4	4.8×10^{-2}	
.5	2.4×10^{0}	= 2.4
.6	1.0×10^{2}	= 100
.7	10^{3}	> 10
.8	10^{5}	
.9		
.10		

So, for $V_{BE} = .5$, $V_C = 2.4$.

"saturated" ↗

What if R = 1K? 100?

More detail near .5

V_{BE}	I_c	$V_{RC} = IR$	Gain = $\frac{\Delta V_{RC}}{V_{BE}}$
.45	3.2 $\times 10^{-5}$	.32	
.46	4.8	.48	$\frac{.16}{.1} = 1.6$
.47	7.0	.7	
.48	1.04 $\times 10^{-4}$	1.04	
.49	1.53	1.53	$\frac{.49}{.1} = 4.9$
.5	2.24 $\times 10^{-4}$	2.24	7.1
.51	3.30	3.30	10.6
.52	4.85	4.85	15.5
.53	7.12	7.12	22.7
.54	1.04 $\times 10^{-3}$	10.4	
.55	1.53	15.3 Saturated	

With $R_c = 100k$

V_{BE}	V_{RC}	
.45	3.2	
.46	4.8	$\frac{1.6}{.1} = 16$
.47	7.0	→ 22
.48	10.4	→ 34

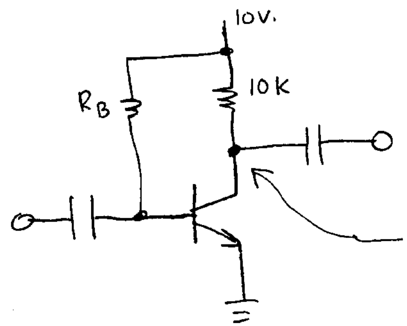
↓ Saturated

→ Higher Load resistance
→ Higher voltage gain.

```
n=0:10
vbe=n/10
vt=.026
ic=exp(vbe/vt)*1e-12
Vcr=ic*1000
```

← Octave program to calculate tables

How to use this amplifier;



set this voltage to half of the supply (5V).

So, 5V $I_c = \frac{5V}{10K} = 5 * 10^{-4}$

$V_{BE} \approx .52$ (from table)

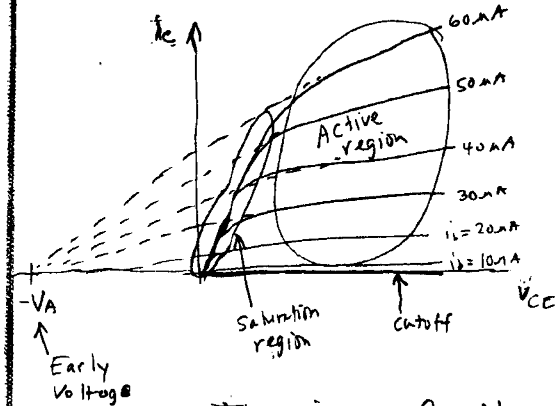
So, $V_{RB} = 10 - .52 \approx 9.5$

$R_B = \frac{V_{RB}}{I_B} = \frac{V_{RB}}{I_c/\beta} = \frac{9.5}{(5{*}10^{-4})/100}$

$= \frac{9.5}{5 * 10^{-6}} = 1.9$ Meg.

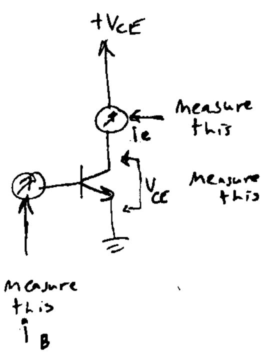
Coupling (DC Block) capacitors allow AC Signal to pass, maintaining transistor DC Bias.

Transistor characteristic curves.



3 regions — Active
Saturation
Cutoff.

This is a family of curves.
"Common emitter characteristics" —
One curve for each sample V_{BE}.

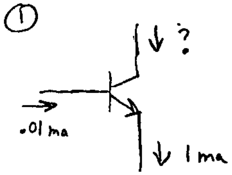


Hold i_B constant —
Sweep V_c
Measure i_c

Breakdown — (3.1.6)
Like a zener diode —
When the voltage is too high, it breaks down —
non-destructive, but current can be destructive.

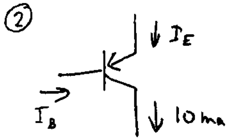
Examples

①



What is β?
α?
I_c?

②



β = 100
What is I_B?
I_E?