Transistors

ECE 320 Electronics I

Jake Glower - Lecture #11

Please visit Bison Academy for corresponding lecture notes, homework sets, and solutions

NPN Transistor Theory

Transistors are similar to diodes in that they are made up on n-type and p-type silicon. They differ in that

- Transistors are 3-terminal devices (NPN or PNP),
- Transistors can operate in three states: off, active, and saturated,
- Transistors can be used as a switch to turn a device on and off electrically, and
- Transistors can be used as an amplifier (a current controlled current amplifier).

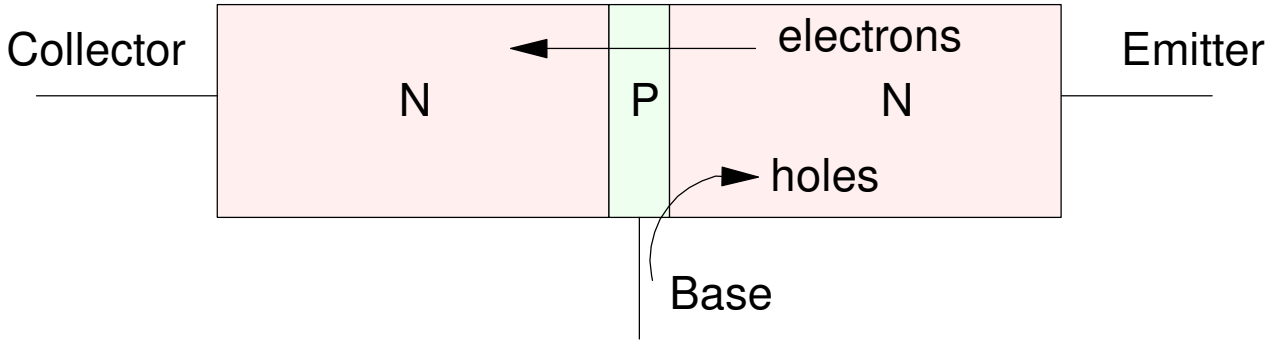
NPN Transistor Operation

- A reverse biased diode (np) blocks current from emitter to collector:
- Base to emitter is a diode (pn junction)

If you apply current base to emitter

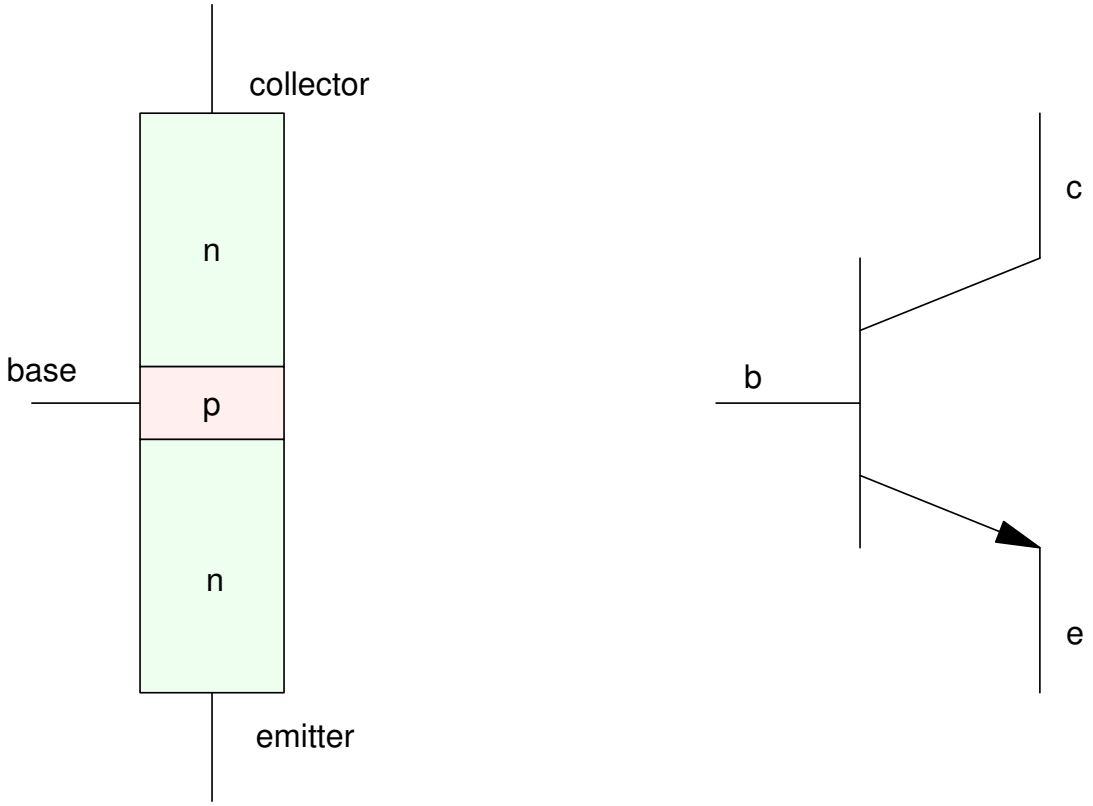
- Holes flow from the base to the emitter
- Electrons flow from the emitter to the base (to the collector)

If the emitter has 100x the doping of the base, you get current gain



An NPN device makes a transistor

The symbol for a transistor is as follows. Note that the arrow represents the diode from base to emitter. It reminds you which way current flows.



Symbol for an NPN transistor: the arrow indicated the diode from base to emitter

Transistor VI Characteristics:

Off:

$$Ib = Ic = 0$$

Active:

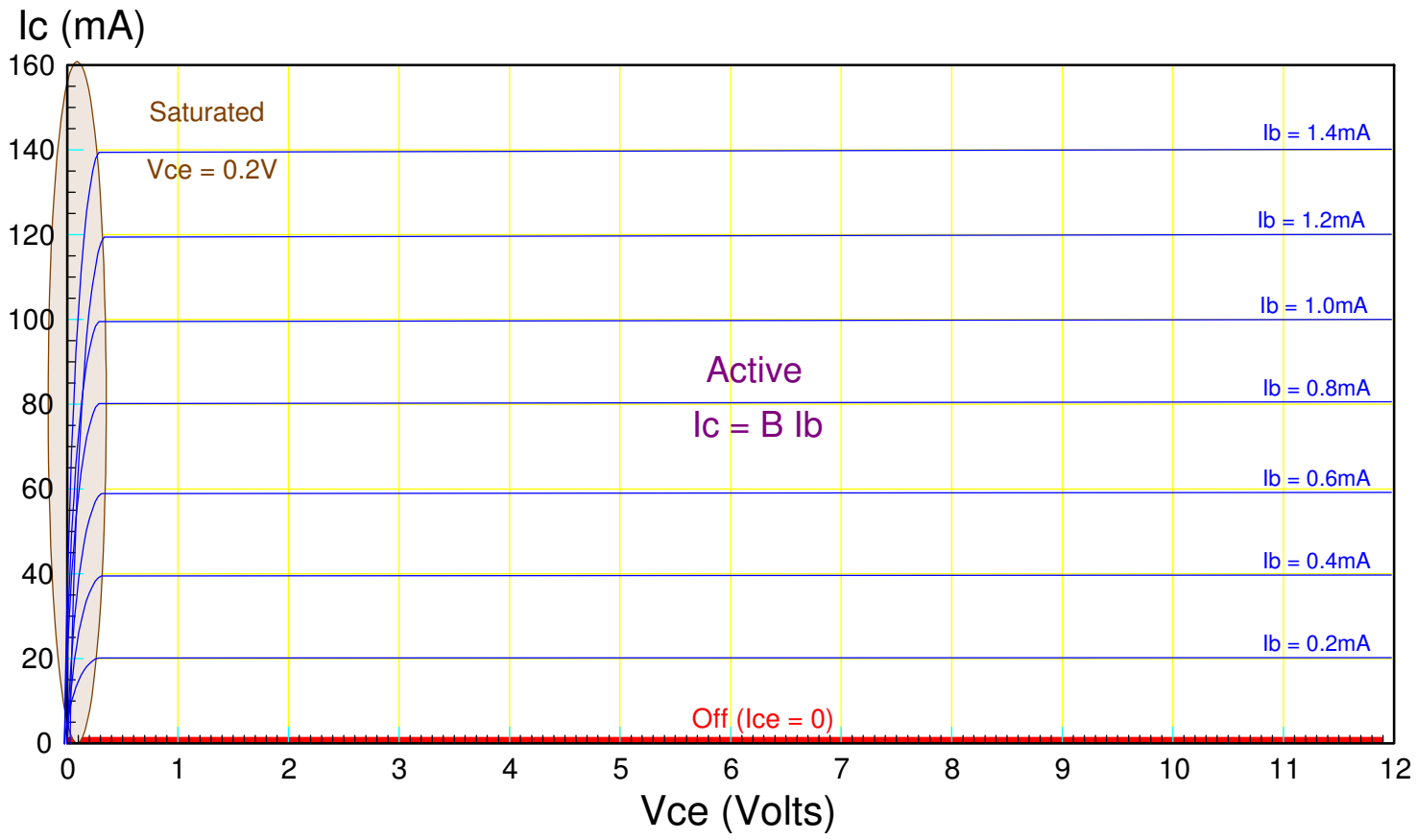
$$I_c = \beta I_b$$

$$\beta = \frac{140mA}{1.4mA} = 100$$

Saturated:

$$\beta I_b > I_c$$

$$V_{ce} \approx 0.2V$$



Off State

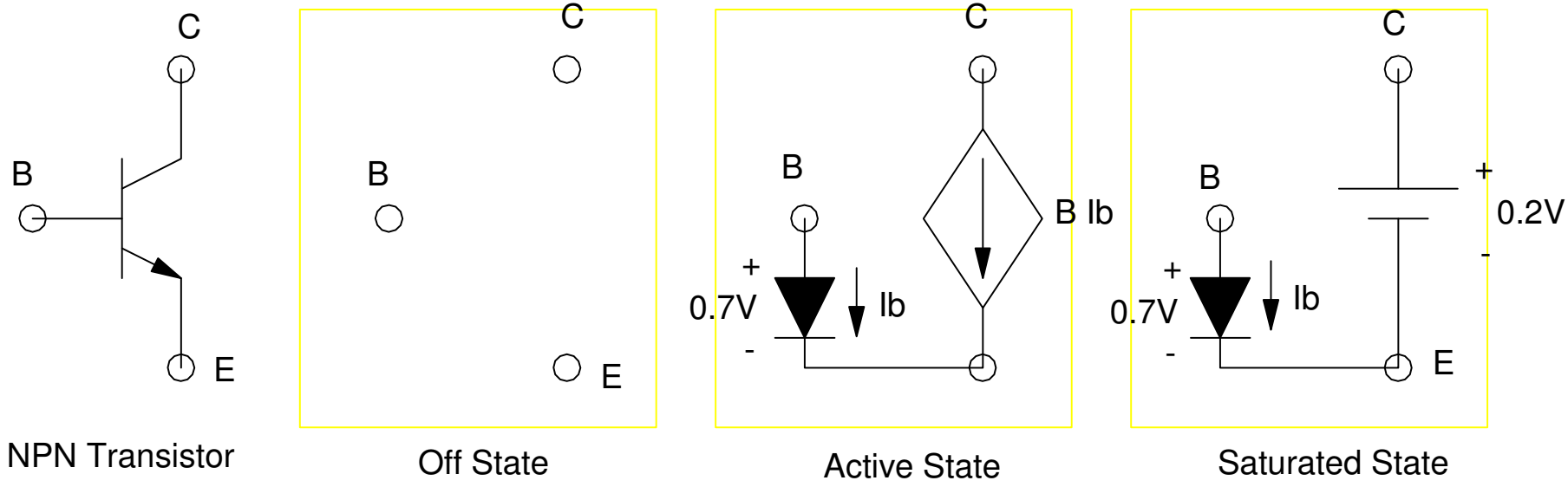
- Ib = 0, Ic = 0

Active State: 0.2V < Vce < Vcc

$I_c = \beta I_b$.

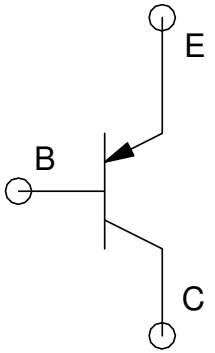
Saturated State: $\beta I_b > I_c$

$V_{ce} = 0.2V$

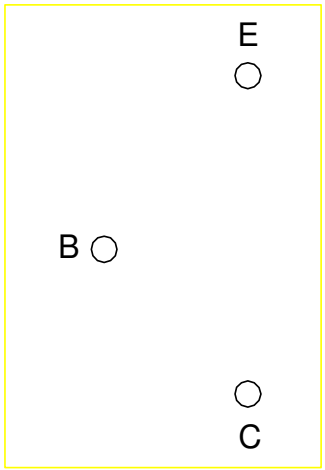


PNP Transistors:

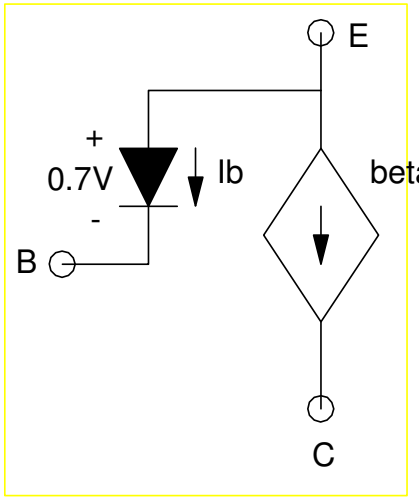
- Note: The arrow represents a diode
- This current determines Ice (or Iec)



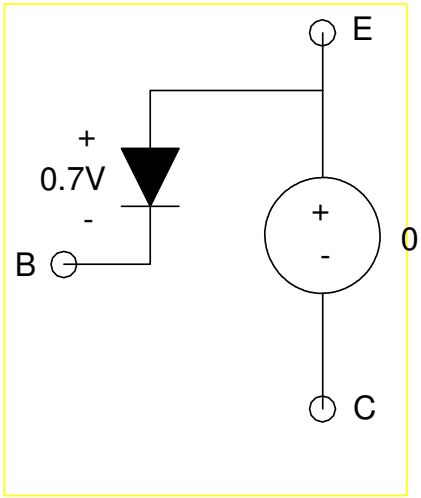
PNP Transistor



Off State

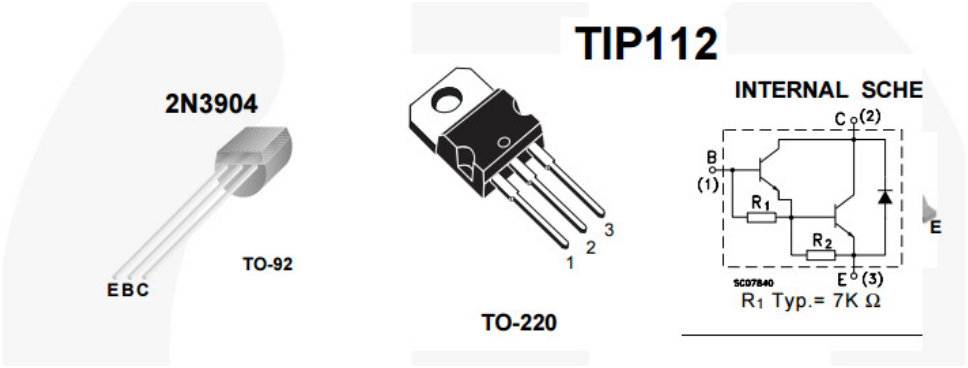


Active State



Saturated State

Transistor Specs



	3904 NPN	6144 NPN	TIP112 NPN
hfe (beta)	100 - 300	200	1,000
Ic (max)	200mA	10A	4A
Vbe	700mV	700mV	1.4V
Vce (max)	40V	50V	40V
Vce (sat)	200mV	360mV	900mV
cost (ea)	$0.03	$0.37	$0.59

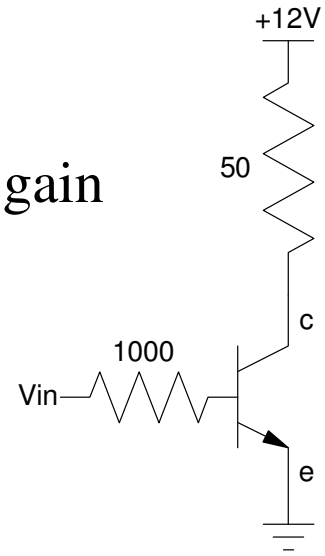
Handout

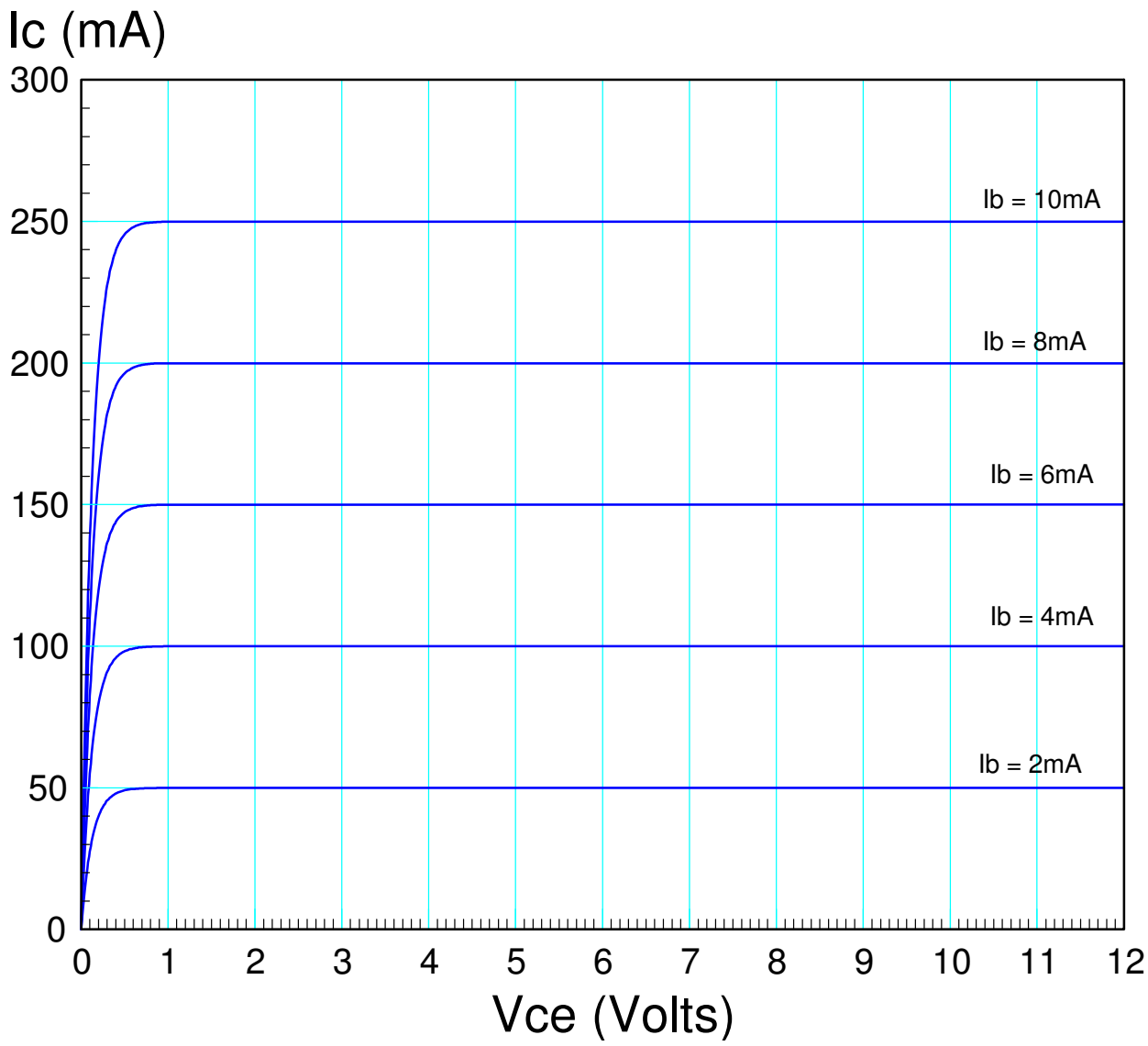
Label the regions

- Saturated
- Active
- Off

Determine the gain

- hfe or β



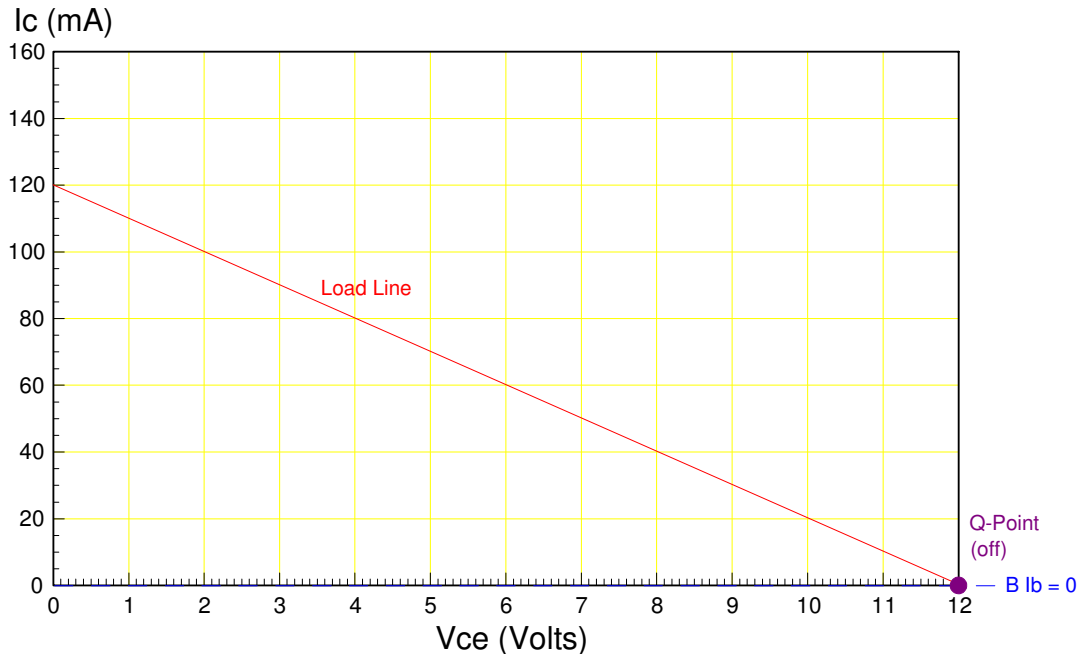


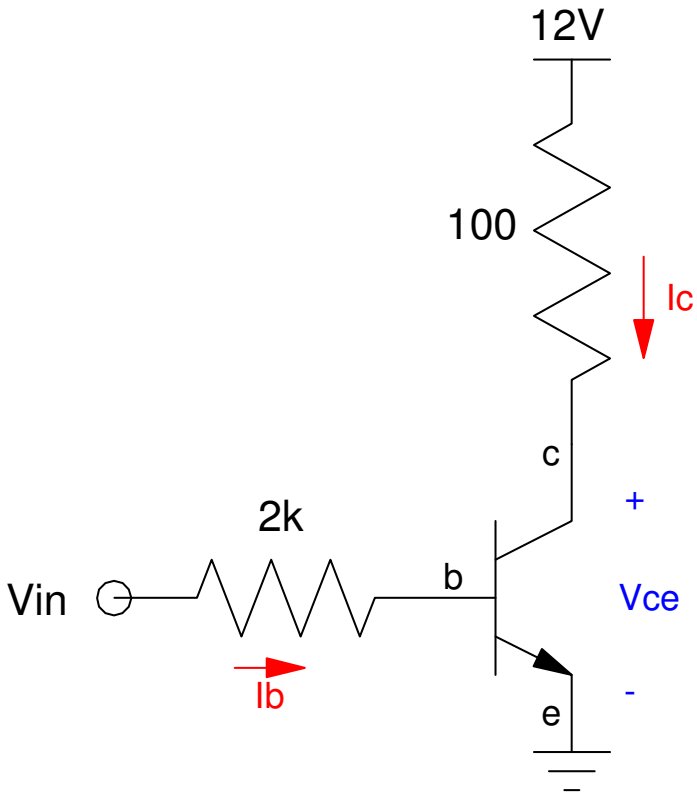
Transistor Circuit Analysis:

a) Vin = 0.5V (Off State):

- Ib = 0
- Ic = 0
- Vce = 12V

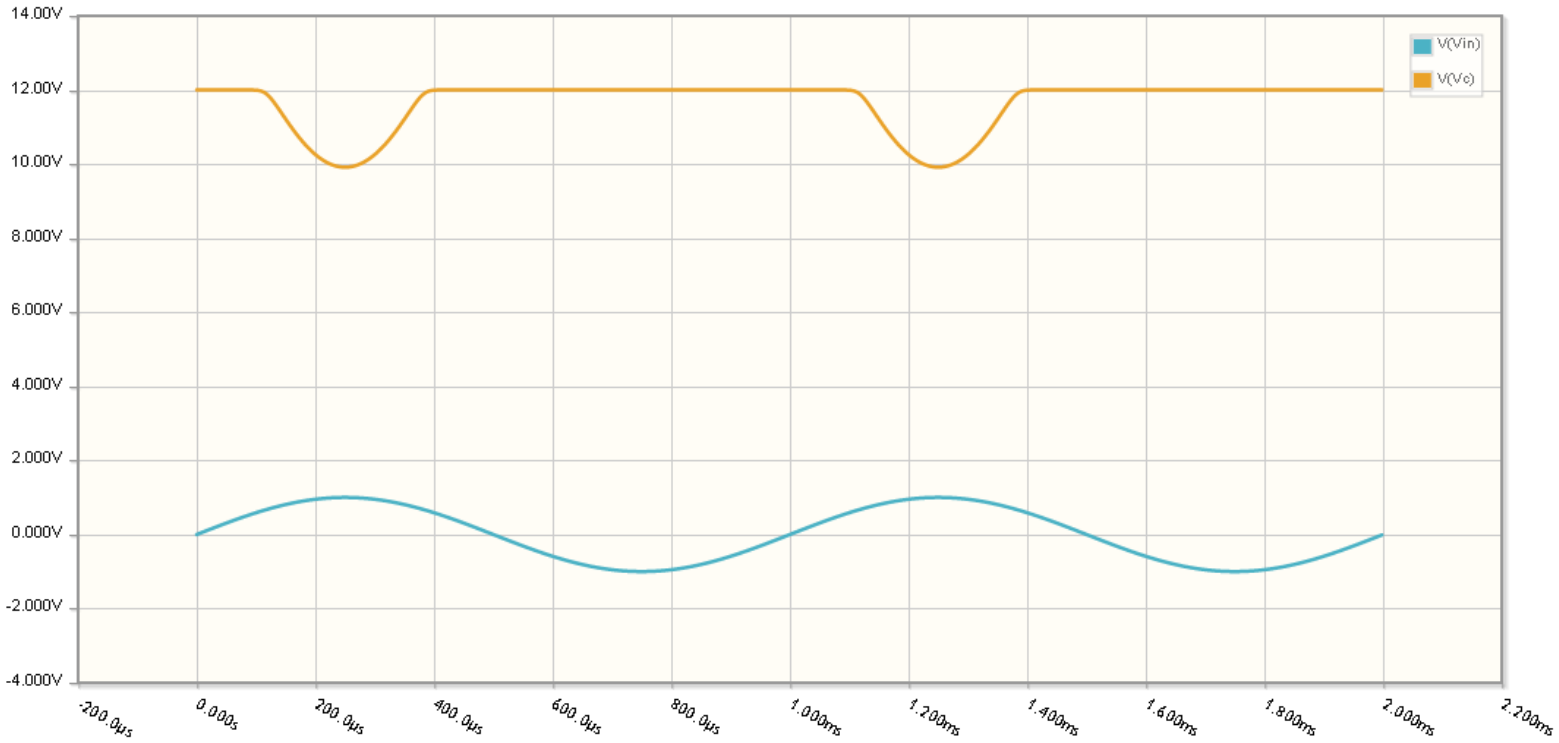
The transistor is off.





Off State in CircuitLab

- If Ib (or Ic) tries to go negative, it clips at 0
- Vc clips at +12V



Vin (blue) and Vc (orange) for a 1Vp sine wave centered at 0V.
When Vc = 12V the transistor turns off.

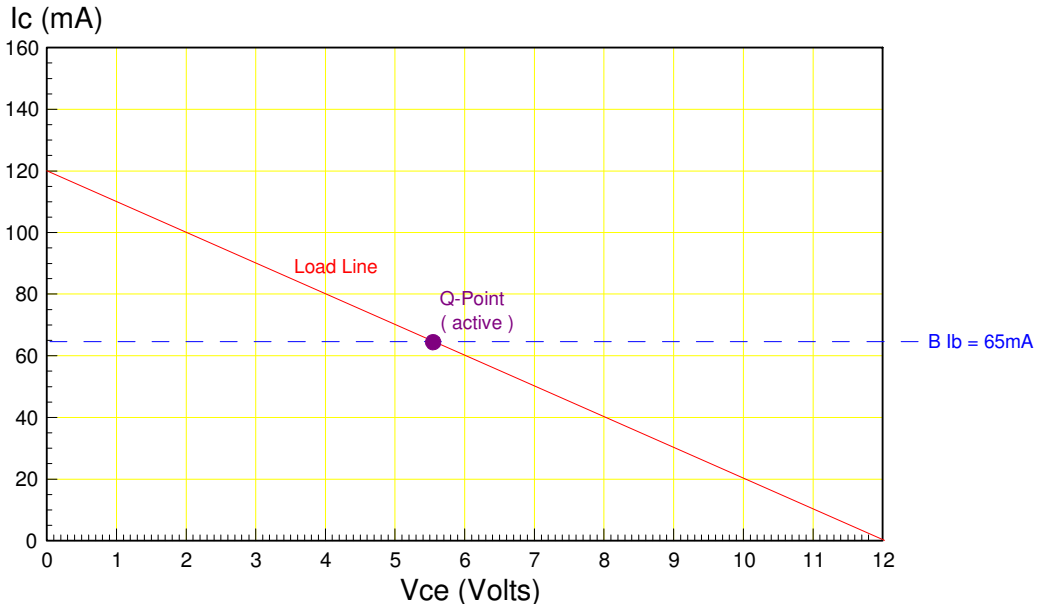
b) Vin = 2.0V (Active Region).

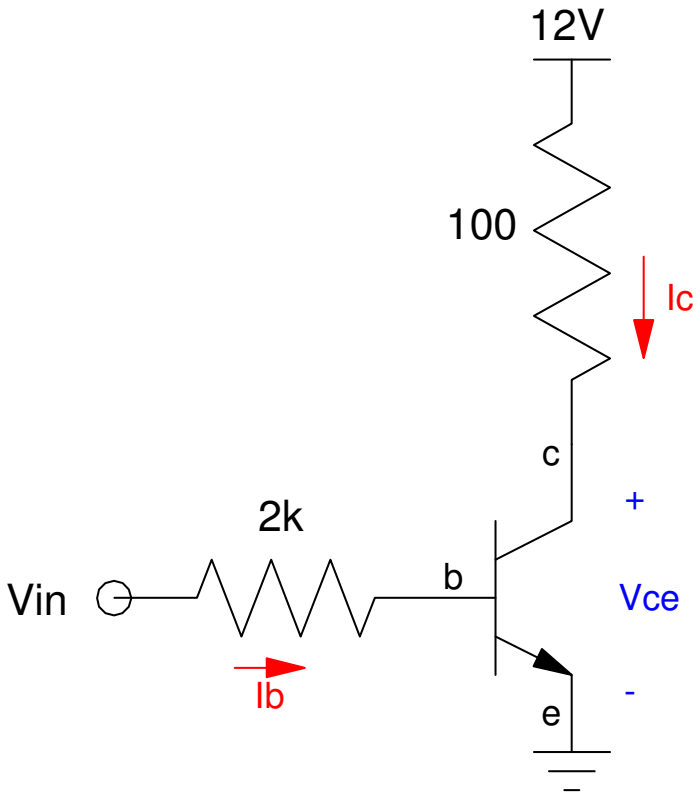
Vb = 0.7V (diode is on)

$$I_b = \left(\frac{2V - 0.7V}{2k\Omega}\right) = 650\mu A$$

$$I_c = \beta I_b = 65mA$$

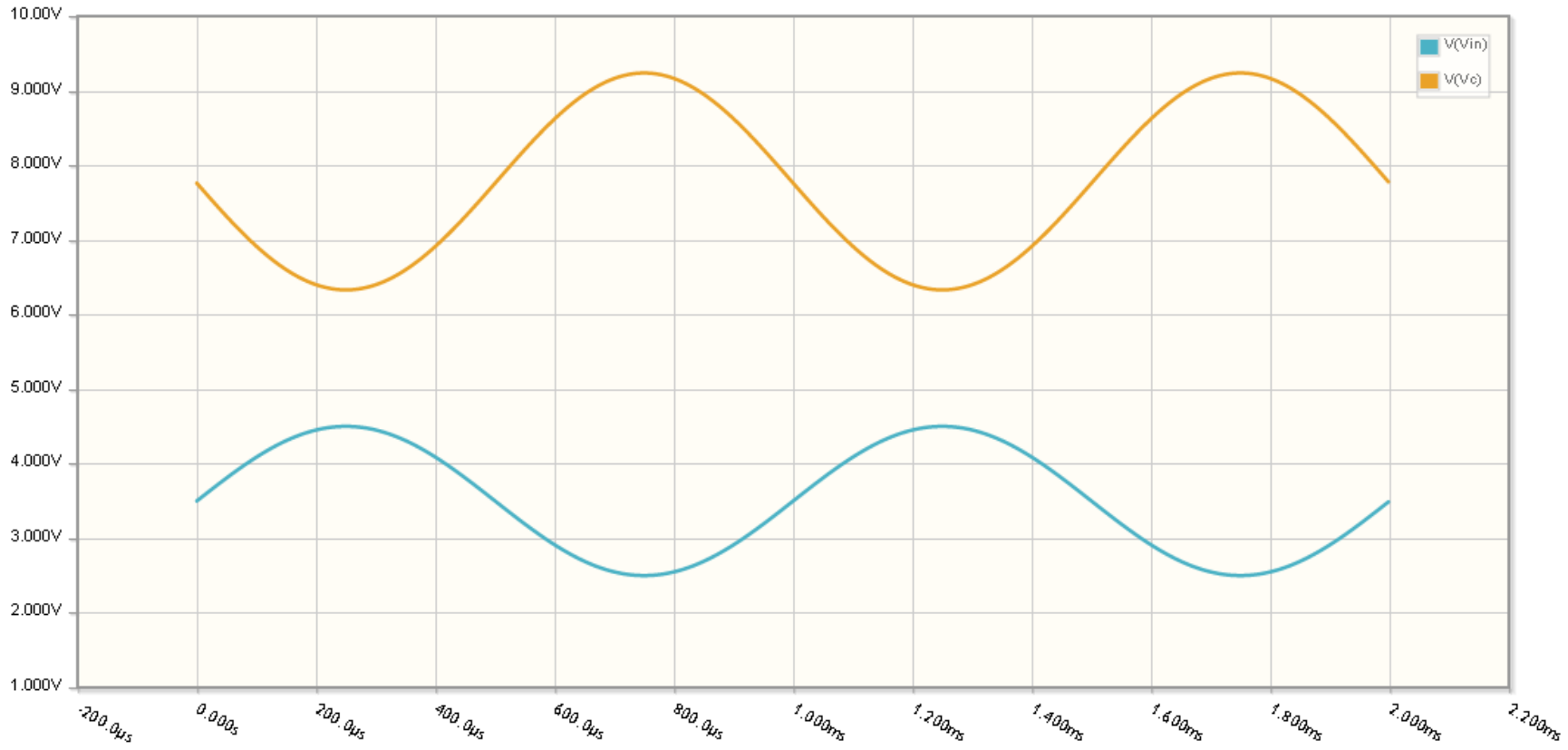
$$V_{ce} = 12 - 100I_c = 5.5V$$





Active Region:

- Increase the DC offset of Vin (blue)
- Increases Ic (decreases Vc)



c) Vin = 3.5V (Saturated Region).

$$I_b = \left(\frac{3.5V - 0.7V}{2k\Omega}\right) = 1.4mA$$

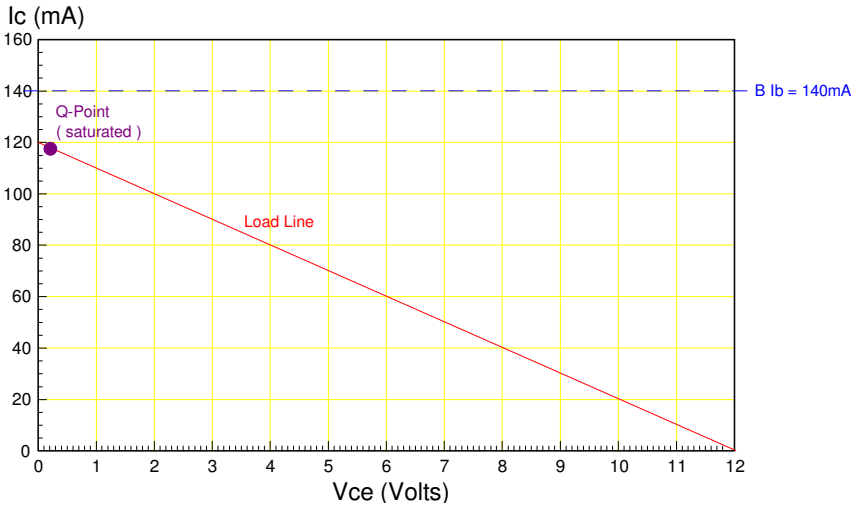
$$I_c = \beta I_b = 140mA$$

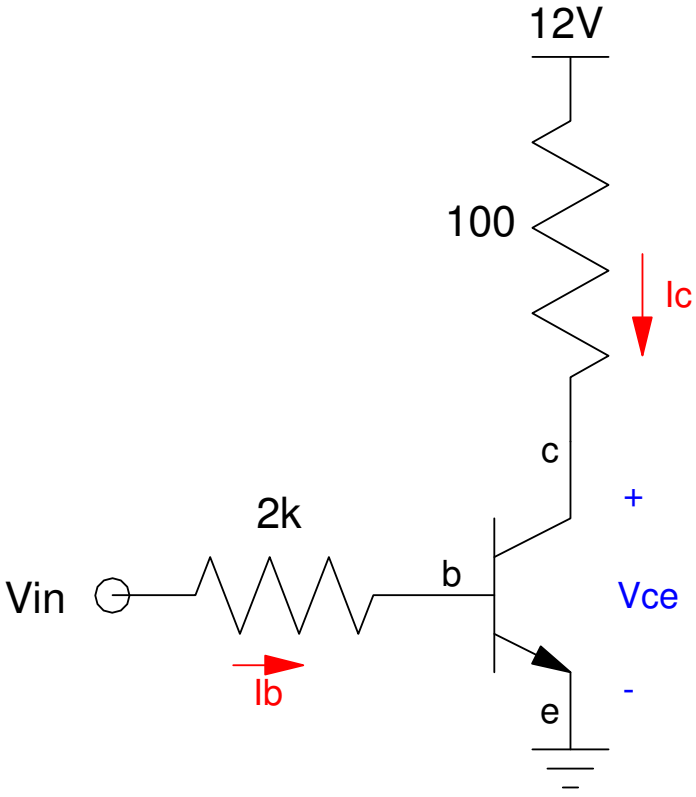
$$V_{ce} = 12 - 100I_c = -2.0V$$

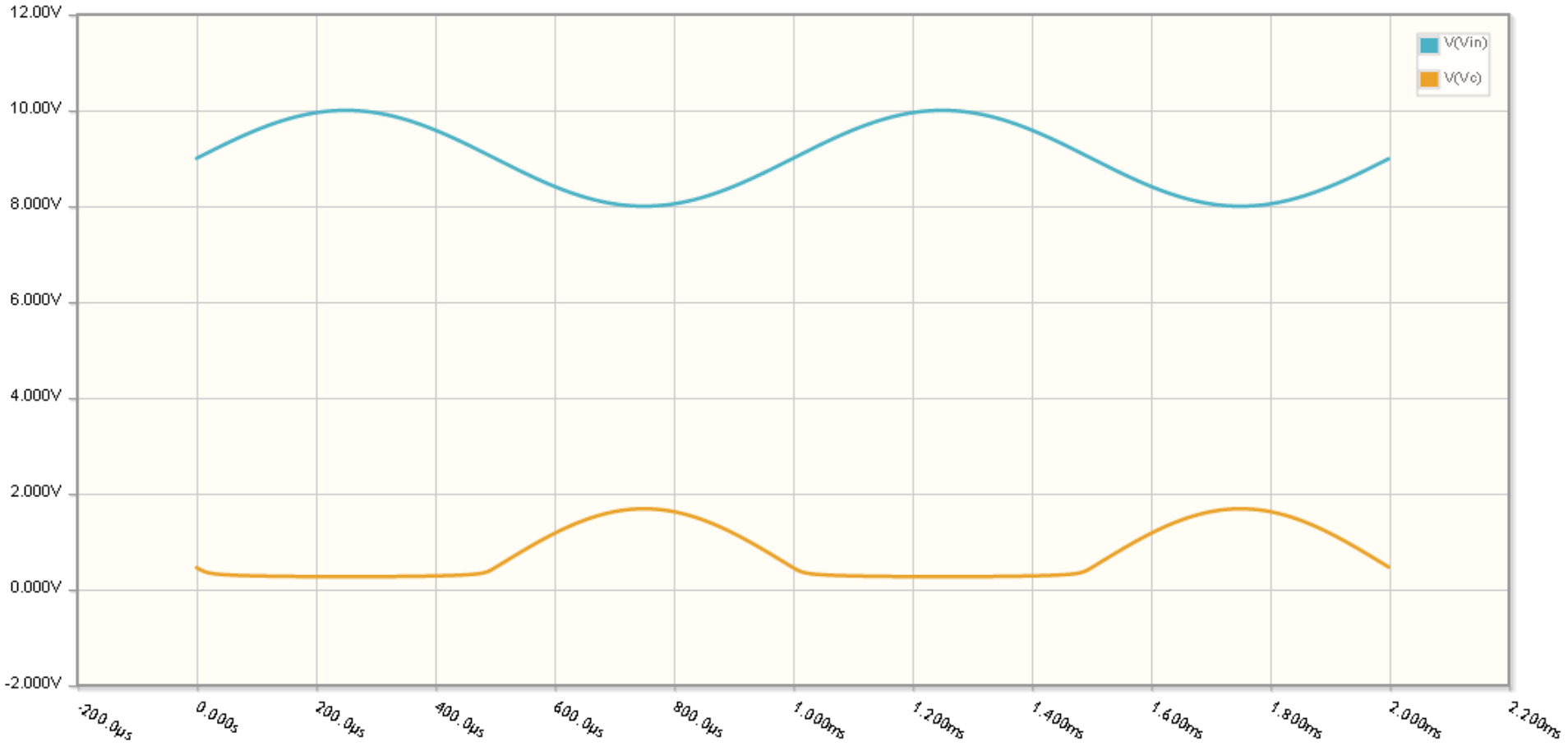
Not Possible

$$V_{ce} = 0.2V$$

$$I_c = \left(\frac{12V - 0.2V}{100}\right) = 118mA$$






12.00V
10.00V
8.000V
6.000V
4.000V
2.000V
0.000V
-2.000V
-200.0µs
0.000s
200.0µs
400.0µs
600.0µs
800.0µs
1.000ms
1.200ms
1.400ms
1.600ms
1.800ms
2.000ms
2.200ms
V(Vin)
V(Vc)

Permutations

N diodes in a circuit

- 2^N permitations of on / off

N transistors in a circuit

- 3^N permitations of off / active / saturated

It helps to know the answer to find the answer

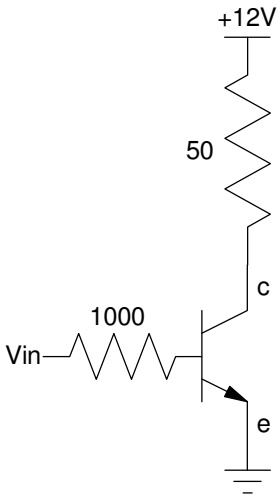
- ECE 320 Digital Electronics: Usually transistors are on or off
- ECE 321 Analog Electronics: Usually transisors are active

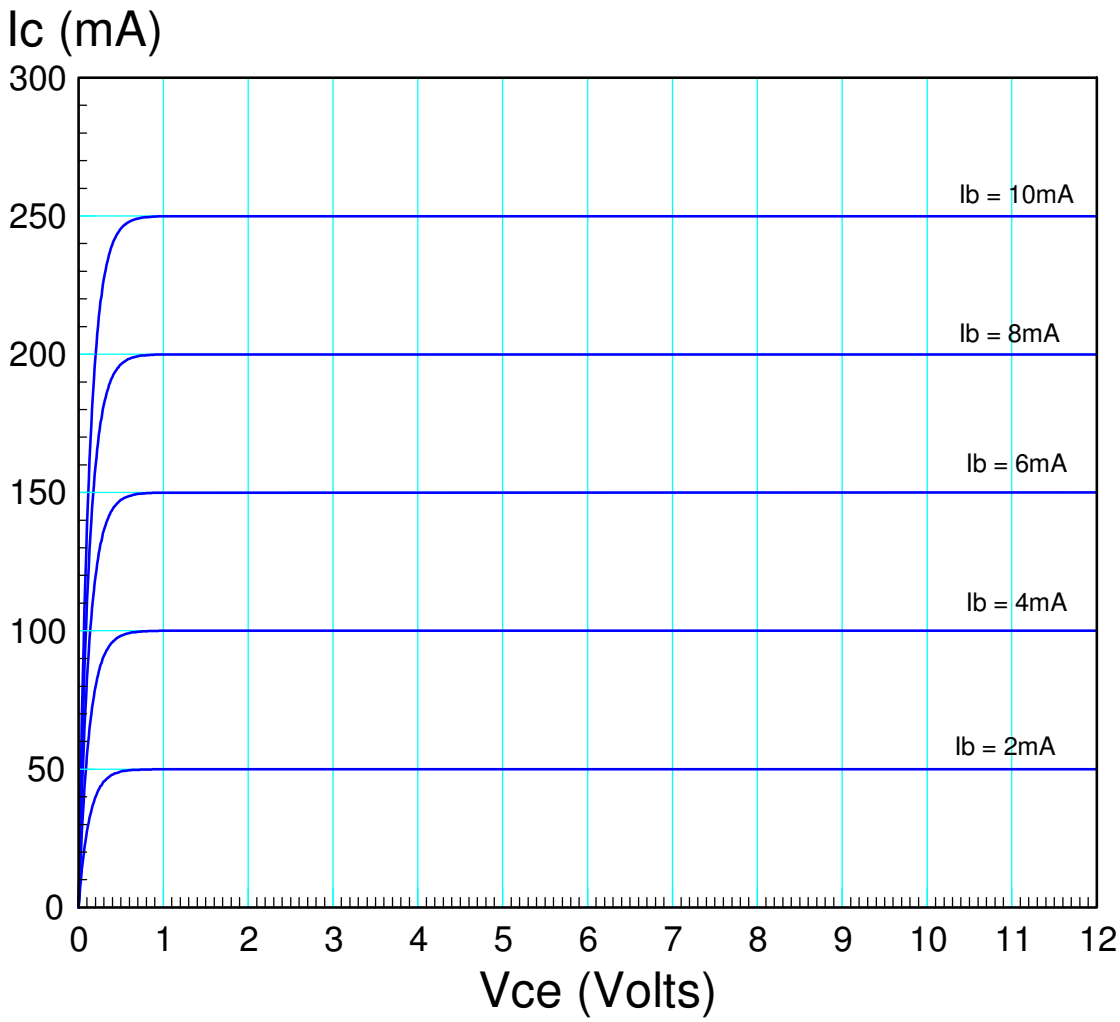
Handout

Draw the Load Line

Determine (Vce, Ic) when

- Vin = 0V
- Vin = 5V
- Vin = 10V
- Vin = 15V





Summary

An npn or pnp device is a transistor.

Transistors have 3 modes of operation

- off / active / saturated

Results in 3^n circuits to analyze

- n = number of transistors
- one of these circuits will be correct

On / Off is primarly used in digital electrionics

Active is primarily used in analog electronics