Notes on *pn* Junctions and Transistors

PHYS 2371/2, Electronics, Northeastern University, Don Heiman 10/3/2009

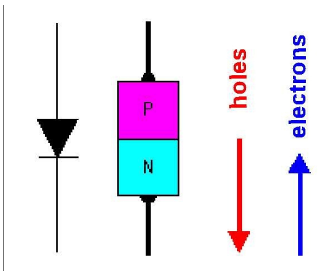
Basic Definitions

Resistivity, ρ (Ωcm or Ωm)
Conductivity, $\sigma=1/\rho$ $(\Omega \text{cm})^{-1}$ or $(\Omega \text{m})^{-1}$
Carrier Density, electrons or holes, **n** (cm^{-3})
Mobility, μ (cm^2/Vs)
$\rho=1/\sigma=1/(ne\mu)$, where $e=1.60\text{x}10^{-19}$ C
Resistance, $\mathbf{R=\rho L/A}$, where L=length, A=cross sectional area of bar or wire

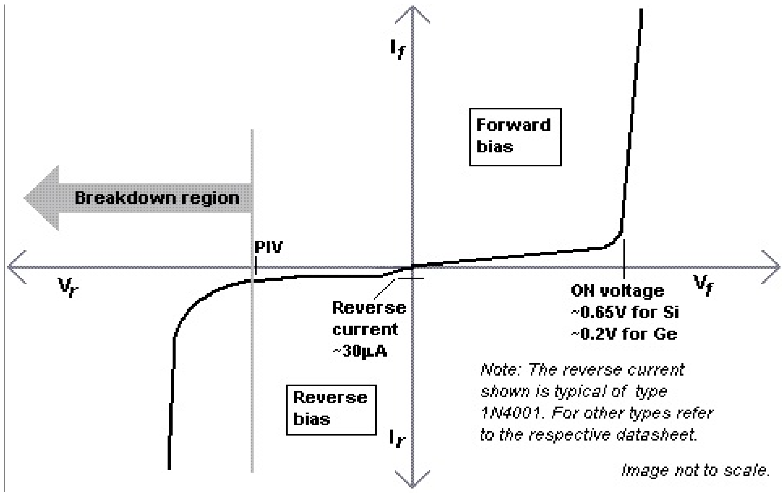
Carrier Doping – Doping adds **mobile** carriers, either electrons or holes. Remember that a dopant atom always leaves behind an **immobile** charge of the opposite sign. Doping examples for silicon:
Donor doping (electrons) – Replacing a group-IV Si atom with a group-V atom such as P.
Acceptor doping (holes) – Replacing a group-IV Si atom with a group-III atom such as In.

***pn* Junction Diode**

$I=I_o[\exp(eV/kT)-1]$



positive current flows down
electrons flow up

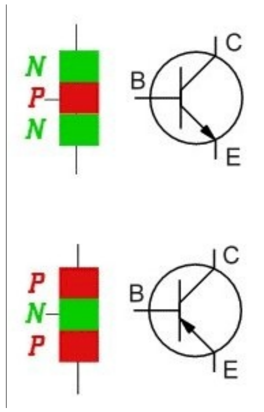


Transistors

A voltage input to the base permits a sizeable collector-emitter (C-E) current.
The base draws very little current, $I_B \ll I_C$, so $I_C \approx I_E$.
Current amplification of circuit, $\beta = I_C/I_B$.

apply negative voltages to *pnp* transistors
apply positive voltages to *npn* transistors

(1) Don't think of transistors as amplifying a current, as with vacuum diodes, rather imagine that a small C-E current leaks out of the base.



(2) In a circuit, treat the transistor C-E as a variable resistor in a **voltage divider**. The effective C-E resistance is then controlled by how much base voltage is applied.

(3) Small or zero base voltage turns **off** C-E current ($R_{transistor}$ ~ large).
Larger base voltage turns **on** C-E current ($R_{transistor}$ ~ 0).

The base-emitter voltage is $|V_{BE}| = 0.6\text{-}0.7\text{V}$ for Si when the transistor is in the linear regime.

Solving Transistor Problems in Chapter 44

Below is a set of rules for determining the regime of a transistor in a circuit: cut-off, linear, or saturated.

In the **cut-off** regime, no current flows ($I_B \approx I_C \approx I_E \approx 0$)
In the **linear** regime, all currents are nonzero (all I_B, I_C, $I_E > 0$)
In the **saturation** regime, all voltages are nearly equal ($V_B \approx V_E \approx V_C$)

The following recipe is over simplified, so please read the chapter carefully.

(1) Initially, treat $\beta >> 1$, so that $I_C \approx I_B$ and $I_B \approx 0$. Then calculate and write down all appropriate voltages on B, E, and C.

(2) Now see which voltages are larger or smaller than other voltages. Write down all the inequalities you know about the circuit, *e.g.* $V_B > V_C$, etc. Use these inequalities to determine whether they violate any of the rules. If any rule is violated then that regime is NOT applicable. Be careful that some voltages are negative, for example in a *pnp* transistor circuit, if $V_E = -10$V and $V_B = -9.4$V, then $V_B > V_E$.

(3) First, apply voltage rules for **cut-off** – if any rule is violated, then apply **linear** rules. If any linear voltage rule is violated, then the circuit is **saturated**.

Cut-off ($I_B \approx I_C \approx I_E \approx 0$)		**Linear** (all I_B, I_C, $I_E > 0$)		**Saturated**
pnp	*npn*	*pnp*	*npn*	$V_B \approx V_E \approx V_C$
$V_B > V_C$	$V_B < V_C$	$V_C < V_B$	$V_C > V_B$	
$V_B > V_E$	$V_B < V_E$	$V_C < V_E$	$V_C > V_E$	

Note that you may need to know that $|V_B - V_E| \approx 0.6$ V when operating in the linear regime.