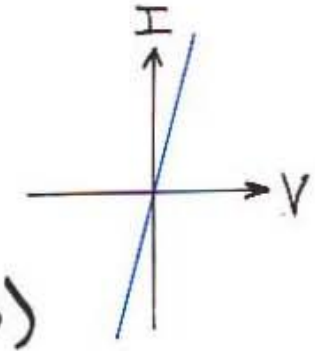
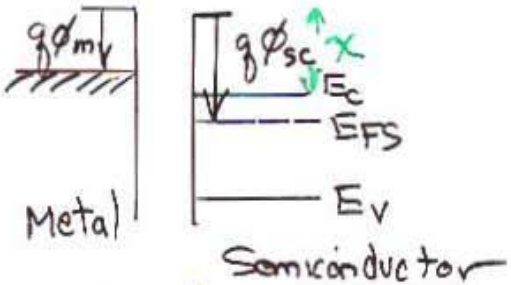
# Ohmic Contacts

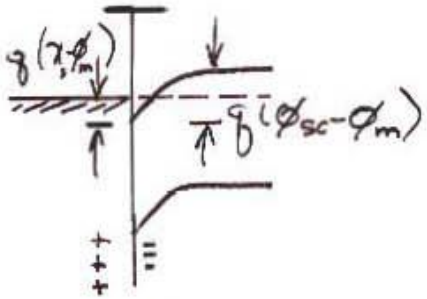



- low resistance
- pass current equally in both directions (no rectification)
- no depletion region

## n-Type : $\phi_m < \phi_{sc}$

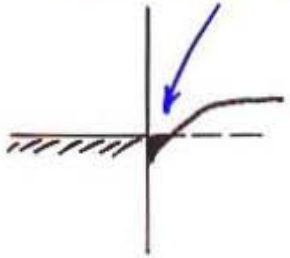



Before




After

accumulation

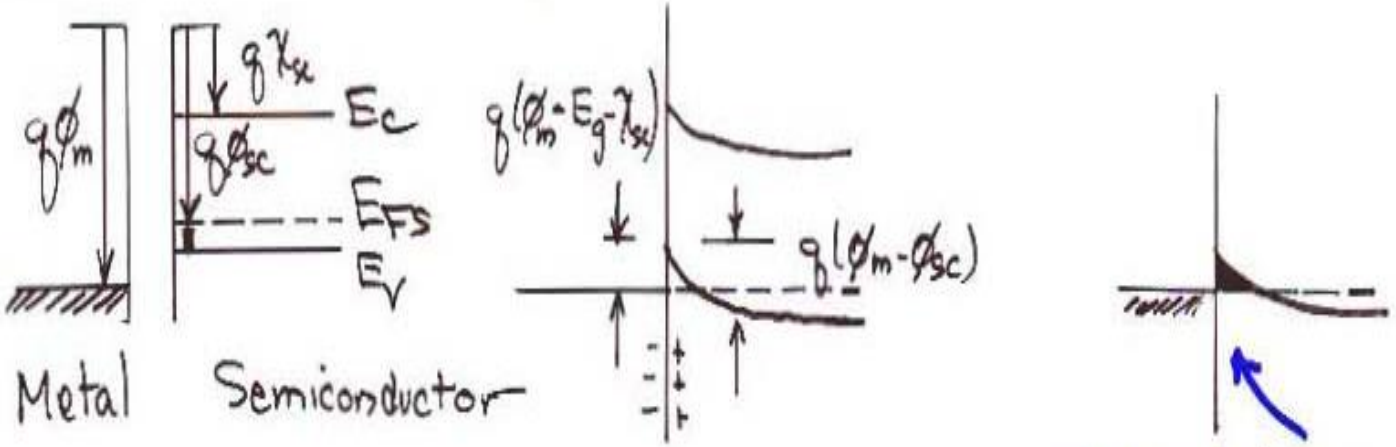


No barrier to $e^-$

Low barrier to bulk

Accumulation of majority carriers.

# P-Type: $\phi_m > \phi_{sc}$




No barriers to holes

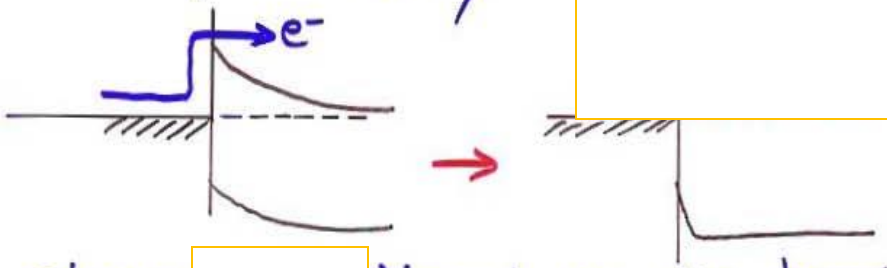
Low barrier to bulk

_____ of majority carriers

# Summary of Metal-Semiconductor Contacts

| | Schottky | ohmic |
|---|---|---|
| n-Type | $\phi_m > \phi_{sc}$ | $\phi_m < \phi_{sc}$ |
| p-Type | $\phi_m < \phi_{sc}$ | $\phi_m > \phi_{sc}$ |

How to "fool" Schottky?




Charge through very thin barriers.

How?

Sometimes need such tricks to control "real" Schottky barriers.

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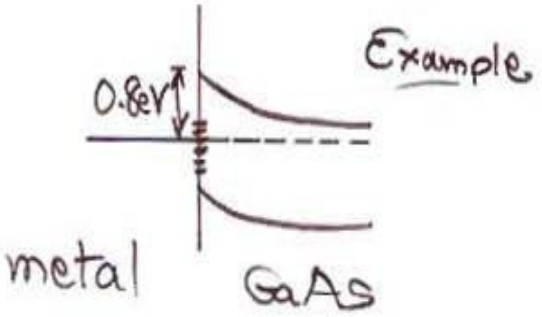
$q V_0 \neq q(\phi_m - \phi_{sc})$

Due to Surface States!




$E_F$ "pinned" in gap

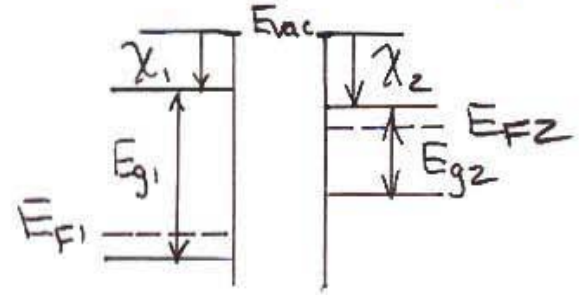
Localized States due to:

- dangling atomic bonds
- reaction
- diffusion

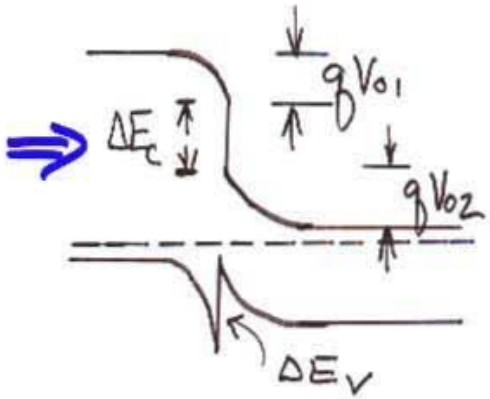
# Heterojunctions

So far: single sc-sc junction : "homojunction"
Metal-sc junction : Schottky junction

Consider now two sc junctions.
→ different $E_g$, $\chi$, $\epsilon$, $E_F$




Before




After

- Now get discontinuities in band edges $\Delta E_c, \Delta E_v$
- Also, different $qV_{01}$ and $qV_{02}$

How to predict?

Important for designing next generation devices!

First, $\Delta E_g = E_{g1} - E_{g2} = \Delta E_c + \Delta E_v$

and $qV_0 = qV_{01} + qV_{02}$

and $\frac{V_{01}}{V_{02}} = \frac{\epsilon_2}{\epsilon_1} \frac{N_{d2}}{N_{d1}}$ ← a

From requirement that $D_1 = D_2$

$$\epsilon_1 E_1 = \epsilon_2 E_2$$

at boundary, $E_1 = E_{1\,max} = \frac{q}{\epsilon_1} N_{a1} X_1$ S&B Eq. 5-17

$$E_2 = E_{2\,max} = \frac{q}{\epsilon_2} N_{d1} X_2$$

so $N_{a1} X_1 = N_{d2} X_2$ (same as with regular homojunctions)

$$\frac{d\mathcal{E}_1}{dx} = \frac{1}{\epsilon_1}(-qN_a)$$

$$\mathcal{E}_1 = \frac{1}{\epsilon_1}(-qN_a)x$$

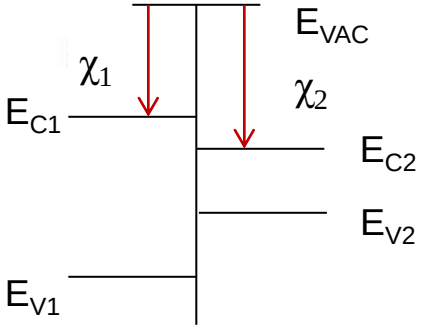
$$V_{01} = \int_{x_1}^{0} \frac{+}{\epsilon_1} (-qN_a)\, x\,dx = \frac{qN_{a1}x_1^2}{2\epsilon_1}$$

$$V_{02} = \frac{qN_{d2}x_2^2}{2\epsilon_2}$$

$$\frac{V_{01}}{V_{02}} = \frac{N_{a1}x_1^2/\epsilon_1}{N_{d2}x_2^2/\epsilon_2}$$

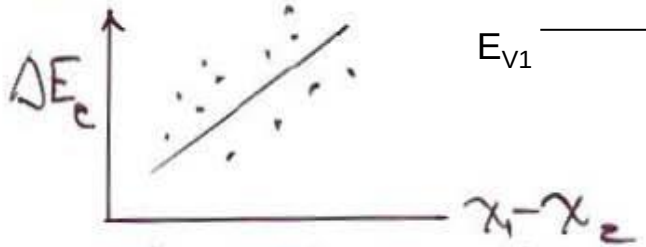
$$\frac{x_1}{x_2} = \frac{N_{d2}}{N_{a1}}$$

$$\frac{V_{01}}{V_{02}} = \frac{N_{d2}}{N_{a1}}\frac{\epsilon_2}{\epsilon_1}$$




Ideal Case: $\Delta E_c = q(\chi_2 - \chi_1)$

But not often seen (Anderson Rule)




For III-V compounds (e.g., GaAs, AlAs, InAs)

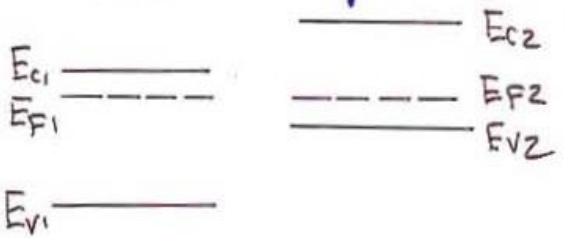
$\frac{2}{3}$ Rule: $\Delta E_g : \frac{2}{3}\Delta E_c, \frac{1}{3}\Delta E_v$

In general, need experimental values.

Exact solution: Poisson's equation with doping, space charge, $\Delta E_c$, $\Delta E_v$.

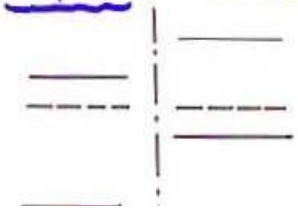
But can sketch approximate band diagrams without detailed calculation. (Art 101)

**Step 1**: Align $E_F$ levels with bands flat




Leave room for transition region

**Step 2**: Locate $X=0$ $(X_1 N_1 = X_2 N_2)$

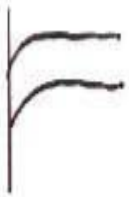


here, $N_1 \sim N_2$

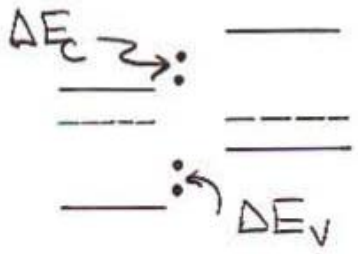
Electrons will flow from n to p and holes " " " p to n.

so n-Type side has

and p-Type side has



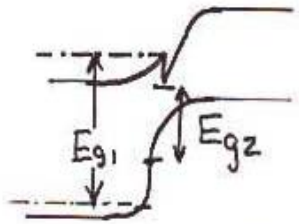
## Step 2b: Put in known




(where the dots go determines the $V_{o1}$ and $V_{o2}$. Only approximate, calculation from Poisson's equation)

## Step 3: Connect up the valence bands and conduction bands with band bending

(only approximate, can calculate from Poisson's equation)




Keep $E_{g1}$ constant at junction
" $E_{g2}$ " " " "

$\Delta E_v$ and $\Delta E_c$ make up the difference.

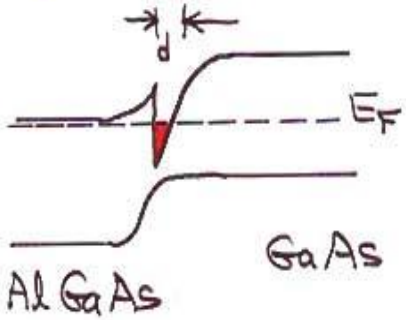
## Observations

1) In general, $\Delta E_c \neq \Delta E_v$

so $e^-$ flow versus $h^+$ flow across junction can be different

In fact, we can control one over the other by choosing semiconductors appropriately.

2) Band bending at hetero-junction can give quantum wells.




Electrons spill into well ($E_F$ above $E_c$)

$d \lesssim 0.02\mu m$ (200Å)

Very sharp levels with d is narrow. Very high mobility and transport

3) Can have n-n heterojunctions
n-p
p-n
p-p

} Potential barrier can now be controlled by material band gap and doping

Semiconductor $E_g$ and doping are extra degrees of freedom.

Basis for