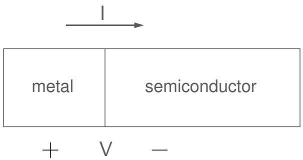
Metal-semiconductor junctions



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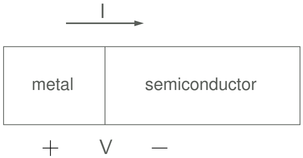

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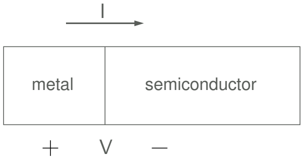

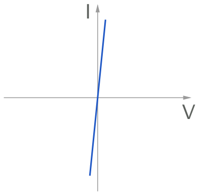

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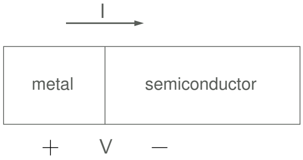

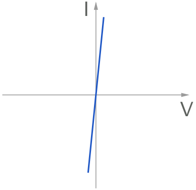

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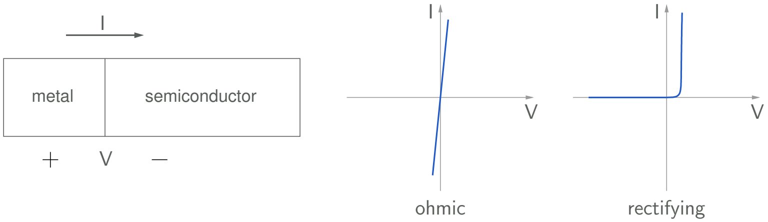
* A *rectifying* M-S junction plays a key role in the operation of some semiconductor devices like the MESFET (Metal-Semiconductor Field-Effect Transistor). As the name implies, a rectifying M-S junction (also called a "Schottky contact") conducts well in one direction but blocks current in the other direction.



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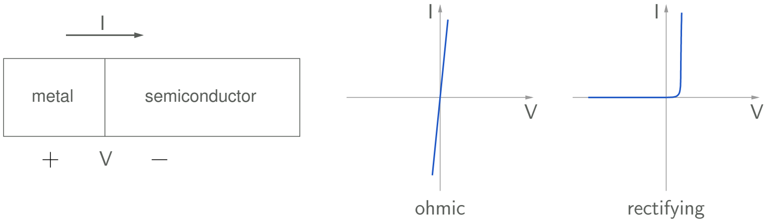

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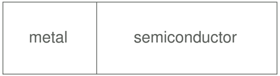
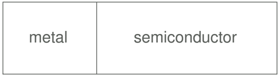
What decides whether a given M-S junction is ohmic or rectifying?



The band diagram of a metal-semiconductor junction is determined by



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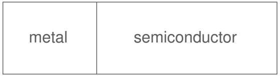

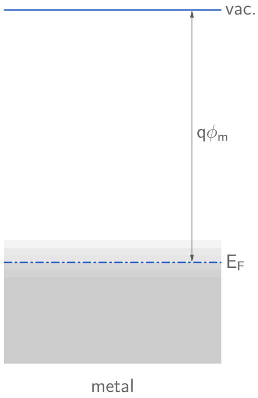

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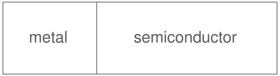

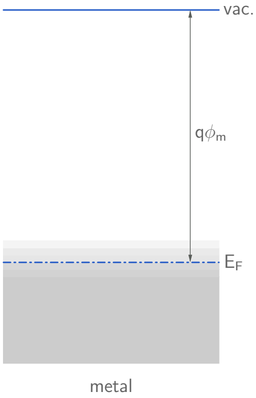

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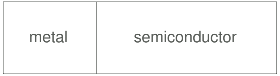

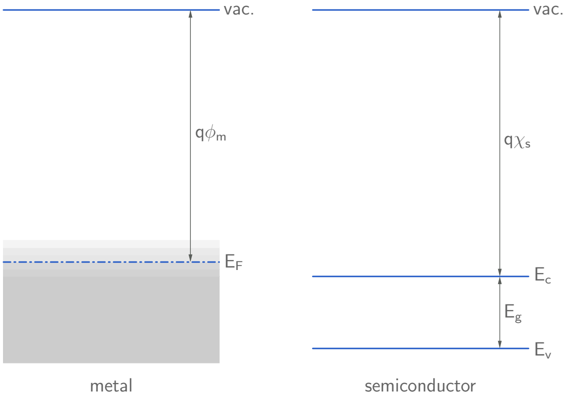

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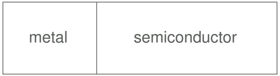

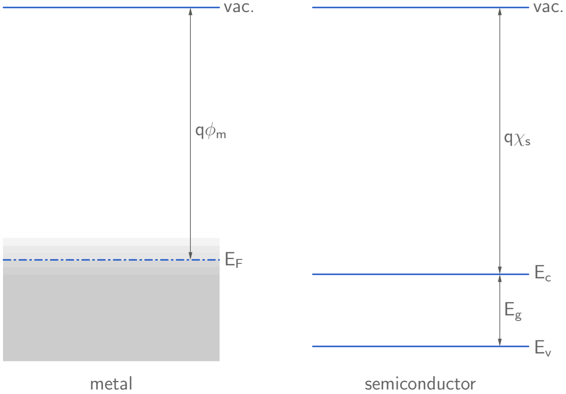

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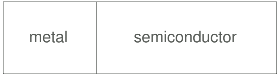

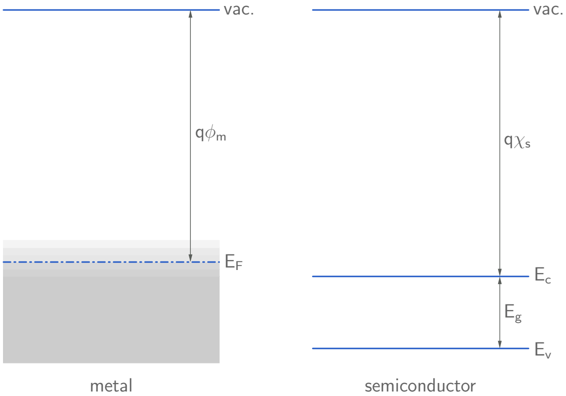

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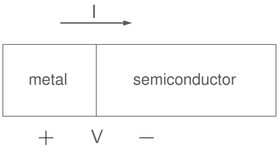
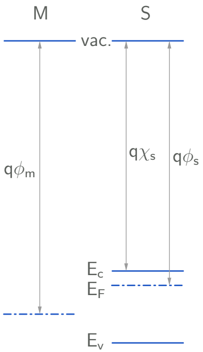
- additional electron states within the band gap at the interface

  (We will ignore this effect, i.e., we will assume the M-S interface to be perfect.)

n-type semiconductor, $\phi_m > \phi_s$





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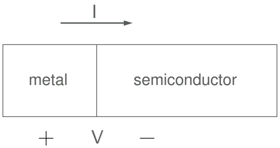

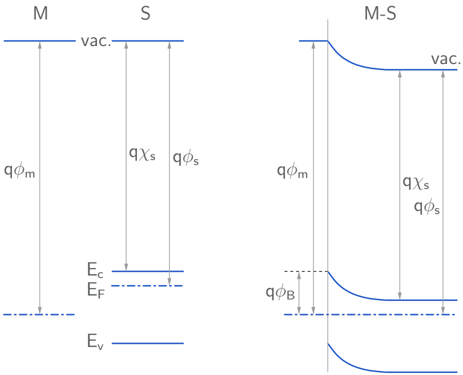

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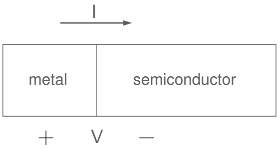

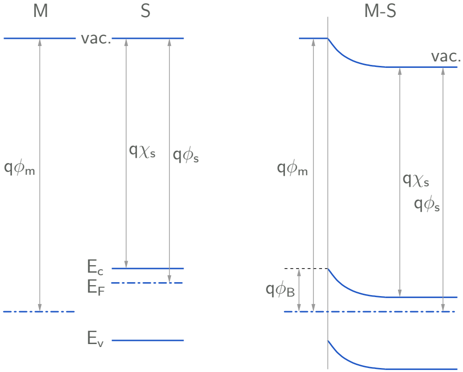

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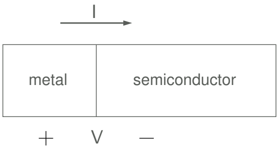

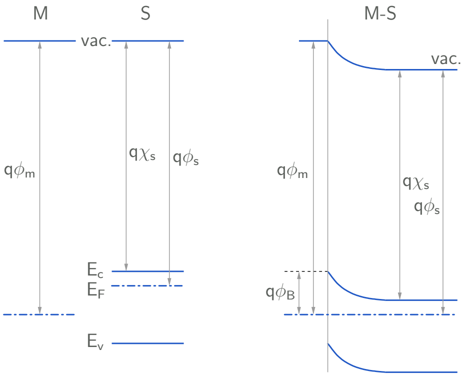

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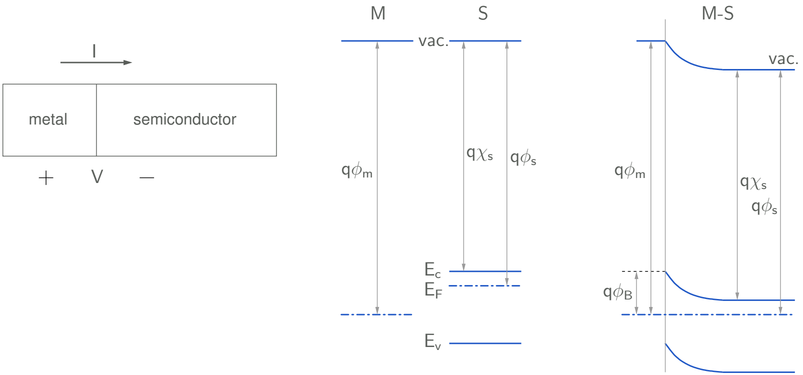

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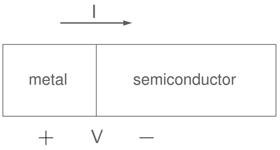

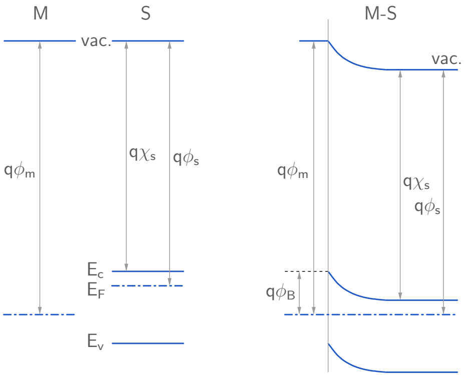

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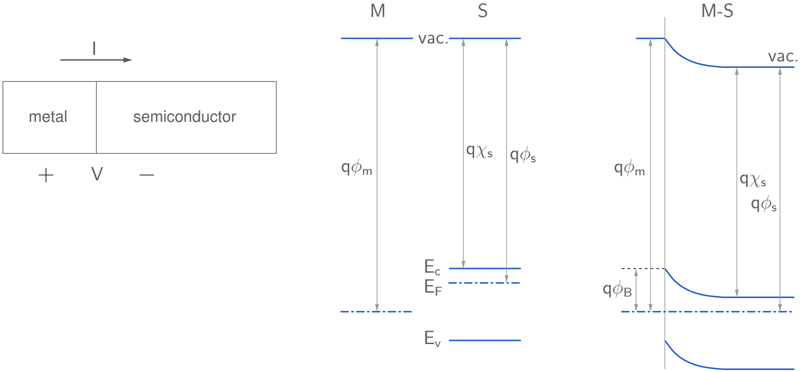

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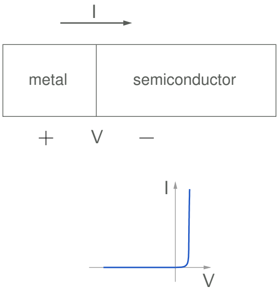

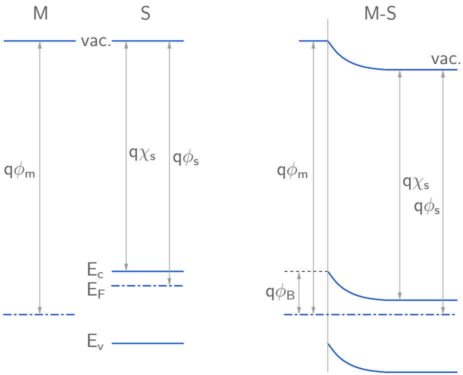

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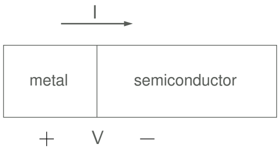

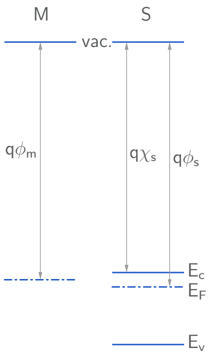

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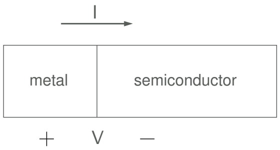

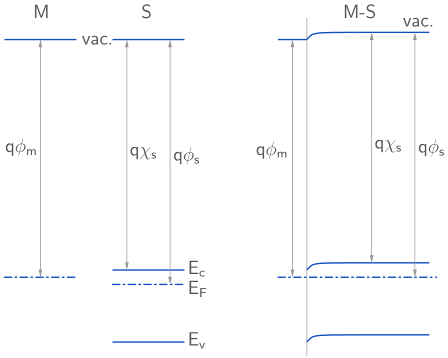

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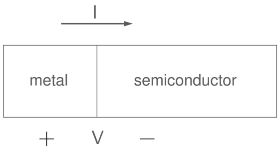

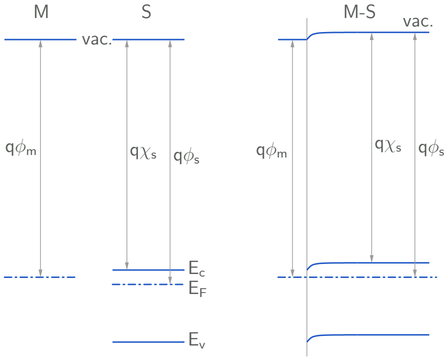

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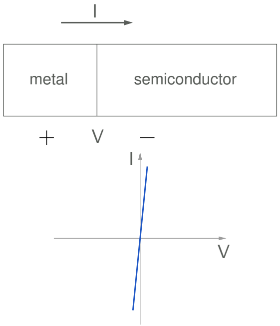

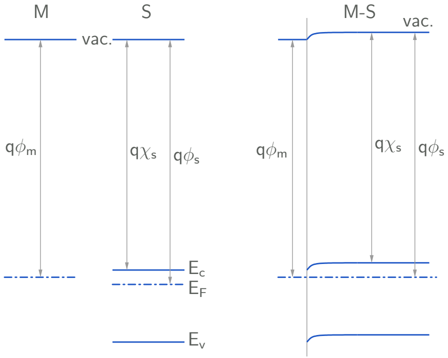

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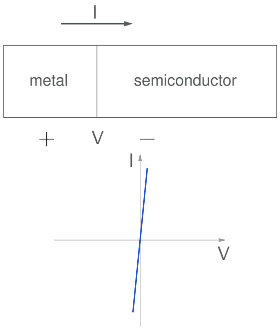

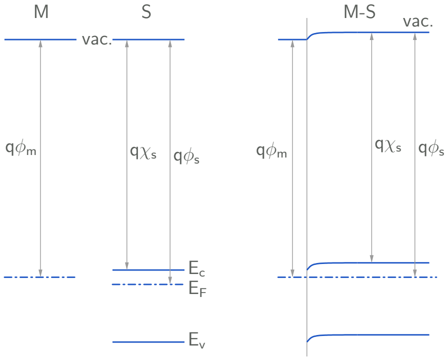

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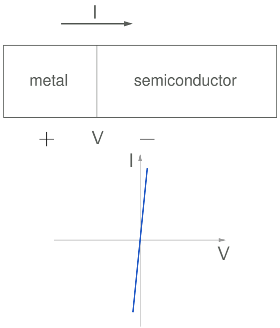

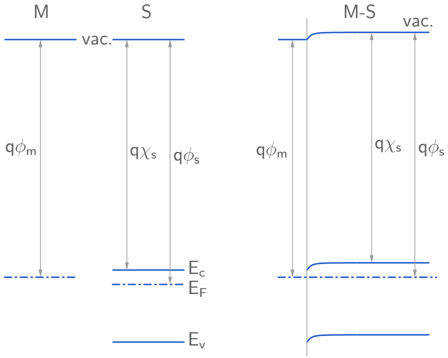

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  - At the M-S interface, the semiconductor crystal structure gets abruptly terminated, which results in incomplete ("dangling") covalent bonds or, in terms of the band picture, electron states within the forbidden gap.

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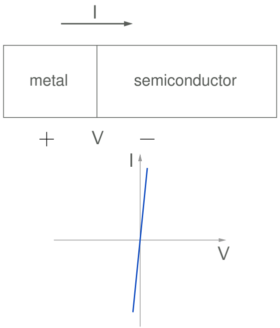

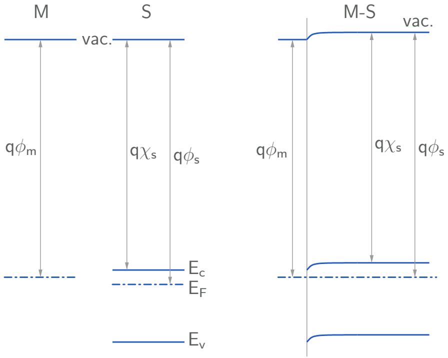

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  - There may be a thin ($\sim 10\,$Å) oxide layer between the metal and the semiconductor.

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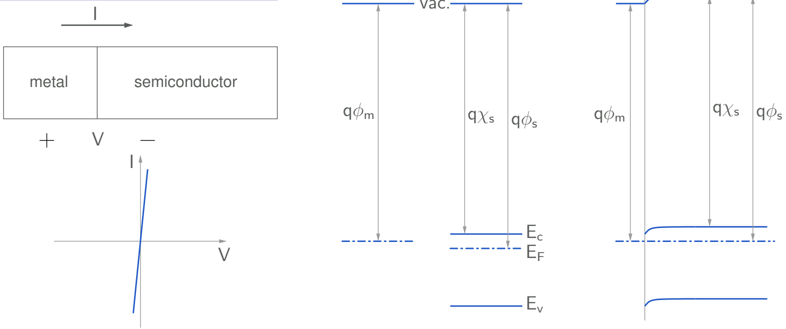

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Because of these complications, the barrier heights get modified. However, the qualitative picture remains valid as long as the actual experimentally measured barrier heights are used.

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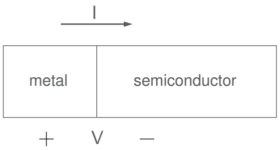

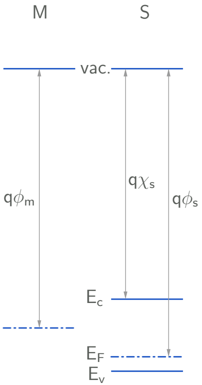

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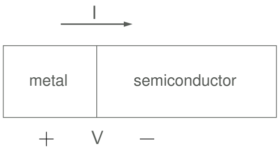

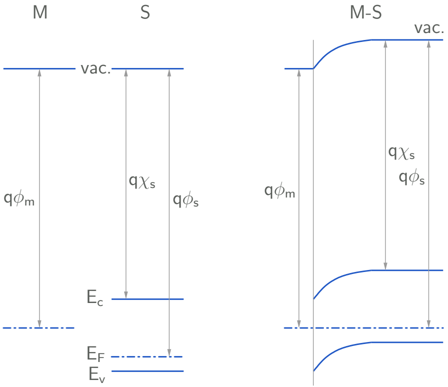

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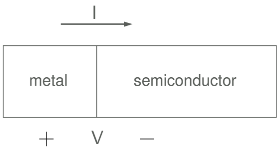

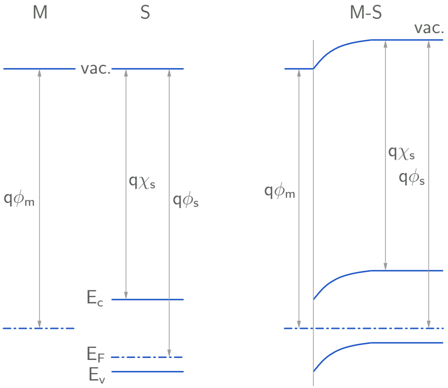

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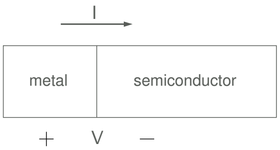

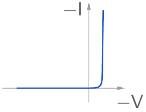

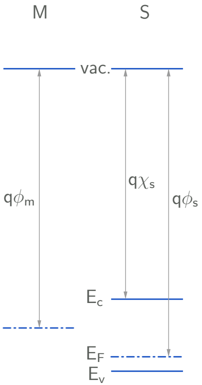

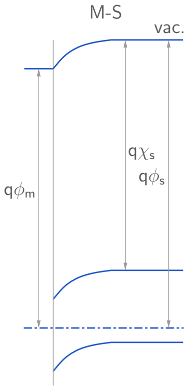

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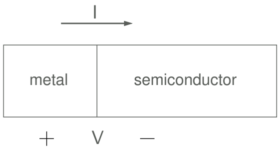

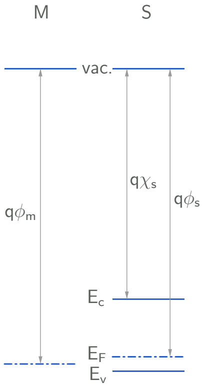

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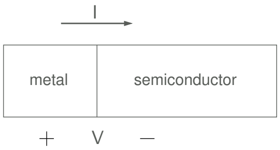

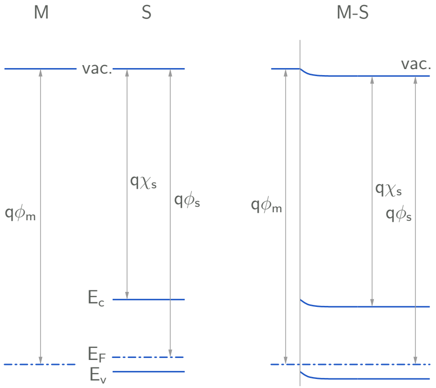

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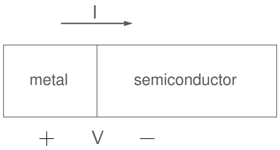

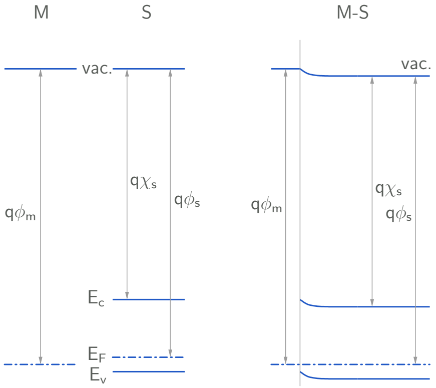

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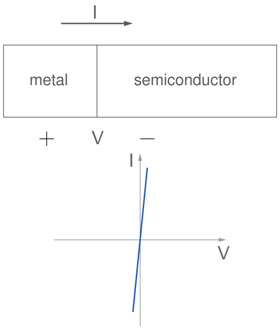

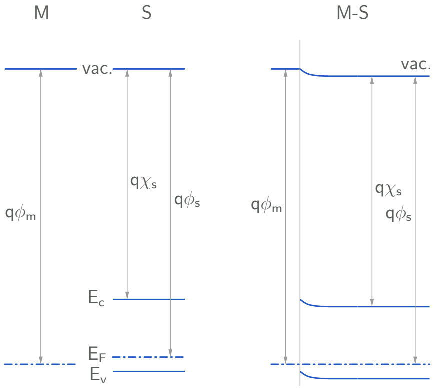

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Current-voltage relationship for a rectifying M-S junction

* The *I*-*V* behaviour of a rectifying M-S junction is similar to that of a *pn* junction:
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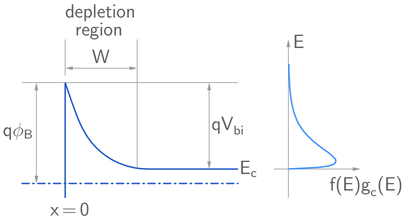

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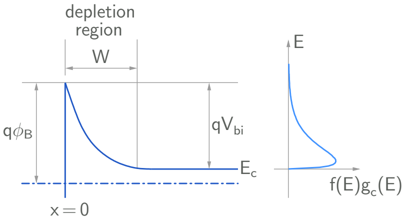

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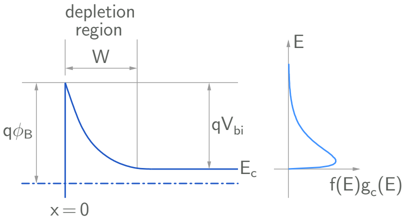

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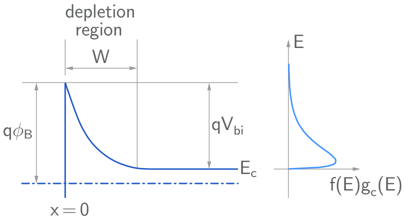

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* In equilibrium, there is an equal and opposite current density,
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  resulting in a net current density $J=0$.

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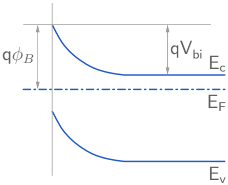

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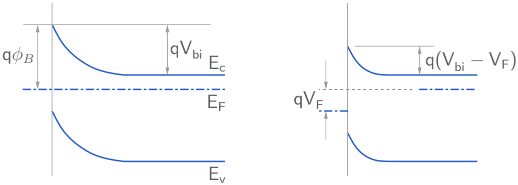

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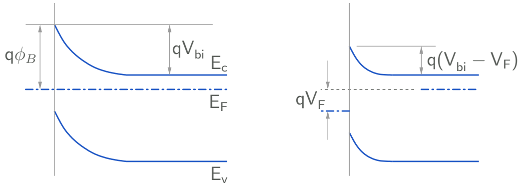

With a forward voltage, the barrier to electron flow from S to M decreases by V_F while that for M to S remains the same, and the net current density is

$$
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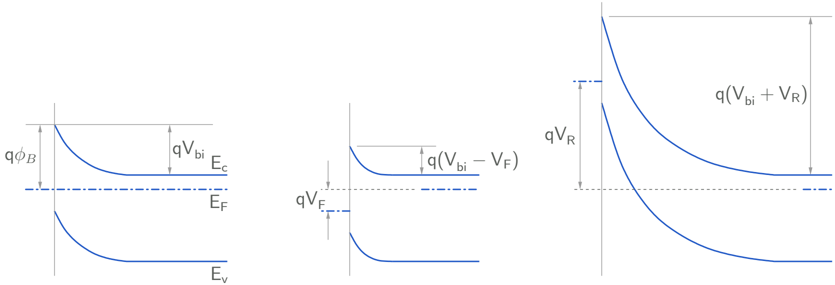

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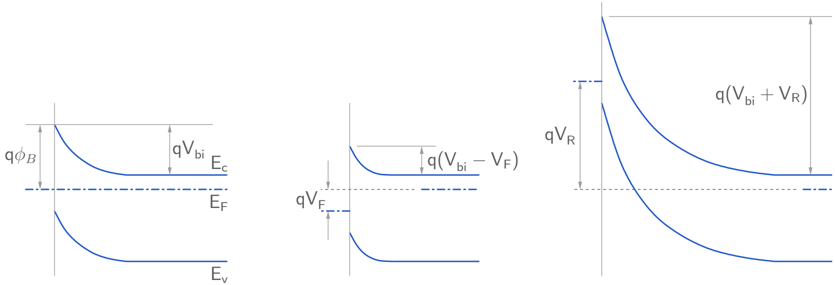

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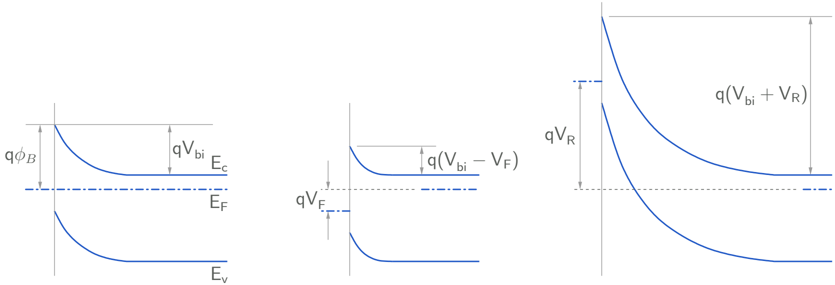

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In summary, $J = J_s \left[e^{V/V_T} - 1 \right]$, where $J_s = A^* T^2 \, e^{-\phi_B/V_T}$.

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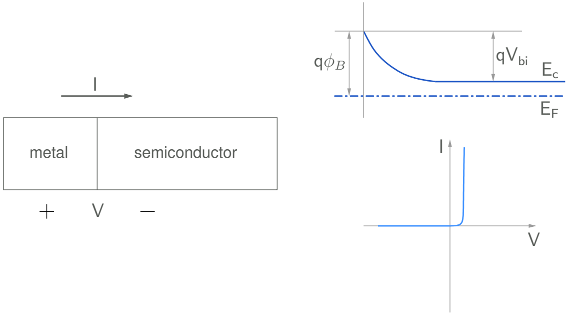
Effect of high doping density



(a)

* The contact in (a) is rectifying because of the potential barrier.

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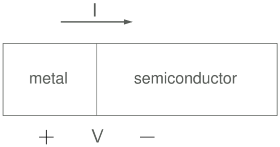

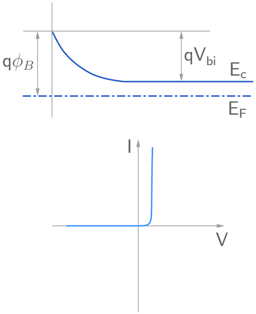

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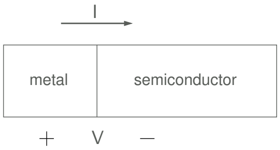

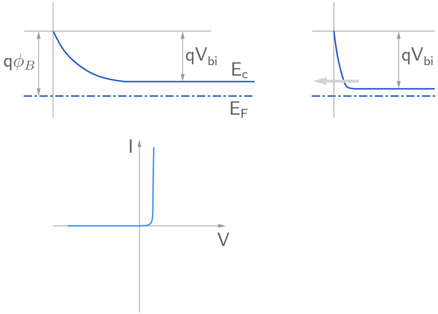

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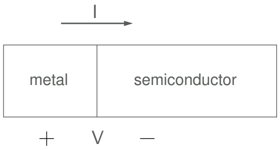

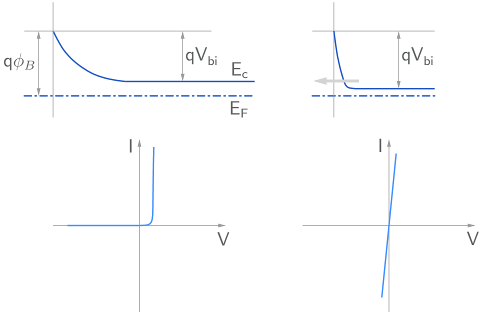

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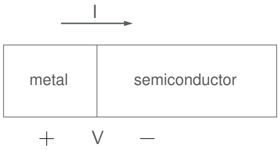

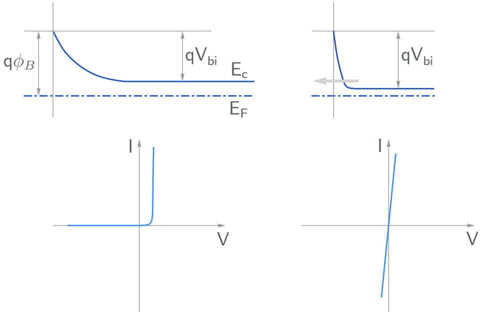

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- ∗ The contact in (a) is rectifying because of the potential barrier.
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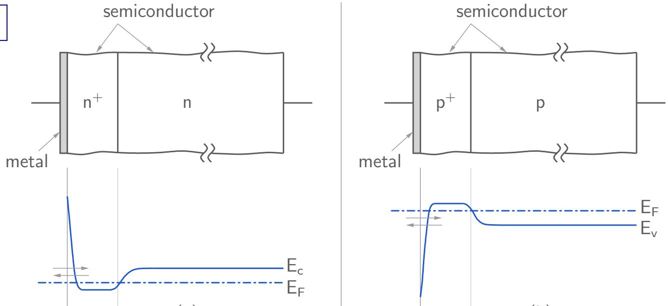
Practical ohmic contacts



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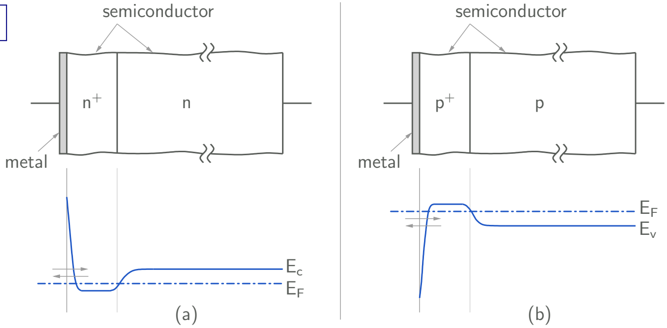

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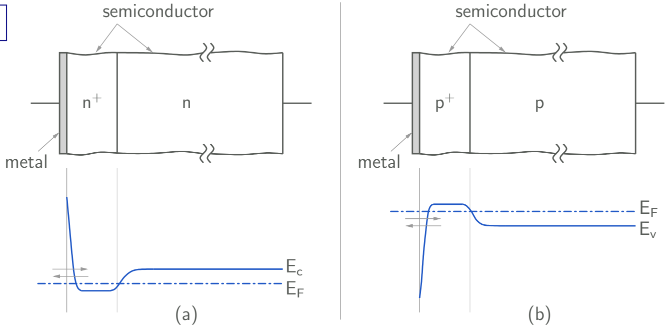

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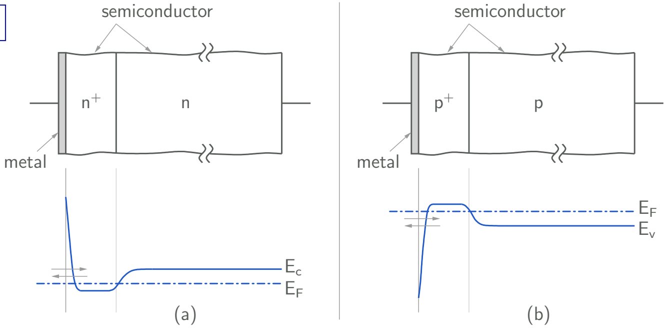

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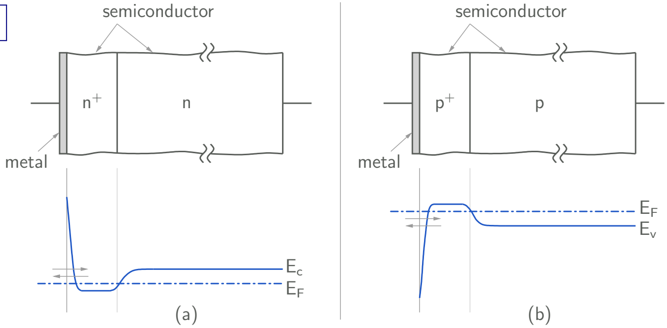

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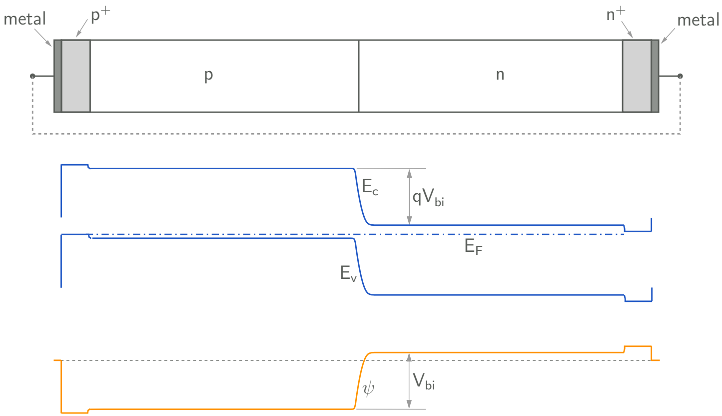
* These n^+n or p^+p junctions are essentially ohmic since a large number of majority carriers (of the same type) are available for conduction on both sides of the junction.
* Next, metal is deposited to make a metal-n^+ or metal-p^+ junction, which is ohmic — irrespective of the barrier ϕ_B — because of tunnelling. In this manner, the objective of making a low-resistance metallic contact is achieved. (In practice, metallic contacts also need to be "alloyed" by subjecting them to temperatures of $\sim 450\,^{\circ}\mathrm{C}$ for a few minutes.)

pn junction: band diagram with contact regions



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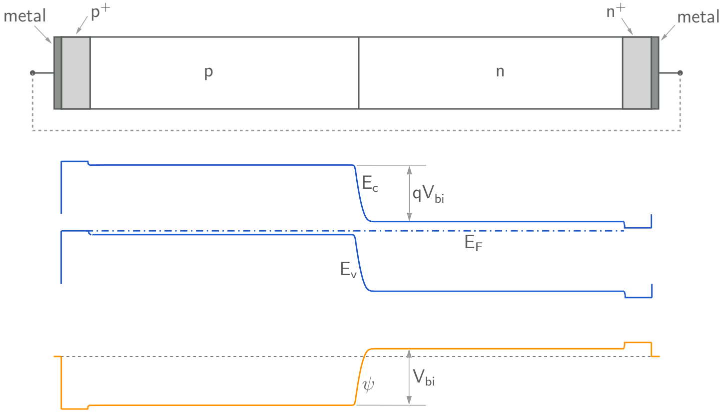
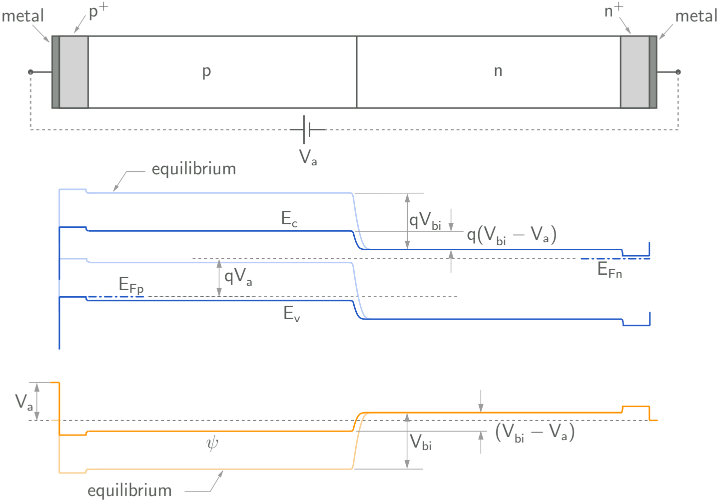
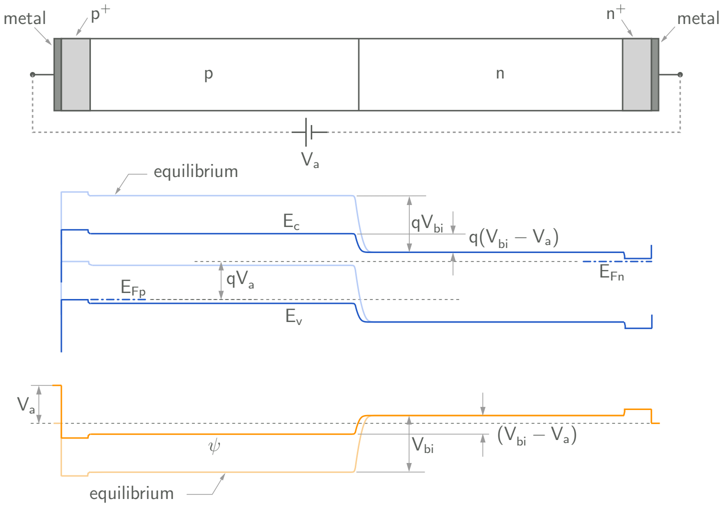


* Equilibrium: The net voltage drop is zero; the voltage drop (V_{bi}) across the depletion region is equal and opposite to the sum of the other voltage drops.

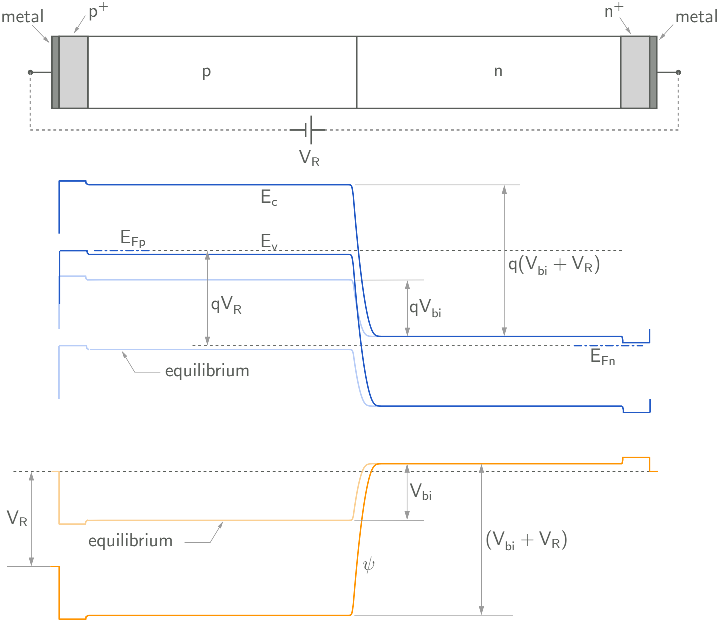
pn junction: band diagram with contact regions

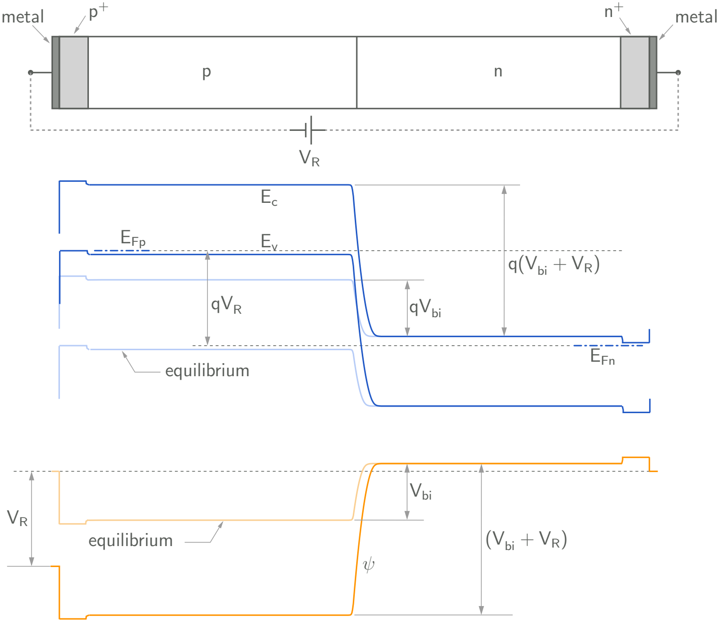


pn junction: band diagram with contact regions



* Forward bias: The voltage drops across the M-S junctions, the n^+-n junction, and the p^+-p junction remain the same as in equilibrium; the applied forward voltage appears across the depletion region ($V_{bi} \rightarrow V_{bi} - V_a$).


metal
p+
n+
metal
p
n
V_R
E_c
E_Fp
E_v
q(V_bi + V_R)
qV_R
qV_bi
equilibrium
E_Fn
V_R
V_bi
equilibrium
(V_bi + V_R)
ψ



* Reverse bias: The voltage drops across the M-S junctions, the n^+-n junction, and the p^+-p junction remain the same as in equilibrium; the applied reverse voltage appears across the depletion region ($V_{bi} \rightarrow V_{bi} + V_R$).