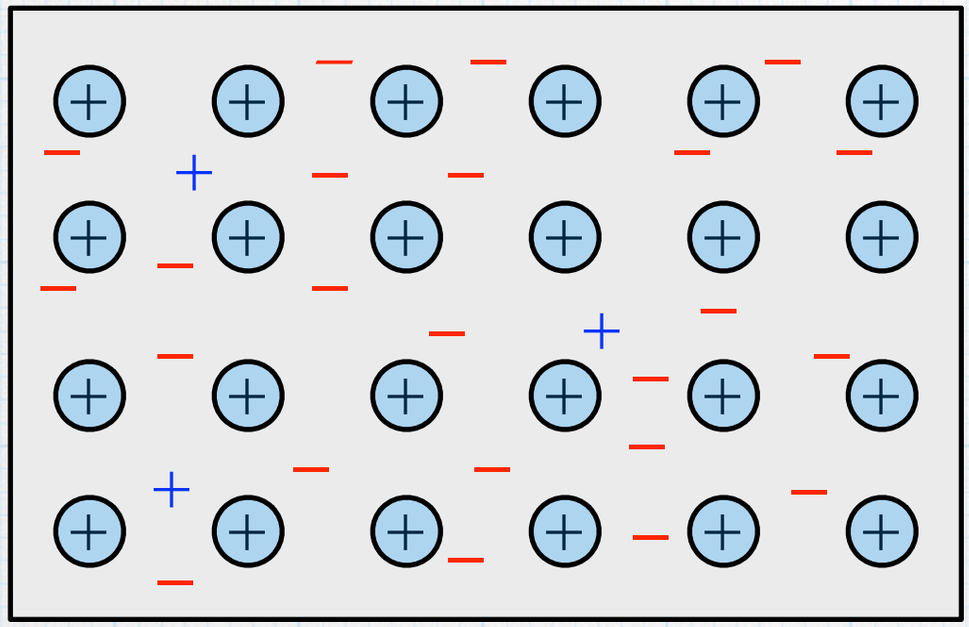
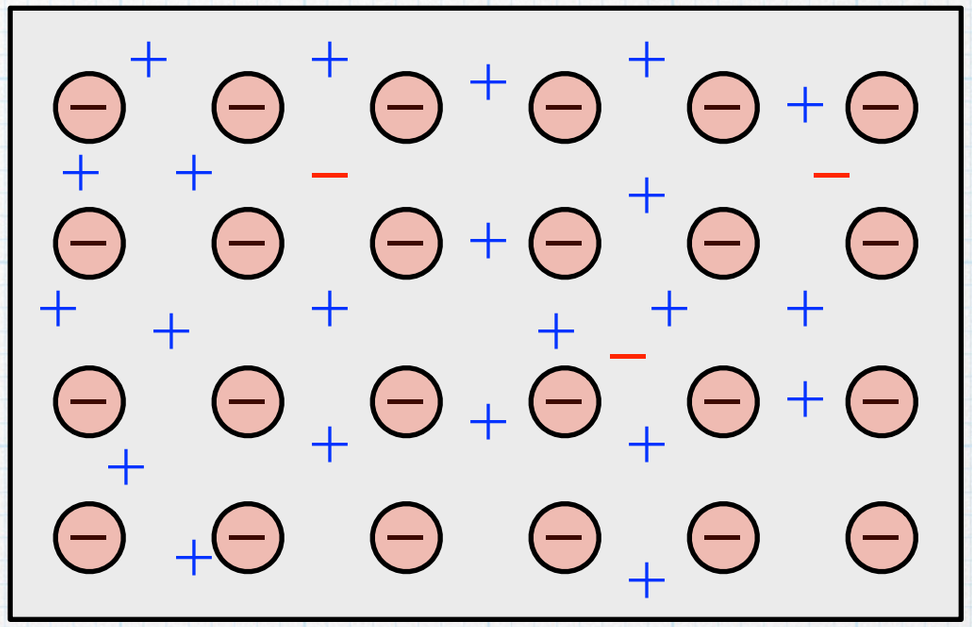
Diodes (p-n junctions)

Two pieces of silicon, one n-type and p-type

n-type



p-type



doping: N_D
electron concentration: $n = N_D$.
also: a small number of holes
(ignore for now)

no net charge:

$$\rho = q(N_D - n + p) = 0$$

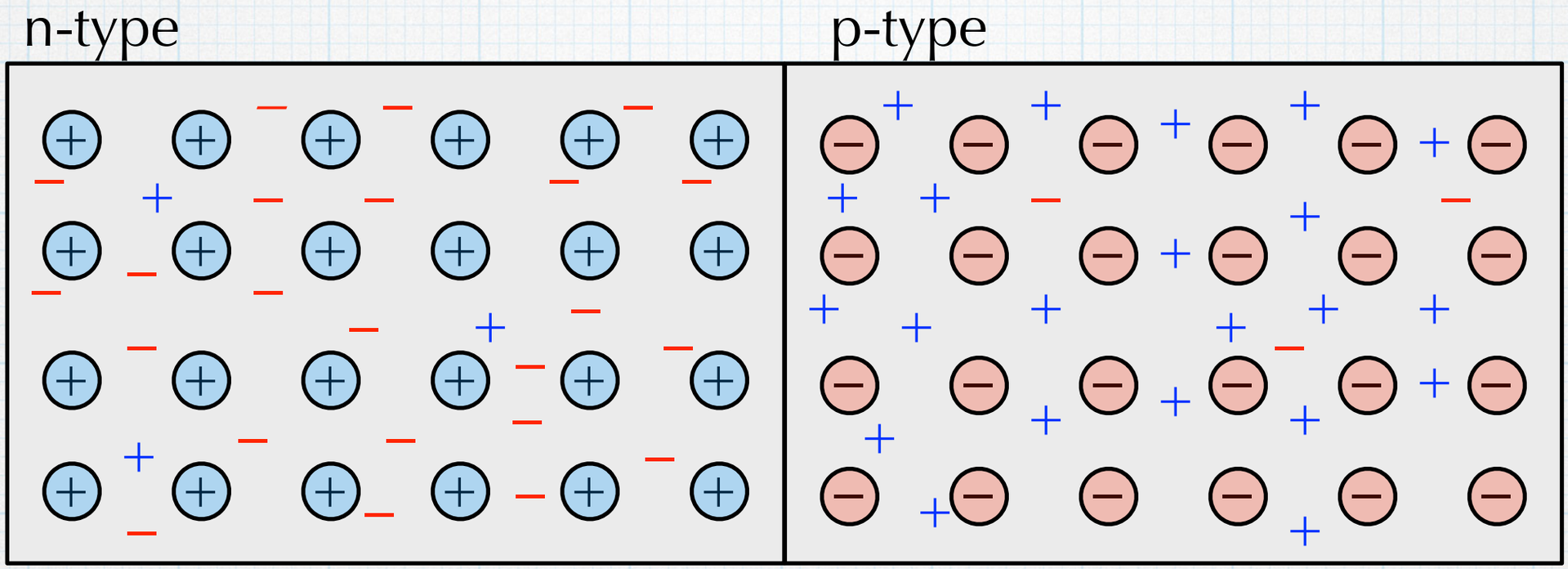
ρ is charge density ($\mathrm{C/cm^{-3}}$)

doping: N_A
hole concentration: $p = N_A$
also: a small number of electrons
(ignore for now)

no net charge:

$$\rho = q(p - N_A + n\ ) = 0$$

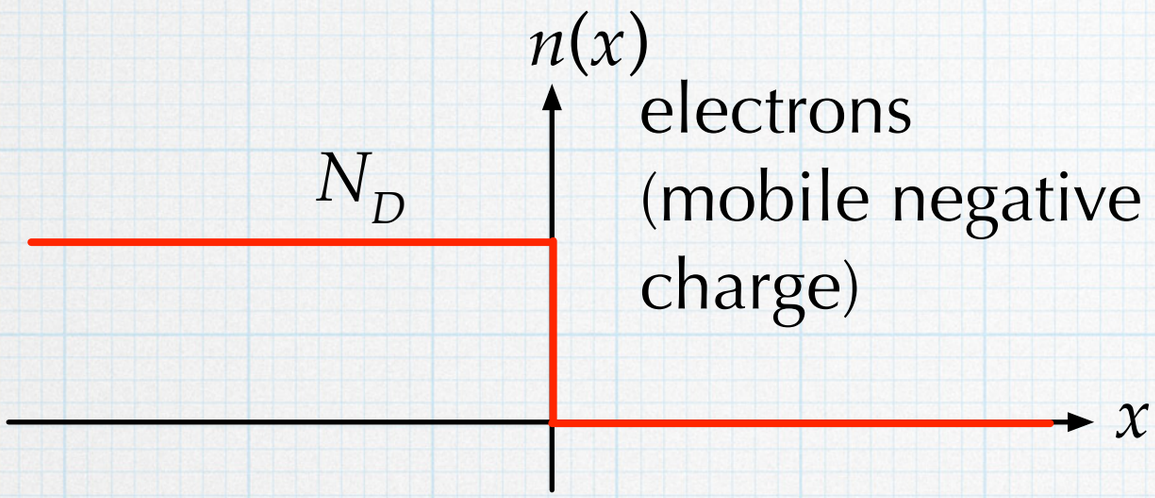
Join them together to make a *p-n junction*



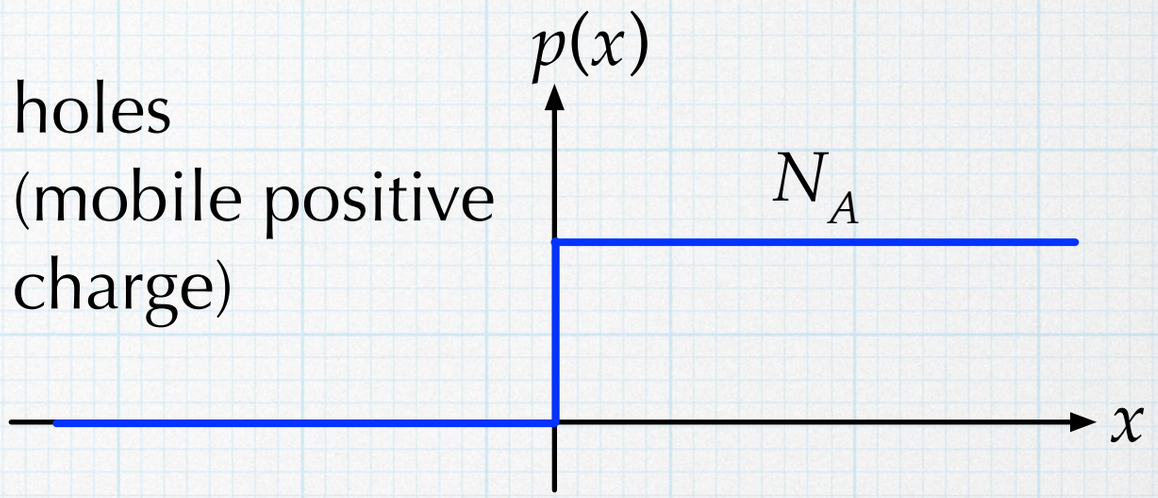
electrons diffusing

holes diffusing

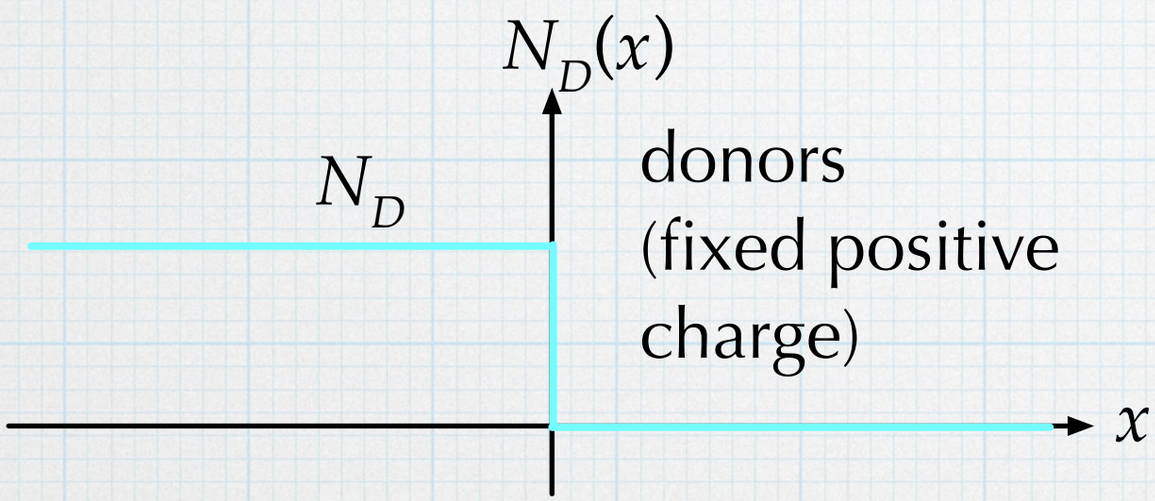
In the initial instant (t < 1 femtosecond, say), the charges look like this.



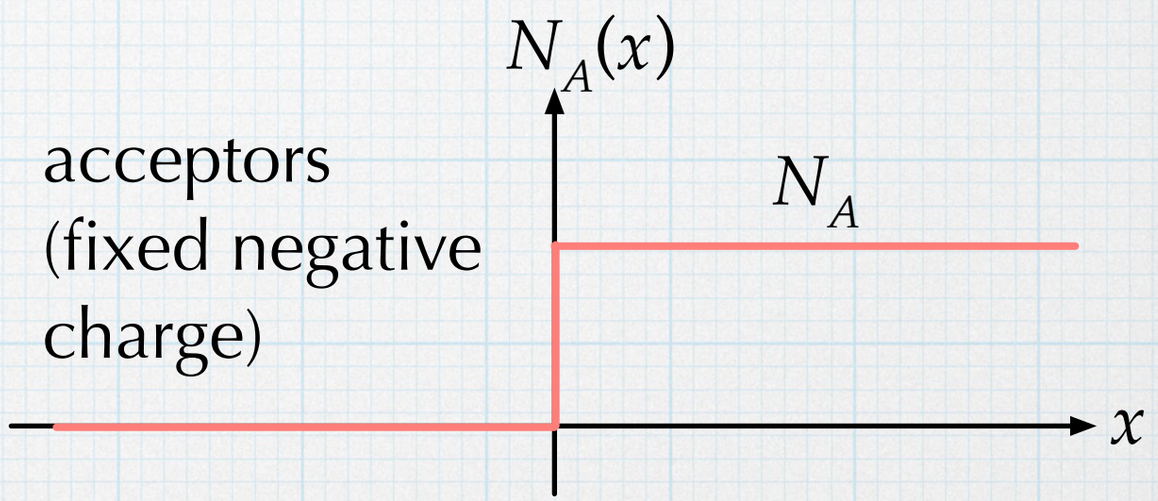
electrons
(mobile negative
charge)



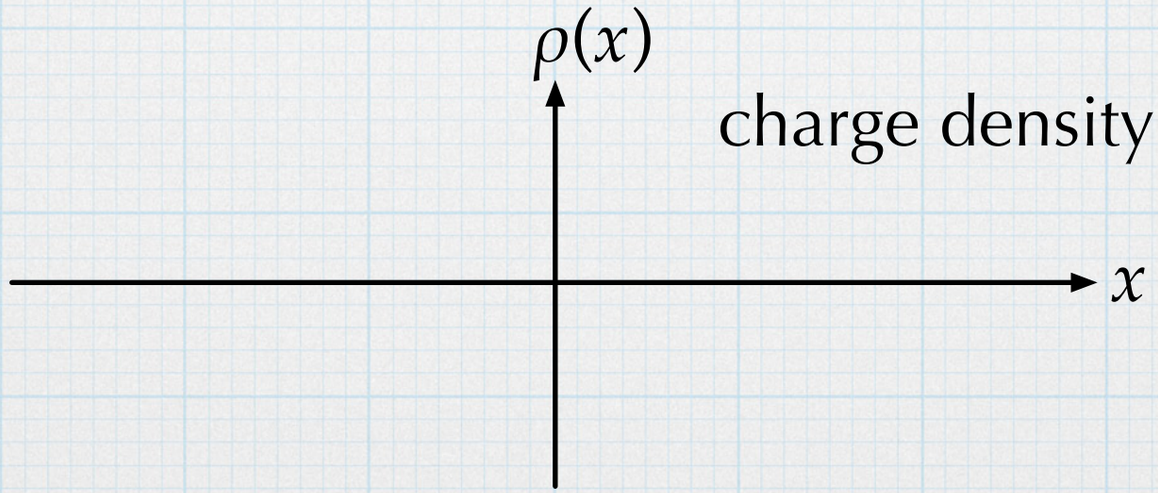
holes
(mobile positive
charge)



donors
(fixed positive
charge)

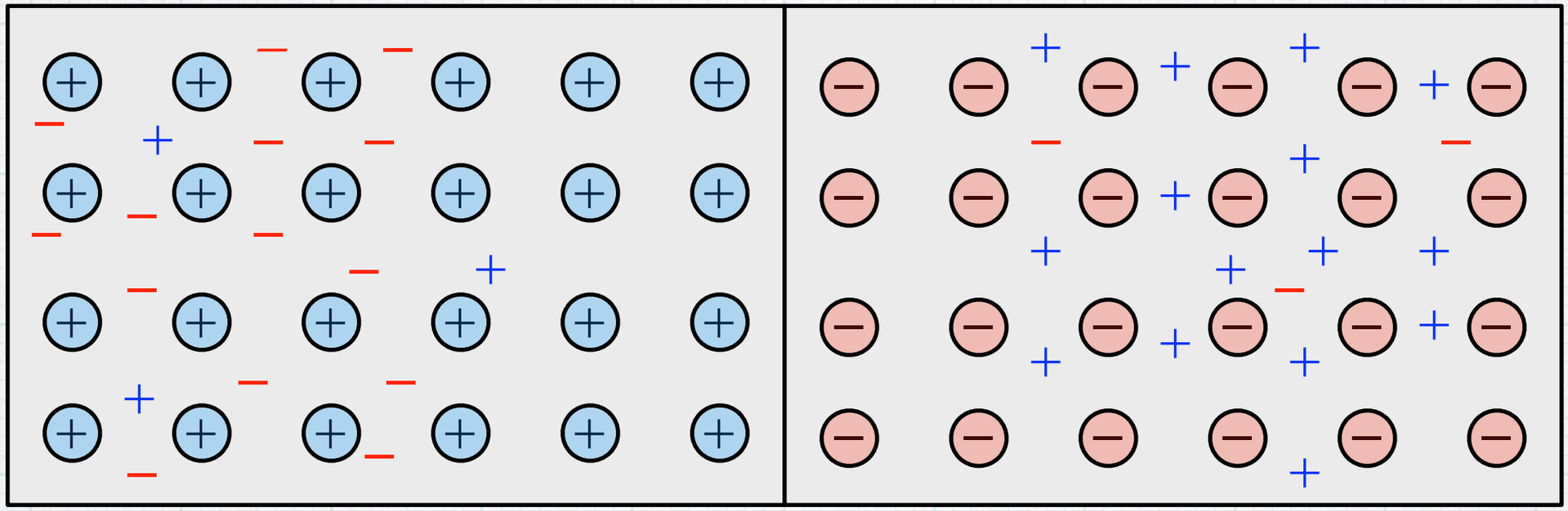


acceptors
(fixed negative
charge)

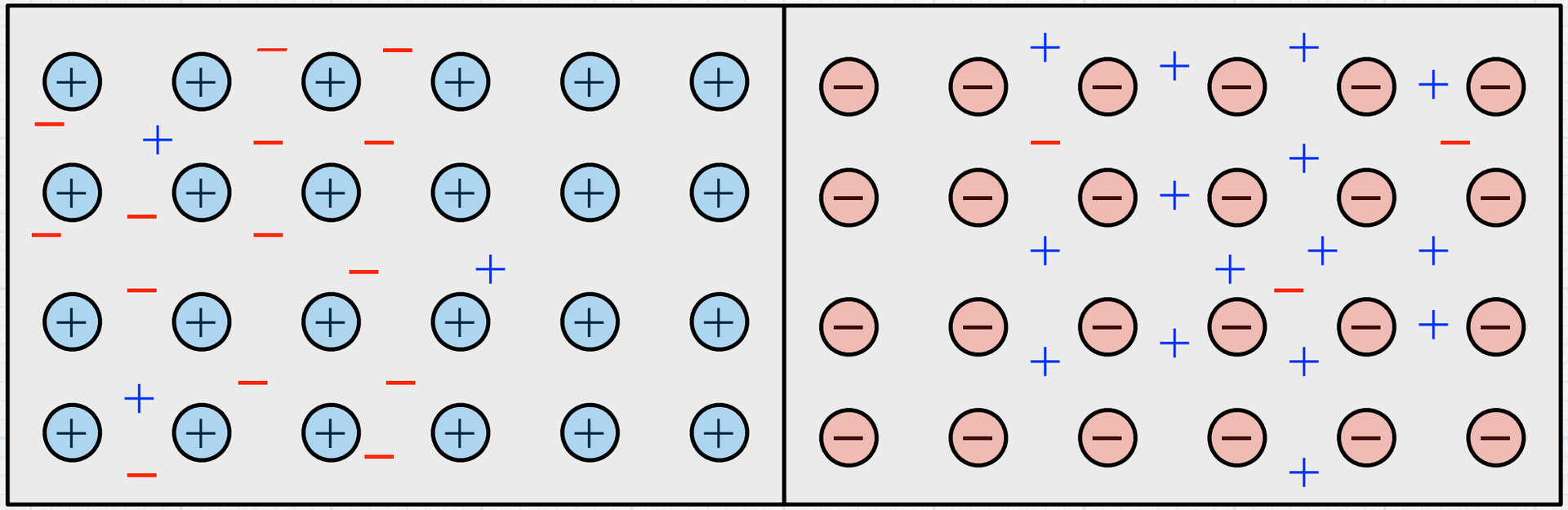


charge density is zero

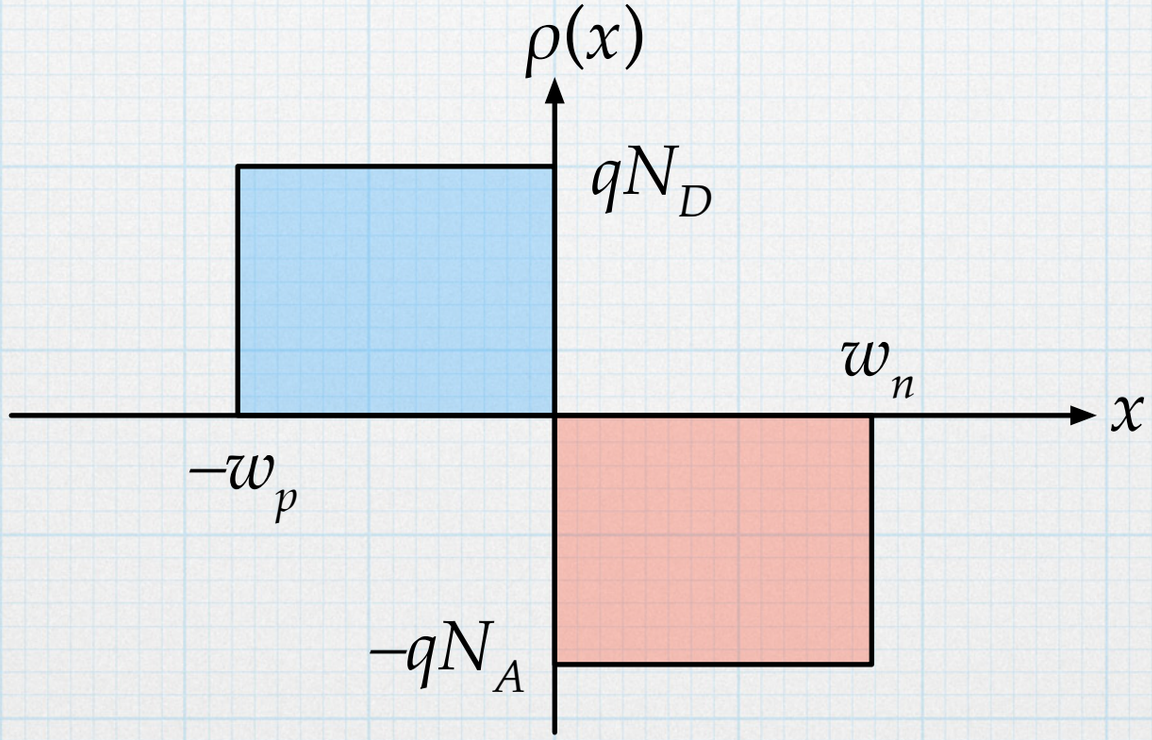
Note the *huge* concentration gradients for both electrons and holes.
Both will start to diffuse — electrons to the right and holes to the left.



Electrons diffusing to the right will vacate the region near the junction. Holes flowing to the left do likewise. The region near the junction becomes depleted of *mobile* carriers. However, the dopant charge is fixed in place and cannot move. This area where the carriers have left is called the *depletion region*.

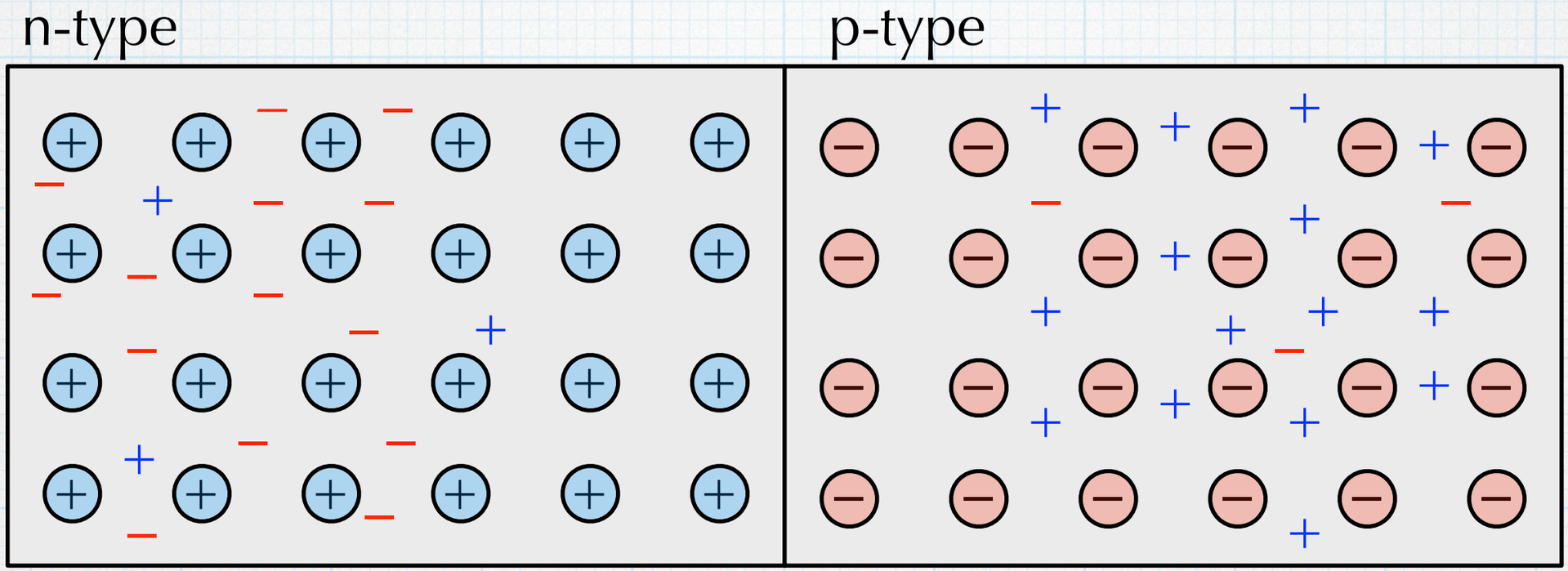


Around the junction, the net charge is no longer zero!



This is called the space charge region.

From electromagnetics, we know that when there is space charge, there will be an electric field pointing from the positive charge to the negative.



As the carriers diffuse across the junction, creating the space-charge layer, the electric field builds up.

The electric field affects the carriers. It pushes electrons to the left and holes to the right – exactly opposite the way that they are diffusing. This is a classic case of Mother Nature using a negative feedback loop. The electric field builds up until drift current exactly cancels the diffusion current.

$$q\mu_n n\mathcal{E} = qD_n \frac{\partial n}{\partial x} \qquad q\mu_p p\mathcal{E} = qD_p \frac{\partial p}{\partial x}$$

Equilibrium – diffusion balances against drift so that there is no current.