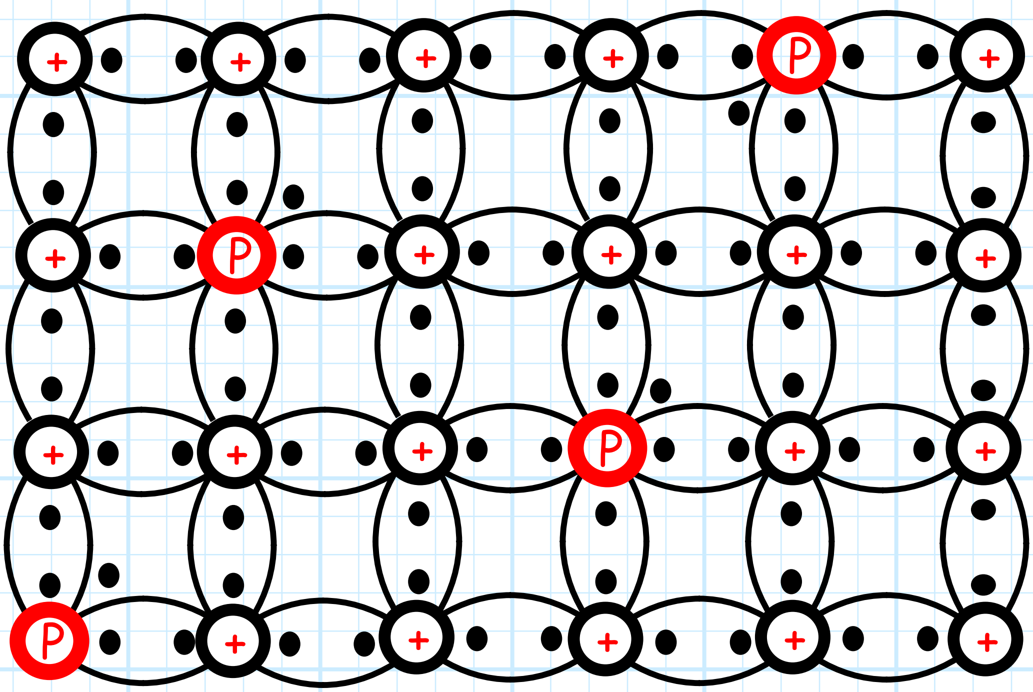
Doped Silicon

We can add **impurities** to Silicon to change the lattice characteristics.

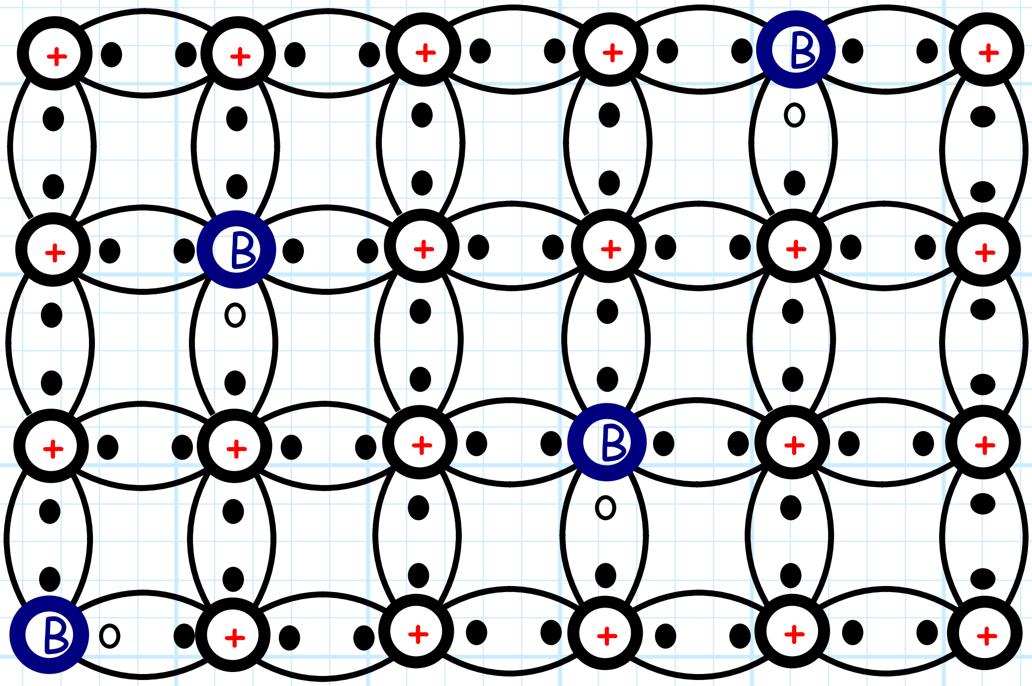
Specifically, we can alter the **particle densities** (i.e., either hole or f.e. densities) of the lattice, such that there are **more** holes than free electrons, or **more** free electrons than holes.

For example, we can add **Phosphorus** (P) to Silicon. Phosphorus has **5** valence electrons (**one more** than Silicon).

Problem !!! There is **no room** for this **extra** electron in the lattice! As a result, a Silicon lattice that has been **"doped"** with Phosphorus has an abundance of **free electrons**!



Or, we can dope the Silicon with **Boron** (B). Boron has **3** valence electrons (one **less** than Silicon). As a result, there are **holes** left in the lattice. An abundance of holes is the result !!!



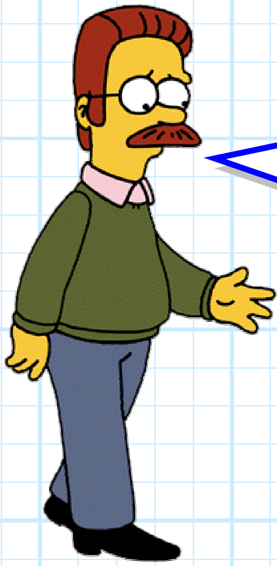
Silicon doped with Phosphorus, such that there is an abundance of free electrons, is called ***n*-type Silicon**. Likewise, Silicon doped with Boron is called ***p*-type Silicon**.

But note that due to **thermal** agitation, there are still **holes in *n*-type** Silicon, and **free electrons in *p*-type** Silicon.

1) For **n-type** Silicon we call free electrons the **majority** carrier, and holes the **minority** carrier.

2) **Conversely**, holes are the majority carrier in **p-type** Silicon, and free electrons the minority carrier.

Therefore, **unlike** intrinsic (i.e., pure) Silicon, the particle density (i.e., concentration) of free electrons **does not equal** the particle density of holes !



Q: *We learned that holes have* ***positive*** *charge, and of course free electrons have* ***negative****. Since in doped Silicon the concentrations of each are* ***unequal****, isn't the* ***charge density*** *of doped Silicon non-zero ??*

A: NO! Remember, a Phosphorus atom has one more **electron** that a Silicon atom, but it **also** has one more **proton** ! Likewise, a Boron atom has the **same** number of electrons as protons. In other words, the lattice remains electrically **neutral**—no **ions** are present!

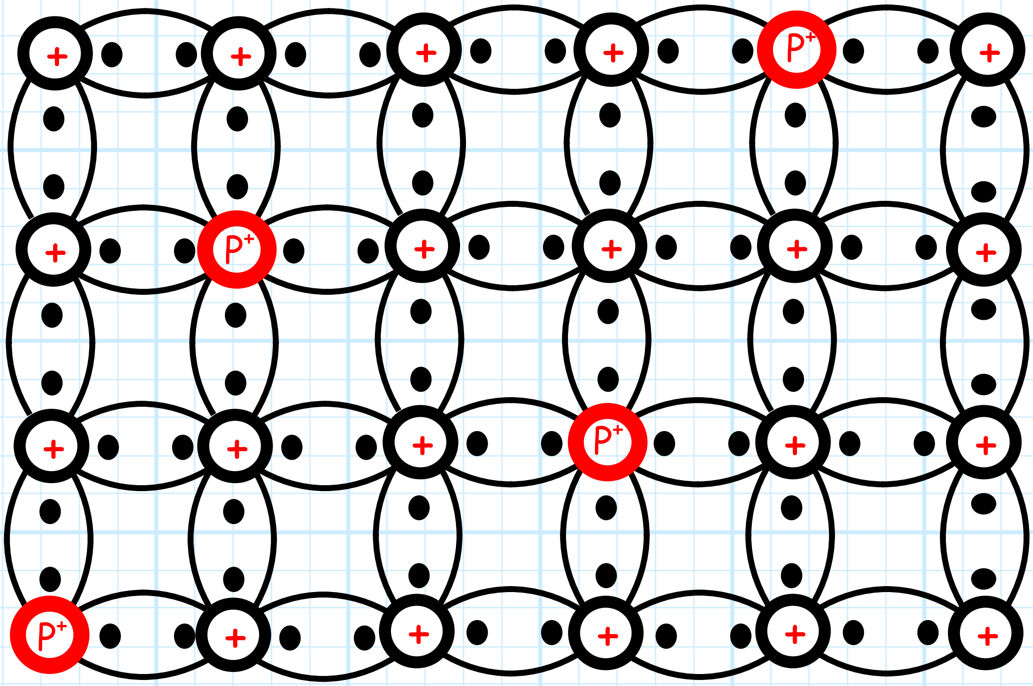
So, generally speaking, in doped Silicon the **charge densities** (electrons and protons) are in **balance**, but the **particle densities** (holes and free electrons) are **out of balance**.

Now, lets consider the case where the particle **concentrations** in Silicon become **rebalanced** !

Q: Rebalanced! *How could* ***this*** *possibly occur ?*

A: The majority carriers **can** move out of a region of the lattice. Recall moving charge is **current**. We now **know** that holes and free electrons can flow in the lattice due to either **drift** current or **diffusion** current.

So, for example, **n-type** Silicon might look like this:



Note the free electrons are gone. We say that this region of the lattice has been **depleted**.

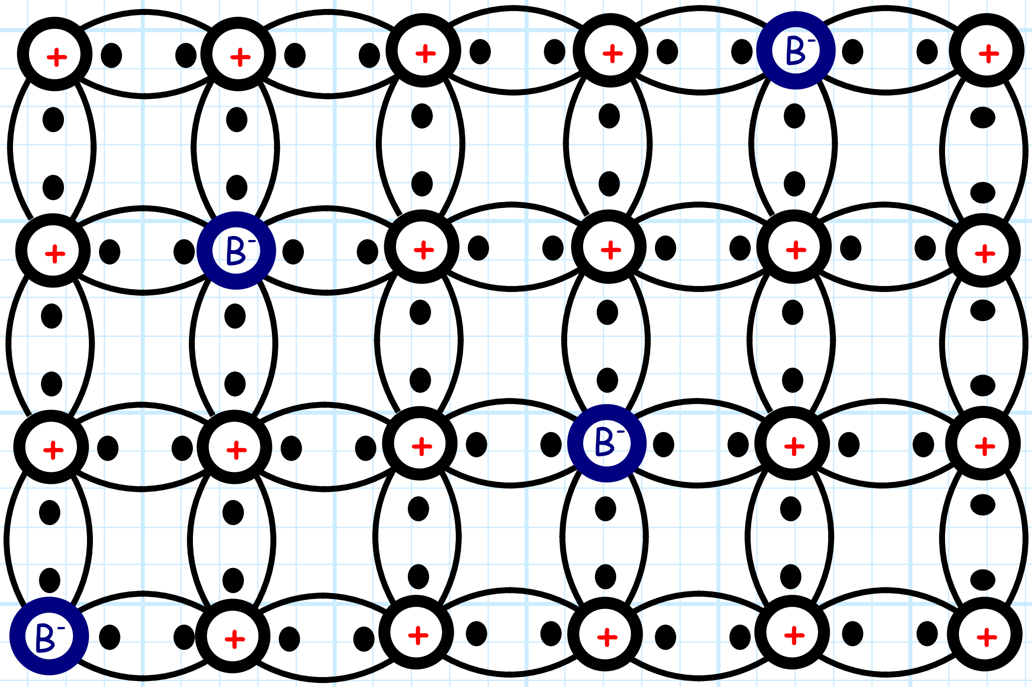
This looks a lot like **intrinsic** Silicon, in that the **particle** densities are now **equal**—there are as many holes as free electrons.

But, **think** about what has happened. The free electrons associated with the Phosphorus atoms have **left**, but no protons left with them—positive Phosphorus **ions** are created !!!

Now the particle densities are **balanced**, but the charge density is **not**—the charge density is now **positive**!

When a free electron is removed from a region of n-type Silicon, we say that a positive **ion** has been **uncovered**.

Now, let's consider what a **depleted** region of **p-type** Silicon would look like:



Note what has happened here is that the **holes** have left, leaving the **concentration** of holes and free electrons **equal**.

But, the "holes left" when **electrons** took their places in the lattice. Each Boron atom therefore has an **extra electron**.

➡ **Negative** ions have been **uncovered** !

What's more, the **charge density** within the lattice is now **negative** !

Recapping:

If we **dope** Silicon with impurities, then we create an imbalance in the number of holes and number of free electrons within the lattice—the **particle densities** are **unequal**. However, the **charge density** within the lattice is still **zero**.

If the **majority** carries are **depleted**, then ions are **uncovered**. The **particle densities** of holes and free electrons are now **equal**, while the **charge density** is now **non-zero**.