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ECE606: Solid State Devices
Lecture 10: Additional Information

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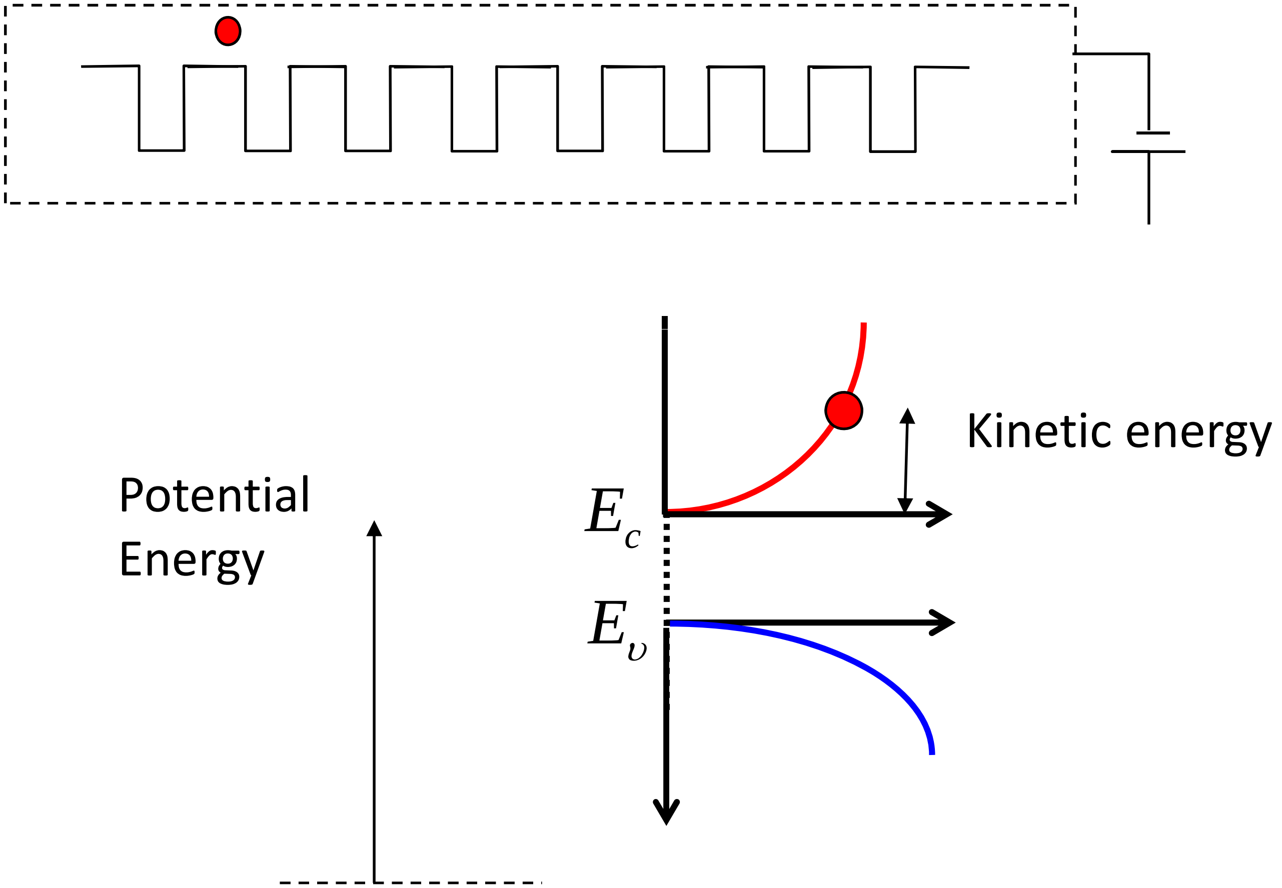
Outline

1) **Potential, field, and charge**
2) E-k diagram vs. band-diagram
3) Basic concepts of donors and acceptors
4) Conclusion

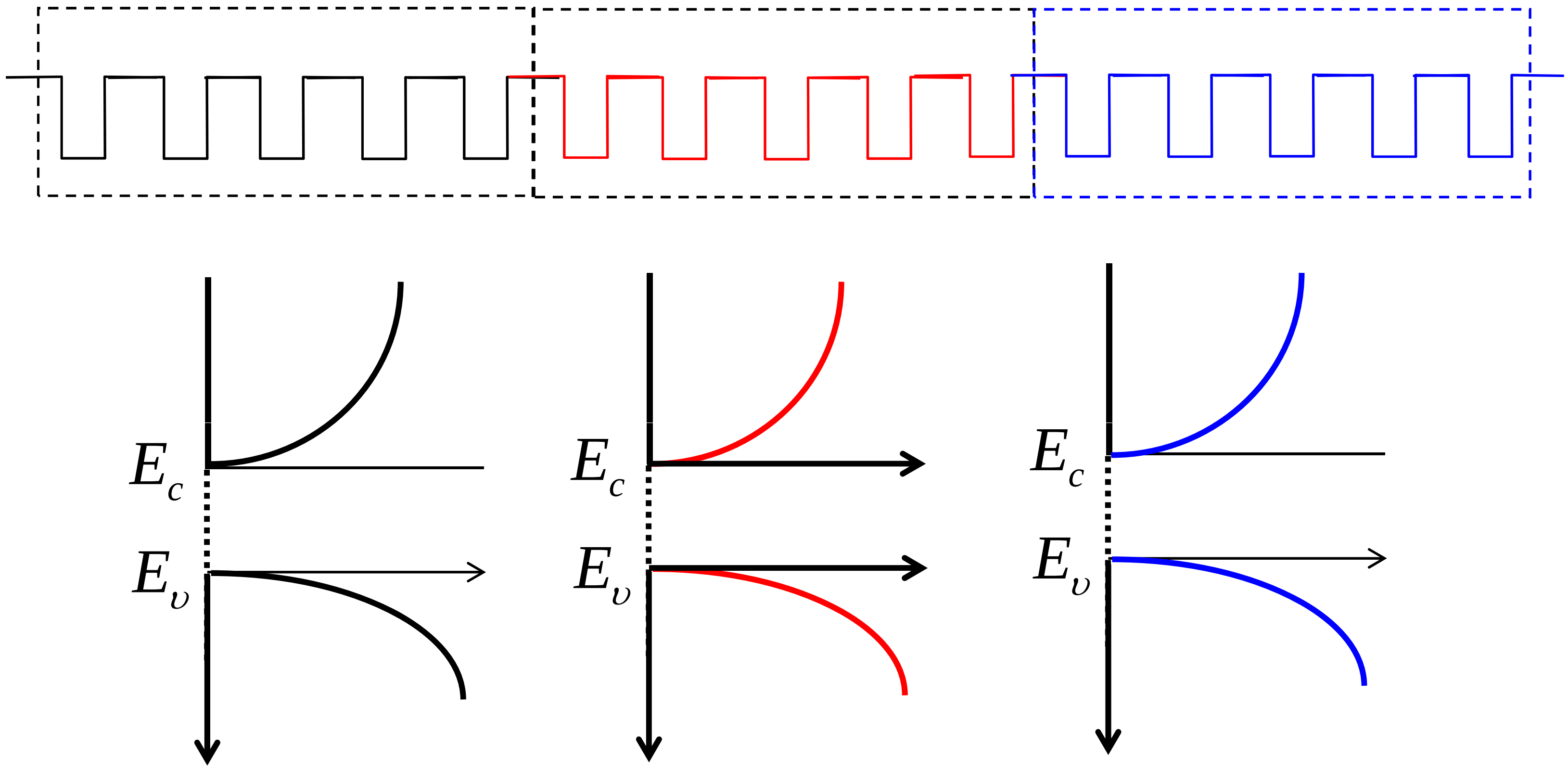
Reference: Vol. 6, Ch. 4 (pages 101-111)

E-k diagram vs. band-diagram

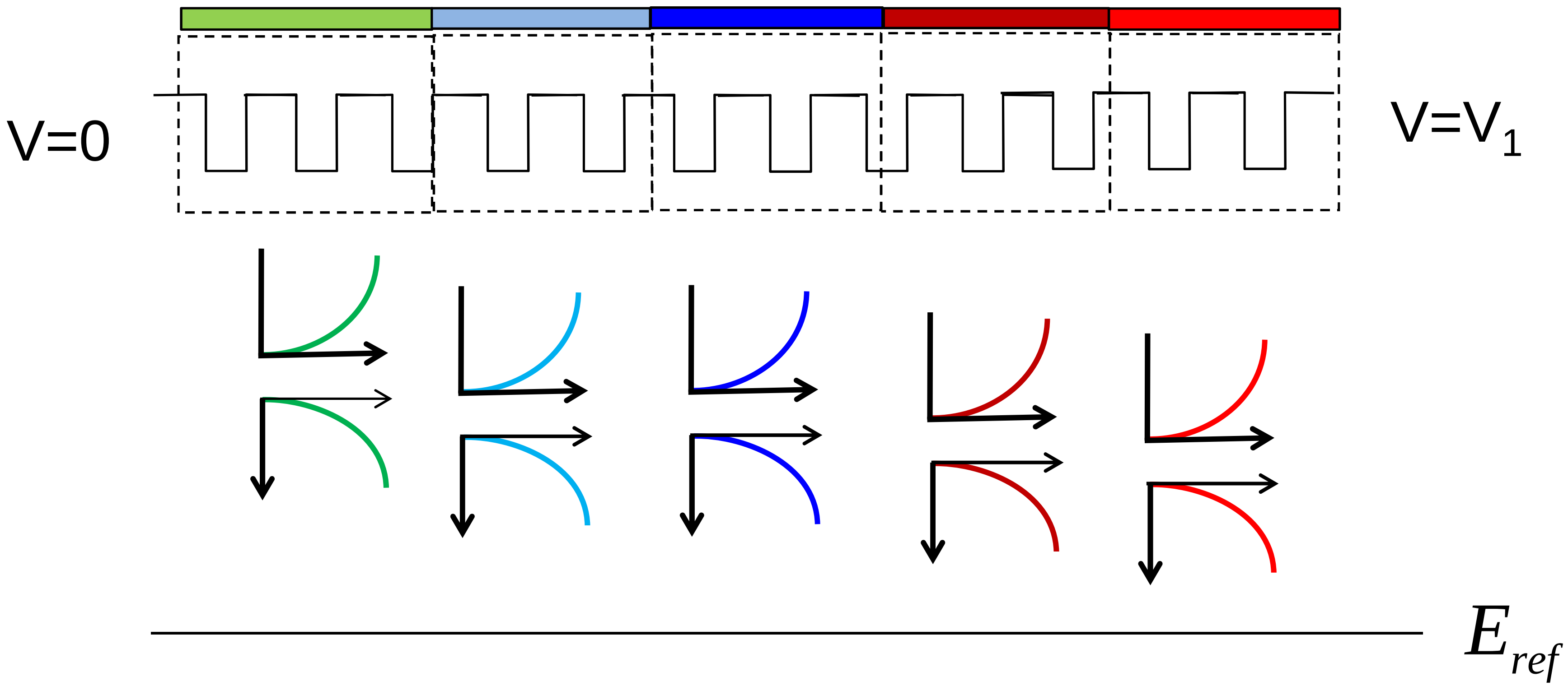


$$P.E. = E_c - E_{ref} = -qV$$

Position Resolved E-k Diagram

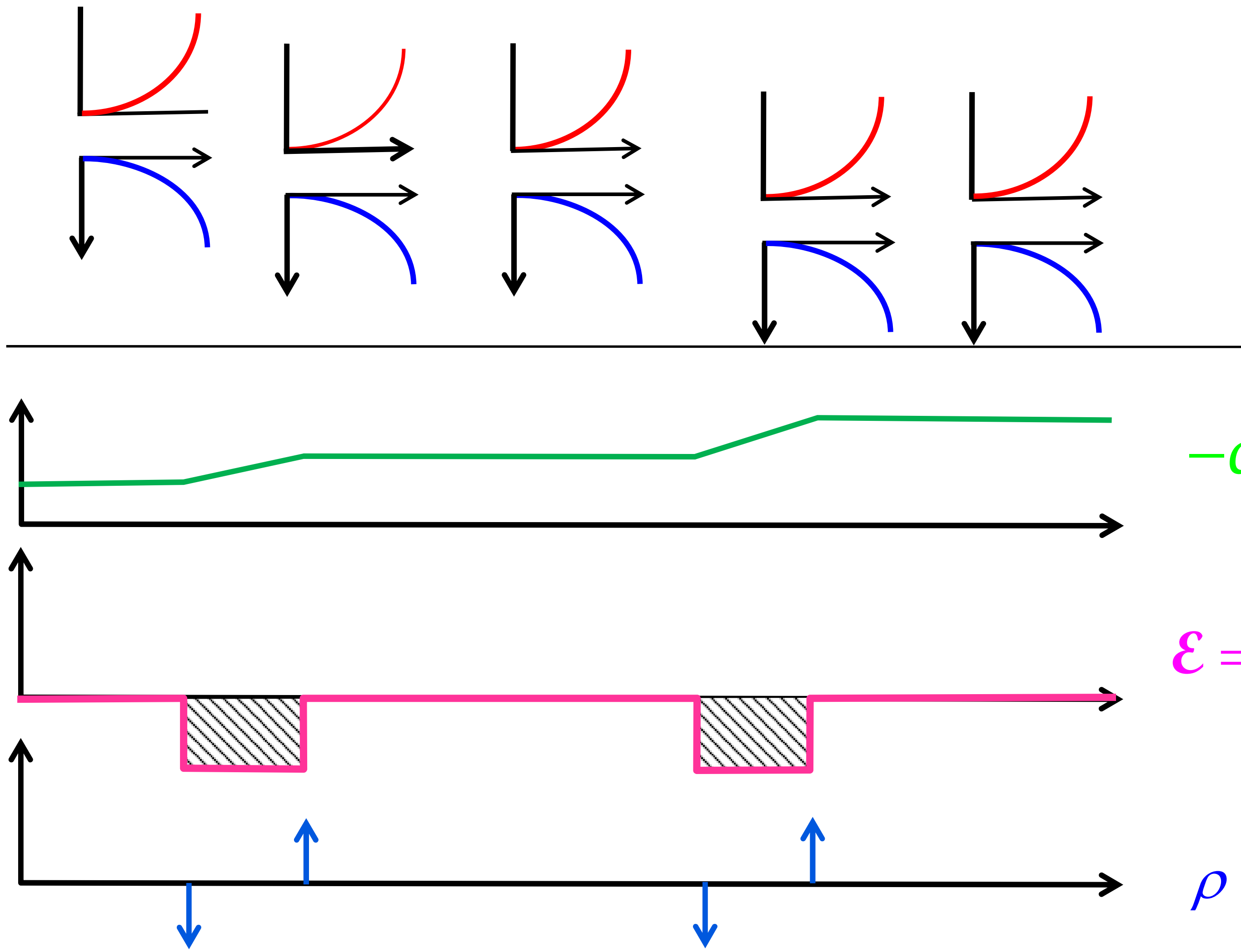


E-k Diagram vs. Band-diagram



$$P.E. = E_c - E_{ref} = -qV(x)$$

Potential, Field and Charge



$$P.E. = E_c - E_{ref}$$

E_{ref}

$$-qV = E_c - E_{ref}$$

$$\mathcal{E} = -\frac{dV}{dx} = \frac{1}{q}\frac{dE_c}{dx}$$

$$\rho = \frac{d\mathcal{E}}{dx} = \frac{d^2V}{dx^2}$$

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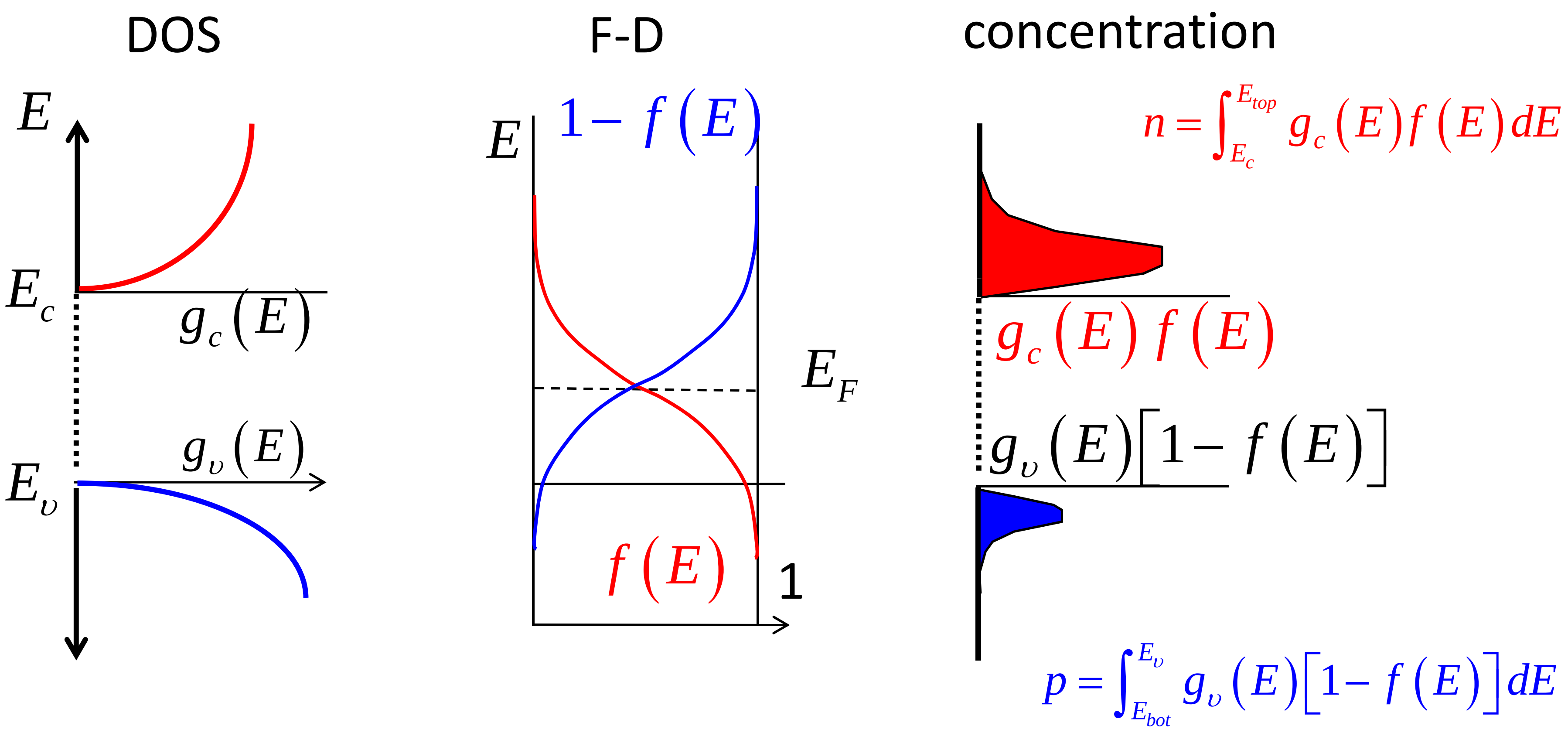
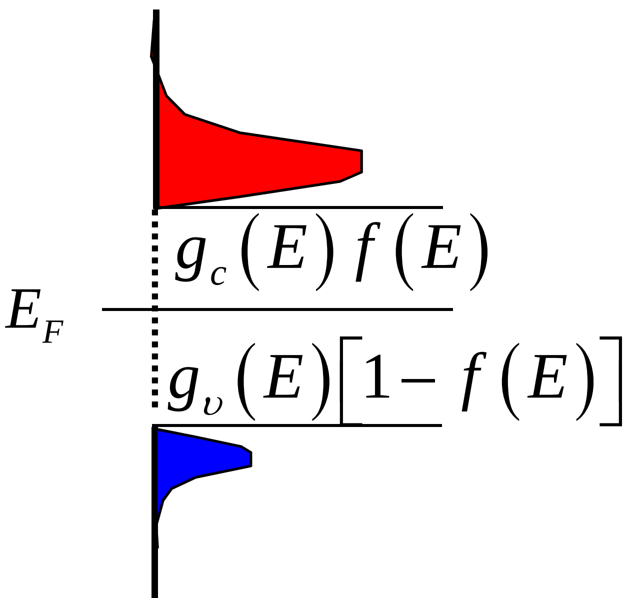
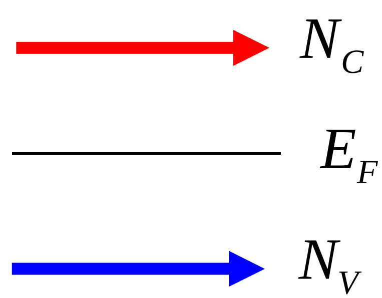
Carrier Distribution



Effective Density of States

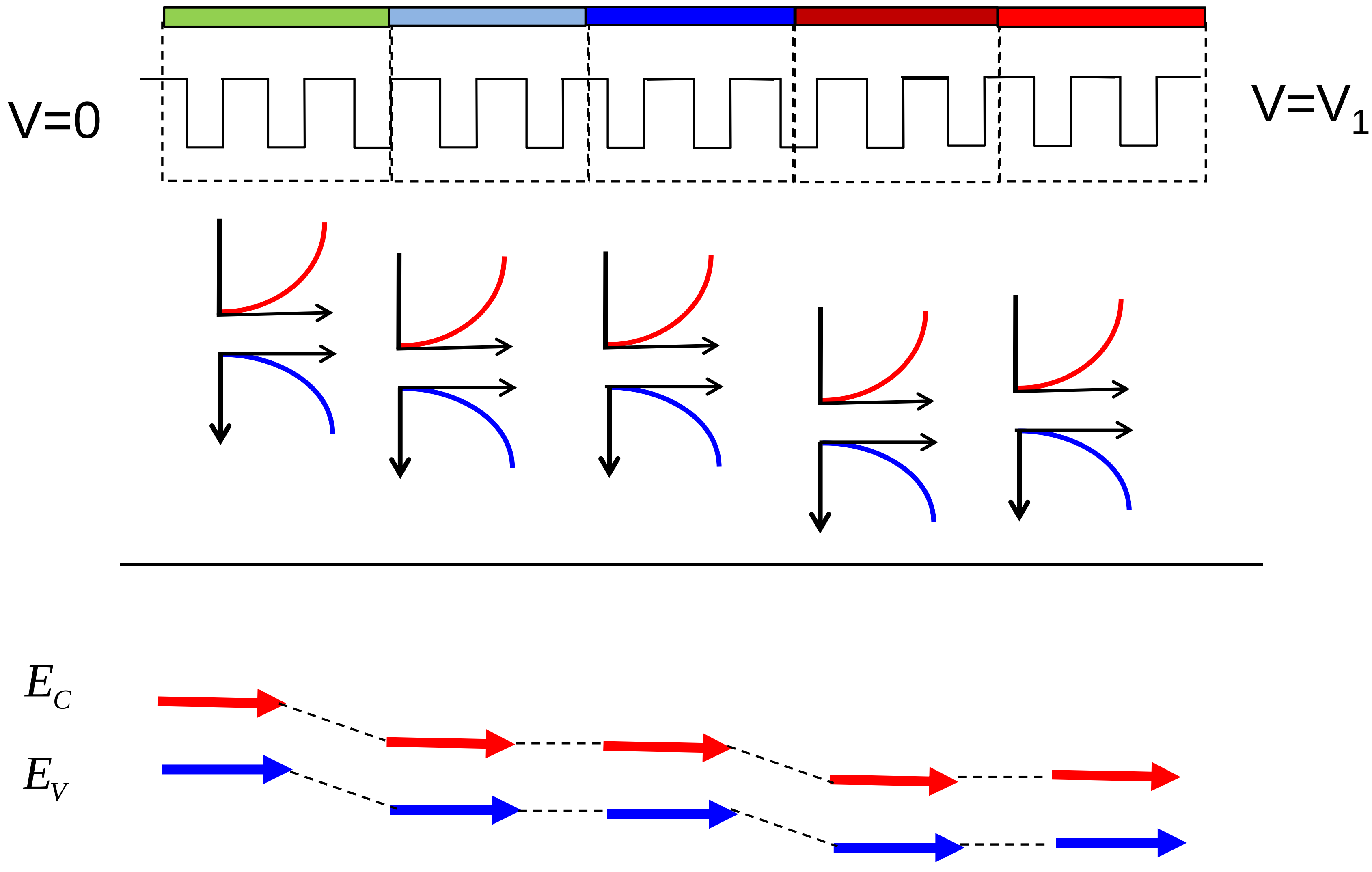
$$n = N_C \frac{2}{\sqrt{\pi}} F_{1/2}(\eta_c) \rightarrow N_C e^{-\beta(E_c - E_F)} \quad if \quad \beta(E_c - E_F) > 3$$



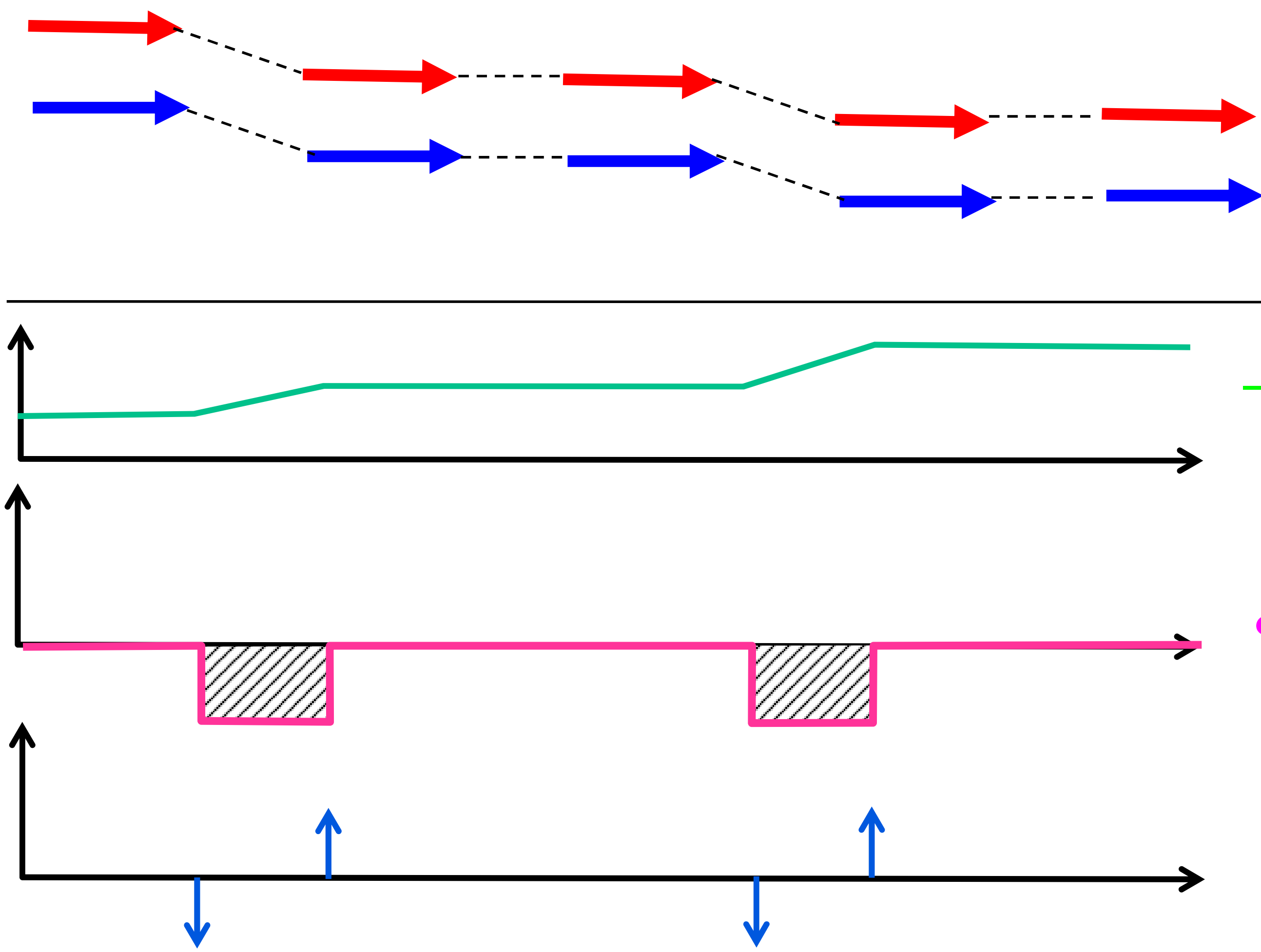


As if all states are at a single level E_C

E-k Diagram vs. Band-diagram



Potential, Field and Charge



$$P.E. = E_c - E_{ref}$$

$$E_{ref}$$

$$-qV = E_c - E_{ref}$$

$$\mathcal{E} = -\frac{dV}{dx} = \frac{1}{q}\frac{dE_c}{dx}$$

$$\rho = \frac{d\mathcal{E}}{dx} = \frac{d^2V}{dx^2}$$

Outline

1) Potential, field, and charge
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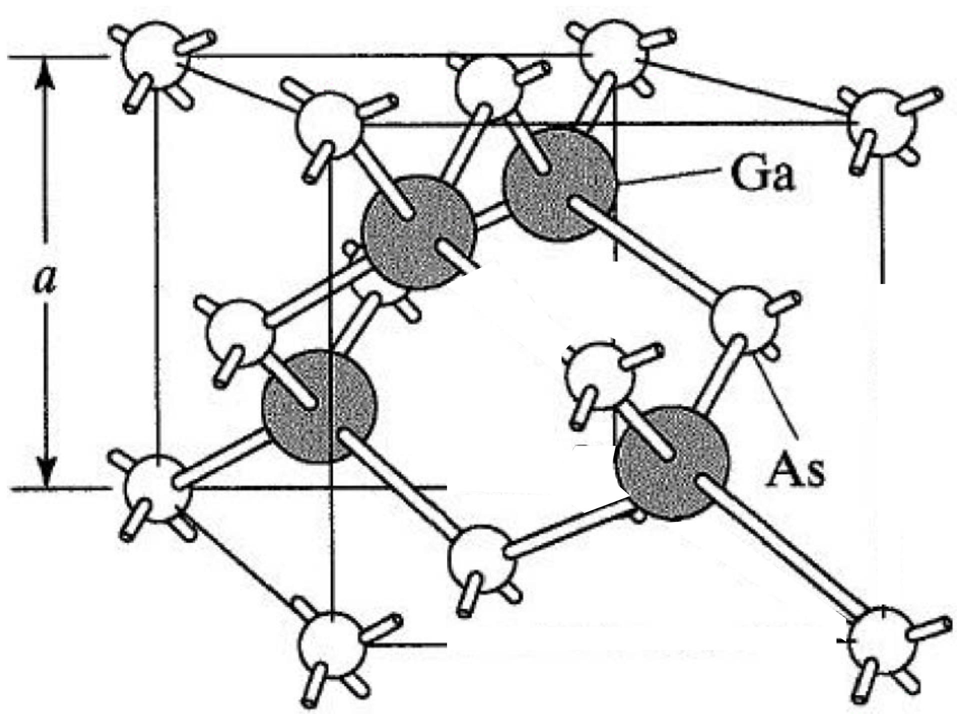
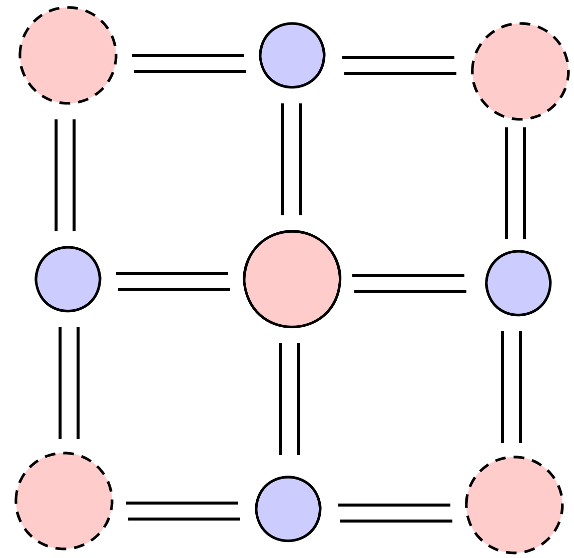
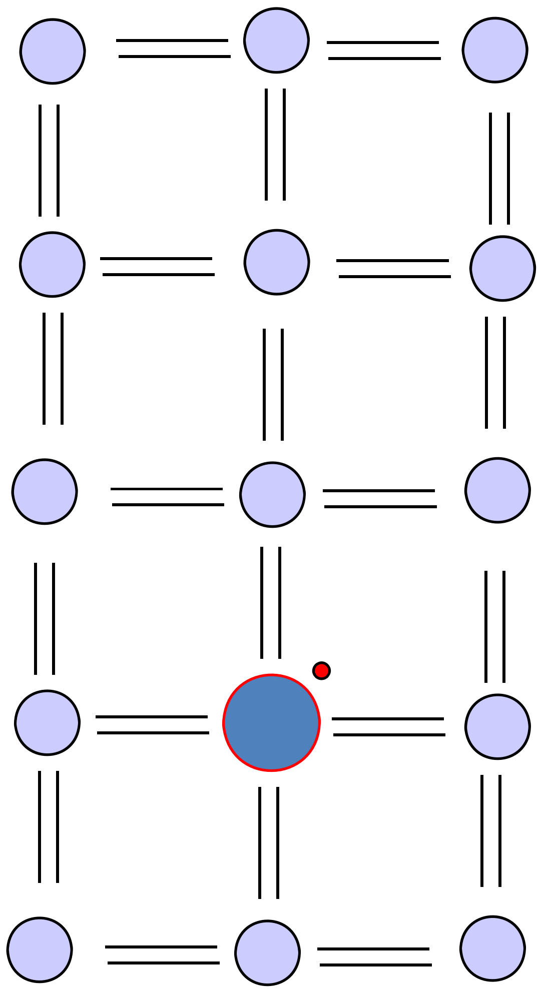
Intrinsic concentration so small that it is no good …

Simplified Planar View of Atoms





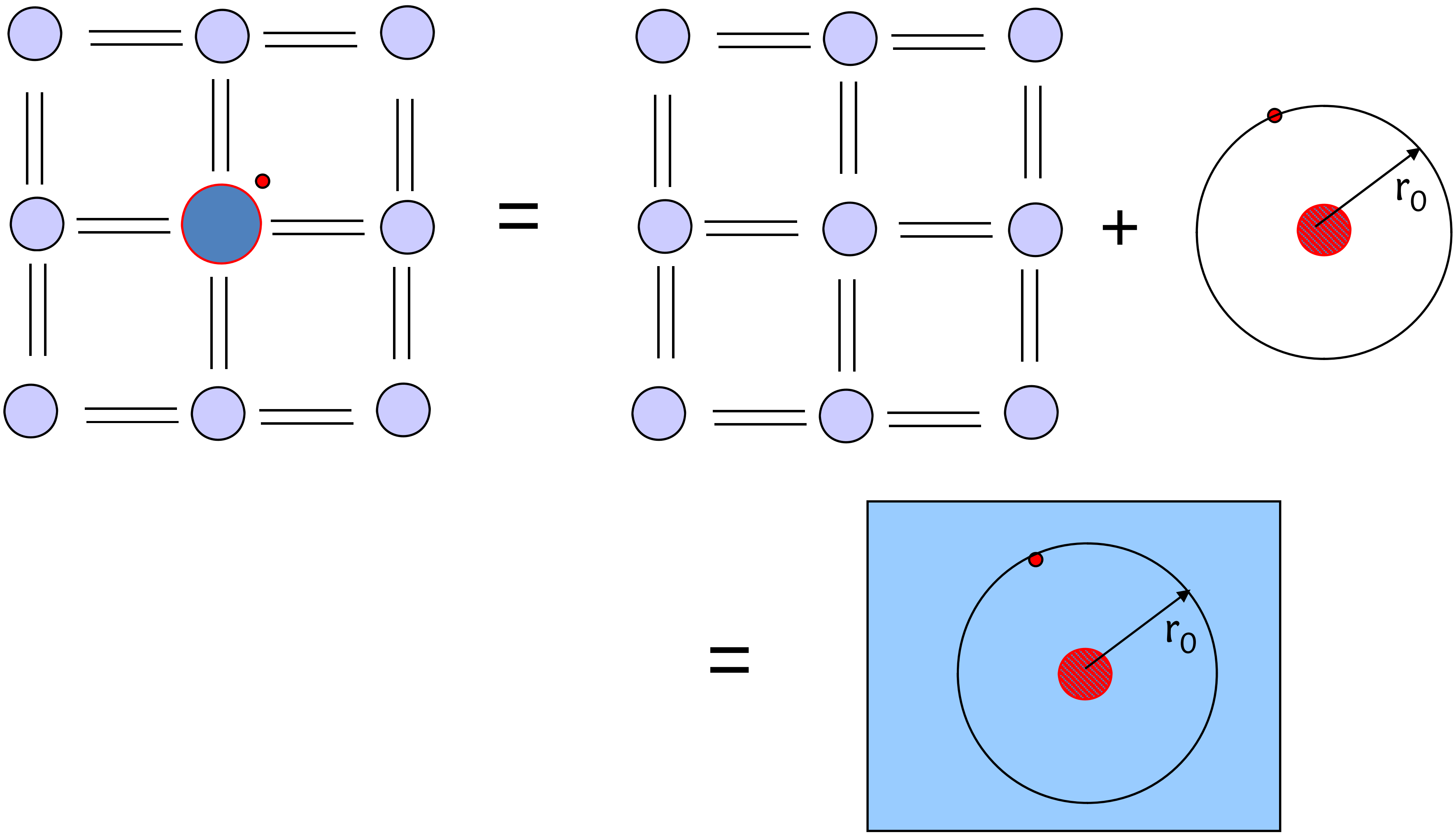
Donor Atoms



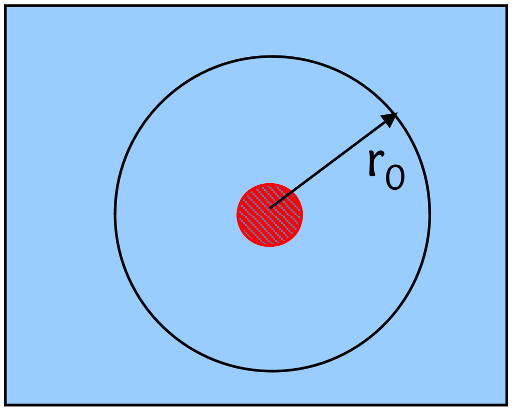
II	III	IV	V	VI
4 Be	5 B	6 C	7 N	8 O
12 Mg	13 **Al**	14 **Si**	15 **P**	16 S
30 **Zn**	31 **Ga**	32 Ge	33 **As**	34 **Se**
48 Cd	49 In	50 Sn	51 Sb	52 Te
80 Hg	81 Tl	82 Pb	83 Bi	84 Po

Even with donors, material is charge neutral

Donor Atoms in H_2-analogy



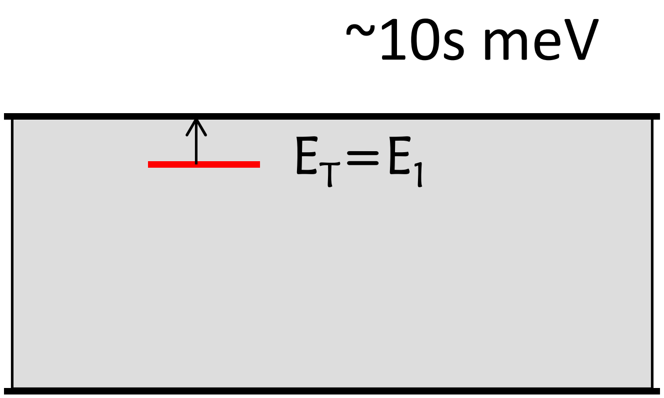
Donor Atoms in Real and Energy Space

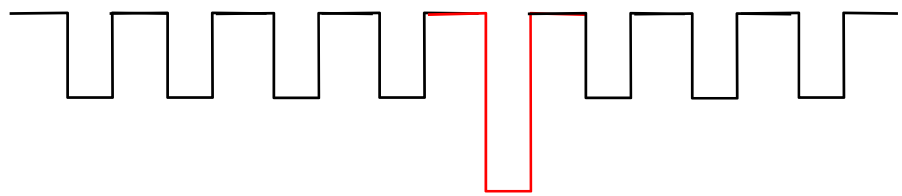


$$E_1 = -\frac{m^*_{host} q^4}{2\left(4\pi\varepsilon_0 K_{s,host} \hbar\right)^2}$$

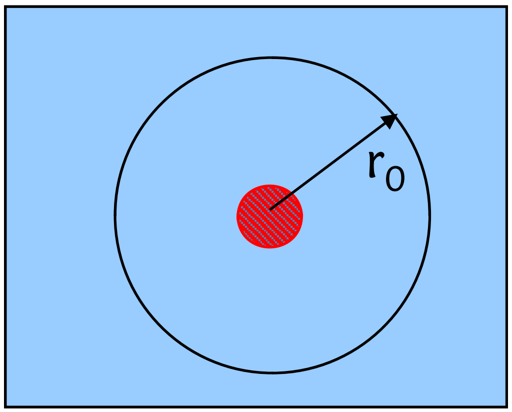
$$= -\frac{m_0 q^4}{2\left(4\pi\varepsilon_0 \hbar\right)^2} \frac{m^*_{host}}{m_0} \frac{1}{K_{s,host}{}^2}$$

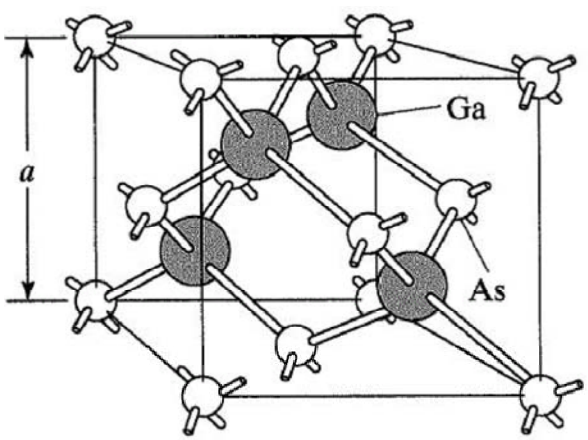
$$= -13.6 \times \frac{m^*_{host}}{m_0} \frac{1}{K_{s,host}{}^2}$$





Assumption of Large Radius ...





$$r_{1,P} = \frac{4\pi\varepsilon_0 K_{s,host}\hbar^2}{m^*_{host} q^2}$$

$$= \frac{4\pi\varepsilon_0\hbar^2}{m_0 q^2}\frac{m_0 K_{s,host}}{m^*_{host}}$$

$$= r_{1,H}\frac{K_{s,host}}{m^*_{host}/m_0}$$

$$r_{1,P} = 0.53\ A \times \frac{12.9}{0.53} = 12.9\ A$$

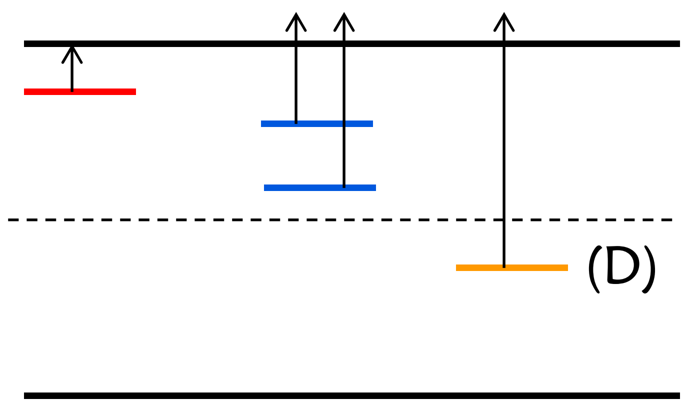
(see tables 1.6 and 4.1)

Characteristics of Donor Atoms

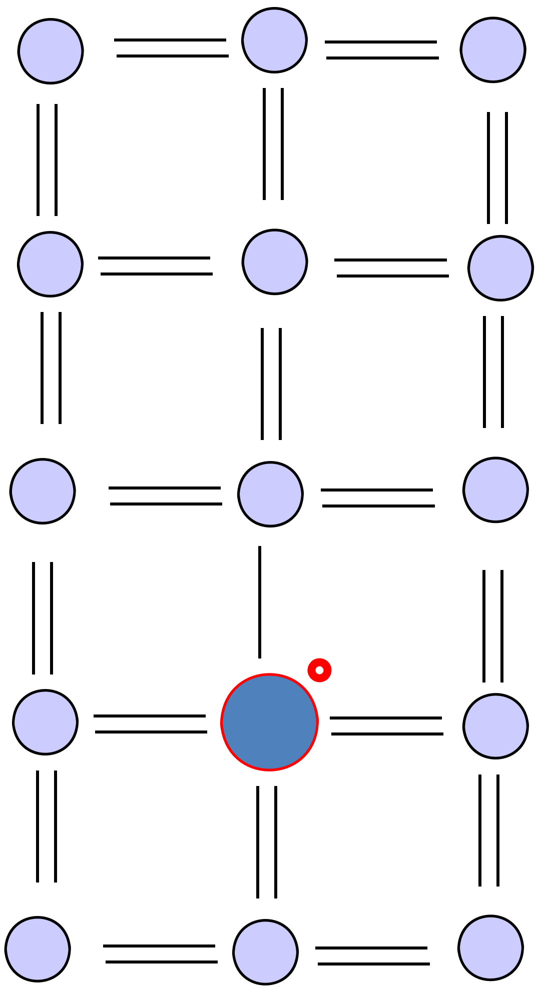
The number of donor atoms is much smaller compared to host atoms. Therefore, the electrons from one donor atom can go to the other donor atoms only via the conduction /valence bands of the host crystal.

Just like a Hydrogen atom, it is possible to have multiple localized level for a given atom (see the blue levels).

Good donors live close to the conduction band, so that they can offer electrons easily. However, if they are below the midgap, the donor levels are marked with (D) to differentiate them from acceptor atoms (which live close to the valence band).



Acceptor Atoms



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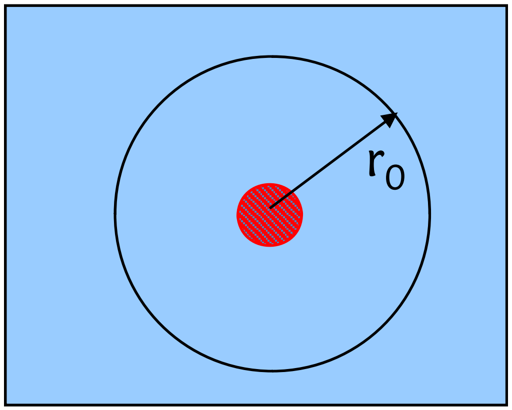
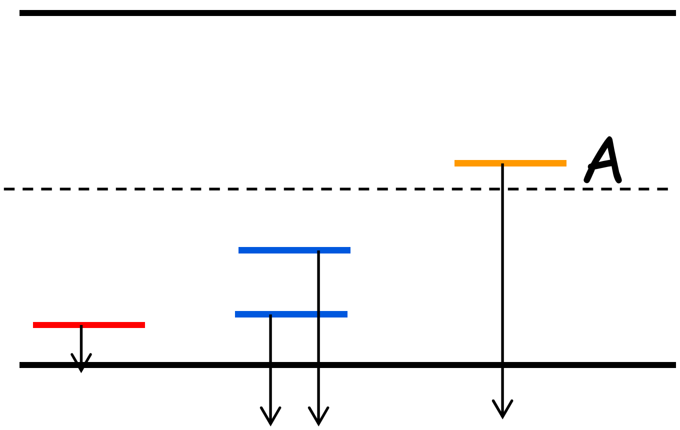
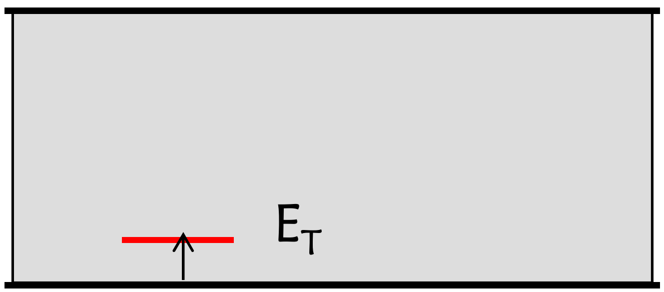
Even with acceptor, material is charge neutral

Characteristics of Acceptor Atoms







Amphoteric Dopants

II	III	IV	V	VI
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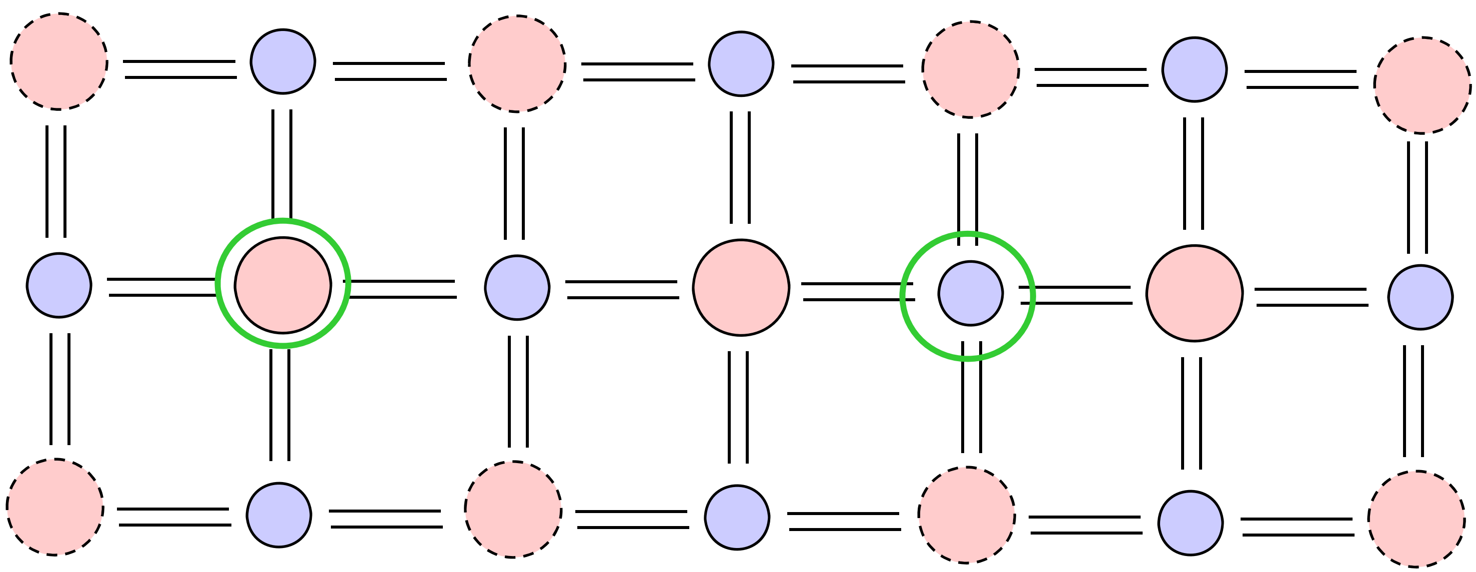
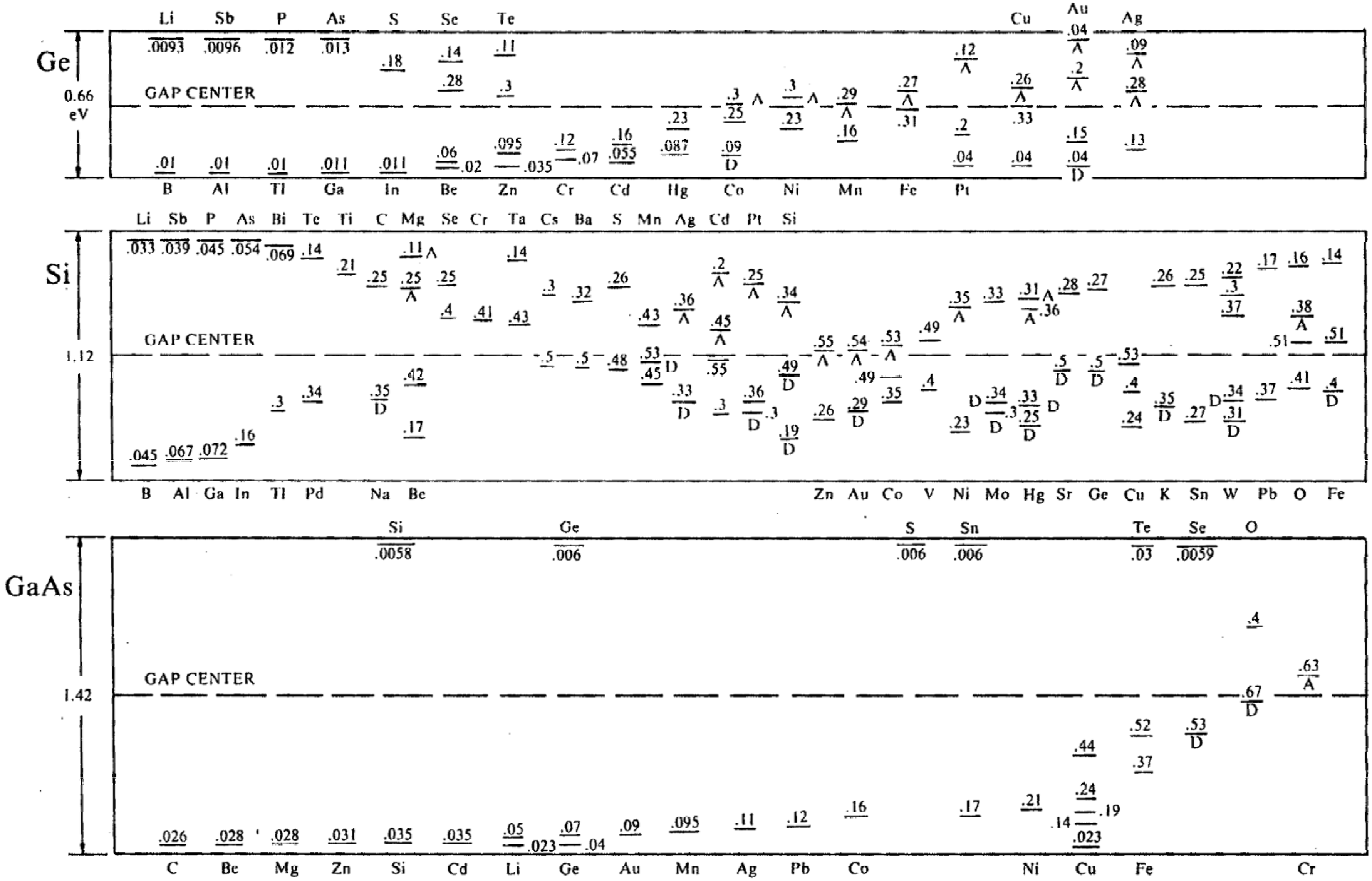
Donor-type

acceptor-type



How to Read the Table …



Conclusion

Bulk electron density in a semiconductor can be calculated by multiplying bulk DOS and F-D function.

Position resolved electron density can be calculated by first converting the bulk E-k diagram to band-diagram.

Intrinsic carrier concentration is so small that semiconductor must be doped to make it useful.

A doping atom behaves like a H-atom, except that the dielectric constant and effective masses are given by by those of the host atom.