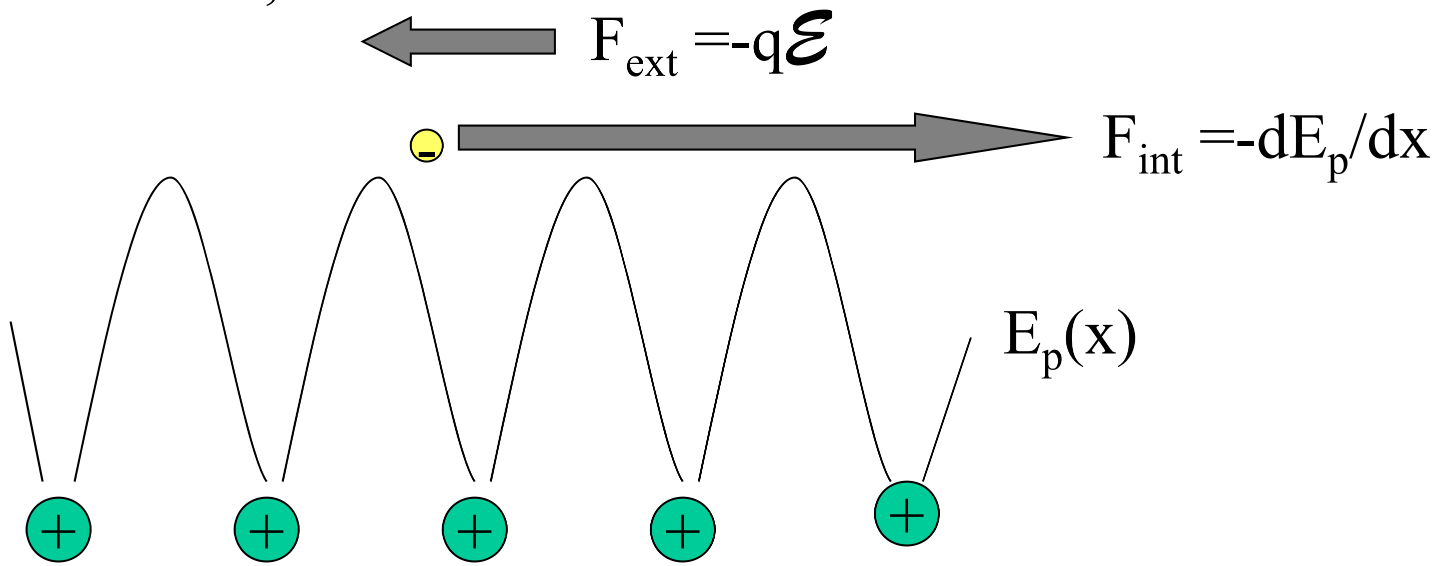
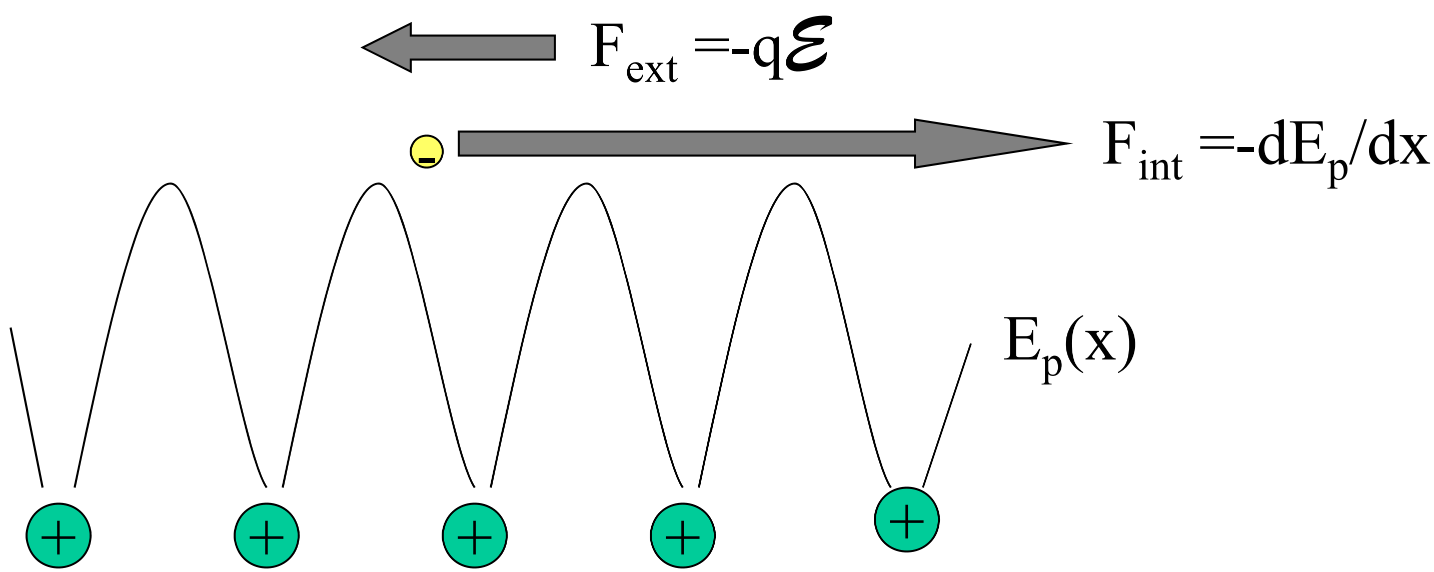
Interpretation

- The electron is subject to <u>internal</u> forces from the lattice (ions and core electrons) AND <u>external</u> forces such as electric fields
- In a crystal lattice, the net force may be <u>opposite</u> the external force, however:



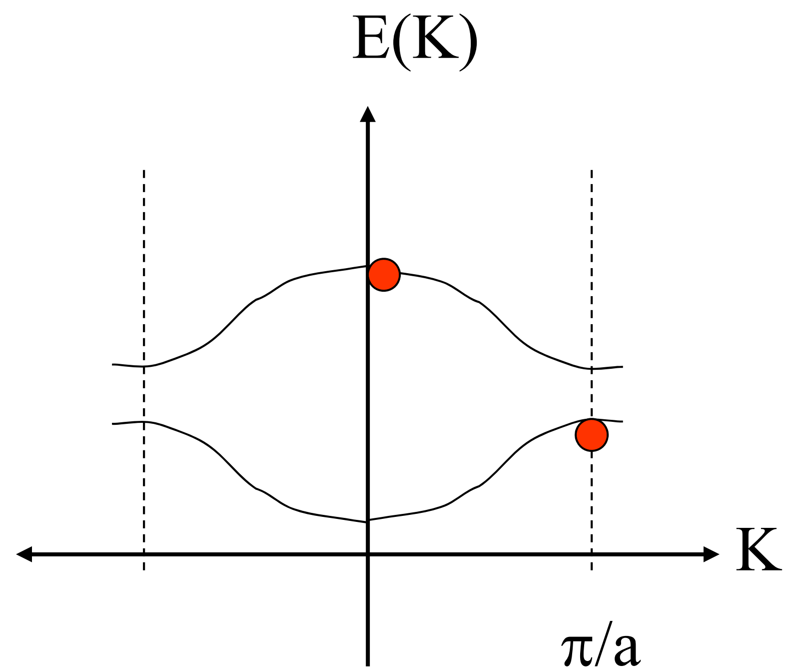
Interpretation

- electron acceleration is not equal to F_{ext}/m_e, but rather…
- $a = (F_{ext} + F_{int})/m_e == F_{ext}/m^*$
- The dispersion relation E(K) compensates for the internal forces due to the crystal and allows us to use *classical* concepts for the electron as long as its mass is taken as m^*



The Hole

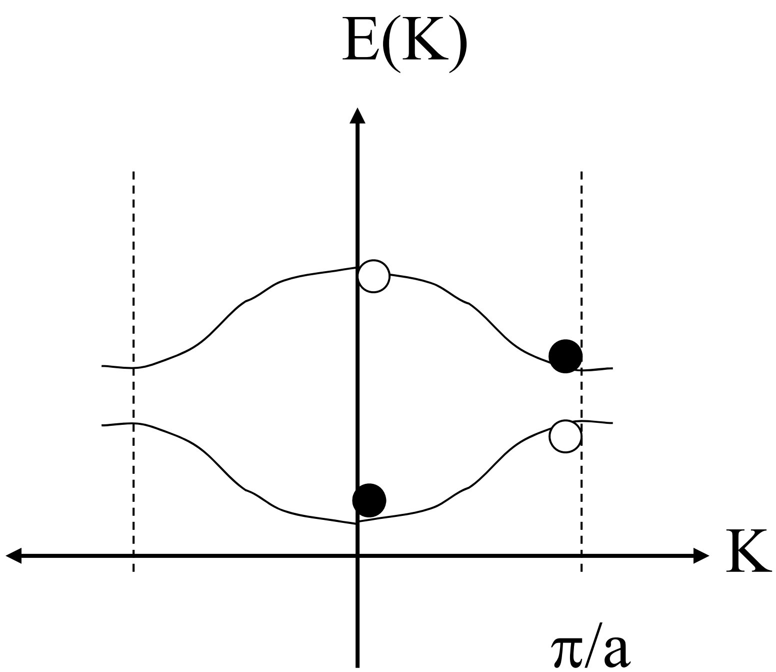
- The hole can be understood as an electron with negative effective mass
- An electron near the top of an energy band will have a negative effective mass
- A negatively charged particle with a negative mass will be <u>accelerated</u> like a positive particle with a positive mass (a hole!)

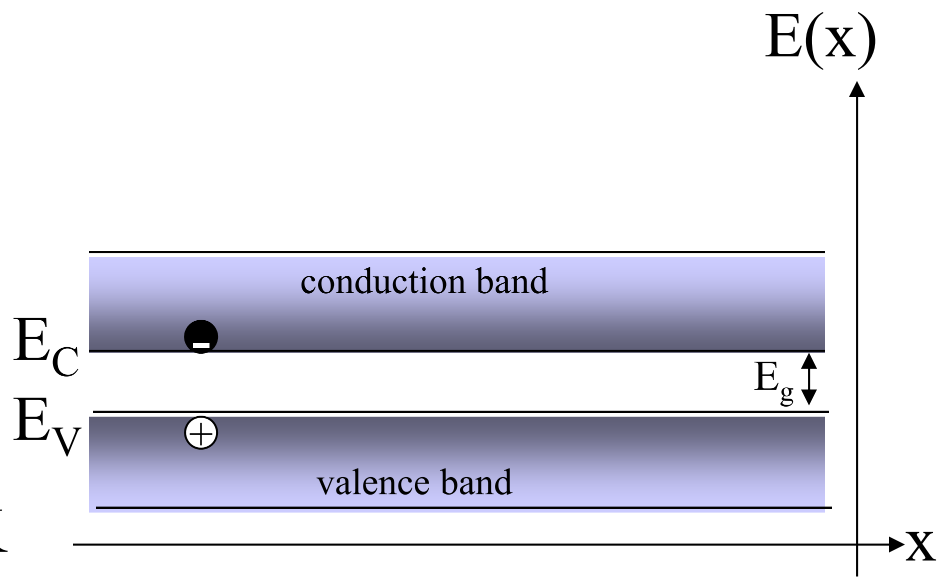


$F = m^{*}a = Q\mathcal{E}$

Without the crystal lattice, the hole cannot exist. It is an artifact of the periodic potential (E_p) created by the crystal.

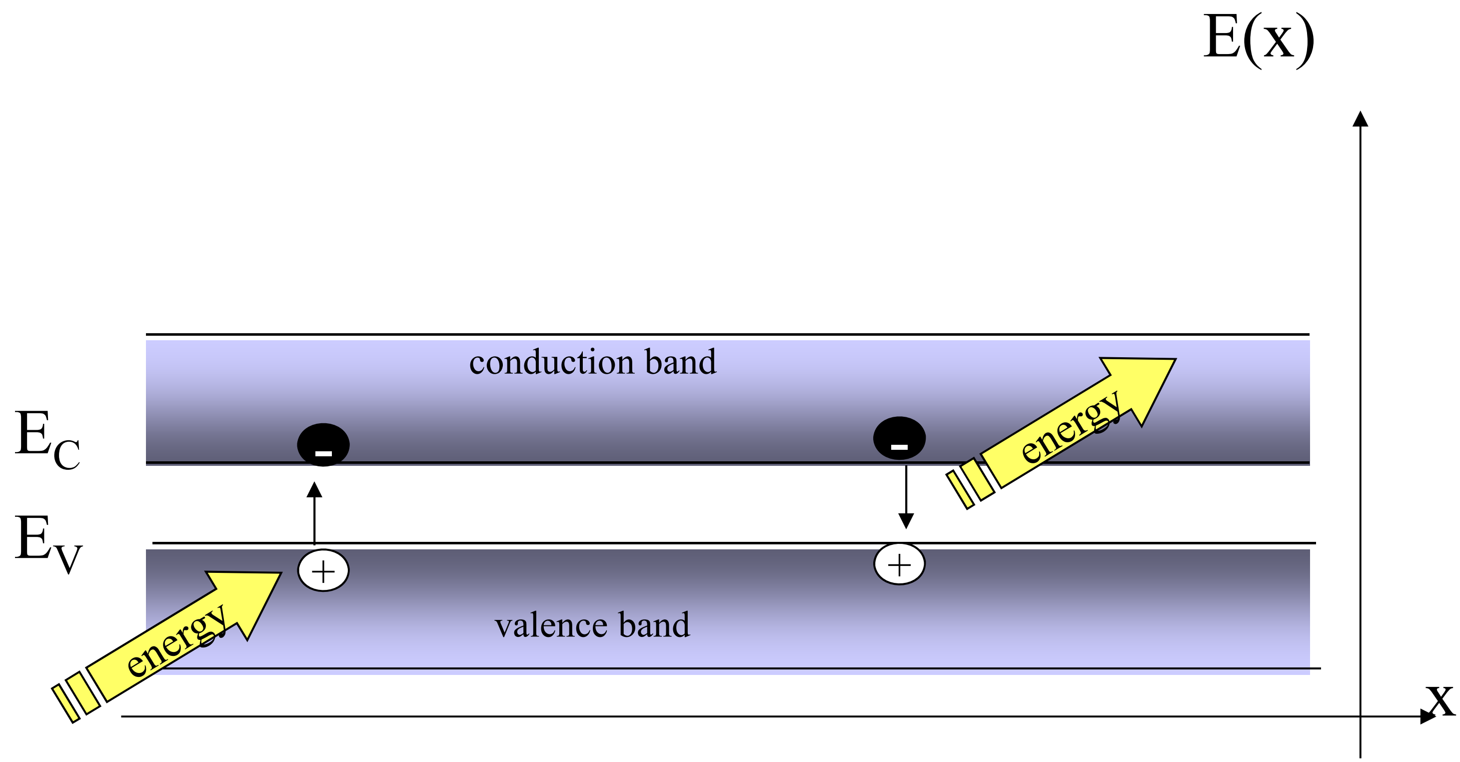
E(K) and E(x)





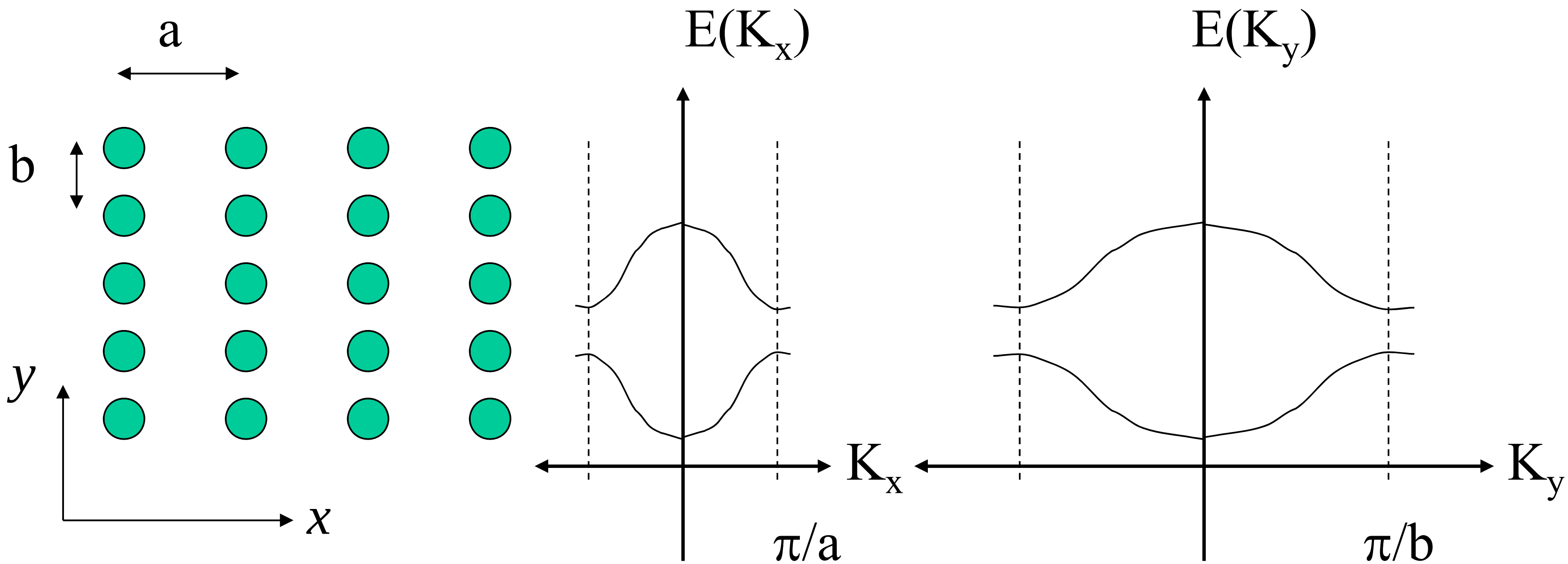
Generation and Recombination

of electron-hole pairs



Non-cubic lattices:

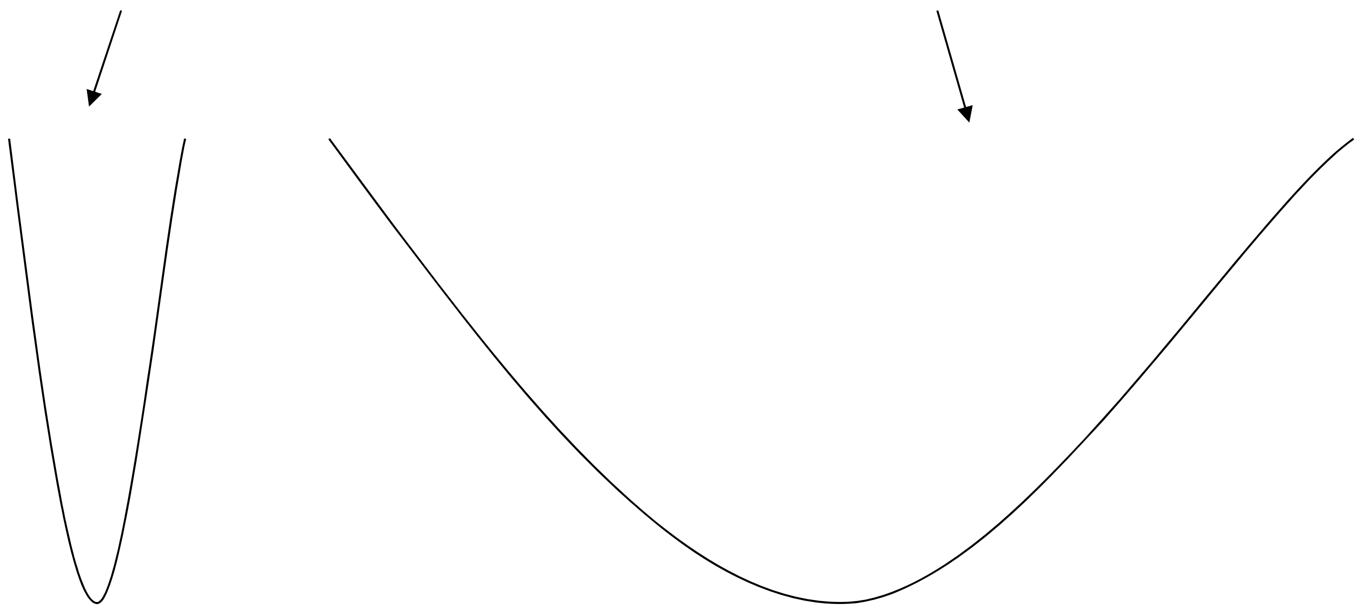
(FCC, BCC, diamond, etc.)



Different lattice spacings lead to different curvatures for E(K) and effective masses that depend on the direction of motion.

Memory Aid

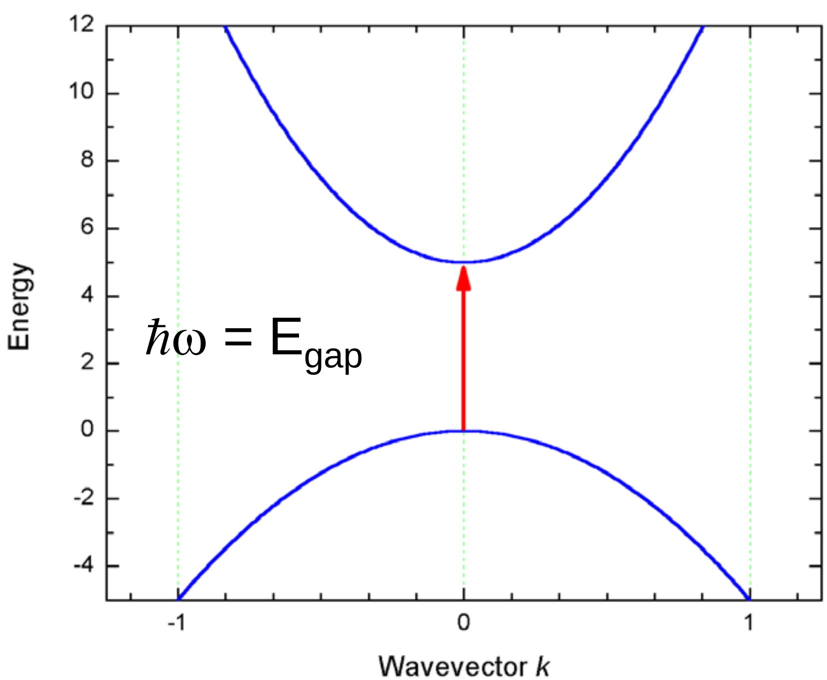
"a hairpin is lighter than a frying pan"



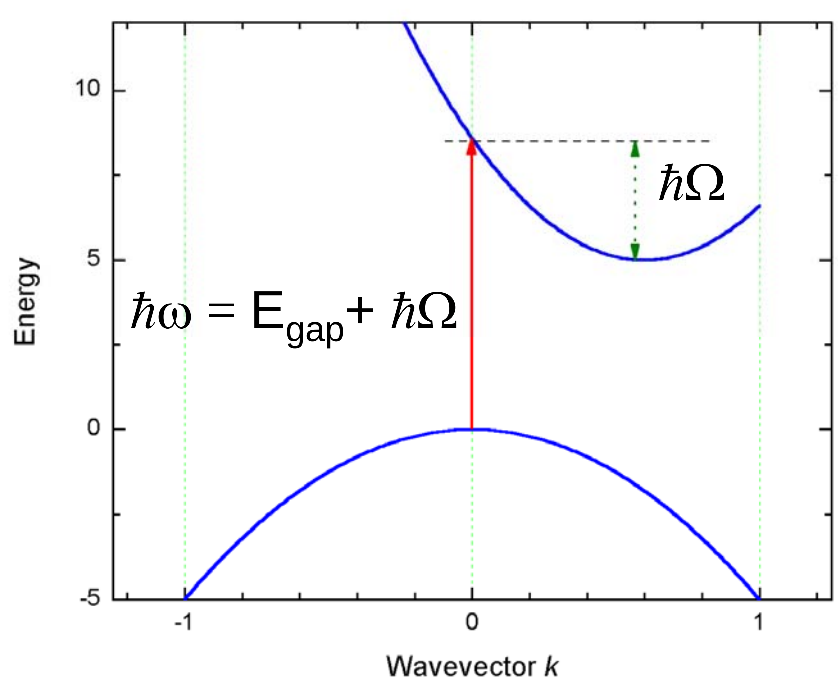
light m^* (larger d^2E/dK^2)

heavy m^* (smaller d^2E/dK^2)

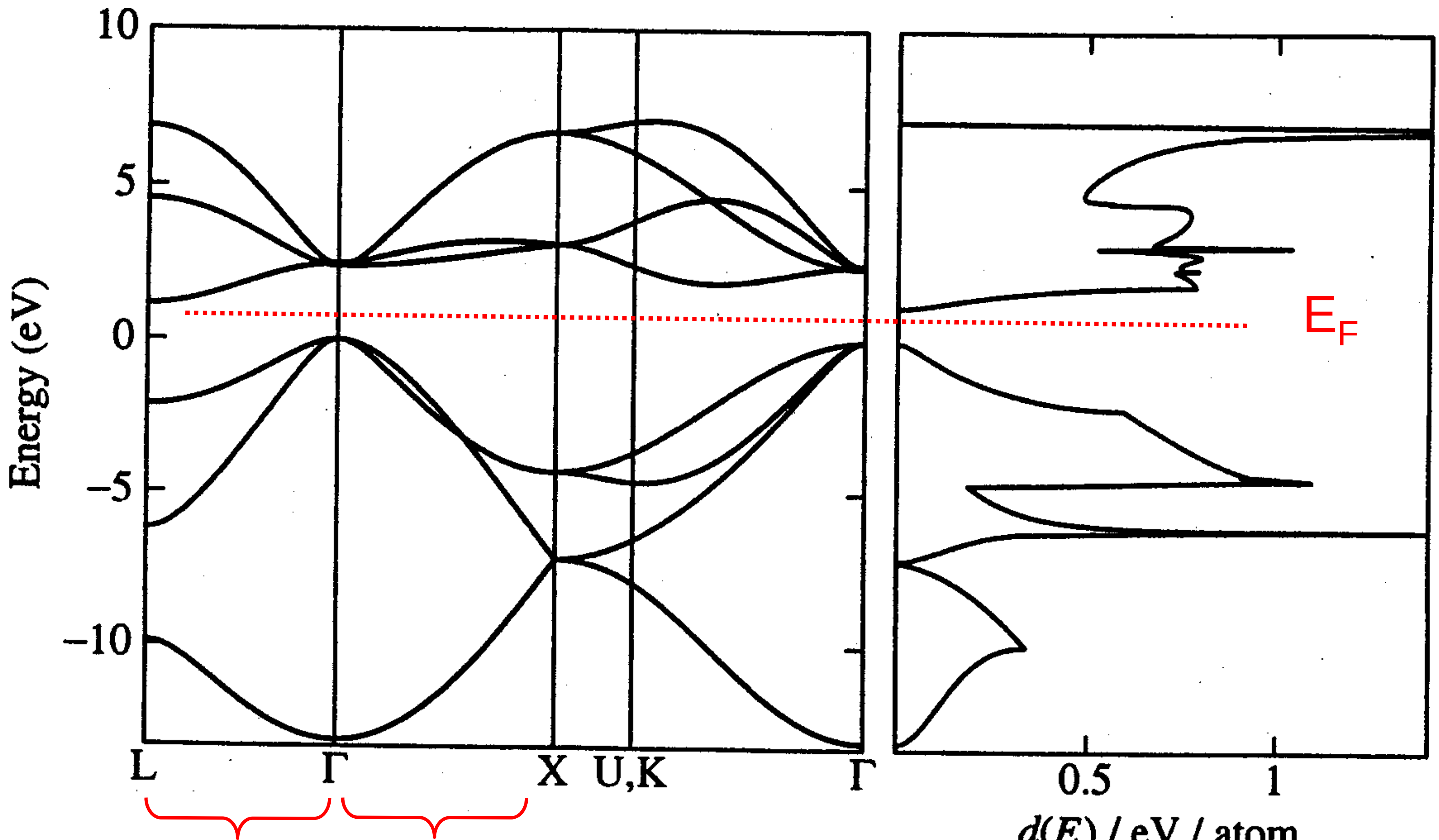
Direct Energy Gap



Indirect Energy Gap



Silicon



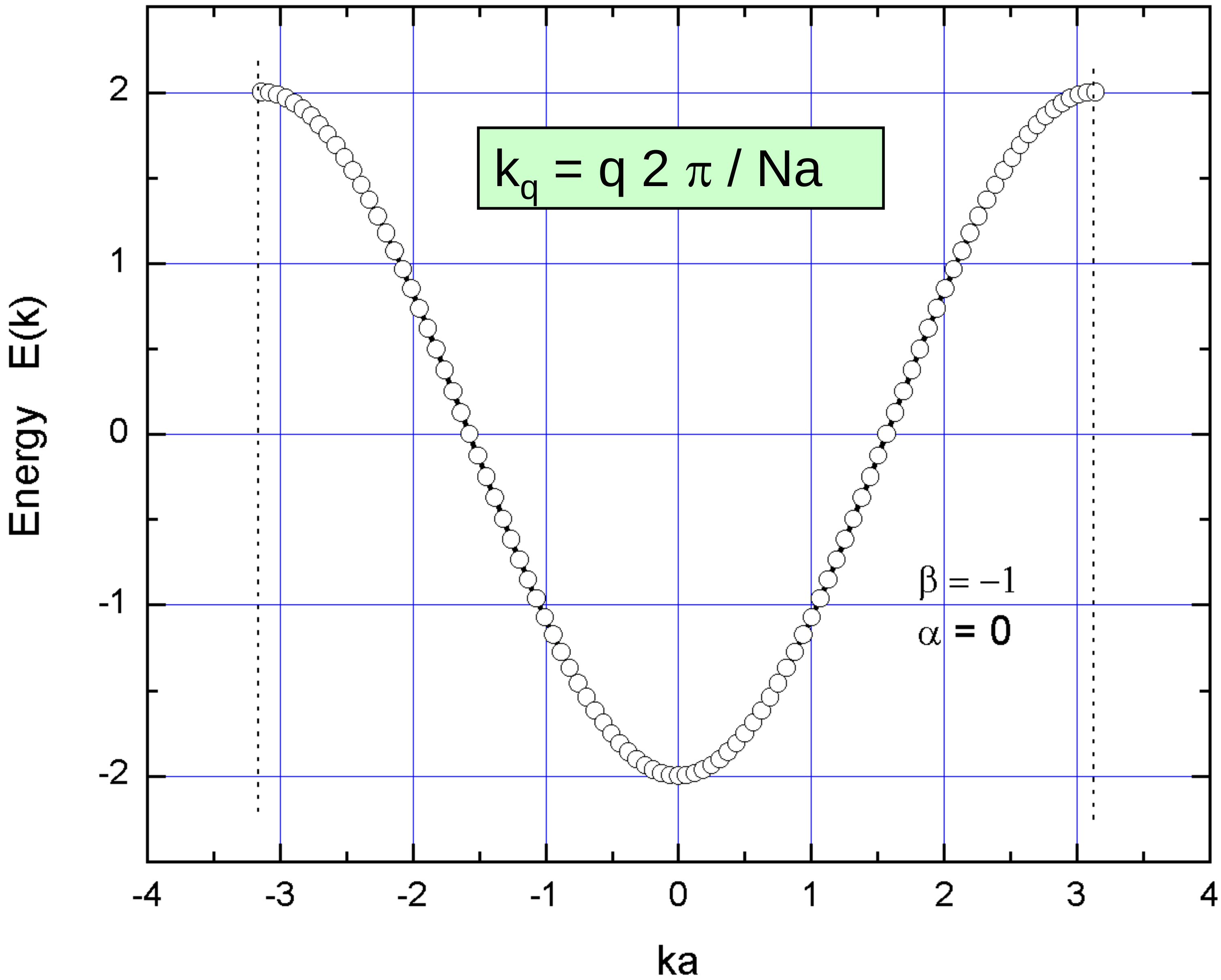
$$\vec{k}=\left[\frac{k}{\sqrt{3}},\frac{k}{\sqrt{3}},\frac{k}{\sqrt{3}}\right] \qquad \vec{k}=[k,0,0]$$

Light Emission

- energy (E) and momentum ($\hbar K$) must be conserved
- energy is released when a quasi-free electron recombines with a hole in the valence band:

$$\Delta E = E_g$$

  - does this energy produce light (photon) or heat (phonon)?
- indirect bandgap: ΔK is large
  - but for a direct bandgap: $\Delta K=0$
- photons have very low momentum
  - but lattice vibrations (heat, phonons) have large momentum
- Conclusion: recombination (e^-+h^+) creates
  - *light* in direct bandgap materials (GaAs, GaN, etc)
  - *heat* in indirect bandgap materials (Si, Ge)



$k_q = q\ 2\ \pi\ /\ Na$
$\beta = -1$
$\alpha = 0$
Energy E(k)
ka
2
1
0
-1
-2
-4
-3
-2
-1
0
1
2
3
4