FYS3410 - Vår 2016 (Kondenserte fasers fysikk)

http://www.uio.no/studier/emner/matnat/fys/FYS3410/v16/index.html

Pensum: Introduction to Solid State Physics
by Charles Kittel (Chapters 1-9 and 17, 18, 20)

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2016 FYS3410 Lectures (based on C.Kittel's Introduction to SSP, Chapters 1-9, 17,18,20)

Module I – Periodic Structures and Defects (Chapters 1-3, 20)

M18/1: 9-12 am	**Introduction. Crystal bonding. Periodicity and lattices, Brag diffraction and Laue condition, reciprocal space**	**3h**
W20/1 cancelled		
M25/1: 9-12 am	**Ewald construction, interpretation of a diffraction experiment , Brag planes, and Brillouin zones**	**3h**
W27/1 cancelled		
M01/2: 10-12 am	**Elastic strain and structural defects in crystals**	**2h**
W03/2: 9-10 am	**Atomic diffusion in solids**	**1h**
M08/2: 10-12 am	**Summary of Module I**	**2h**

Module II – Phonons (Chapters 4 and 5)

W10/2: 9-10 am	**Vibrations in monoatomic and diatomic chains of atoms**	**1h**
M15/2: 10-12am	**Periodic boundary conditions, phonons and density of states (DOS)**	**2h**
W17/2: 9-10 am	**Planck distribution**	**1h**
M22/2 : 10-12am	**Lattice heat capacity: Dulong-Petit, Einstein, and Debye models**	**2h**
W24/2 cancelled		
M29/2: 9-12am	**Comparison of different models for lattice heat capacity, thermal conductivity with phonons**	**3h**
W02/3: 9-10 am	**Thermal expansion**	**1h**
M07/3: 10-12am	**Summary of Module II.**	**2h**

Module III – Electrons (Chapters 6, 7, 18 - pp.528-530, and Appendix D)

W09/3: 9-10 am	**Free electron gas (FEG) versus free electron Fermi gas (FEFG)**	**1h**
M14/3: 10-12am	**DOS of FEFG in 3D. Effect of temperature – Fermi-Dirac distribution**	**2h**
W16/3: 9-10 am	**Heat capacity of FEFG in 3D**	**1h**
W30/3: 9-10 am	**DOS in 2D - quantum wells**	**1h**
M04/4: 10-12am	**DOS in 1D and 0D, i.e. quantum wires and quantum dots; transport properties of electrons**	**2h**
W06/4: 9-10 am	**Origin of the energy band gap**	
M11/4: 10-12am	**Nearly free electron model. Kronig-Penney model. Empty lattice approximation.**	**2h**
W13/4: 9-10 am	**Number of orbitals in a band**	**1h**
M18/4: 10-12am	**Summary of Module III.**	**2h**

Module IV – Semiconductors and interfaces (Chapters 8, 9-pp 223-231, 17)

W20/4: 9-10 am	**Metals versus semiconductors. Surfaces and interfaces.**	**1h**
M25/4: 9-12 am	**Effective mass method.**	**3h**
W27/4: 9-10 am	**Intrinsic carrier generation – elctrons and holes.**	**1h**
M02/5: 9-12 am	**Localized levels for hydrogen-like impurities – donors and acceptors. Doping.**	**3h**
W04/5: 9-10 am	**Carrier statistics in semiconductors**	**1h**
M09/5: 9-12 am	**p-n junctions**	**3h**
W11/5: 9-10 am	**Optoelectronic semiconductor properties and devices**	**1h**
M18/5: 9-12 am	**Device demonstrations. Summary of Module IV**	**3h**

Repetition

M23/5 9-12 am	**The course in a nutshell**	**2h**

W25/5, M30/5 and W1/6 cancelled

Exam during week 22 (tentatively 30-31/5)

Origin of energy bands and nearly free electron model

- Recap of the one-electron approximation
- Intuitive picture
- Bragg-reflection for nearly free electrons
- Gap opening for nearly free electrons
- Solution of the Schrödinger equation

Recap of one electron approximation

$$-\frac{\hbar^2\nabla^2}{2m_e}\psi(\mathbf{r}) + U(\mathbf{r})\psi(\mathbf{r}) = E\psi(\mathbf{r})$$

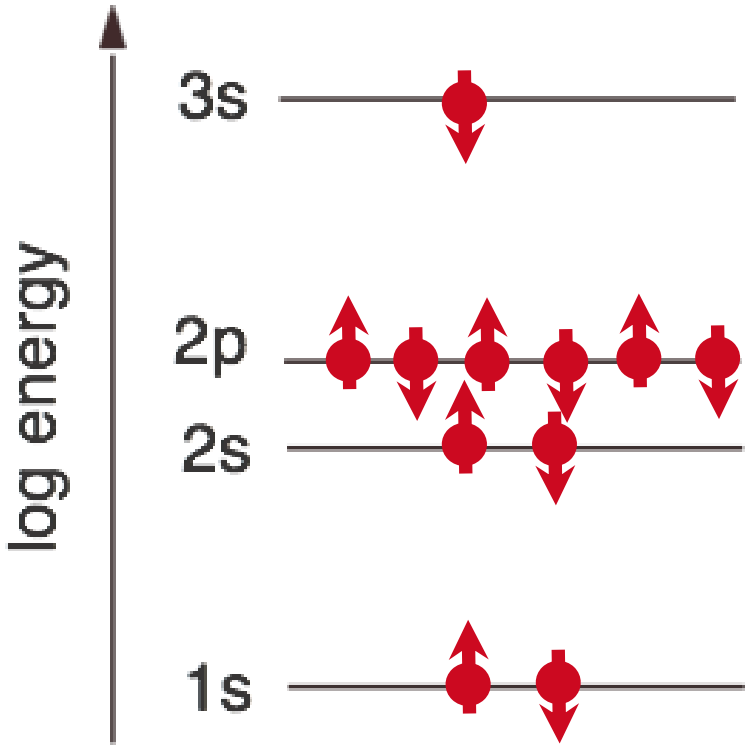
we know for sure that

$$U(\mathbf{r}) = U(\mathbf{r}+\mathbf{R})$$

...but not much more

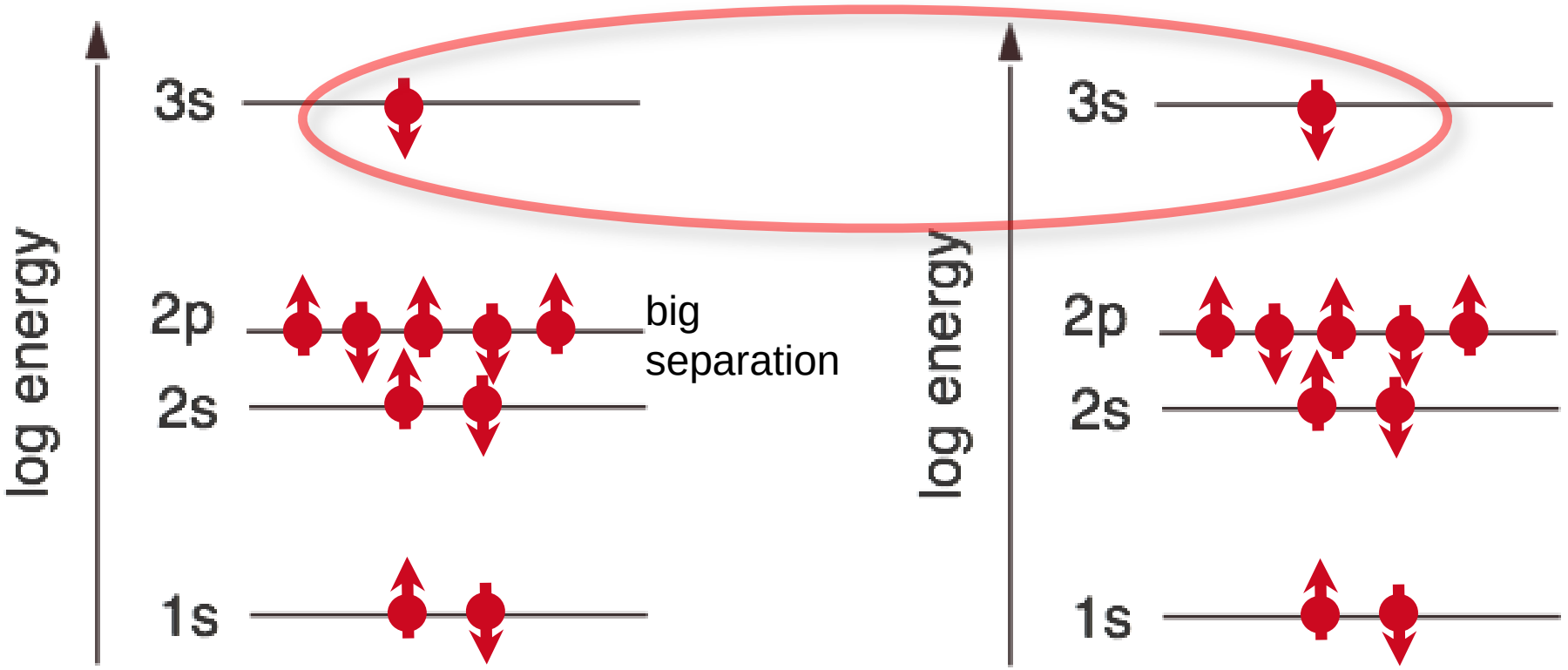
The idea of energy bands: Na

consider one atom of Na: 11 electrons



The idea of energy bands: Na

consider tow Na atoms / a Na_2 molecule: 22 electrons

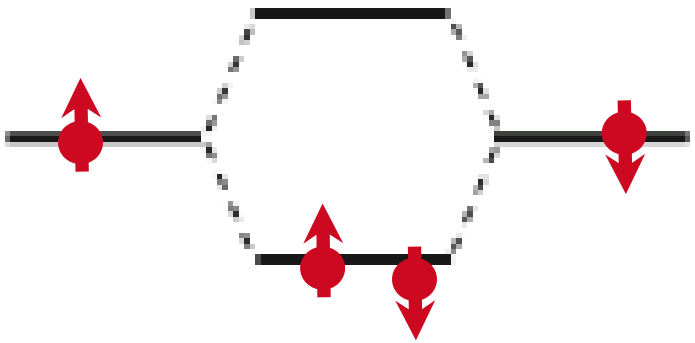


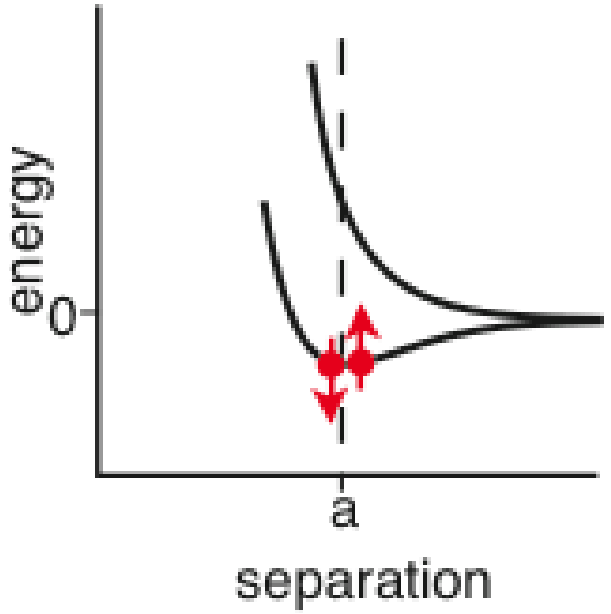
- Focus only on the valence (outer) electrons (3s).
- What happens when we move them together?

The idea of energy bands: Na

consider tow Na atoms / a Na_2 molecule: 22 electrons

molecular
energy levels
capacity: 2x2=4 electrons

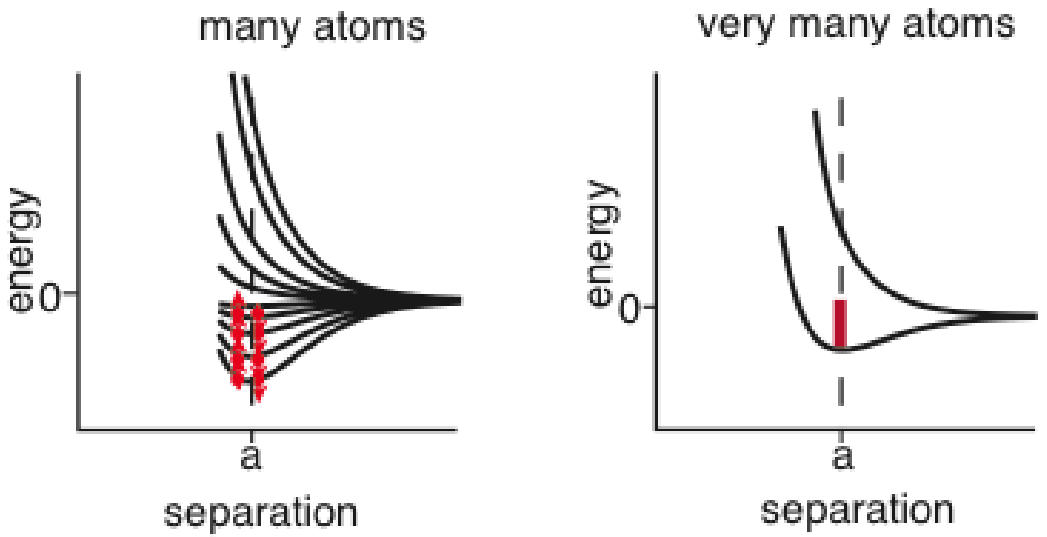




- Levels split up in bonding and anti bonding molecular orbitals and are occupied according to the Pauli principle.
- The distance between the atoms must be such that there is an energy gain.

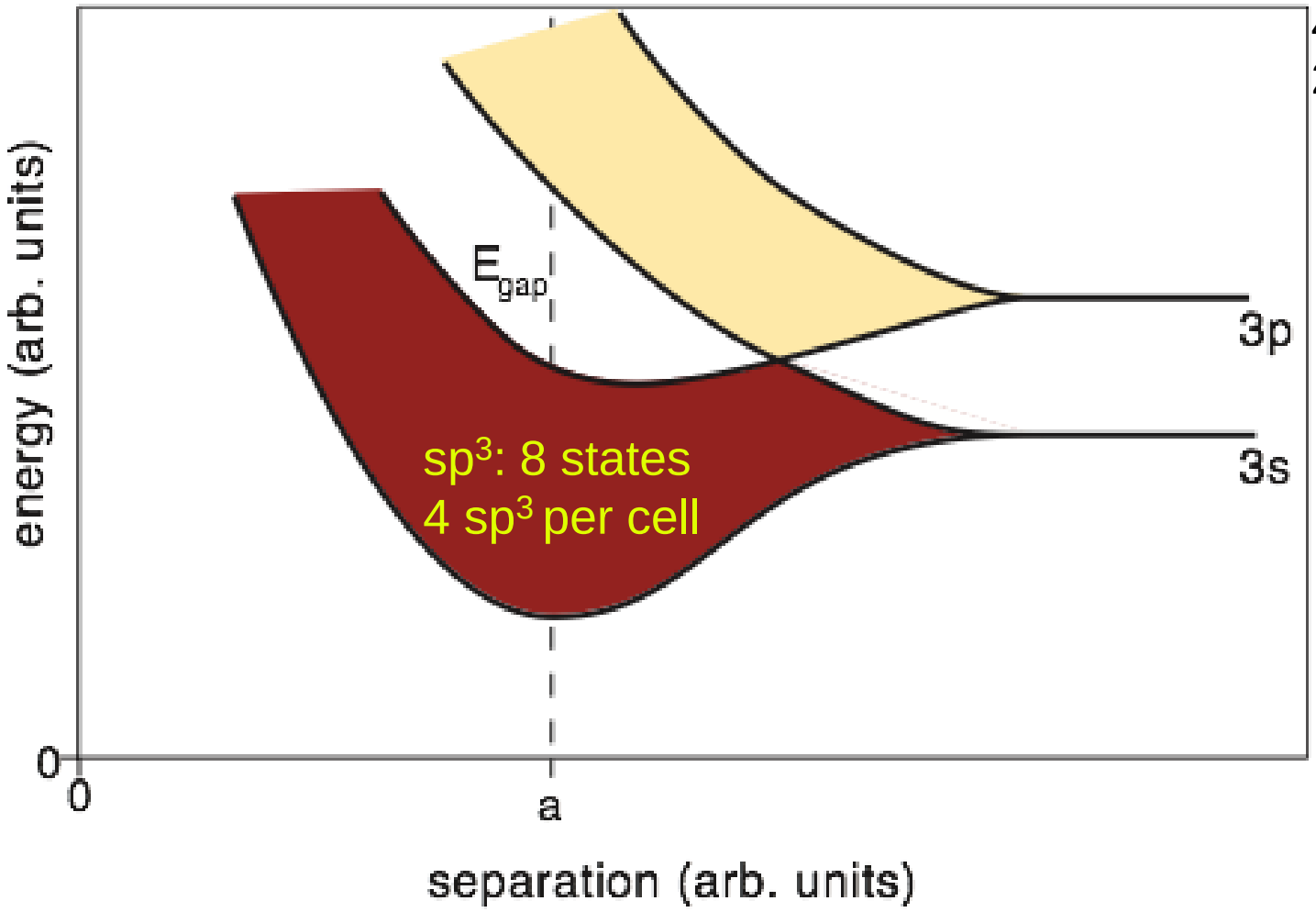
The idea of energy bands: Na

consider many (N) Na atoms (only 3s level)



- N levels with very similar energies, like in a super-giant molecule. We can speak of a “band” of levels.
- Every band has N levels. We can put 2N electrons into it (but we have only N electrons from N Na atoms).

The idea of energy bands: Si

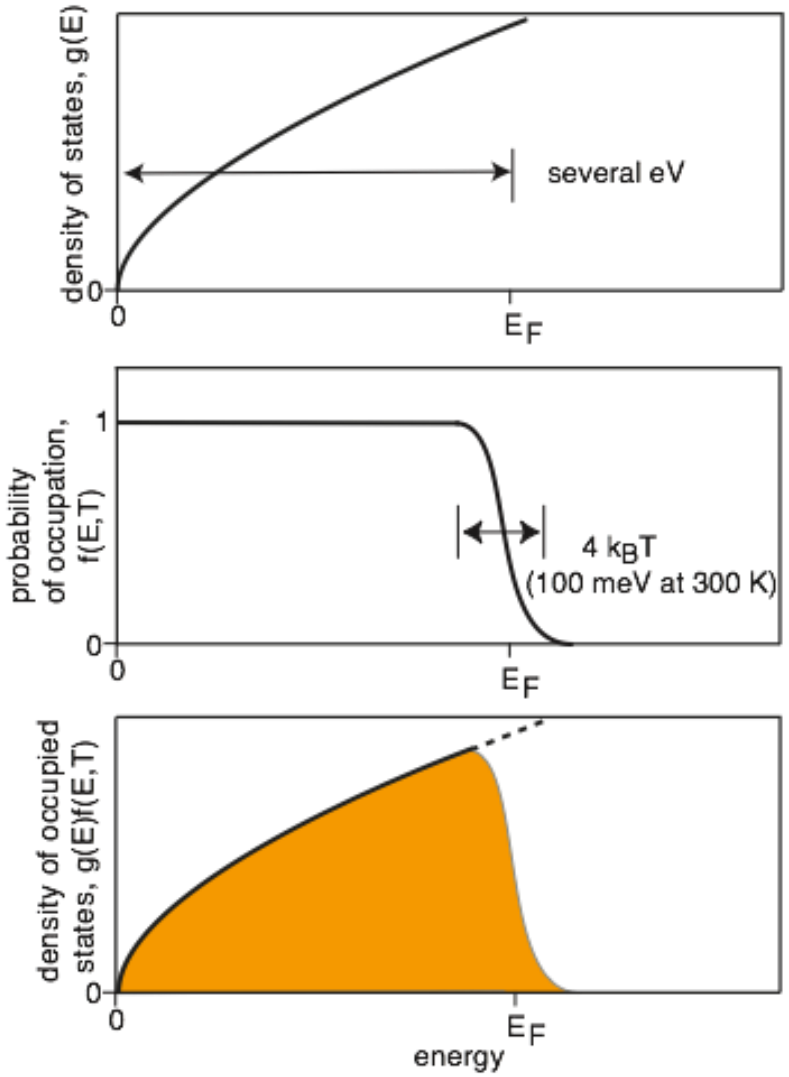


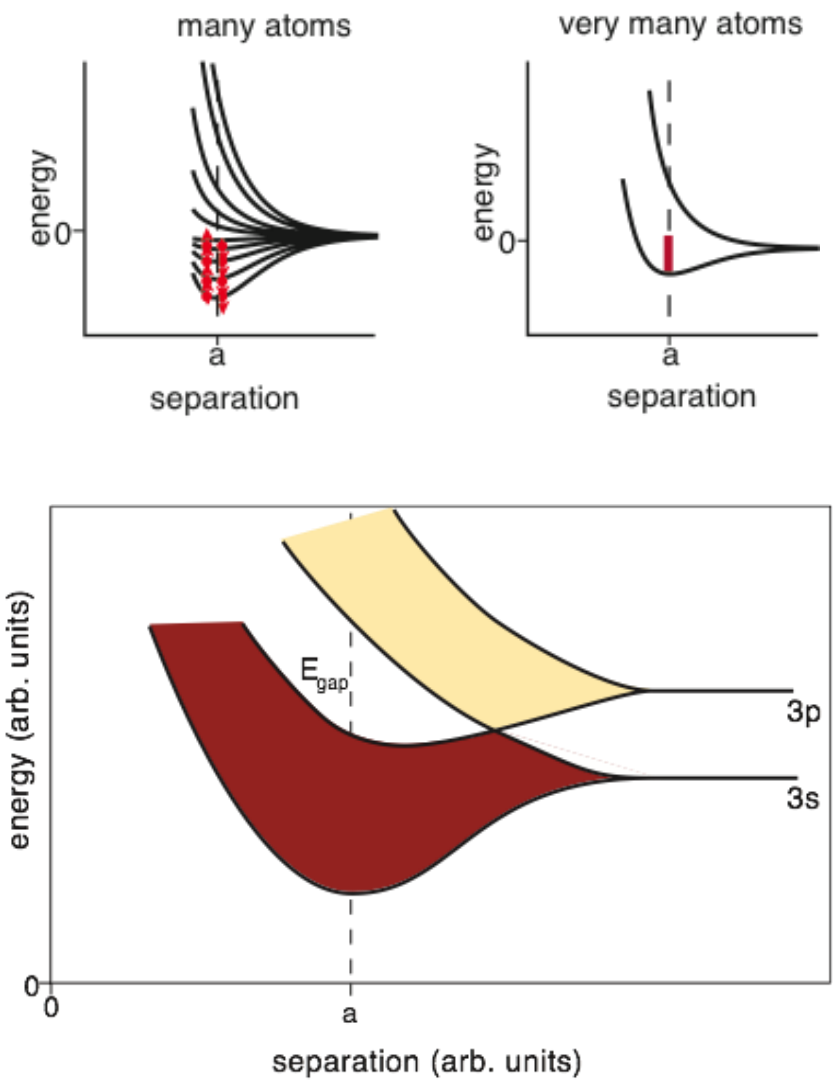
4 electrons per atom
2 atoms per unit cell

8 states per atom
16 states per unit cell

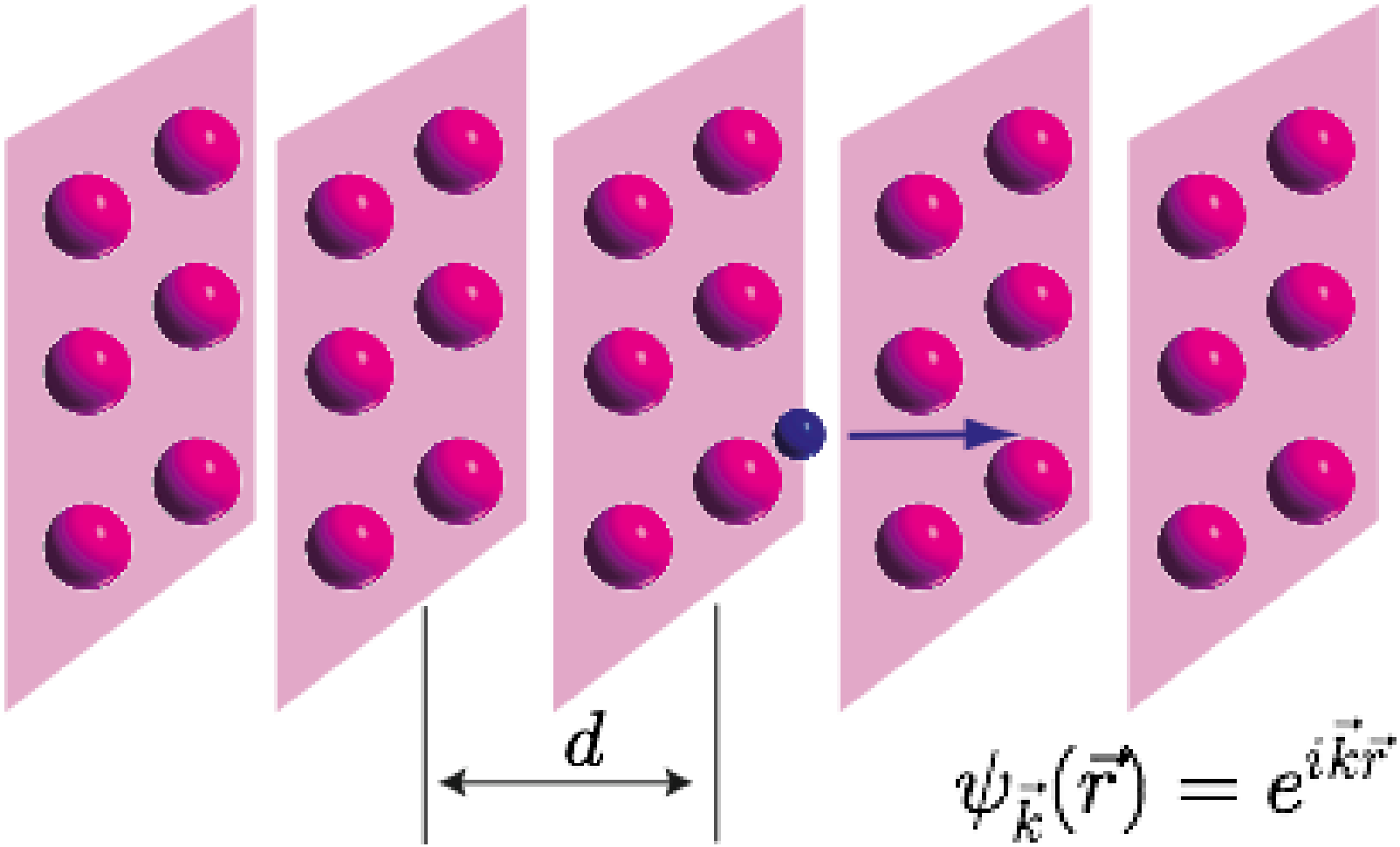
free electron model

naive band picture





Bragg-reflection for nearly free electrons

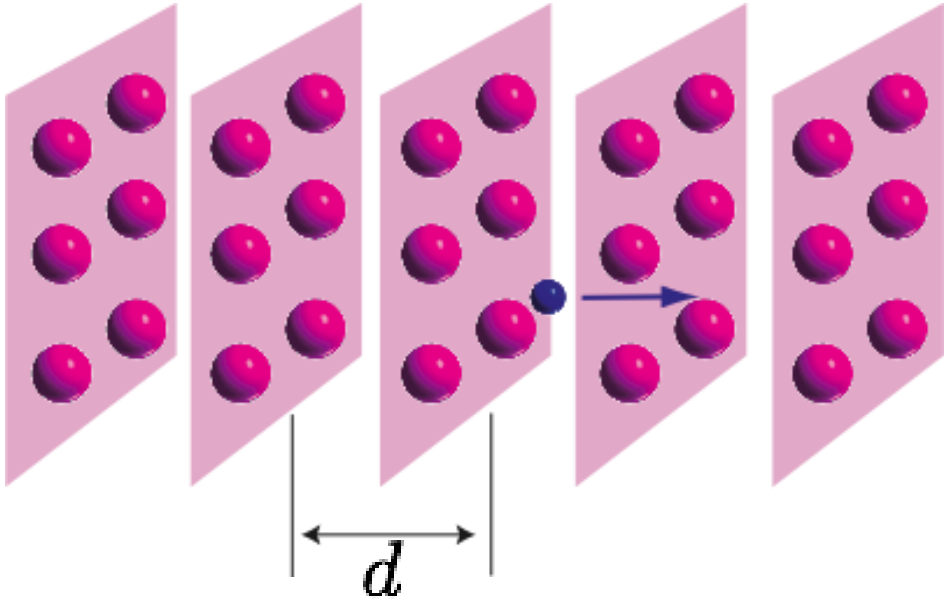


$$\psi_{\vec{k}}(\vec{r}) = e^{i\vec{k}\vec{r}}$$

electron traveling perpendicular to crystal planes

Bragg-reflection for nearly free electrons

consider only one direction (x)



free electron wave function

$$\psi(r) = e^{ikr}$$

with a de Broglie wavelength

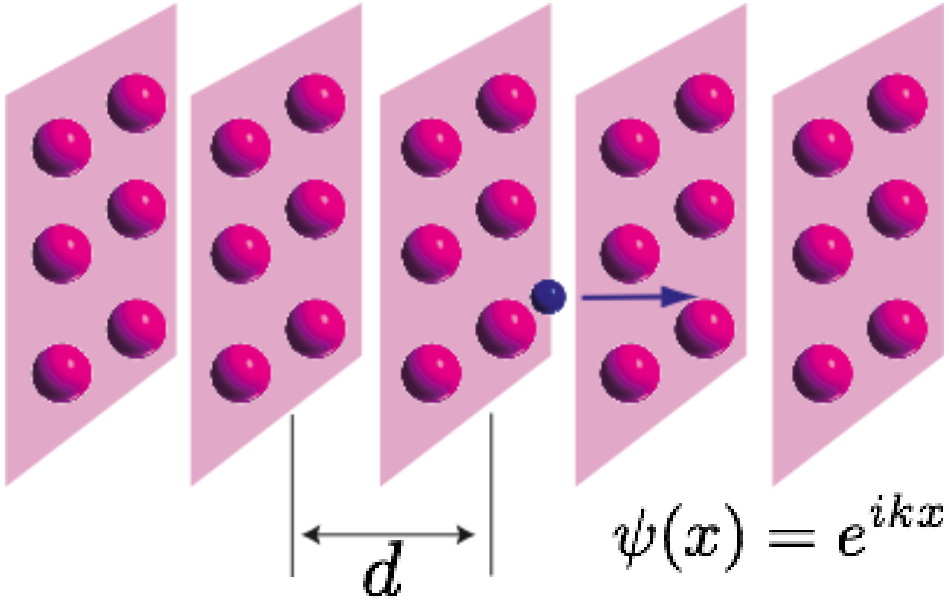
$$k = \frac{2\pi}{\lambda} \qquad \lambda = \frac{2\pi}{k}$$

Bragg condition $n\lambda = 2dsin\theta$ with $\theta = 90°, -90°$

this gives a Bragg condition for electron waves:

$$k = \pm\frac{n\pi}{d}$$

Bragg-reflection for nearly free electrons



Bragg condition for electron waves:

$$k = \pm \frac{n\pi}{d}$$

Bragg reflection results in standing, not traveling electron waves

two possible linear combinations of $\exp(\pm i\frac{\pi}{d}x)$

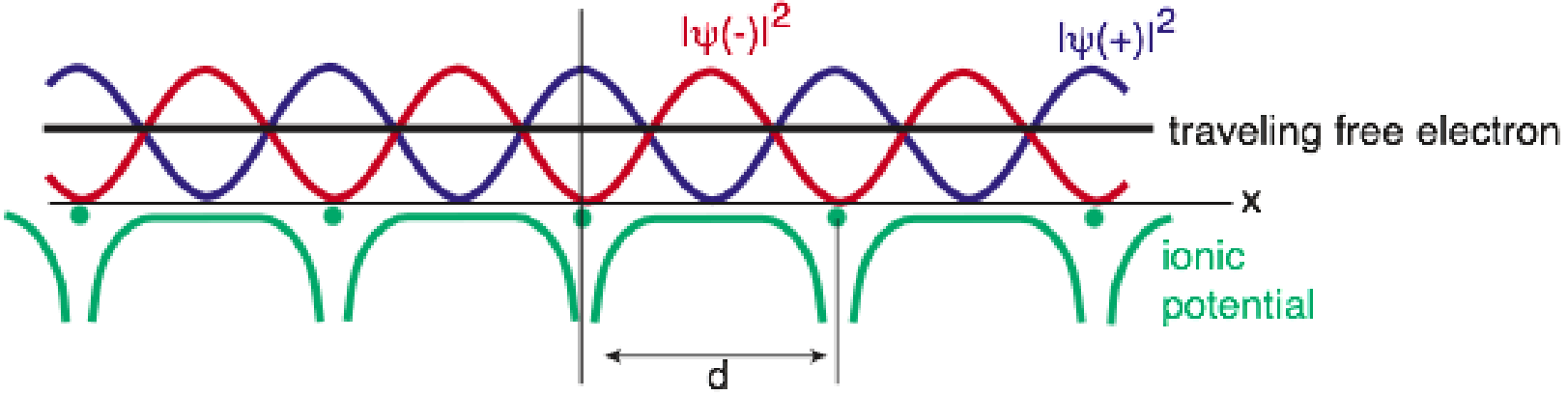
$$\Psi(+) = \exp(i\frac{\pi}{d}x) + \exp(-i\frac{\pi}{d}x) = 2\cos(\frac{\pi}{d}x)$$

$$\Psi(-) = \exp(i\frac{\pi}{d}x) - \exp(-i\frac{\pi}{d}x) = 2i\sin(\frac{\pi}{d}x)$$

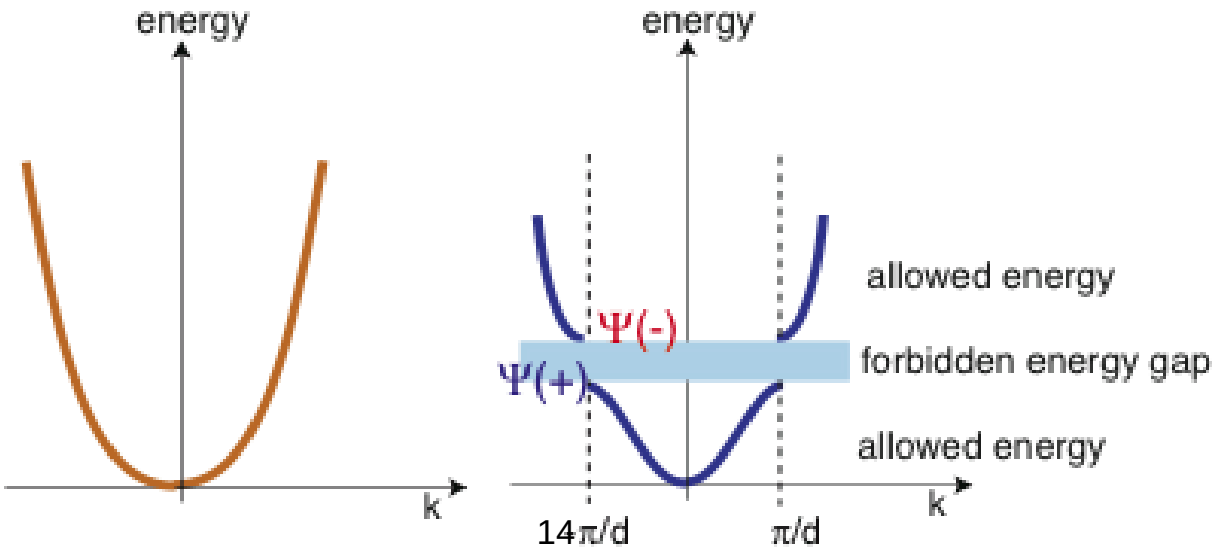
Gap opening for nearly free electrons

$$\Psi(-) = 2i\sin(\frac{\pi}{d}x) \qquad |\Psi(-)|^2 = 4\sin^2(\frac{\pi}{d}x)$$

$$\Psi(+) = 2\cos(\frac{\pi}{d}x) \qquad |\Psi(+)|^2 = 4\cos^2(\frac{\pi}{d}x)$$



$$E = \frac{\hbar^2 k^2}{2m_e}$$



General form of Bloch theory

Schrödinger equation for a periodic potential

$$U(\mathbf{r}) = U(\mathbf{r}+\mathbf{R})$$

$$-\frac{\hbar^2\nabla^2}{2m_e}\psi(\mathbf{r}) + U(\mathbf{r})\psi(\mathbf{r}) = E\psi(\mathbf{r})$$

solutions have the form of **Bloch waves**

$$\psi_{\mathbf{k}}(\mathbf{r}) = e^{i\mathbf{k}\mathbf{r}}u_{\mathbf{k}}(\mathbf{r})$$

plane wave

lattice-periodic function

$$u_{\mathbf{k}}(\mathbf{r}) = u_{\mathbf{k}}(\mathbf{r}+\mathbf{R})$$