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Lecture SCT2 - Process Integration

2. Web-based virtual Lecture: April 22 2021

Prof. Dr. Johann W. Bartha

Inst. f. Halbleiter und Mikrosystemtechnik
Technische Universität Dresden

Summer Semester 2021

Start lecture here

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„Semiconductor Technology 2"

at TU-Dresden.

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Outline

Lecture Semiconductor Technology I,
Prof. Dr. J. W. Bartha

Content

Outline

Lect

http://www.computerhistory.org/siliconengine/timeline/

TECHNISCHE UNIVERSITÄT DRESDEN

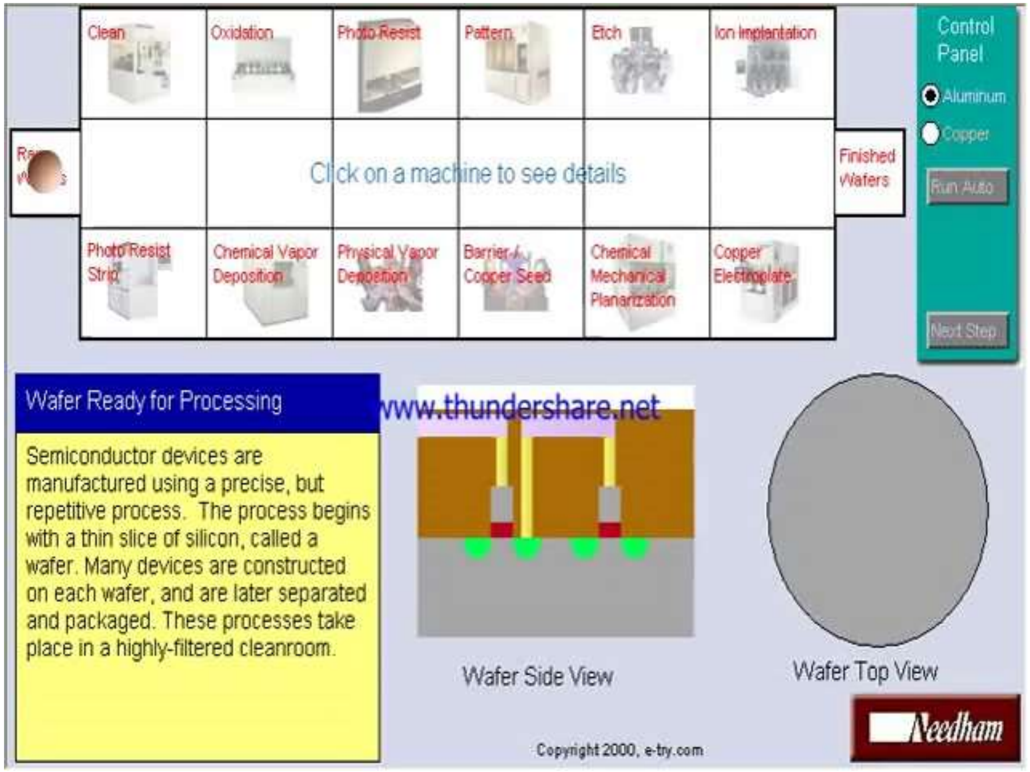
Outline

SC-Basics

0. Introduction/Lab organization/DMA/SCT1/Motivation
1. Process integration
   1. MOS Structure, MOS Capacitor
   2. Structure of a MOSFET
   3. I/V behaviour
2. Circuits in Metal-Gate FET Technology
   1. Process sequence of N-MOSFET in Metal Gate
   2. From inverter to memory cell
   3. SRAM in NMOS Metal Gate
   4. The threshold voltage of the MOSFET
      1. Parasitic FET
      2. Enhancement/Depletion Transistor
      3. N-MOS Logic by E/D Transitors
      4. Process sequence of the N-MOS E/D Process
3. Self aligned Process
   1. Metal Gate -> Si Gate
   2. Channel-Stop & LOCOS Technology
      1. Example: Process flow of E/D SiGate LOCOS Inverter
      2. LOCOS Variation
      3. Shallow Trench Isolation
   3. Lightly doped drain
   4. SALICIDE
   5. Self Aligned Contacts (SAC)
   6. Resist trimming
4. Transition to CMOS Technology
   1. MOS Transistor Types
   2. CMOS Inverter
      1. Consideration NMOS E/D Inverter
      2. Comparison CMOS Inverter
   3. CMOS Process flow (Example CMOS 180 nm process)
5. Further Considerations
   1. Scaling
      1. Challenges
      2. Material Equivalent Scaling
      3. Further Concepts

Lect

http://www.computerhistory.org/siliconengine/timeline/



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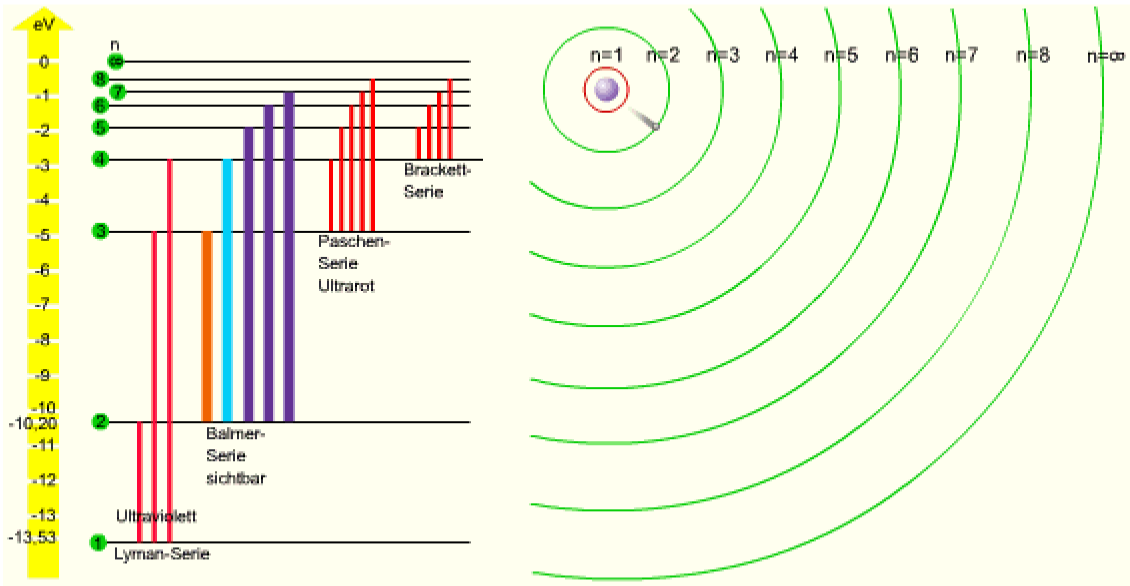
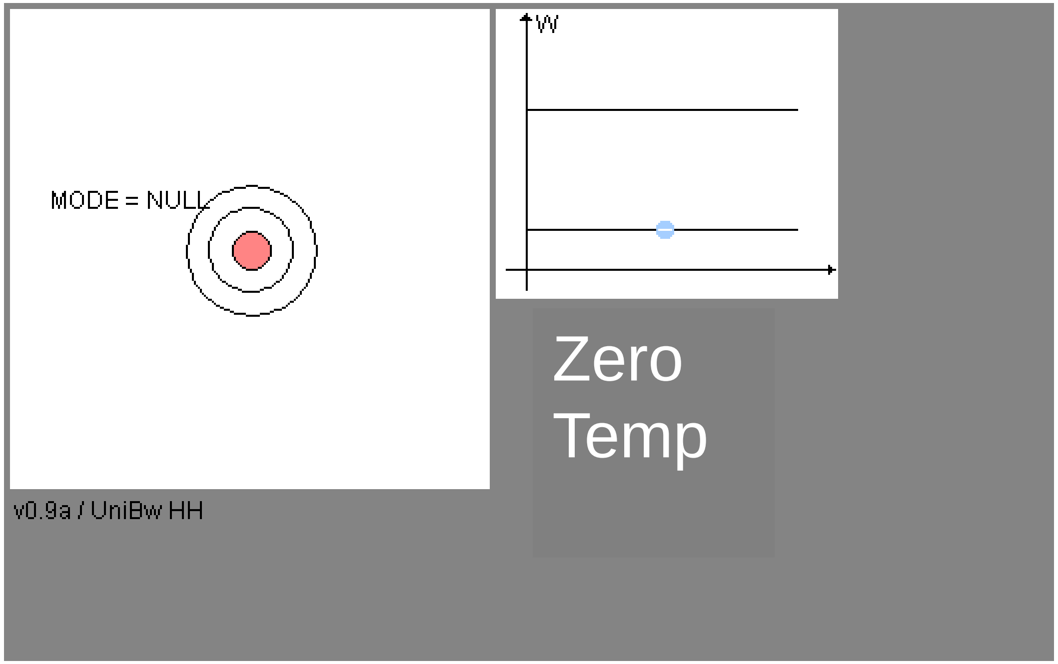
Energy states of electrons in atoms





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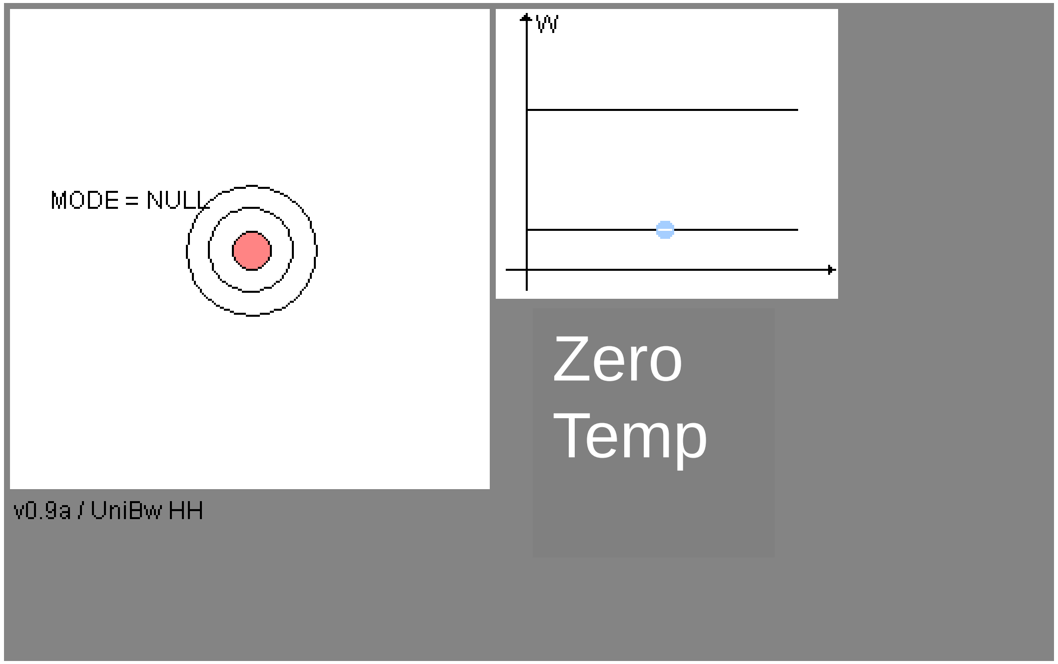

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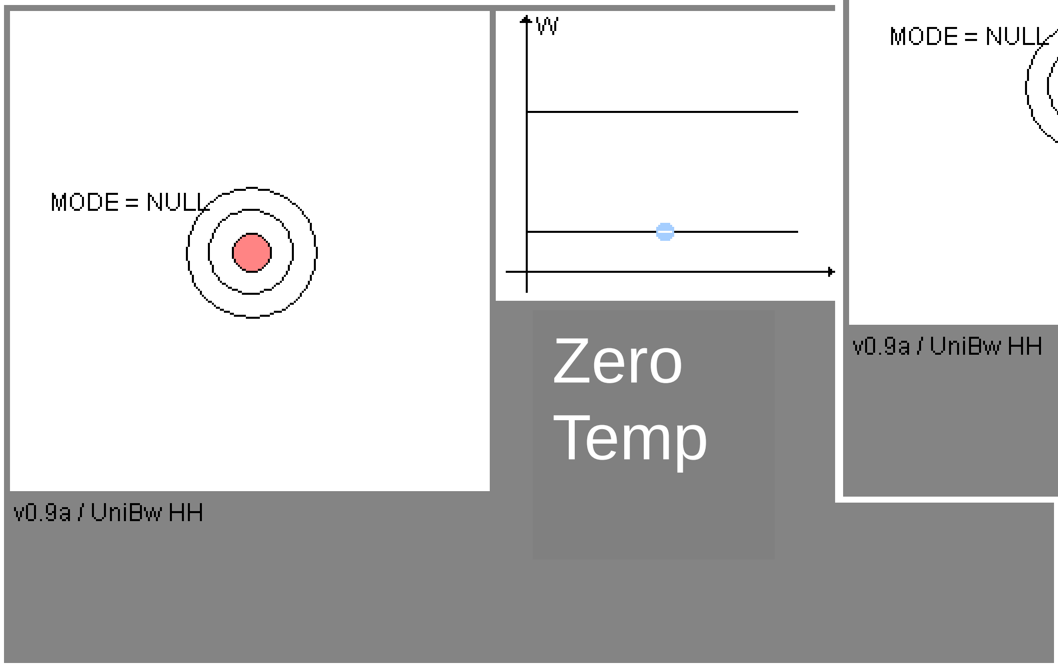
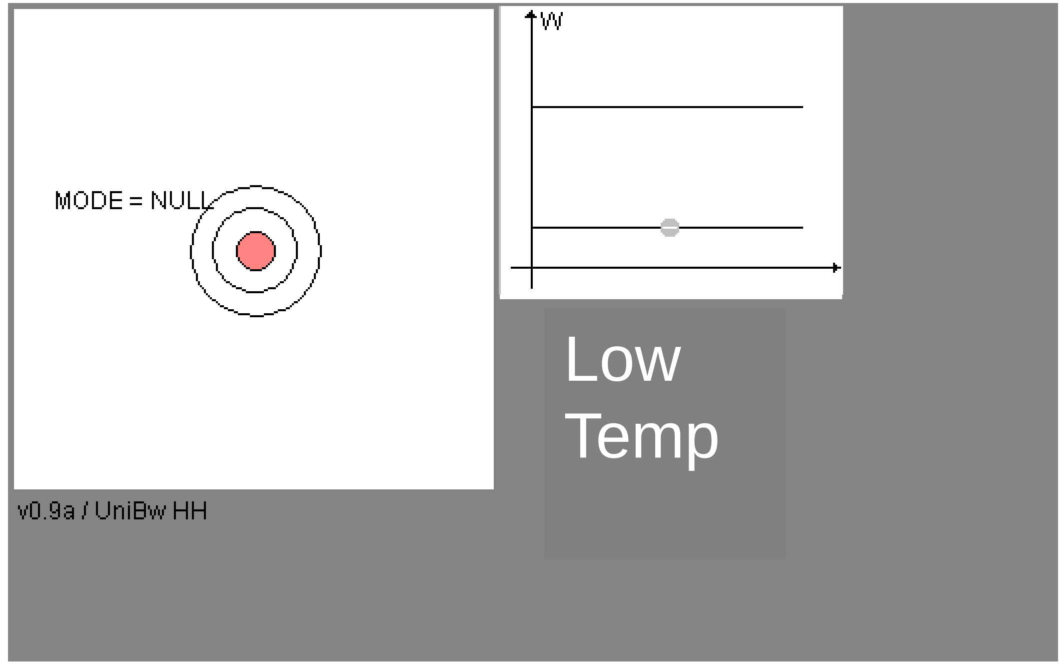
Temporary occupation of states depends on temperature
3/2kT(RT)=25meV





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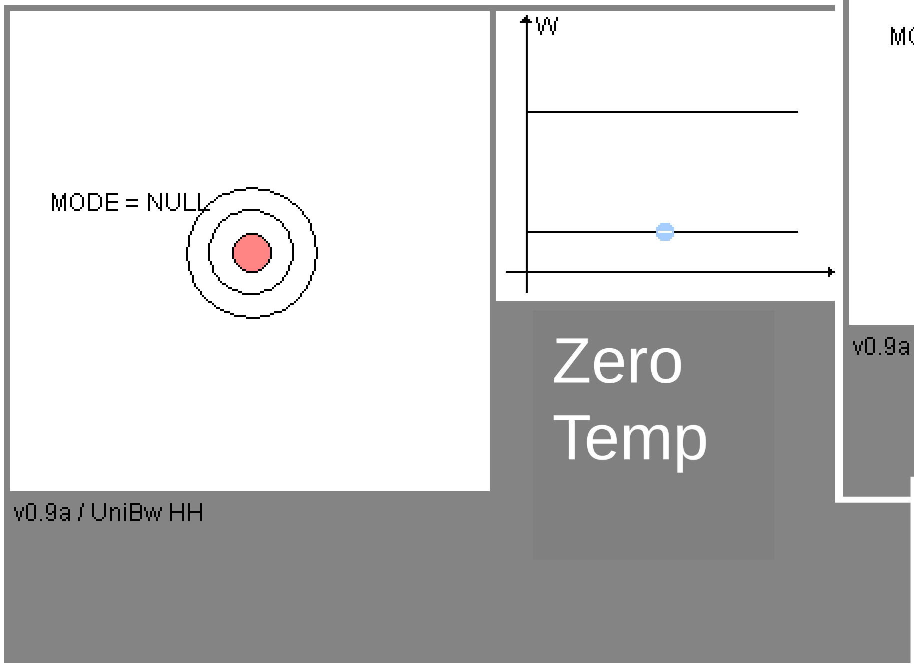

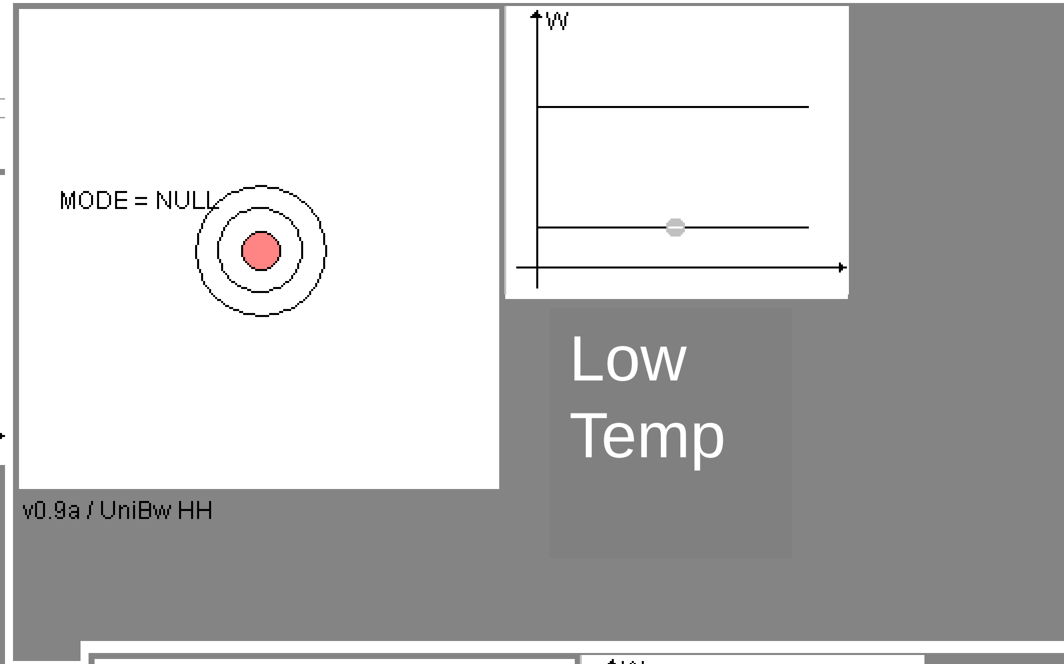

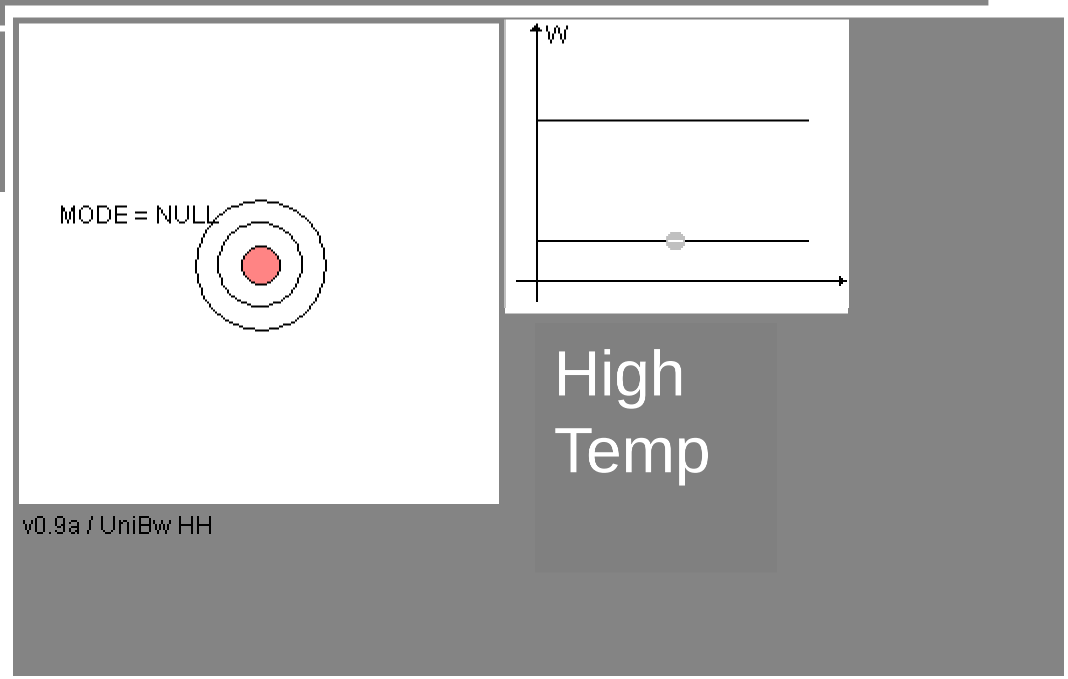

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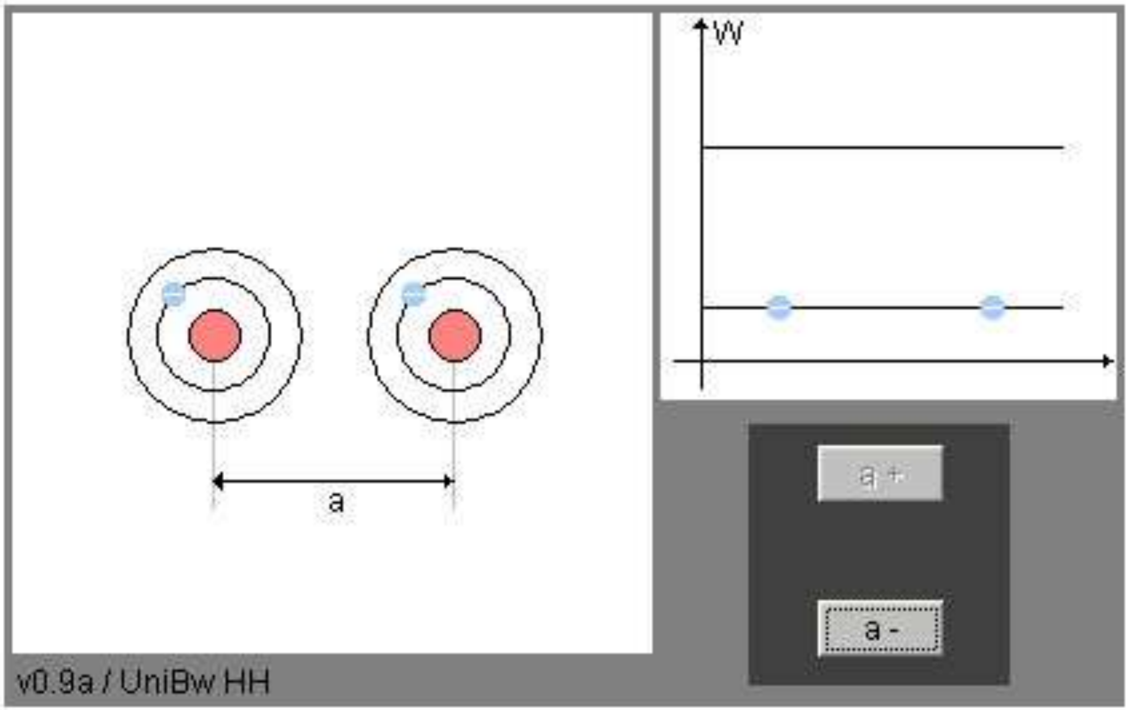
Interaction of atoms causes splitting of energy states



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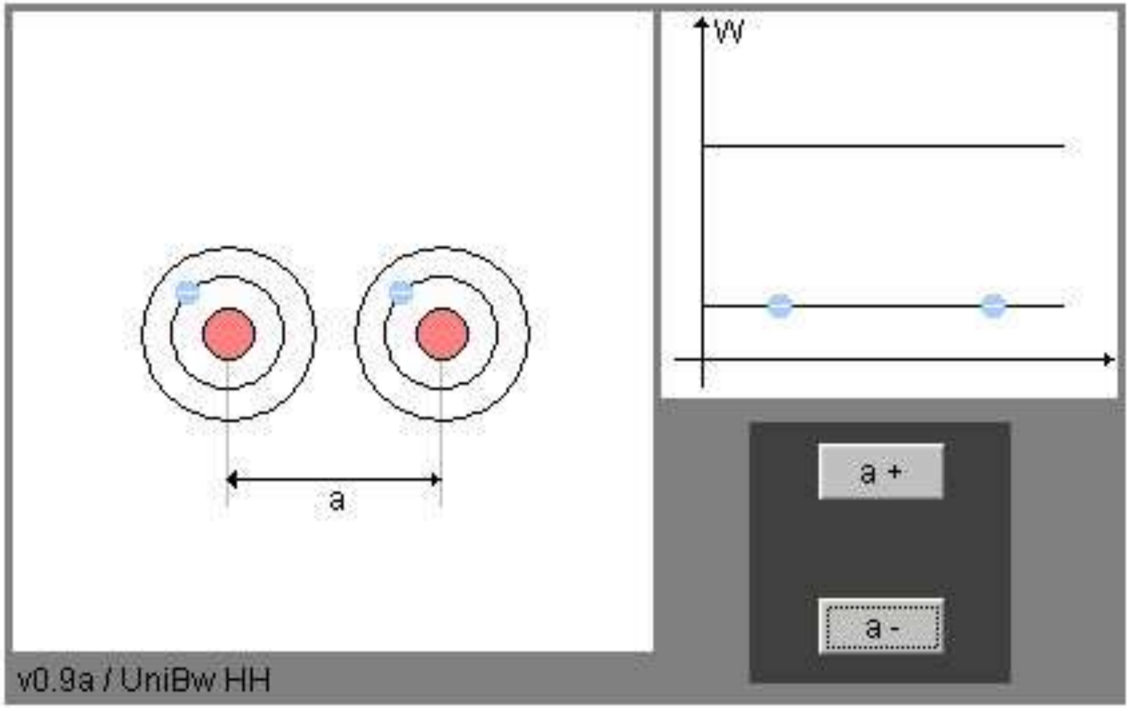

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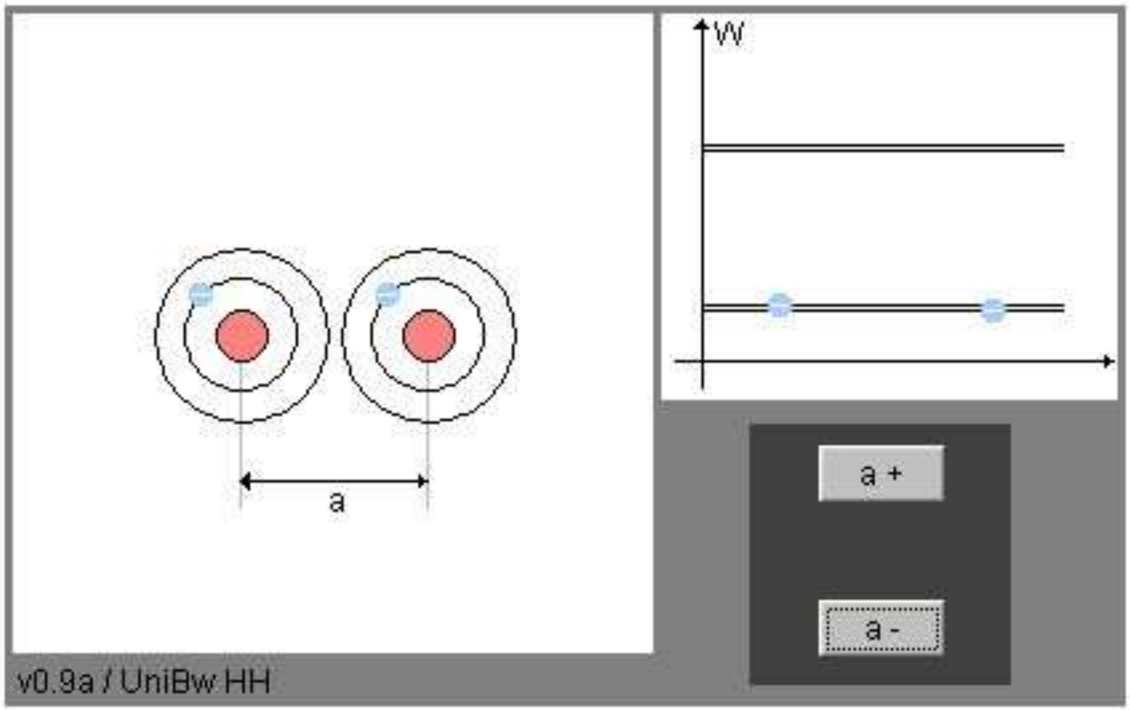

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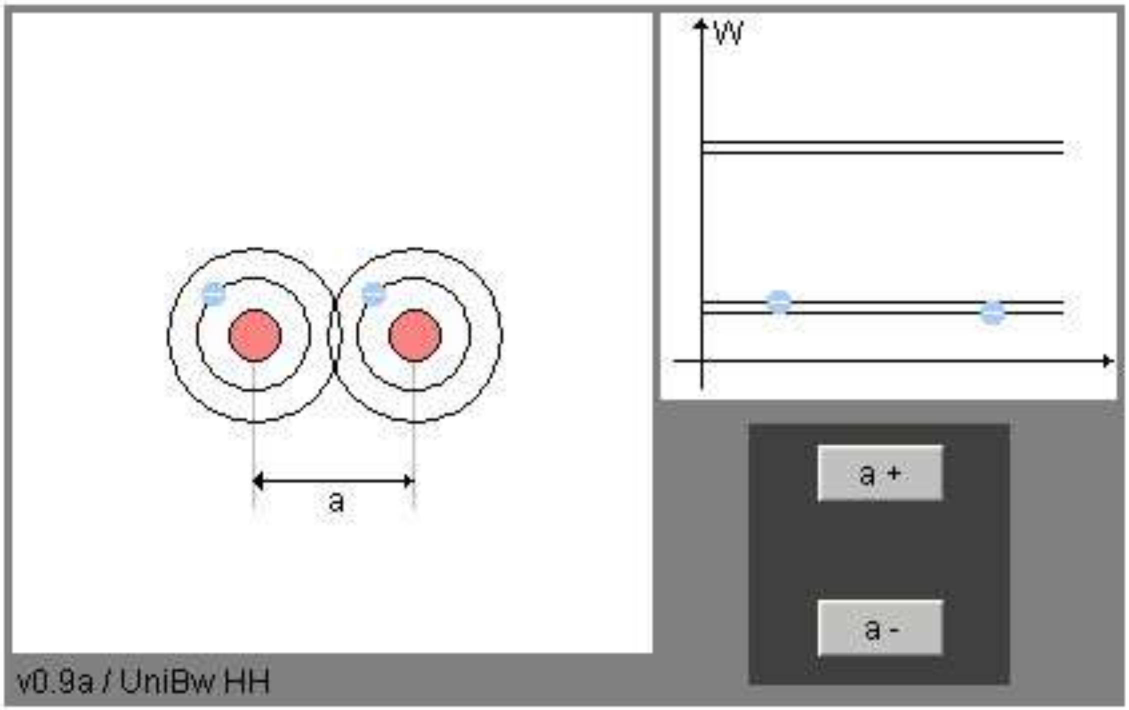

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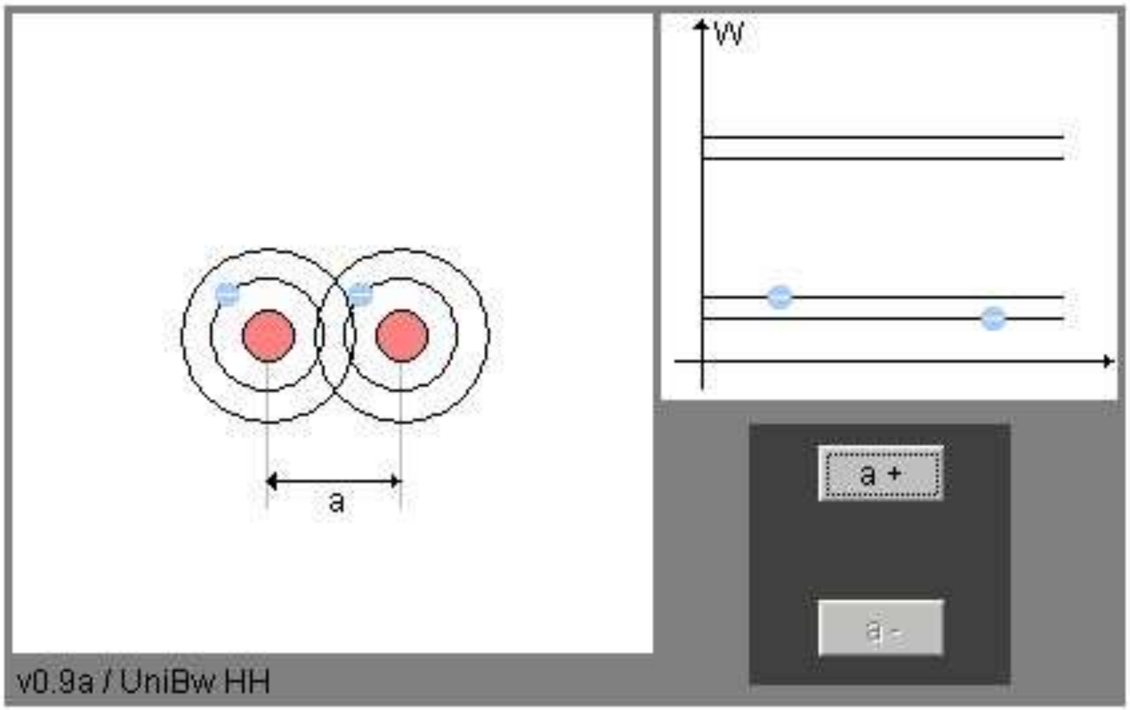

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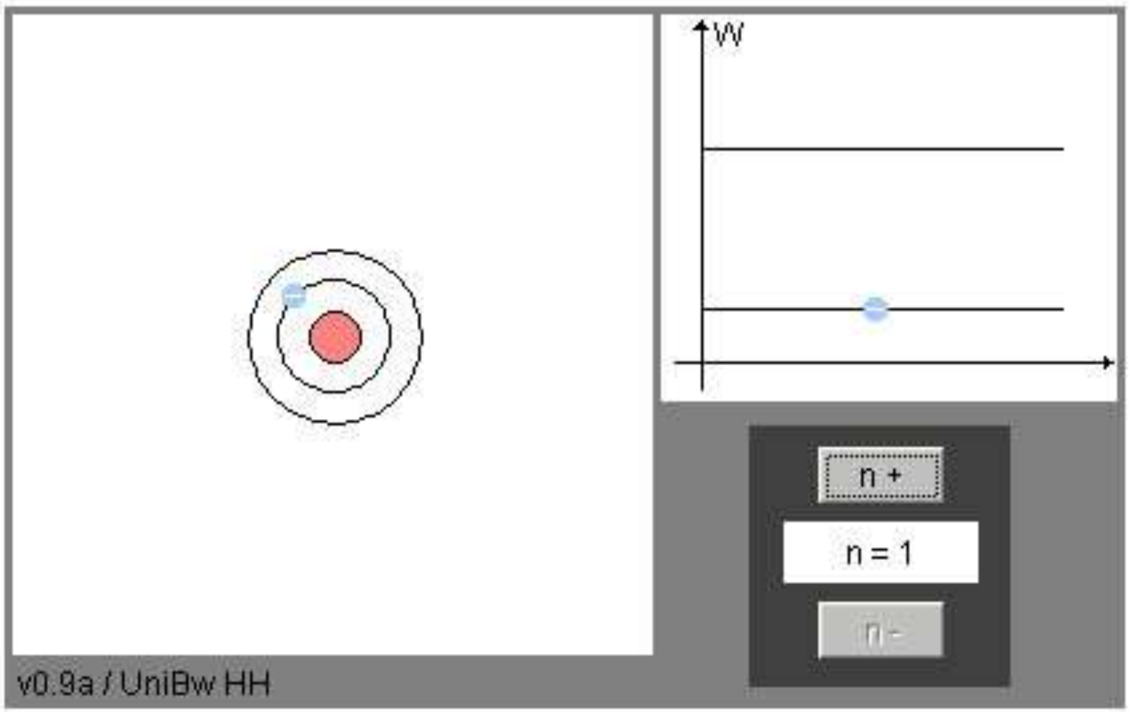
Transition from states in atoms to bands in solids



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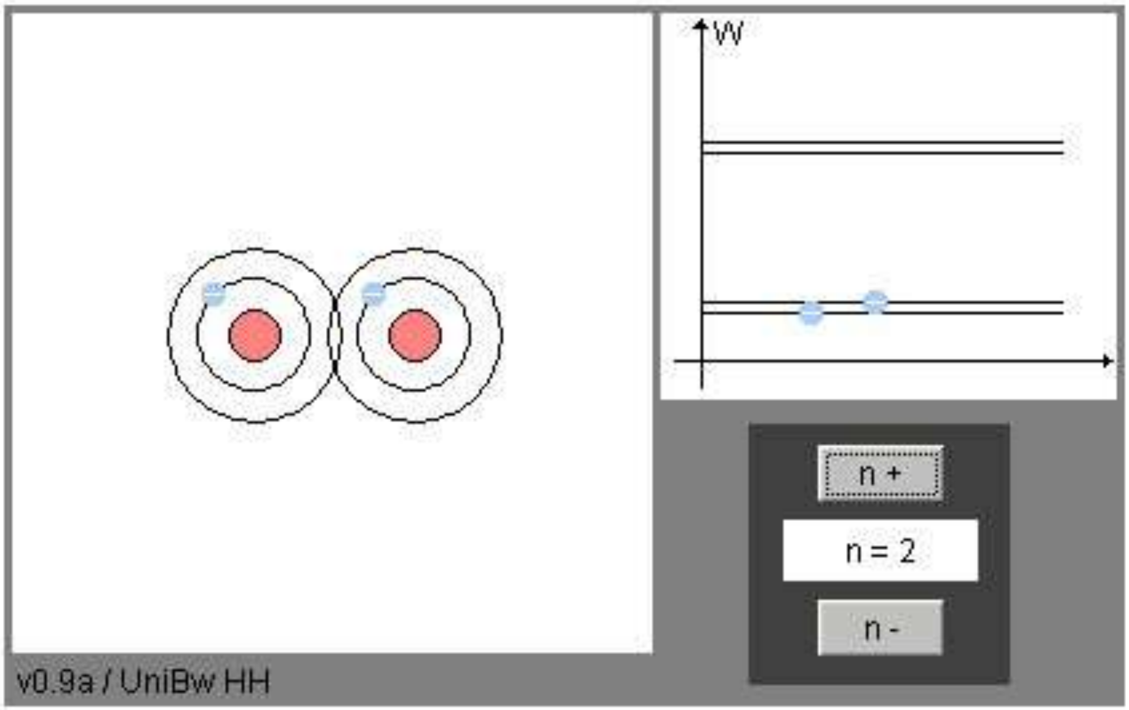

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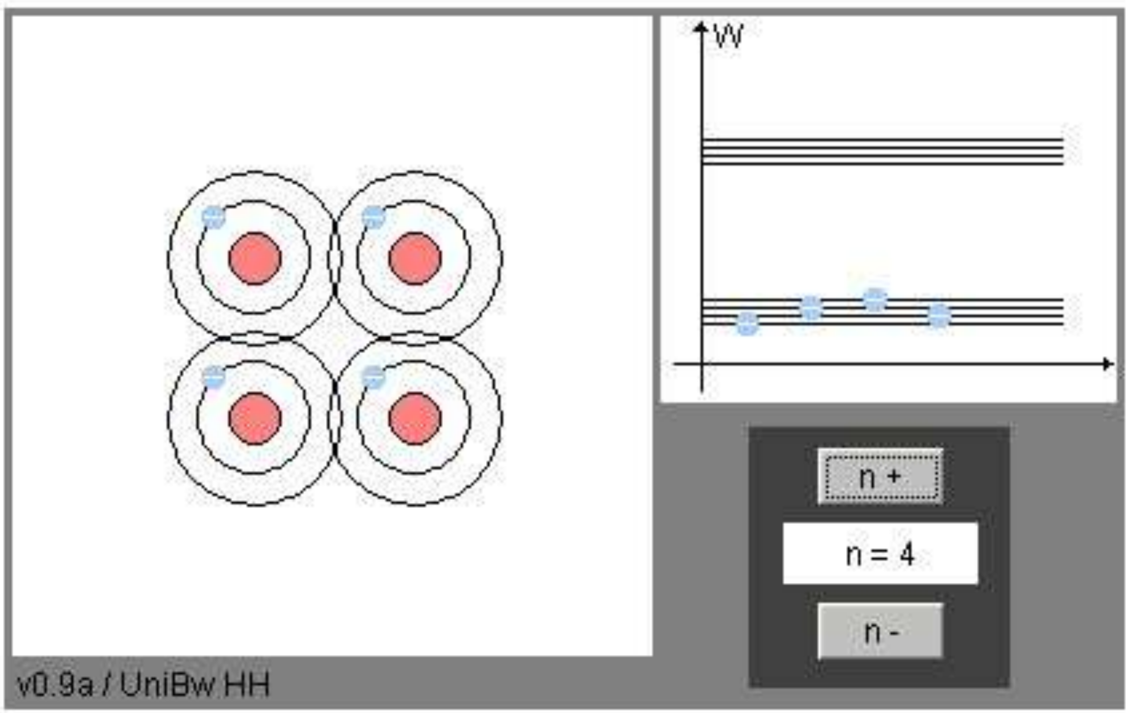

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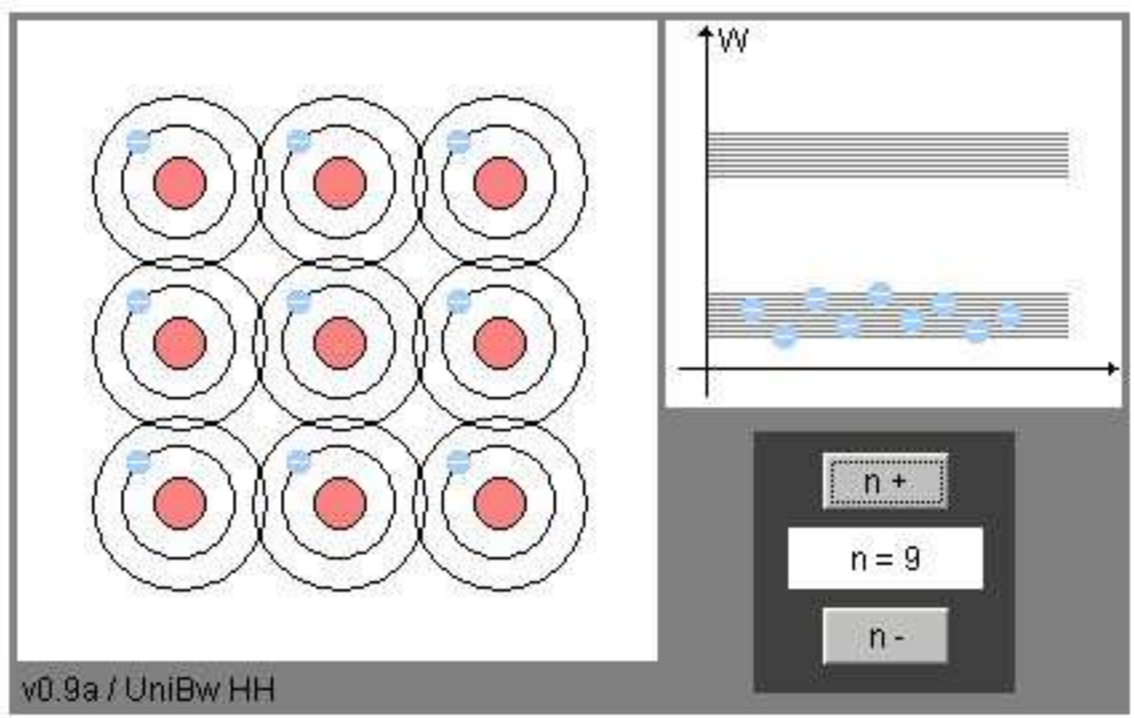

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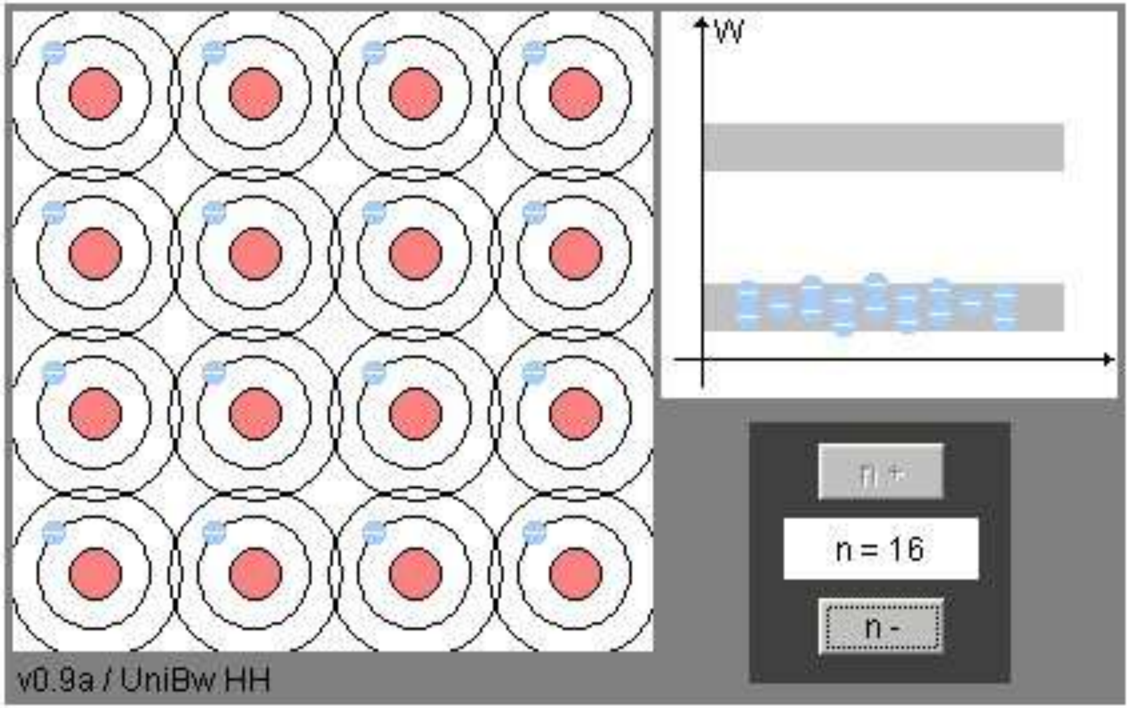

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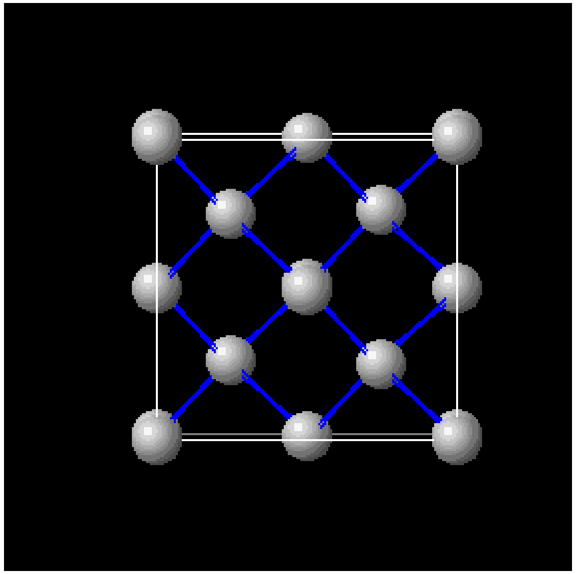
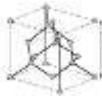
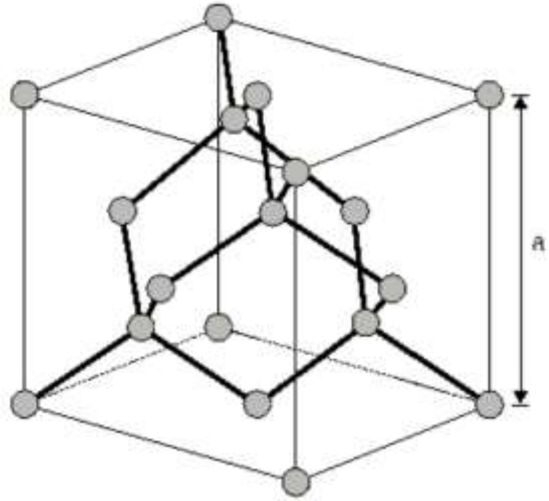
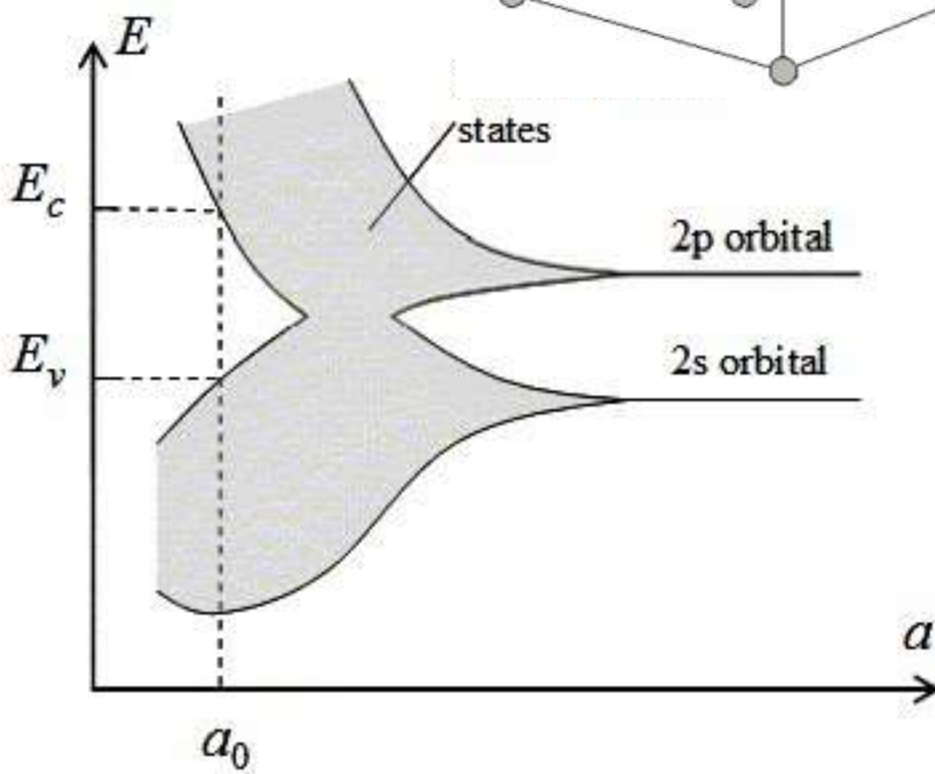
Origin of bands:



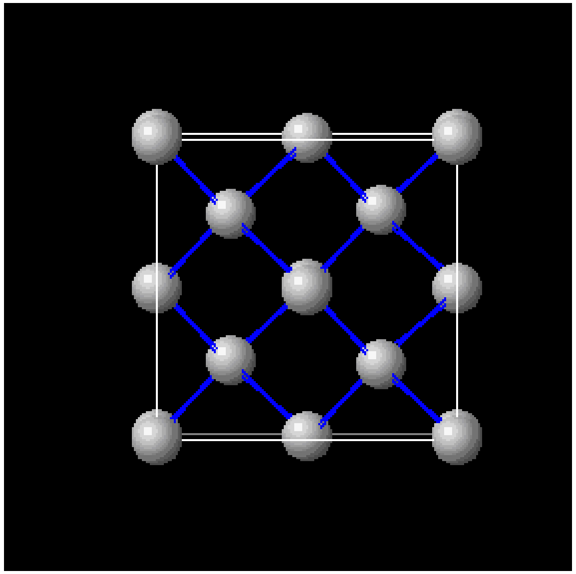


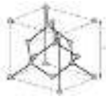


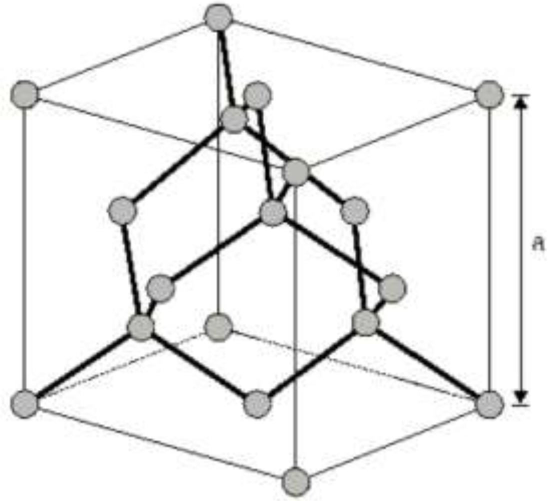


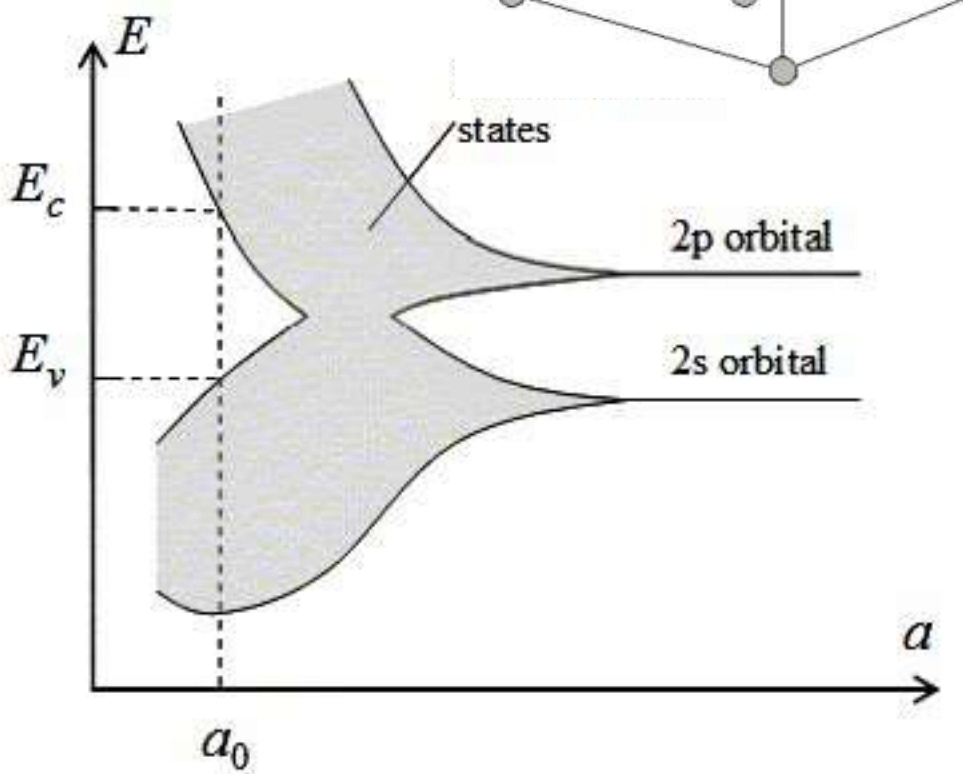
Energy bands for diamond versus lattice constant.

Origin of bands:









Energy bands for diamond versus lattice constant.

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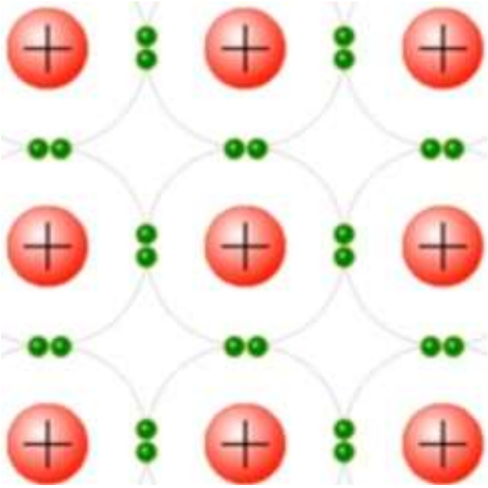
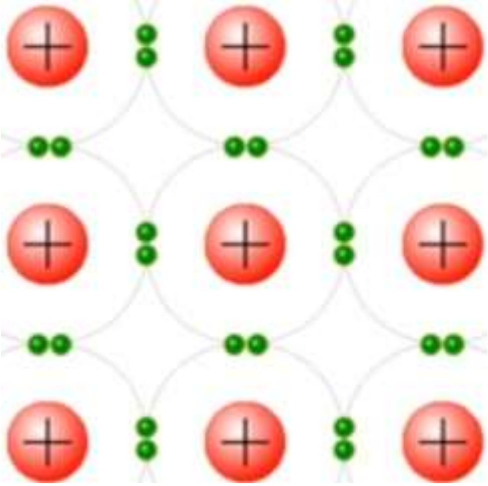
Situation of the valence electrons



T=0K

Considering one material at different temperatures

Situation of the valence electrons



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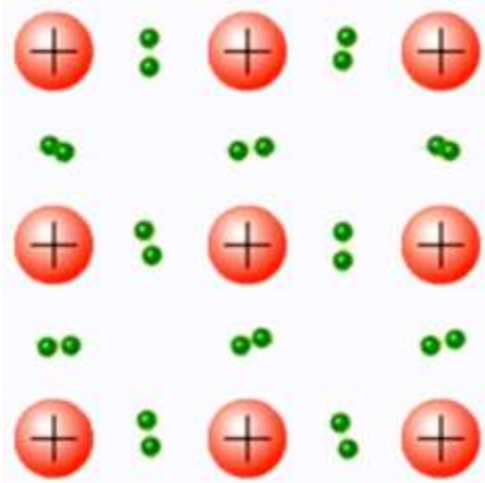
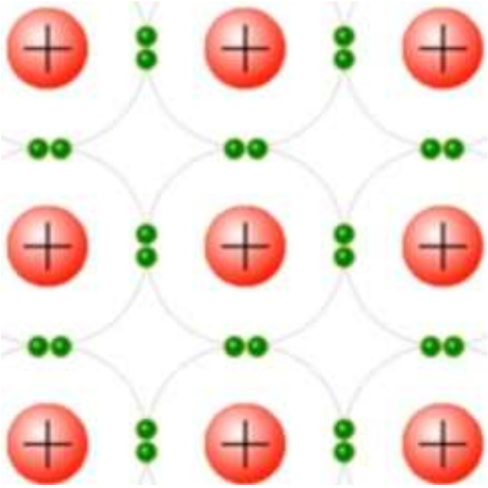


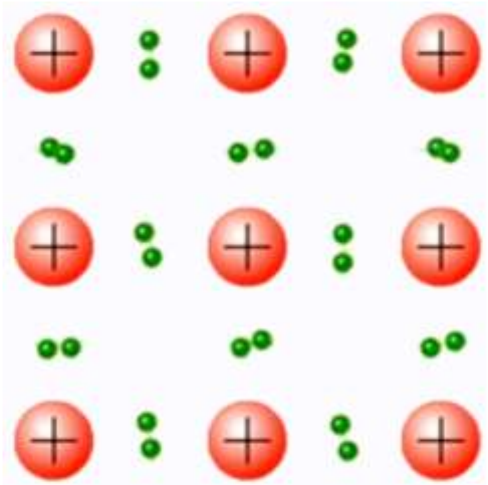
T=low

Considering one material at different temperatures

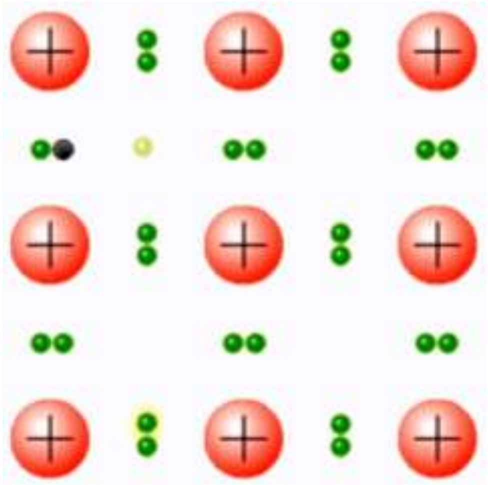
Situation of the valence electrons



T=0K



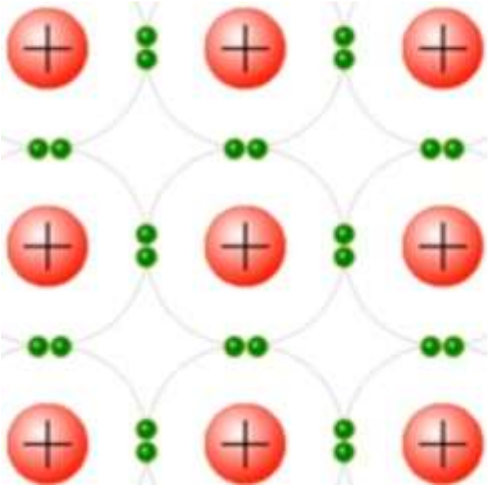
T=low



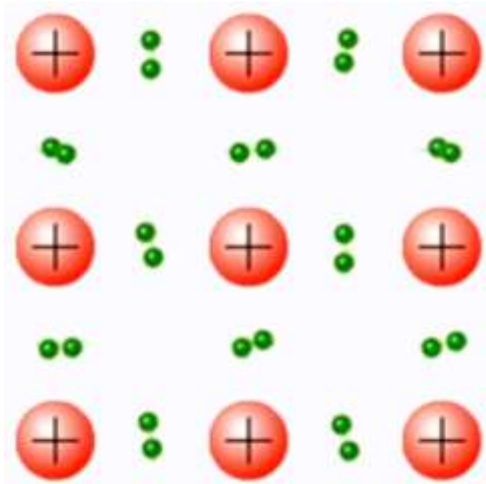
T=higher

Considering one material at different temperatures

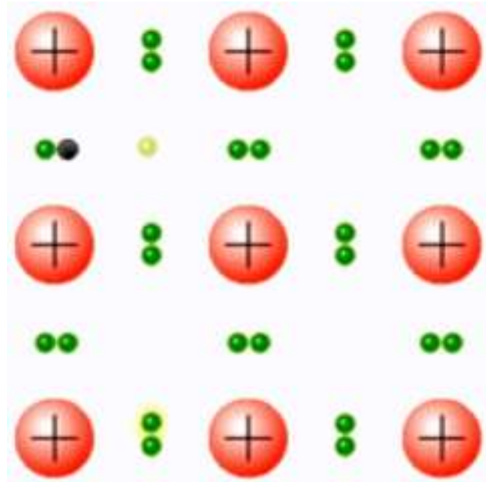
Situation of the valence electrons



T=0K



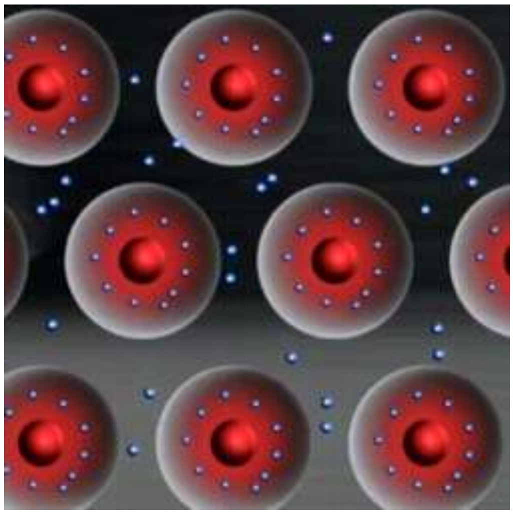
T=low



T=higher

Considering one material at different temperatures

T=very high



Or fixing T at room emperature (~300K) and

considering different kind of materials with different binding energies of the valence electrons

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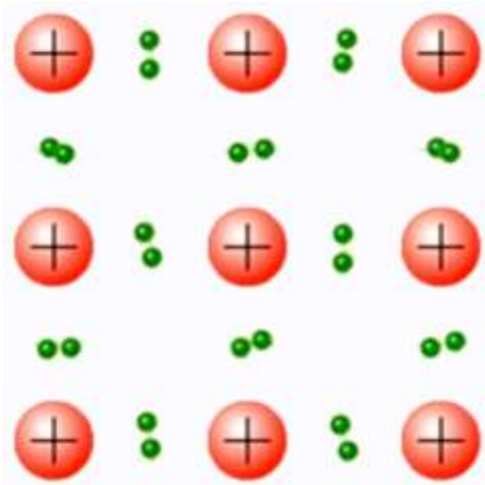

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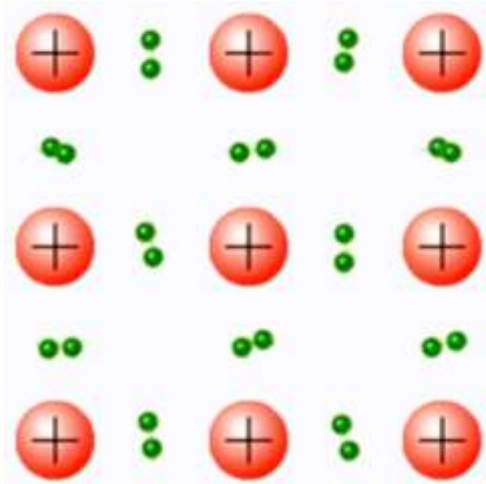

Insulator

Or fixing T at room emperature (~300K) and

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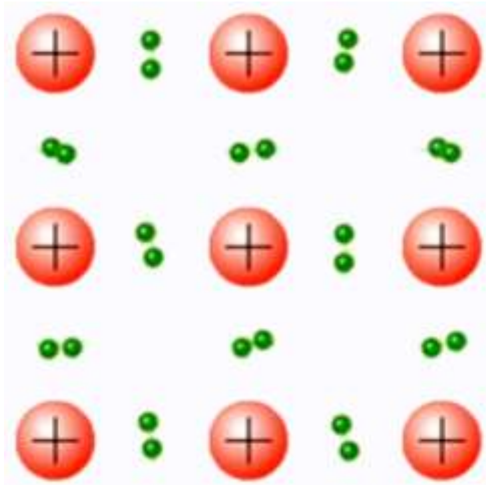

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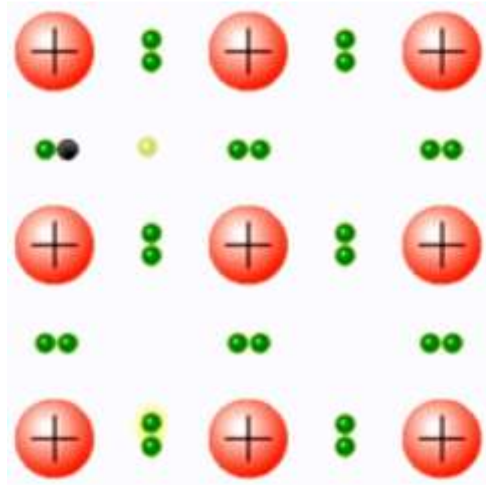

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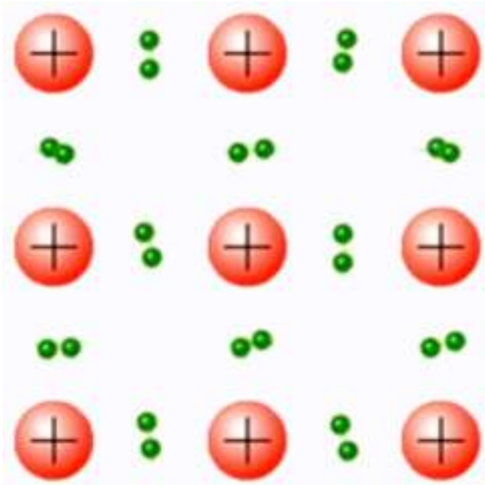

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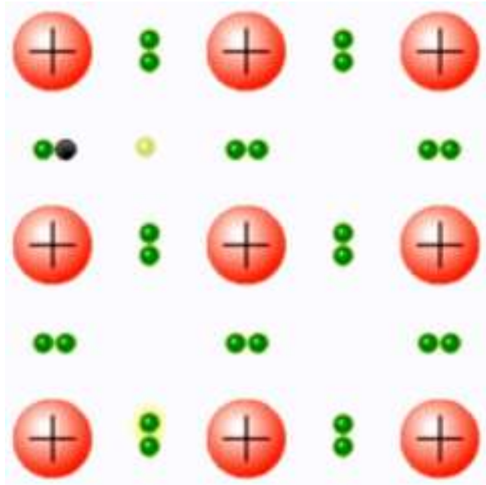

Semiconductor

Intrinsic carrier concentration for Si at RT is ~ $1{\cdot}10^{10}$ 1/cm^3

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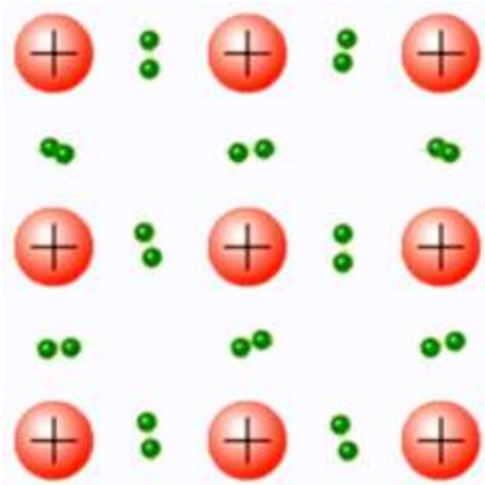

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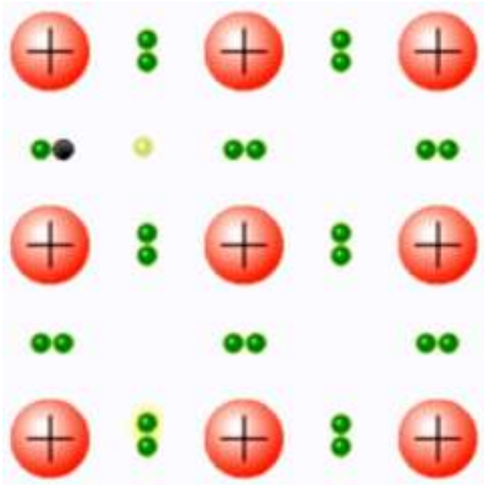

Semiconductor

To compare: The atomic density of Si is $5{\cdot}10^{22}$ $1/cm^3$

Intrinsic carrier concentration for Si at RT is ~ $1{\cdot}10^{10}$ $1/cm^3$

Or fixing T at room emperature (~300K) and

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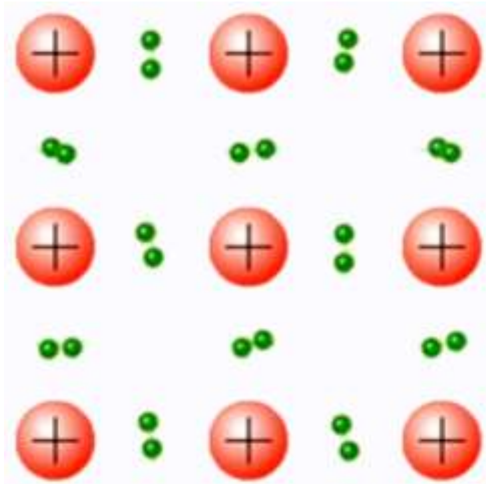

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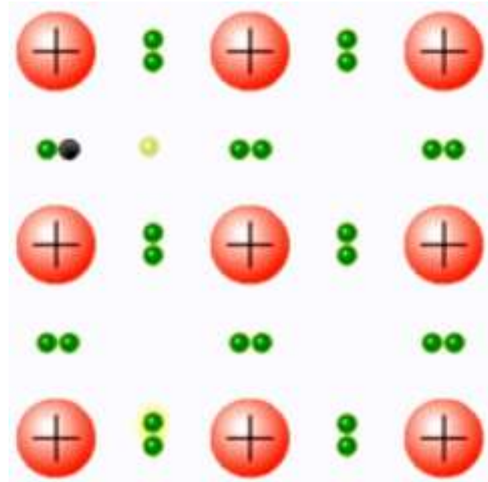

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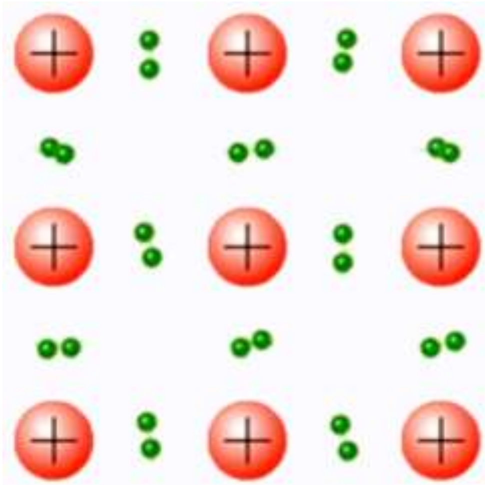

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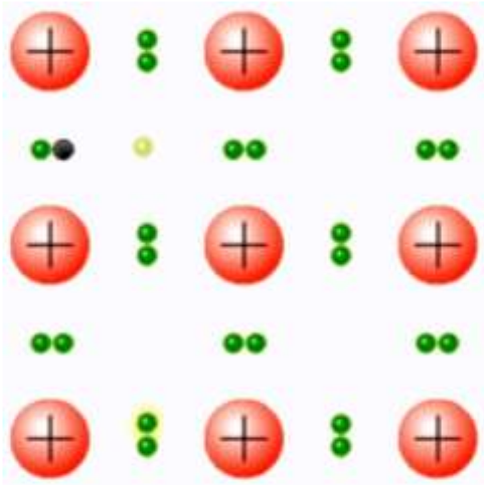
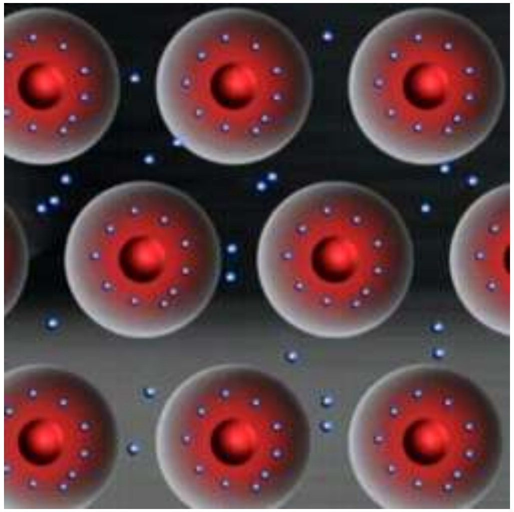
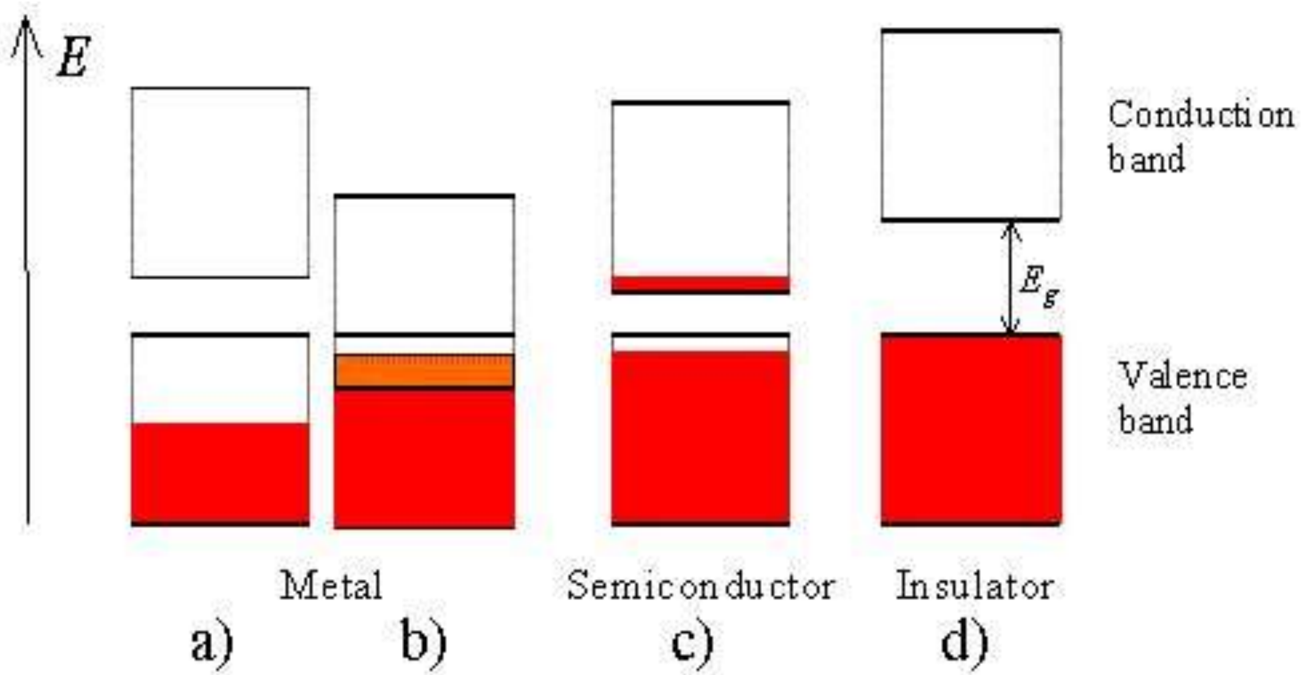


Semiconductor

Metal



Electrical conductivity and bandgap



Possible energy band diagrams of a crystal. Shown are: a) a half filled band, b) two overlapping bands, c) an almost full band separated by a small bandgap from an almost empty band and d) a full band and an empty band separated by a large bandgap.

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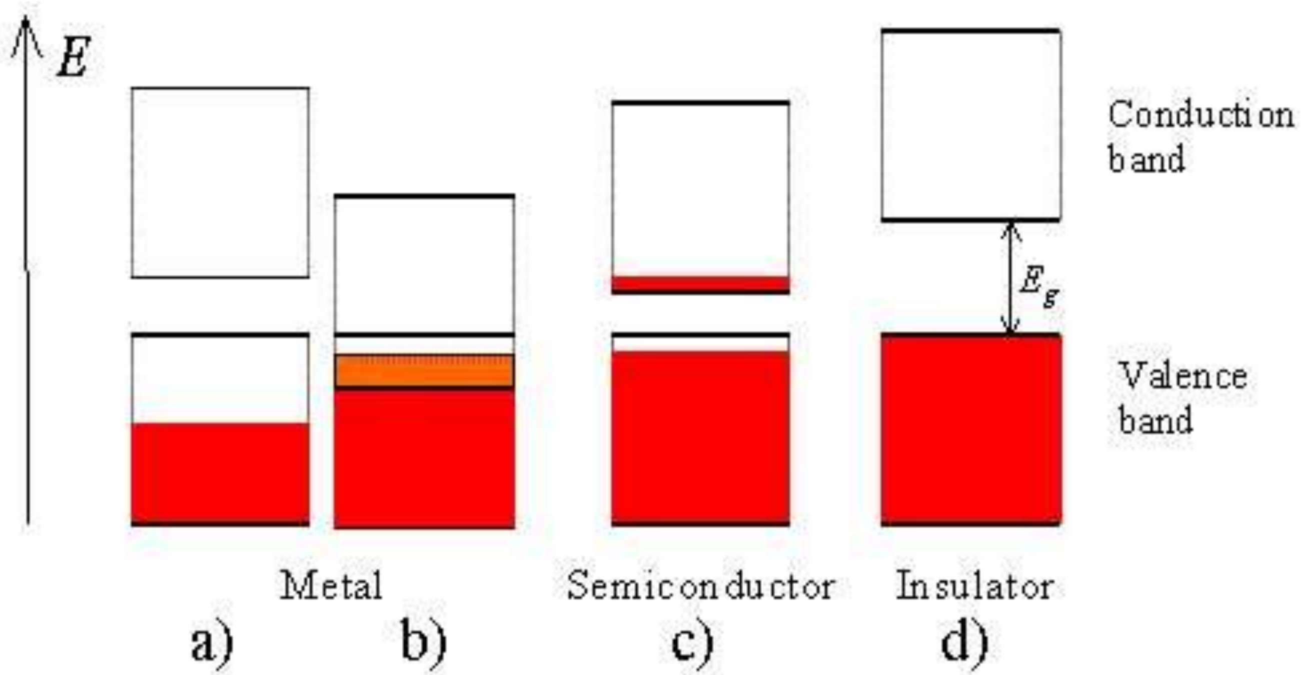

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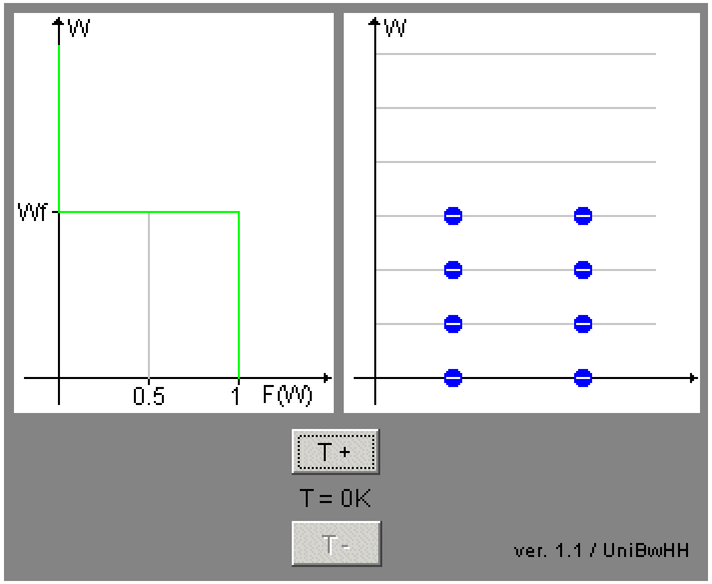
Occupation of states vs. temperature for metal



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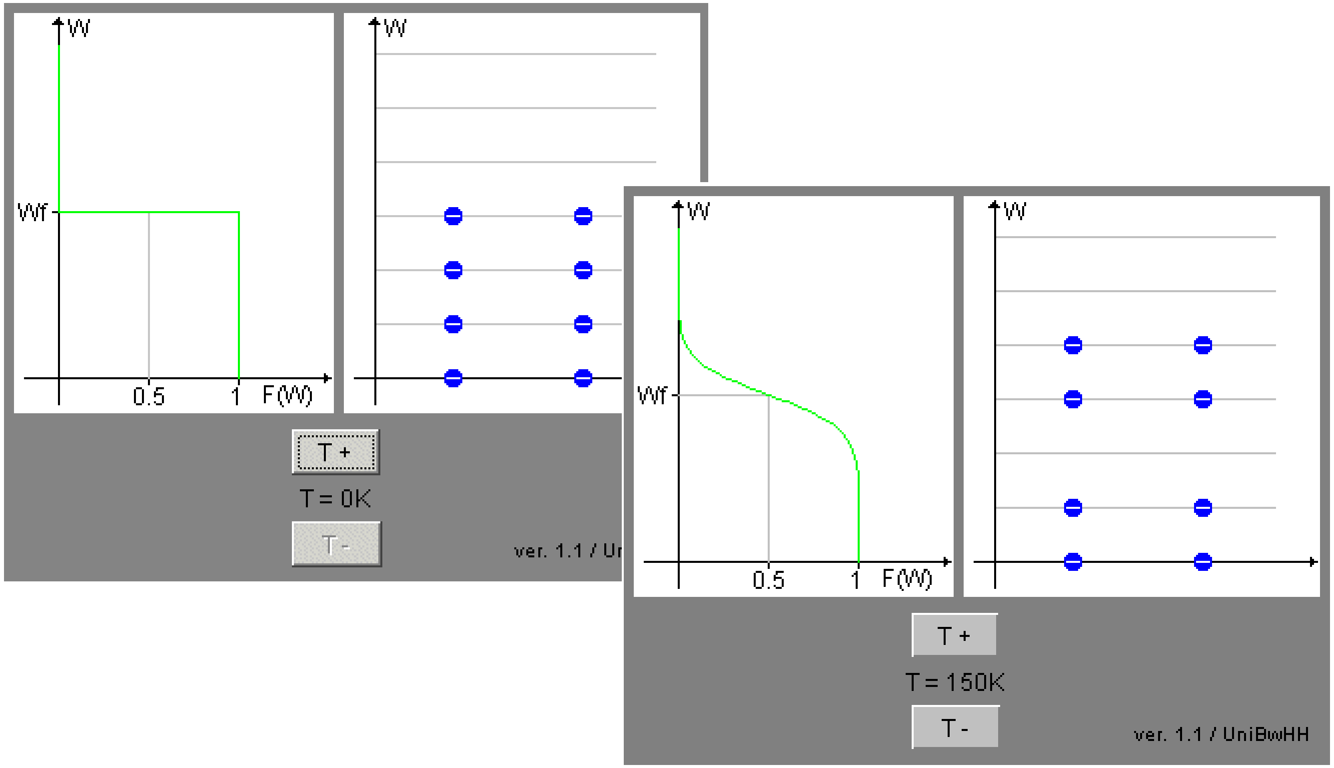

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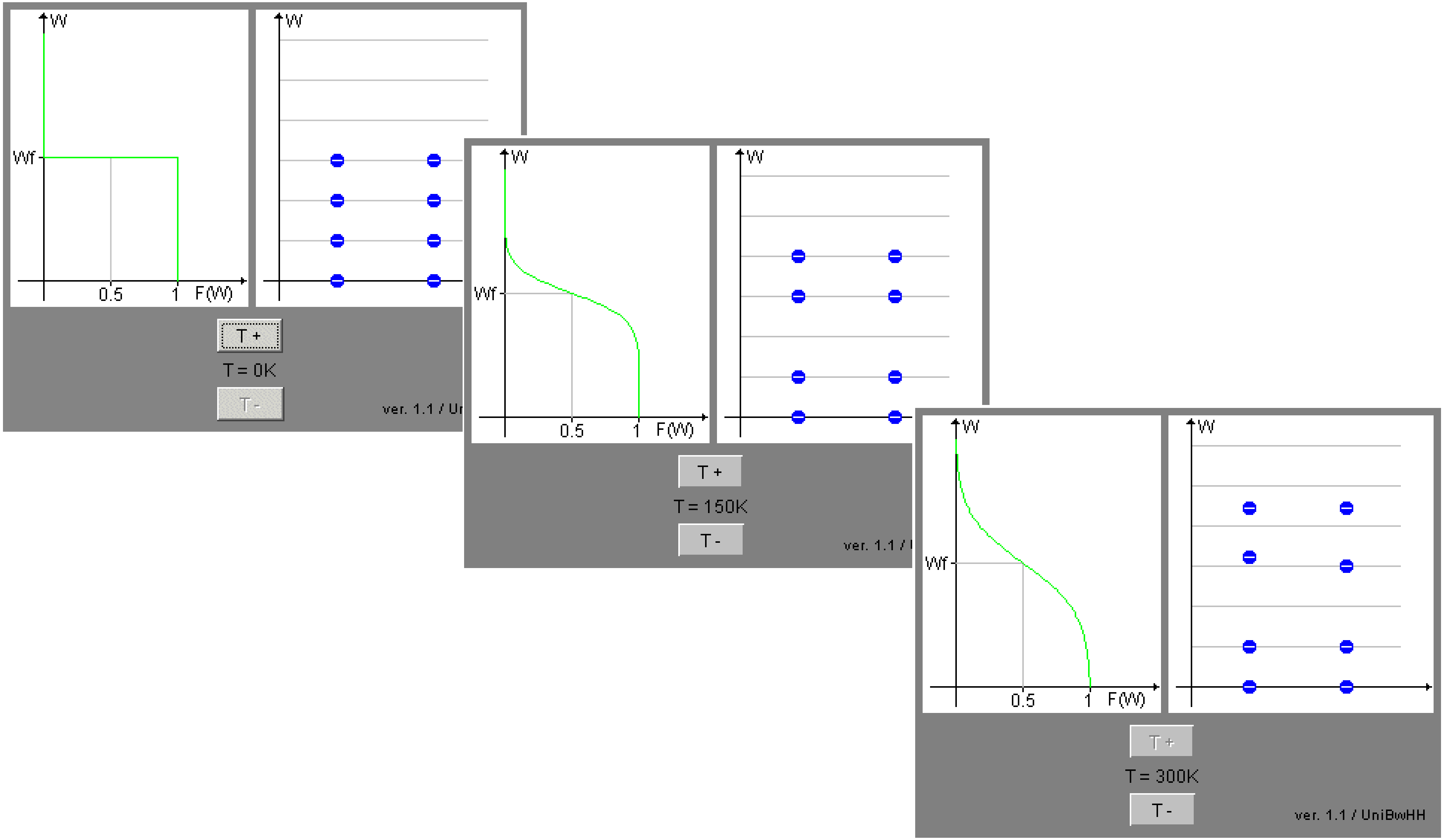

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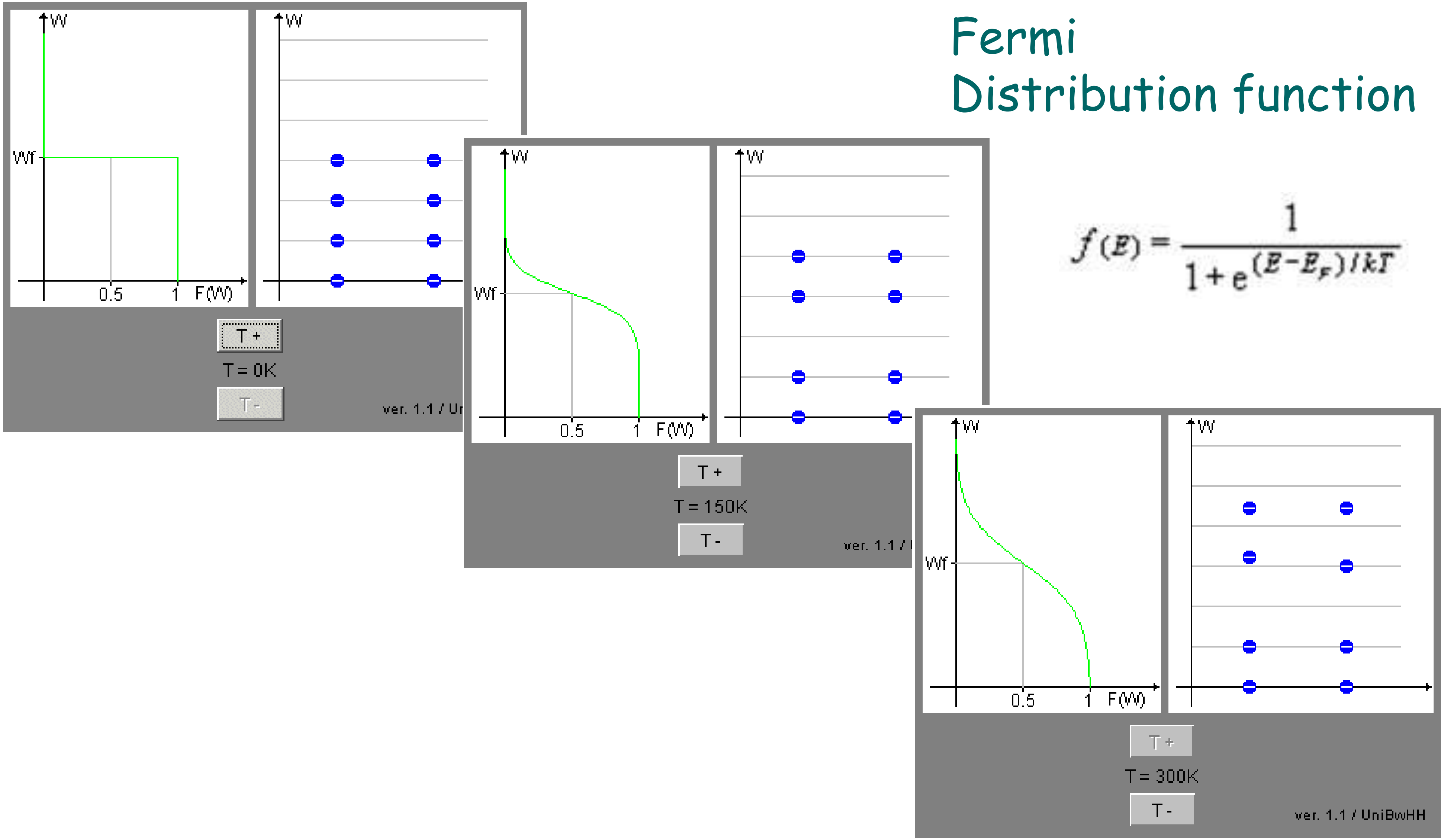

Fermi Distribution function

$$f(E) = \frac{1}{1 + e^{(E-E_F)/kT}}$$

Occupation of states vs. temperature for metal

Fermi Distribution function

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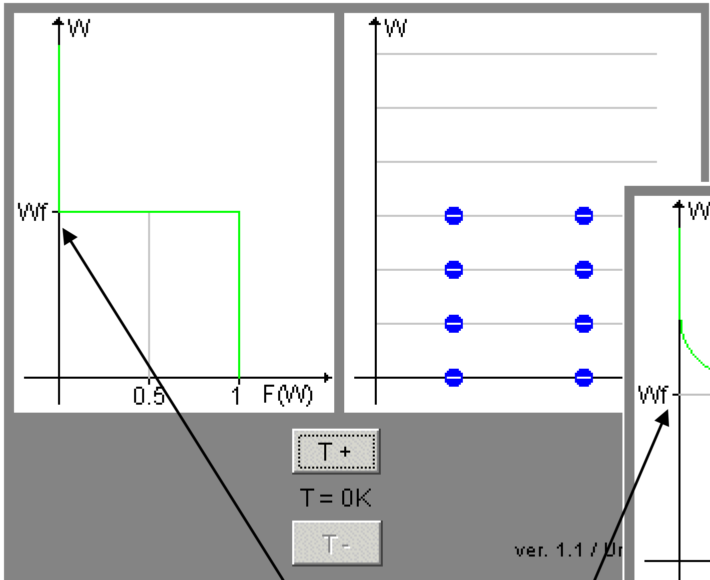
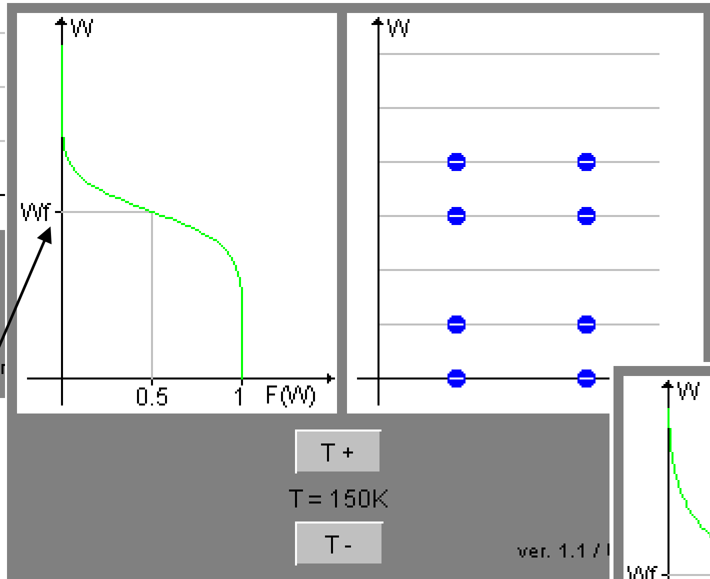
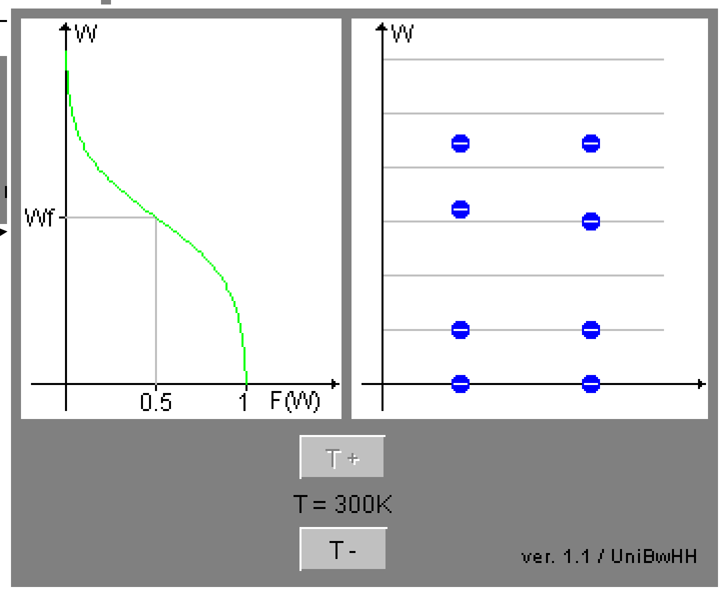
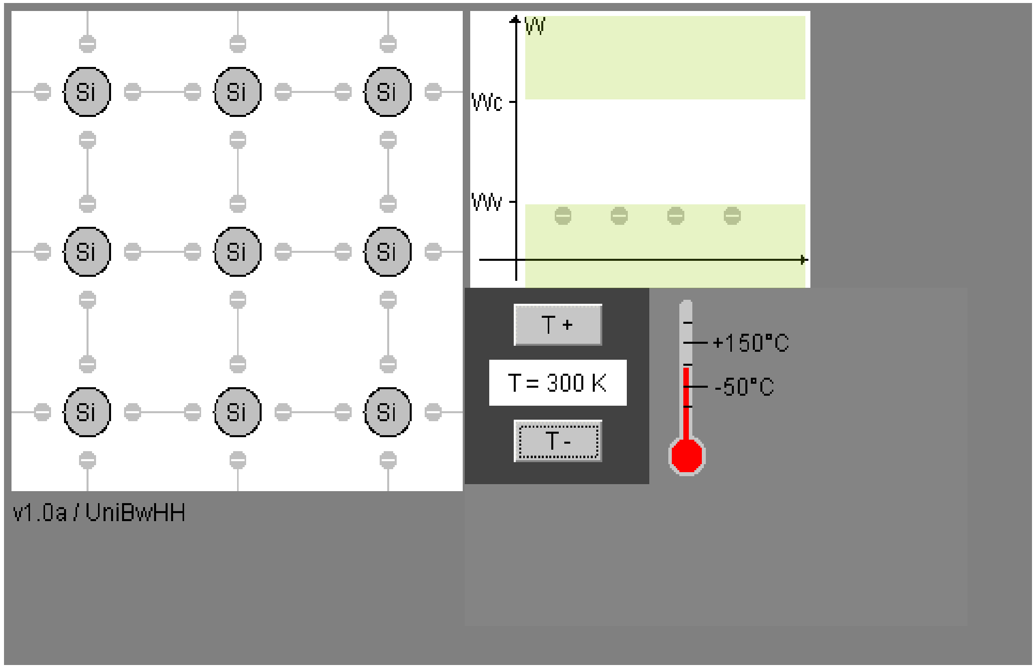




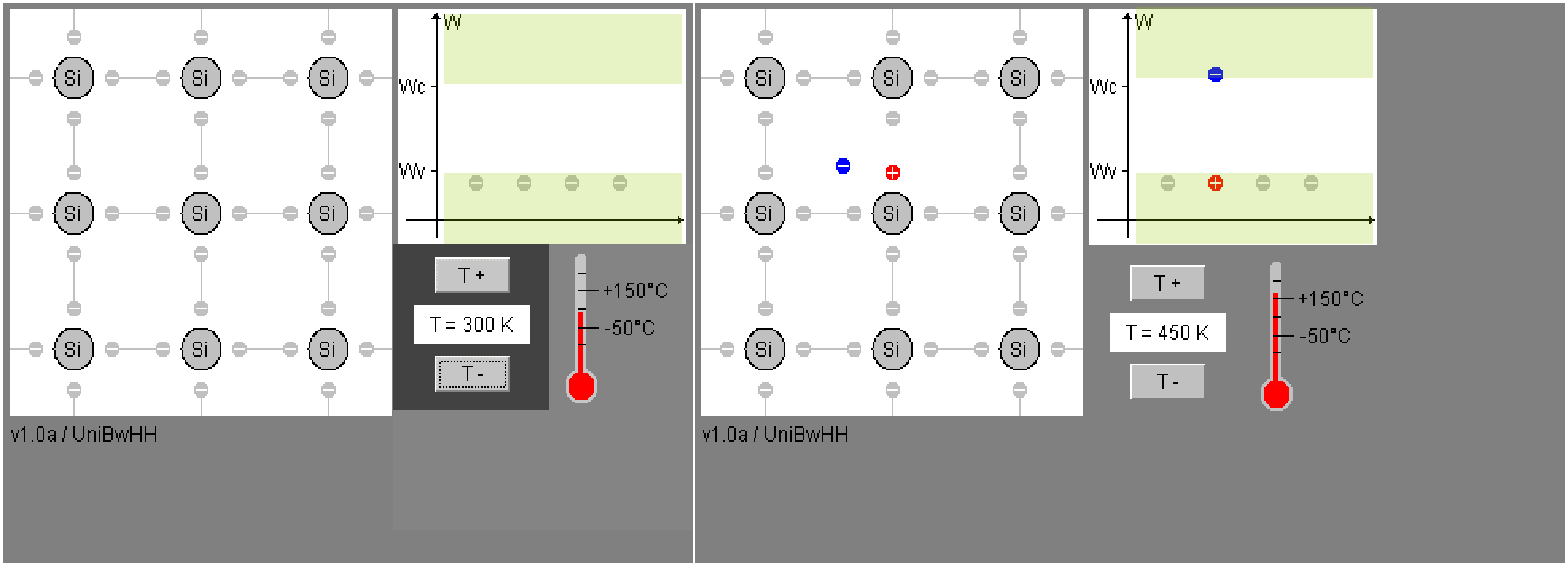


Fermi energy E_f = energy at which occupation probability is 0.5

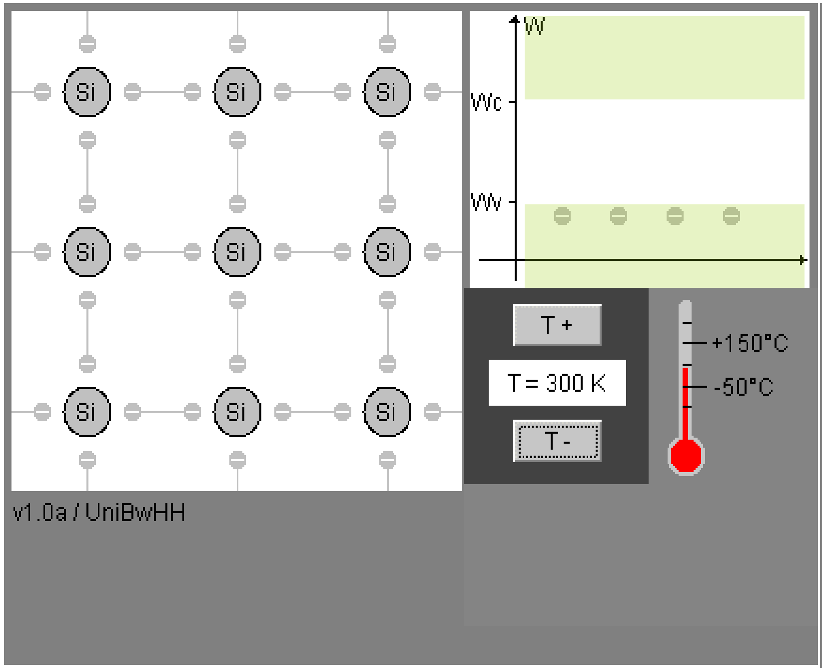
Occupation of states vs. temperature for Semiconductors

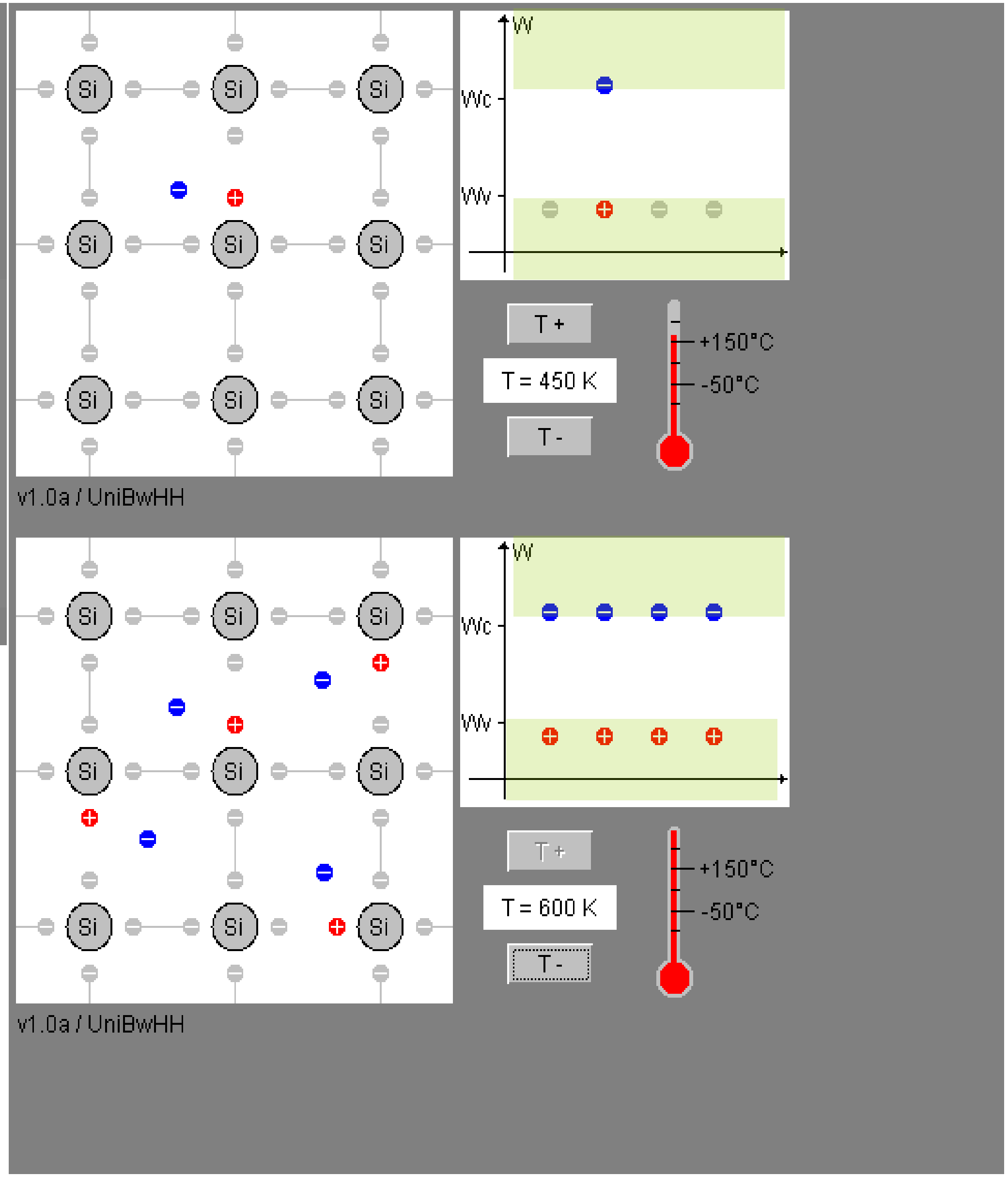


Occupation of states vs. temperature for Semiconductors



Occupation of states vs. temperature for Semiconductors





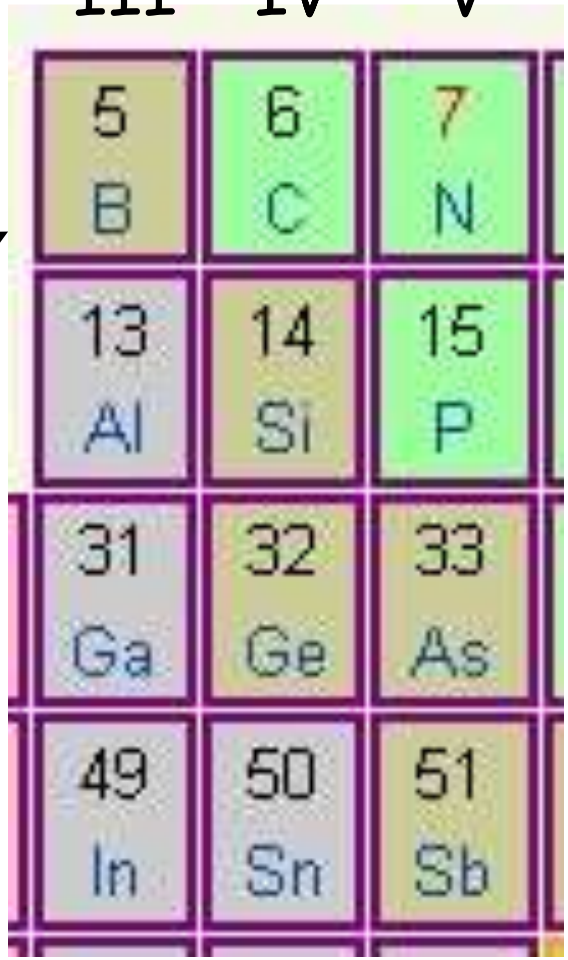
Periodic Table

Group: I II Transition III IV V VI VII VIII

Period																		
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo
* Lanthanoids			57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
** Actinoids			89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

Group III to V

III IV V



Substitutional element in the silicon lattice:

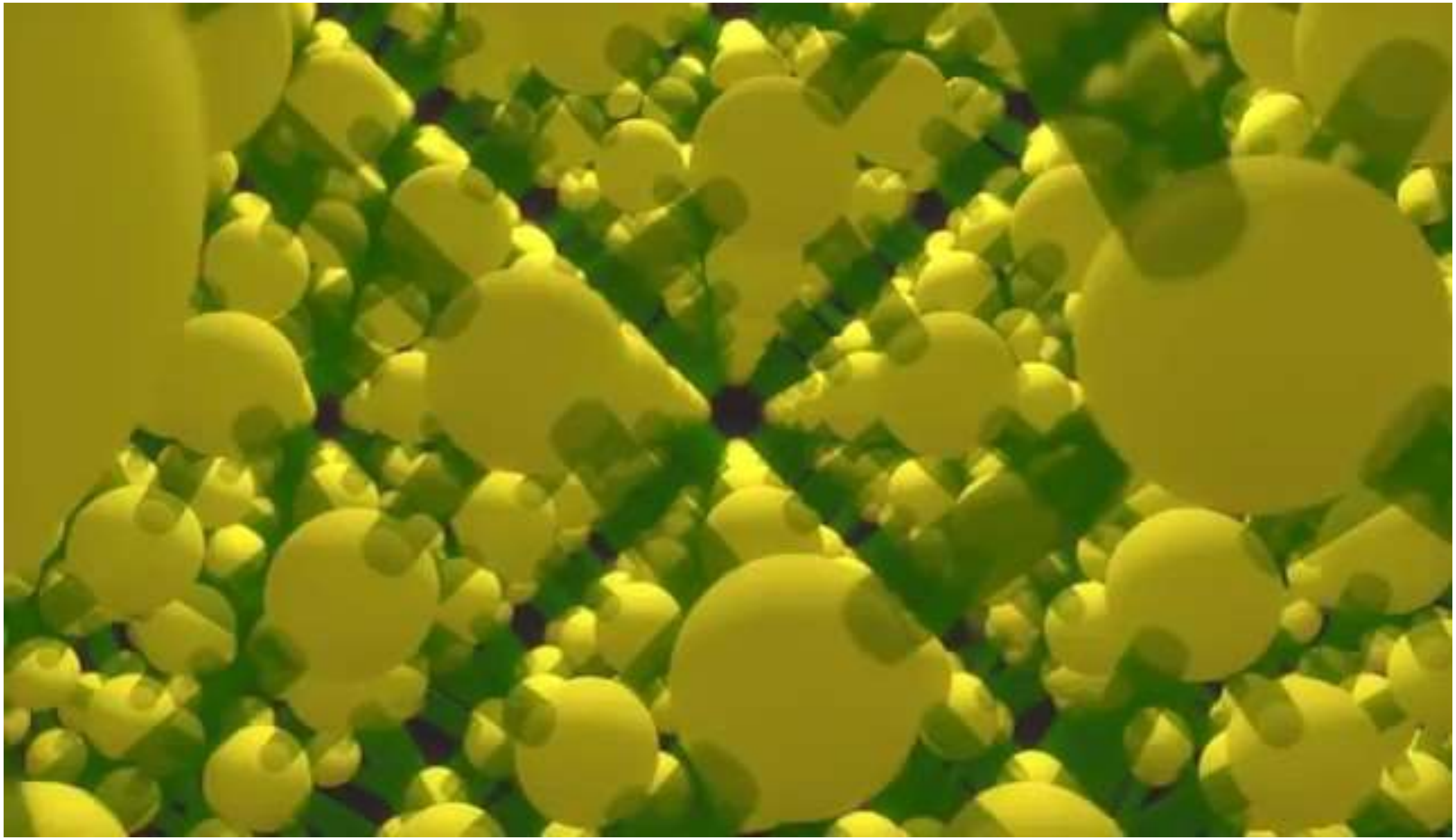
Boron

(one electron less than Si)

Substitutional element in the silicon lattice:

Phosphorus
Arsenic
Antimon

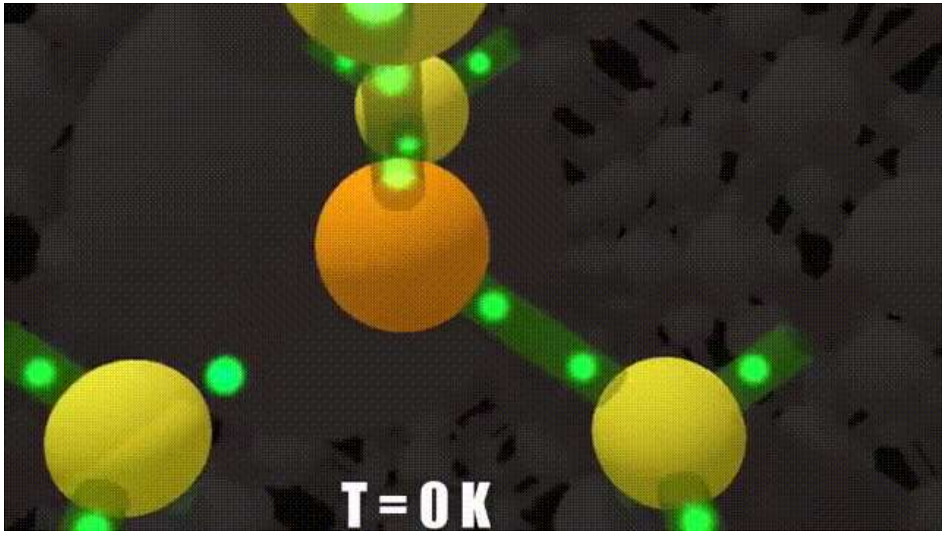
(one electron more than Si)



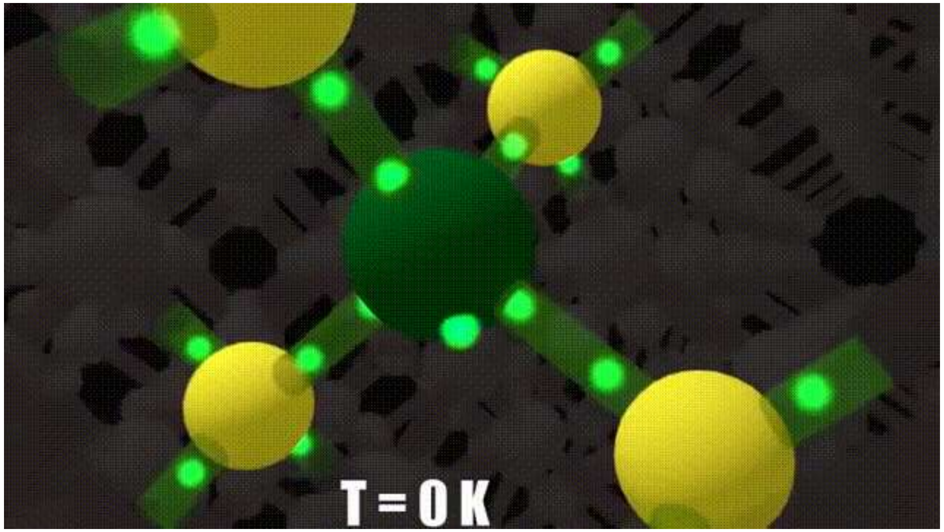
Taken from:
https://www.youtube.com/watch?v=JBtEckh3L9Q&t=4s

Doping

P - type

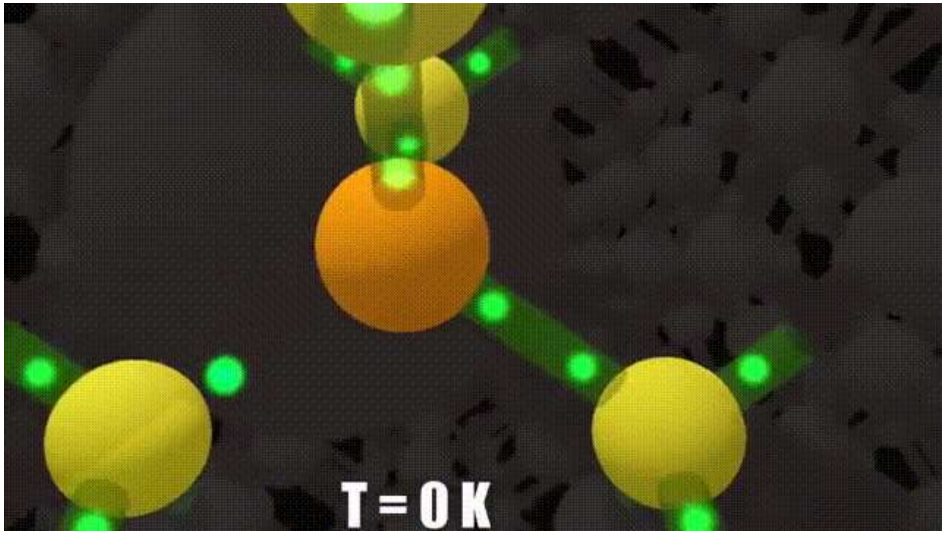


n - type

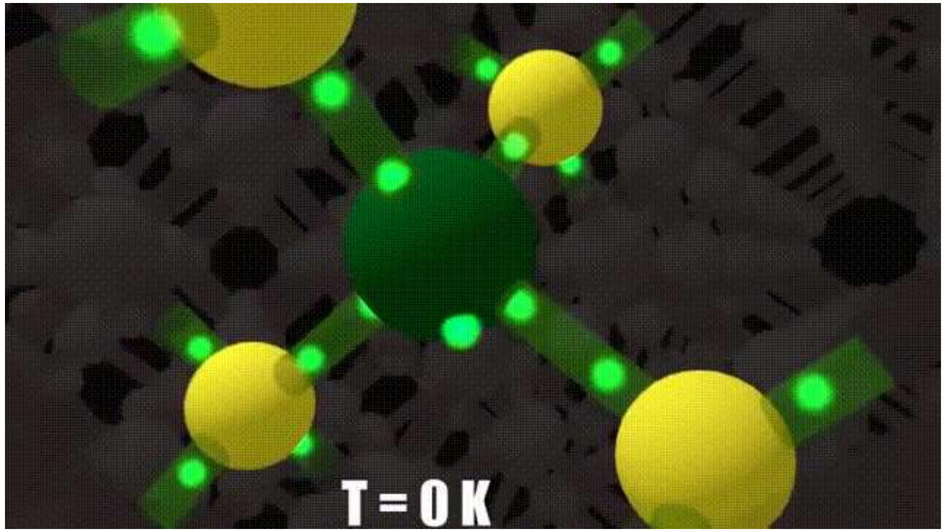


Doping

P - type



n - type



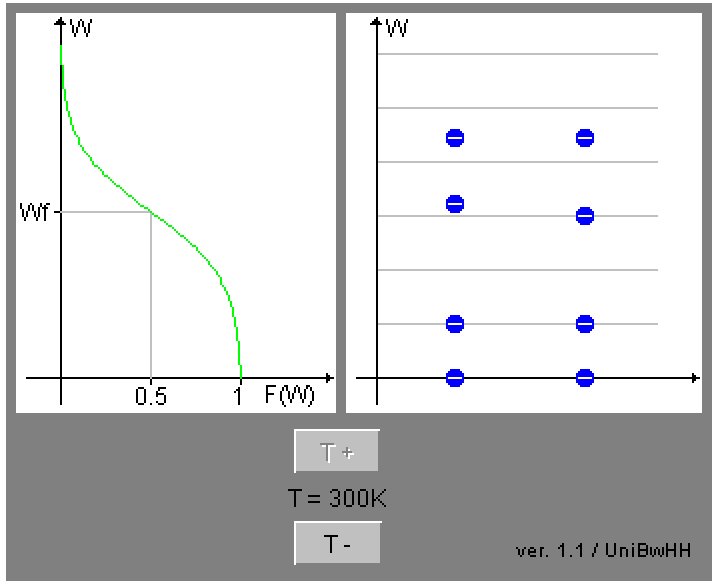
Continue ⇨ VIDEO CAMPUS SACHSEN

"SCT_SS20_02.5" 13:41

Occupation of states for a metal

Fermi Distribution function

$$f(E) = \frac{1}{1 + e^{(E-E_F)/kT}}$$



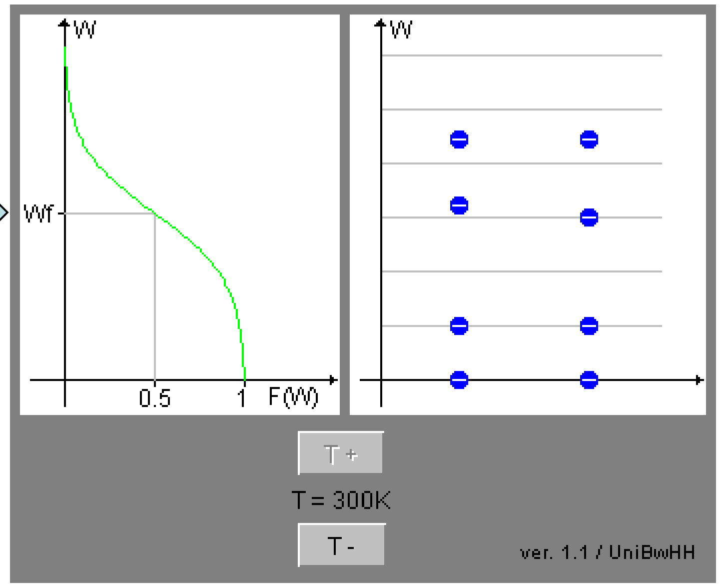
Occupation of states for a metal

Fermi Distribution function

$$f(E) = \frac{1}{1 + e^{(E-E_F)/kT}}$$

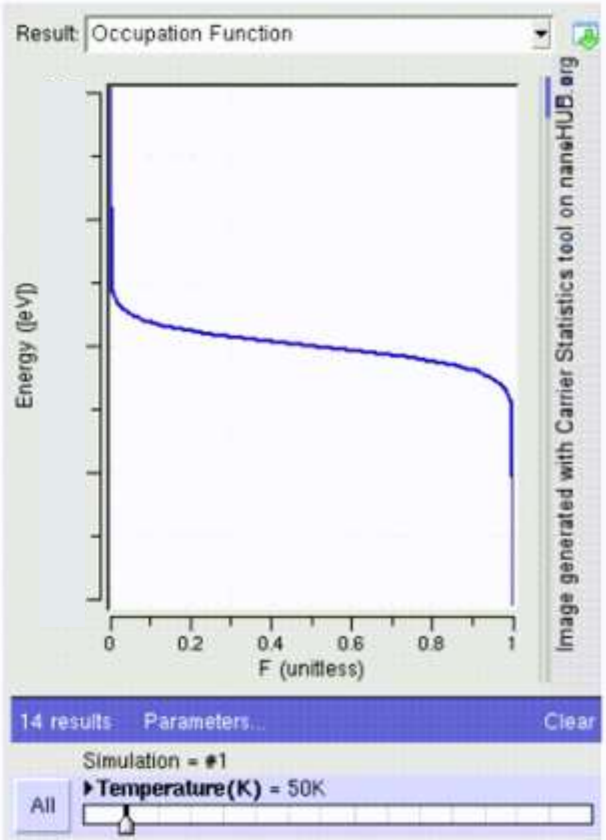
Parameter: Fermi-Level

Energy at which occupation probability = 0,5



Occupation of states for a metal

Parameter: Temperature



http://ecee.colorado.edu/~bart/book/contents.htm

Fermi Distribution function

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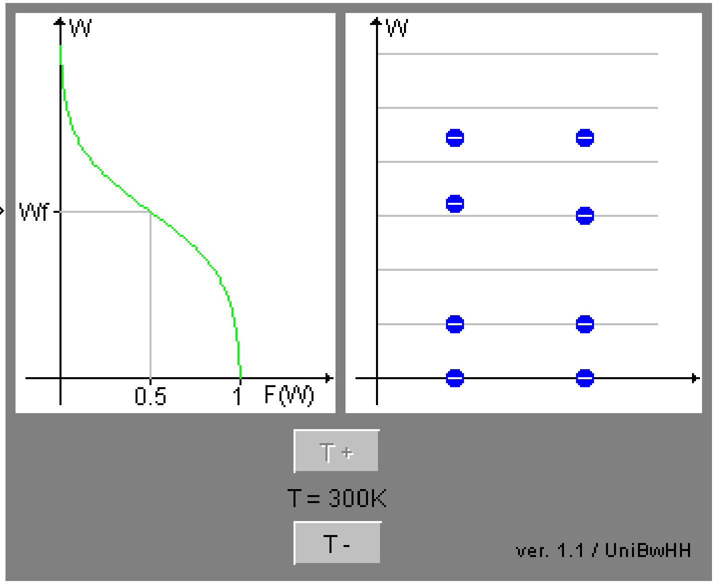
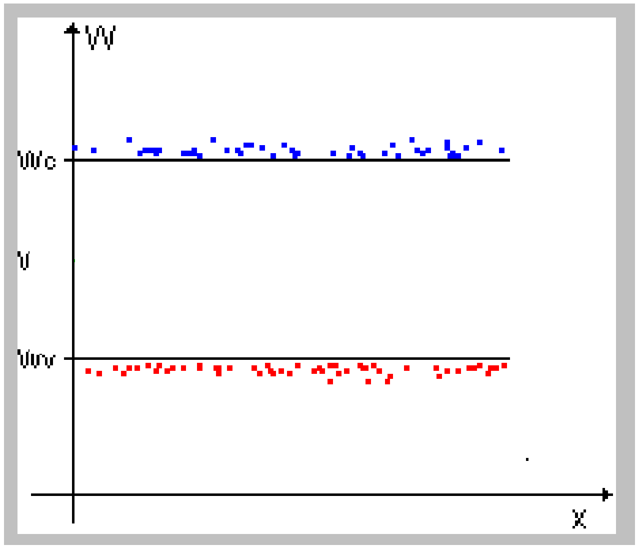


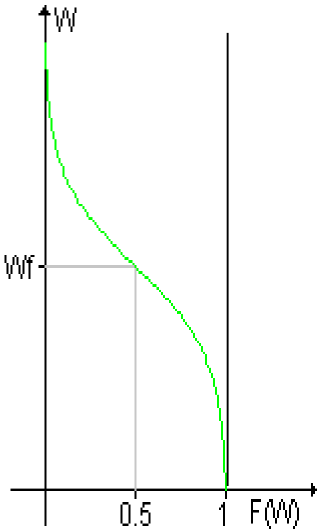
Doping and Fermi level for a semiconductor

Where do we locate the Fermi level?

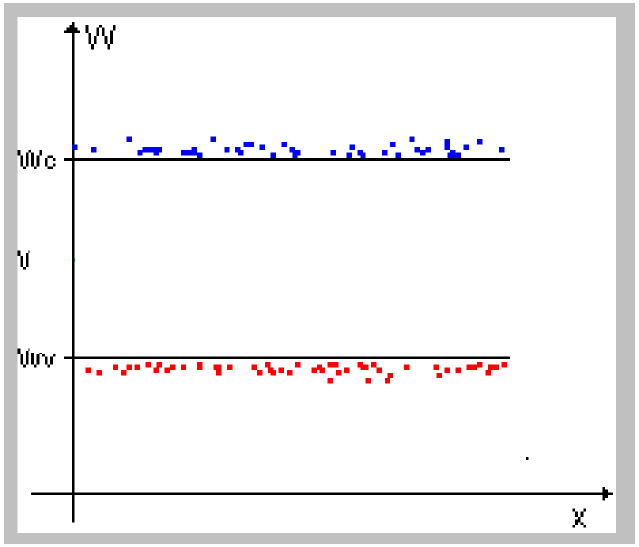
intrinsic p=n



Where do we locate the Fermi level?



intrinsic p=n



Doping and Fermi level for a semiconductor

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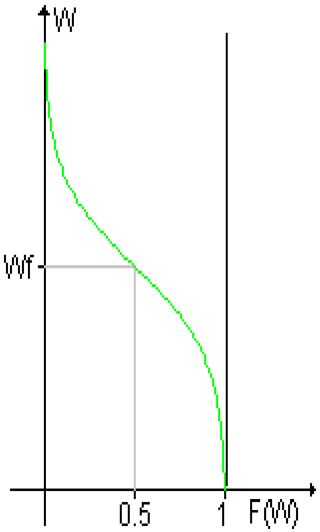
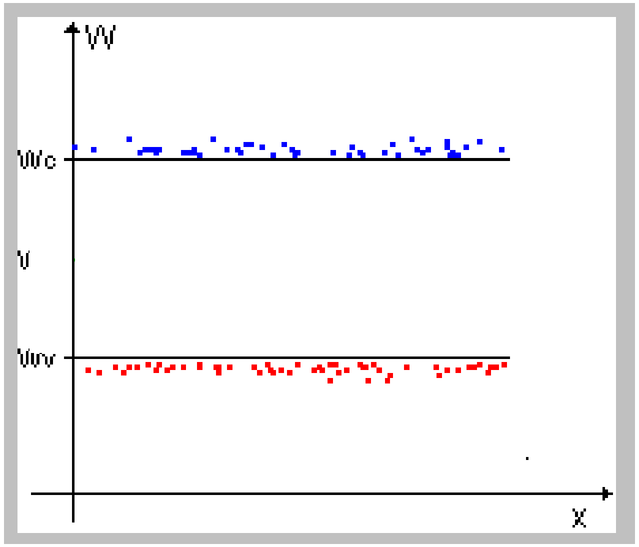
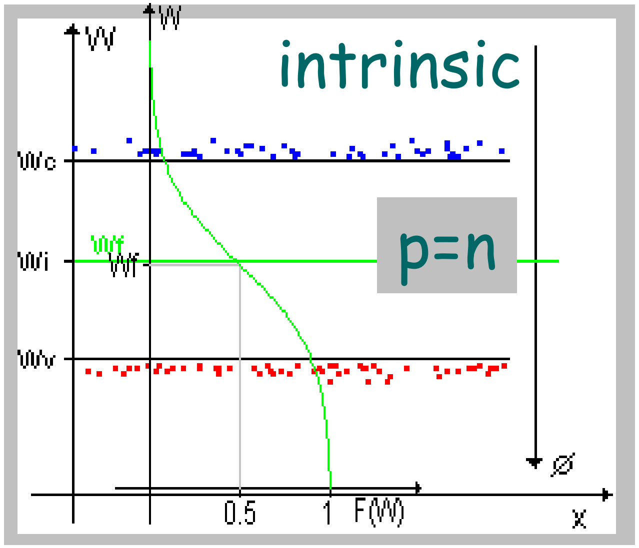


intrinsic p=n

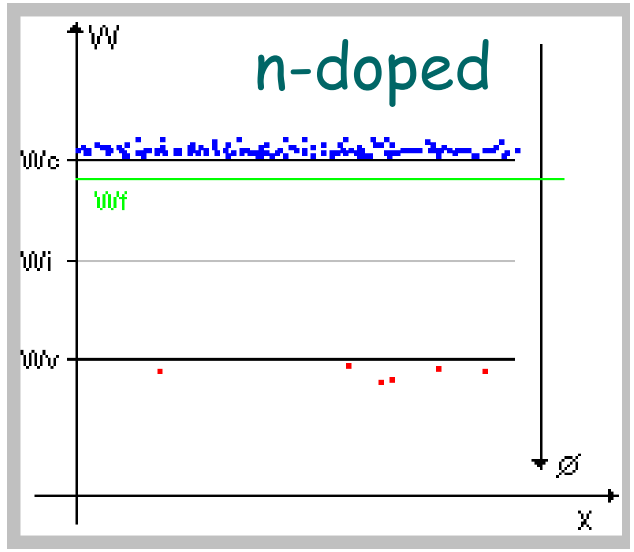


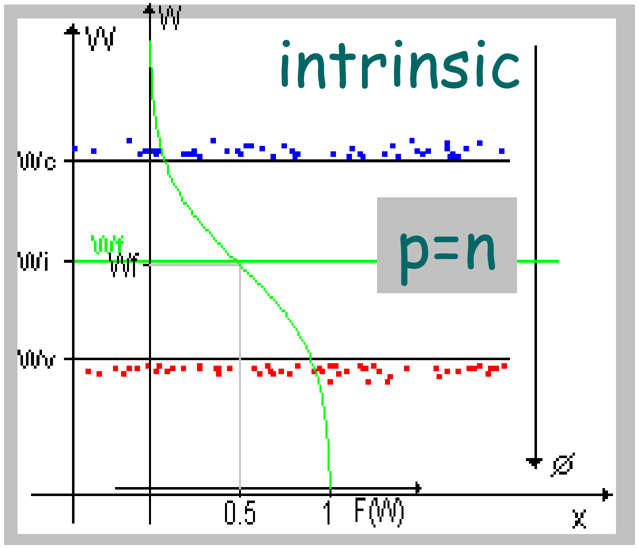
For intrinsic Si it must be in the middle of the bandgap!

Doping and Fermi level for a semiconductor

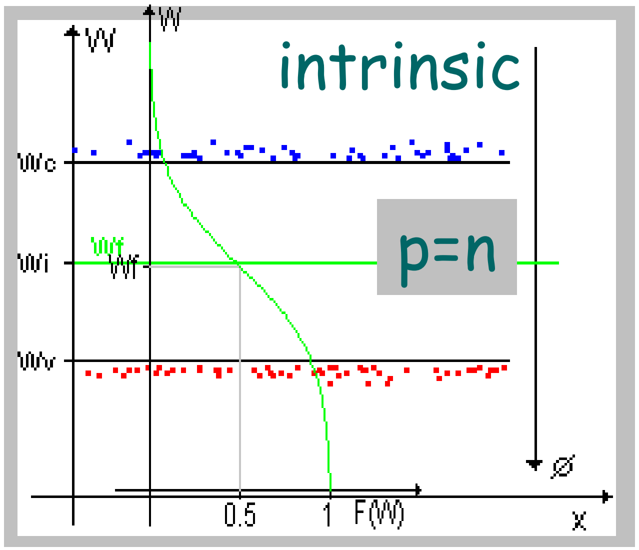


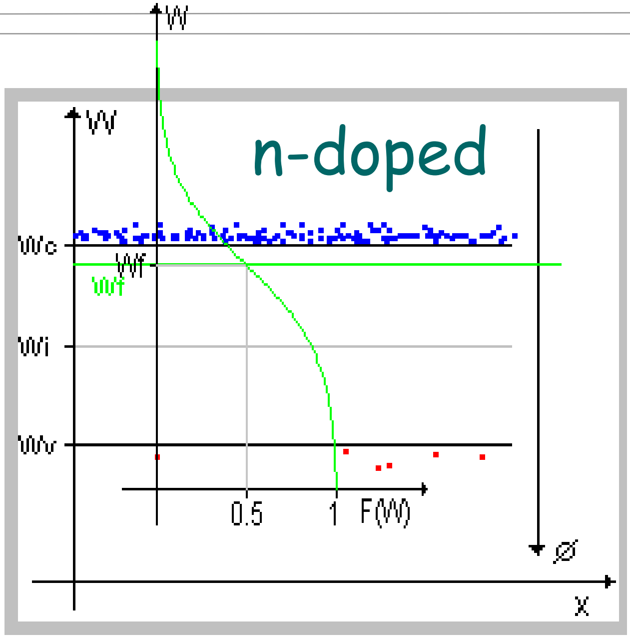
Doping and Fermi level for a semiconductor



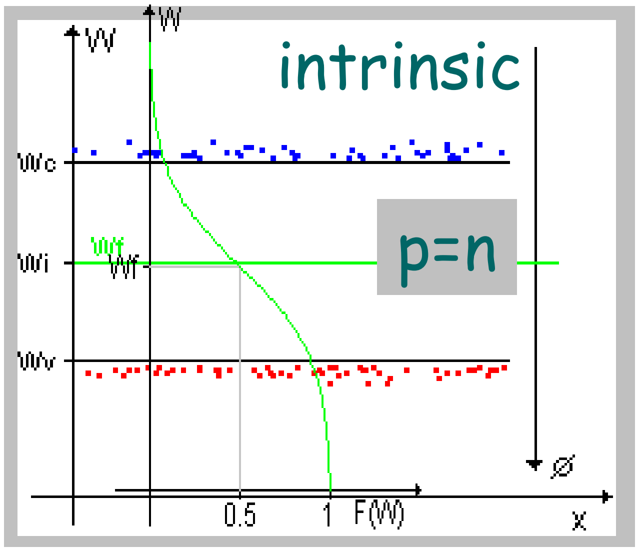


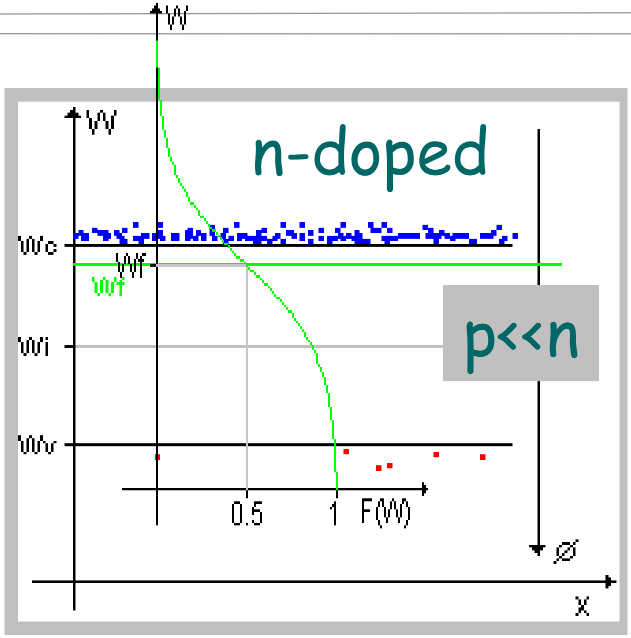
Doping and Fermi level for a semiconductor



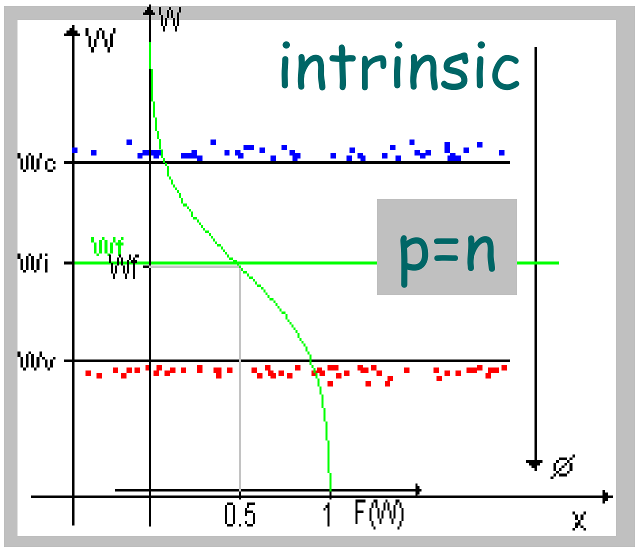


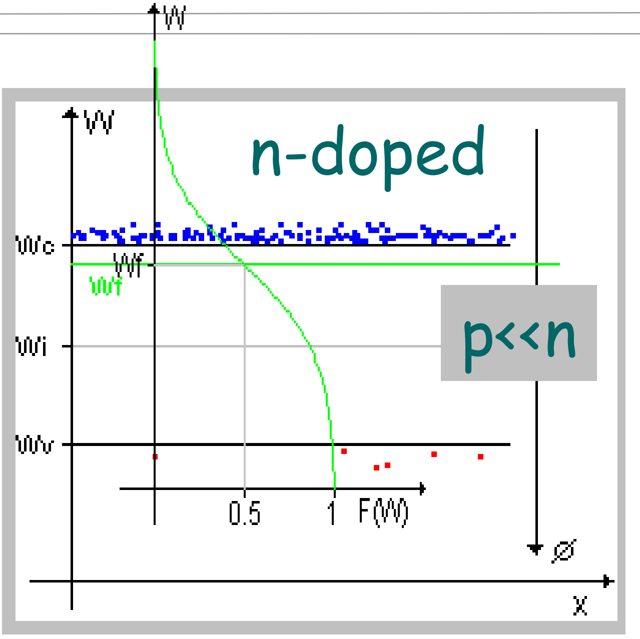
Doping and Fermi level for a semiconductor

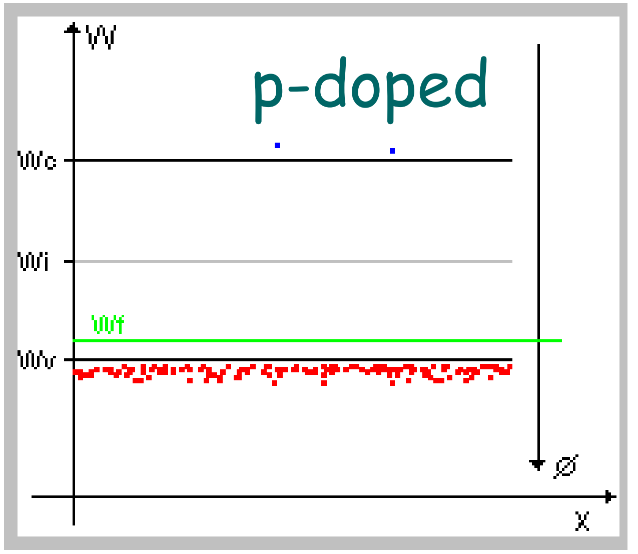




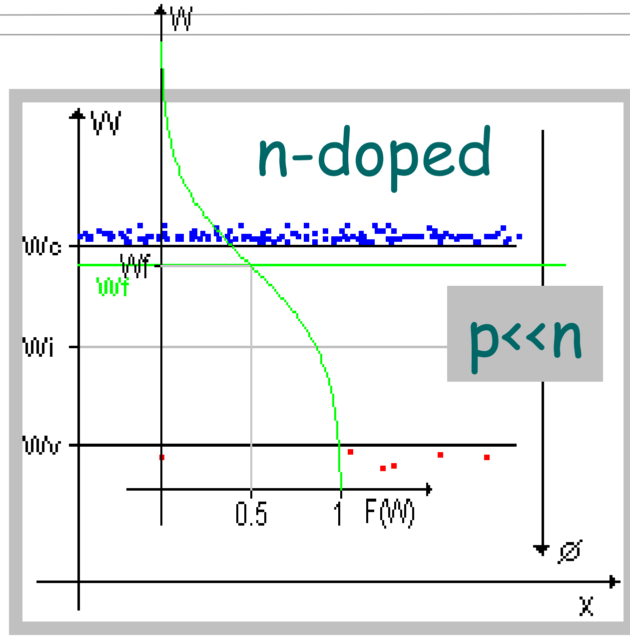
Doping and Fermi level for a semiconductor

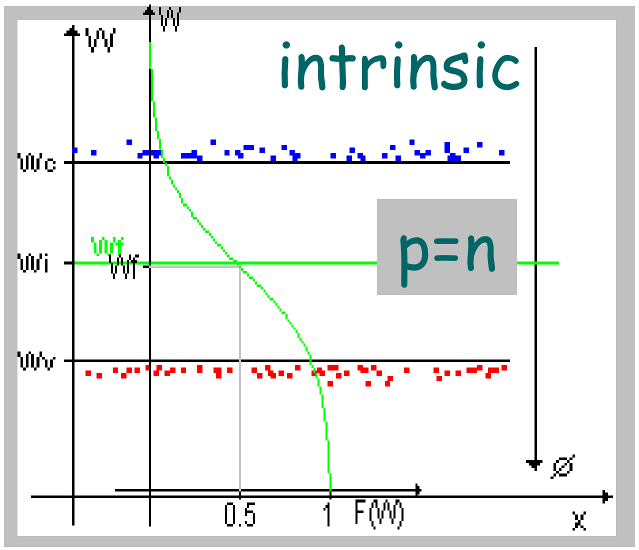


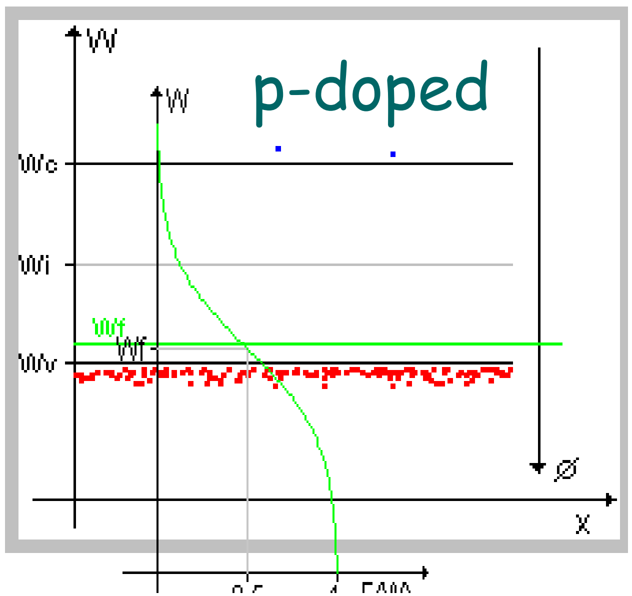




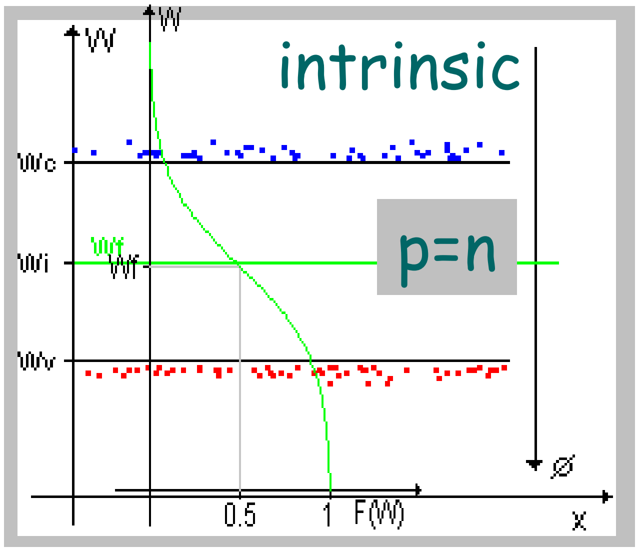
Doping and Fermi level for a semiconductor

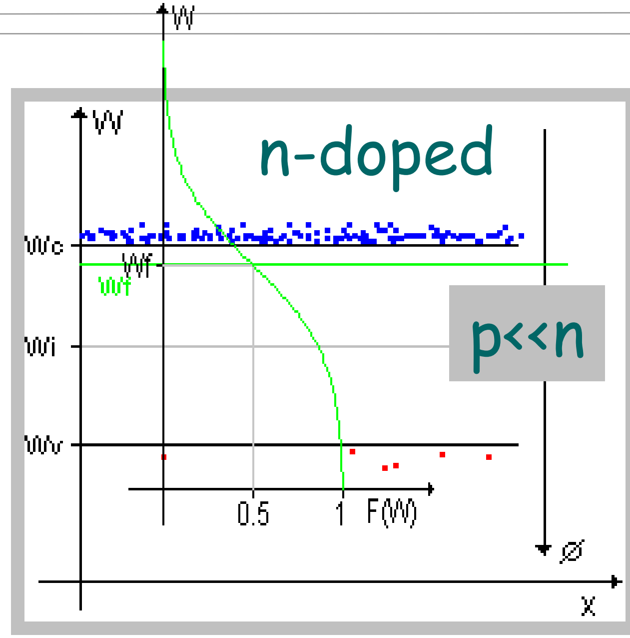


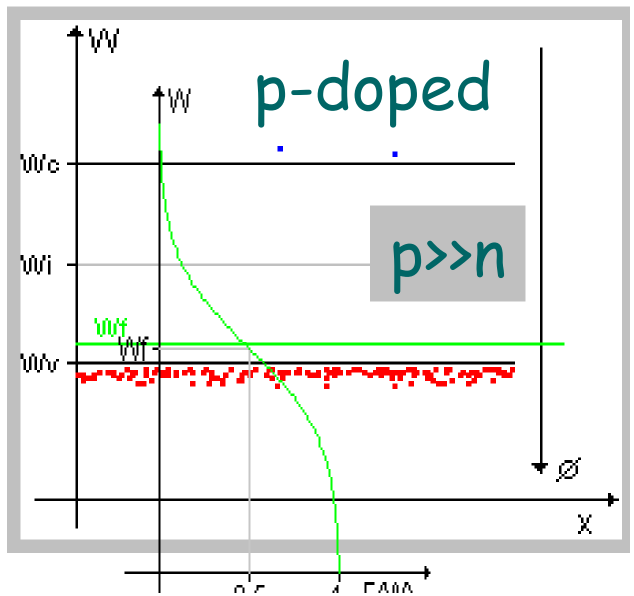




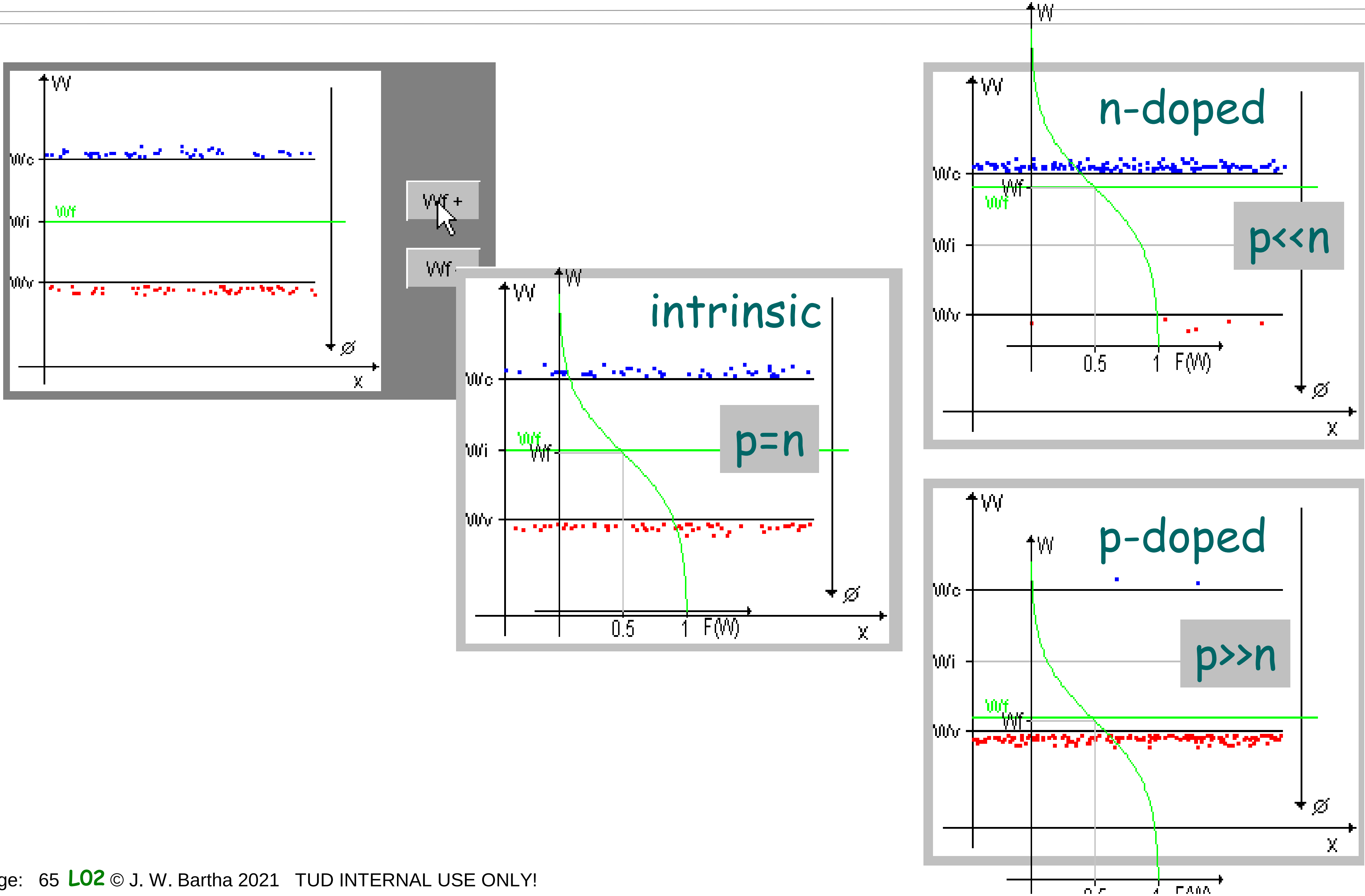
Doping and Fermi level for a semiconductor



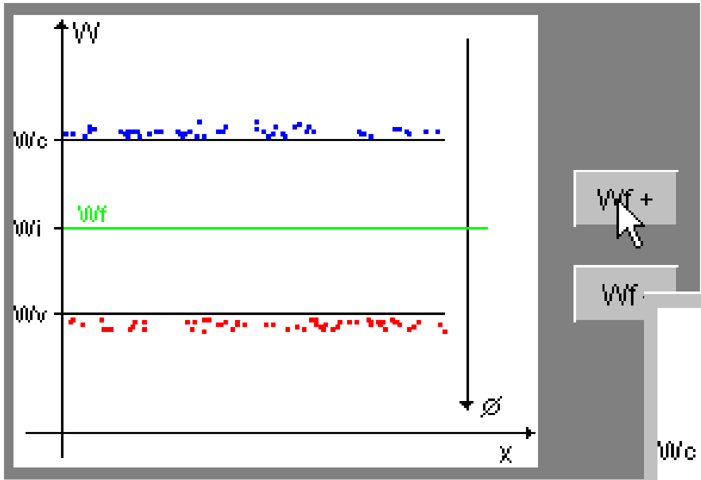


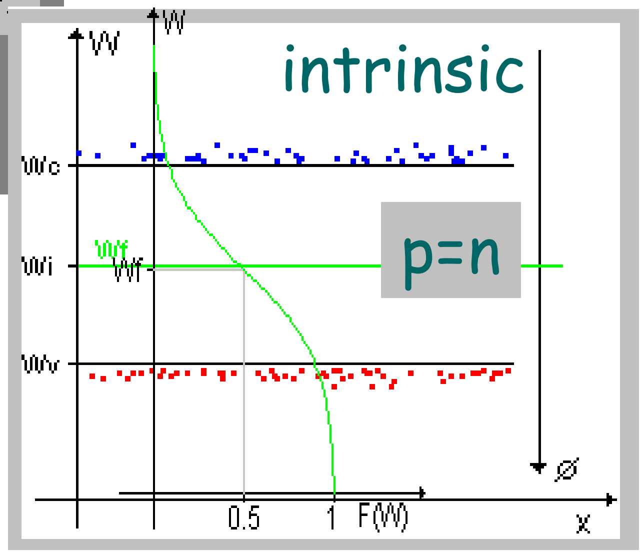


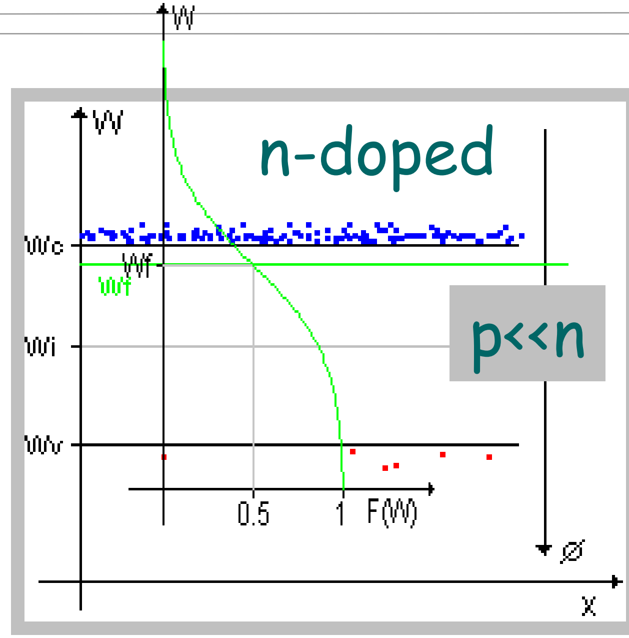
Doping and Fermi level for a semiconductor

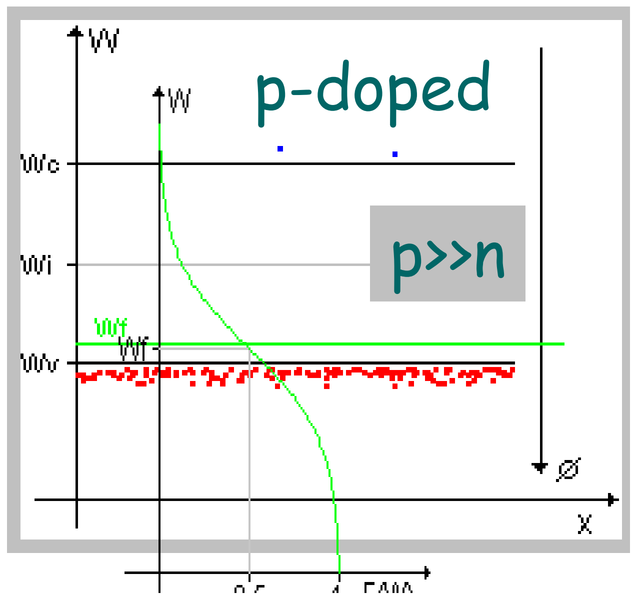


Doping and Fermi level for a semiconductor



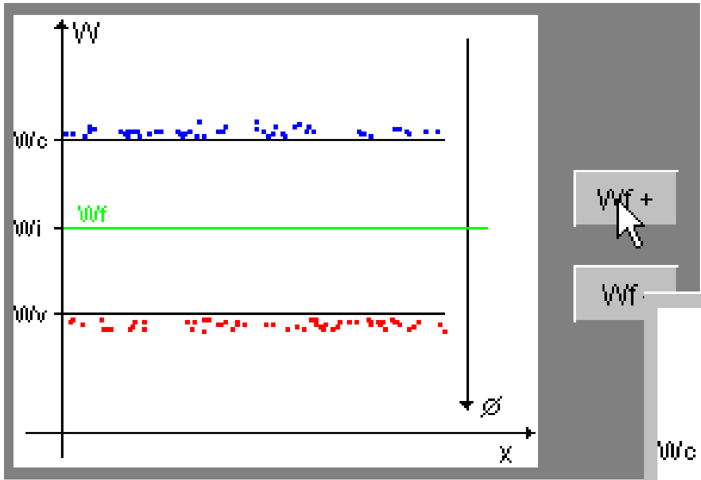


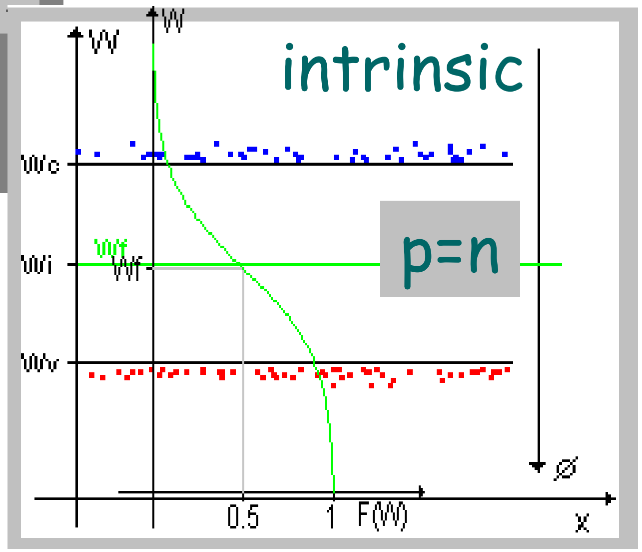


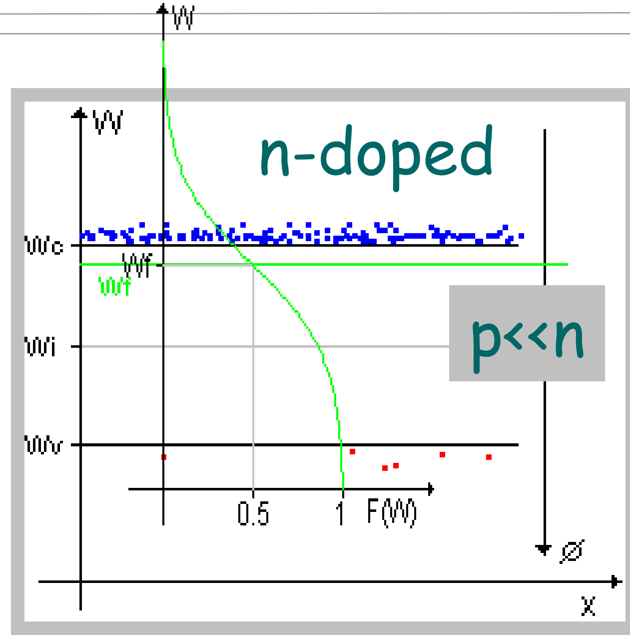


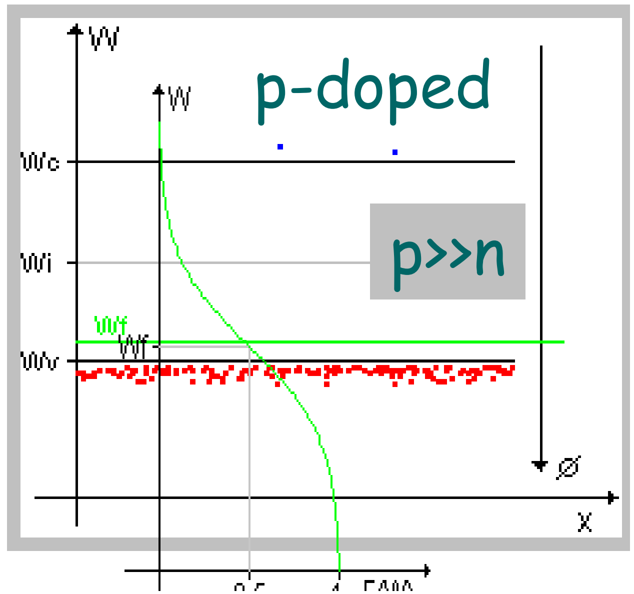
Product of
hole concentration
times
electron concentration
is a constant: $p \cdot n = n_i^2$

Doping and Fermi level for a semiconductor









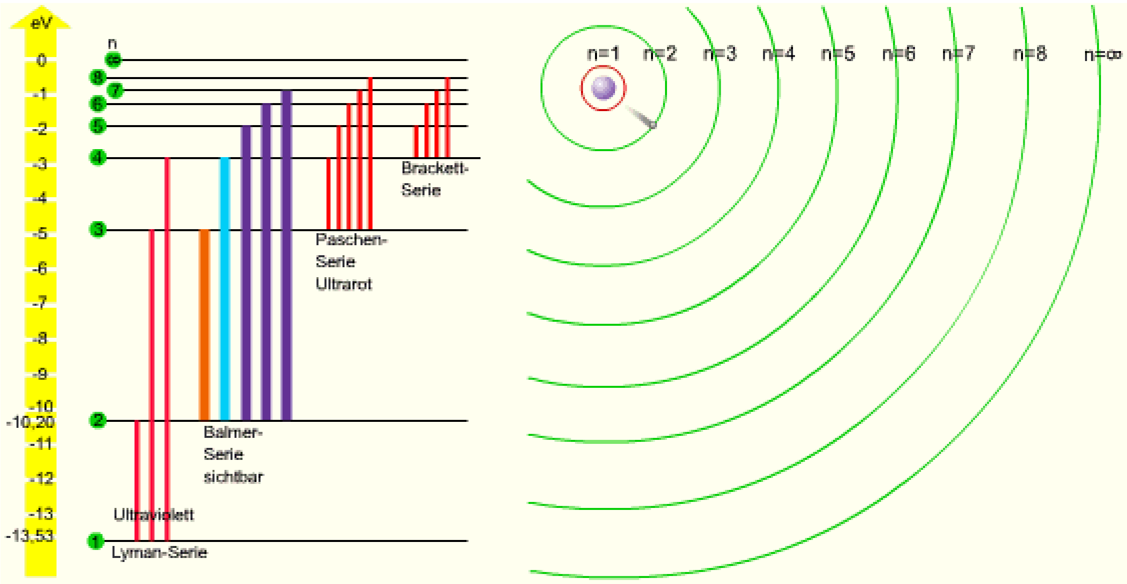
Product of
hole concentration
times
electron concentration
is a constant: $p \cdot n = n_i^2$

But where do we locate E_f on the E scale **Continue**

"SCT_SS20_02.6" 11:30

O.K. Fermi level relative to band edges, but where on an absolute scale?

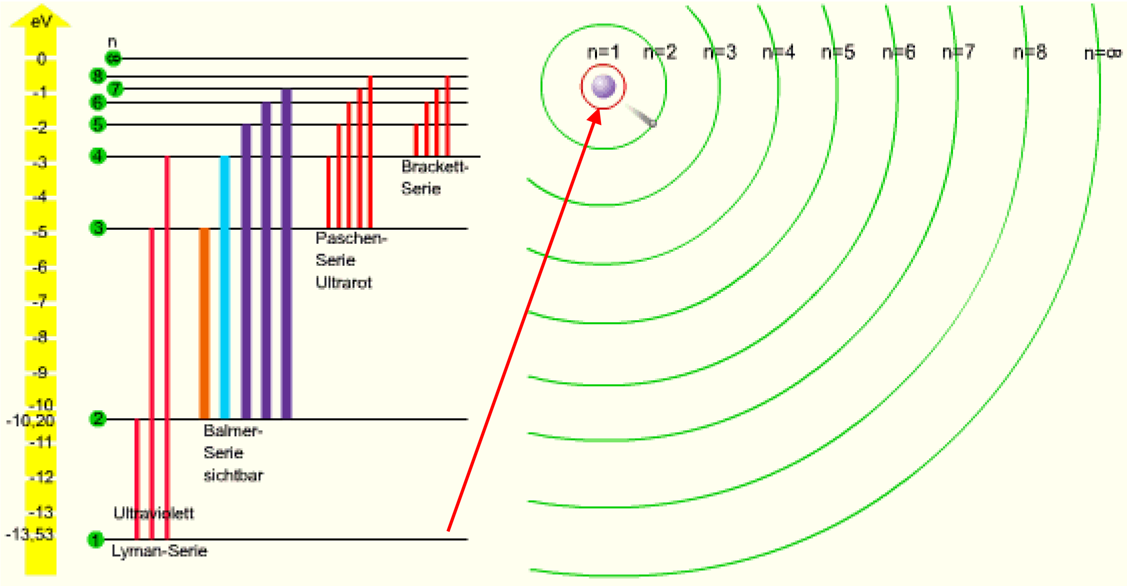
Reminder:
Energy states of electrons in **atoms**



O.K. Fermi level relative to band edges, but where on an absolute scale?

Reminder:
Energy states of electrons in **atoms**

Strongest bonded state 1

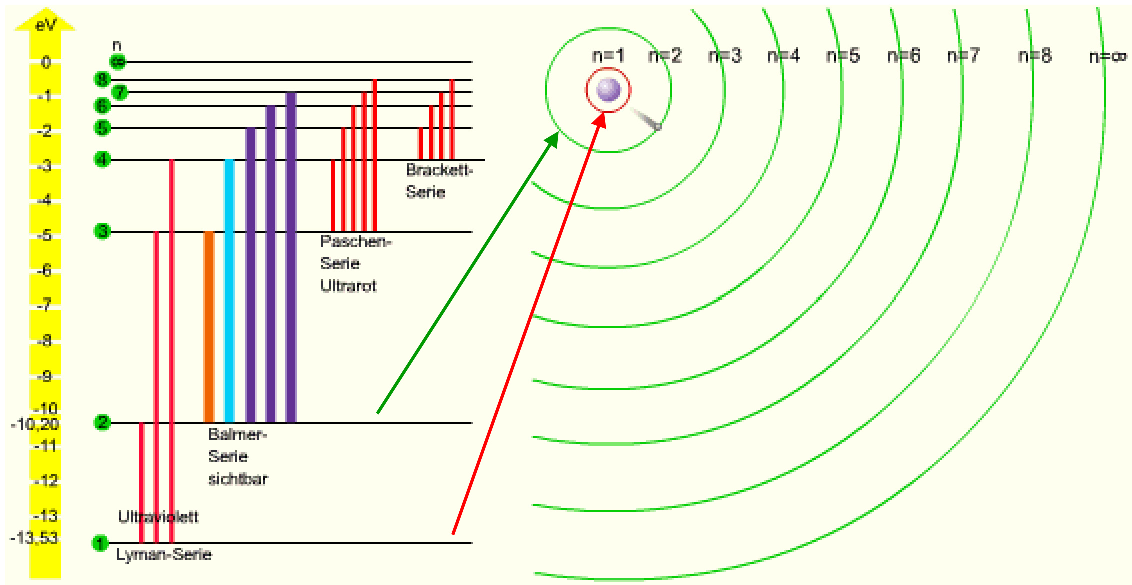


O.K. Fermi level relative to band edges, but where on an absolute scale?

Reminder:
Energy states of electrons in **atoms**

Weaker bonded state 2

Strongest bonded state 1



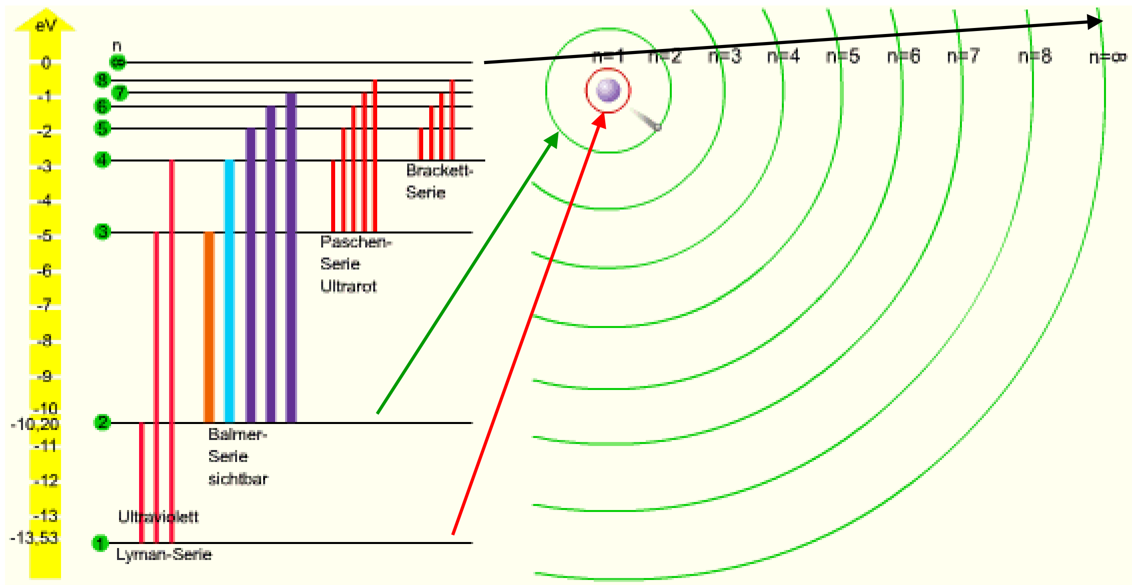
O.K. Fermi level relative to band edges, but where on an absolute scale?

Reminder:
Energy states of electrons in **atoms**

Very weakly bonded state
large # n

Weaker bonded state 2

Strongest bonded state 1



O.K. Fermi level relative to band edges, but where on an absolute scale?

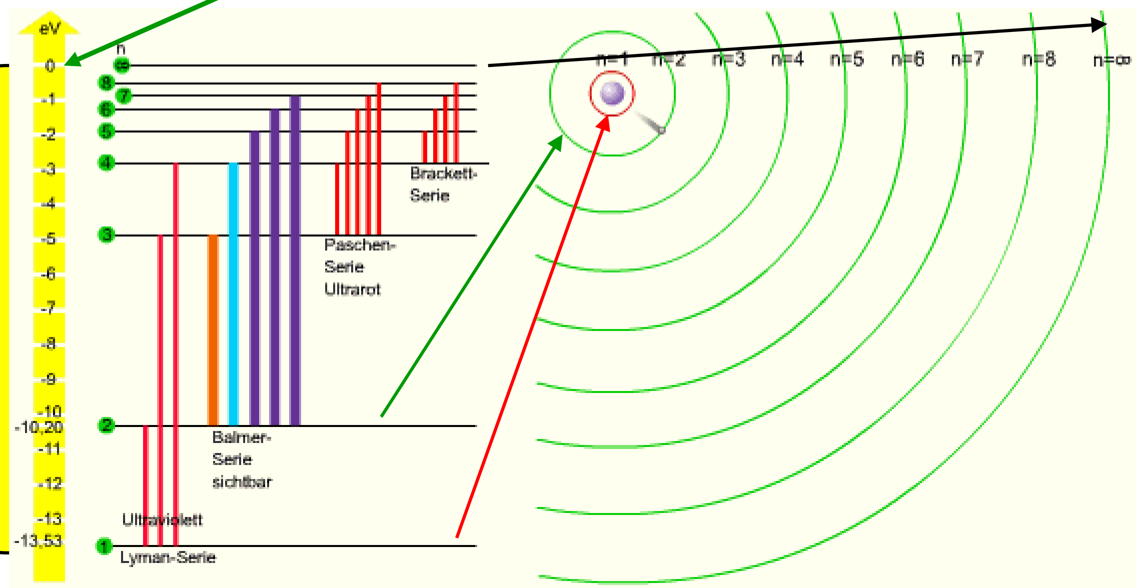
Reminder:
Energy states of electrons in **atoms**

Conveniently the energy between the loosest bonded state and the next energy above at which an electron is released is used as zero point on the scale. The Energy difference between the highest occupied state and zero is called ionization potential.

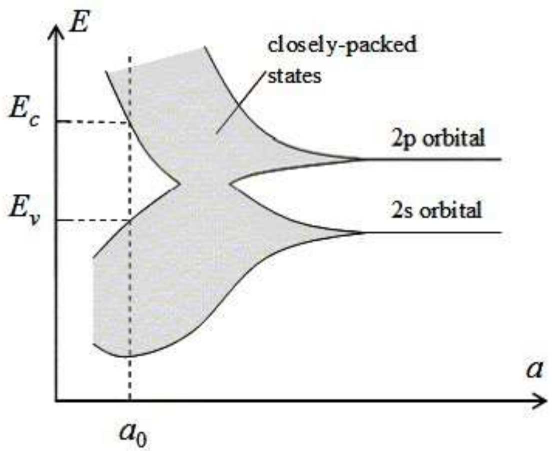
Very weakly bonded state
large # n

Weaker bonded state 2

Strongest bonded state 1

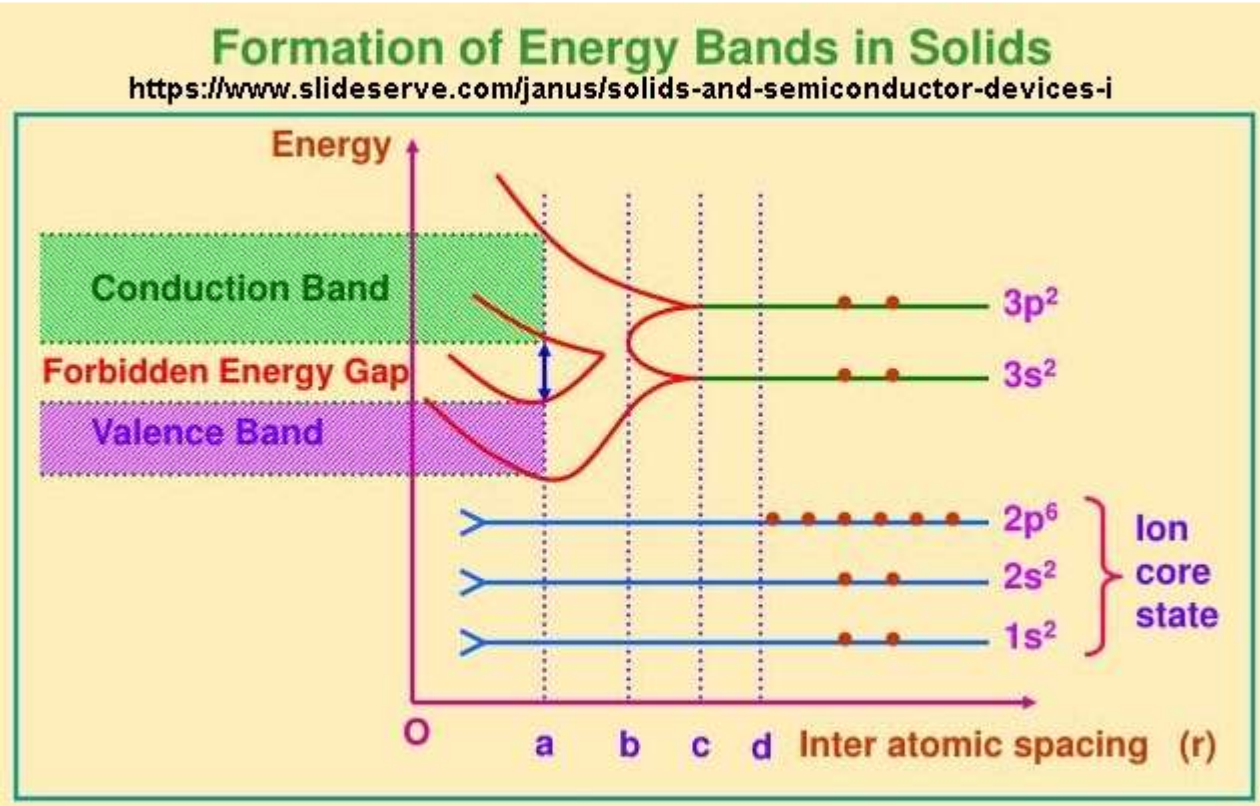


Energy states of electrons in solids

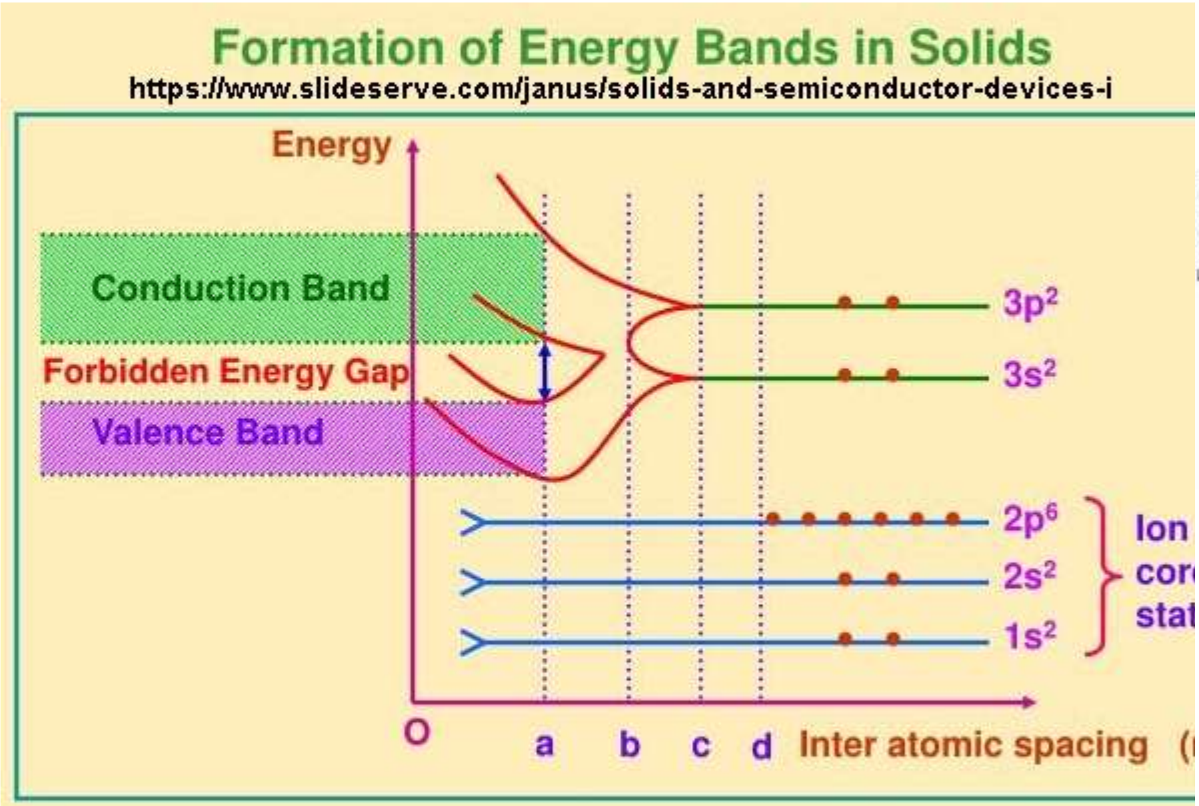


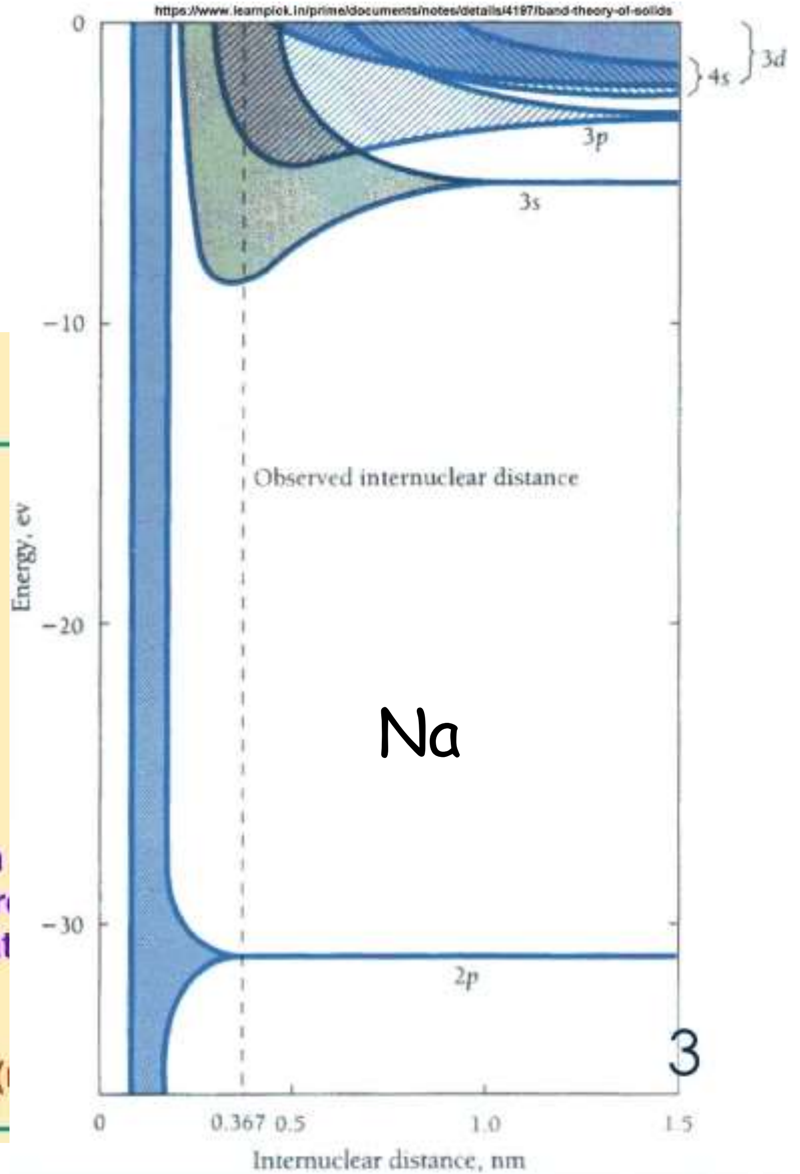
Energy bands for diamond versus lattice constant.

Energy states of electrons in solids



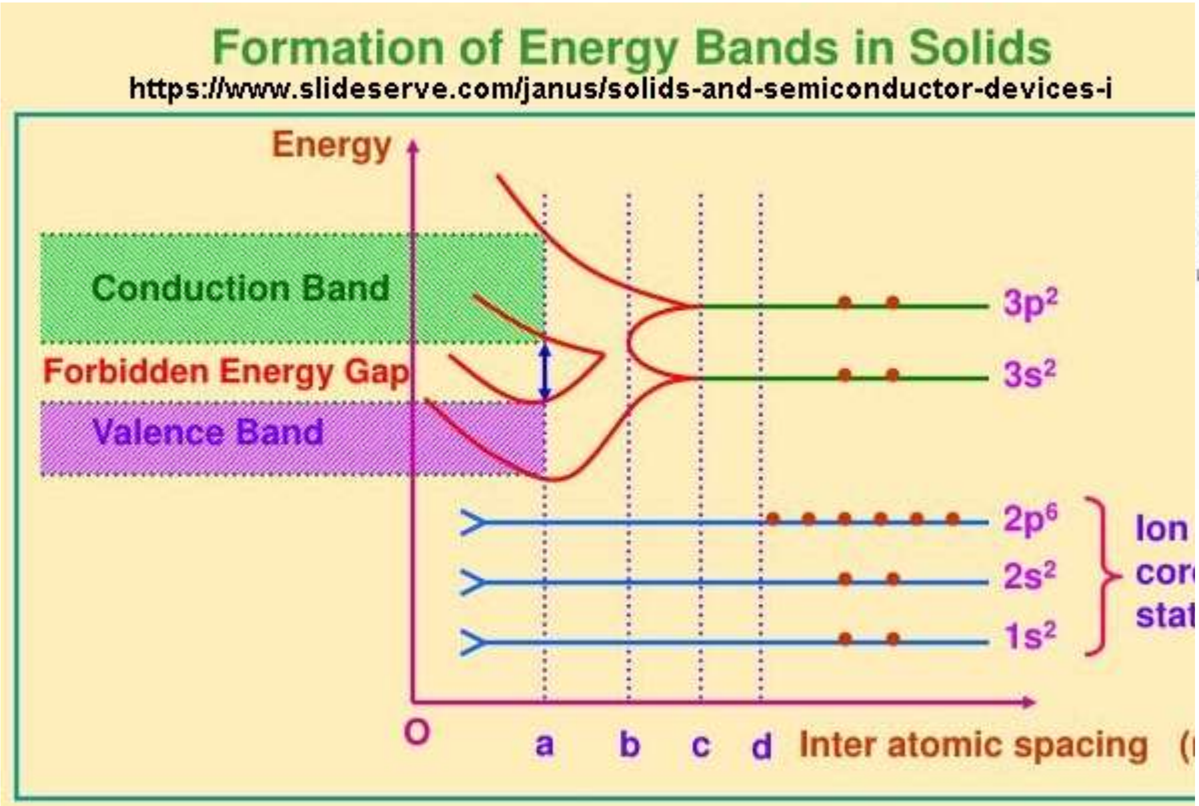
Energy states of electrons in solids

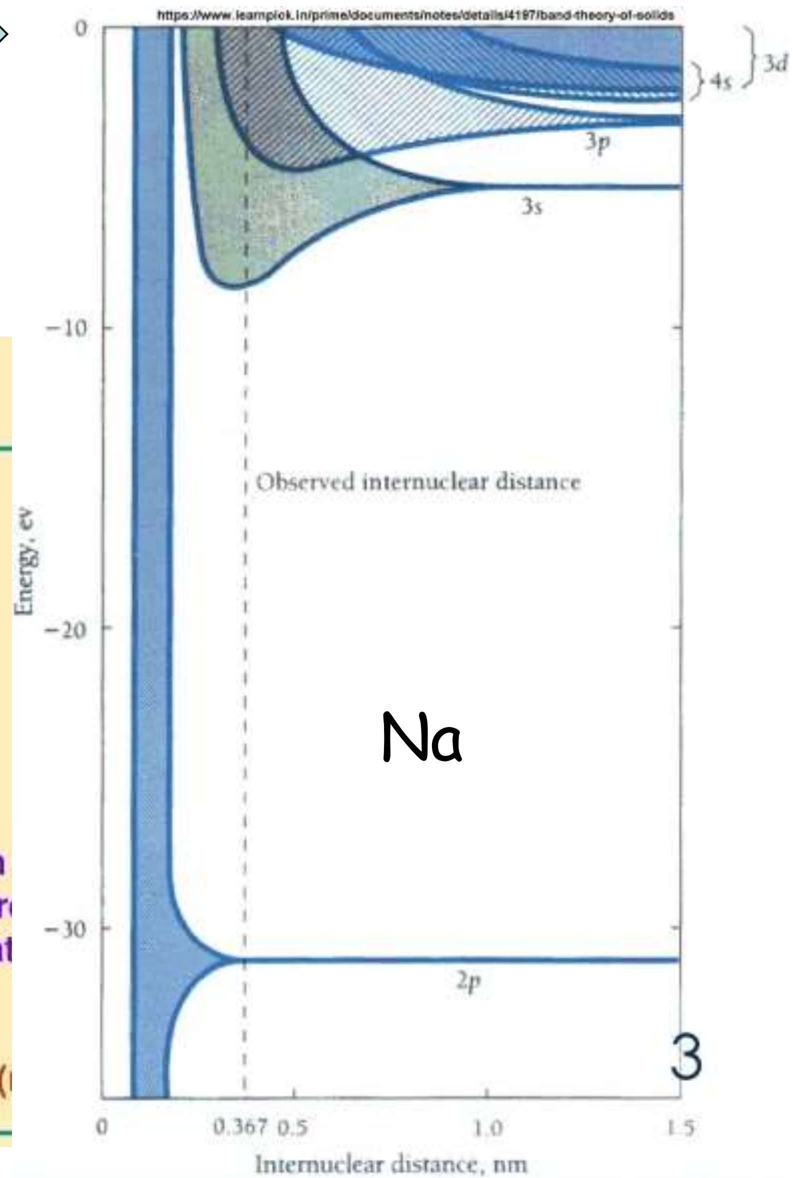




Energy states of electrons in solids

Binding energy 0 corresponds to the point at which the electron is released. For a solid this is named **Vacuum Level**

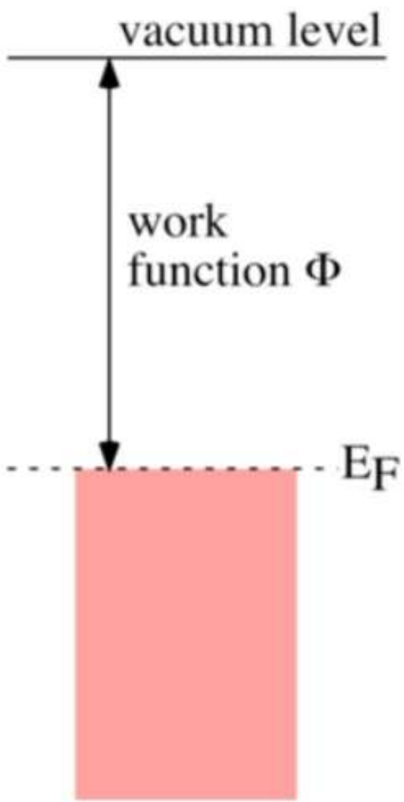




work function (German: Austrittsarbeit)

The work function is the energy required to release an electron from a solid

For a metal:



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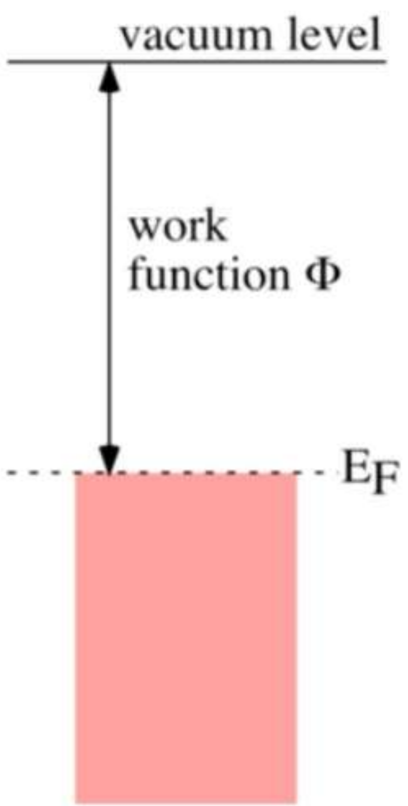
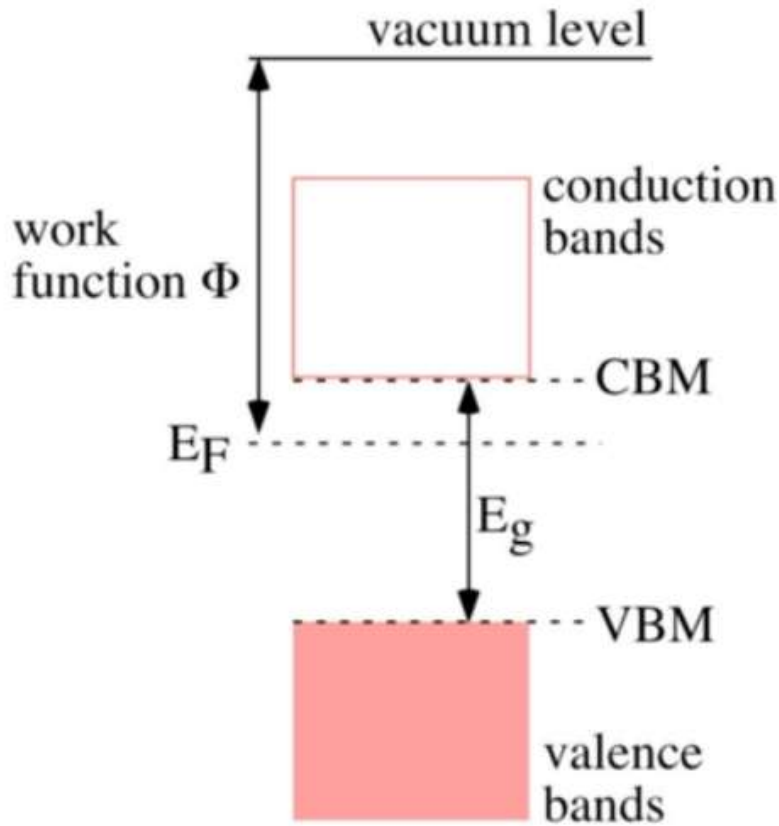


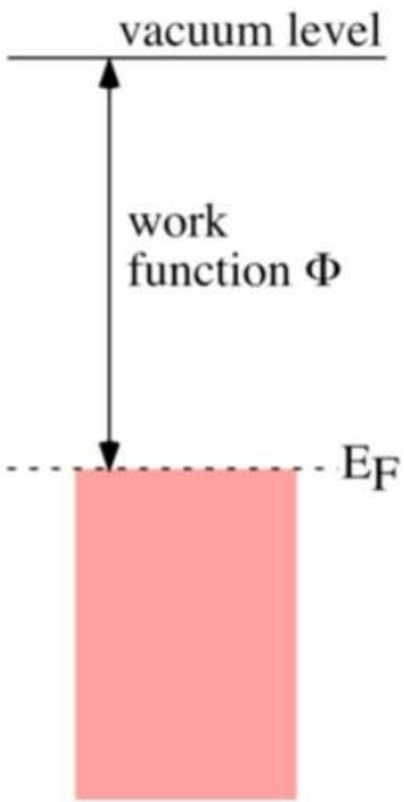
For a Semiconductor:



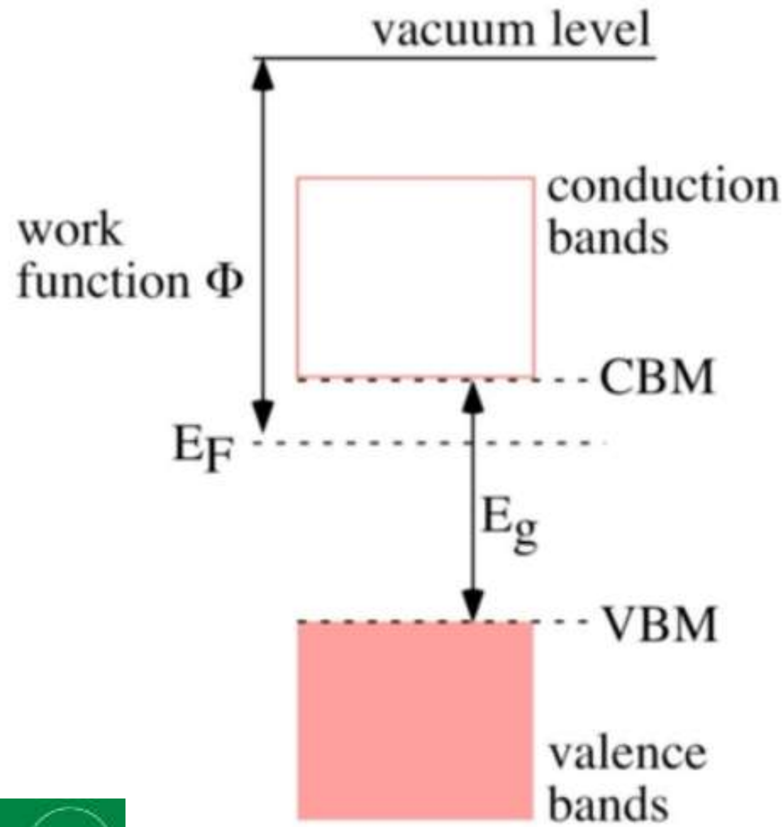
work function (German: Austrittsarbeit)

The work function is the energy required to release an electron from a solid

For a metal:



For a Semiconductor:



How about conduction **Continue**
"SCT_SS20_02.7" 4:39

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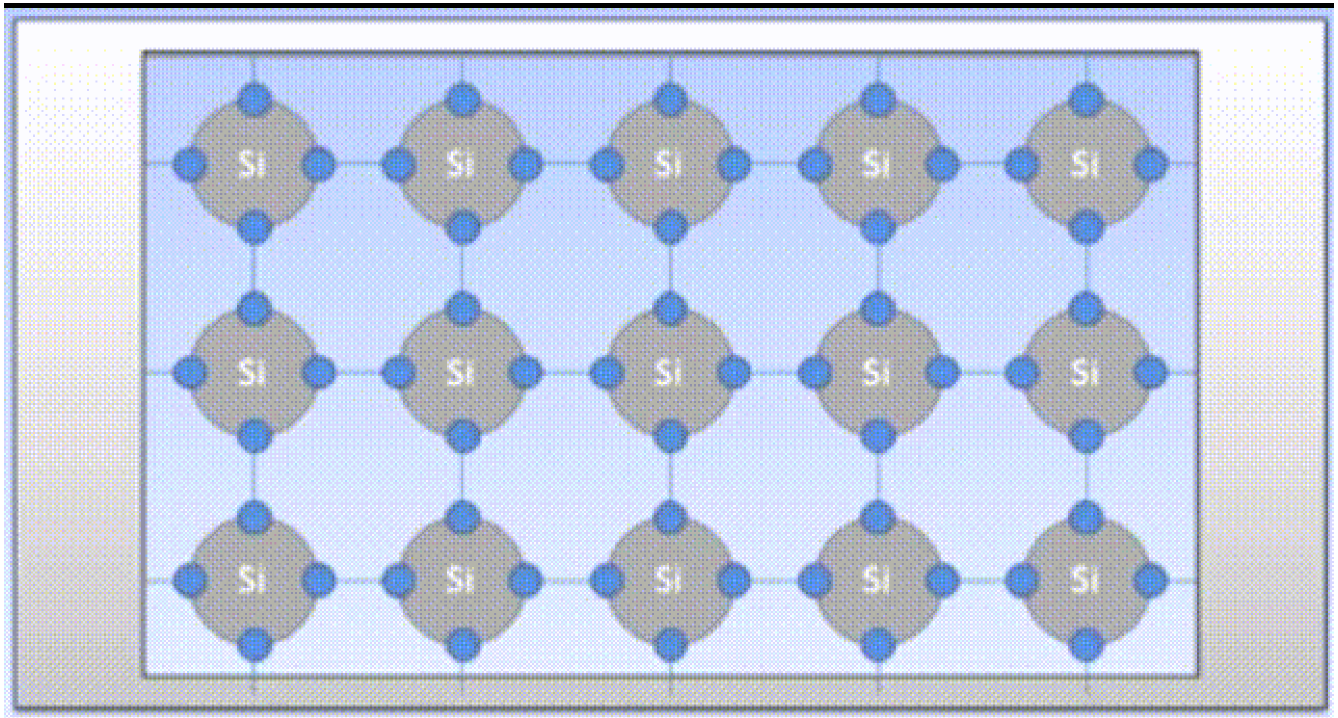
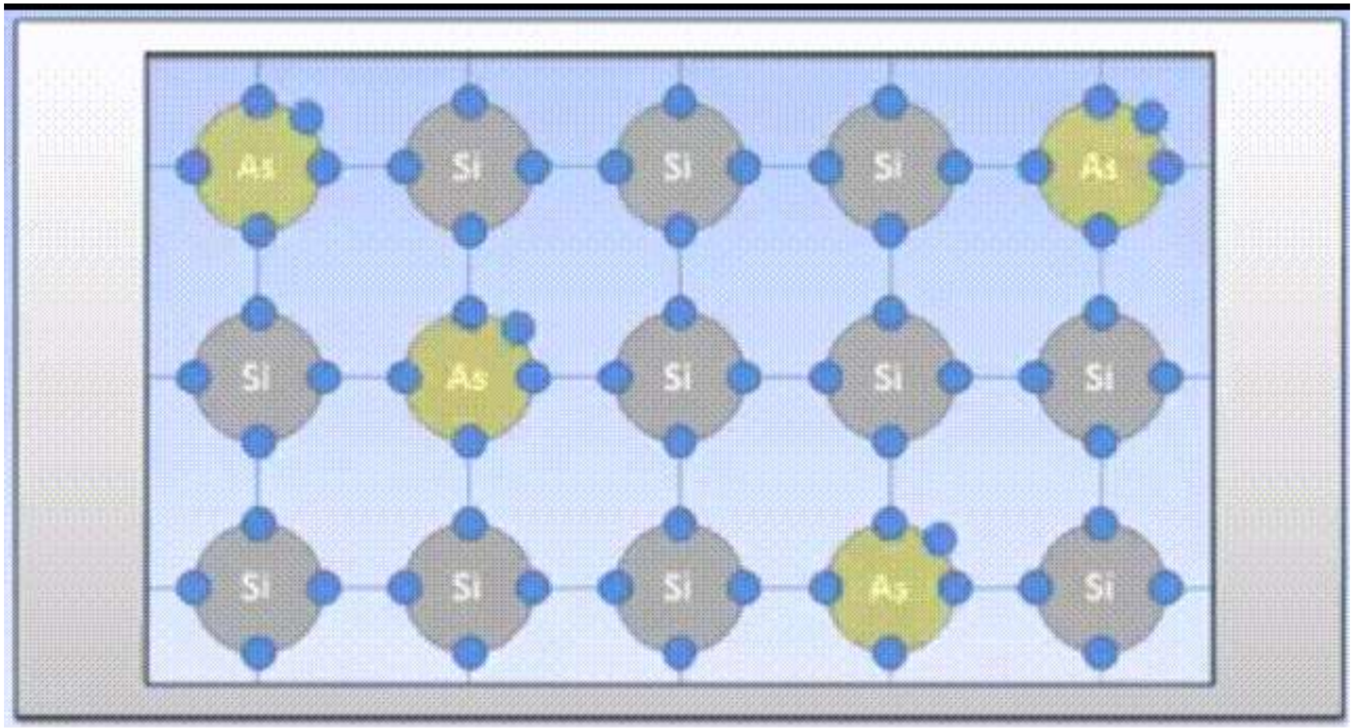
Conduction in an intrinsic semiconductor:



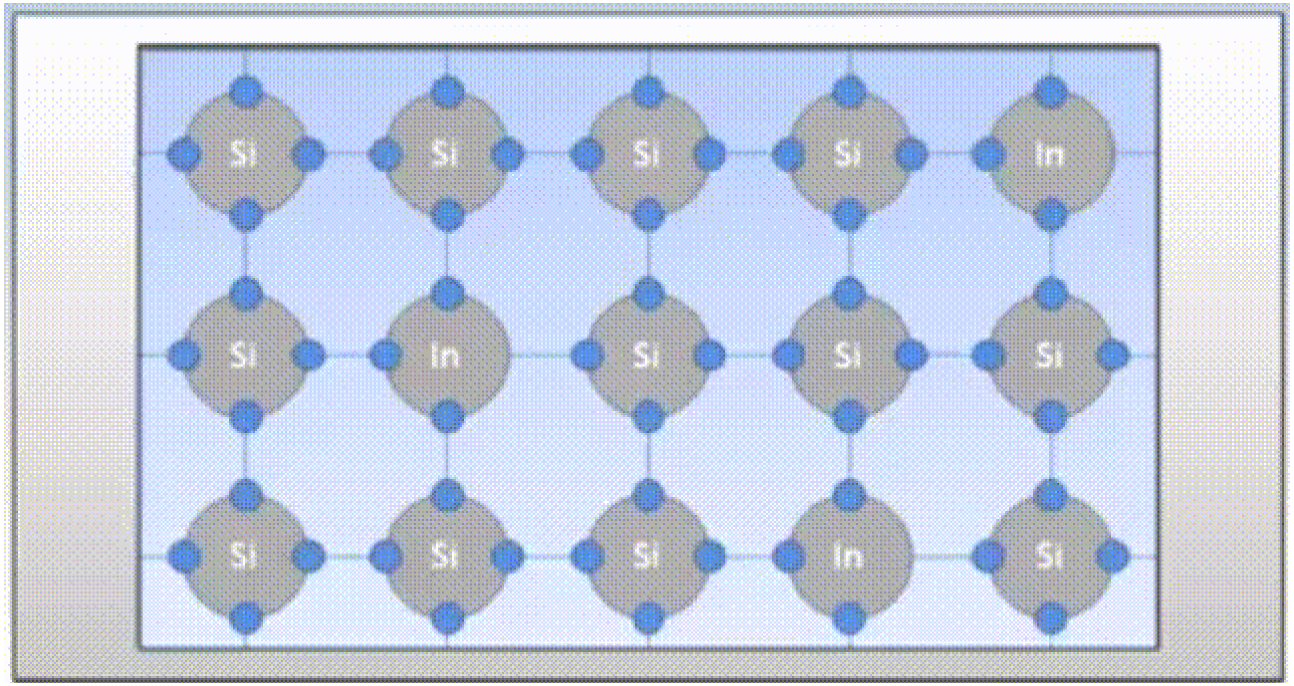
Conduction in an extrinsic semiconductor:

n- conduction

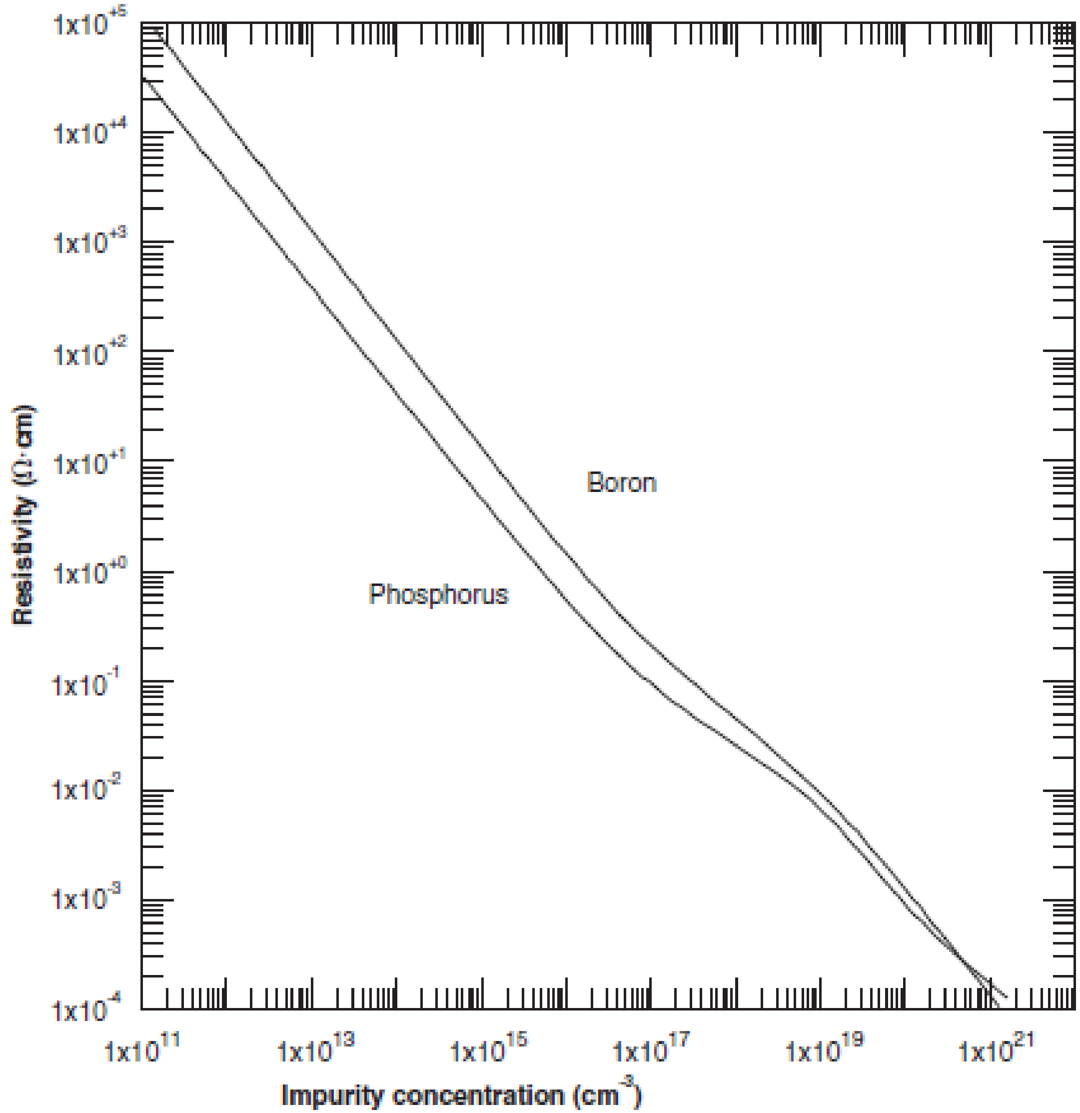


Conduction in an extrinsic semiconductor:

p- conduction



Si - Resistivity vs. doping



And now the p/n junction

Continue

"SCT_SS20_02.8" 15:24

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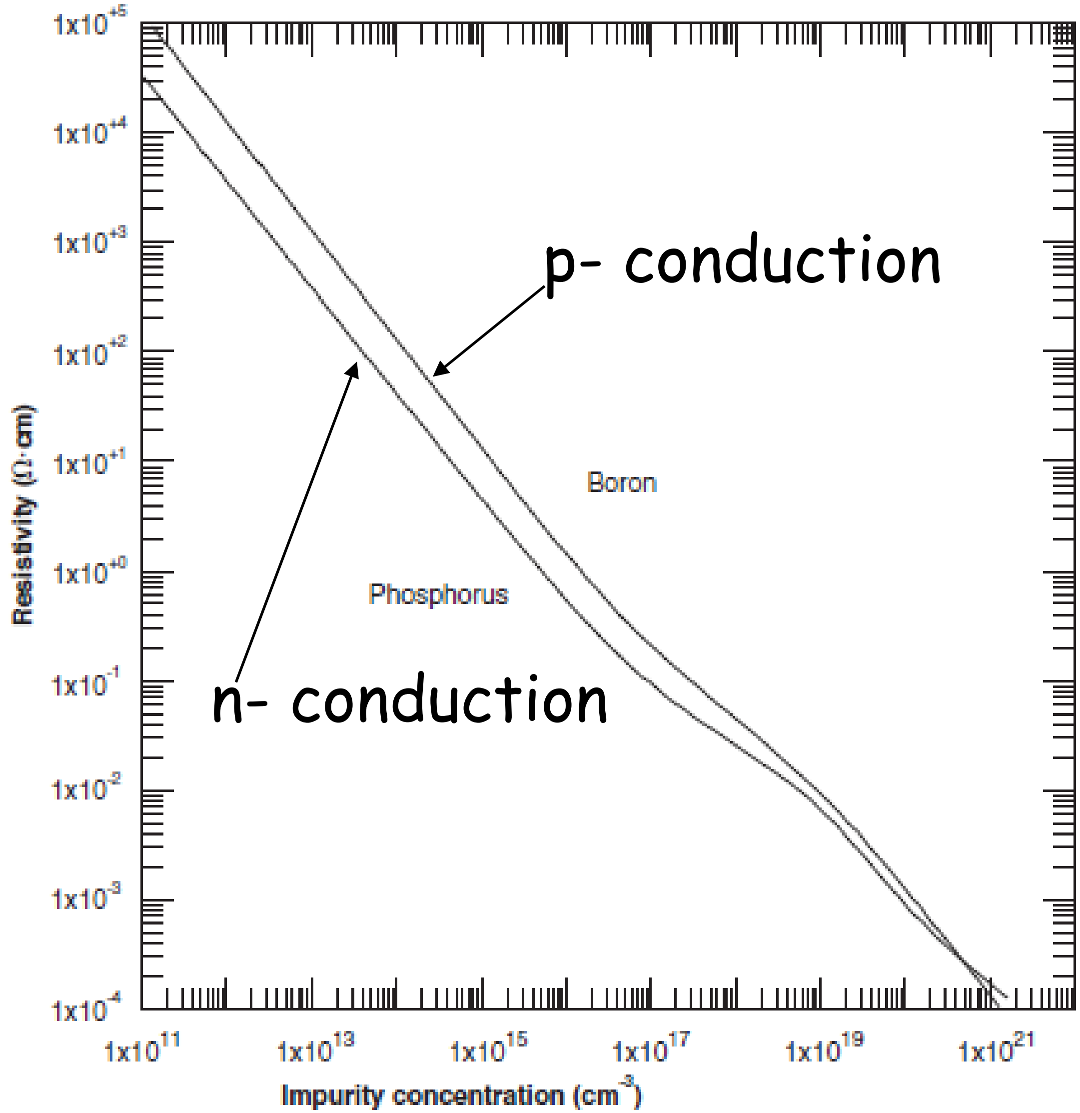
Si - Resistivity vs. doping



And now the p/n junction

Continue

"SCT_SS20_02.8" 15:24

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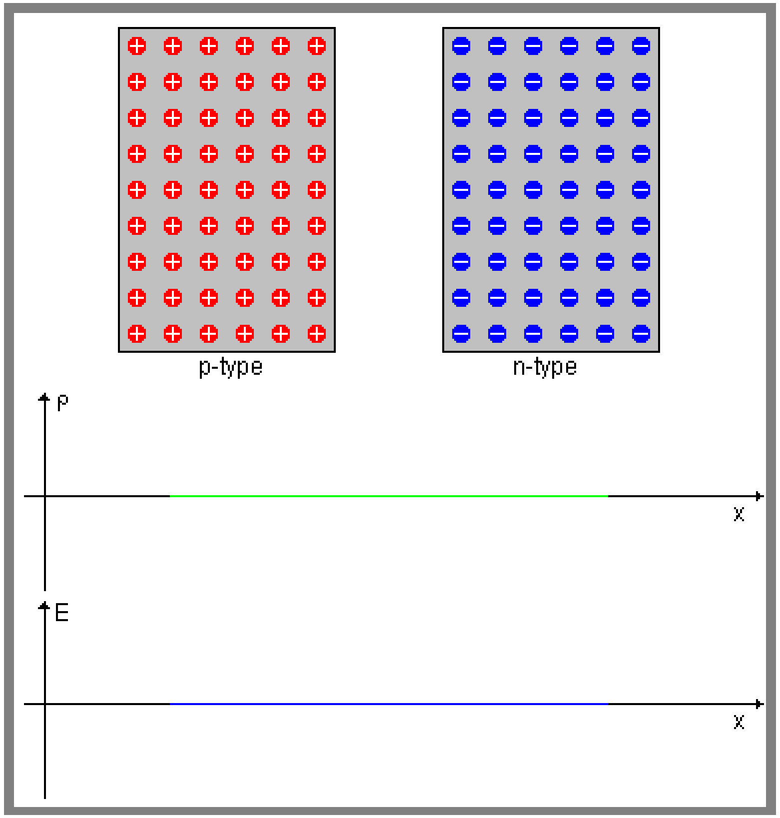
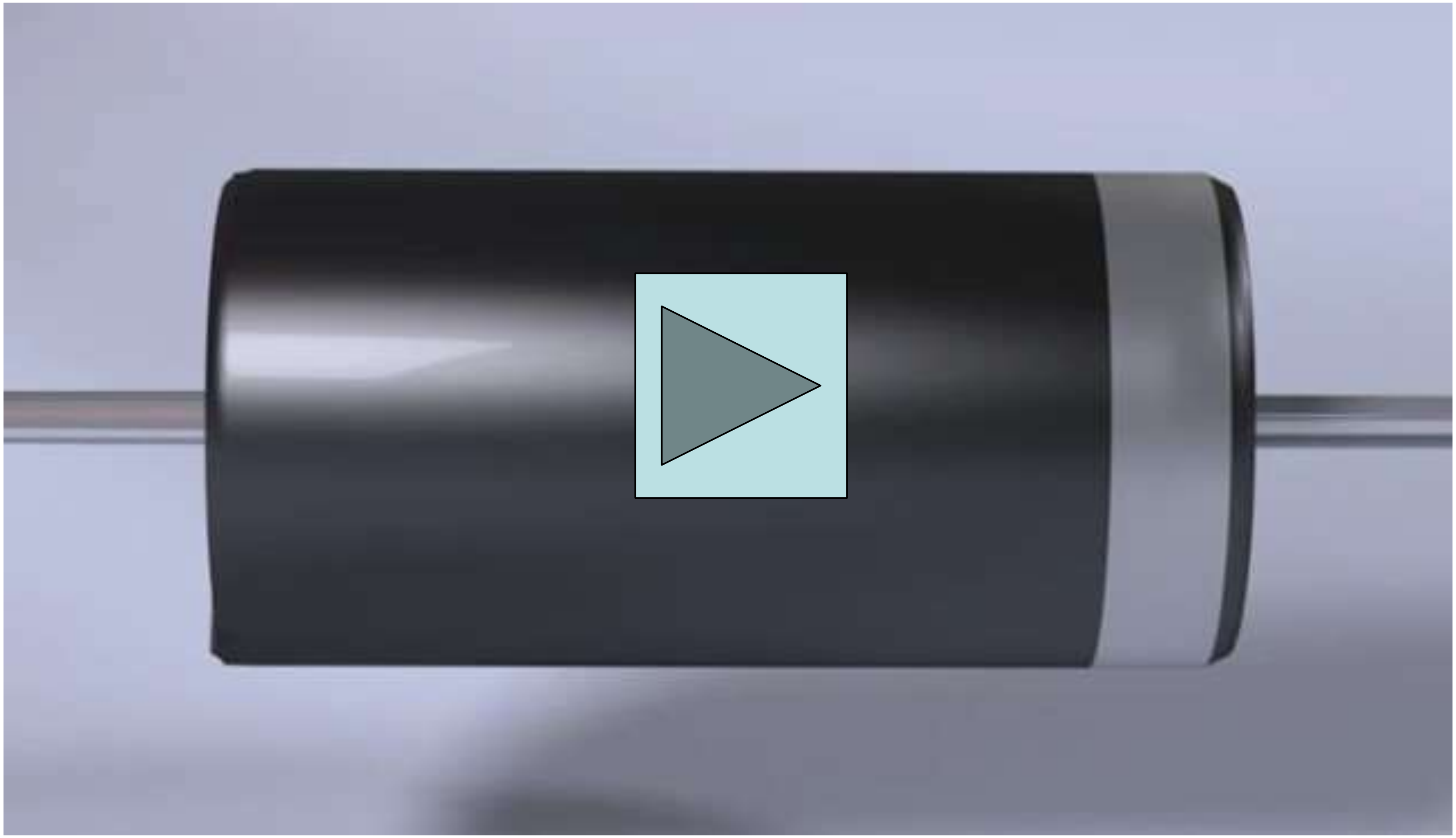
p/n junction

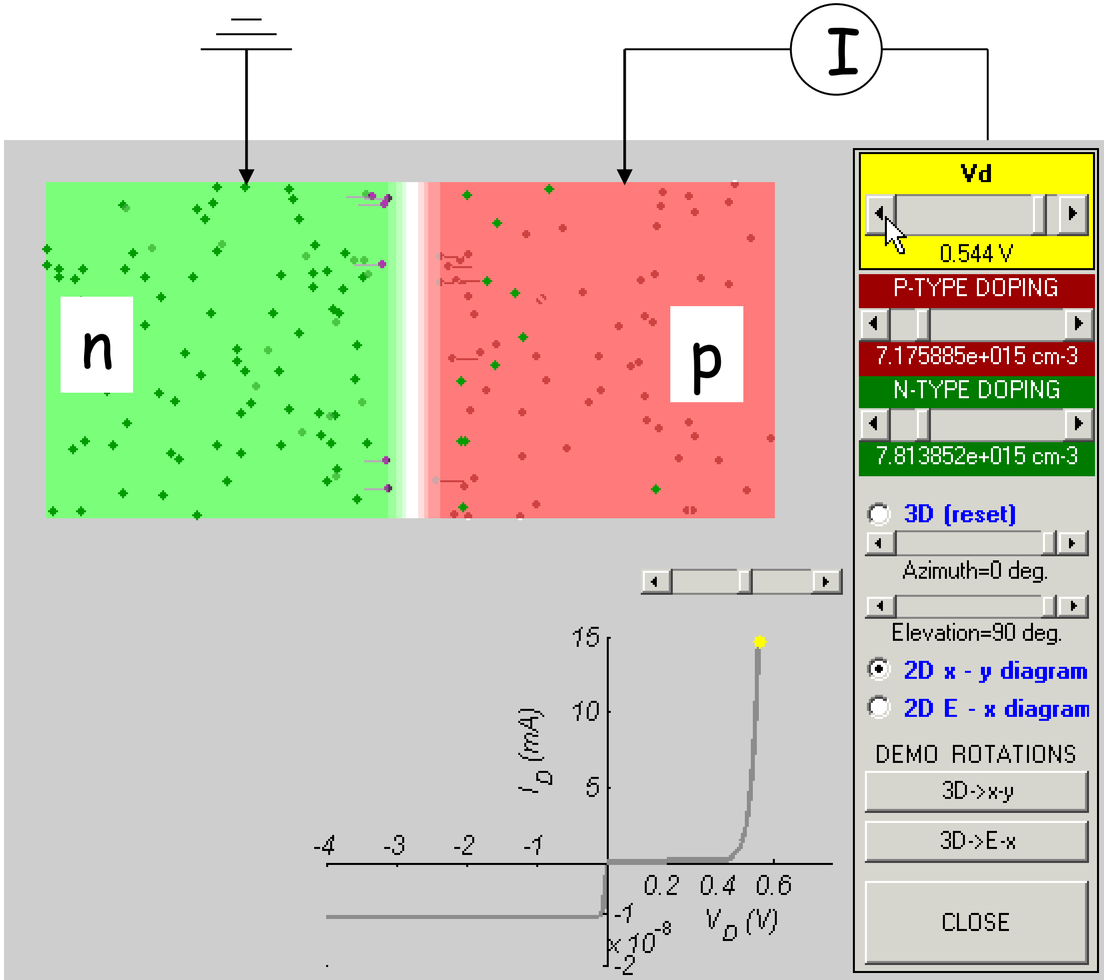


p/n junction



Taken from:
https://www.youtube.com/watch?v=JBtEckh3L9Q&t=4s

p/n junction



From:
Sima Dimitrijev, Understanding Semiconductor,Oxford University Press 2000

End of the chapter on semiconductor basics!

»Wissen schafft Brücken.«