Materials-and-Production-Engineering - Materials

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Parts of the script are adopted from

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Image Reference

Lecture

Framework

- Eating or drinking is okay, but quietly
- Problems with childcare
- Everything stays in the room!
- Questions

Content

- Materials
- Structure of materials
  - Atoms and bonds
  - Fine structure
  - Microstructure
- Structure of materials
- Material properties
  - physical
  - non-physical
- Phase diagrams
- …

Materials

- What are materials?

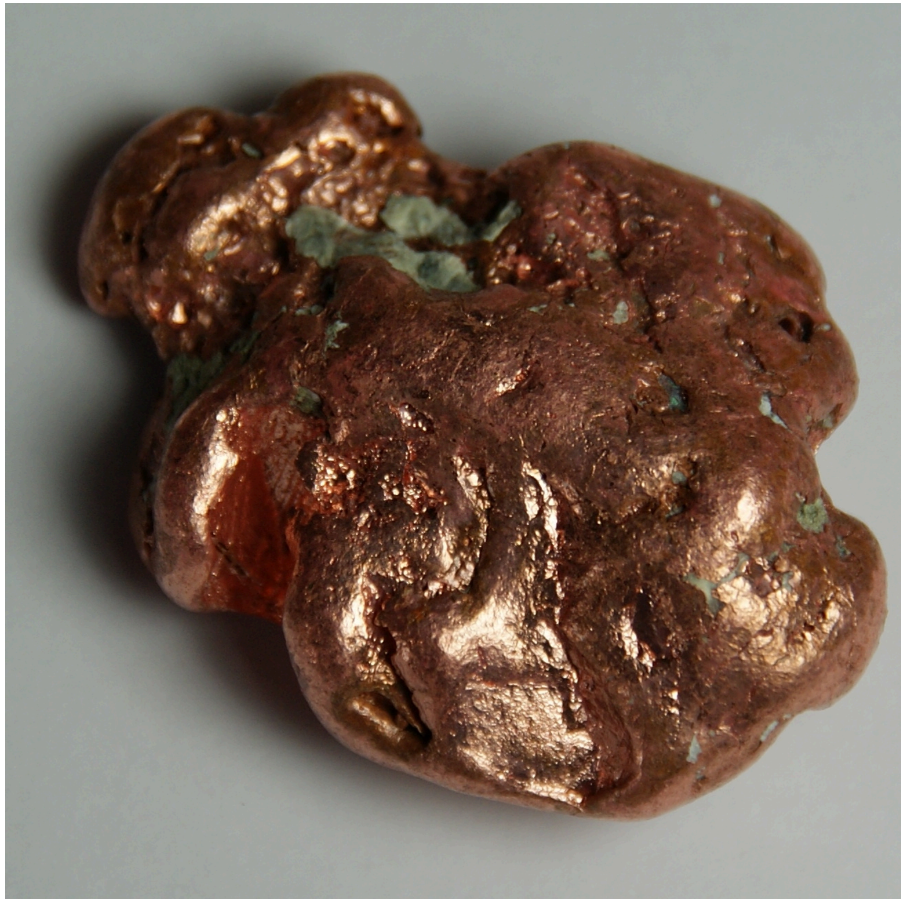
Application Areas

- Metals
  - Iron steel
  - Non-ferrous
- Plastics
- Ceramics
- Composites

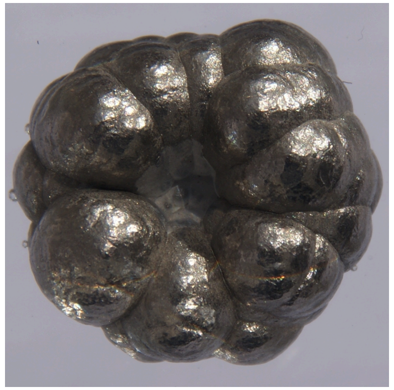
Cast Iron - Steel

Non-Ferrous Metals

- Copper is a very good electrical and thermal conductor



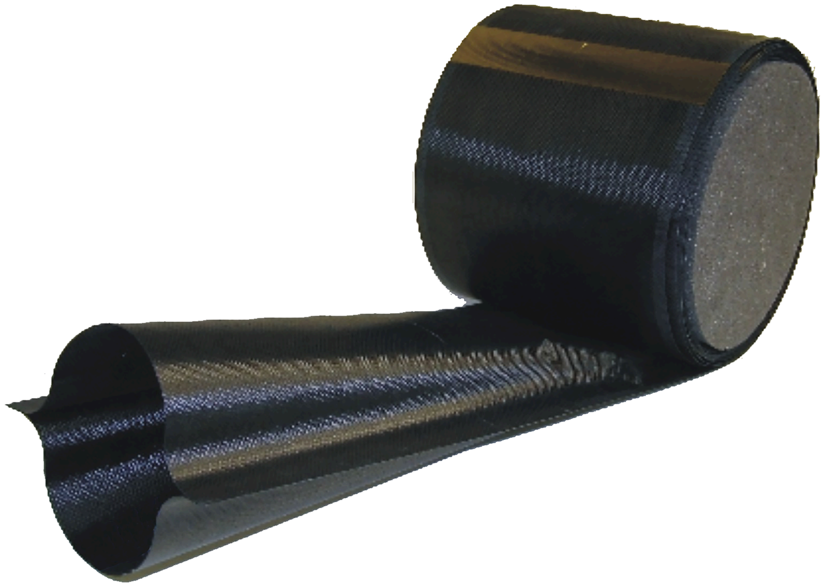
- Magnesium is used in lightweight construction
- Titanium and titanium alloys
    - high strength and heat resistance
    - Corrosion resistant
- Nickel
    - Corrosion resistance
    - high heat resistance



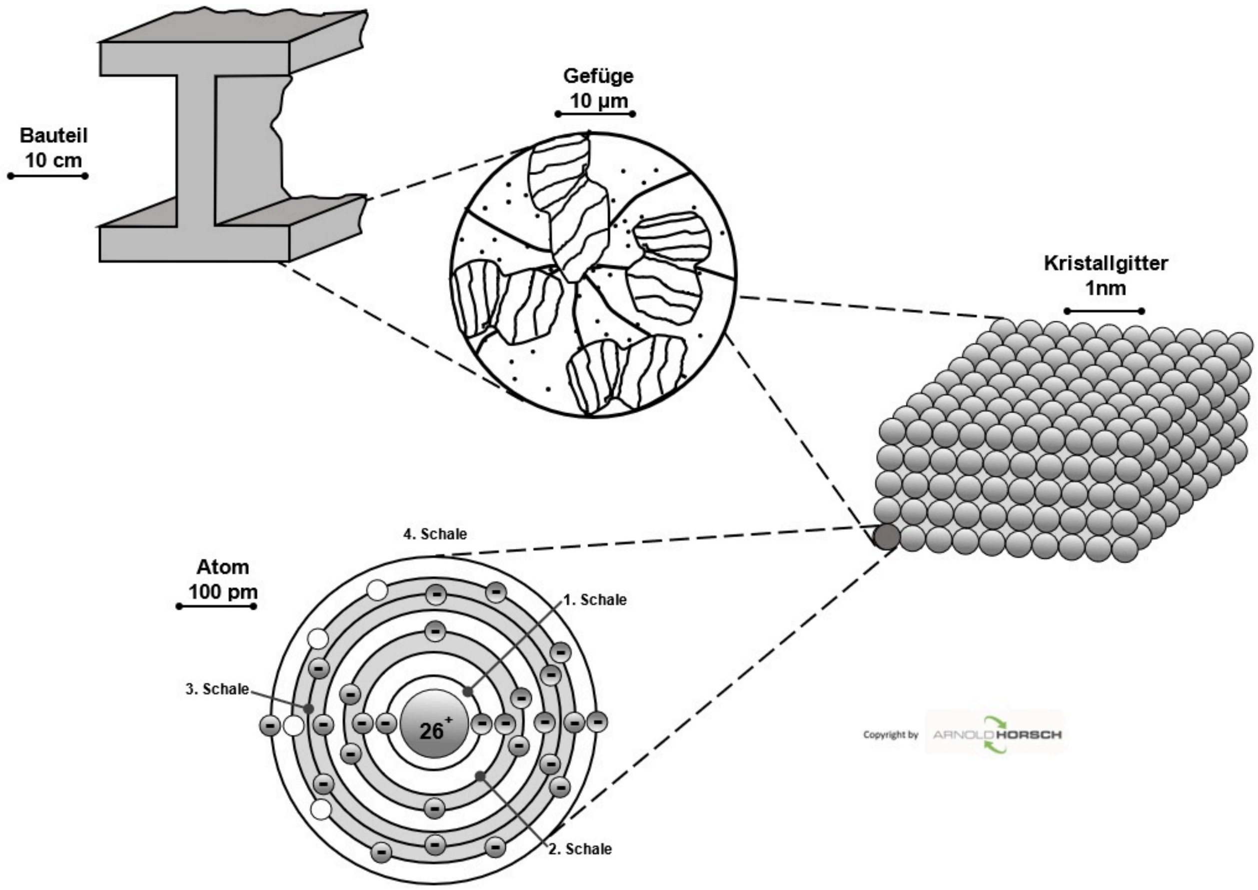
Ceramics

Glasses

Fiber Composites



Structure of Materials



- Atomic structure (type of atomic building blocks)
- Fine structure (bonds between atomic building blocks and their geometric arrangement)
- Microstructure (structure - areas of geometric arrangement separated by interfaces inside the material)
- Macrostructure (coarse structure - overall appearance of a material during production and application of a component)

Bonds

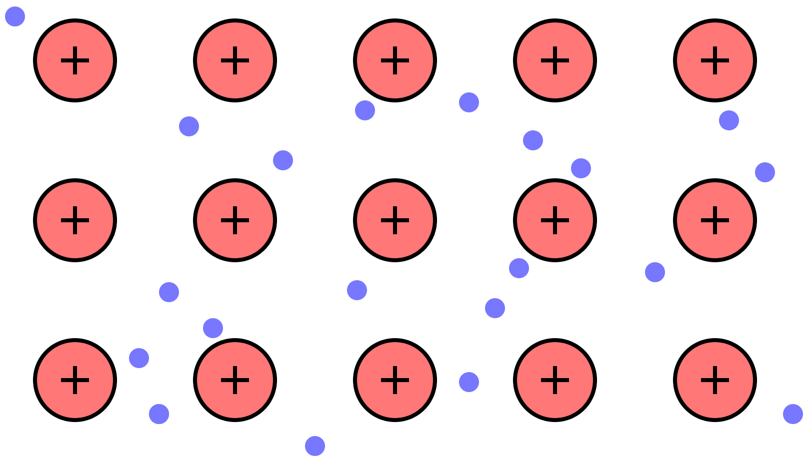
Primary Bonds

Primary bonds - high bond energy, strong bond

- Ionic or heteropolar bond
- Covalent bond: polar (O-H) and non-polar (C-C, C-H)
- Metallic bond

Metallic Bond

- Valence electrons are only weakly bound
- a lattice (periodically arranged) of positively charged metal ions (atomic cores) is formed
- Valence electrons can move almost freely within the lattice, known as **electron gas**
- Results: good electrical conductivity + high thermal conductivity



Legende

Ordnungszahl | Atomgewicht | Symbol | Name | Elektronegativität | Dichte | Serie

Beispiel: 17 35,451 Cl Chlor 3,16 3,21

Symbol
- schwarz = Feststoff
- blau = Flüssigkeit
- rot = Gas
- grau = unbekannt
- unterstrichen = radioaktiv

Dichte
- rot = kg / m³
- schwarz = kg / dm³
- grau = unbestimmt

Serie (Flächenfarbe)
- Alkalimetalle
- Erdalkalimetalle
- Übergangsmetalle
- Lanthanoide
- Actinoide
- Metalle
- Halbmetalle
- Nichtmetalle
- Halogene
- Edelgase
- unbekannt

Schraffur
- durchgehend = natürliches Element
- schraffiert = künstliches Element

Gruppe / Periode

Periode	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 1,008 H Wasserstoff 2,2 0,09																	2 4,0026 He Helium — 0,18
2	3 6,94 Li Lithium 0,98 0,53	4 9,0122 Be Beryllium 1,57 1,85											5 10,81 B Bor 2,04 2,46	6 12,011 C Kohlenstoff 2,55 2,26	7 14,007 N Stickstoff 3,04 1,25	8 15,999 O Sauerstoff 3,44 1,43	9 18,998 F Fluor 3,98 1,70	10 20,180 Ne Neon — 0,90
3	11 22,990 Na Natrium 0,93 0,97	12 24,305 Mg Magnesium 1,31 1,74											13 26,982 Al Aluminium 1,61 2,70	14 28,085 Si Silicium 1,90 2,34	15 30,974 P Phosphor 2,19 2,69	16 32,06 S Schwefel 2,58 2,07	17 35,45 Cl Chlor 3,16 3,21	18 39,948 Ar Argon — 1,78
4	19 39,098 K Kalium 0,82 0,86	20 40,078 Ca Calcium 1,0 1,55	21 44,956 Sc Scandium 1,36 2,98	22 47,867 Ti Titan 1,54 4,50	23 50,942 V Vanadium 1,63 6,11	24 51,996 Cr Chrom 1,66 7,14	25 54,938 Mn Mangan 1,55 7,43	26 55,845 Fe Eisen 1,83 7,87	27 58,933 Co Cobalt 1,88 8,90	28 58,693 Ni Nickel 1,91 8,91	29 63,546 Cu Kupfer 1,90 8,92	30 65,380 Zn Zink 1,65 7,14	31 69,723 Ga Gallium 1,81 5,90	32 72,630 Ge Germanium 2,01 5,32	33 74,922 As Arsen 2,18 5,73	34 78,971 Se Selen 2,55 4,82	35 79,904 Br Brom 2,96 3,12	36 83,798 Kr Krypton 3,0 3,75
5	37 85,468 Rb Rubidium 0,82 1,53	38 87,62 Sr Strontium 0,95 2,63	39 88,906 Y Yttrium 1,22 4,47	40 91,224 Zr Zirconium 1,33 6,50	41 92,906 Nb Niob 1,6 8,57	42 95,95 Mo Molybdän 2,16 10,28	43 96,906 Tc Technetium 1,9 11,50	44 101,07 Ru Ruthenium 2,2 12,37	45 102,91 Rh Rhodium 2,28 12,45	46 106,42 Pd Palladium 2,20 12,02	47 107,87 Ag Silber 1,93 10,49	48 112,41 Cd Cadmium 1,69 8,64	49 114,82 In Indium 1,78 7,31	50 118,71 Sn Zinn 1,96 7,26	51 121,76 Sb Antimon 2,05 6,70	52 127,60 Te Tellur 2,1 6,25	53 126,90 I Iod 2,66 4,94	54 131,29 Xe Xenon 2,6 5,90
6	55 132,91 Cs Caesium 0,79 1,90	56 137,33 Ba Barium 0,89 3,59	57 138,91 La Lanthan 1,10 6,15 / 58–71 siehe unten	72 178,49 Hf Hafnium 1,3 13,3	73 180,95 Ta Tantal 1,5 16,65	74 183,84 W Wolfram 2,36 19,25	75 186,21 Re Rhenium 1,9 21,0	76 190,23 Os Osmium 2,2 22,6	77 192,22 Ir Iridium 2,2 22,56	78 195,08 Pt Platin 2,28 21,45	79 196,97 Au Gold 2,54 19,32	80 200,59 Hg Quecksilber 2,0 13,55	81 204,38 Tl Thallium 1,62 11,85	82 207,20 Pb Blei 2,33 11,35	83 208,98 Bi Bismut 2,02 9,75	84 209,98 Po Polonium 2,0 9,20	85 209,99 At Astat 2,2 ?	86 222,02 Rn Radon — 9,73
7	87 223,03 Fr Francium 0,7 ?	88 226,03 Ra Radium 0,9 5,5	89 227,03 Ac Actinium 1,1 10,1 / 90–103 siehe unten	104 267,12 Rf Rutherfordium ? ?	105 270,13 Db Dubnium ? ?	106 269,13 Sg Seaborgium ? ?	107 270,13 Bh Bohrium ? ?	108 269,13 Hs Hassium ? ?	109 278,16 Mt Meitnerium ? ?	110 281,17 Ds Darmstadtium ? ?	111 281,17 Rg Roentgenium ? ?	112 285,18 Cn Copernicium ? ?	113 286,18 Nh Nihonium ? ?	114 289,19 Fl Flerovium ? ?	115 289,20 Mc Moscovium ? ?	116 293,20 Lv Livermorium ? ?	117 293,21 Ts Tenness ? ?	118 294,21 Og Oganesson ? ?

Lanthanoide	58 140,12 Ce Cer 1,12 6,77	59 140,91 Pr Praseodym 1,13 6,48	60 144,24 Nd Neodym 1,14 7,01	61 144,91 Pm Promethium — 7,22	62 150,36 Sm Samarium 1,17 7,54	63 151,96 Eu Europium — 5,25	64 157,25 Gd Gadolinium 1,2 7,89	65 158,93 Tb Terbium — 8,25	66 162,50 Dy Dysprosium 1,22 8,55	67 164,93 Ho Holmium 1,23 8,78	68 167,26 Er Erbium 1,24 9,05	69 168,93 Tm Thulium 1,25 9,32	70 173,05 Yb Ytterbium — 6,97	71 174,97 Lu Lutetium 1,27 9,84
Actinoide	90 232,04 Th Thorium 1,3 11,72	91 231,04 Pa Protactinium 1,5 15,4	92 238,03 U Uran 1,38 18,95	93 237,05 Np Neptunium 1,36 20,45	94 244,06 Pu Plutonium 1,28 19,82	95 243,06 Am Americium 1,3 13,67	96 247,07 Cm Curium 1,3 13,51	97 247,07 Bk Berkelium 1,3 14,78	98 251,08 Cf Californium 1,3 15,1	99 252,08 Es Einsteinium 1,3 ?	100 257,10 Fm Fermium 1,3 ?	101 258,10 Md Mendelevium 1,3 ?	102 259,10 No Nobelium 1,3 ?	103 262,11 Lr Lawrencium — ?

Relevant Quantities

Atomic number

Number of protons in the nucleus

Atomic mass

Defines the mass of the element

The mass of the material is a combination of atomic mass and density

Electronegativity

Defines whether atoms are donated or accepted in a bond

Metallic bonds tend to the left

Covalent bonds tend to the right

Secondary Bonds

Secondary bonds - low bond energy, weak bond

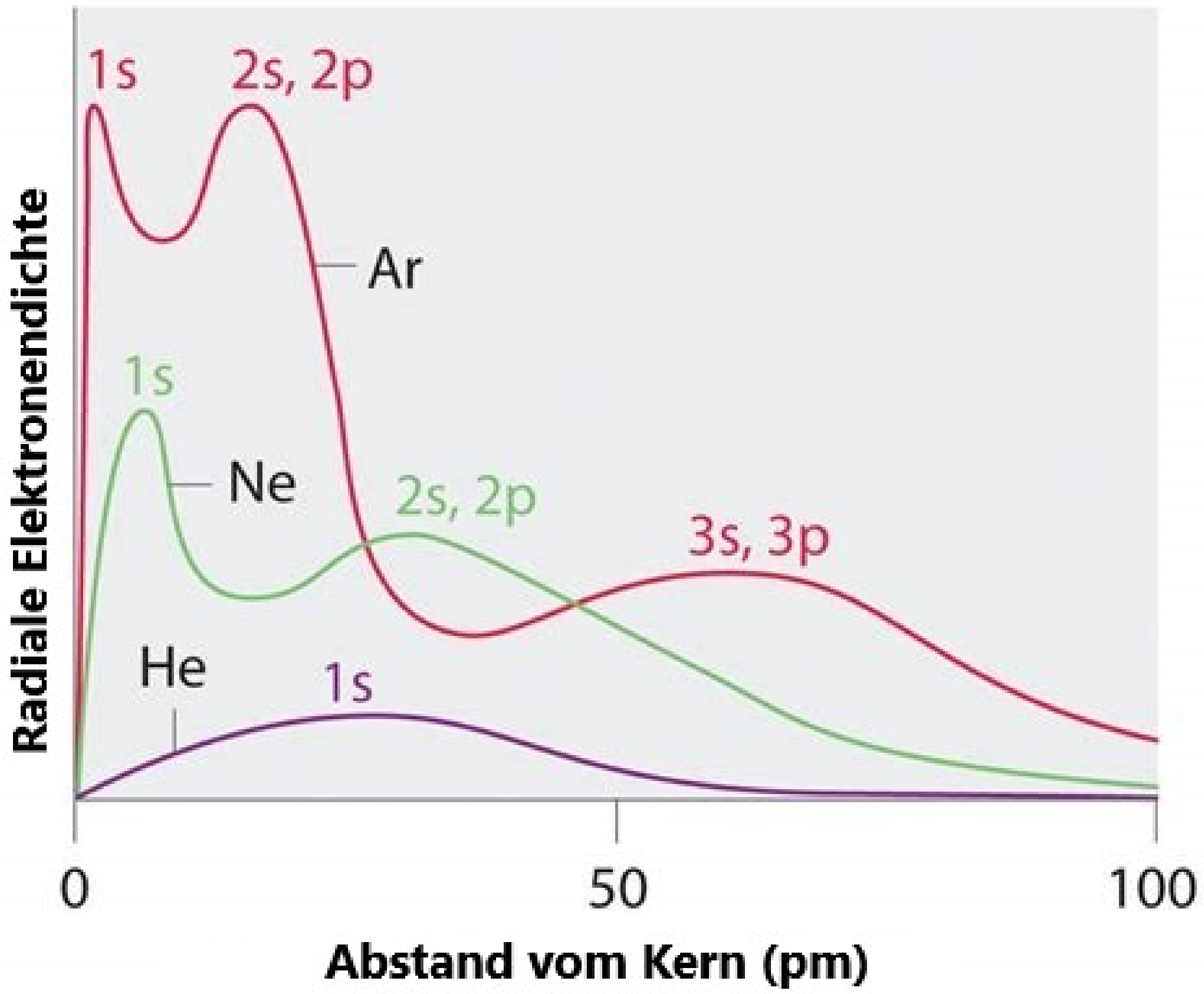
- Van der Waals bond: intermolecular forces
- Hydrogen bond: two molecules or two suitably distant parts of a macromolecule interact via hydrogen atoms
- The bond energies are one to two orders of magnitude smaller than atomic bonds.

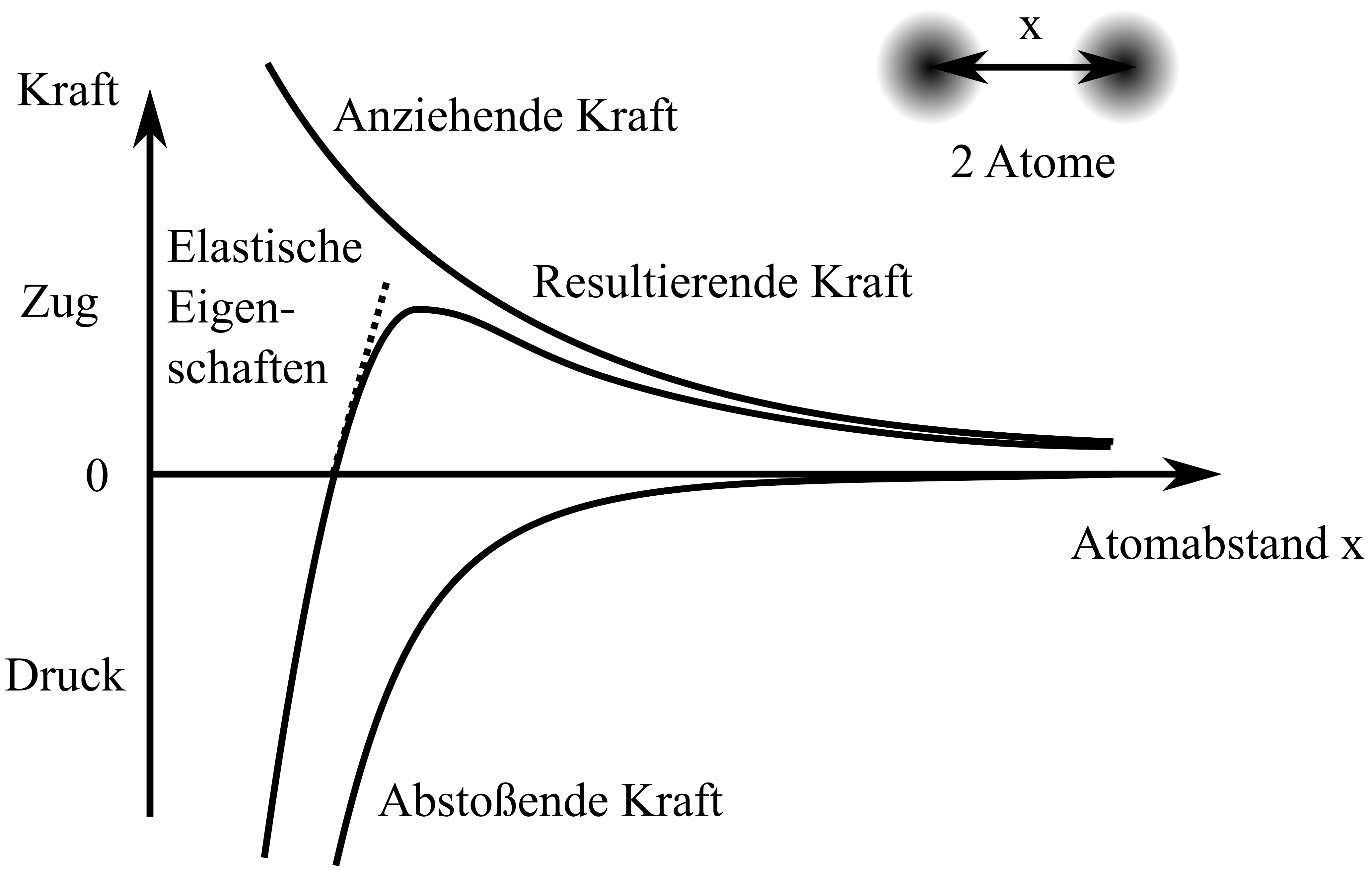
Name	Ionic or heteropolar bond	Covalent homopolar (covalent) bond	Metallic bond
Components	Ions (metal + non-metal)	Same atom type (non-metal + non-metal)	Same atom type (metal + metal)
Description of electrical charge state	Positively charged ion + negatively charged ion (cation + anion)	Atoms have one or more shared electron pairs to reach noble gas configuration	Atoms donate their valence electrons to the whole bond. Electrons move freely in the lattice

Atomic Structure

Consists of

- Nucleus (Protons + Neutrons) which defines the mass
- Shell (Electrons) with various layers that define chemical and many physical properties




x
2 Atome
Kraft
Anziehende Kraft
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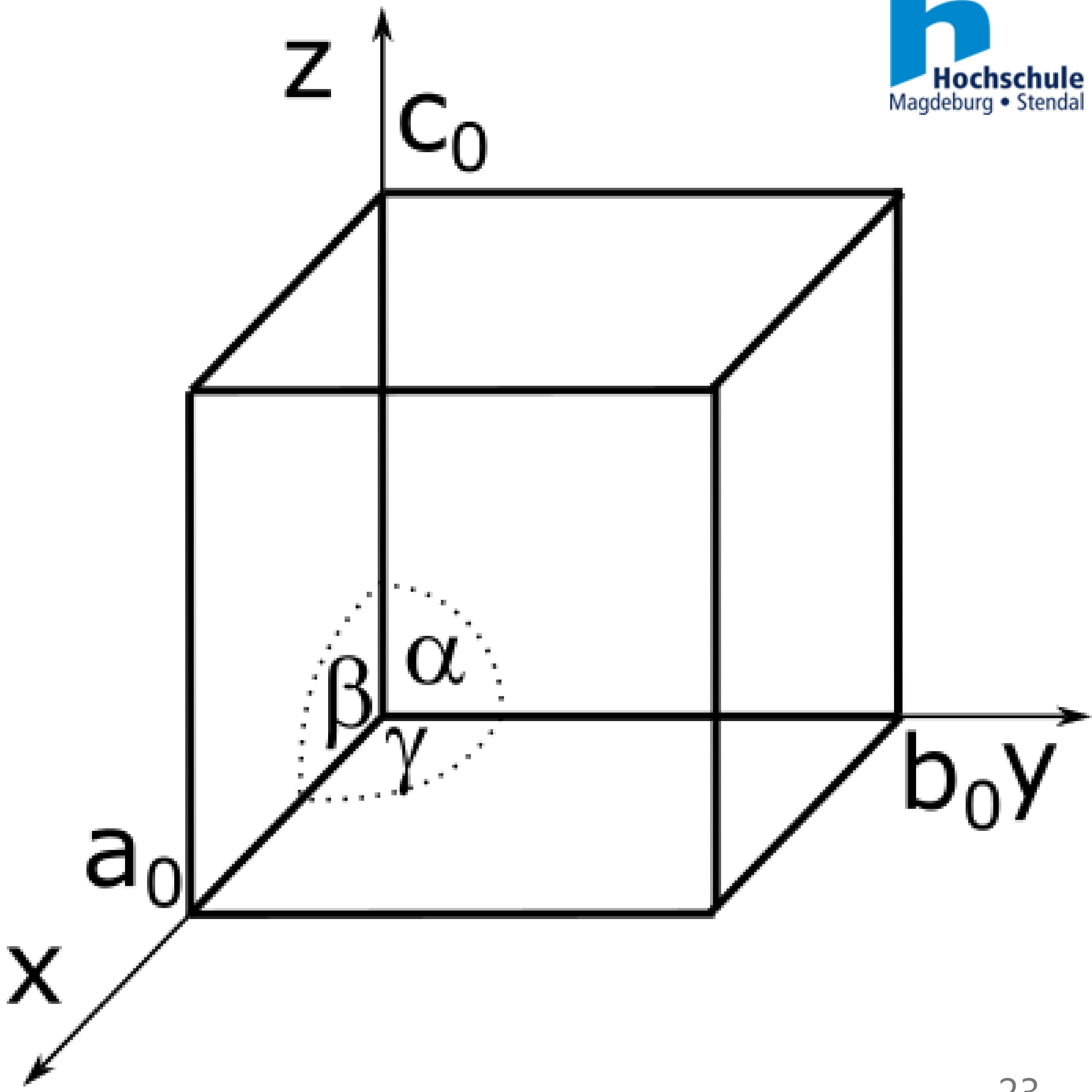
Abstoßende Kraft

Fine Structure

- Crystal structures
- Molecular structures
- Glassy-amorphous structures
- Real structure

Space Lattice

- Formed by the three-dimensional periodic shift of its components
- Characterized by three spatial axes x, y, and z, with angles α, β, γ and distances on the axes defining the respective space lattice
- a_0, b_0, and c_0 (lattice constants) -> Unit cell



Crystal System	Lattice Constants	Angles	Examples
Triclinic	$a_0 \neq b_0 \neq c_0$	$\alpha \neq \beta \neq \gamma \neq 90°$	Silicate minerals
Monoclinic	$a_0 \neq b_0 \neq c_0$	$\alpha = \gamma = 90°; \beta \neq 90°$	Mo_2S_3; β-Pu
Orthorhombic	$a_0 \neq b_0 \neq c_0$	$\alpha = \beta = \gamma = 90°$	U, S, P, Ga, γ-Sn
Rhombohedral	$a_0 = b_0 = c_0$	$\alpha = \beta = \gamma \neq 90°$	As, Hg, Sb
Hexagonal	$a_0 = b_0 \neq c_0$	$\alpha = \beta = 90°; \gamma = 120°$	α-Ti, Mg, Zn
Tetragonal	$a_0 = b_0 \neq c_0$	$\alpha = \beta = \gamma = 90°$	B, $CuTi_3$, Sn (T > 13.5°C)

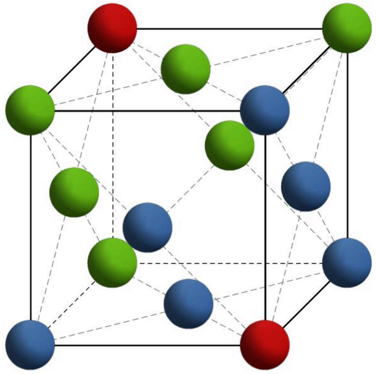
Common Lattice Structures in Metals

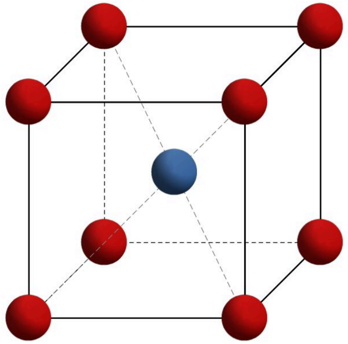
Crystal System	Lattice Constants	Angles	Examples
Cubic	$a_0 = b_0 = c_0$	$\alpha = \beta = \gamma = 90°$	Cu, Al, Ni, Au, Ag; γ-Iron (FCC); α-Iron, V, Cr, W (BCC); Mn, Po (SC)

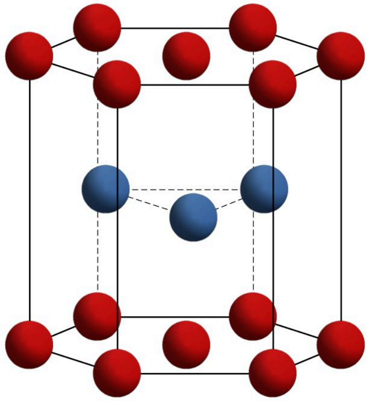
Face-Centered Cubic (FCC)

Body-Centered Cubic (BCC)

Hexagonal Close-Packed (HCP)







Influences

- **Corrosion**: Aggressive media attack preferred planes.
- **Deformation**: Plastic deformation occurs along preferred crystallographic planes and directions → Slip systems.
- **Ultrasound**: Use of quartz crystals with specific crystallographic surfaces.
- **Conductivity**: Use of germanium or silicon wafers in (1 1 1)- or (1 0 0)- orientation for semiconductor elements.
- **Magnetization**: Easiest magnetization of iron-silicon transformer sheets along the cube edge [1 0 0].

Polymorphism in Metals

- **Polymorphism**: Formation of different lattice structures depending on temperature.
- The different lattice forms are the allotropic modifications.

(Also: Carbon polymorphism: graphite, diamond, etc.)

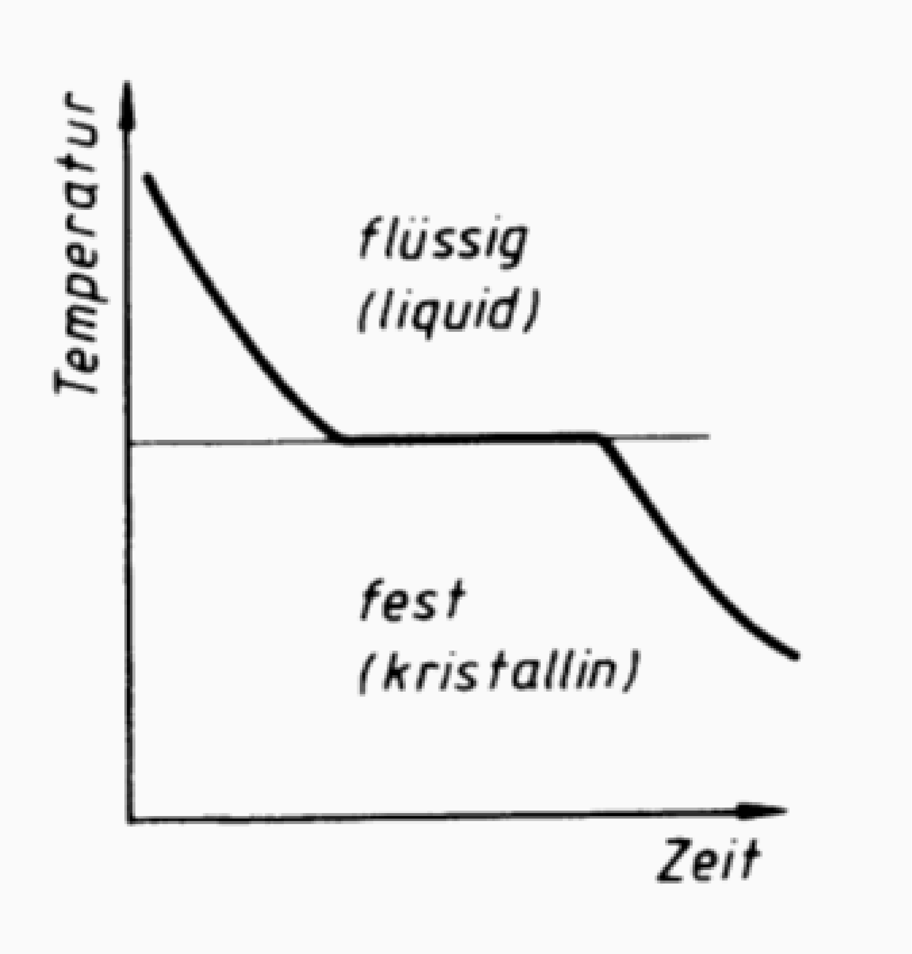
Determining Transformation Points

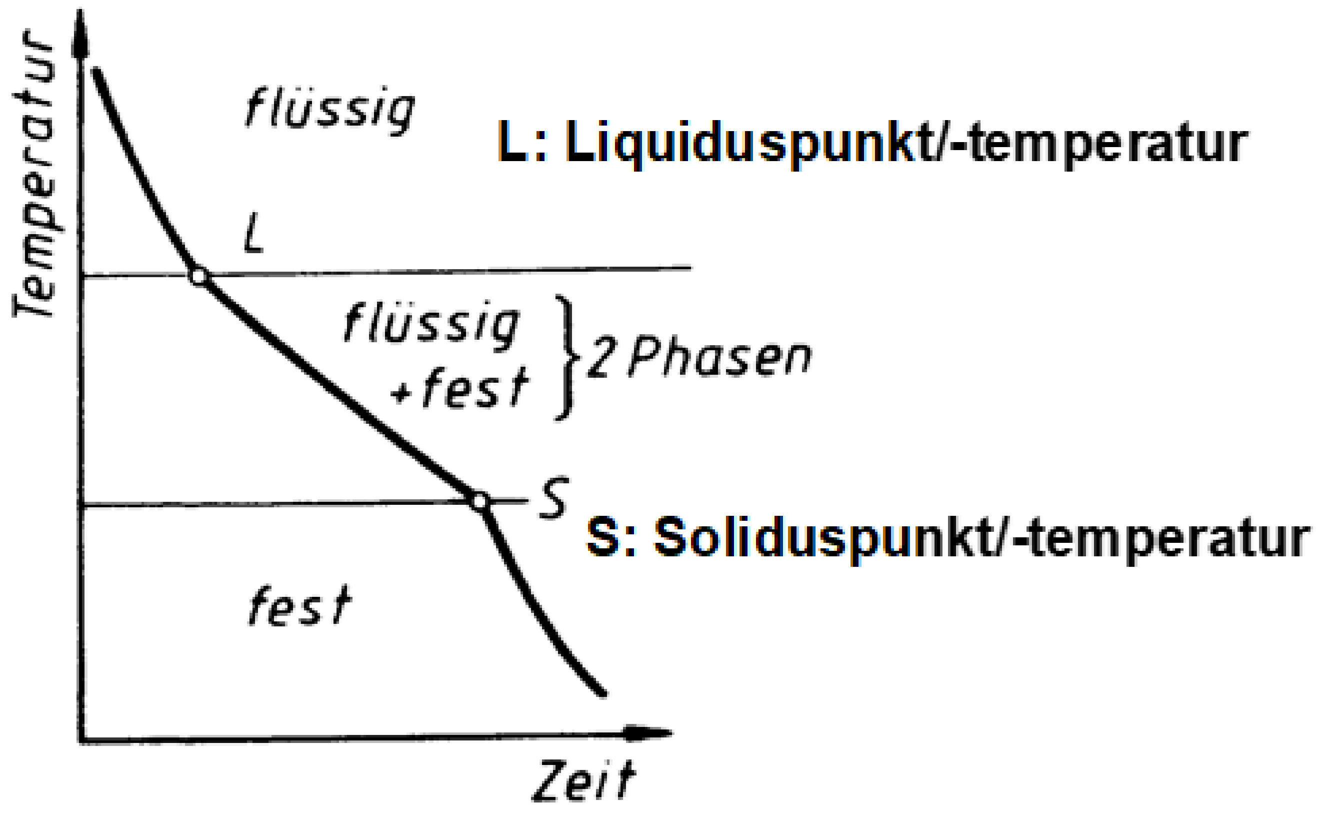
Dilatometry

- Measurement of length changes due to lattice transformation.

Thermal Analysis

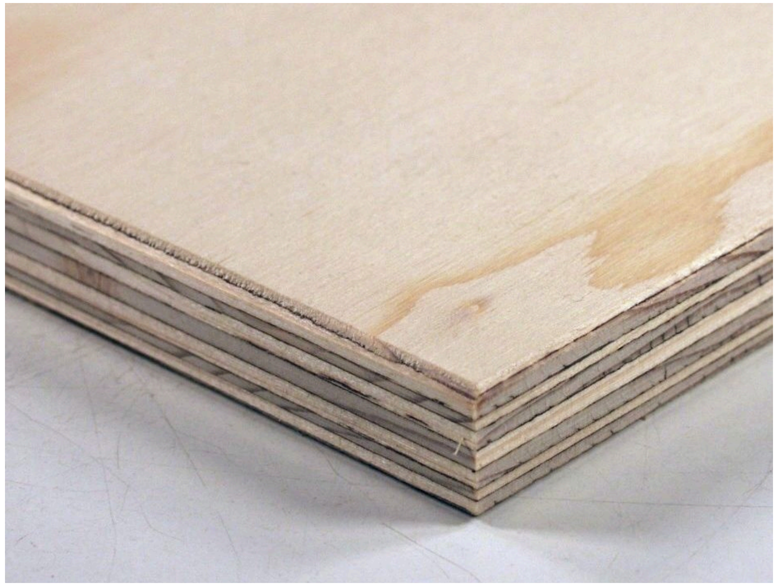
- Recording of the temperature curve.
- Lattice transformations (phase changes) require or release thermal energy.
- Holding or inflection points in heating or cooling curves.
- Holding points: In pure metals.


Temperatur
flüssig
(liquid)
fest
(kristallin)
Zeit

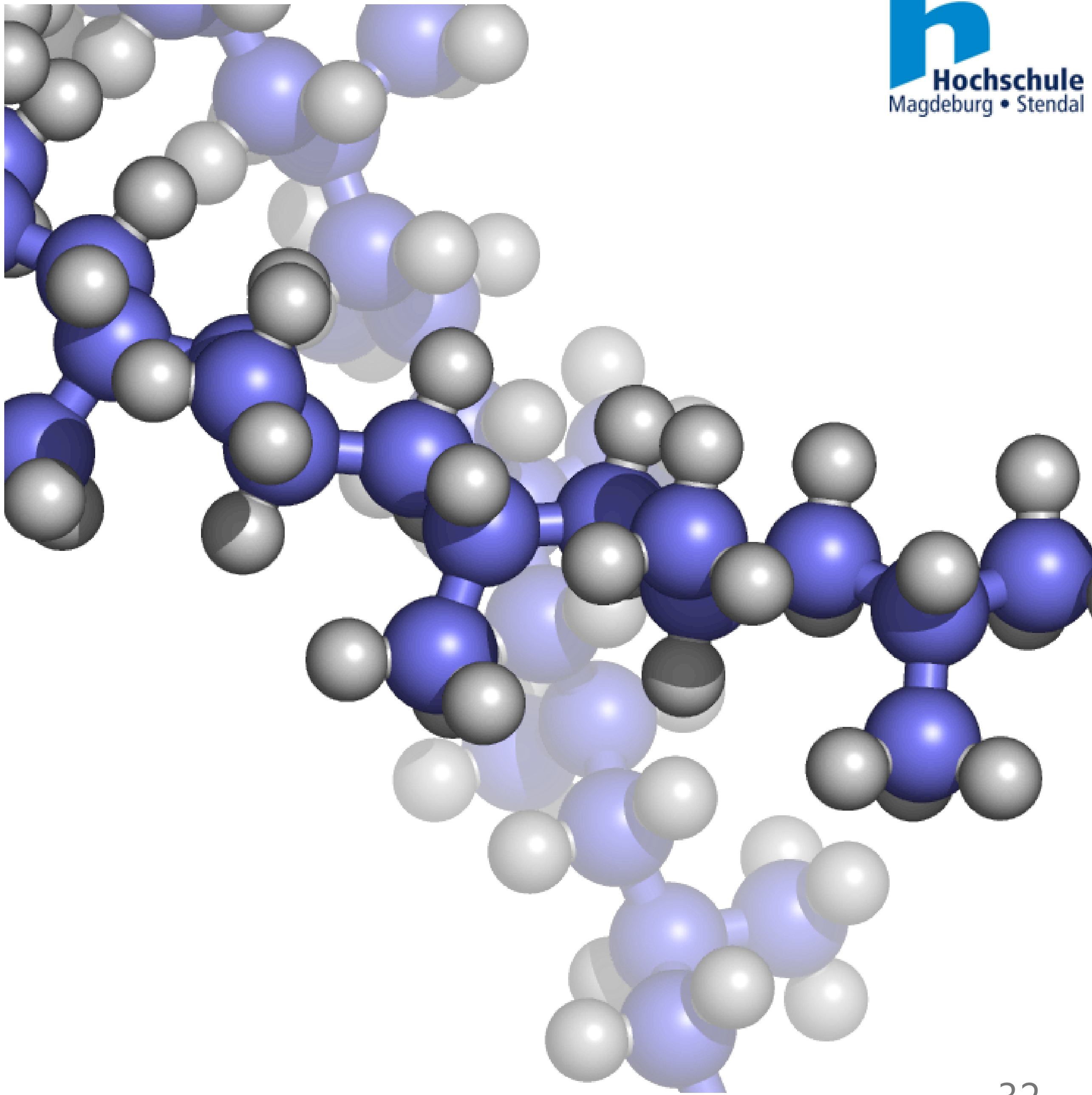

Temperatur
flüssig
L: Liquiduspunkt/-temperatur
L
flüssig
+fest
2 Phasen
S
S: Soliduspunkt/-temperatur
fest
Zeit

Molecular Structures

- Typical for non-metallic organic materials.
  - Natural materials: Wood, rubber, leather, fibers, etc.
  - Synthetic plastics: PMMA, epoxy, etc.



- Formed by assembly reactions of monomeric building blocks into chain molecules.
- Atomic bonds occur within the chains.
- Van der Waals forces and molecular entanglements exist between the chains.

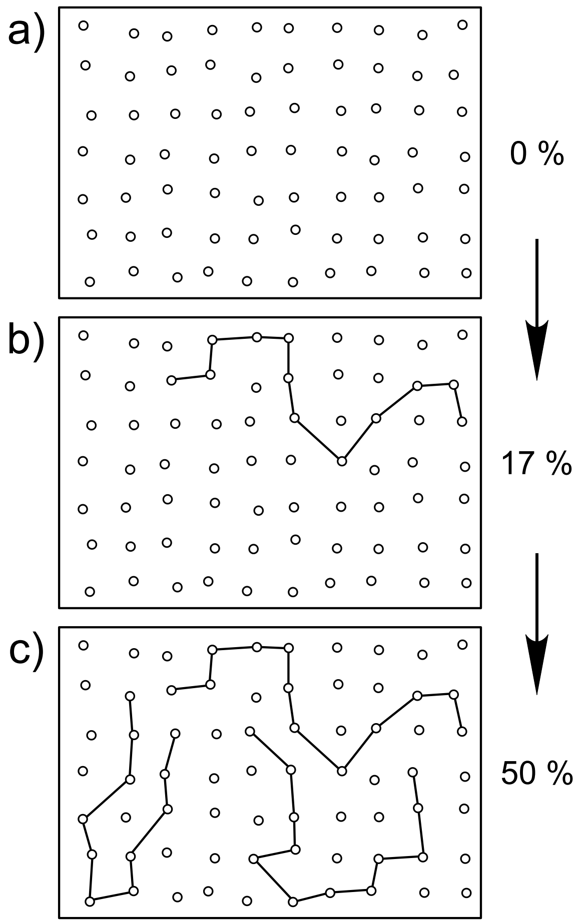


Assembly Reaction (Polymerization)

- Free bonds must be created in the monomers.
- The monomers "need" new partners to reach an energetic minimum.

Chain Polymerizations

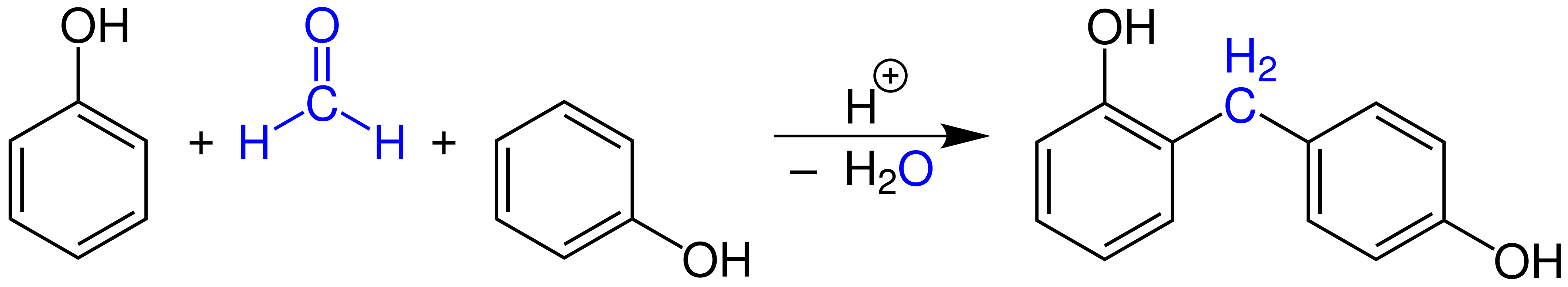
- Breaking of C=C double bonds in the monomer (catalytic process through pressure, temperature, catalyst).
- Linking the split monomers to macromolecules.



Step-Growth Reactions

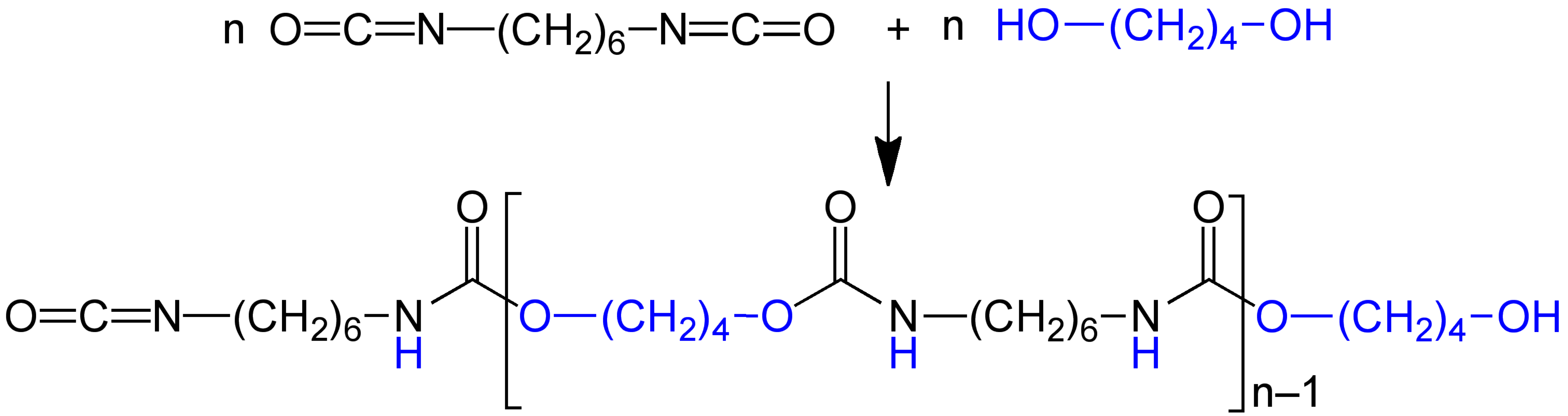
Polycondensation

- Release of low molecular weight reaction products (e.g., H_2O) through a chemical reaction creates free bonds.
- Stepwise reaction or interruption leads to the formation of linear, branched, or cross-linked polymers (thermoplastics, elastomers, or thermosets).



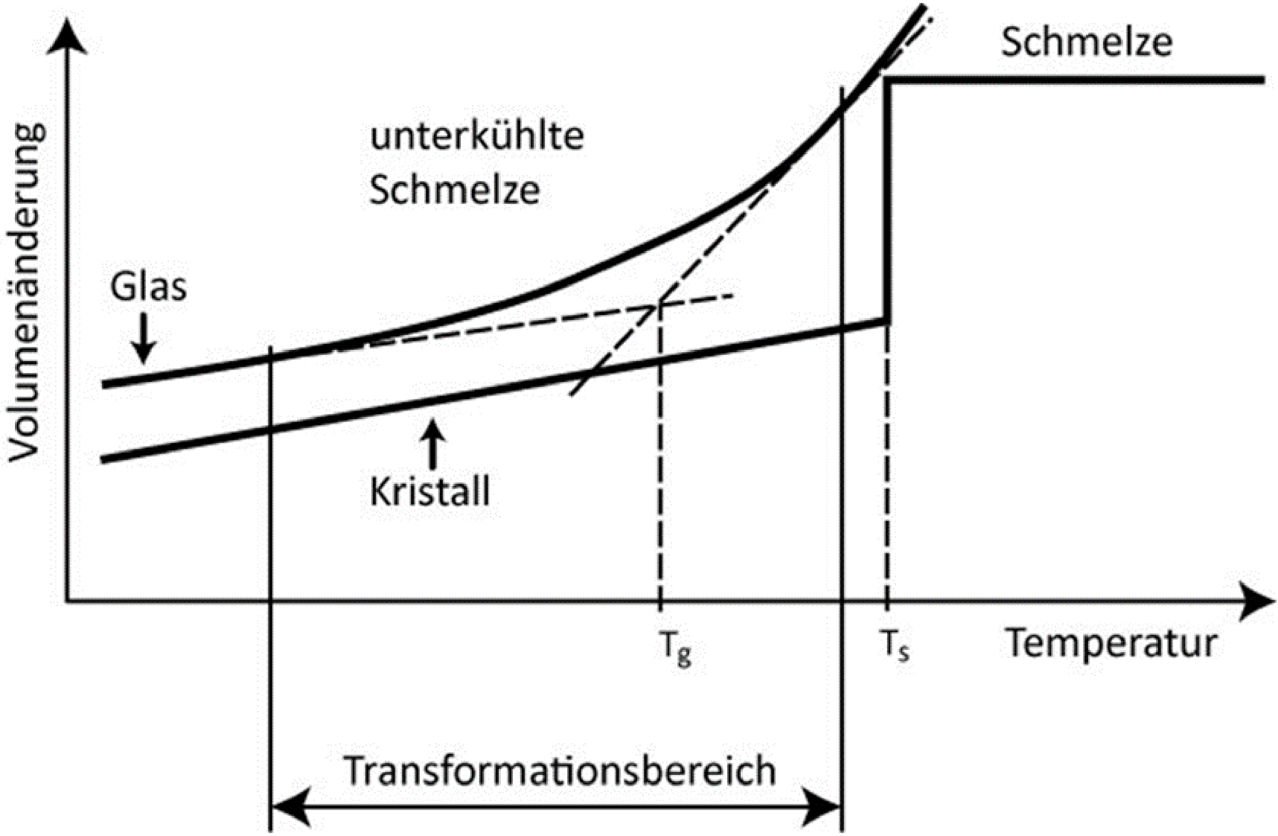
Polyaddition

- Free bonds are formed by rearrangement of double bonds between two different monomer molecules.
- These then form molecular chains.



Glassy-Amorphous Structures

- Glasses are non-metallic inorganic, primarily silicate melt products.
- They are in a non-crystalline (amorphous) state.
- In glass, the melt is first undercooled and then "frozen" below the transformation temperature (Tg).



Material Properties

- Properties are significantly influenced by the microstructure and electrons (outer shell).

Work Function

- Thermal expansion
- Electrical conductivity
- Thermal conductivity