

The image features a dense, repeating pattern of interlocking polygons, primarily hexagons and pentagons, in various shades of blue, gray, and white. The polygons are outlined in black, creating a complex, crystalline structure. In the center of the image, there is a semi-transparent gray rectangular box containing the text "VIII. Magnetismus" in a bold, yellow, serif font.

VIII. Magnetismus

$$\vec{B} = \mu_0(\vec{M} + \vec{H}) \quad \vec{B} \approx \mu_0\vec{H}$$

$$\chi = \frac{M}{H} \quad \chi \approx \frac{\mu_0 M}{B}$$

$M \ll H$ *Temperaturunabhängige Beiträge:*

Pauli-Paramagnetismus

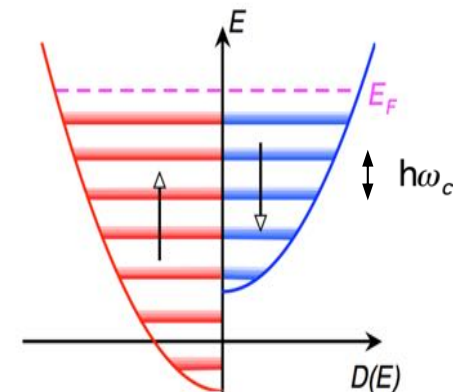
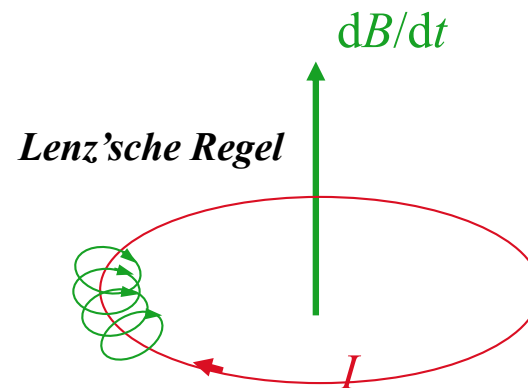
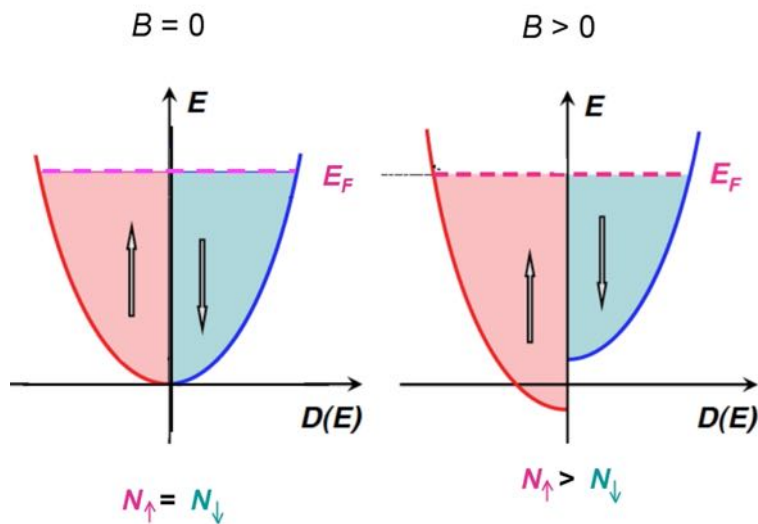
Larmor-Diamagnetismus

Landau-Diamagnetismus

Metalle

alle Atome mit gefüllten
Elektronenschalen

Metalle



\approx Korrektur auf Grund der
Landau-Quantisierung

\approx atomare Abschirmströme

$$\chi_{Pauli} = \frac{\mu_0 \mu_B^2 D(E_F)}{V}$$

$$\approx \frac{3\mu_0 \mu_B^2 N}{2E_F V} \approx 10^{-5} > 0$$

$$\chi_{Larmor} = -\frac{\mu_0 e^2 Z_a r_a^2 N}{m_e V} \approx -10^{-6} < 0$$

Z_a : Anzahl Elektronen in äusserster Schale
 r_a : Atomradius

$$\chi_{Landau} = -1/3 \chi_{Pauli}$$

$$\vec{B} = \mu_0(\vec{M} + \vec{H})$$

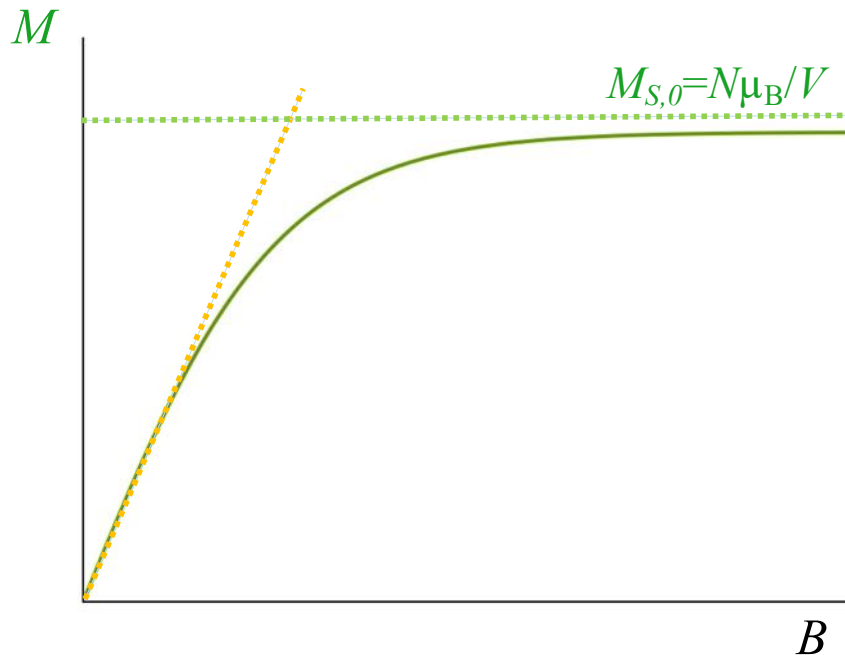
$$\vec{B} \approx \mu_0\vec{H}$$

$$\chi = \frac{M}{H}$$

$$\chi \approx \frac{\mu_0 M}{B}$$

$$M \ll H$$

**Isolierte magnetische Momente:
Curie-Gesetz**



$$M(B) = \mu_B \frac{N}{V} \tanh\left(\frac{\mu_B B}{k_B T}\right) \quad \text{für } s = \pm 1/2$$

$$\chi_{\text{Curie}}(T) = \frac{\mu_0 \mu_B^2 N}{k_B T V} = \frac{C}{T} \quad (\mu_B B \ll k_B T)$$

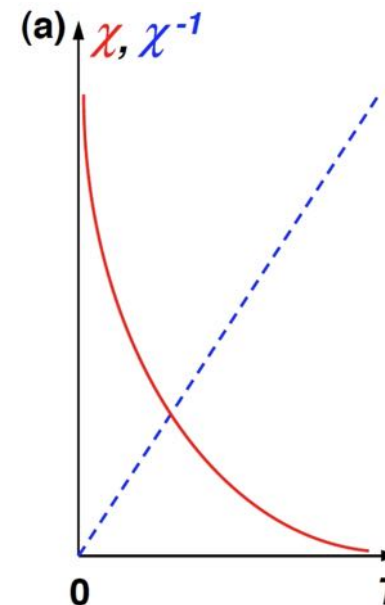
Curie-Gesetz

Allgemeine isolierte magnetische Momente:

$$M(B) = gJ\mu_B B_j(x)N/V \quad \text{mit "Brioullin-Funktion" } B_j(x) \quad \text{und } x = gJ\mu_B B/k_B T$$

$$\chi_{\text{Curie}}(T) = \frac{\mu_0 \mu_B^2 p^2 N}{3k_B T V} = \frac{C}{T} \quad p = g\sqrt{J(J+1)} \quad \vec{J} = \vec{L} + \vec{S}$$

J : Gesamtdrehimpulsquantenzahl g : Landé-Faktor p : effektive Magnetonenzahl



$$\vec{B} = \mu_0(\vec{M} + \vec{H})$$

$$\chi = \frac{M}{H}$$

$$\vec{B} \approx \mu_0 \vec{H}$$

$$\chi \approx \frac{\mu_0 M}{B} \quad M \ll H$$

**Isolierte magnetische Momente:
Curie-Gesetz**

| Ion | Konfiguration | Schema $m_l = +2, +1, 0, -1, -2$ | S | L | J | Term | $p = g_J [J(J+1)]^{1/2}$ | $p = g_S [S(S+1)]^{1/2}$ | p (Exp.) |
|--------------------------------------|----------------------|-------------------------------------|-----|---|-----|-------------------------------|--------------------------|--------------------------|---------------|
| Ti ³⁺ V ⁴⁺ | [Ar]3d ¹ | ↑ | 1/2 | 2 | 3/2 | ² D _{3/2} | 1.55 | 1.73 | 1.8 |
| V ³⁺ | [Ar]3d ² | ↑ ↑ | 1 | 3 | 2 | ³ F ₂ | 1.63 | 2.83 | 2.8 |
| Cr ³⁺ V ²⁺ | [Ar]3d ³ | ↑ ↑ ↑ | 3/2 | 3 | 3/2 | ⁴ F _{3/2} | 0.77 | 3.87 | 3.8 |
| Mn ³⁺ Cr ²⁺ | [Ar]3d ⁴ | ↑ ↑ ↑ ↑ | 2 | 2 | 0 | ⁵ D ₀ | 0 | 4.90 | 4.9 |
| Fe ³⁺ Mn ²⁺ | [Ar]3d ⁵ | ↑ ↑ ↑ ↑ ↑ | 5/2 | 0 | 5/2 | ⁶ S _{5/2} | 5.92 | 5.92 | 5.9 |
| Fe ²⁺ | [Ar]3d ⁶ | ↑ ↓ ↑ ↑ ↑ ↑ | 2 | 2 | 4 | ⁵ D ₄ | 6.70 | 4.90 | 5.4 |
| Co ²⁺ | [Ar]3d ⁷ | ↑ ↓ ↑ ↓ ↑ ↑ ↑ | 3/2 | 3 | 9/2 | ⁴ F _{9/2} | 6.63 | 3.87 | 4.8 |
| Ni ²⁺ | [Ar]3d ⁸ | ↑ ↓ ↑ ↓ ↑ ↓ ↑ | 1 | 3 | 4 | ³ F ₄ | 5.59 | 2.83 | 3.2 |
| Cu ²⁺ | [Ar]3d ⁹ | ↑ ↓ ↑ ↓ ↑ ↓ ↑ ↑ | 1/2 | 2 | 5/2 | ² D _{5/2} | 3.55 | 1.73 | 1.9 |
| Zn ²⁺ | [Ar]3d ¹⁰ | ↑ ↓ ↑ ↓ ↑ ↓ ↑ ↓ | 0 | 0 | 0 | ¹ S ₀ | 0 | 0 | 0 |

Grundzustandskonfiguration und effektive Magnetonzahl p einiger Ionen der Übergangsmetalle.

Allgemeine isolierte magnetische Momente:

$$M(B) = gJ\mu_B B_J(x)N/V \text{ mit "Brioullin-Funktion" } B_J(x) \text{ und } x = gJ\mu_B B/k_B T$$

$$\chi_{Curie}(T) = \frac{\mu_0 \mu_B^2 p^2 N}{3k_B T V} = \frac{C}{T} \quad p = g\sqrt{J(J+1)} \quad \vec{J} = \vec{L} + \vec{S}$$

J : Gesamtdrehimpulsquantenzahl g : Landé-Faktor p : effektive Magnetonzahl

| Ion | Konfiguration | Schema $m_l = +3, +2, +1, 0, -1, -2, -3$ | S | L | J | Term | p (berechnet) | p (Experiment) |
|------------------|----------------------|---|-----|---|------|--------------------------------|--------------------|---------------------|
| La ³⁺ | [Xe]4f ⁰ | | 0 | 0 | 0 | ¹ S ₀ | 0 | 0 |
| Ce ³⁺ | [Xe]4f ¹ | ↑ | 1/2 | 3 | 5/2 | ² F _{5/2} | 2.54 | 2.4 |
| Pr ³⁺ | [Xe]4f ² | ↑ ↑ | 1 | 5 | 4 | ³ H ₄ | 3.58 | 3.5 |
| Nd ³⁺ | [Xe]4f ² | ↑ ↑ ↑ | 3/2 | 6 | 9/2 | ⁴ I _{9/2} | 3.62 | 3.5 |
| Pm ³⁺ | [Xe]4f ⁴ | ↑ ↑ ↑ ↑ | 2 | 6 | 4 | ⁵ I ₄ | 2.68 | -- |
| Sm ³⁺ | [Xe]4f ⁵ | ↑ ↑ ↑ ↑ ↑ | 5/2 | 5 | 5/2 | ⁶ H _{5/2} | 0.84 | 1.5 |
| Eu ³⁺ | [Xe]4f ⁶ | ↑ ↑ ↑ ↑ ↑ ↑ | 3 | 3 | 0 | ⁷ F ₀ | 0 | 3.4 |
| Gd ³⁺ | [Xe]4f ⁷ | ↑ ↑ ↑ ↑ ↑ ↑ ↑ | 7/2 | 0 | 7/2 | ⁸ S _{7/2} | 7.94 | 8.0 |
| Tb ³⁺ | [Xe]4f ⁸ | ↑ ↓ ↑ ↑ ↑ ↑ ↑ | 3 | 3 | 6 | ⁷ F ₆ | 9.72 | 9.5 |
| Dy ³⁺ | [Xe]4f ⁹ | ↑ ↓ ↑ ↓ ↑ ↑ ↑ ↑ | 5/2 | 5 | 15/2 | ⁶ H _{15/2} | 10.63 | 10.6 |
| Ho ³⁺ | [Xe]4f ¹⁰ | ↑ ↓ ↑ ↓ ↑ ↓ ↑ ↑ | 2 | 6 | 8 | ⁵ I ₈ | 10.60 | 10.4 |
| Er ³⁺ | [Xe]4f ¹¹ | ↑ ↓ ↑ ↓ ↑ ↓ ↑ ↑ ↑ | 3/2 | 6 | 15/2 | ⁴ I _{15/2} | 9.59 | 9.5 |
| Tm ³⁺ | [Xe]4f ¹² | ↑ ↓ ↑ ↓ ↑ ↓ ↑ ↓ ↑ | 1 | 5 | 6 | ³ H ₆ | 7.57 | 7.3 |
| Yb ³⁺ | [Xe]4f ¹³ | ↑ ↓ ↑ ↓ ↑ ↓ ↑ ↓ ↑ ↑ | 1/2 | 3 | 7/2 | ² F _{7/2} | 4.54 | 4.5 |
| Lu ³⁺ | [Xe]4f ¹⁴ | ↑ ↓ ↑ ↓ ↑ ↓ ↑ ↓ ↑ ↓ | 0 | 0 | 0 | ¹ S ₀ | 0 | 0 |

Tabelle 12.1: Grundzustandskonfiguration und effektive Magnetonzahl p der dreiwertigen Ionen der Seltenen Erden.

In Verbindungen meist unvollständig gefüllte Orbitale

Meist vollständig gefüllte Orbitale

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|--|--|--|--|--|--|---|--|---|--|---|---|---|--|--|---|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|---|---|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|---|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|---|---|---|--|---|--|--|---|---|---|---|---|--|---|--|--|---|---|---|--|---|---|--|--|--|--|--|--|--|---|--|--|--|--|---|--|--|--|---|--|--|--|---|---|--|--|---|---|---|--|--|---|--|--|---|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|---|--|--|--|--|--|--|---|--|---|--|---|--|---|---|--|--|---|--|---|--|---|--|--|--|--|---|---|
| 1 | | | | | | | | | | | | | | | | | | 18 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| <table border="1"> <tr> <td>1 1.0079 -252.7 -259.2 0.071 1s¹ Wasserstoff H</td> <td colspan="17"></td> <td>2 4.0026 -268.9 -269.7 0.126 1s² Helium He</td> </tr> <tr> <td>3 6.941 1330 180.5 0.53 [He] 2s¹ Lithium Li</td> <td>4 9.0122 2770 1277 1.85 [He] 2s² Beryllium Be</td> <td colspan="16"></td> <td>5 10.811 2030 2.34 [He] 2s² 2p¹ Bor B</td> <td>6 12.011 3727g 2.26 [He] 2s² 2p² Kohlenstoff C</td> <td>7 14.0067 -195.8 0.81 [He] 2s² 2p³ Stickstoff N</td> <td>8 15.9994 -183 1.14 [He] 2s² 2p⁴ Sauerstoff O</td> <td>9 18.9984 -188.2 1.505 [He] 2s² 2p⁵ Fluor F</td> <td>10 20.1797 -246 -218.6 1.20 [He] 2s² 2p⁶ Neon Ne</td> </tr> <tr> <td>11 22.9898 892 97.8 0.97 [Ne] 3s¹ Natrium Na</td> <td>12 24.3050 1107 650 1.74 [Ne] 3s² Magnesium Mg</td> <td colspan="16"></td> <td>13 26.9815 2450 660 2.70 [Ne] 3s² 3p¹ Aluminium Al</td> <td>14 28.0855 2680 1410 2.33 [Ne] 3s² 3p² Silizium Si</td> <td>15 30.9738 280w 1410 1.82w [Ne] 3s² 3p³ Phosphor P</td> <td>16 32.066 444.6 44.2w 2.07 [Ne] 3s² 3p⁴ Schwefel S</td> <td>17 35.4527 -34.7 5.32 2.07 [Ne] 3s² 3p⁵ Chlor Cl</td> <td>18 39.948 -185.8 -189.4 1.40 [Ne] 3s² 3p⁶ Argon Ar</td> </tr> <tr> <td>19 39.0983 760 63.7 0.86 [Ar] 4s¹ Kalium K</td> <td>20 40.078 1440 838 1.55 [Ar] 4s² Kalzium Ca</td> <td>21 44.9559 2730 1539 3.0 [Ar] 3d¹ 4s² Scandium Sc</td> <td>22 47.88 3260 1668 4.51 [Ar] 3d² 4s² Titan Ti</td> <td>23 50.9415 3450 1900 6.1 [Ar] 3d³ 4s² Vanadium V</td> <td>24 51.9961 2665 1875 7.19 [Ar] 3d⁴ 4s¹ Chrom Cr</td> <td>25 54.9380 2150 1245 7.43 [Ar] 3d⁵ 4s¹ Mangan Mn</td> <td>26 55.847 3000 1536 7.86 [Ar] 3d⁶ 4s² Eisen Fe</td> <td>27 58.9332 2900 1495 8.9 [Ar] 3d⁷ 4s² Kobalt Co</td> <td>28 58.69 2730 1453 8.9 [Ar] 3d⁸ 4s² Nickel Ni</td> <td>29 63.546 2595 1083 8.96 [Ar] 3d⁹ 4s¹ Kupfer Cu</td> <td>30 65.39 906 419.5 7.14 [Ar] 3d¹⁰ 4s¹ Zink Zn</td> <td>31 69.723 2237 29.8 5.91 [Ar] 3d¹⁰ 4s² Gallium Ga</td> <td>32 72.61 2830 937.4 5.32 [Ar] 3d¹⁰ 4s² 4p¹ Silizium Ge</td> <td>33 74.9216 613 5.72 [Ar] 3d¹⁰ 4s² 4p² Arsen As</td> <td>34 78.96 685 217 4.79 [Ar] 3d¹⁰ 4s² 4p³ Selen Se</td> <td>35 79.904 58 -7.2 3.12 [Ar] 3d¹⁰ 4s² 4p⁴ Brom Br</td> <td>36 83.80 -152 -187.4 2.6 [Ar] 3d¹⁰ 4s² 4p⁵ Krypton Kr</td> </tr> <tr> <td>37 85.4678 688 38.9 1.53 [Kr] 5s¹ Rubidium Rb</td> <td>38 87.62 1380 768 2.6 [Kr] 5s² Strontium Sr</td> <td>39 88.9058 2927 1509 4.47 [Kr] 4d¹ 5s² Yttrium Y</td> <td>40 91.224 3580 1852 6.49 [Kr] 4d² 5s² Zirkon Zr</td> <td>41 92.9064 3300 2468 8.4 [Kr] 4d³ 5s¹ Niob Nb</td> <td>42 95.94 2610 10.2 [Kr] 4d⁴ 5s¹ Molybdän Mo</td> <td>43 98.9063 2140 11.5 [Kr] 4d⁵ 5s¹ Technetium Tc</td> <td>44 101.07 4900 2500 12.2 [Kr] 4d⁶ 5s¹ Ruthenium Ru</td> <td>45 102.9055 4500 1966 12.4 [Kr] 4d⁷ 5s² Rhodium Rh</td> <td>46 106.42 3980 1552 12.0 [Kr] 4d⁸ 5s² Palladium Pd</td> <td>47 107.8682 2210 960.8 10.5 [Kr] 4d⁹ 5s¹ Silber Ag</td> <td>48 112.411 765 320.9 8.65 [Kr] 4d¹⁰ 5s¹ Cadmium Cd</td> <td>49 114.82 2000 156.2 7.31 [Kr] 4d¹⁰ 5s² 5p¹ Indium In</td> <td>50 118.710 2270 231.9 7.30 [Kr] 4d¹⁰ 5s² 5p² Zinn Sn</td> <td>51 121.75 1380 630.5 6.62 [Kr] 4d¹⁰ 5s² 5p³ Antimon Sb</td> <td>52 127.60 989.8 449.5 6.24 [Kr] 4d¹⁰ 5s² 5p⁴ Tellur Te</td> <td>53 126.9045 183 113.7 4.94 [Kr] 4d¹⁰ 5s² 5p⁵ Jod I</td> <td>54 131.29 -108.0 -111.9 3.06 [Kr] 4d¹⁰ 5s² 5p⁶ Xenon Xe</td> </tr> <tr> <td>55 132.9054 690 28.7 1.90 [Xe] 6s¹ Cäsium Cs</td> <td>56 137.327 1640 714 3.5 [Xe] 6s² Barium Ba</td> <td>57 138.9055 3470 2222 6.17 [Xe] 5d¹ 6s² Lanthan La</td> <td>72 178.49 5400 13.1 [Xe] 4f¹⁴ 5d¹ 6s² Hafnium Hf</td> <td>73 180.9479 5425 2996 16.6 [Xe] 4f¹⁴ 5d² 6s² Tantal Ta</td> <td>74 183.85 5930 3410 19.3 [Xe] 4f¹⁴ 5d³ 6s² Wolfram W</td> <td>75 186.207 5900 3180 21.0 [Xe] 4f¹⁴ 5d⁴ 6s² Rhenium Re</td> <td>76 190.2 5500 22.6 [Xe] 4f¹⁴ 5d⁵ 6s² Osmium Os</td> <td>77 192.22 5300 22.5 [Xe] 4f¹⁴ 5d⁶ 6s² Iridium Ir</td> <td>78 195.08 4530 1769 21.4 [Xe] 4f¹⁴ 5d⁷ 6s² Platin Pt</td> <td>79 196.9665 2970 1063 19.3 [Xe] 4f¹⁴ 5d⁹ 6s¹ Gold Au</td> <td>80 200.59 357 13.6 [Xe] 4f¹⁴ 5d¹⁰ 6s¹ Quecksilber Hg</td> <td>81 204.3833 1457 303 11.85 [Xe] 4f¹⁴ 5d¹⁰ 6s² 6p¹ Thallium Tl</td> <td>82 207.2 1725 327.4 11.4 [Xe] 4f¹⁴ 5d¹⁰ 6s² 6p² Blei Pb</td> <td>83 208.9804 1560 271.3 9.8 [Xe] 4f¹⁴ 5d¹⁰ 6s² 6p³ Bismuth Bi</td> <td>84 208.9824 - 254 (9.2) [Xe] 4f¹⁴ 5d¹⁰ 6s² 6p⁴ Polonium Po</td> <td>85 209.9871 - (302) (9.2) [Xe] 4f¹⁴ 5d¹⁰ 6s² 6p⁵ Astat At</td> <td>86 222.0176 (-61.8) (-71) [Xe] 4f¹⁴ 5d¹⁰ 6s² 6p⁶ Radon Rn</td> </tr> <tr> <td>87 223.0197 - (27) [Rn] 7s¹ Francium Fr</td> <td>88 226.0254 700 5.0 [Rn] 7s² Radium Ra</td> <td>89 227.0278 - 1050 [Rn] 6d¹ 7s² Actinium Ac</td> <td colspan="16"></td> </tr> </table> | | | | | | | | | | | | | | | | | | 1 1.0079 -252.7 -259.2 0.071 1s ¹ Wasserstoff H | | | | | | | | | | | | | | | | | | 2 4.0026 -268.9 -269.7 0.126 1s ² Helium He | 3 6.941 1330 180.5 0.53 [He] 2s ¹ Lithium Li | 4 9.0122 2770 1277 1.85 [He] 2s ² Beryllium Be | | | | | | | | | | | | | | | | | 5 10.811 2030 2.34 [He] 2s ² 2p ¹ Bor B | 6 12.011 3727g 2.26 [He] 2s ² 2p ² Kohlenstoff C | 7 14.0067 -195.8 0.81 [He] 2s ² 2p ³ Stickstoff N | 8 15.9994 -183 1.14 [He] 2s ² 2p ⁴ Sauerstoff O | 9 18.9984 -188.2 1.505 [He] 2s ² 2p ⁵ Fluor F | 10 20.1797 -246 -218.6 1.20 [He] 2s ² 2p ⁶ Neon Ne | 11 22.9898 892 97.8 0.97 [Ne] 3s ¹ Natrium Na | 12 24.3050 1107 650 1.74 [Ne] 3s ² Magnesium Mg | | | | | | | | | | | | | | | | | 13 26.9815 2450 660 2.70 [Ne] 3s ² 3p ¹ Aluminium Al | 14 28.0855 2680 1410 2.33 [Ne] 3s ² 3p ² Silizium Si | 15 30.9738 280w 1410 1.82w [Ne] 3s ² 3p ³ Phosphor P | 16 32.066 444.6 44.2w 2.07 [Ne] 3s ² 3p ⁴ Schwefel S | 17 35.4527 -34.7 5.32 2.07 [Ne] 3s ² 3p ⁵ Chlor Cl | 18 39.948 -185.8 -189.4 1.40 [Ne] 3s ² 3p ⁶ Argon Ar | 19 39.0983 760 63.7 0.86 [Ar] 4s ¹ Kalium K | 20 40.078 1440 838 1.55 [Ar] 4s ² Kalzium Ca | 21 44.9559 2730 1539 3.0 [Ar] 3d ¹ 4s ² Scandium Sc | 22 47.88 3260 1668 4.51 [Ar] 3d ² 4s ² Titan Ti | 23 50.9415 3450 1900 6.1 [Ar] 3d ³ 4s ² Vanadium V | 24 51.9961 2665 1875 7.19 [Ar] 3d ⁴ 4s ¹ Chrom Cr | 25 54.9380 2150 1245 7.43 [Ar] 3d ⁵ 4s ¹ Mangan Mn | 26 55.847 3000 1536 7.86 [Ar] 3d ⁶ 4s ² Eisen Fe | 27 58.9332 2900 1495 8.9 [Ar] 3d ⁷ 4s ² Kobalt Co | 28 58.69 2730 1453 8.9 [Ar] 3d ⁸ 4s ² Nickel Ni | 29 63.546 2595 1083 8.96 [Ar] 3d ⁹ 4s ¹ Kupfer Cu | 30 65.39 906 419.5 7.14 [Ar] 3d ¹⁰ 4s ¹ Zink Zn | 31 69.723 2237 29.8 5.91 [Ar] 3d ¹⁰ 4s ² Gallium Ga | 32 72.61 2830 937.4 5.32 [Ar] 3d ¹⁰ 4s ² 4p ¹ Silizium Ge | 33 74.9216 613 5.72 [Ar] 3d ¹⁰ 4s ² 4p ² Arsen As | 34 78.96 685 217 4.79 [Ar] 3d ¹⁰ 4s ² 4p ³ Selen Se | 35 79.904 58 -7.2 3.12 [Ar] 3d ¹⁰ 4s ² 4p ⁴ Brom Br | 36 83.80 -152 -187.4 2.6 [Ar] 3d ¹⁰ 4s ² 4p ⁵ Krypton Kr | 37 85.4678 688 38.9 1.53 [Kr] 5s ¹ Rubidium Rb | 38 87.62 1380 768 2.6 [Kr] 5s ² Strontium Sr | 39 88.9058 2927 1509 4.47 [Kr] 4d ¹ 5s ² Yttrium Y | 40 91.224 3580 1852 6.49 [Kr] 4d ² 5s ² Zirkon Zr | 41 92.9064 3300 2468 8.4 [Kr] 4d ³ 5s ¹ Niob Nb | 42 95.94 2610 10.2 [Kr] 4d ⁴ 5s ¹ Molybdän Mo | 43 98.9063 2140 11.5 [Kr] 4d ⁵ 5s ¹ Technetium Tc | 44 101.07 4900 2500 12.2 [Kr] 4d ⁶ 5s ¹ Ruthenium Ru | 45 102.9055 4500 1966 12.4 [Kr] 4d ⁷ 5s ² Rhodium Rh | 46 106.42 3980 1552 12.0 [Kr] 4d ⁸ 5s ² Palladium Pd | 47 107.8682 2210 960.8 10.5 [Kr] 4d ⁹ 5s ¹ Silber Ag | 48 112.411 765 320.9 8.65 [Kr] 4d ¹⁰ 5s ¹ Cadmium Cd | 49 114.82 2000 156.2 7.31 [Kr] 4d ¹⁰ 5s ² 5p ¹ Indium In | 50 118.710 2270 231.9 7.30 [Kr] 4d ¹⁰ 5s ² 5p ² Zinn Sn | 51 121.75 1380 630.5 6.62 [Kr] 4d ¹⁰ 5s ² 5p ³ Antimon Sb | 52 127.60 989.8 449.5 6.24 [Kr] 4d ¹⁰ 5s ² 5p ⁴ Tellur Te | 53 126.9045 183 113.7 4.94 [Kr] 4d ¹⁰ 5s ² 5p ⁵ Jod I | 54 131.29 -108.0 -111.9 3.06 [Kr] 4d ¹⁰ 5s ² 5p ⁶ Xenon Xe | 55 132.9054 690 28.7 1.90 [Xe] 6s ¹ Cäsium Cs | 56 137.327 1640 714 3.5 [Xe] 6s ² Barium Ba | 57 138.9055 3470 2222 6.17 [Xe] 5d ¹ 6s ² Lanthan La | 72 178.49 5400 13.1 [Xe] 4f ¹⁴ 5d ¹ 6s ² Hafnium Hf | 73 180.9479 5425 2996 16.6 [Xe] 4f ¹⁴ 5d ² 6s ² Tantal Ta | 74 183.85 5930 3410 19.3 [Xe] 4f ¹⁴ 5d ³ 6s ² Wolfram W | 75 186.207 5900 3180 21.0 [Xe] 4f ¹⁴ 5d ⁴ 6s ² Rhenium Re | 76 190.2 5500 22.6 [Xe] 4f ¹⁴ 5d ⁵ 6s ² Osmium Os | 77 192.22 5300 22.5 [Xe] 4f ¹⁴ 5d ⁶ 6s ² Iridium Ir | 78 195.08 4530 1769 21.4 [Xe] 4f ¹⁴ 5d ⁷ 6s ² Platin Pt | 79 196.9665 2970 1063 19.3 [Xe] 4f ¹⁴ 5d ⁹ 6s ¹ Gold Au | 80 200.59 357 13.6 [Xe] 4f ¹⁴ 5d ¹⁰ 6s ¹ Quecksilber Hg | 81 204.3833 1457 303 11.85 [Xe] 4f ¹⁴ 5d ¹⁰ 6s ² 6p ¹ Thallium Tl | 82 207.2 1725 327.4 11.4 [Xe] 4f ¹⁴ 5d ¹⁰ 6s ² 6p ² Blei Pb | 83 208.9804 1560 271.3 9.8 [Xe] 4f ¹⁴ 5d ¹⁰ 6s ² 6p ³ Bismuth Bi | 84 208.9824 - 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(1230) 4,5 15.4 [Rn] 5f¹⁴ 6d¹ 7s² Protactinium Pa</td> <td>92 238.0289 3818 1132 19.07 [Rn] 5f¹⁴ 6d¹ 7s² Uran U</td> <td>93 237.0482 - 637 19.5 [Rn] 5f¹⁴ 6d¹ 7s² Neptunium Np</td> <td>94 244.0642 3235 640 11.7 [Rn] 5f¹⁴ 6d² 7s² Plutonium Pu</td> <td>95 243.0614 - 3,4,5,6 [Rn] 5f¹⁴ 6d¹ 7s² Americium Am</td> <td>96 247.0703 - 3 [Rn] 5f¹⁴ 6d¹ 7s² Curium Cm</td> <td>97 247.0703 - 3,4 [Rn] 5f¹⁴ 6d¹ 7s² Berkelium Bk</td> <td>98 251.0796 - [Rn] 5f¹⁴ 6d¹ 7s² Californium Cf</td> <td>99 252.0829 - [Rn] 5f¹⁴ 6d¹ 7s² Einsteinium Es</td> <td>100 257.095 - [Rn] 5f¹⁴ 6d¹ 7s² Fermium Fm</td> <td>101 258.099 - [Rn] 5f¹⁴ 6d¹ 7s² Mendelevium Md</td> <td>102 259.101 - [Rn] 5f¹⁴ 6d¹ 7s² Nobelium No</td> <td>103 260.105 - [Rn] 5f¹⁴ 6d¹ 7s² Lawrencium Lw</td> </tr> </table> | | | | | | | | | | | | | | | | | | 58 140.115 3468 795 6.67 [Xe] 4f ¹⁴ 5d ¹ 6s ² Cer Ce | 59 140.9076 3127 935 6.77 [Xe] 4f ¹⁴ 5d ¹ 6s ² Praseodym Pr | 60 144.24 3027 1024 7.00 [Xe] 4f ¹⁴ 5d ¹ 6s ² Neodym Nd | 61 146.9151 - (1027) 3 [Xe] 4f ¹⁴ 5d ¹ 6s ² Promethium Pm | 62 150.36 1900 1072 7.54 [Xe] 4f ¹⁴ 5d ² 6s ² Samarium Sm | 63 151.965 1439 826 5.26 [Xe] 4f ¹⁴ 5d ¹ 6s ² Europium Eu | 64 157.25 3000 1312 7.89 [Xe] 4f ¹⁴ 5d ¹ 6s ² Gadolinium Gd | 65 158.9253 2800 1356 8.27 [Xe] 4f ¹⁴ 5d ¹ 6s ² Terbium Tb | 66 162.50 2600 1407 8.54 [Xe] 4f ¹⁴ 5d ¹ 6s ² Dysprosium Dy | 67 164.9303 2600 1461 8.80 [Xe] 4f ¹⁴ 5d ¹ 6s ² Holmium Ho | 68 167.26 2900 1497 9.05 [Xe] 4f ¹⁴ 5d ¹ 6s ² Erbium Er | 69 168.9342 1727 1545 9.33 [Xe] 4f ¹⁴ 5d ¹ 6s ² Thulium Tm | 70 173.04 1427 824 6.98 [Xe] 4f ¹⁴ 5d ¹ 6s ² Ytterbium Yb | 71 174.967 3327 1652 9.84 [Xe] 4f ¹⁴ 5d ¹ 6s ² Lutetium Lu | 90 232.0381 3850 1750 11.7 [Rn] 5f ¹⁴ 6d ² 7s ² Thorium Th | 91 231.0359 - (1230) 4,5 15.4 [Rn] 5f ¹⁴ 6d ¹ 7s ² Protactinium Pa | 92 238.0289 3818 1132 19.07 [Rn] 5f ¹⁴ 6d ¹ 7s ² Uran U | 93 237.0482 - 637 19.5 [Rn] 5f ¹⁴ 6d ¹ 7s ² Neptunium Np | 94 244.0642 3235 640 11.7 [Rn] 5f ¹⁴ 6d ² 7s ² Plutonium Pu | 95 243.0614 - 3,4,5,6 [Rn] 5f ¹⁴ 6d ¹ 7s ² Americium Am | 96 247.0703 - 3 [Rn] 5f ¹⁴ 6d ¹ 7s ² Curium Cm | 97 247.0703 - 3,4 [Rn] 5f ¹⁴ 6d ¹ 7s ² Berkelium Bk | 98 251.0796 - [Rn] 5f ¹⁴ 6d ¹ 7s ² Californium Cf | 99 252.0829 - [Rn] 5f ¹⁴ 6d ¹ 7s ² Einsteinium Es | 100 257.095 - [Rn] 5f ¹⁴ 6d ¹ 7s ² Fermium Fm | 101 258.099 - [Rn] 5f ¹⁴ 6d ¹ 7s ² Mendelevium Md | 102 259.101 - [Rn] 5f ¹⁴ 6d ¹ 7s ² Nobelium No | 103 260.105 - [Rn] 5f ¹⁴ 6d ¹ 7s ² Lawrencium Lw |
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| 3 6.941 1330 180.5 0.53 [He] 2s ¹ Lithium Li | 4 9.0122 2770 1277 1.85 [He] 2s ² Beryllium Be | | | | | | | | | | | | | | | | | 5 10.811 2030 2.34 [He] 2s ² 2p ¹ Bor B | 6 12.011 3727g 2.26 [He] 2s ² 2p ² Kohlenstoff C | 7 14.0067 -195.8 0.81 [He] 2s ² 2p ³ Stickstoff N | 8 15.9994 -183 1.14 [He] 2s ² 2p ⁴ Sauerstoff O | 9 18.9984 -188.2 1.505 [He] 2s ² 2p ⁵ Fluor F | 10 20.1797 -246 -218.6 1.20 [He] 2s ² 2p ⁶ Neon Ne | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 11 22.9898 892 97.8 0.97 [Ne] 3s ¹ Natrium Na | 12 24.3050 1107 650 1.74 [Ne] 3s ² Magnesium Mg | | | | | | | | | | | | | | | | | 13 26.9815 2450 660 2.70 [Ne] 3s ² 3p ¹ Aluminium Al | 14 28.0855 2680 1410 2.33 [Ne] 3s ² 3p ² Silizium Si | 15 30.9738 280w 1410 1.82w [Ne] 3s ² 3p ³ Phosphor P | 16 32.066 444.6 44.2w 2.07 [Ne] 3s ² 3p ⁴ Schwefel S | 17 35.4527 -34.7 5.32 2.07 [Ne] 3s ² 3p ⁵ Chlor Cl | 18 39.948 -185.8 -189.4 1.40 [Ne] 3s ² 3p ⁶ Argon Ar | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 19 39.0983 760 63.7 0.86 [Ar] 4s ¹ Kalium K | 20 40.078 1440 838 1.55 [Ar] 4s ² Kalzium Ca | 21 44.9559 2730 1539 3.0 [Ar] 3d ¹ 4s ² Scandium Sc | 22 47.88 3260 1668 4.51 [Ar] 3d ² 4s ² Titan Ti | 23 50.9415 3450 1900 6.1 [Ar] 3d ³ 4s ² Vanadium V | 24 51.9961 2665 1875 7.19 [Ar] 3d ⁴ 4s ¹ Chrom Cr | 25 54.9380 2150 1245 7.43 [Ar] 3d ⁵ 4s ¹ Mangan Mn | 26 55.847 3000 1536 7.86 [Ar] 3d ⁶ 4s ² Eisen Fe | 27 58.9332 2900 1495 8.9 [Ar] 3d ⁷ 4s ² Kobalt Co | 28 58.69 2730 1453 8.9 [Ar] 3d ⁸ 4s ² Nickel Ni | 29 63.546 2595 1083 8.96 [Ar] 3d ⁹ 4s ¹ Kupfer Cu | 30 65.39 906 419.5 7.14 [Ar] 3d ¹⁰ 4s ¹ Zink Zn | 31 69.723 2237 29.8 5.91 [Ar] 3d ¹⁰ 4s ² Gallium Ga | 32 72.61 2830 937.4 5.32 [Ar] 3d ¹⁰ 4s ² 4p ¹ Silizium Ge | 33 74.9216 613 5.72 [Ar] 3d ¹⁰ 4s ² 4p ² Arsen As | 34 78.96 685 217 4.79 [Ar] 3d ¹⁰ 4s ² 4p ³ Selen Se | 35 79.904 58 -7.2 3.12 [Ar] 3d ¹⁰ 4s ² 4p ⁴ Brom Br | 36 83.80 -152 -187.4 2.6 [Ar] 3d ¹⁰ 4s ² 4p ⁵ Krypton Kr | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 37 85.4678 688 38.9 1.53 [Kr] 5s ¹ Rubidium Rb | 38 87.62 1380 768 2.6 [Kr] 5s ² Strontium Sr | 39 88.9058 2927 1509 4.47 [Kr] 4d ¹ 5s ² Yttrium Y | 40 91.224 3580 1852 6.49 [Kr] 4d ² 5s ² Zirkon Zr | 41 92.9064 3300 2468 8.4 [Kr] 4d ³ 5s ¹ Niob Nb | 42 95.94 2610 10.2 [Kr] 4d ⁴ 5s ¹ Molybdän Mo | 43 98.9063 2140 11.5 [Kr] 4d ⁵ 5s ¹ Technetium Tc | 44 101.07 4900 2500 12.2 [Kr] 4d ⁶ 5s ¹ Ruthenium Ru | 45 102.9055 4500 1966 12.4 [Kr] 4d ⁷ 5s ² Rhodium Rh | 46 106.42 3980 1552 12.0 [Kr] 4d ⁸ 5s ² Palladium Pd | 47 107.8682 2210 960.8 10.5 [Kr] 4d ⁹ 5s ¹ Silber Ag | 48 112.411 765 320.9 8.65 [Kr] 4d ¹⁰ 5s ¹ Cadmium Cd | 49 114.82 2000 156.2 7.31 [Kr] 4d ¹⁰ 5s ² 5p ¹ Indium In | 50 118.710 2270 231.9 7.30 [Kr] 4d ¹⁰ 5s ² 5p ² Zinn Sn | 51 121.75 1380 630.5 6.62 [Kr] 4d ¹⁰ 5s ² 5p ³ Antimon Sb | 52 127.60 989.8 449.5 6.24 [Kr] 4d ¹⁰ 5s ² 5p ⁴ Tellur Te | 53 126.9045 183 113.7 4.94 [Kr] 4d ¹⁰ 5s ² 5p ⁵ Jod I | 54 131.29 -108.0 -111.9 3.06 [Kr] 4d ¹⁰ 5s ² 5p ⁶ Xenon Xe | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 55 132.9054 690 28.7 1.90 [Xe] 6s ¹ Cäsium Cs | 56 137.327 1640 714 3.5 [Xe] 6s ² Barium Ba | 57 138.9055 3470 2222 6.17 [Xe] 5d ¹ 6s ² Lanthan La | 72 178.49 5400 13.1 [Xe] 4f ¹⁴ 5d ¹ 6s ² Hafnium Hf | 73 180.9479 5425 2996 16.6 [Xe] 4f ¹⁴ 5d ² 6s ² Tantal Ta | 74 183.85 5930 3410 19.3 [Xe] 4f ¹⁴ 5d ³ 6s ² Wolfram W | 75 186.207 5900 3180 21.0 [Xe] 4f ¹⁴ 5d ⁴ 6s ² Rhenium Re | 76 190.2 5500 22.6 [Xe] 4f ¹⁴ 5d ⁵ 6s ² Osmium Os | 77 192.22 5300 22.5 [Xe] 4f ¹⁴ 5d ⁶ 6s ² Iridium Ir | 78 195.08 4530 1769 21.4 [Xe] 4f ¹⁴ 5d ⁷ 6s ² Platin Pt | 79 196.9665 2970 1063 19.3 [Xe] 4f ¹⁴ 5d ⁹ 6s ¹ Gold Au | 80 200.59 357 13.6 [Xe] 4f ¹⁴ 5d ¹⁰ 6s ¹ Quecksilber Hg | 81 204.3833 1457 303 11.85 [Xe] 4f ¹⁴ 5d ¹⁰ 6s ² 6p ¹ Thallium Tl | 82 207.2 1725 327.4 11.4 [Xe] 4f ¹⁴ 5d ¹⁰ 6s ² 6p ² Blei Pb | 83 208.9804 1560 271.3 9.8 [Xe] 4f ¹⁴ 5d ¹⁰ 6s ² 6p ³ Bismuth Bi | 84 208.9824 - 254 (9.2) [Xe] 4f ¹⁴ 5d ¹⁰ 6s ² 6p ⁴ Polonium Po | 85 209.9871 - (302) (9.2) [Xe] 4f ¹⁴ 5d ¹⁰ 6s ² 6p ⁵ Astat At | 86 222.0176 (-61.8) (-71) [Xe] 4f ¹⁴ 5d ¹⁰ 6s ² 6p ⁶ Radon Rn | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 87 223.0197 - (27) [Rn] 7s ¹ Francium Fr | 88 226.0254 700 5.0 [Rn] 7s ² Radium Ra | 89 227.0278 - 1050 [Rn] 6d ¹ 7s ² Actinium Ac | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 58 140.115 3468 795 6.67 [Xe] 4f ¹⁴ 5d ¹ 6s ² Cer Ce | 59 140.9076 3127 935 6.77 [Xe] 4f ¹⁴ 5d ¹ 6s ² Praseodym Pr | 60 144.24 3027 1024 7.00 [Xe] 4f ¹⁴ 5d ¹ 6s ² Neodym Nd | 61 146.9151 - (1027) 3 [Xe] 4f ¹⁴ 5d ¹ 6s ² Promethium Pm | 62 150.36 1900 1072 7.54 [Xe] 4f ¹⁴ 5d ² 6s ² Samarium Sm | 63 151.965 1439 826 5.26 [Xe] 4f ¹⁴ 5d ¹ 6s ² Europium Eu | 64 157.25 3000 1312 7.89 [Xe] 4f ¹⁴ 5d ¹ 6s ² Gadolinium Gd | 65 158.9253 2800 1356 8.27 [Xe] 4f ¹⁴ 5d ¹ 6s ² Terbium Tb | 66 162.50 2600 1407 8.54 [Xe] 4f ¹⁴ 5d ¹ 6s ² Dysprosium Dy | 67 164.9303 2600 1461 8.80 [Xe] 4f ¹⁴ 5d ¹ 6s ² Holmium Ho | 68 167.26 2900 1497 9.05 [Xe] 4f ¹⁴ 5d ¹ 6s ² Erbium Er | 69 168.9342 1727 1545 9.33 [Xe] 4f ¹⁴ 5d ¹ 6s ² Thulium Tm | 70 173.04 1427 824 6.98 [Xe] 4f ¹⁴ 5d ¹ 6s ² Ytterbium Yb | 71 174.967 3327 1652 9.84 [Xe] 4f ¹⁴ 5d ¹ 6s ² Lutetium Lu | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 90 232.0381 3850 1750 11.7 [Rn] 5f ¹⁴ 6d ² 7s ² Thorium Th | 91 231.0359 - (1230) 4,5 15.4 [Rn] 5f ¹⁴ 6d ¹ 7s ² Protactinium Pa | 92 238.0289 3818 1132 19.07 [Rn] 5f ¹⁴ 6d ¹ 7s ² Uran U | 93 237.0482 - 637 19.5 [Rn] 5f ¹⁴ 6d ¹ 7s ² Neptunium Np | 94 244.0642 3235 640 11.7 [Rn] 5f ¹⁴ 6d ² 7s ² Plutonium Pu | 95 243.0614 - 3,4,5,6 [Rn] 5f ¹⁴ 6d ¹ 7s ² Americium Am | 96 247.0703 - 3 [Rn] 5f ¹⁴ 6d ¹ 7s ² Curium Cm | 97 247.0703 - 3,4 [Rn] 5f ¹⁴ 6d ¹ 7s ² Berkelium Bk | 98 251.0796 - [Rn] 5f ¹⁴ 6d ¹ 7s ² Californium Cf | 99 252.0829 - [Rn] 5f ¹⁴ 6d ¹ 7s ² Einsteinium Es | 100 257.095 - [Rn] 5f ¹⁴ 6d ¹ 7s ² Fermium Fm | 101 258.099 - [Rn] 5f ¹⁴ 6d ¹ 7s ² Mendelevium Md | 102 259.101 - [Rn] 5f ¹⁴ 6d ¹ 7s ² Nobelium No | 103 260.105 - [Rn] 5f ¹⁴ 6d ¹ 7s ² Lawrencium Lw | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

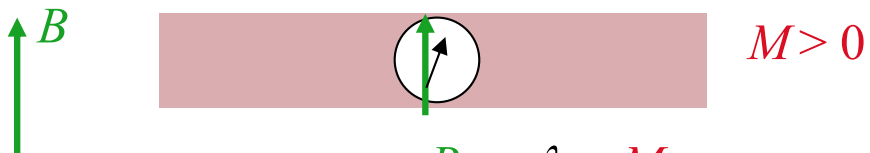
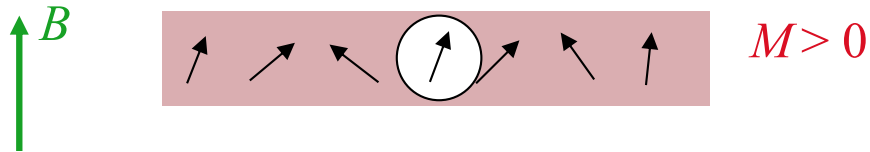
Ordnungszahl ↓
Relative Atommasse ↓
Siedepunkt, °C →
Schmelzpunkt, °C →
Dichte, g/cm³ (++) →
Oxidationszahl (fett: stabilste) →
Symbol (+) →
Elektronenkonfiguration →
Name ↑

| |
|--|
| 26 55.847 3000 1536 7.86 [Ar] 3d ⁶ 4s ² Fe Eisen |
|--|

Bemerkungen:

- (+) schwarz – fest, rot – gasförmig, lila – flüssig, grau – instabil, nicht in der Natur vorkommend
- (++) Die Dichte für gasförmige Elemente entspricht dem Wert der flüssigen Form beim Siedepunkt.

Ferromagnetismus:



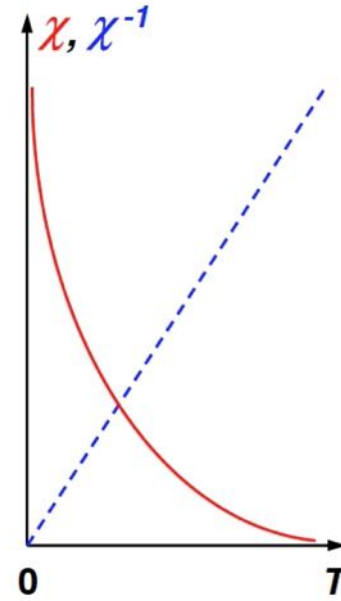
$$B_A = \lambda \mu_0 M$$

B_A : molekulares Austauschfeld ("Molekularfeld")

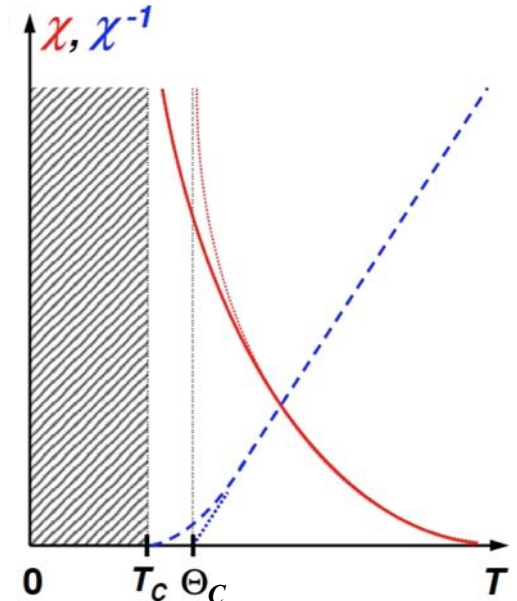
$$\mu_0 M = \chi_{Curie}(T) B_{total} = \chi_{Curie}(T) (B + \lambda \mu_0 M)$$

$$\chi(T) = \frac{C}{T - \lambda C} = \frac{C}{T - \Theta_C}$$

Curie-Weiss-Gesetz



Curie-Gesetz



Curie-Weiss-Gesetz

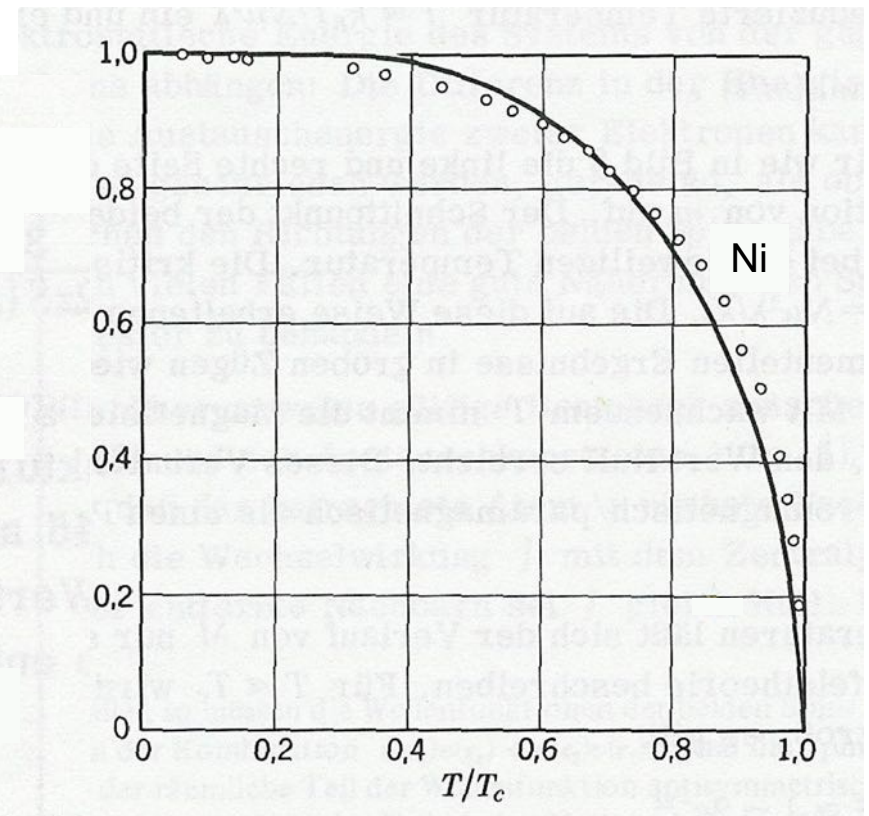
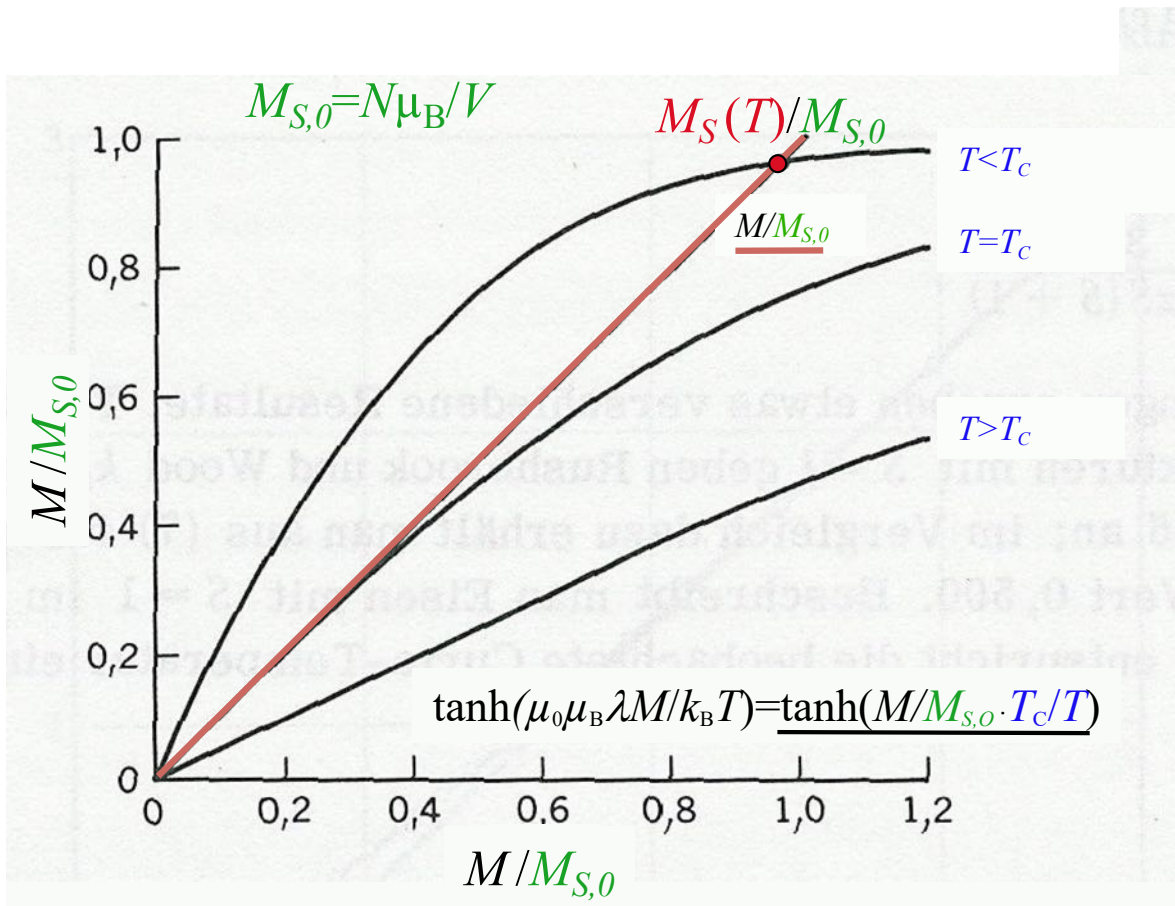
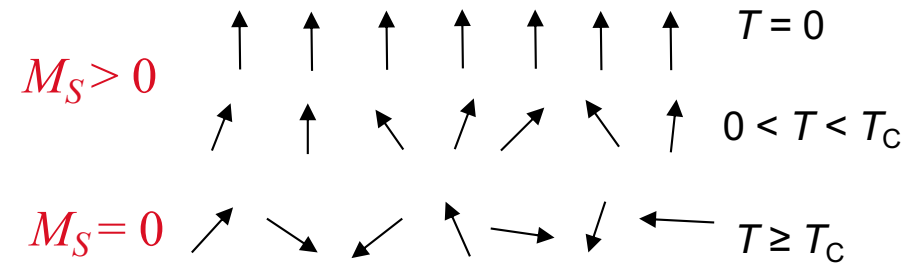
| Material | T_C (K) | Θ_C (K) | C (K) | M_{sp} (10^6 A/m) | n_B = M_{s0}/μ_B pro Atom |
|--------------------------------|-----------|----------------|---------|------------------------|------------------------------------|
| Fe | 1043 | 1100 | 2.22 | 1.746 | 2.22 |
| Co | 1395 | 1415 | 2.24 | 1.446 | 1.72 |
| Ni | 629 | 649 | 0.588 | 0.510 | 0.060 |
| Gd | 289 | 302 | 5.00 | 2.060 | 7.63 |
| Dy | 87 | 157 | — | 2.920 | 10.2 |
| EuO | 69.4 | 78 | 4.68 | 1.930 | 6.8 |
| MnAs | 630 | 318 | — | 870 | 3.4 |
| Fe ₃ O ₄ | 858 | — | — | 510 | 4.1 |

$\Theta_C \approx T_C$: Curie-Temperatur ("Curie-Punkt")

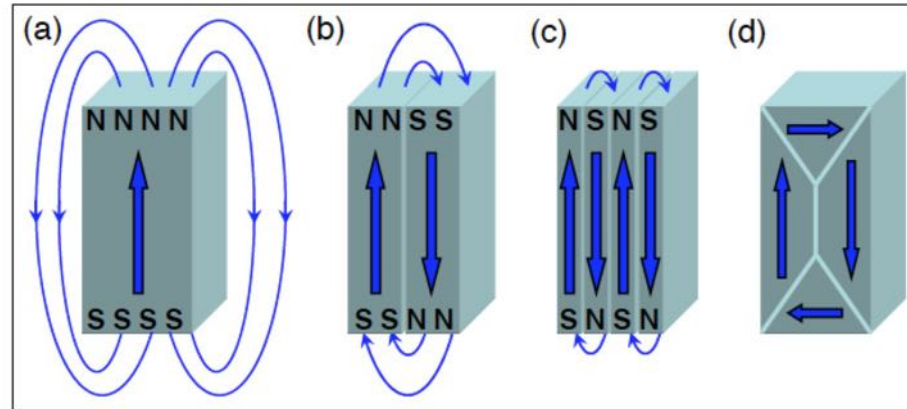
Ferromagnetismus:

Sättigungsmagnetisierung für $B = 0$:

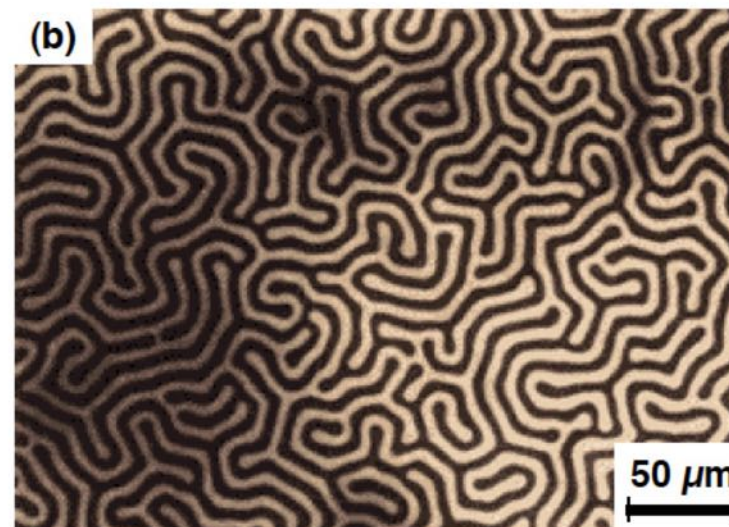
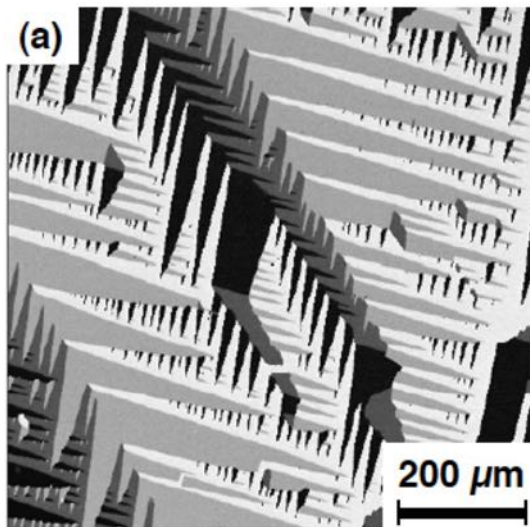
$$M_S = M_{S,0} \tanh\left(\frac{\mu_0 \mu_B \lambda M_S}{k_B T}\right) \quad (\text{für } s = \pm 1/2)$$



Ferromagnetismus: Domänenbildung für $T < T_c$



Zur Ursache der Domänenstruktur in Ferromagneten. Die magnetische Feldenergie nimmt von links nach rechts ab, die Wandenergie dagegen zu.

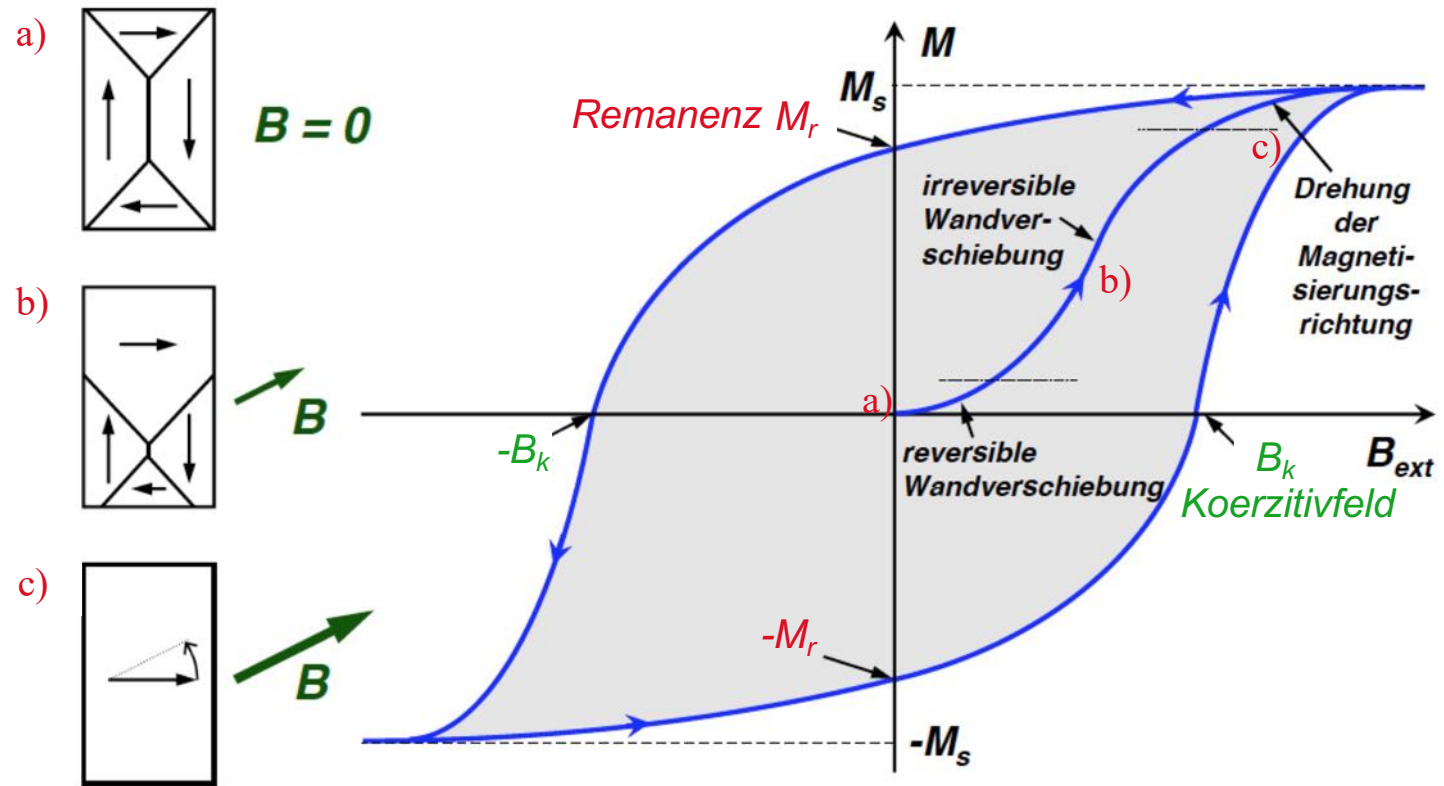


(a) Domänenstrukturen in einem Fe (100) Film aufgenommen mit einem spinpolarisierten Rasterelektronenmikroskop. (b) Magnetooptische Abbildung der Domänenstruktur in einem amorphen Gd-Co-Film.

Ferromagnetismus:

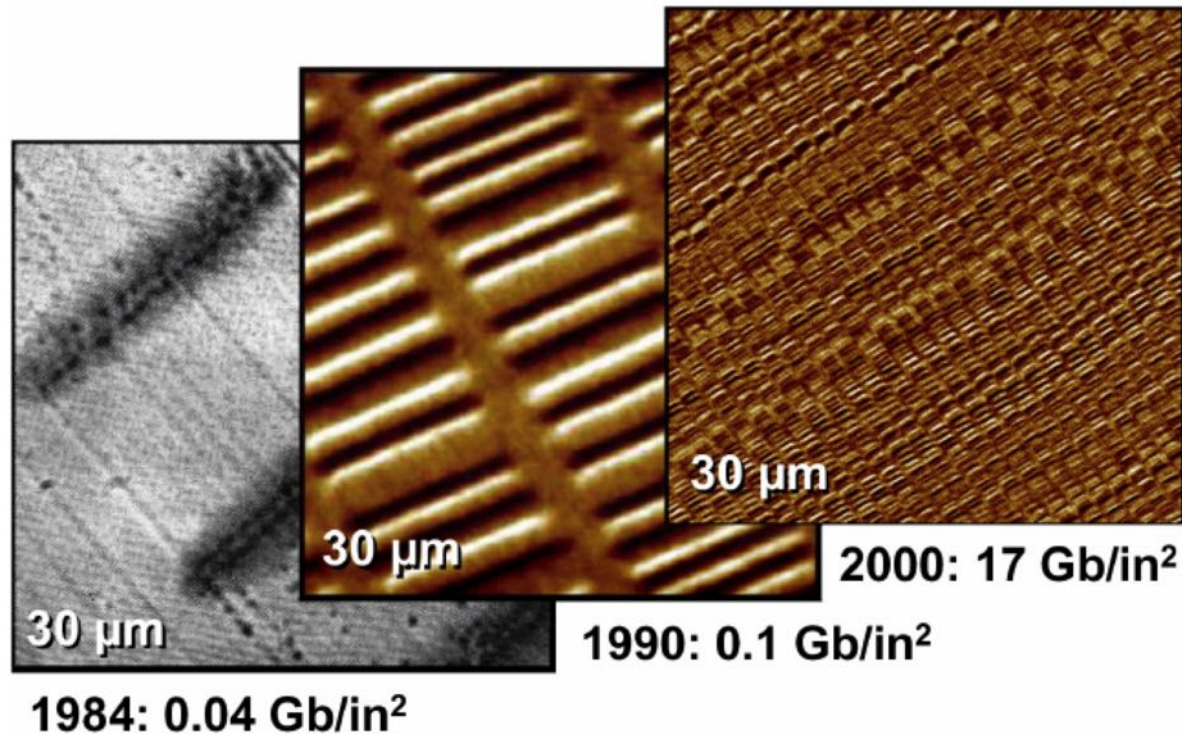
Domänenbildung für $T < T_c$

Ursache für Hysterese im magnetischen Verhalten



Ferromagnetismus: Domänenbildung für $T < T_c$
Ursache für Hysterese im magnetischen Verhalten

Technische Anwendung: magnetische Festplatten!
1 Bit = durch den magnetischen Schreibkopf erzeugte Domäne,
deren remanente Magnetisierung nach dem Schreibvorgang erhalten bleibt

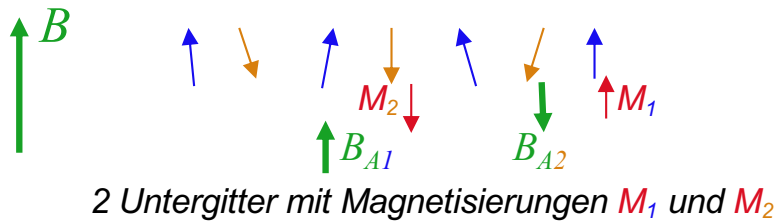


Verkleinerung des Bitmusters auf einer magnetischen Festplatte zwischen 1984 und 2000. Der Bildausschnitt beträgt jeweils $30 \times 30 \mu\text{m}^2$ (Quelle: IBM Deutschland).

Antiferromagnetismus:

$$B_A = -\lambda \mu_0 M$$

molekulares Austauschfeld mit negativer Austauschkopplung



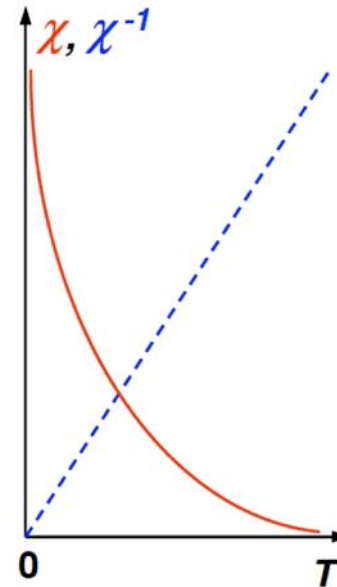
$$B_{A1} = -\lambda \mu_0 M_2 \quad B_{A2} = -\lambda \mu_0 M_1$$

$$\mu_0 M_i = 1/2 \chi_{Curie}(T)(B - \lambda \mu_0 M_j)$$

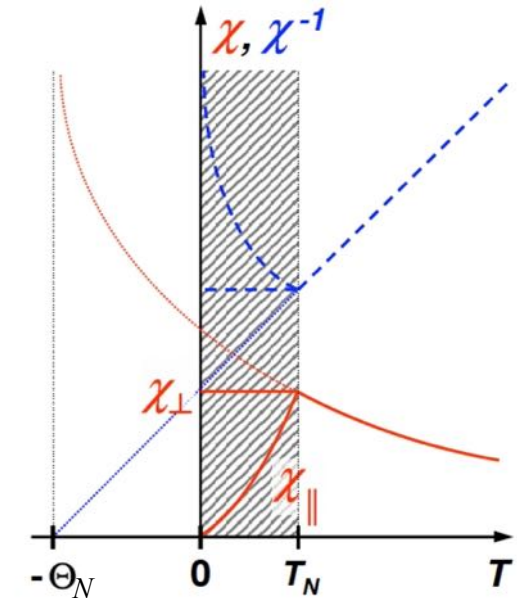
$$\mu_0 M = \mu_0 (M_1 + M_2)$$

$$= \chi_{Curie}(T)B - 1/2 \chi_{Curie}(T) \lambda \mu_0 M$$

$$\chi(T) = \frac{C}{T + \lambda C/2} = \frac{C}{T + \Theta_N}$$



Curie-Gesetz

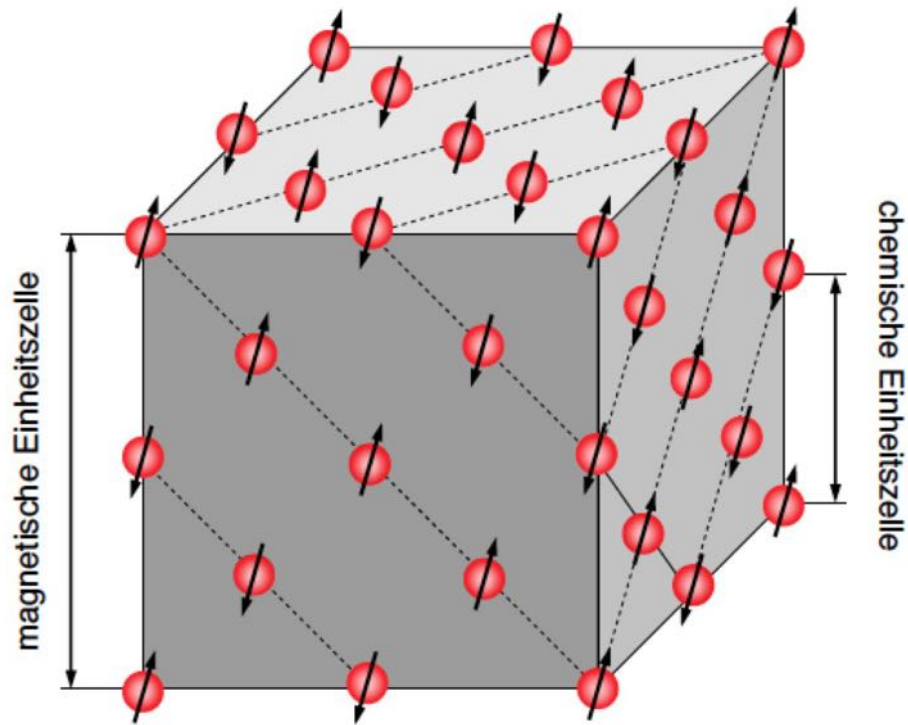


Antiferromagnet

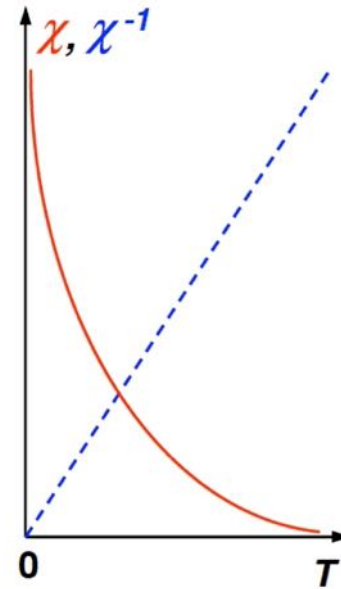
| Substanz | T_N (K) | Θ_N (K) | Θ_N/T_N |
|-------------------|-----------|----------------|----------------|
| MnO | 122 | 610 | 5.3 |
| MnF ₂ | 67 | 82 | 1.24 |
| FeO | 195 | 570 | 2.9 |
| FeCl ₂ | 24 | 48 | 2 |
| CoO | 291 | 330 | 1.14 |
| CoCl ₂ | 25 | 38.1 | 1.53 |
| NiO | 525 | ~ 2000 | ~ 4 |
| NiCl ₂ | 50 | 68.2 | 1.37 |

$\Theta_N \approx T_N$: Néel-Temperatur

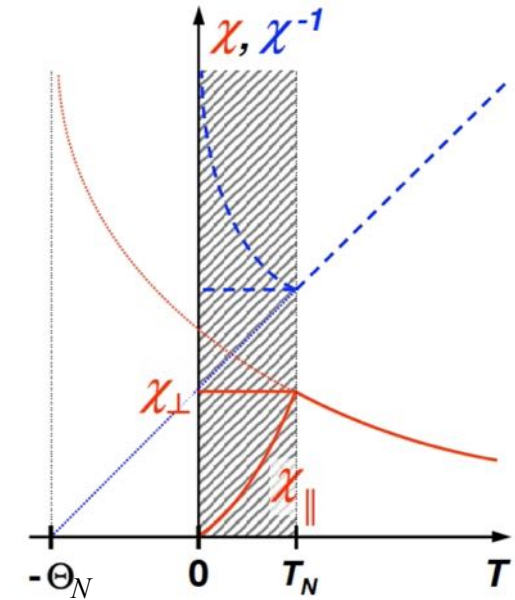
Antiferromagnetismus:



Anordnung der Spins der Mn^{2+} -Ionen in antiferromagnetischem MnO. Die zwischen den Mn^{2+} -Ionen liegenden O^{2-} -Ionen sind nicht gezeigt.



Curie-Gesetz

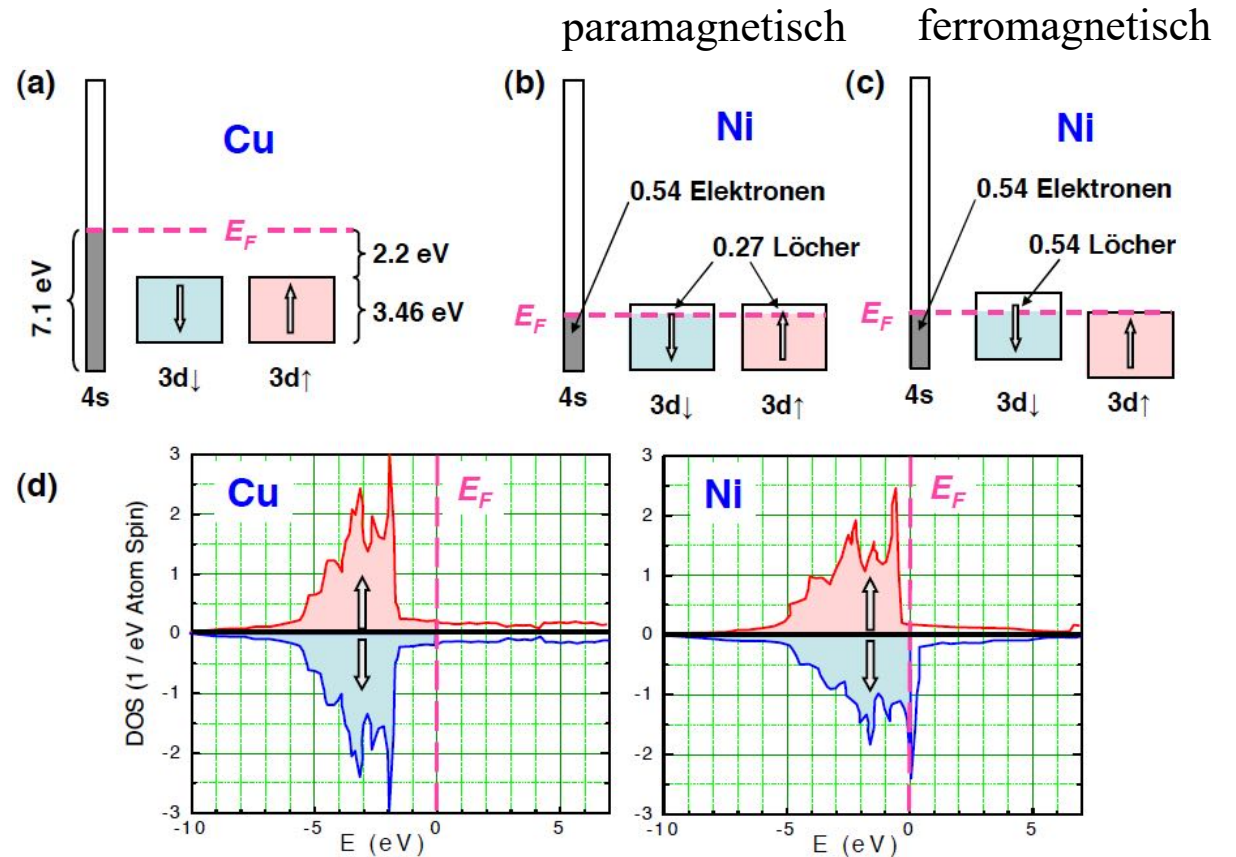
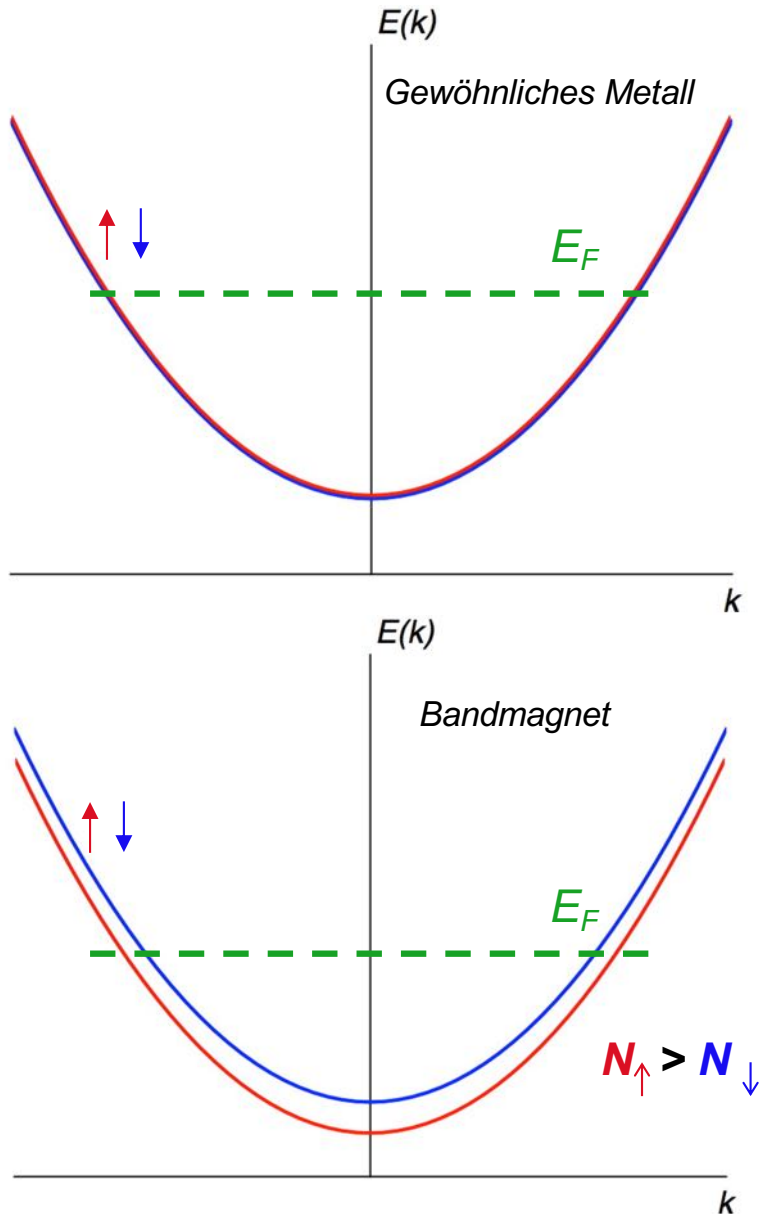


Antiferromagnet

| Substanz | T_N (K) | Θ_N (K) | Θ_N/T_N |
|-------------------|-----------|----------------|----------------|
| MnO | 122 | 610 | 5.3 |
| MnF ₂ | 67 | 82 | 1.24 |
| FeO | 195 | 570 | 2.9 |
| FeCl ₂ | 24 | 48 | 2 |
| CoO | 291 | 330 | 1.14 |
| CoCl ₂ | 25 | 38.1 | 1.53 |
| NiO | 525 | ~ 2000 | ~ 4 |
| NiCl ₂ | 50 | 68.2 | 1.37 |

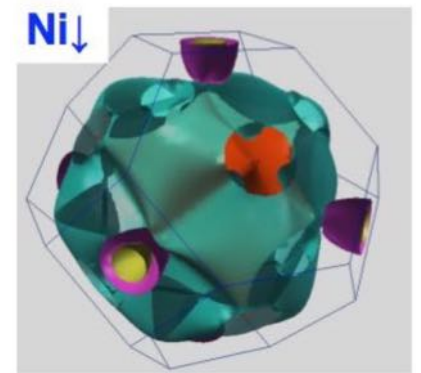
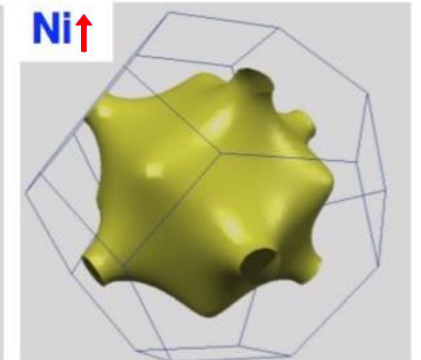
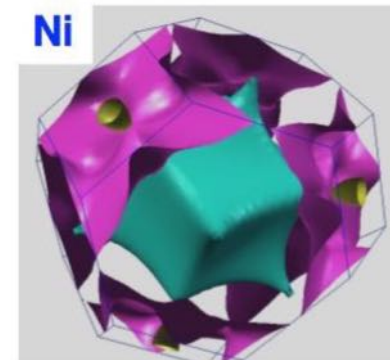
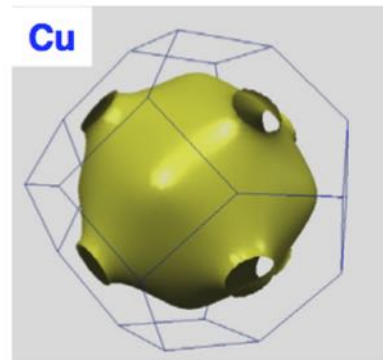
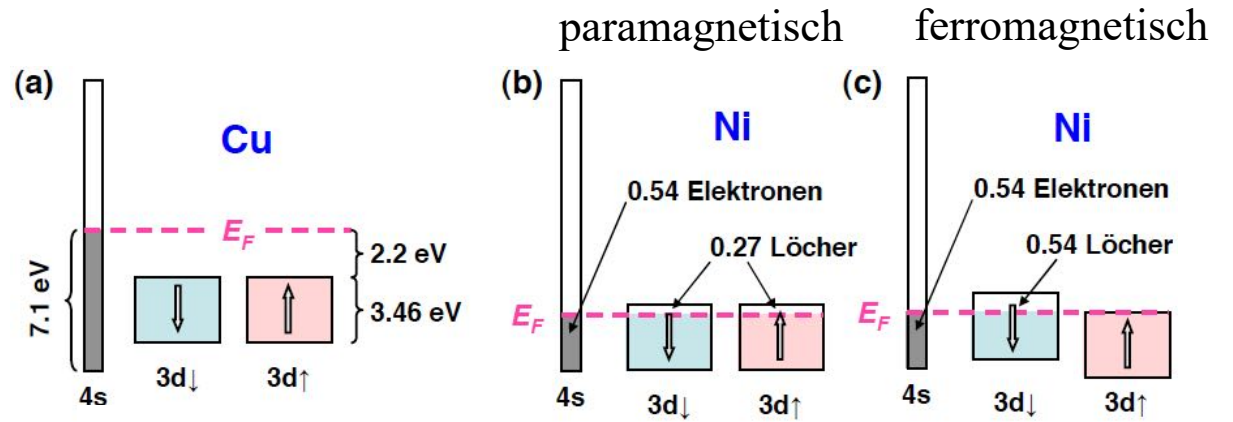
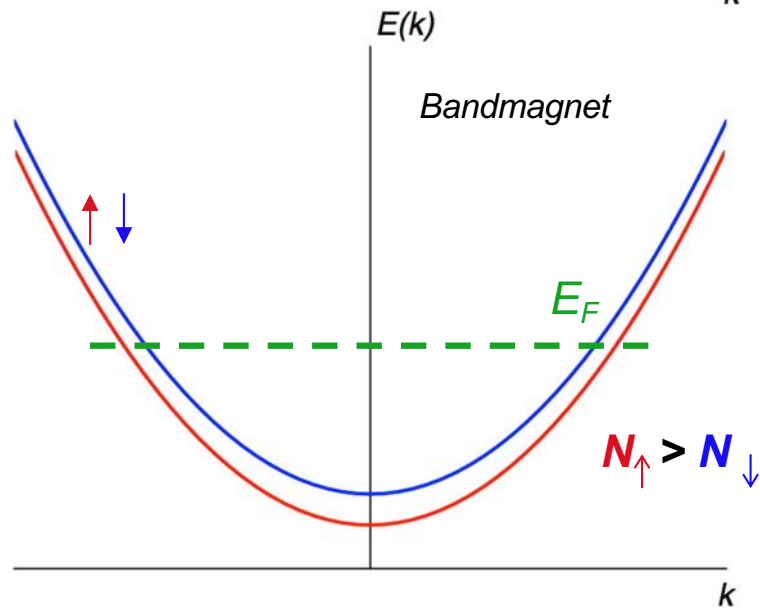
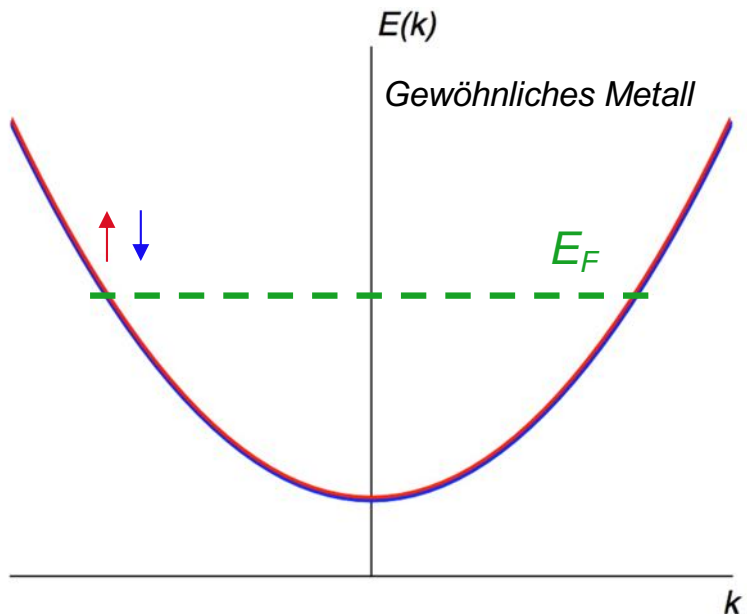
$\Theta_N \approx T_N$: Néel-Temperatur

Bandferromagnetismus:

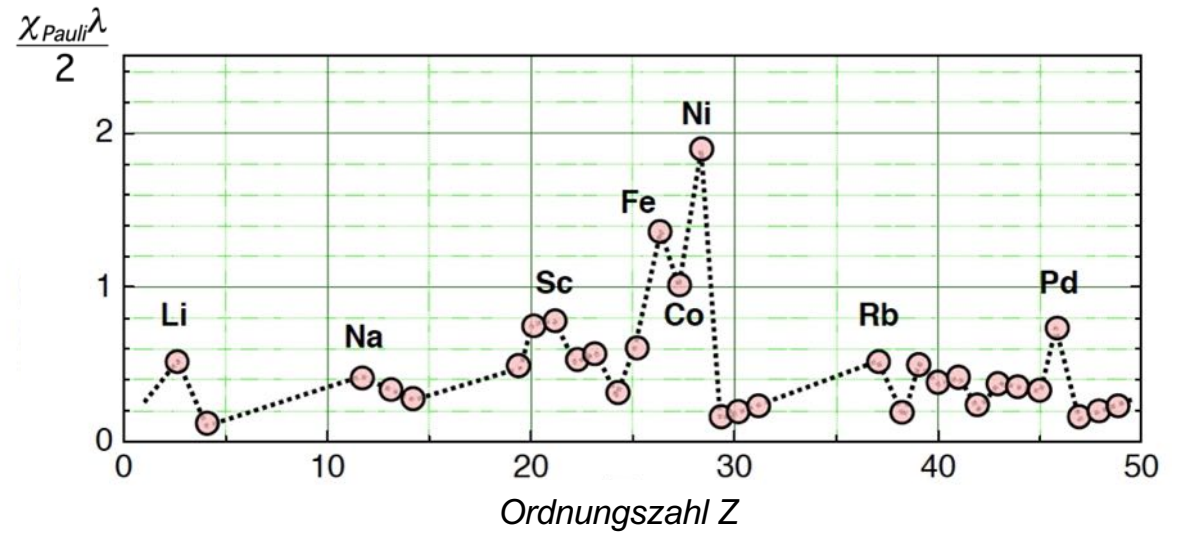
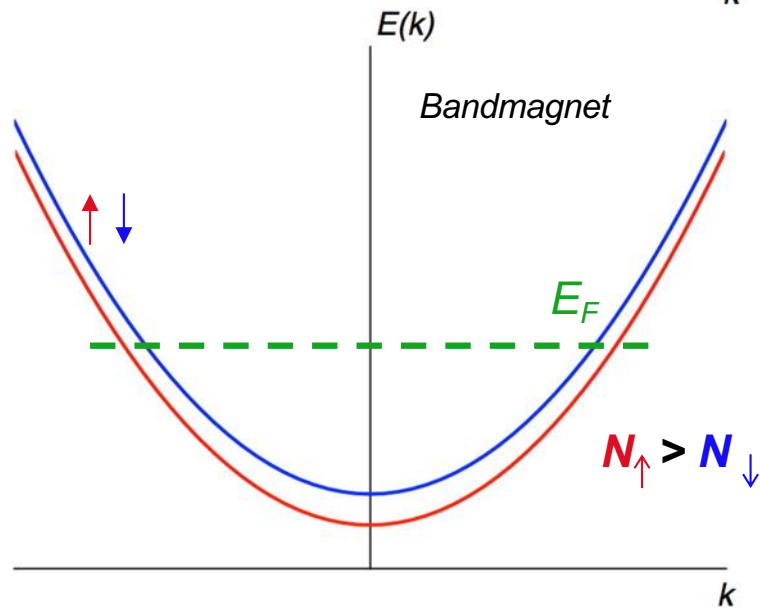
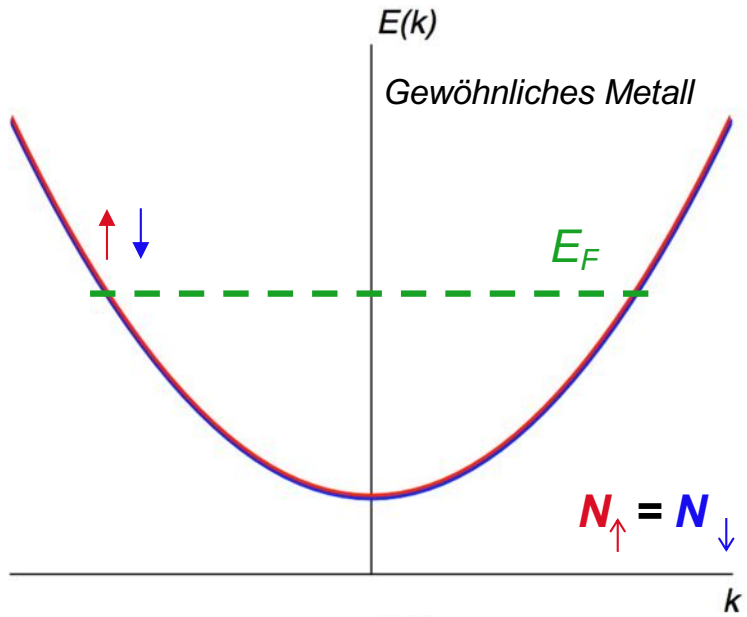


Schematische Darstellung der Besetzung der 3d- und 4s-Niveaus bei Cu (a) und Ni im paramagnetischen (b) und ferromagnetischen Zustand (c). In (d) ist die berechnete Zustandsdichte der 3d- und 4s-Elektronen von Cu und Ni gezeigt (nach J. Callaway und C.S. Wang, Phys. Rev. B 7, 1096 (1983)). Die 4s-Elektronen resultieren in einer geringen Zustandsdichte, die sich über einen weiten Energiebereich (große Bandbreite) von etwa -10 bis +7 eV erstreckt. Die 3d-Elektronen resultieren dagegen in einer hohen Zustandsdichte in einem schmalen Band mit einer Breite von etwa 4 eV.

Bandferromagnetismus:



Bandferromagnetismus:



Bandmagnet: Aufspaltung der Energiebänder für $B = 0$, sobald

$$\frac{\chi_{\text{Pauli}} \lambda}{2} > 1 \quad (\text{Stoner-Kriterium})$$