

# **Von Einzelgängern und Teamplayern**

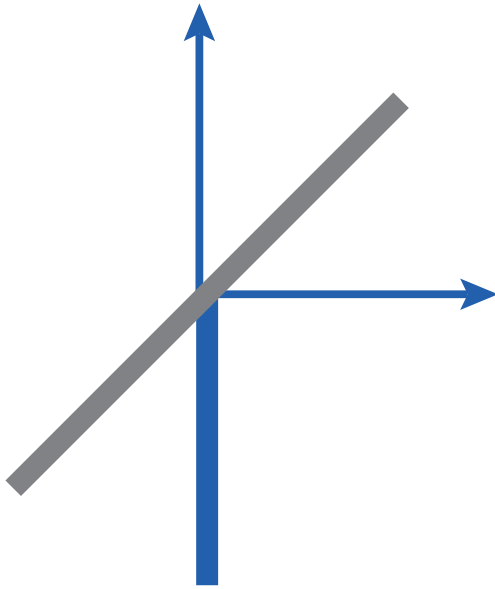
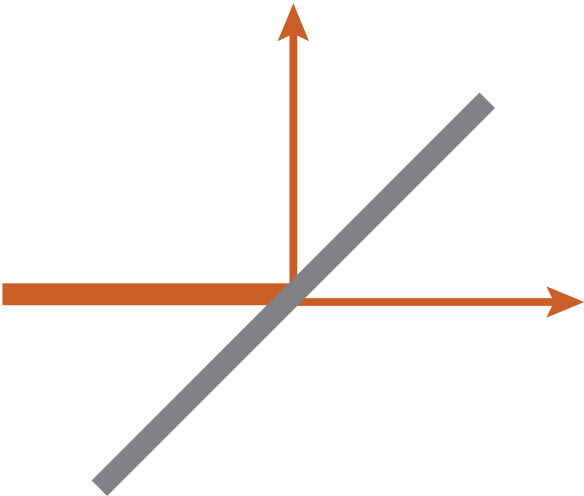
Wie sich Fermionen und Bosonen in unserer Alltagswelt bemerkbar machen

**Gert-Ludwig Ingold**

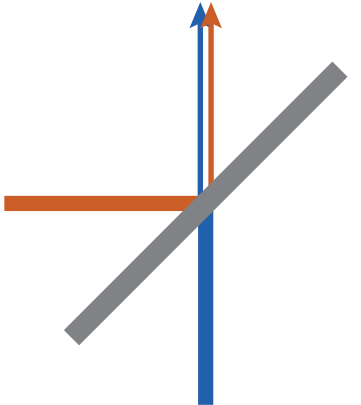
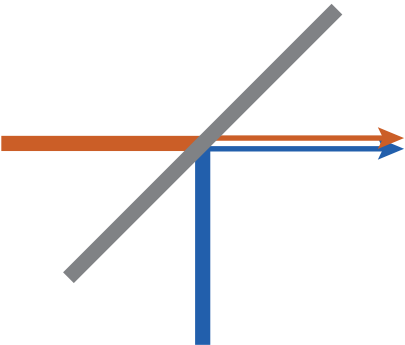
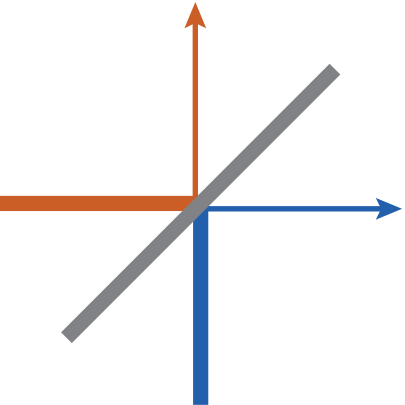
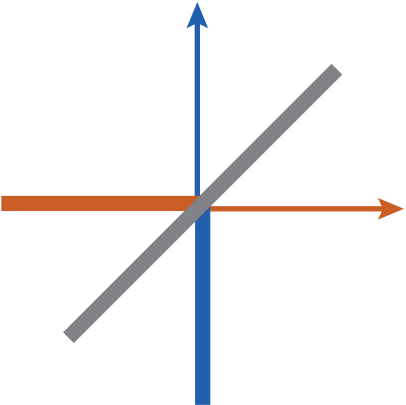
Universität Augsburg



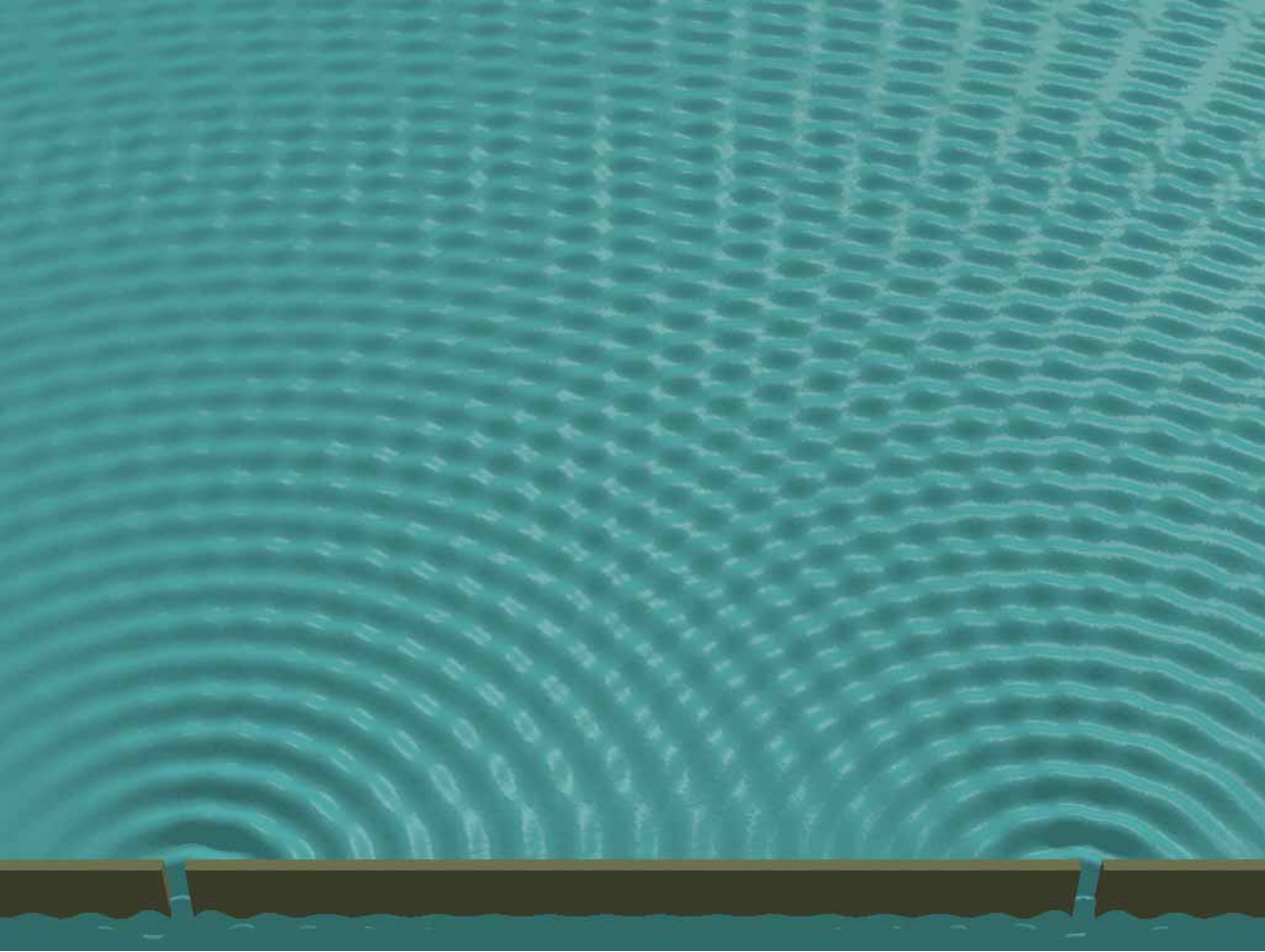
# Halbdurchlässiger Spiegel



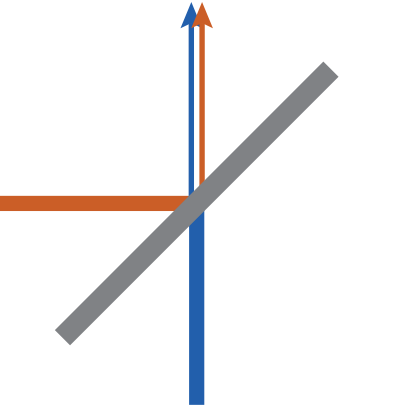
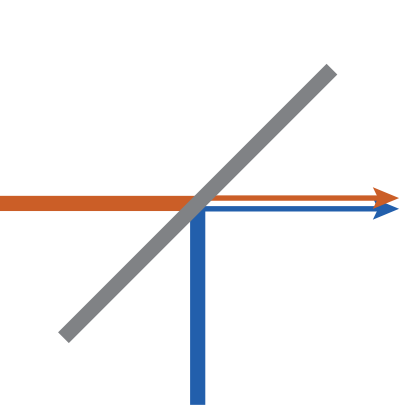
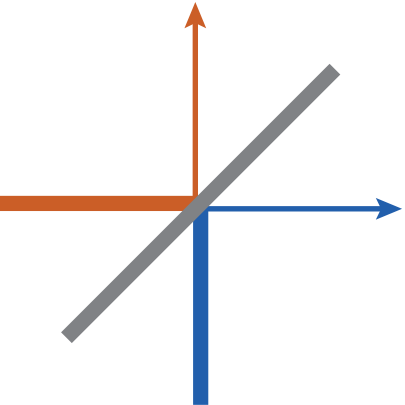
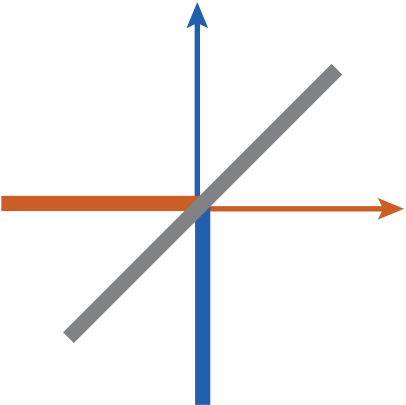
# Zwei unterscheidbare Teilchen am halbdurchlässigen Spiegel



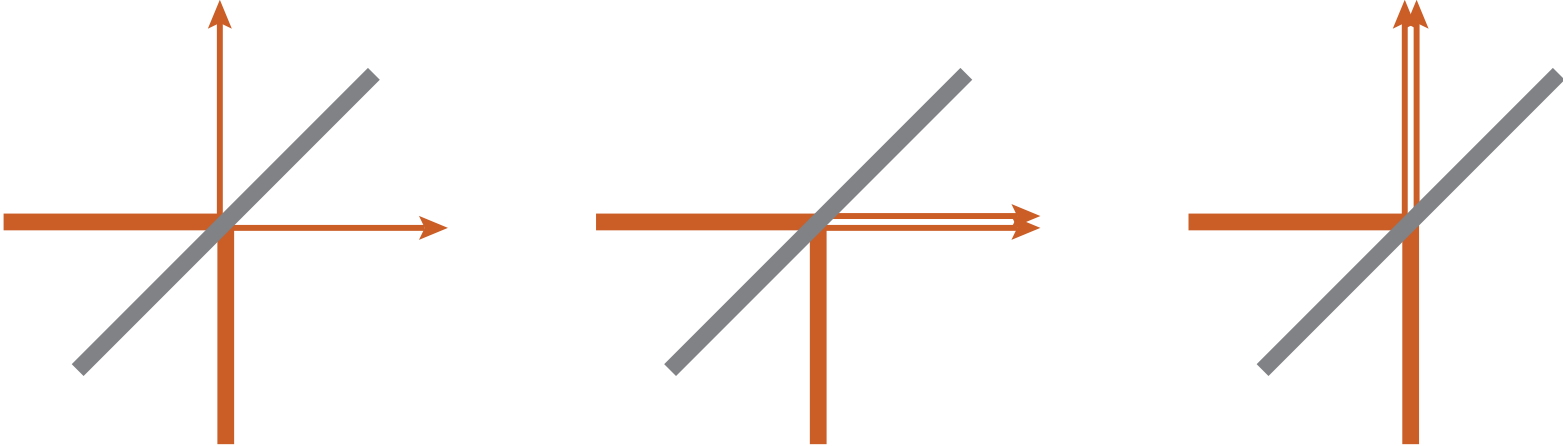
# Interferenz



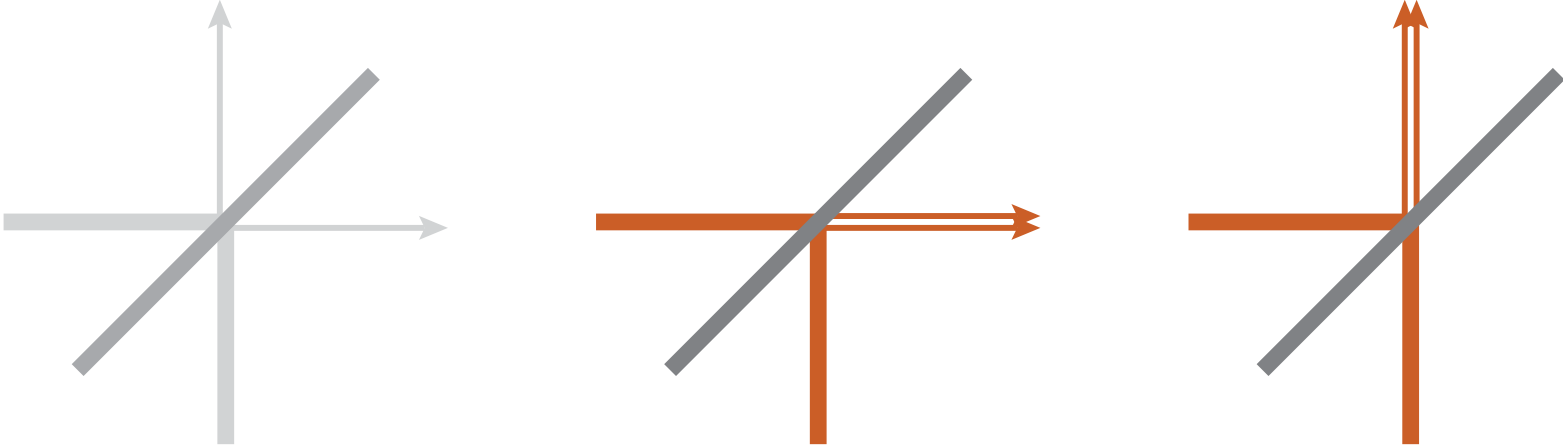
# Zwei unterscheidbare Teilchen am halbdurchlässigen Spiegel



# Zwei *ununterscheidbare* Teilchen am halbdurchlässigen Spiegel



# Zwei *ununterscheidbare* Teilchen am halbdurchlässigen Spiegel



Bosonen – die Teamplayer



# Zwei *ununterscheidbare* Teilchen am halbdurchlässigen Spiegel

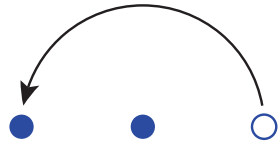


Fermionen – die Einzelgänger

# Vertauschen von Teilchen



$$\psi(1, 2)$$



$$\alpha \psi(2, 1)$$



$$\alpha^2 \psi(1, 2)$$



$$\alpha^2 = 1$$

$\alpha = 1$ : Bosonen

$\alpha = -1$ : Fermionen

# Unterschiedliche Möglichkeiten

unterscheidbare Teilchen

The diagram shows four boxes, each representing a possible arrangement of two distinguishable particles (one orange, one blue) in two energy levels (top and bottom).  
1. The orange particle is in the bottom level, and the blue particle is in the top level.  
2. The orange particle is in the bottom level, and the blue particle is in the bottom level.  
3. The orange particle is in the top level, and the blue particle is in the bottom level.  
4. The orange particle is in the top level, and the blue particle is in the top level.

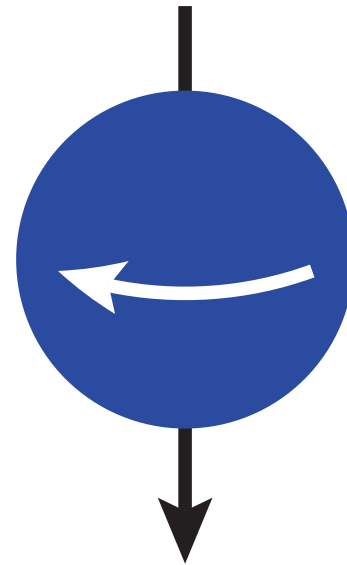
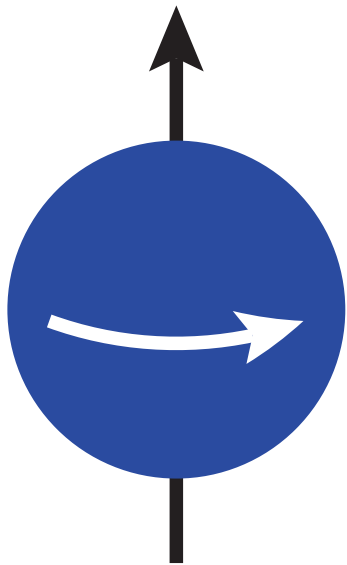
Bosonen

The diagram shows three boxes, each representing a possible arrangement of two indistinguishable bosons in two energy levels (top and bottom).  
1. One boson is in the bottom level, and one boson is in the top level.  
2. Two bosons are in the bottom level.  
3. Two bosons are in the top level.

Fermionen

The diagram shows one box, representing the arrangement of two indistinguishable fermions in two energy levels (top and bottom).  
1. One fermion is in the bottom level, and one fermion is in the top level.

# Spin



# Spin-Statistik-Theorem

ganzzahliger Spin  
Boson

---

Spin 0

Pion

Spin 1

Photon

W- und Z-Boson

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Helium-4



halbzahliger Spin  
Fermion

---

Spin 1/2

Elektron

Proton

Neutron

---

Helium-3

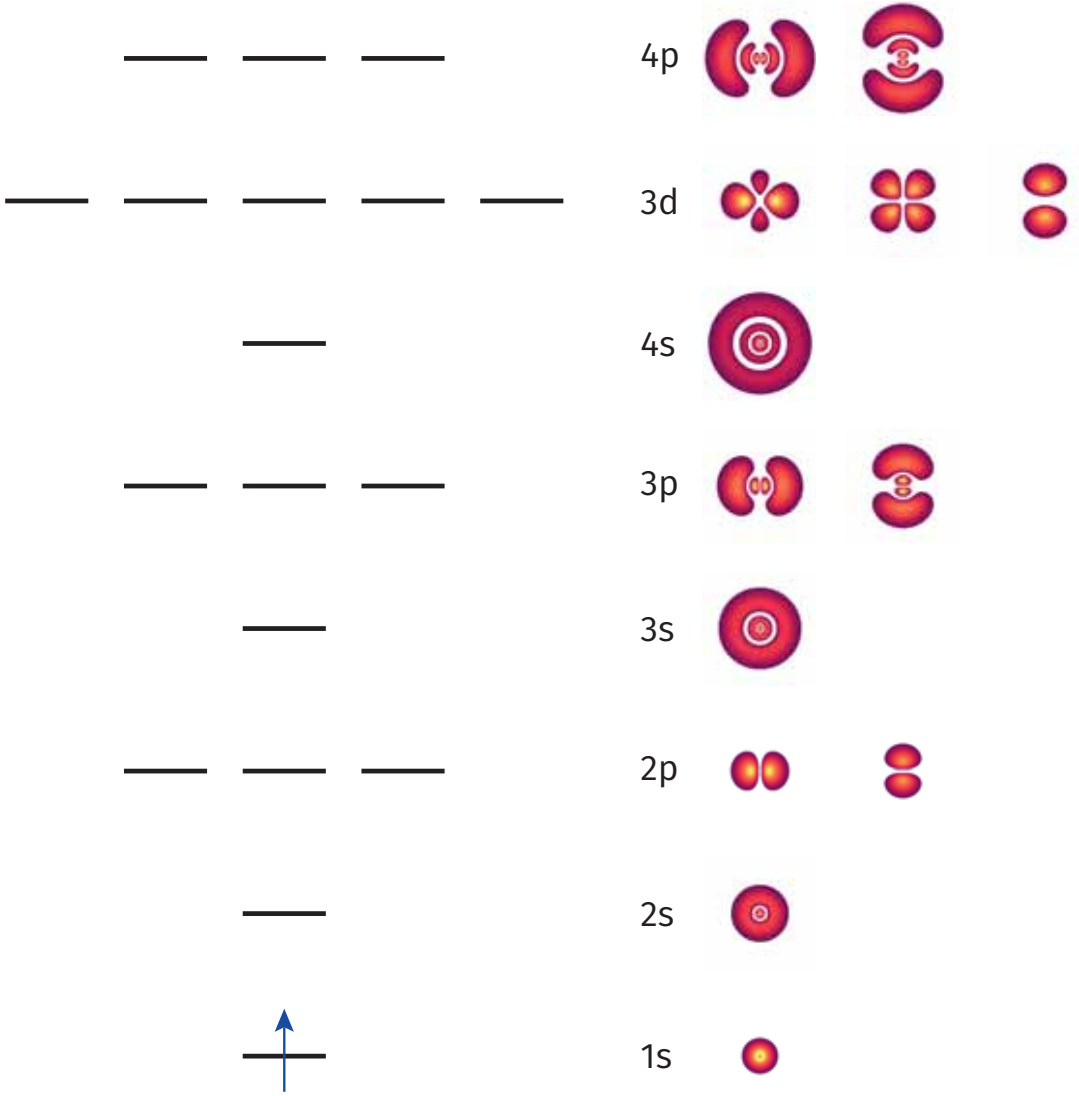
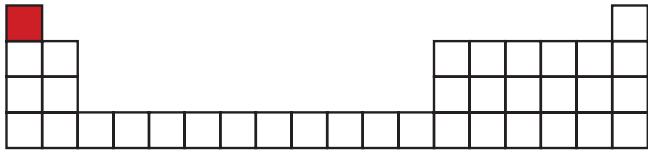


# Periodensystem der Elemente

1 <b>H</b> Wasserstoff																	2 <b>He</b> Helium													
3 <b>Li</b> Lithium	4 <b>Be</b> Beryllium															5 <b>B</b> Bor	6 <b>C</b> Kohlenstoff	7 <b>N</b> Stickstoff	8 <b>O</b> Sauerstoff	9 <b>F</b> Fluor	10 <b>Ne</b> Neon									
11 <b>Na</b> Natrium	12 <b>Mg</b> Magnesium															13 <b>Al</b> Aluminium	14 <b>Si</b> Silizium	15 <b>P</b> Phosphor	16 <b>S</b> Schwefel	17 <b>Cl</b> Chlor	18 <b>Ar</b> Argon									
19 <b>K</b> Kalium	20 <b>Ca</b> Calcium	21 <b>Sc</b> Scandium	22 <b>Ti</b> Titan	23 <b>V</b> Vanadium	24 <b>Cr</b> Chrom	25 <b>Mn</b> Mangan	26 <b>Fe</b> Eisen	27 <b>Co</b> Kobalt	28 <b>Ni</b> Nickel	29 <b>Cu</b> Kupfer	30 <b>Zn</b> Zink	31 <b>Ga</b> Gallium	32 <b>Ge</b> Germanium	33 <b>As</b> Arsen	34 <b>Se</b> Selen	35 <b>Br</b> Brom	36 <b>Kr</b> Krypton													
37 <b>Rb</b> Rubidium	38 <b>Sr</b> Strontium	39 <b>Y</b> Yttrium	40 <b>Zr</b> Zirkon	41 <b>Nb</b> Niob	42 <b>Mo</b> Molybdän	43 <b>Tc</b> Technetium	44 <b>Ru</b> Ruthenium	45 <b>Rh</b> Rhodium	46 <b>Pd</b> Palladium	47 <b>Ag</b> Silber	48 <b>Cd</b> Cadmium	49 <b>In</b> Indium	50 <b>Sn</b> Zinn	51 <b>Sb</b> Antimon	52 <b>Te</b> Tellur	53 <b>I</b> Jod	54 <b>Xe</b> Xenon													
55 <b>Cs</b> Cäsium	56 <b>Ba</b> Barium	57 <b>La</b> Lanthan	* 62 <b>Hf</b> Hafnium	73 <b>Ta</b> Tantal	74 <b>W</b> Wolfram	75 <b>Re</b> Rhenium	76 <b>Os</b> Osmium	77 <b>Ir</b> Iridium	78 <b>Pt</b> Platin	79 <b>Au</b> Gold	80 <b>Hg</b> Quecksilber	81 <b>Tl</b> Thallium	82 <b>Pb</b> Blei	83 <b>Bi</b> Bismut	84 <b>Po</b> Polonium	85 <b>At</b> Astat	86 <b>Rn</b> Radon													
87 <b>Fr</b> Francium	88 <b>Ra</b> Radium	89 <b>Ac</b> Actinium	* 104 <b>Rf</b> Rutherfordium	105 <b>Db</b> Dubnium	106 <b>Sg</b> Seaborgium	107 <b>Bh</b> Bohrium	108 <b>Hs</b> Hassium	109 <b>Mt</b> Meitnerium	110 <b>Ds</b> Darmstadtium	111 <b>Rg</b> Röntgenium	112 <b>Cn</b> Copernicium	113 <b>Nh</b> Nihonium	114 <b>Fl</b> Flerovium	115 <b>Mc</b> Moscovium	116 <b>Lv</b> Livermorium	117 <b>Ts</b> Tenness	118 <b>Og</b> Oganesson													
* 58 <b>Ce</b> Cer																		59 <b>Pr</b> Praseodym	60 <b>Nd</b> Neodym	61 <b>Pm</b> Promethium	62 <b>Sm</b> Samarium	63 <b>Eu</b> Europium	64 <b>Gd</b> Gadolinium	65 <b>Tb</b> Terbium	66 <b>Dy</b> Dysprosium	67 <b>Ho</b> Holmium	68 <b>Er</b> Erbium	69 <b>Tm</b> Thulium	70 <b>Yb</b> Ytterbium	71 <b>Lu</b> Lutetium
* 90 <b>Th</b> Thorium																		91 <b>Pa</b> Protactinium	92 <b>U</b> Uran	93 <b>Np</b> Neptunium	94 <b>Pu</b> Plutonium	95 <b>Am</b> Americium	96 <b>Cm</b> Curium	97 <b>Bk</b> Berkelium	98 <b>Cf</b> Californium	99 <b>Es</b> Einsteinium	100 <b>Fm</b> Fermium	101 <b>Md</b> Mendelevium	102 <b>No</b> Nobelium	103 <b>Lr</b> Lawrencium

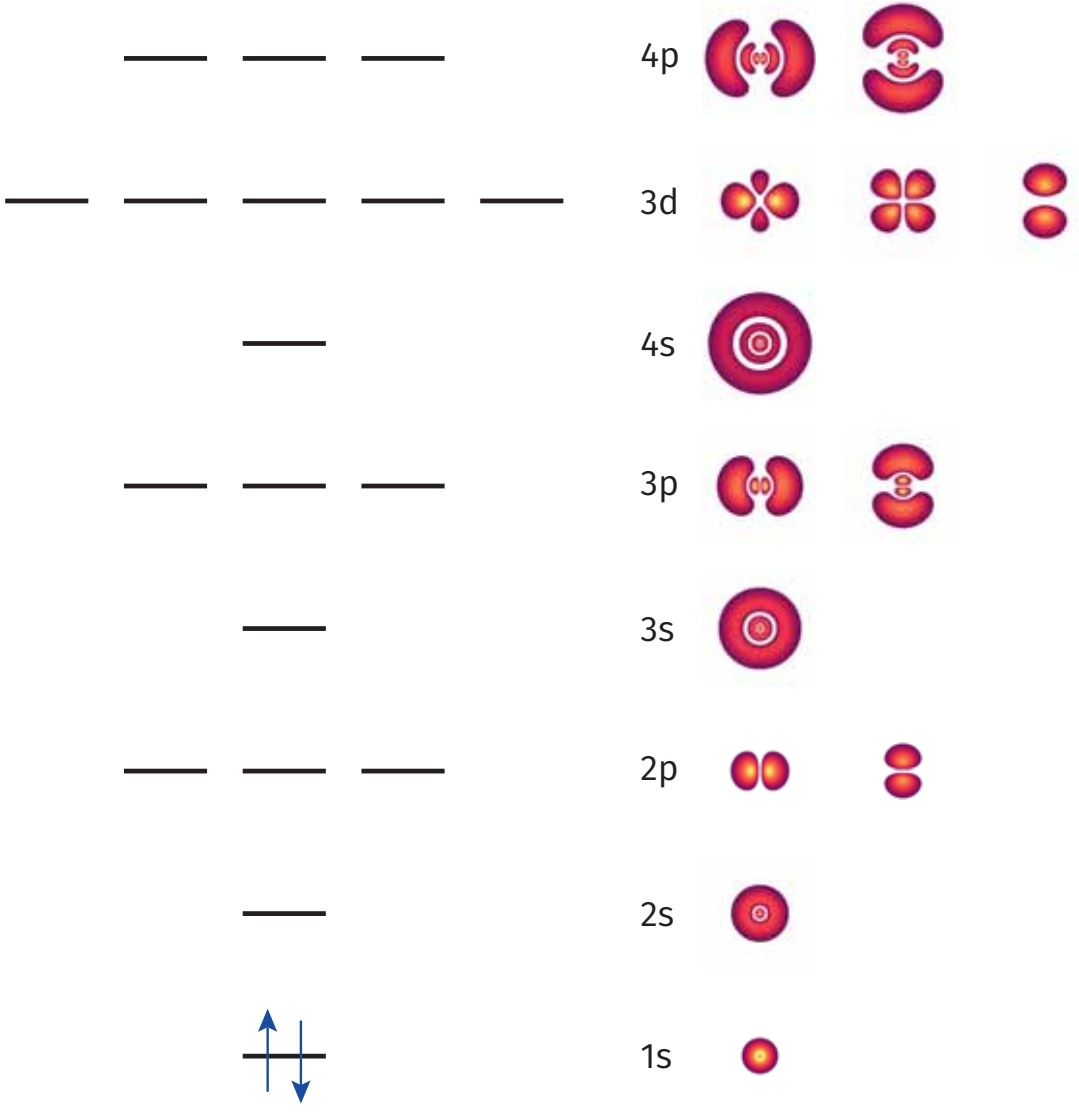
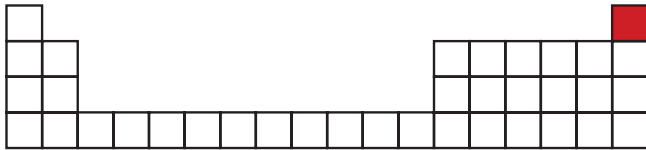
# Elektronenkonfiguration

**Wasserstoff (H): 1 Elektron**



# Elektronenkonfiguration

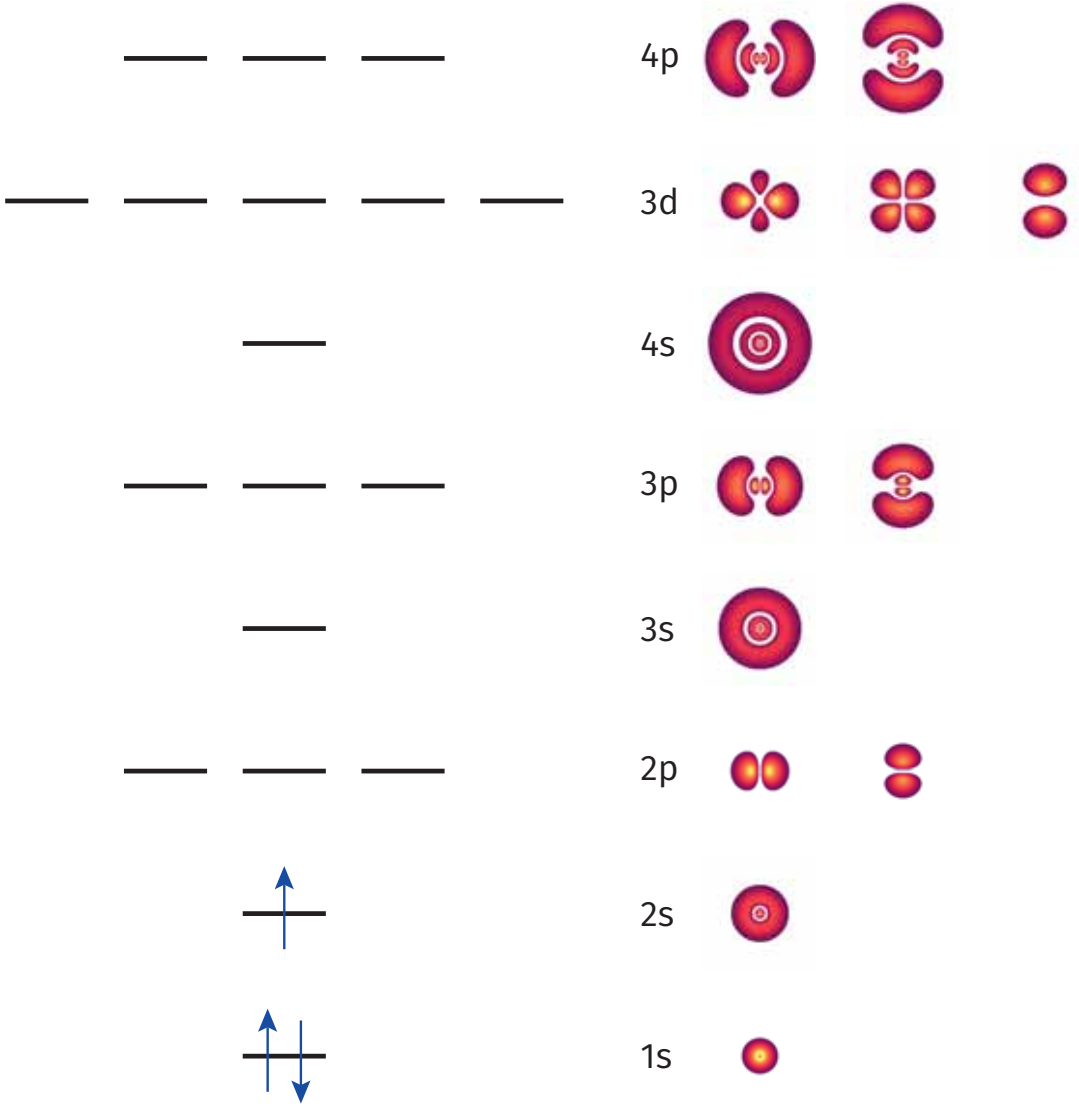
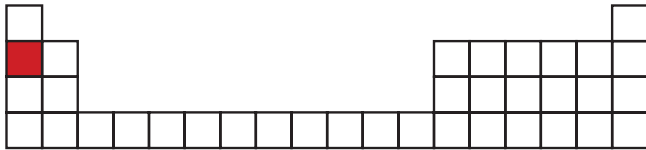
Helium (He): 2 Elektronen





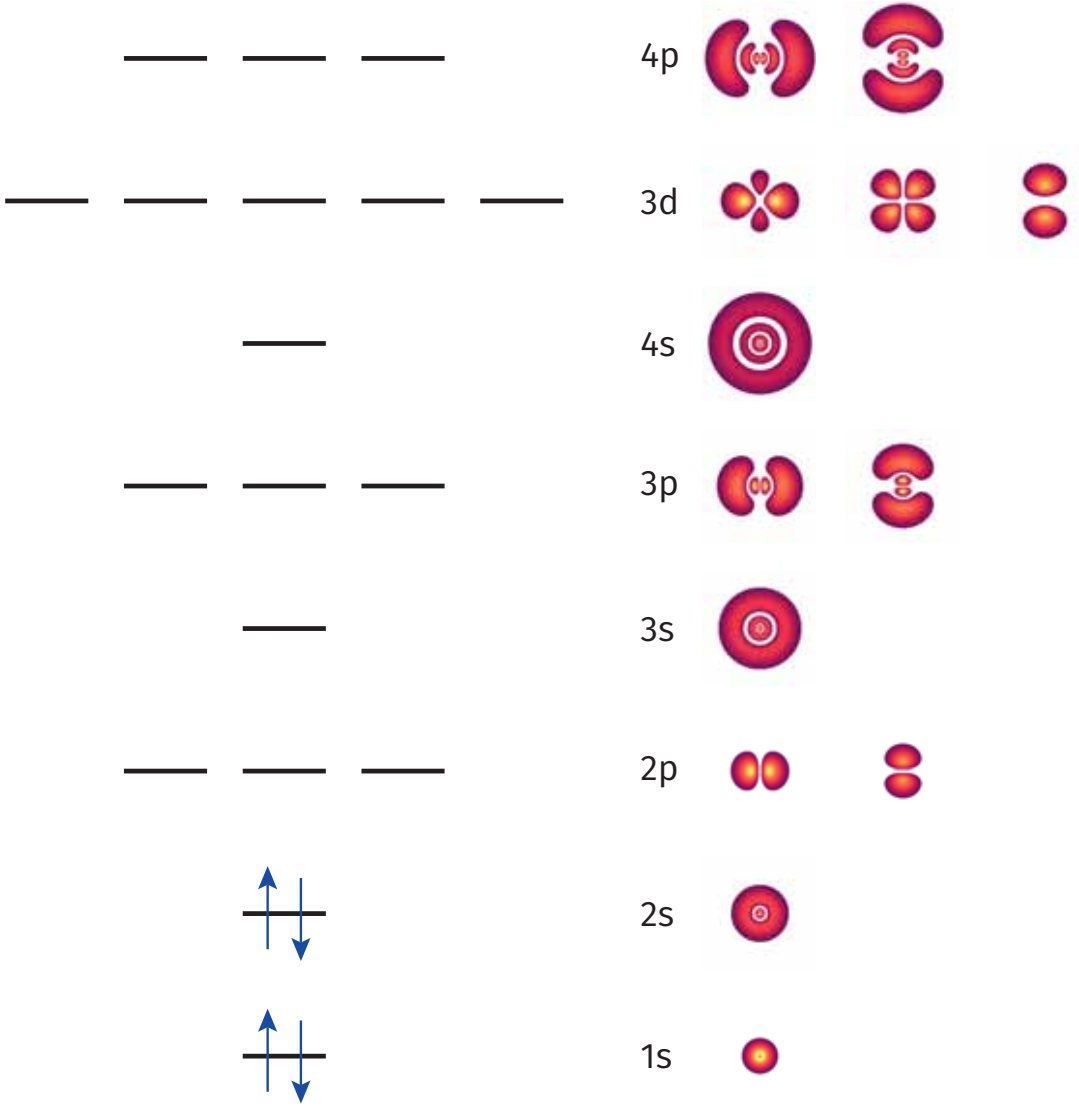
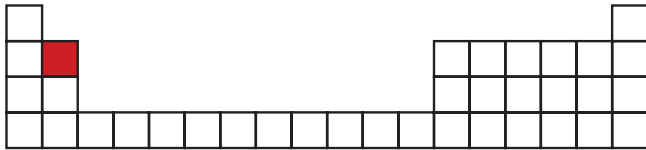
# Elektronenkonfiguration

Lithium (Li): 3 Elektronen



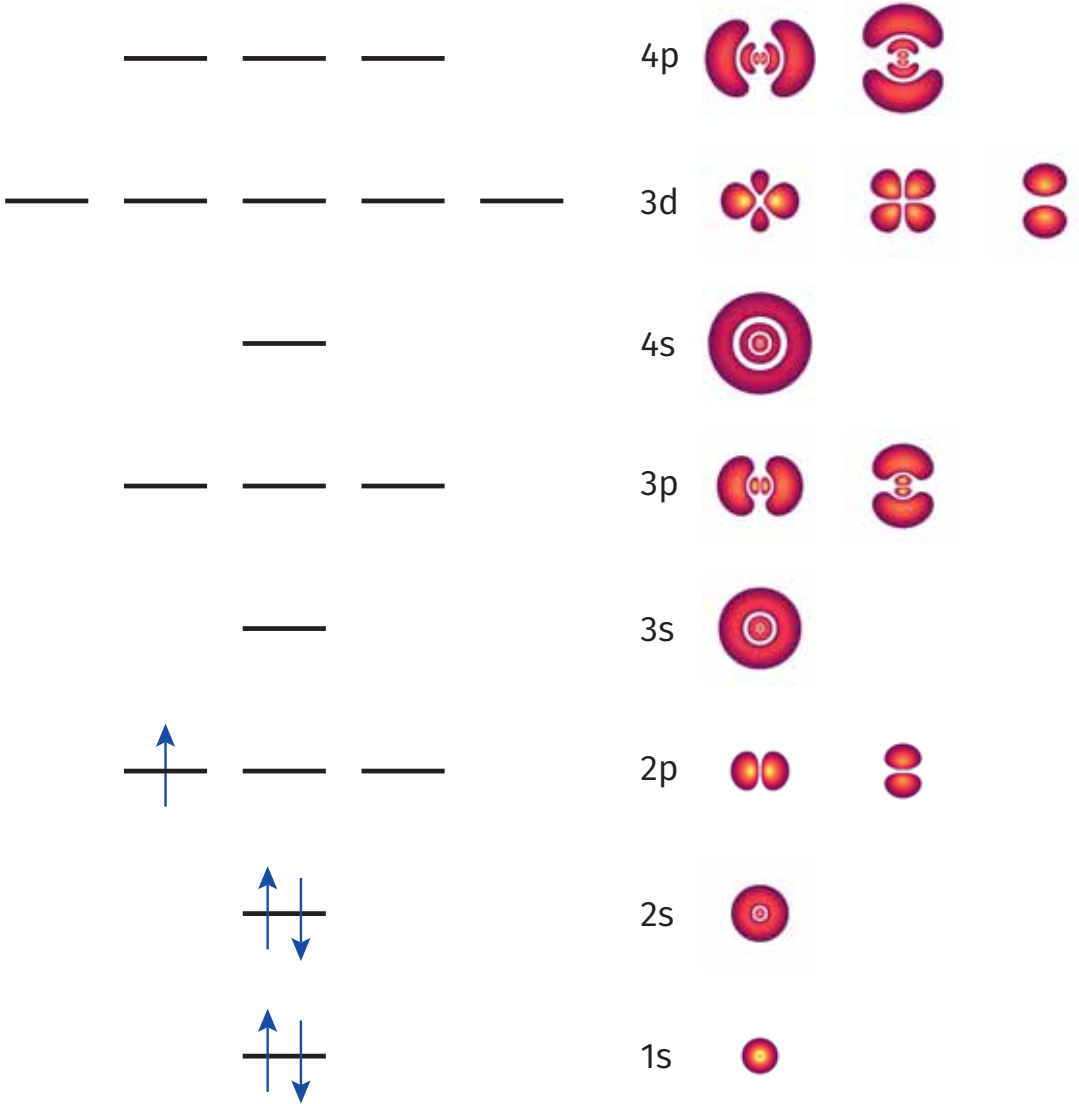
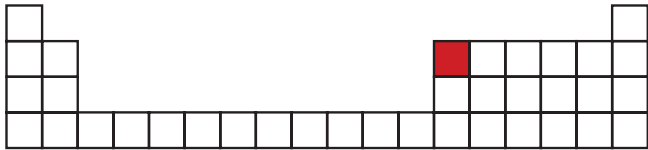
# Elektronenkonfiguration

**Beryllium (Be): 4 Elektronen**



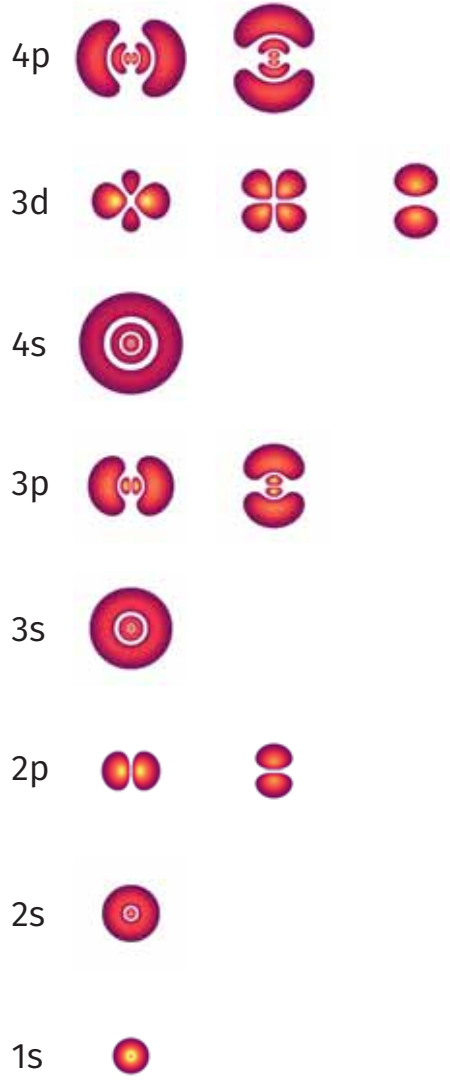
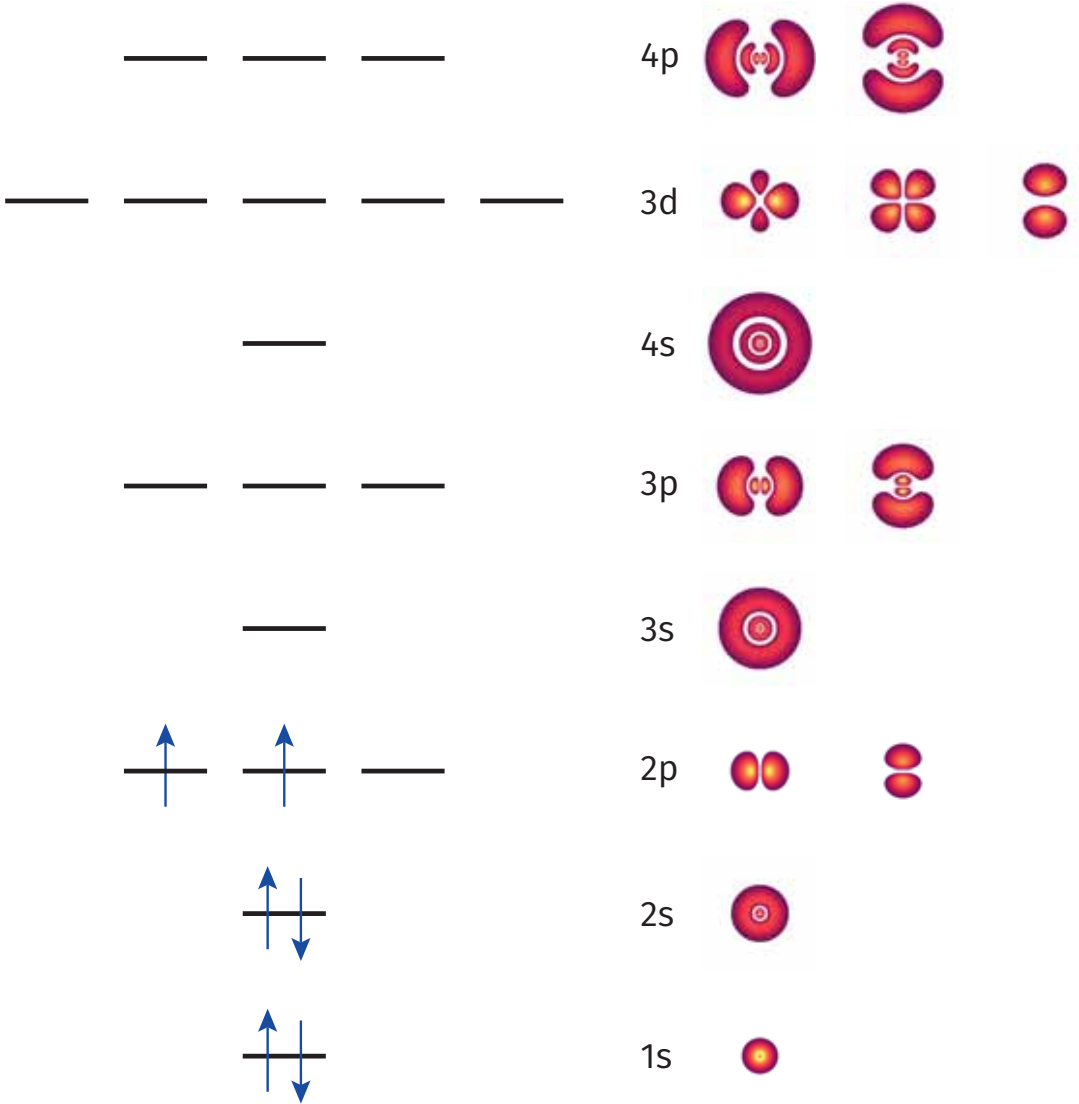
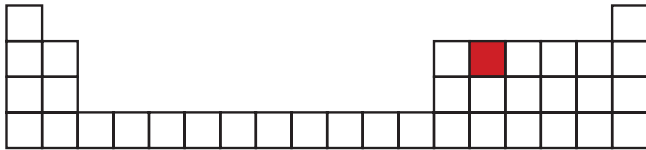
# Elektronenkonfiguration

**Bor (B): 5 Elektronen**



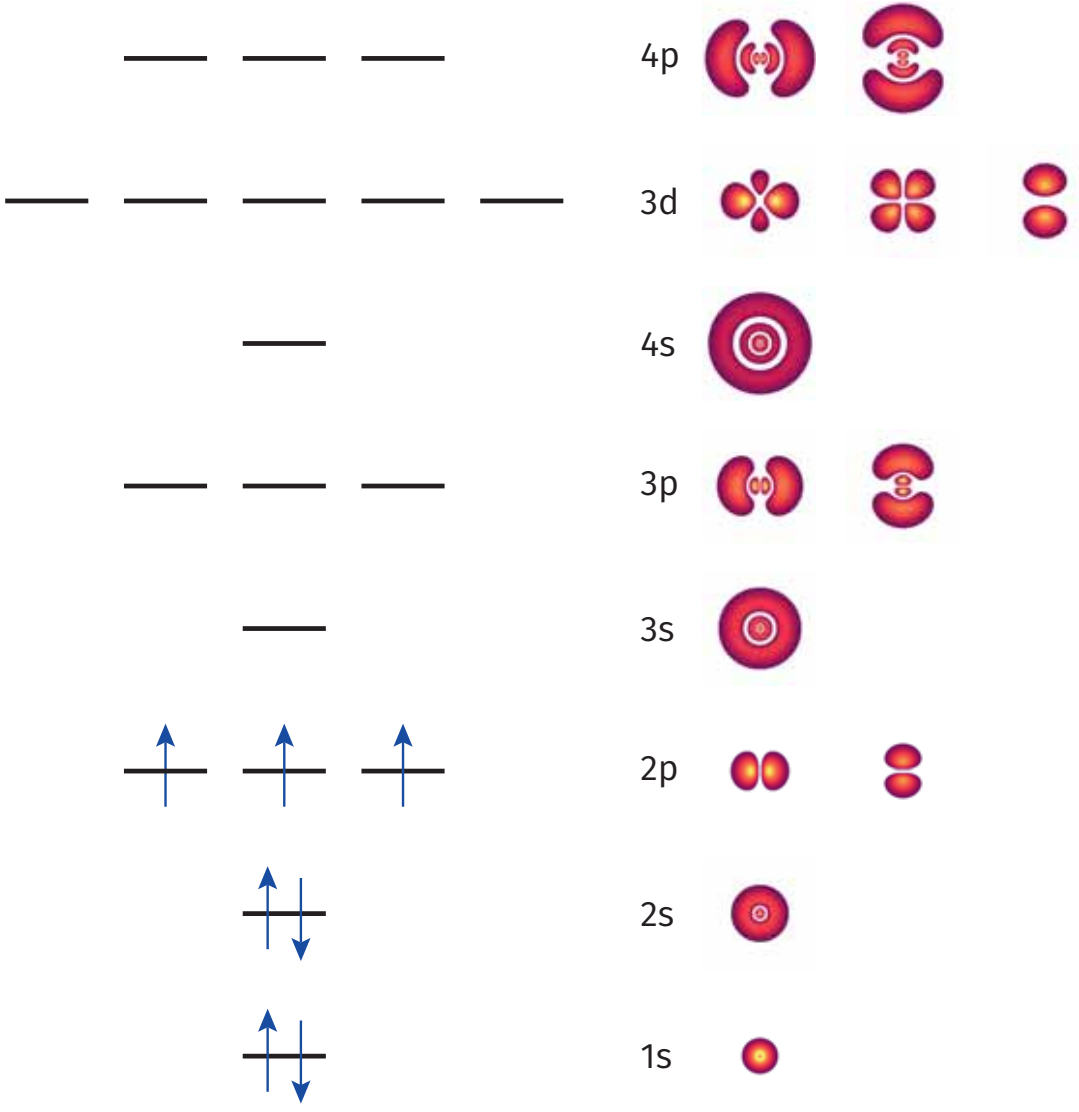
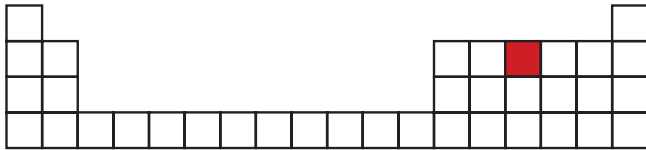
# Elektronenkonfiguration

**Kohlenstoff (C): 6 Elektronen**



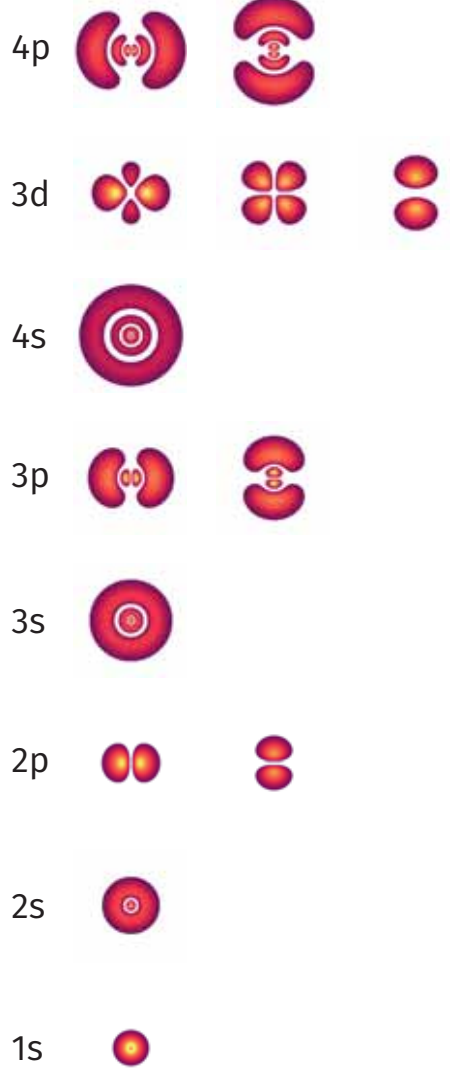
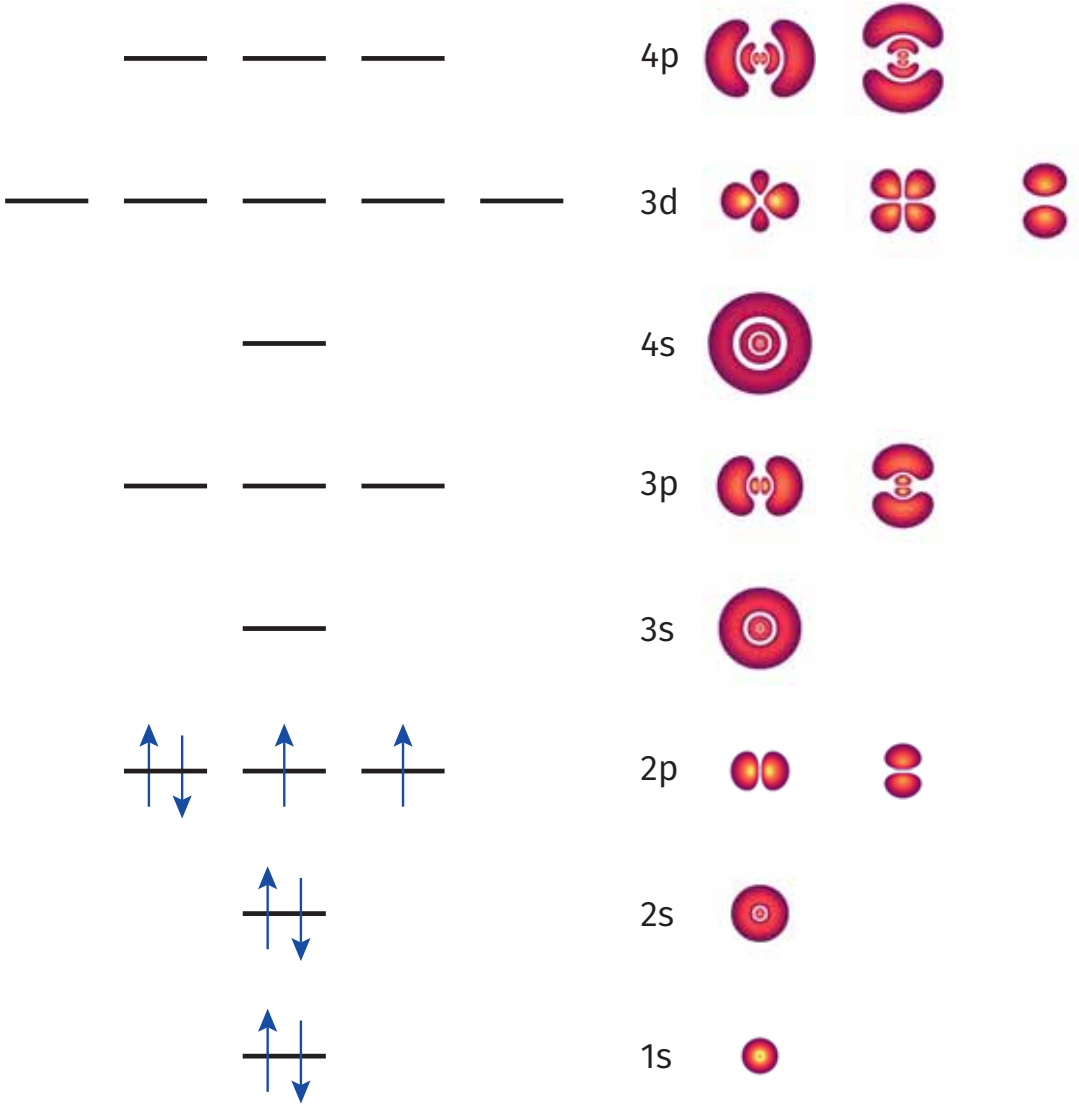
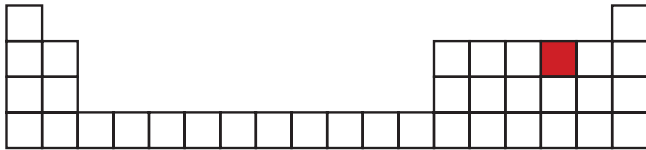
# Elektronenkonfiguration

**Stickstoff (N): 7 Elektronen**



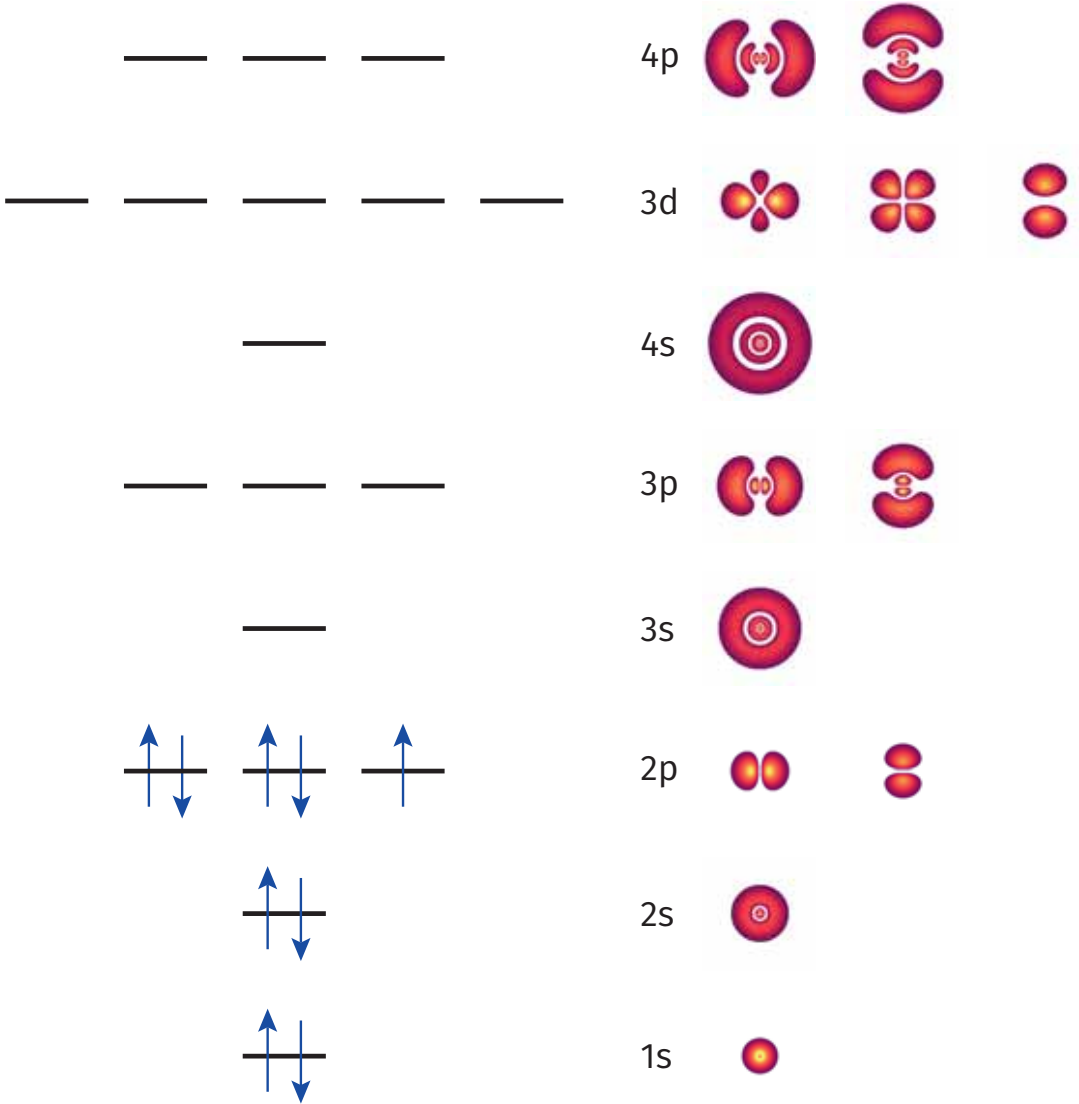
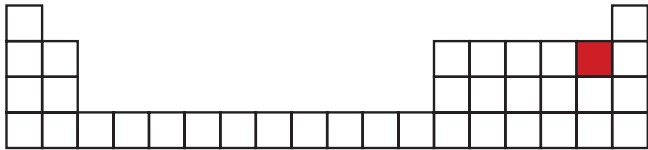
# Elektronenkonfiguration

Sauerstoff (O): 8 Elektronen



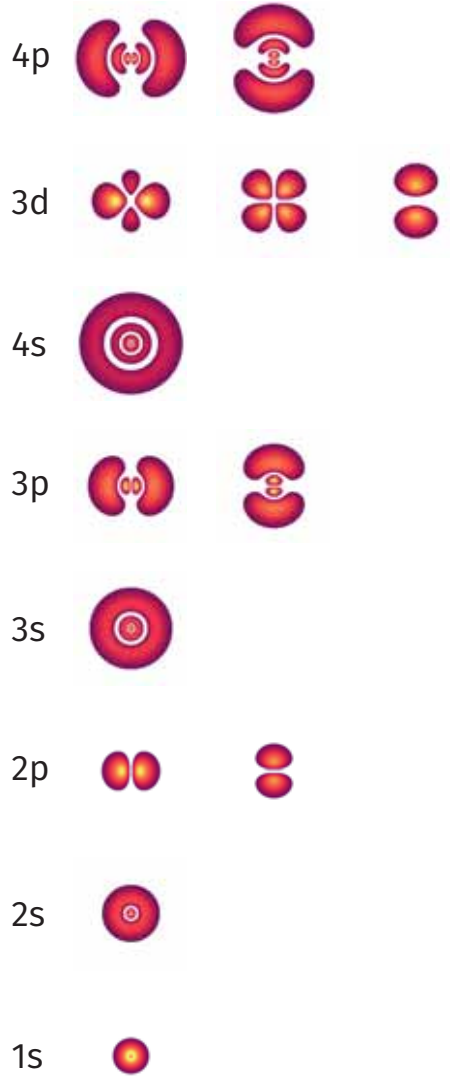
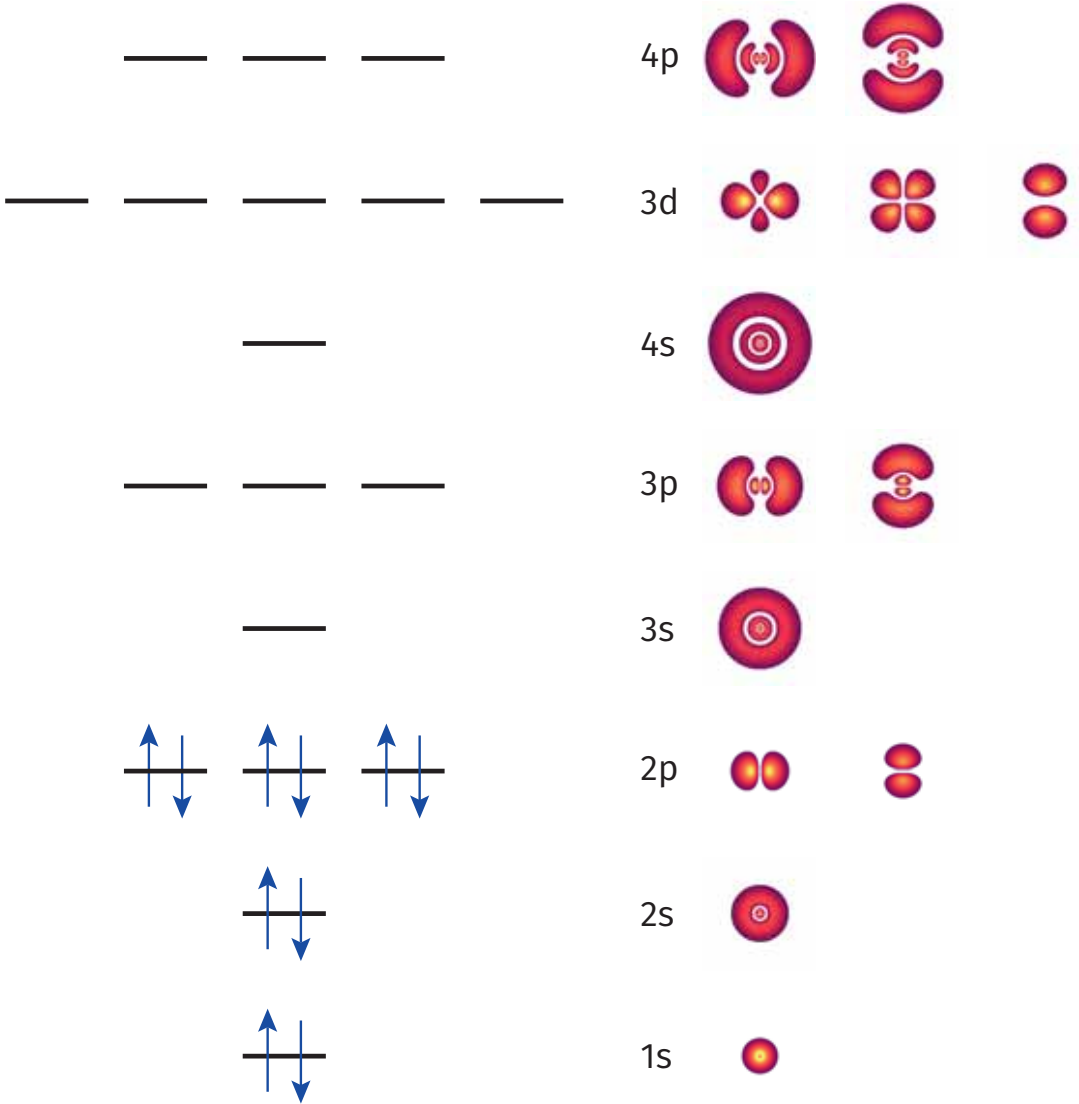
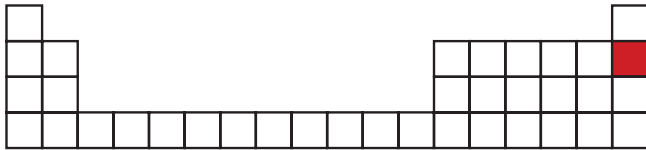
# Elektronenkonfiguration

**Fluor (F): 9 Elektronen**



# Elektronenkonfiguration

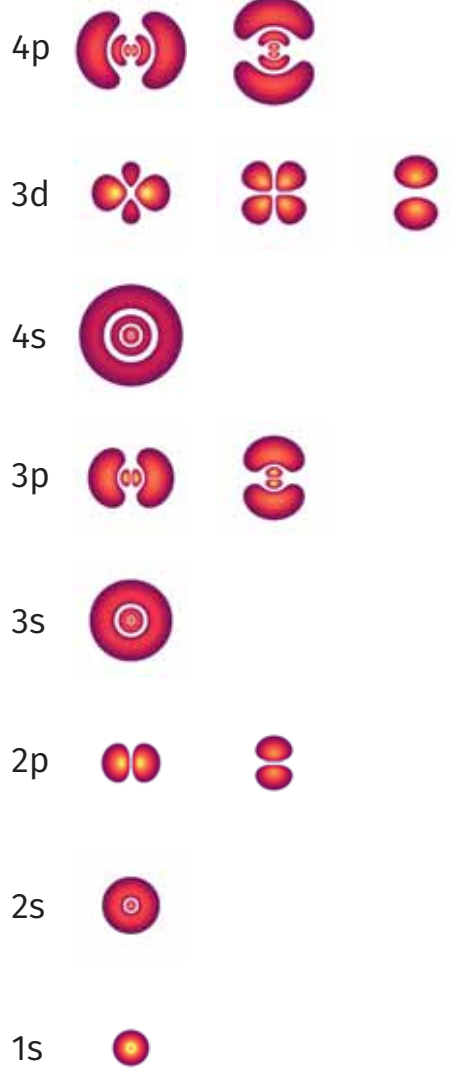
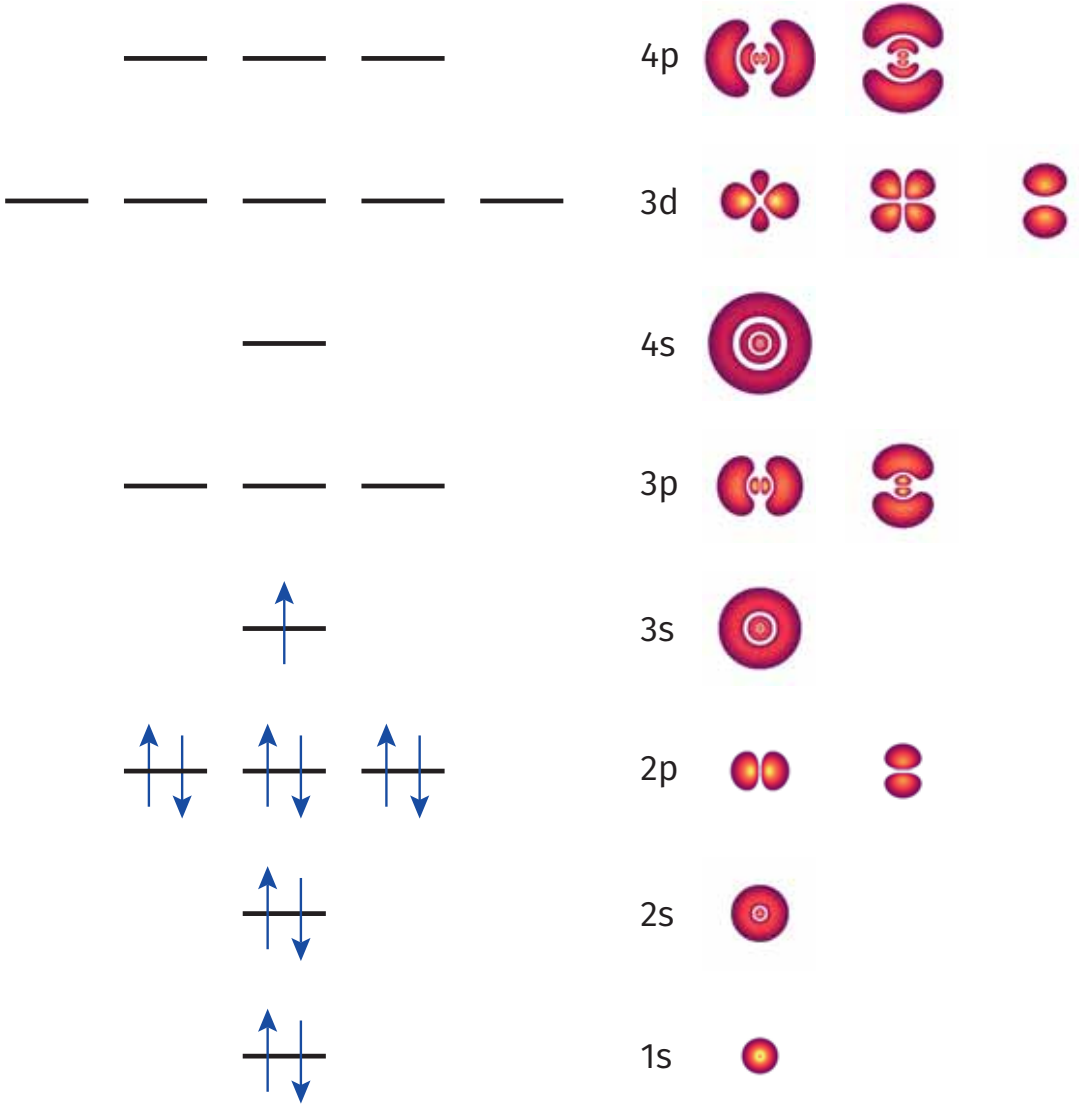
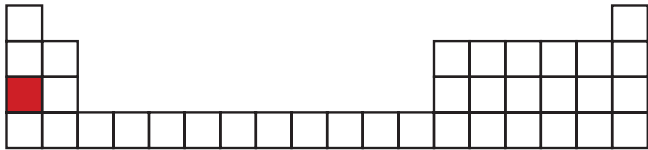
Neon (Ne): 10 Elektronen





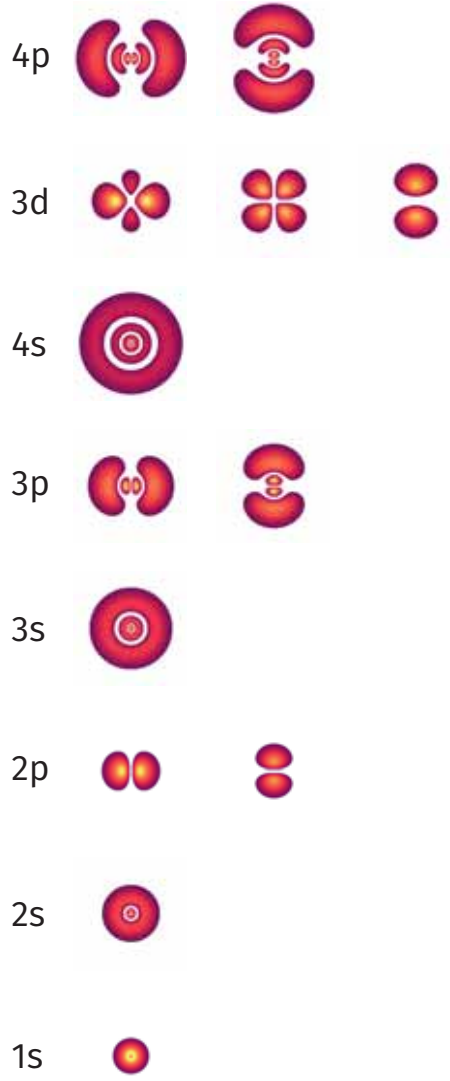
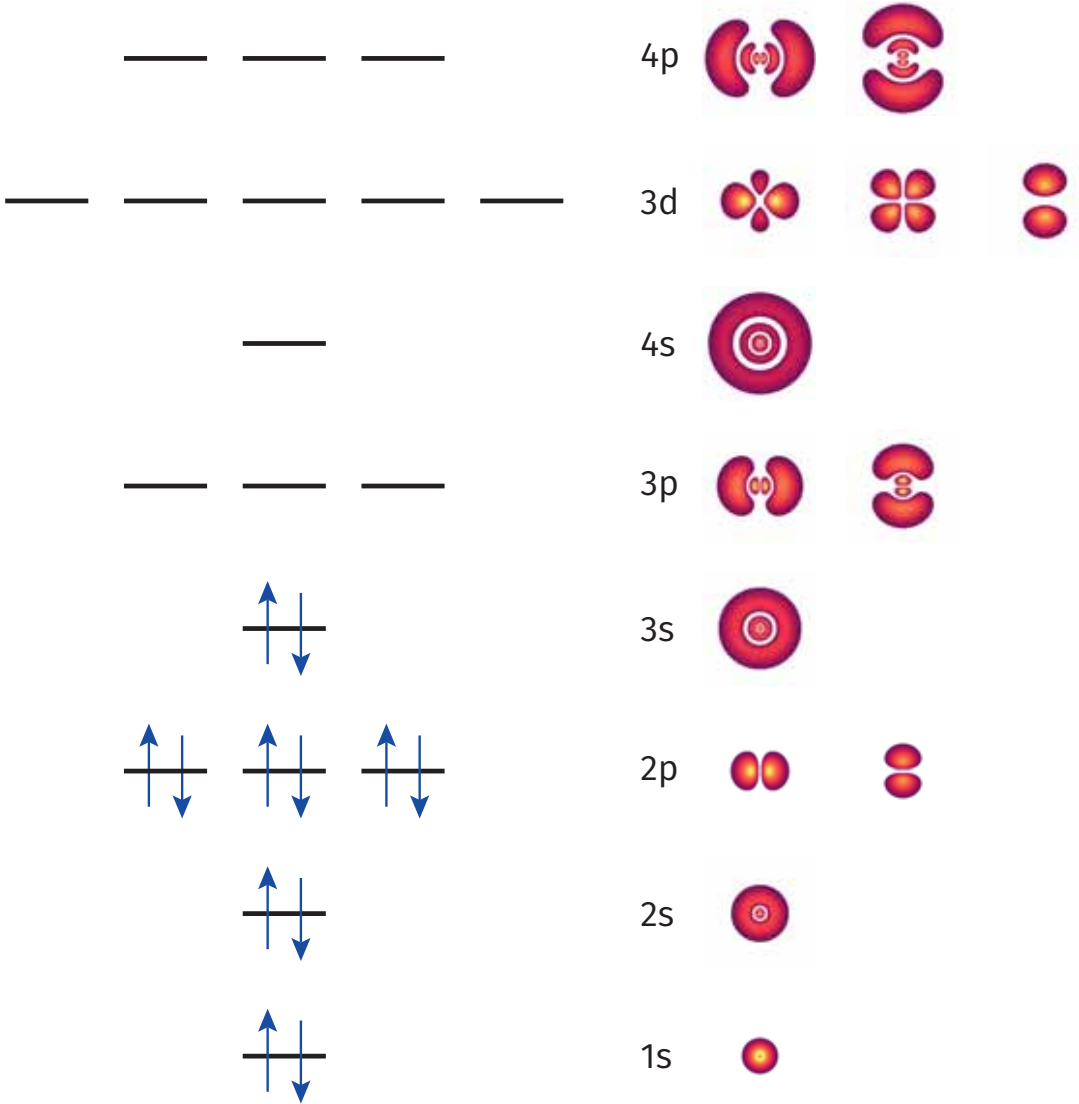
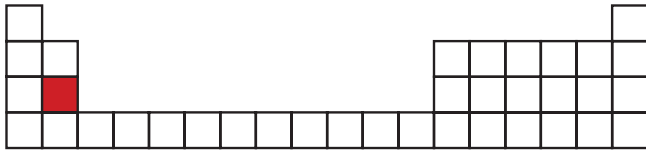
# Elektronenkonfiguration

**Natrium (Na): 11 Elektronen**



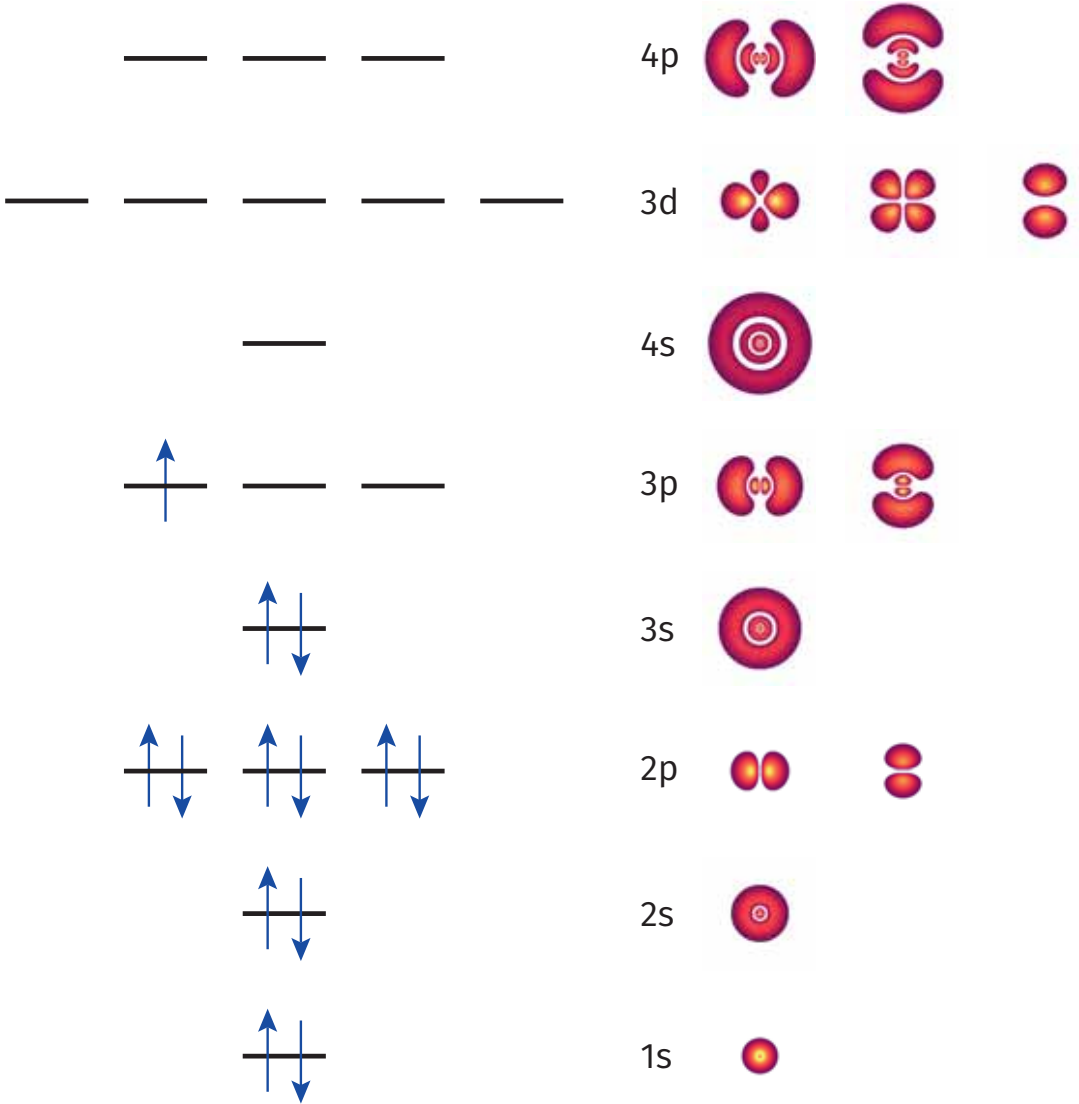
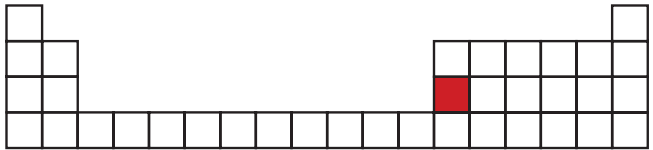
# Elektronenkonfiguration

**Magnesium (Mg): 12 Elektronen**



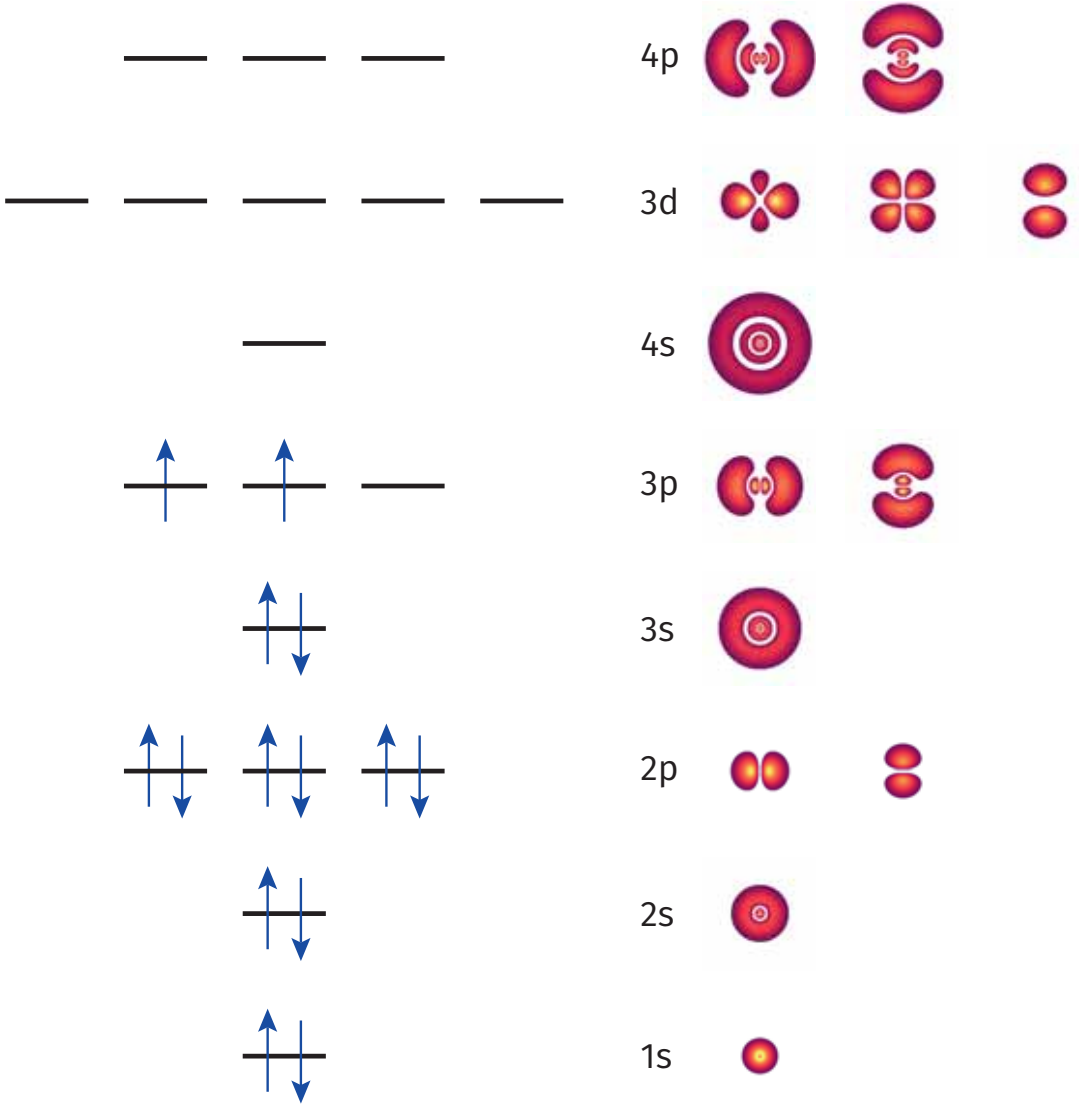
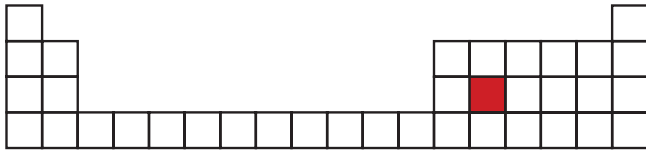
# Elektronenkonfiguration

**Aluminum (Al): 13 Elektronen**



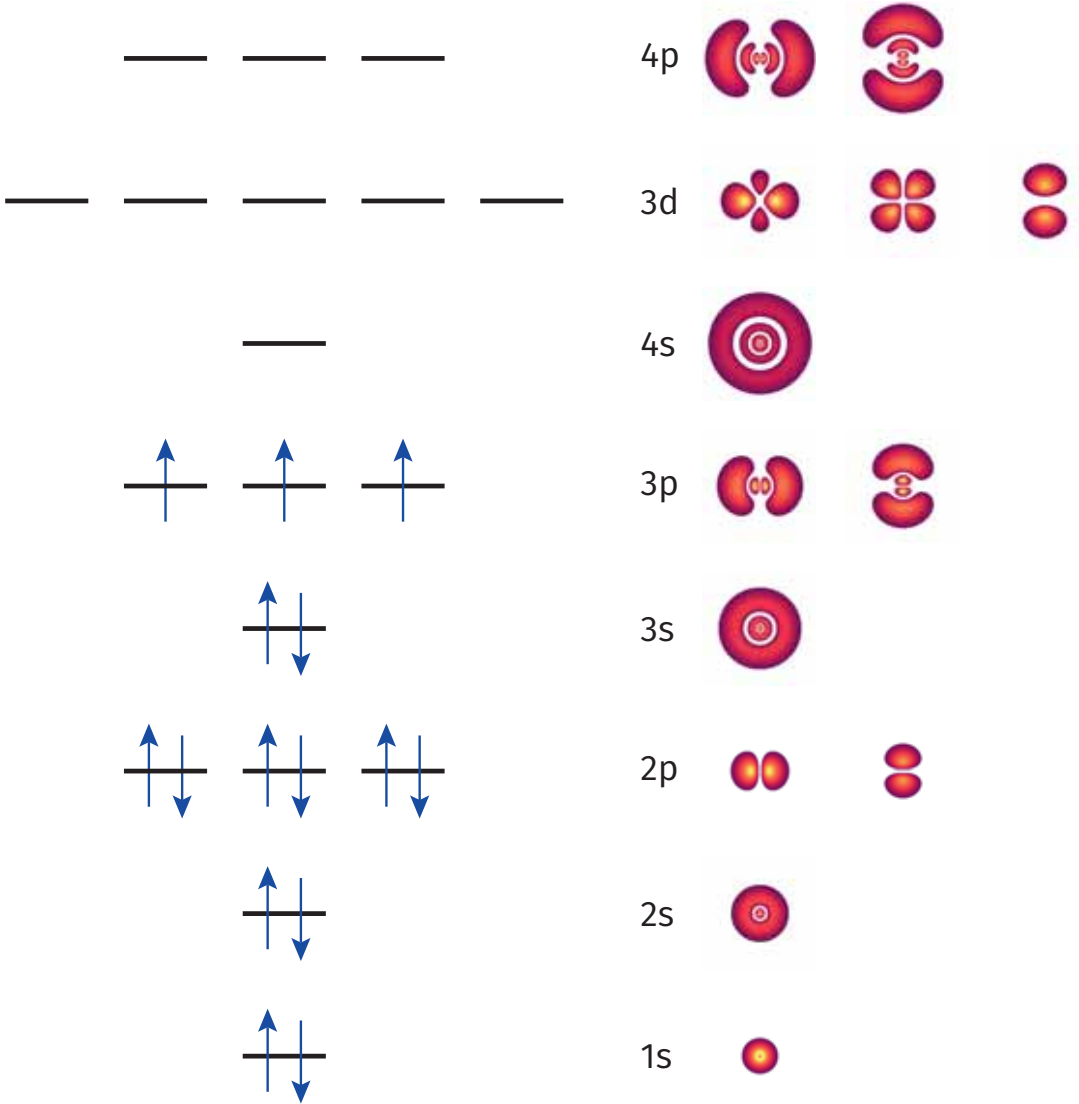
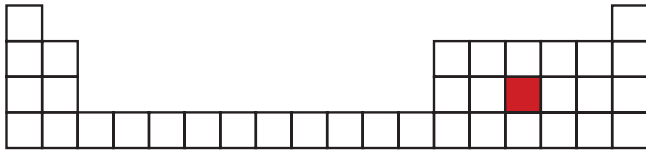
# Elektronenkonfiguration

**Silizium (Si): 14 Elektronen**



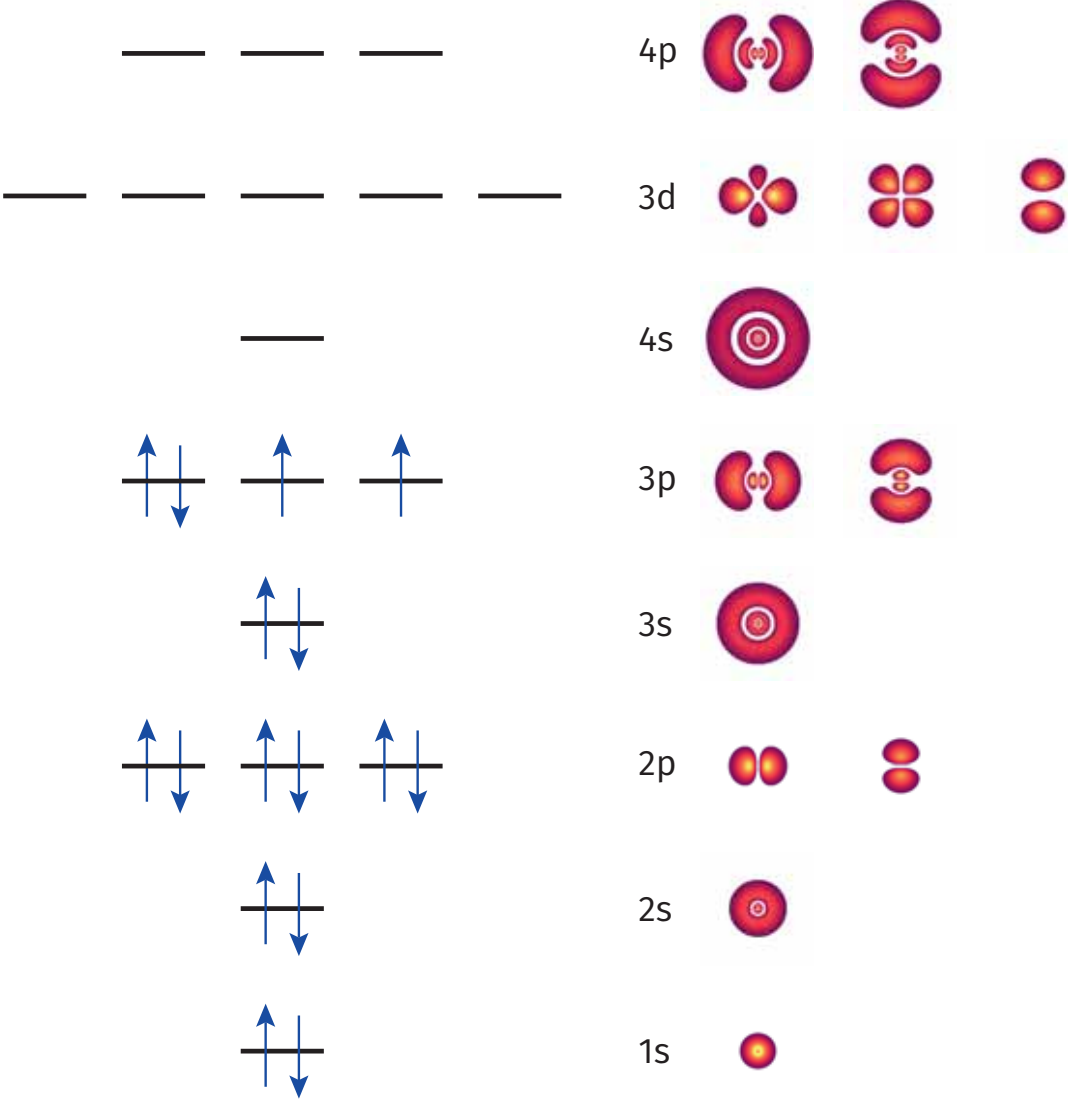
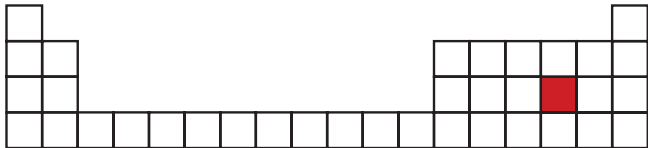
# Elektronenkonfiguration

**Phosphor (P): 15 Elektronen**



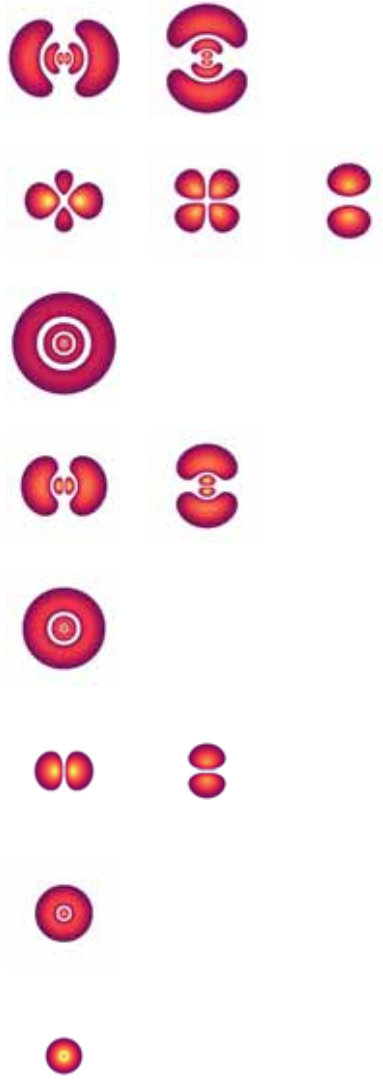
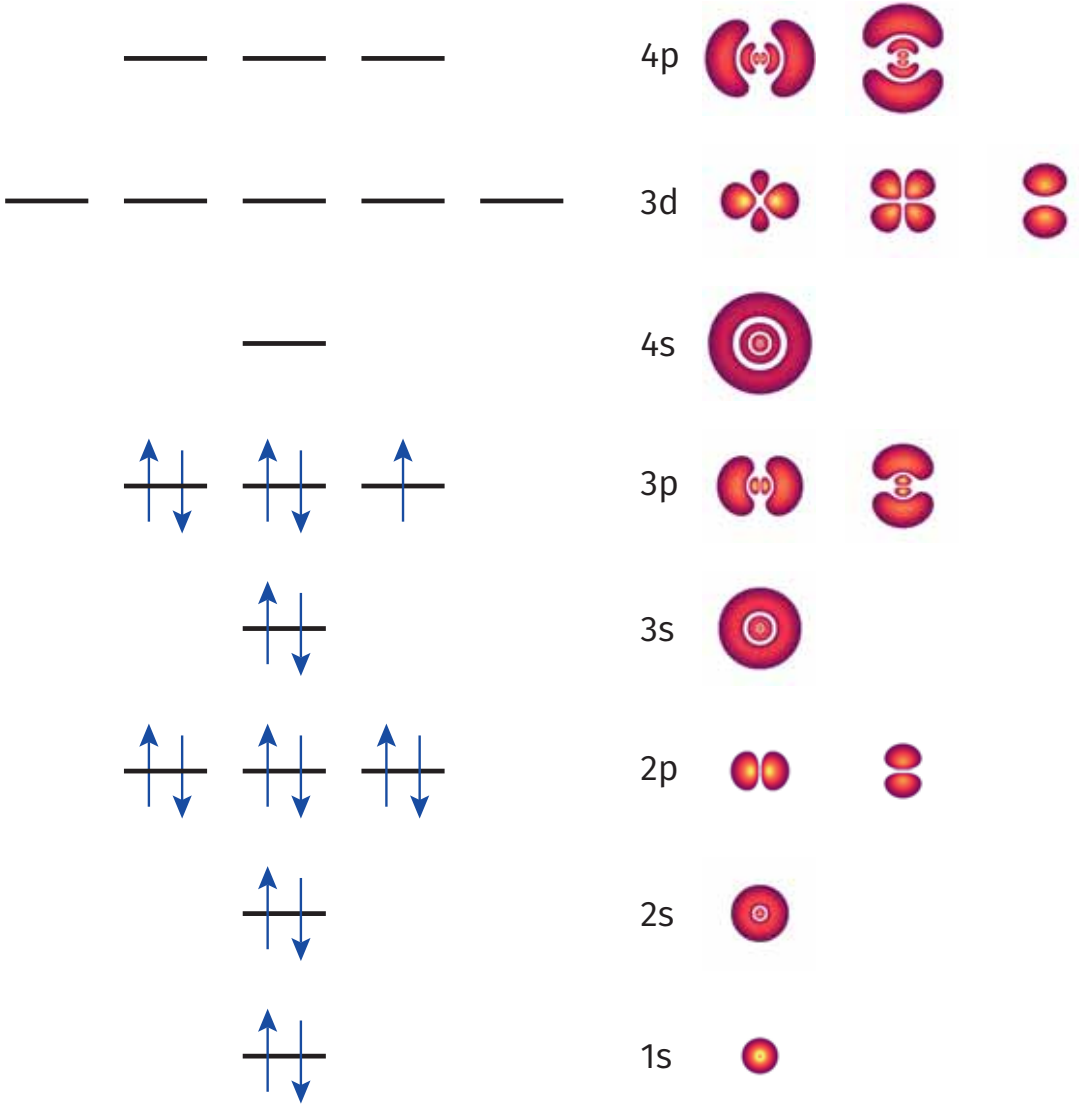
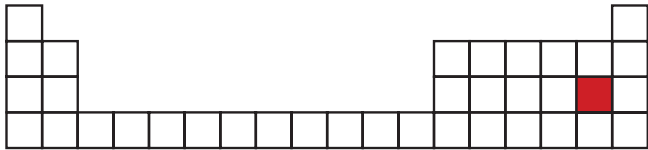
# Elektronenkonfiguration

Schwefel (S): 16 Elektronen



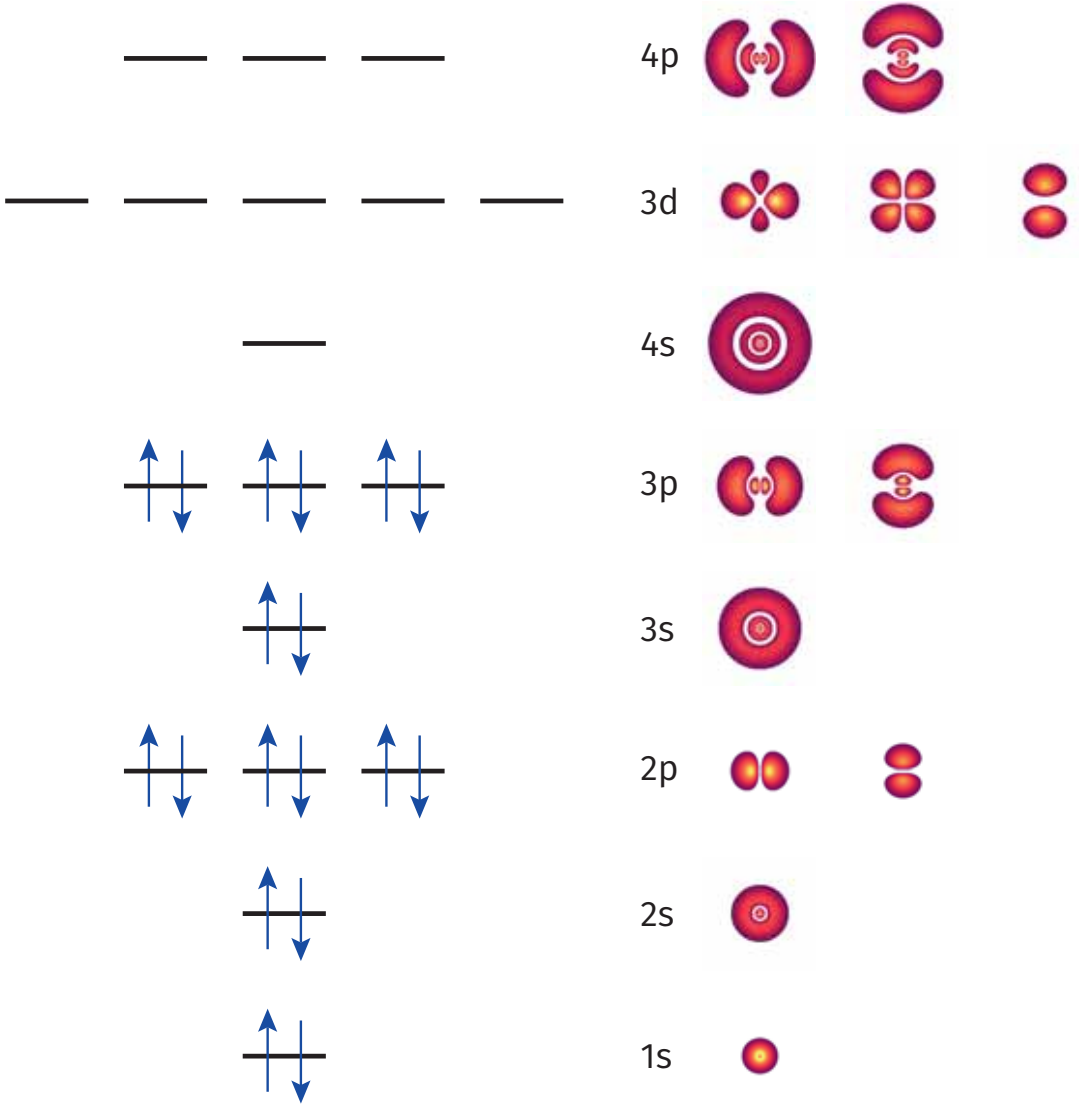
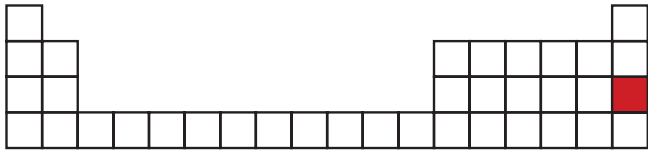
# Elektronenkonfiguration

**Chlor (Cl): 17 Elektronen**



# Elektronenkonfiguration

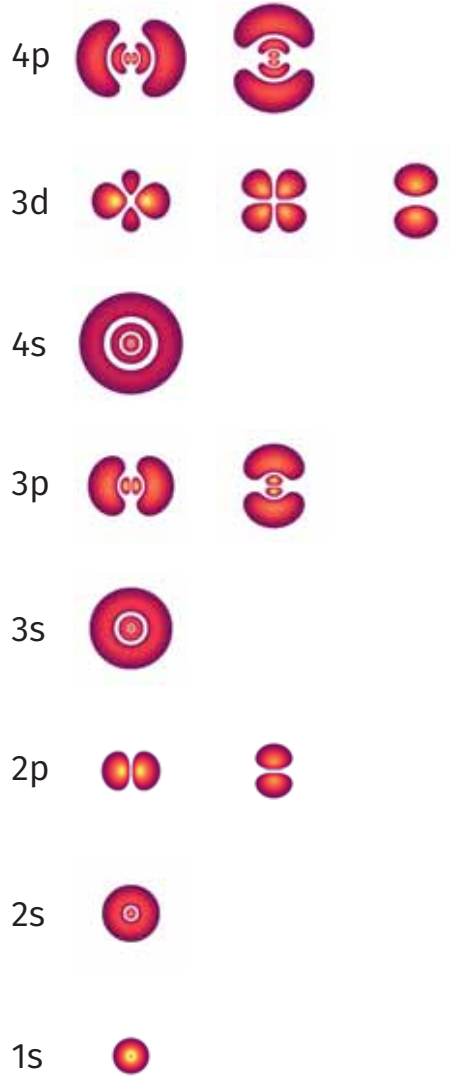
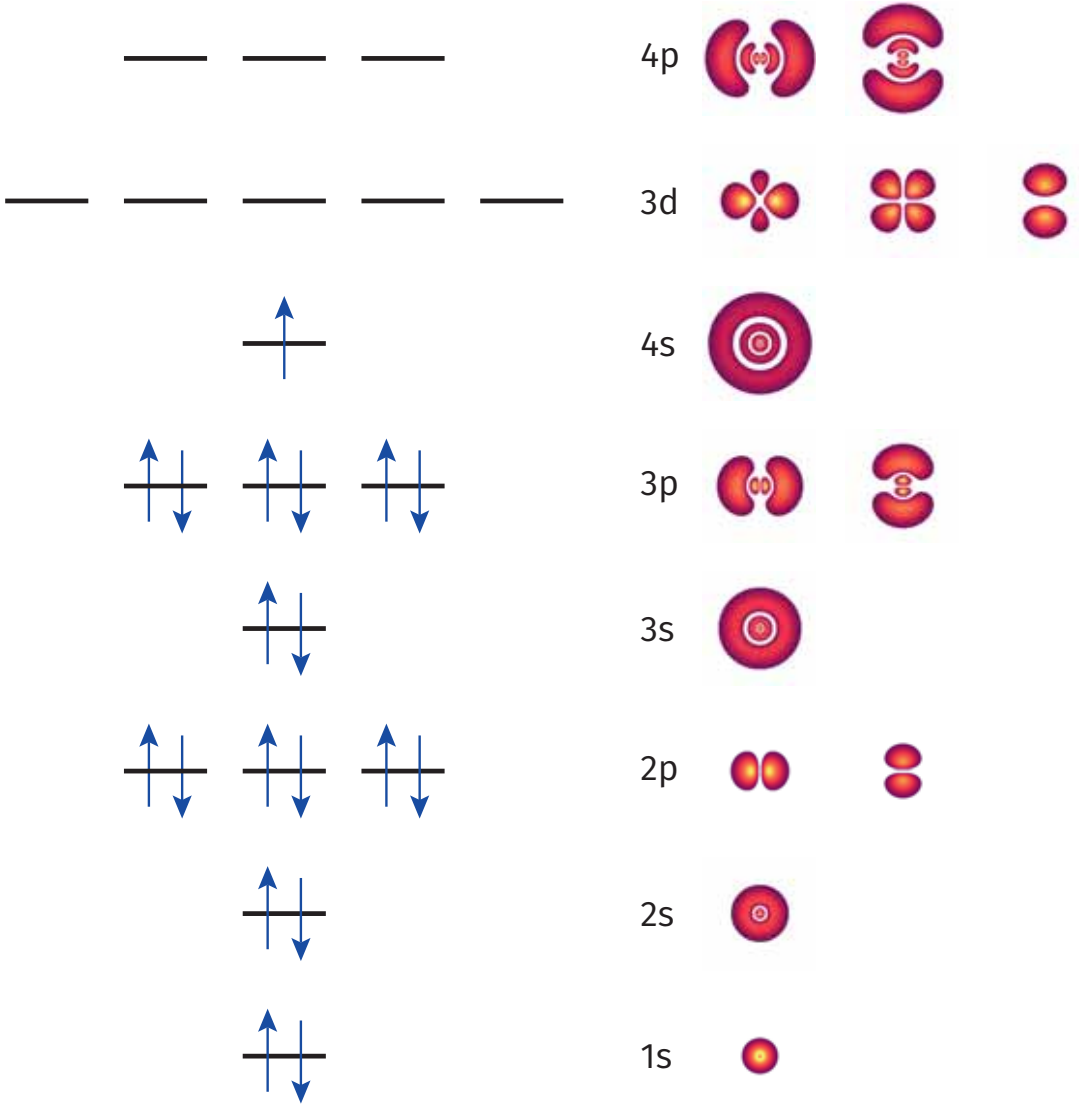
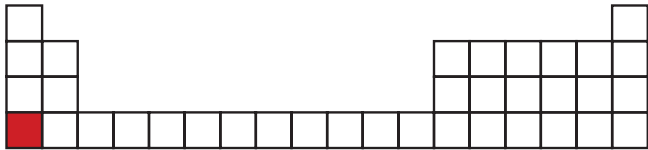
**Argon (Ar): 18 Elektronen**





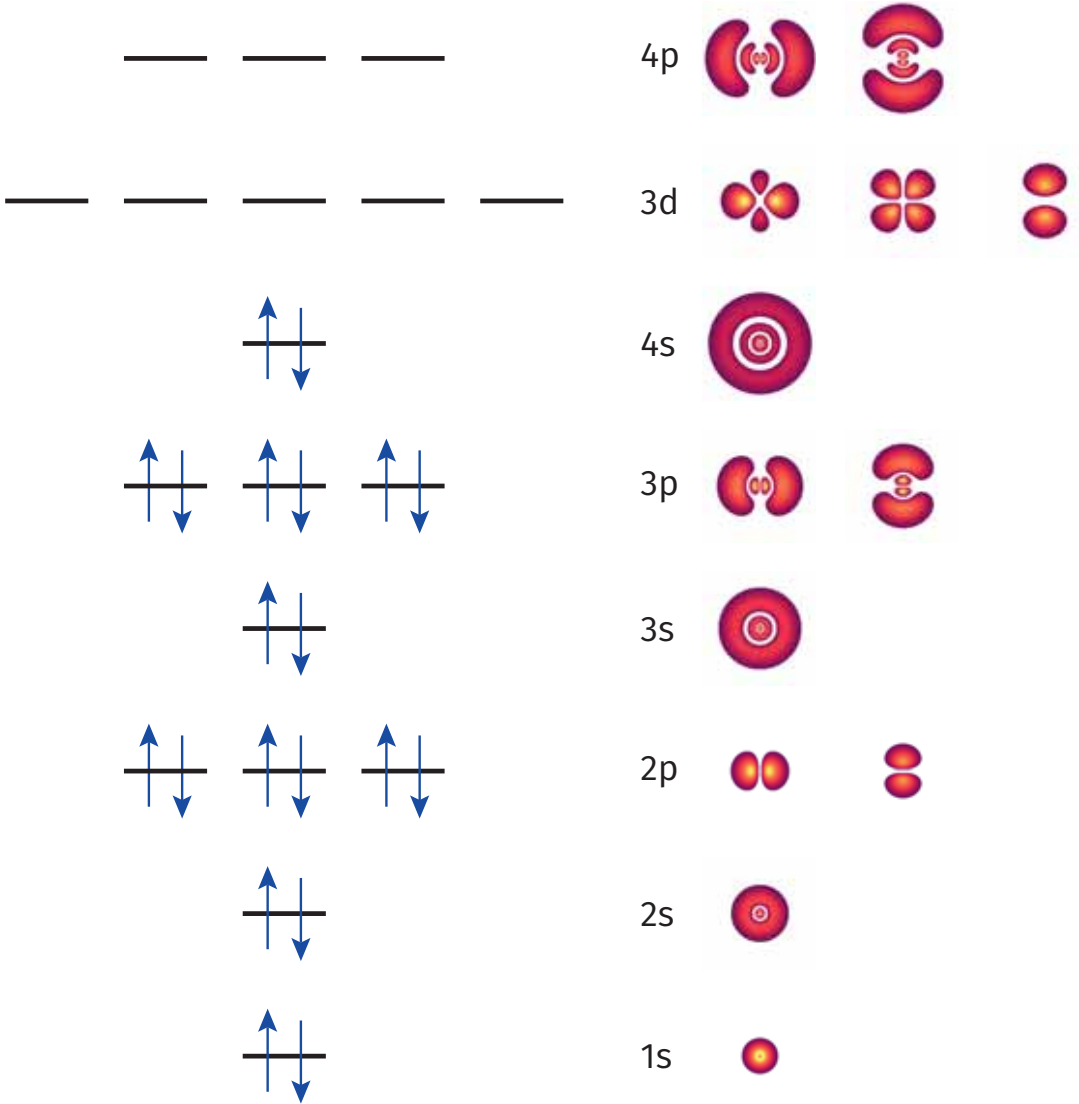
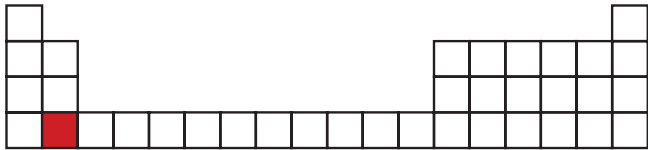
# Elektronenkonfiguration

**Kalium (K): 19 Elektronen**



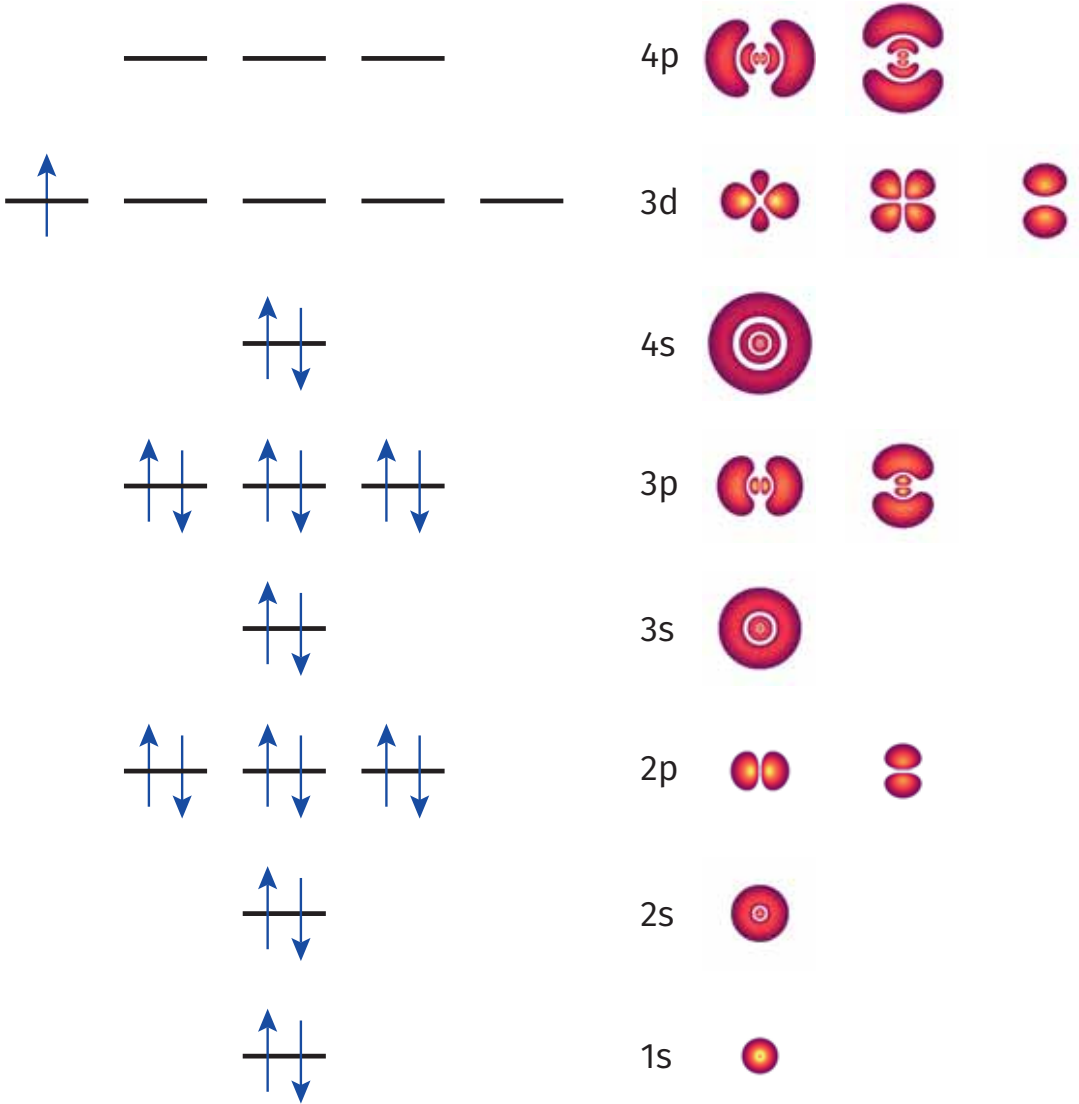
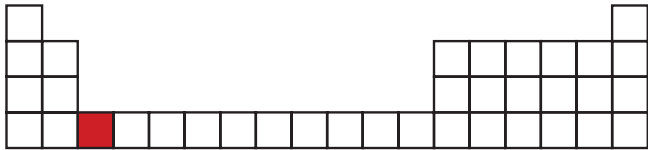
# Elektronenkonfiguration

**Calcium (Ca): 20 Elektronen**



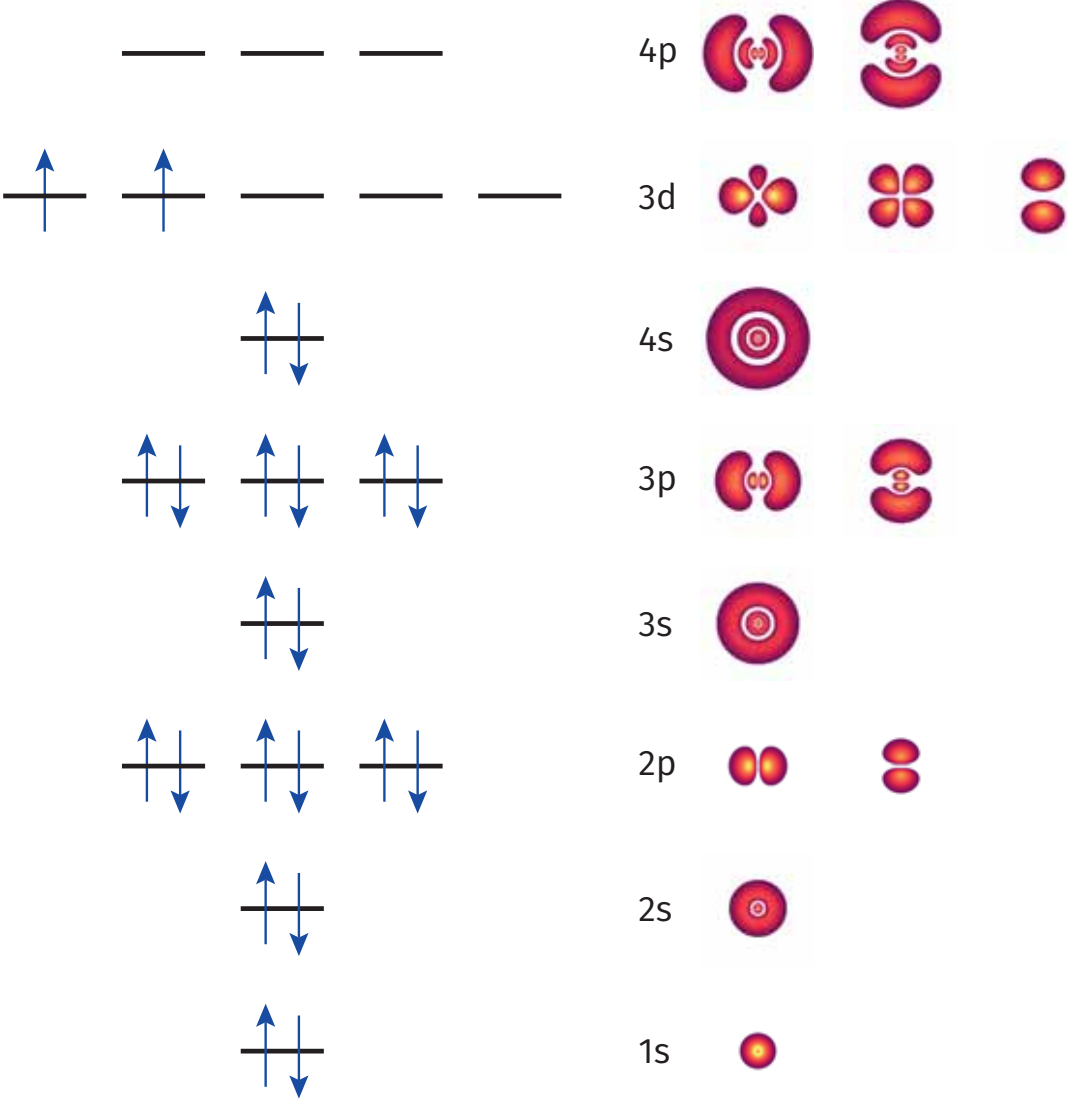
# Elektronenkonfiguration

**Scandium (Sc): 21 Elektronen**



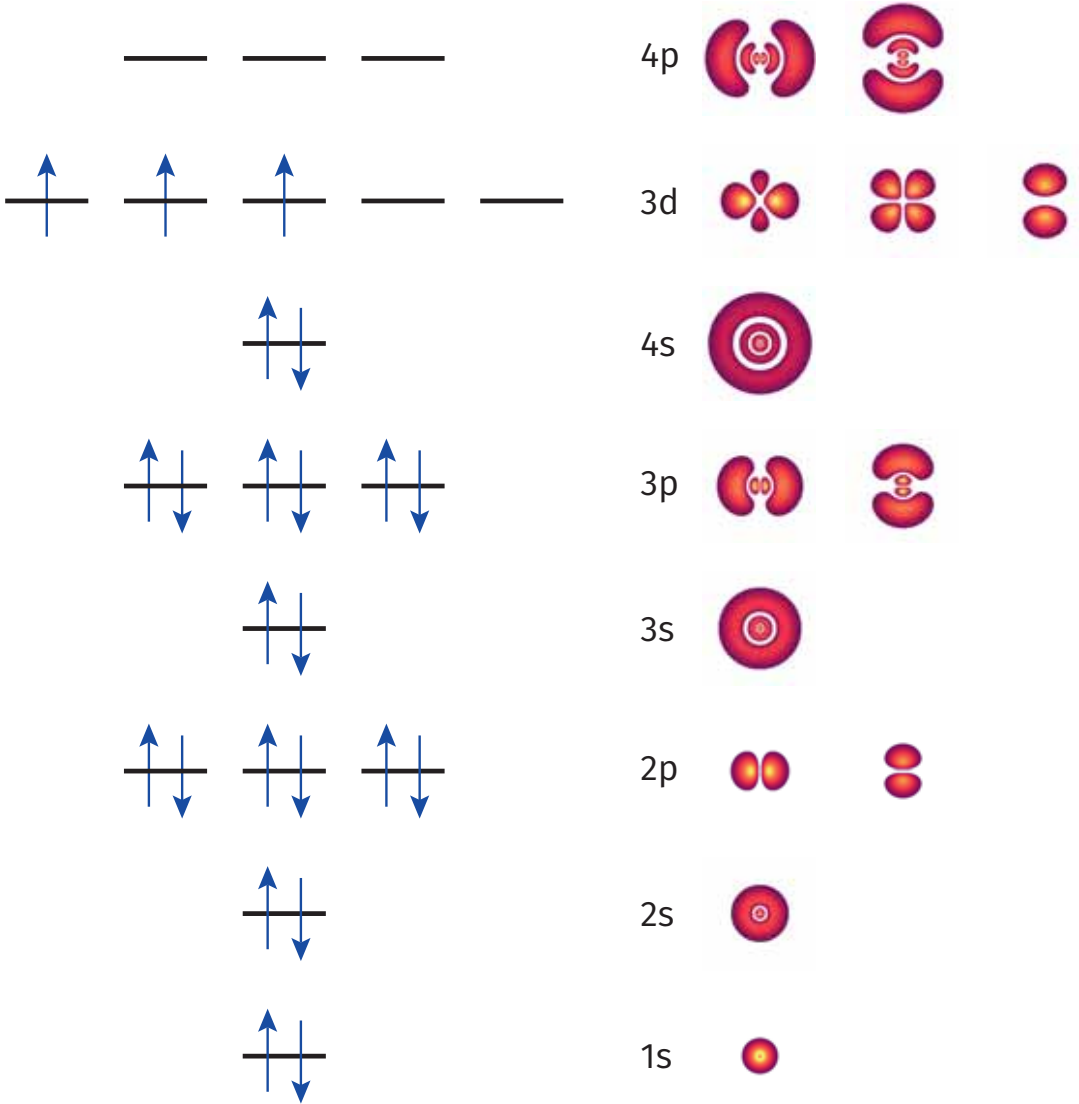
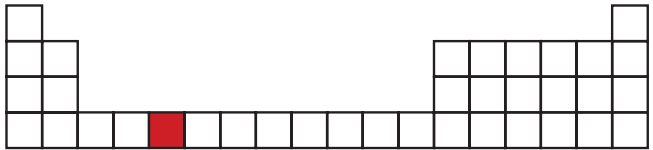
# Elektronenkonfiguration

**Titan (Ti): 22 Elektronen**



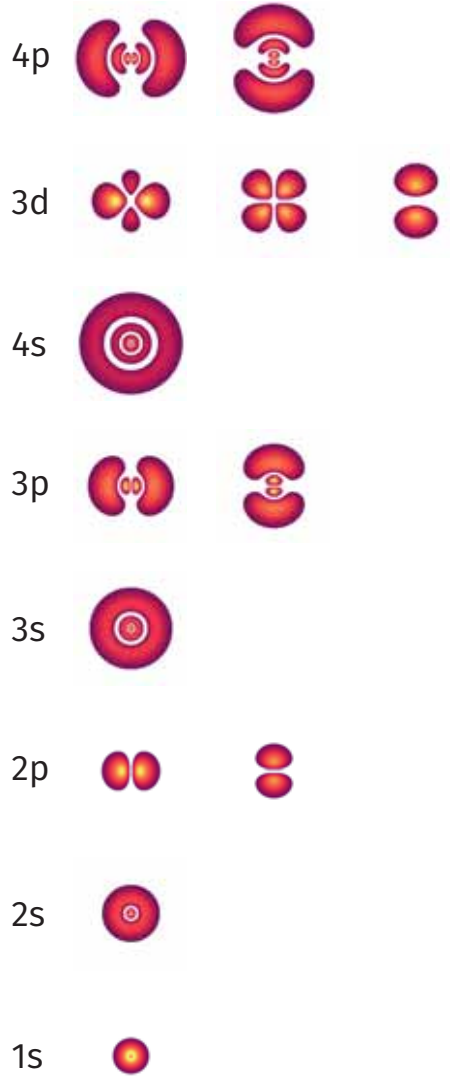
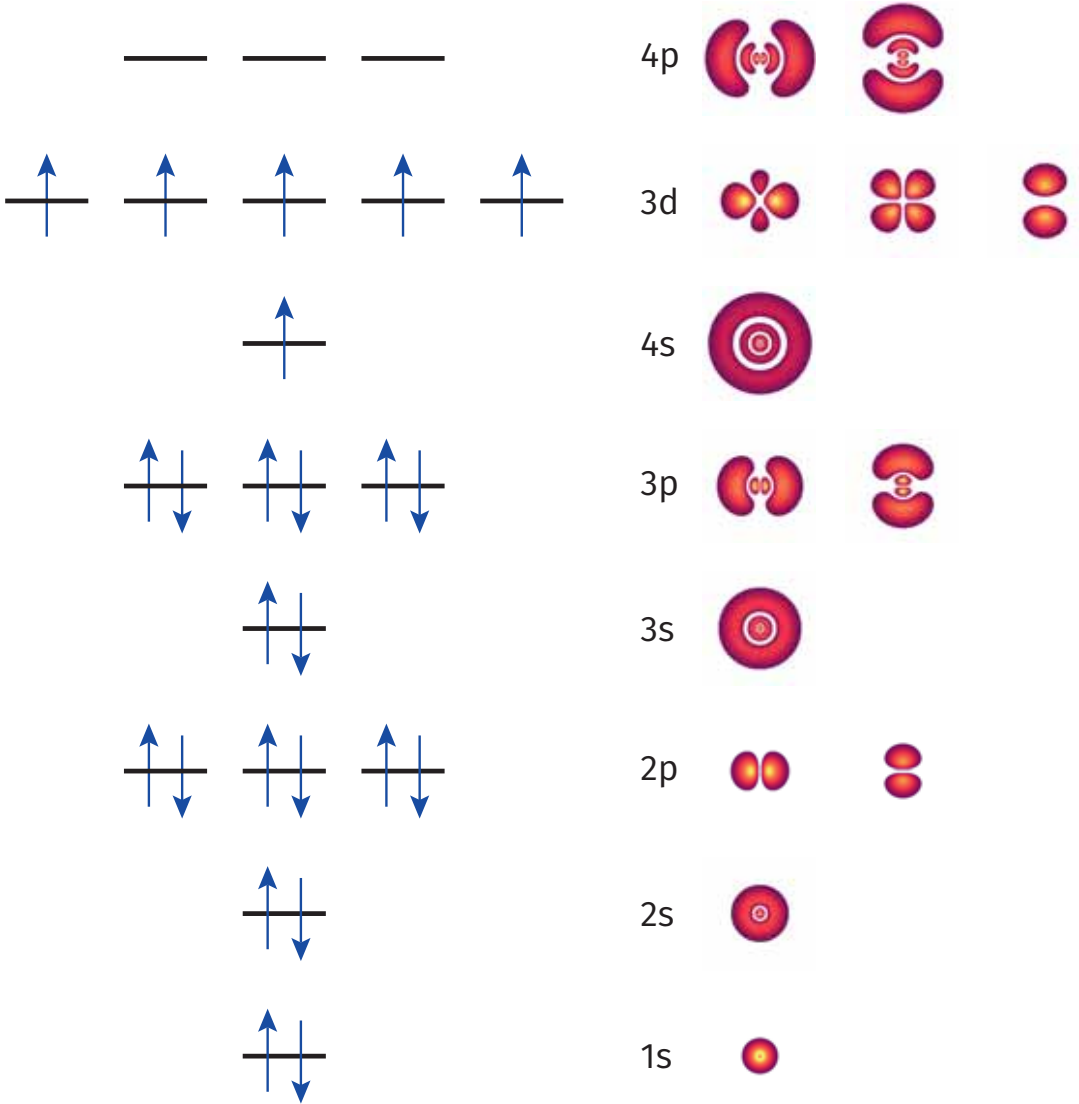
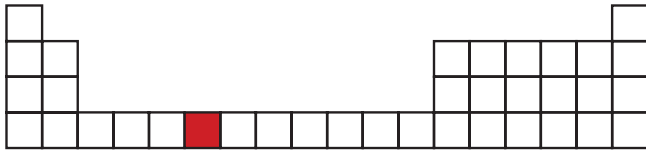
# Elektronenkonfiguration

**Vanadium (V): 23 Elektronen**



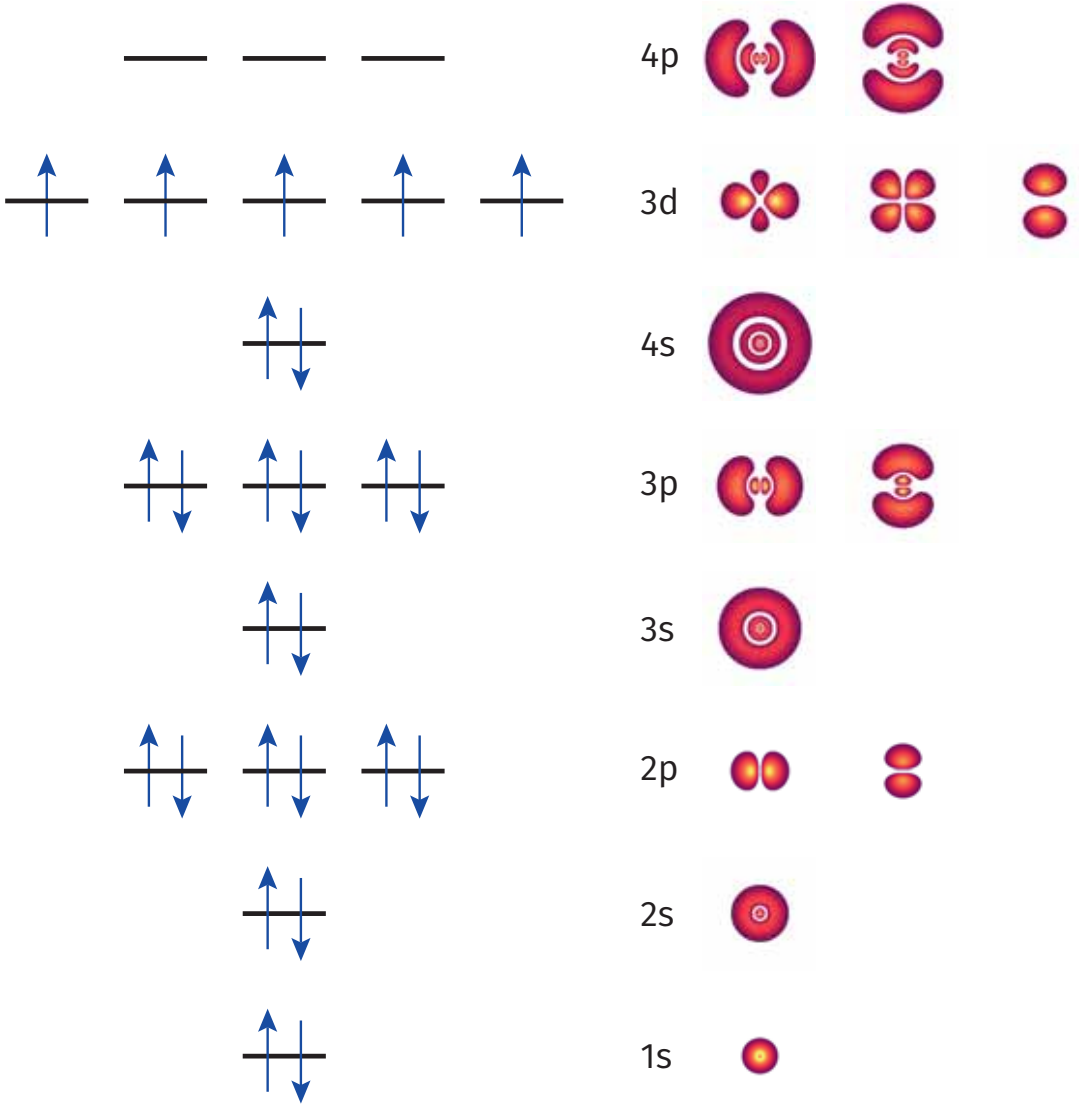
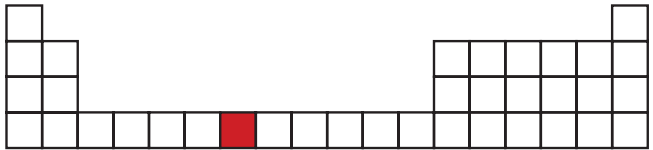
# Elektronenkonfiguration

**Chrom (Cr): 24 Elektronen**



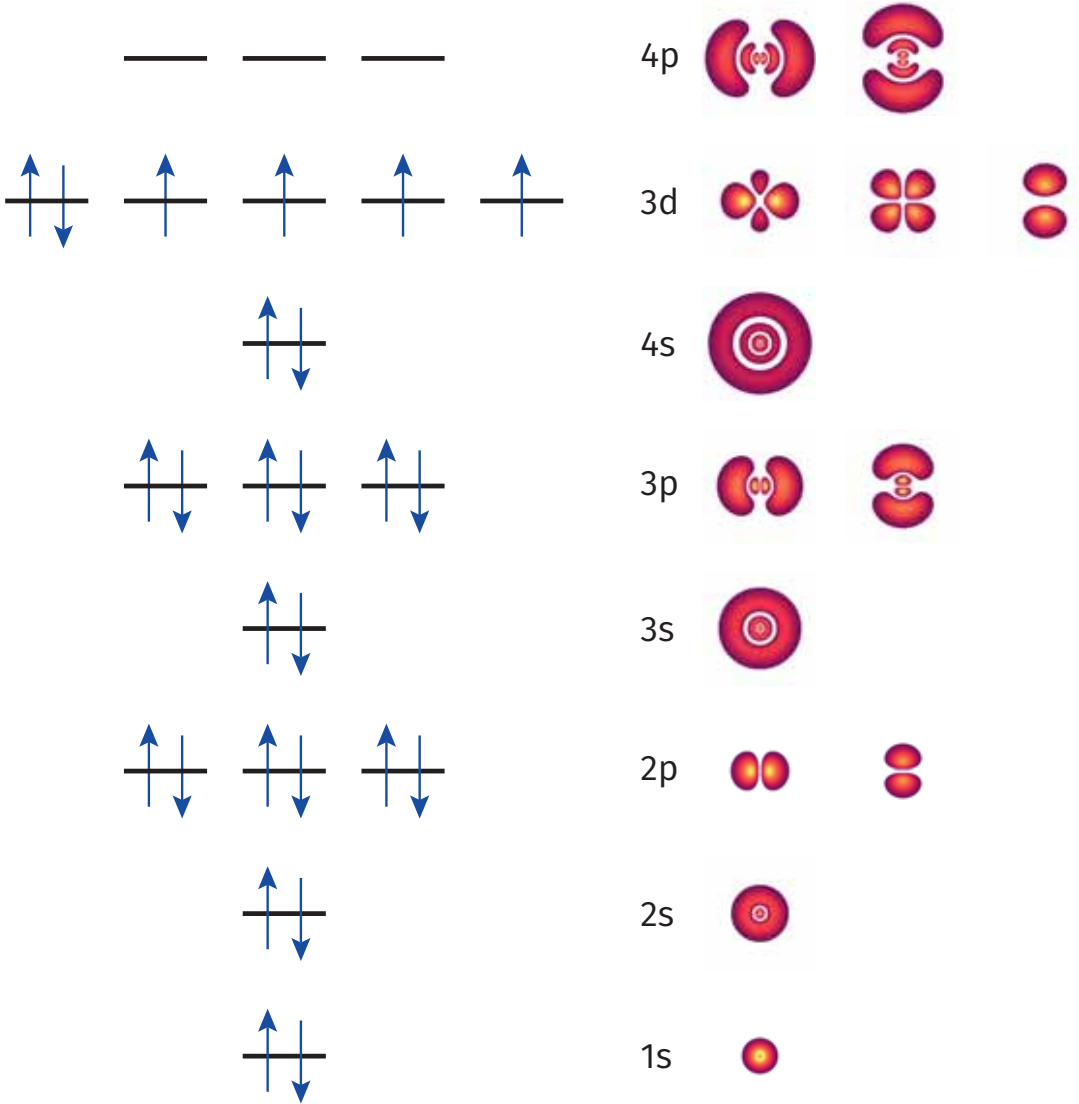
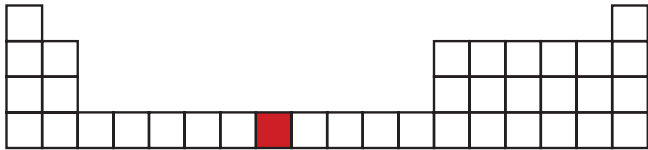
# Elektronenkonfiguration

Mangan (Mn): 25 Elektronen



# Elektronenkonfiguration

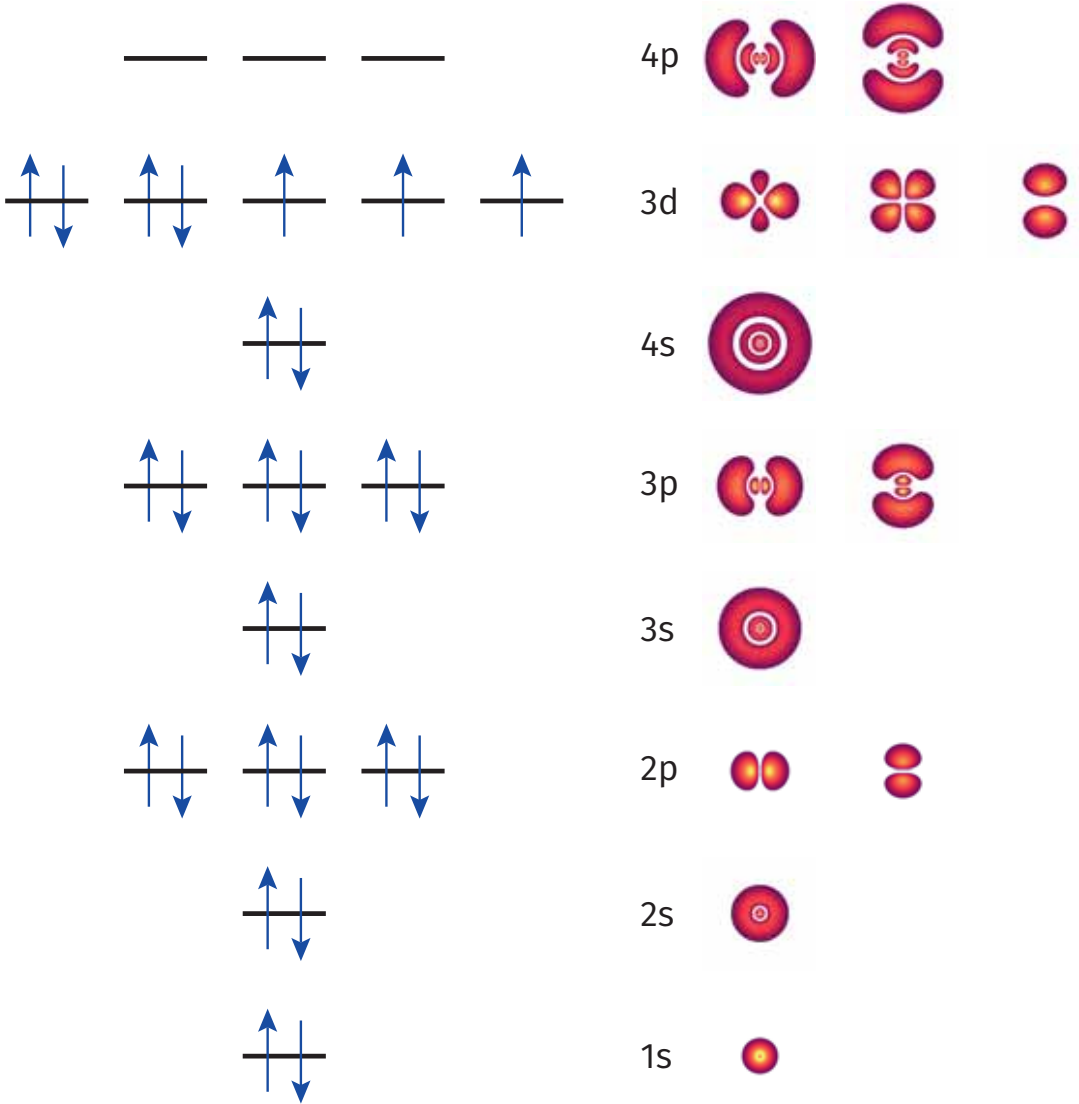
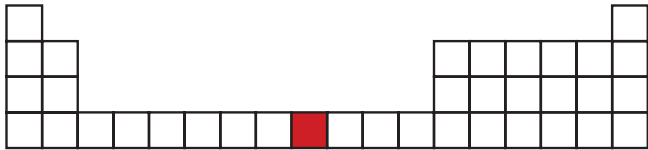
**Eisen (Fe): 26 Elektronen**





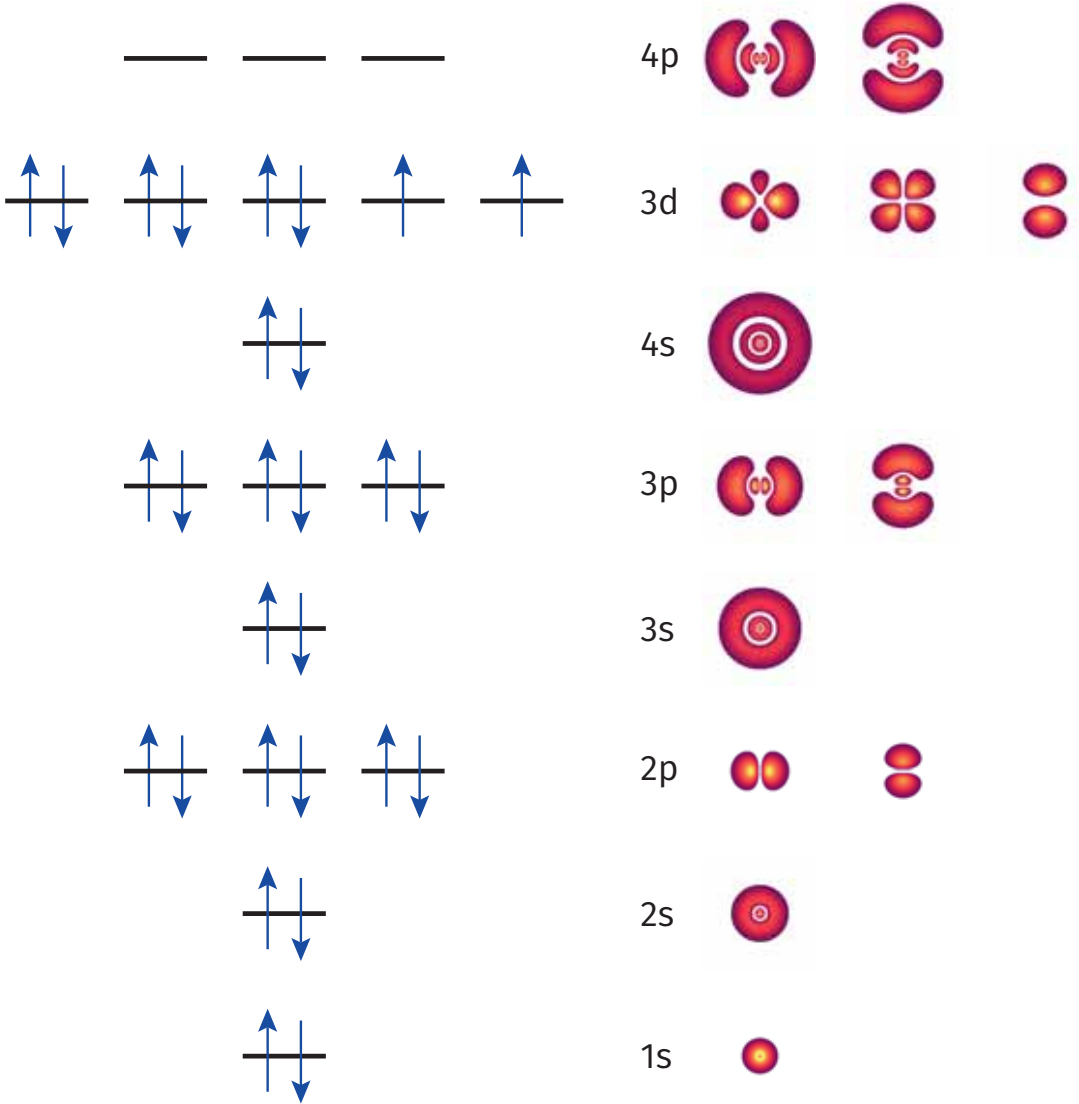
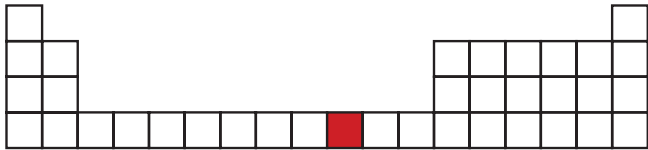
# Elektronenkonfiguration

**Kobalt (Co): 27 Elektronen**



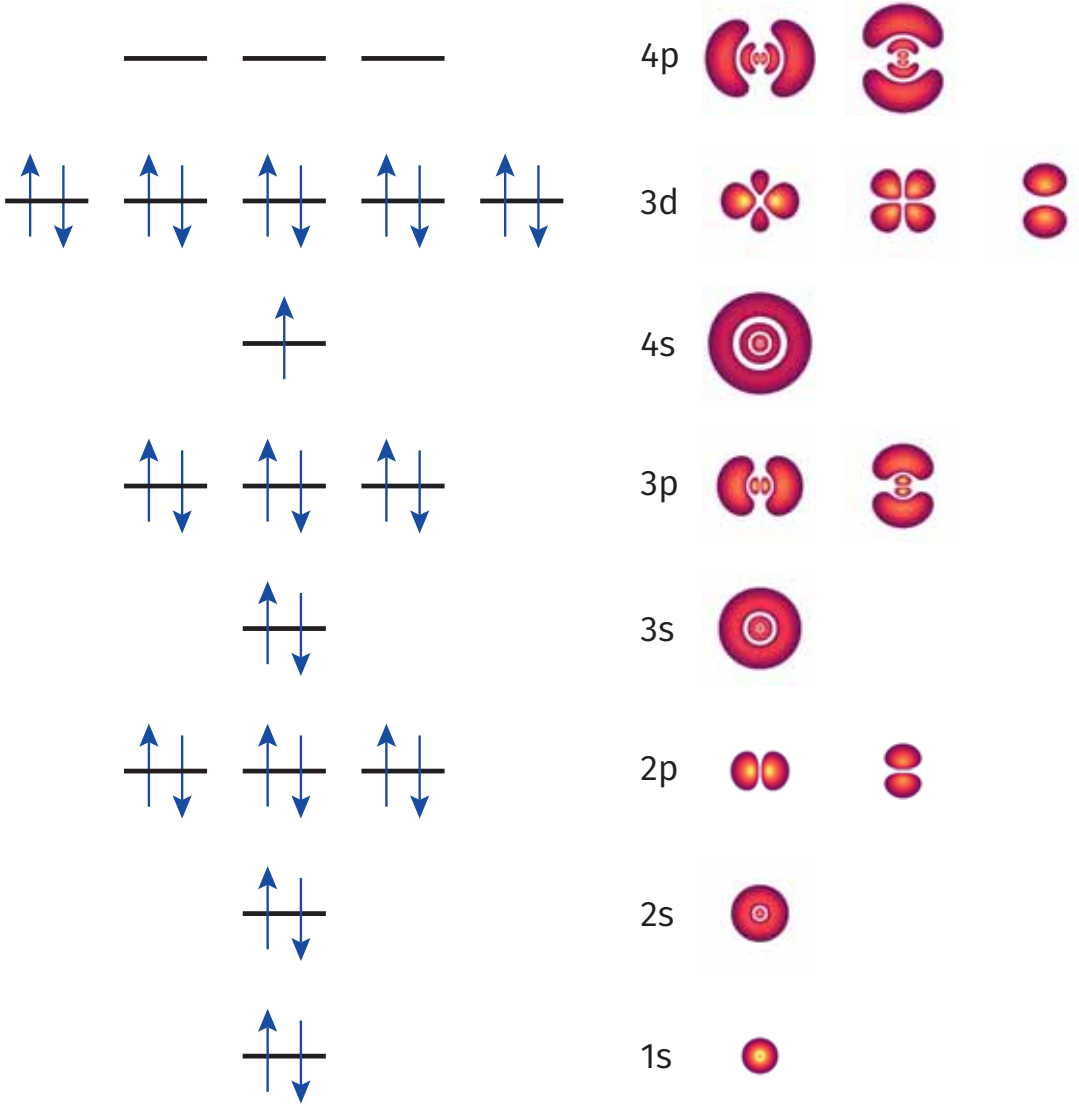
# Elektronenkonfiguration

**Nickel (Ni): 28 Elektronen**



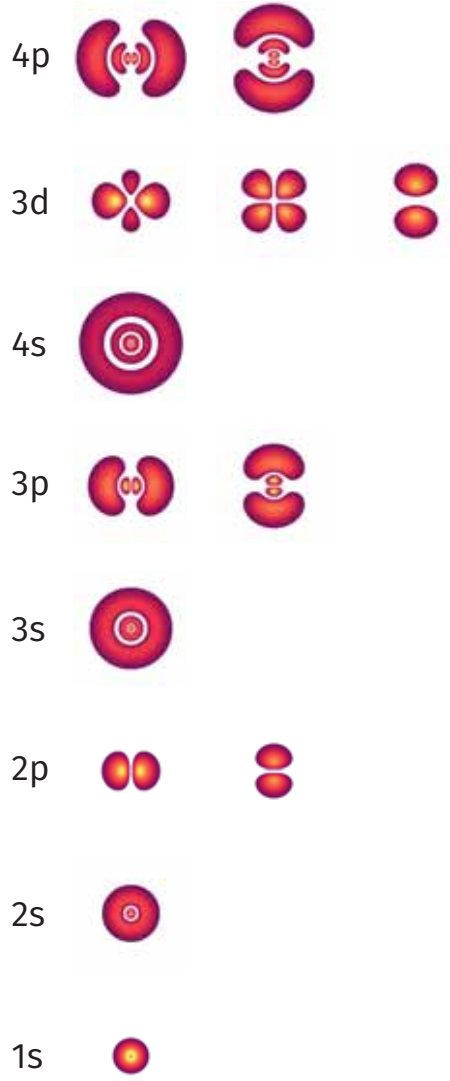
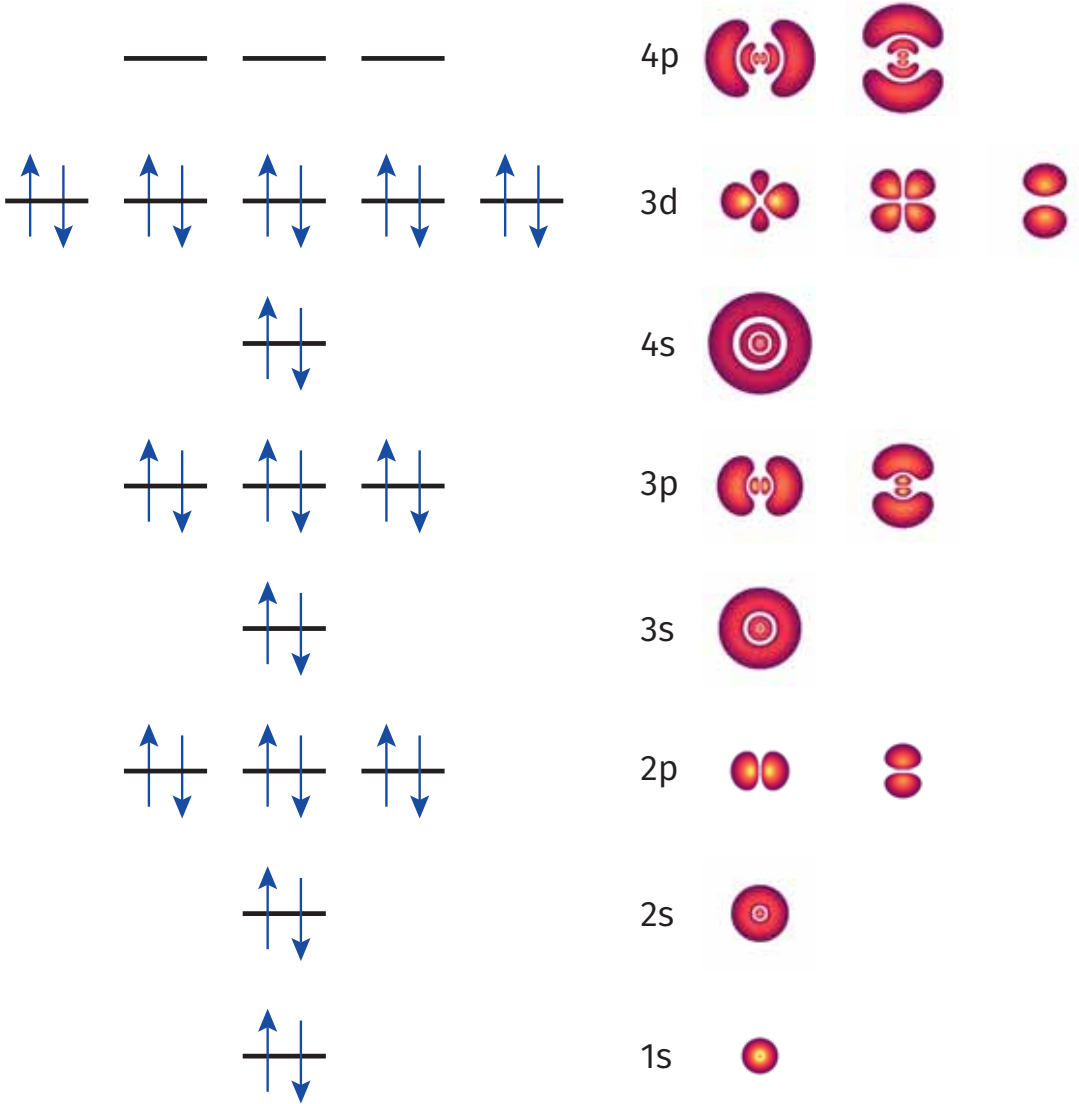
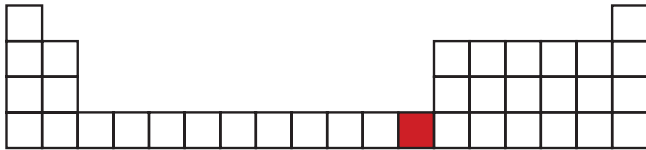
# Elektronenkonfiguration

**Kupfer (Cu): 29 Elektronen**



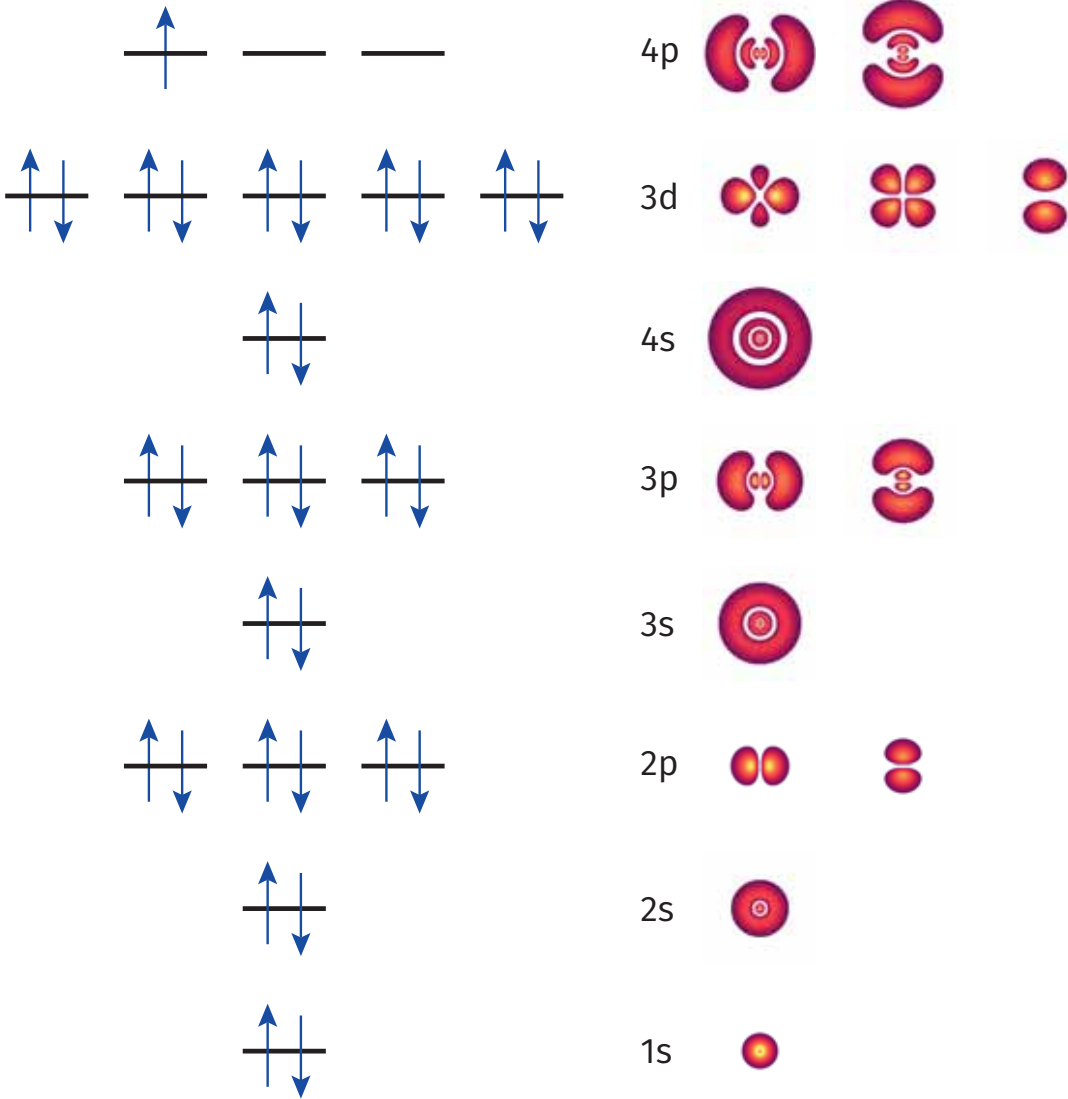
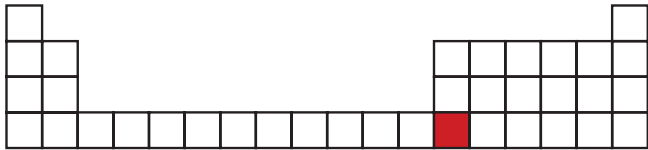
# Elektronenkonfiguration

Zink (Zn): 30 Elektronen



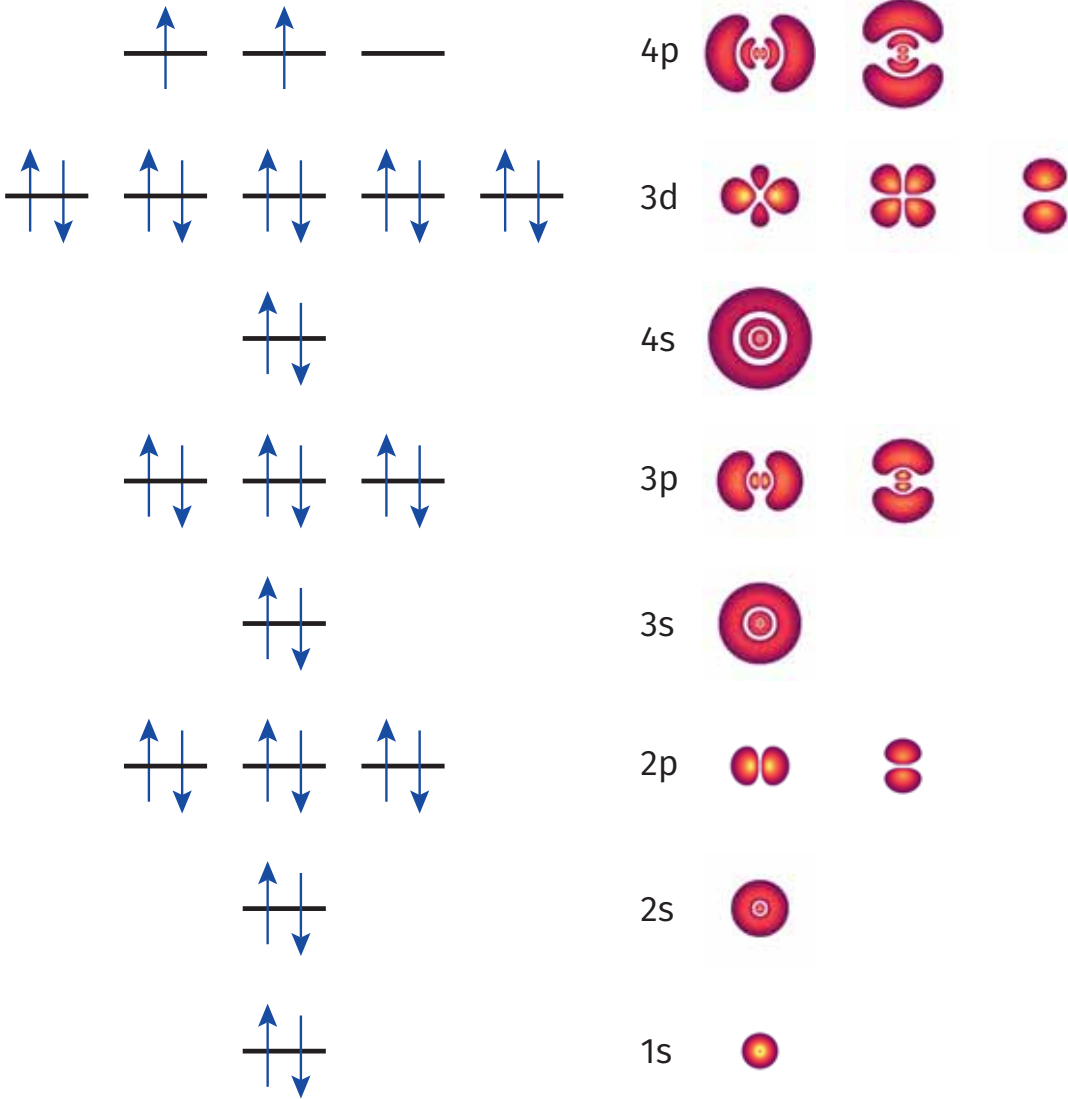
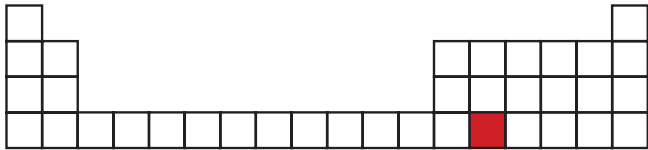
# Elektronenkonfiguration

**Gallium (Ga): 31 Elektronen**



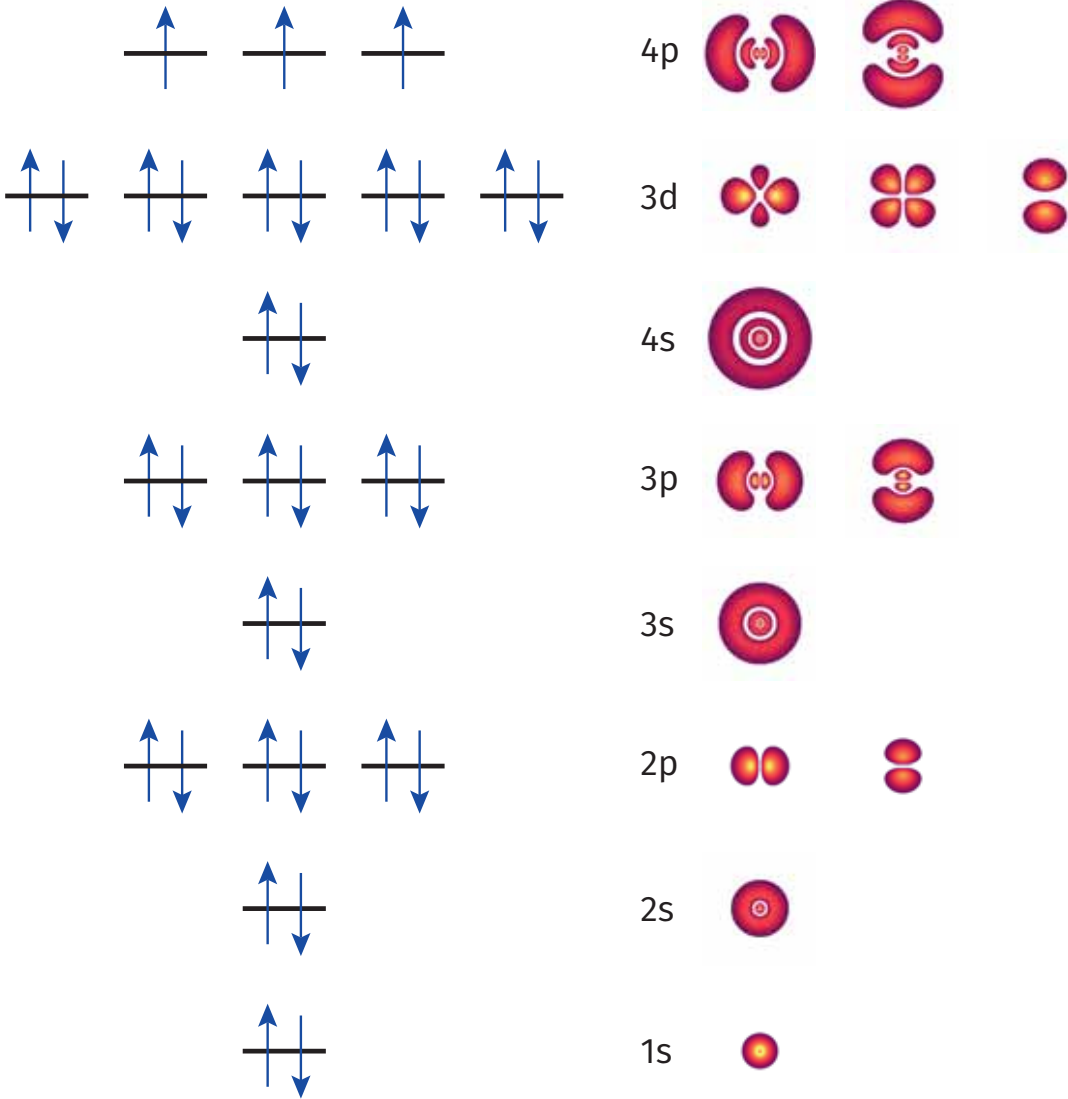
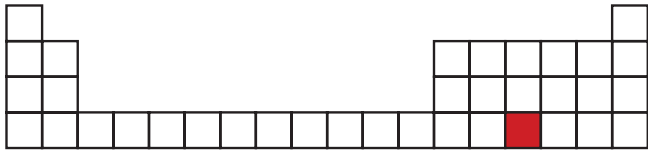
# Elektronenkonfiguration

**Germanium (Ge): 32 Elektronen**



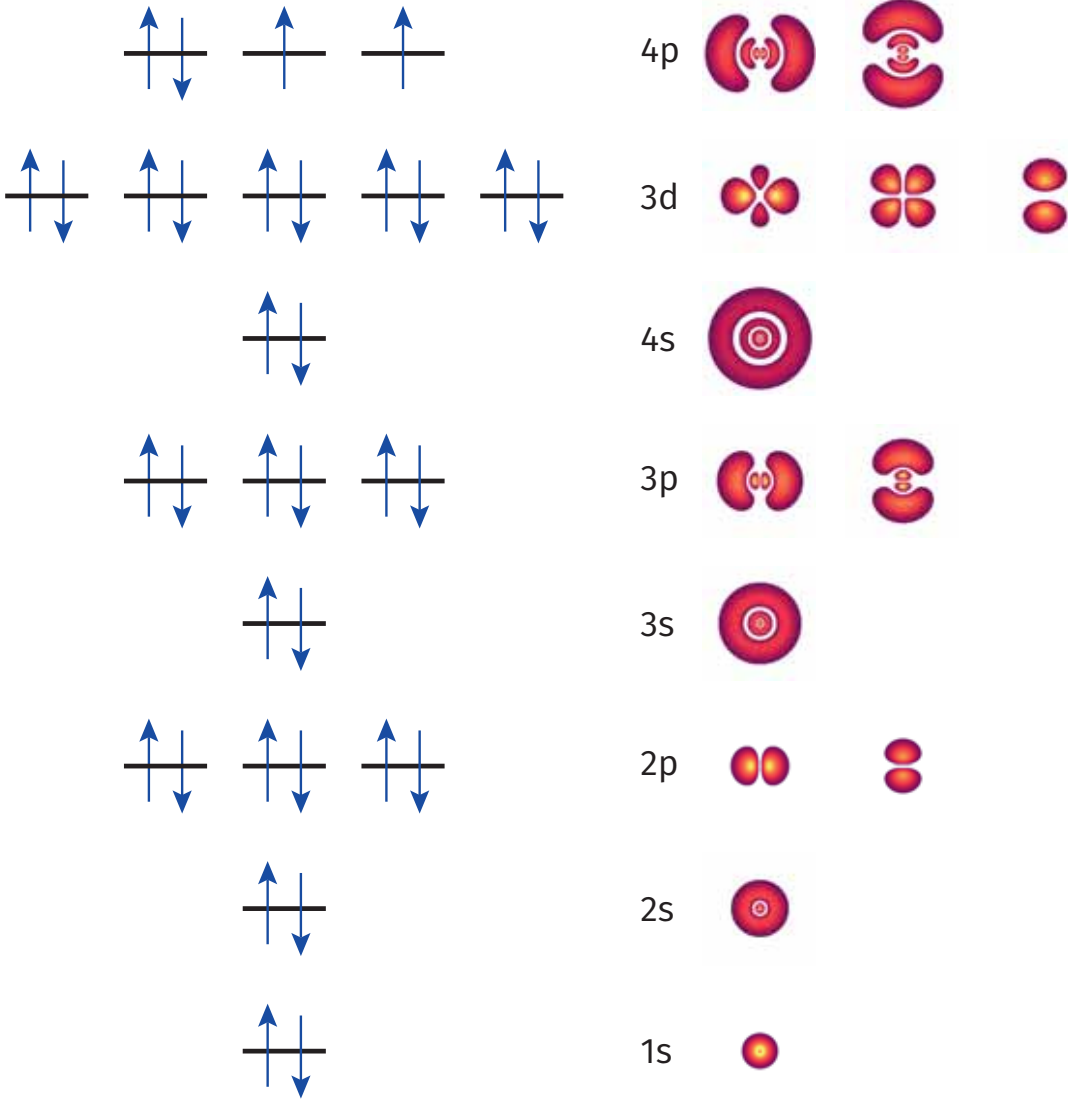
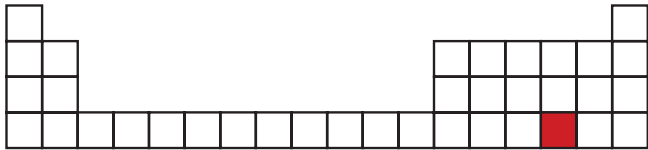
# Elektronenkonfiguration

**Arsen (As): 33 Elektronen**



# Elektronenkonfiguration

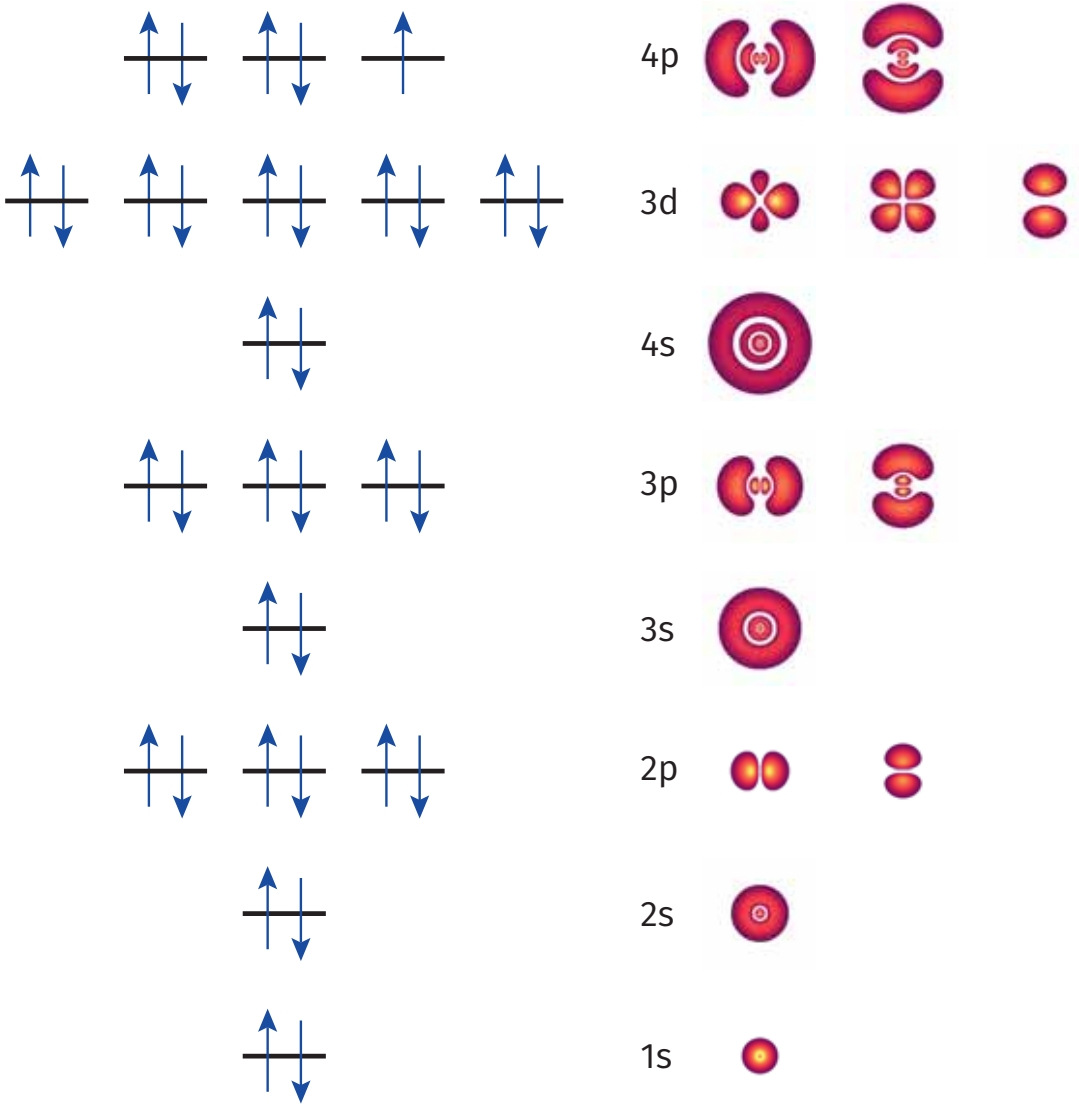
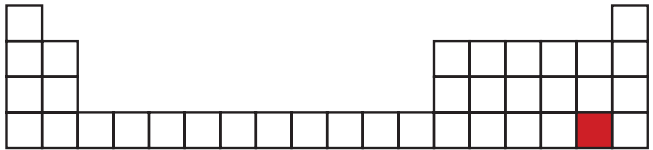
**Selen (Se): 34 Elektronen**





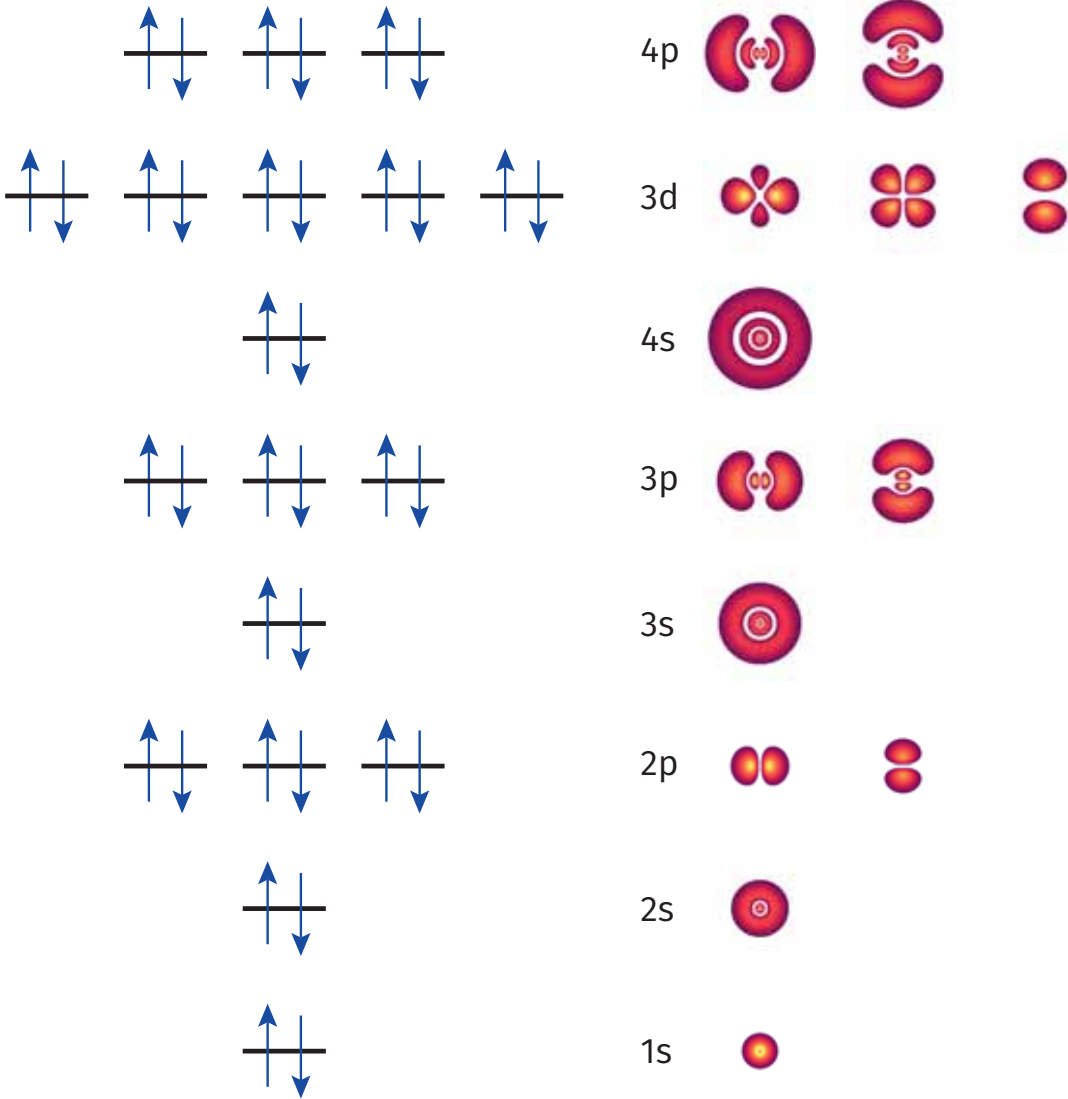
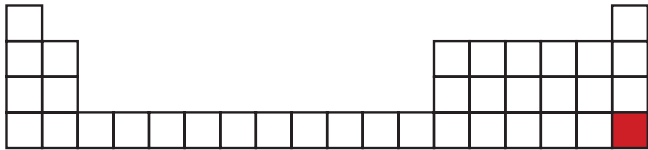
# Elektronenkonfiguration

**Brom (Br): 35 Elektronen**



# Elektronenkonfiguration

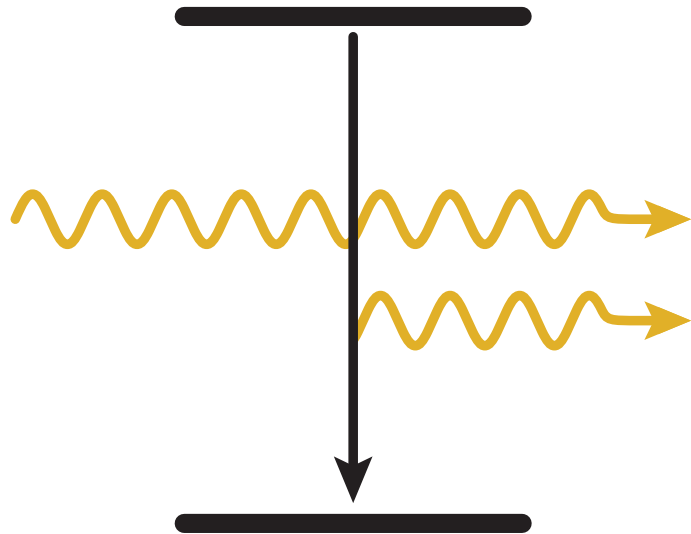
**Krypton (Kr): 36 Elektronen**



# Bosonen

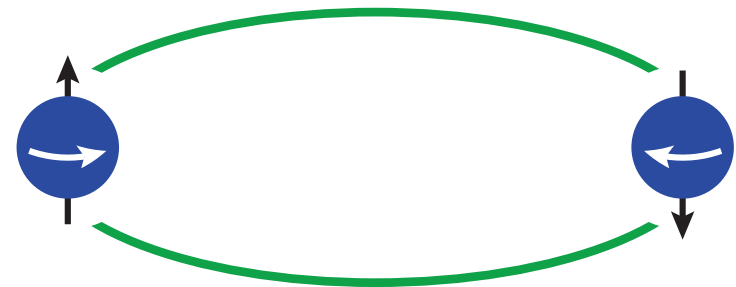
Laser

light **a**mplification by  
stimulated **e**mission of **r**adiation



Supraleitung

aus zwei Fermionen mach' ein Boson



Cooper-Paar