1 The Photon

$c\ \left[\frac{m}{s}\right]$	speed of light	$c = 2.998 \cdot 10^8\ \left[\frac{m}{s}\right]$
$h\ \left[\frac{m^2\,kg}{s}\right]$	planc's constant	$h = 6.626 \cdot 10^{-34}\ \left[\frac{m^2\,kg}{s}\right]$
		$\hbar = \frac{h}{2\pi}$
e [C]	electorn charge	$e = 1.602 \cdot 10^{-19}$ [C]
m_e [kg]	electron mass	$m_e = 9.109 \cdot 10^{-31}$ [kg]
$k_B\ \left[\frac{m^2\,kg}{s^2\,K}\right]$	bolzmann constant	$k_B = 1.381 \cdot 10^{-23}\ \left[\frac{m^2\,kg}{s^2\,K}\right]$
$\epsilon_0\ \left[\frac{F}{m}\right]$	vacuum permittivity	$\epsilon_0 = 8.854 \cdot 10^{-12}\ \left[\frac{F}{m}\right]$
		1 [eV] $= 1.602 \cdot 10^{-19}$ [J]

1.1 Photon & Electron

λ [m] , $\nu\ \left[\frac{1}{s}\right]$	Wavelength, Freq.
k	Wavenumber
E [J]	Energy
$\vec{F_c}$ [N]	Coulomb Force

$$\lambda = \frac{c}{\nu} \quad \nu = \frac{c}{\lambda} \quad \omega = 2\pi\nu$$

$$k = \frac{2\pi\nu}{c}$$

$$E = h \cdot \nu = \hbar \cdot \omega$$

$$\left|\vec{F_c}\right| = \frac{Q_1 \cdot Q_2}{4\pi\epsilon_0 r^2}$$

1.2 Photoelectric effect

V [V]	Voltage
ϕ_0 [eV]	Work function
I [A]	Photo-current
$n\ \left[m^{-3}\right]$	Volume density of electrons
$A\ \left[m^2\right]$	Area
$v\ \left[\frac{m}{s}\right]$	velocity of electrons

$$h\nu - \phi_0 = \frac{1}{2}mv^2 = eV$$

$$V(\nu) = \frac{h}{e}\nu - \frac{\phi_0}{e}$$

$$I = nAve$$

1.3 Blackbody Radiation

L [m]	length of blackbody cube	k_i	wave constants
E_x	Electric field in x-direction	$< E >$	Average Energy
N	Number of states	D	Density of states
u	Blackbody radiation	I	Power radiated

$$E_x(x,y,z) = E_{0x}\cos(k_x x) sin(k_y y) sin(k_z z)$$

$$k_x = n\frac{\pi}{L} \quad k_y = m\frac{\pi}{L} \quad k_z = l\frac{\pi}{L} \qquad k = \sqrt{k_x^2 + k_y^2 + k_z^2}$$

$$N(k) = \frac{1}{3\pi^2}k^3L^3 \qquad D(k) = \frac{k^2}{\pi^2}$$

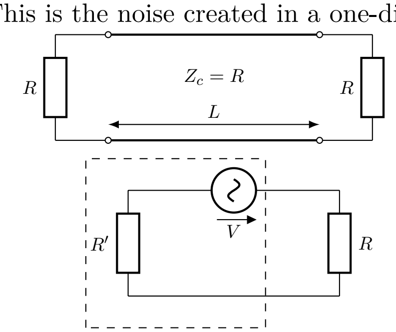
$$u(\omega) = \frac{\omega^2}{\pi^2c^3} \cdot \frac{\hbar\omega}{\exp\left(\frac{-\hbar\omega}{kT}\right) - 1}d\omega \qquad u(\nu) = \frac{8\pi h\nu^3}{c^3\left(\exp\left(\frac{h\nu}{kT}\right) - 1\right)}d\nu$$

$$I(\omega) = c \cdot u(\omega)$$

Equipartition-Theorem: Each degree of Freedom has an energy of kT

1.4 Johnson-Noise

This is the noise created in a one-dimensional circuit (like a coax-cable).

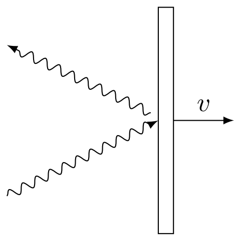


$\langle V^2 \rangle$	Noise Voltage
$\Delta\nu$	Bandwidth

$$E = E_0 \cdot \sin(k_x \cdot x)$$

$$\langle V^2 \rangle = 4R \cdot k_B T \cdot \Delta\nu$$

1.5 Momentum of a photon

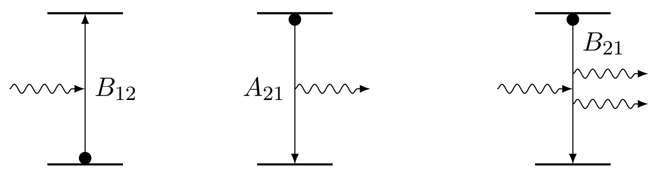


$p \left[\frac{\text{kg m}}{\text{s}}\right]$ momentum

$$p_{absorbing} = \frac{h\nu}{c} = m \cdot v$$

$$p_{reflecting} = 2 \cdot \frac{h\nu}{c}$$

1.6 Absorption, spontaneous and stimulated emission



absorbtion spontaneous emission stimulated emission

n_1 Number of electrons in the lower energy state

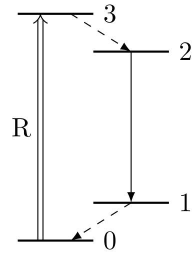
n_2 Number of electrons in the higher energy state

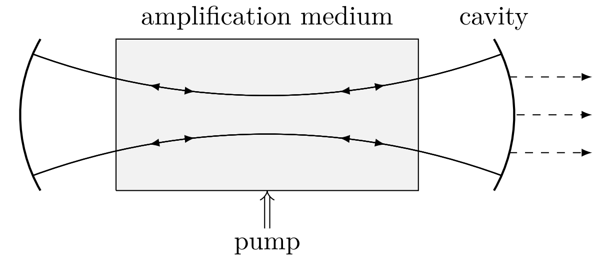
$$\frac{dn_2}{dt} = \underbrace{n_1 \cdot u(\nu) \cdot B_{12}}_{\text{absorbtion}} - \underbrace{n_2 \cdot u(\nu) \cdot B_{21}}_{\text{stimulated emission}} - \underbrace{n_2 \cdot A_{21}}_{\text{spontaneous emission}}$$

$$\frac{n_2}{n_1} = e^{-\frac{h\nu}{k_B T}} = \frac{u(\nu)B_{12}}{u(\nu)B_{21} + A_{21}}$$

$$B_{21} = B_{12} = B \qquad A_{21} = \frac{8\pi h \nu^3}{c^3}$$

1.7 Laser-optical amplification





Electrons are excited from the ground state “0” to the level “3” by pumping through incoherent radiation. The electrons then fall onto a long-lived state n_2 (State “2”) from level “3”. The pumping can be done either optically by shining a strong incoherent light or by passing a current. It is also assumed that the lower state is quickly emptied by a fast process with lifetime τ_1. As a result, the population in state “2” is:

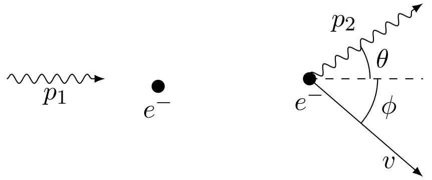
$$n_2 = \frac{R}{A_{21}} \quad \text{whereas} \quad n_1 \approx 0 \quad \text{because} \quad A_{21} < \frac{1}{\tau_1}$$

We have rherefore a population inversion between the two states. The likelihood of a stimulated emission process is larger than the one of absorbtion. If we enclose the system in an optical cavity, we can achieve self-sustained oscillation at the frequency ν.

2 Wave mechanics

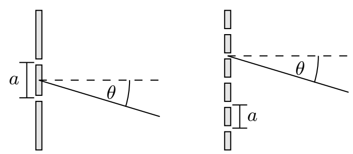
	frequency	wavelength	momentum	energy
Particle		$\lambda_b = \frac{h}{p}$	$p = mv$	$E = \frac{1}{2}mv^2$
Wave	ω	$\lambda = \frac{2\pi c}{\omega}$	$p = \frac{\hbar\omega}{c}$	$E = \hbar\omega$

2.1 Compton Scattering



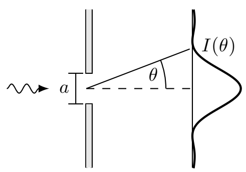
$$p_1 = \frac{h\nu_1}{c} \qquad p' = \frac{h\nu_2}{c}$$
$$\nu_2 = \nu_1 - \frac{P_e^2}{2m_e h}$$
$$\lambda_2 - \lambda_1 = \frac{h}{m_e c}(1-\cos\theta);$$

2.2 Double Slit and Bragg Diffraction



$$\text{Constructive} \quad \sin\theta = \frac{n\lambda}{a}$$
$$\text{Destructive} \quad \sin\theta = \frac{(n+\frac{1}{2})\lambda}{a}$$
$$n \in \mathbb{Z}$$

2.3 Single slit



$$I(\theta) = I_0 \frac{\sin^2\theta}{\theta^2}$$
$$\sin\theta = \frac{\lambda}{a}$$

2.4 Bohr-Sommerfeld equalization

Every single particle must satisfy the following equation. The quantized energy levels below relate to the hydrogen atom

$$\int_{length} p \cdot ds = n \cdot h \qquad n \in \mathbb{N}$$
$$E_n = -\frac{Z}{n^2} \cdot \frac{m_e e^4}{8\epsilon_0^2 h^2} = -\frac{Z}{n^2} \cdot E_{ry}$$
$$r_n = \frac{n^2}{Z} \cdot \frac{2\epsilon_0 h}{m_e e^2} = \frac{n^2}{Z} \cdot a_0$$
$$E_{ry} = 13.6 \ \text{[eV]}$$
$$a_0 = 5.292 \cdot 10^{-11} \ \text{[m]}$$

p	Momentum of particle
E_n	Energy of the nth state
E_{ry}	Rydberg Energy
a_0	Bohr-radius
Z	Number of protons

3 Quantum Mechanics

3.1 Wave function

$$\psi(\vec{x},t) : \mathbb{R}^4 \to \mathbb{C} \qquad \iiint \left|\psi(\vec{x},t)\right|^2 d^3r = 1$$
$$\psi(\vec{x},t) = a\psi_1(\vec{x},t) + b\psi_2(\vec{x},t), \qquad |a|^2 + |b|^2 = 1$$

3.2 The Schrödinger equation

$V(x,t)$	potential	m	mass

$$i\hbar \cdot \frac{\partial\psi}{\partial t}(\vec{x},t) = -\frac{\hbar^2}{2m} \cdot \nabla^2\psi(\vec{x},t) + V(\vec{x},t)\psi(\vec{x},t)$$
$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$
$$\psi = A \cdot e^{i(\vec{k}\vec{x}-\omega t)} \qquad \vec{k} = \begin{bmatrix} k_x & k_y & k_z \end{bmatrix}, \quad \vec{x} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$
$$E = \omega\hbar = \frac{\hbar^2 k^2}{2m}, \qquad k^2 = |k|^2$$

3.2.1 Phase and Group Velocity

The phase velocity v_φ describes how fast the phase of the wave moves forward. The group velocity v_g describes how fast the energy is moving forward.

$$v_\varphi = \frac{\omega}{k} \qquad v_g = \frac{\partial\omega}{\partial k}$$

For a particle wave, the phase velocity v_φ is half the group velocity v_g

$$v_\varphi \cdot 2 = v_g$$

3.2.2 Stationary (Time independent) States

In a stationary state, the wave function is a product of a function $\varphi(\vec{x})$ independent of time and a function $\chi(t)$ independent of space.

$$\psi_n(\vec{x},t) = \varphi_n(\vec{x}) \cdot \chi_n(t) = \varphi_n(\vec{x}) \cdot e^{-i\frac{E_n}{\hbar}t}$$

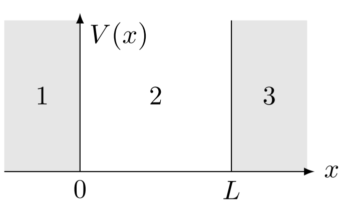
$$-\frac{\hbar^3}{2m}\nabla^2\varphi_n(\vec{x}) + V(\vec{x})\varphi_n(\vec{x}) = \varphi_n(\vec{x}) \cdot E_n$$

$$\iiint |\psi|^2 \, d^3\vec{x} = \iiint |\varphi|^2 \, d^3\vec{x} = 1$$

$$\psi(\vec{x},t) = \sum a_n\varphi_n(\vec{x}) \cdot e^{-i\frac{E_n}{\hbar}t} \qquad \sum |a_n|^2 = 1$$

Requirements: The wave function must be continous, as well as it's derivative

3.2.3 Example: 1D infinite potential well



$$\psi_1 = \psi_3 = 0$$

$$-\frac{\hbar^3}{2m}\frac{\partial^2}{\partial x^2}\varphi_2(x,t) = E\varphi_2(x,t)$$

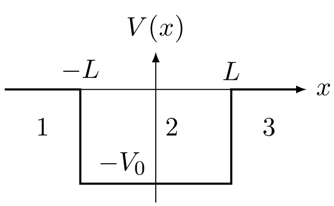
$$\varphi_2 = A\sin(kx) + B\cos(kx)$$

Boundary cond.: $\varphi_2(0) = \varphi_2(L) = 0$

$$\varphi_{2_n} = A \cdot \sin(k_n x) \quad \psi_{2_n} = A \cdot \sin(k_n x) \cdot e^{-i\frac{E_n}{\hbar}x}, \quad \text{Normalize:} \quad A = \sqrt{\frac{2}{L}}$$

$$E_n = n^2 \cdot \frac{\hbar^2\pi^2}{2mL} = n^2 \cdot E_0, \qquad k_n = \frac{n\pi}{L}$$

3.2.4 Example: 1D finite potential well



The Energy E can be either bigger or smaller than 0. If $E > 0$, the wave function will decay exponentially in region 1 and 3. If $E < 0$, the wave will propagate away from the potential well.

Inside the well: The general solution to the rearranged Schrödinger's is:

$$-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\varphi_2(x) = (E - V_0)\varphi_2(x)$$

$$\varphi_2(x) = A_2 e^{ikx} + A_2' e^{-ikx} \qquad E = \frac{k^2\hbar^2}{2m} \quad k = \sqrt{\frac{2m(E-V_0)}{\hbar^2}}$$

Outside the well: There are two cases, which can apply:

$$-\frac{\hbar}{2m}\frac{\partial^2}{\partial x^2}\varphi_1(x) = E\varphi_1(x)$$

1. $E > 0$:**Unbound state**

   $$\varphi_1 = A_1 e^{ikx} + A_1' e^{-ikx} \qquad k = \sqrt{\frac{2mE}{\hbar^2}}$$

   The unbound state does not make sense to be investigated, because the particle is free to be anywhere. In the following, only the unbound state is considered.

2. $E < 0$: **Bound state**

   $$\varphi_1 = B_1 e^{\delta x} + B_1' e^{-\delta x} \qquad \delta = \sqrt{-\frac{2mE}{\hbar^2}}$$

   We see that as $x \to -\infty$, the Term B_1', as well as B_3 approaches ∞. Since the wave function cannot approach ∞, $B_1' = B_3 = 0$ is a condition.

$$\varphi = \begin{cases} \varphi_1 = B_1 e^{\delta x} & x < -L \\ \varphi_2 = A_2 e^{ikx} + A_2' e^{-ikx} & -L < x < L \\ \varphi_3 = B_3' e^{-\delta x} & L < x \end{cases}$$

Boundary conditions: We require, that the wave function is continuous, as well as it's spacial derivative. Therefore, we have:

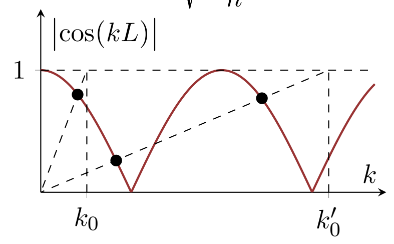
$$\varphi_1(-L) = \varphi_2(-L) \qquad \varphi_2(L) = \varphi_3(L)$$

$$\frac{\partial}{\partial x}\varphi_1(-L) = \frac{\partial}{\partial x}\varphi_2(-L) \qquad \frac{\partial}{\partial x}\varphi_2(L) = \frac{\partial}{\partial x}\varphi_3(L)$$

Even solutions: only even (cosine) components

$$\left|\cos(kL)\right| = \frac{k}{k_o}, \quad \tan(kL) > 0$$

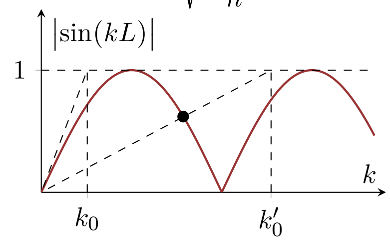
$$k_0 = \sqrt{\frac{2mV_0}{\hbar^2}}$$



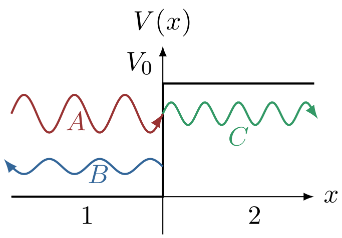
Odd solutions: only odd (sine) components

$$\left|\sin(kL)\right| = \frac{k}{k_o}, \quad \tan(kL) > 0$$

$$k_0 = \sqrt{\frac{2mV_0}{\hbar^2}}$$



3.3 Example: 1D potential step function



An incoming plane wave from the left hits a potential step at $x = 0$. In region 1, two waves are added together, one is traveling to the right and one to the left. If $E > V_0$, the wave is transmitted to region 2. if $E < V_0$, the wave decays exponentially in region 2.

In **Region 1**, the general solution to the Schrödinger equation is:

$$\frac{-\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\varphi_1(x) = E\varphi_1(x), \quad \varphi_1(x) = Ae^{ik_1x} + Be^{-ik_1x}, \quad k = \sqrt{\frac{2mE}{\hbar^2}}$$

In **Region 2**, there are two cases, which can apply:

$$-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2}\varphi_2 = (E - V_0)\varphi_2(x)$$

1. $\mathbf{E > V_0}$: **Transmission**

$$\varphi_2 = Ce^{ik_2x}, \qquad k_2 = \sqrt{\frac{2m(E - V_0)}{\hbar^2}}$$

2. $\mathbf{E < V_0}$: **Complete reflection**

$$\varphi_2 = Ce^{\delta_2 x}, \qquad \delta_2 = \sqrt{\frac{2m(V_0 - 2)}{\hbar^2}}$$

Applying the **initial conditions**, which require the wave function and it's derivative to be continuous at $x = 0$, we get the following expression for A, B, C:

$$\varphi_1(x = 0) = \varphi_2(x = 0) \qquad \frac{\partial}{\partial x}\varphi_1(x = 0) = \frac{\partial}{\partial x}\varphi_2(x = 0)$$

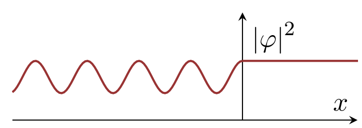
$\mathbf{E > V_0}$	$\mathbf{E < V_0}$
$A + B = C$	$A + B = C$
$k_1(A - B) = k_2C$	$A = B$

The **probability density function** $\left|\psi(x,t)\right|^2 = \left|\varphi(x)\right|^2 = \varphi \cdot \varphi^*$ can then be computed and sketched:

$\mathbf{E > V_0}$

$$|\varphi_1|^2 = A^2 + B^2 + 2AB\cos(2k_1x)$$

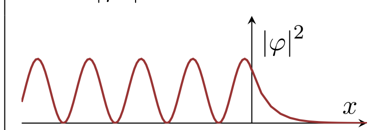
$$|\varphi_2|^2 = C^2$$



$\mathbf{E < V_0}$

$$|\varphi_1|^2 = 2A^2 \cdot \big(1 - \sin(2k_1x)\big)$$

$$|\varphi_2|^2 = C^2 \cdot e^{-2\delta x}$$

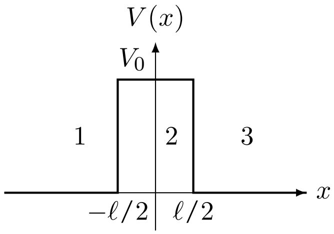


To find the **transmission coefficient** T and the **reflection coefficient** R, we normalize $A = 1$. Then, we can define $B = \sqrt{R}$ and $C = \sqrt{T}$. Then, we can solve for R and T:

$$T = \frac{4k_1k_2}{(k_1 + k_2)^2} \qquad R = \left(\frac{k_1 - k_2}{k_1 + k_2}\right)^2$$

If $E < V_0$, nothing is transmitted and therefore $T = 0$ and $R = 1$.

3.3.1 Example: 1D finite potential barrier



An incoming plane wave from the left hits a potential barrier with length l. The Transmission coefficient tells, how much of the wave can continue at the other side of the barrier (quantum tunneling).

In **Region 1 and 3**, the general expression for the wave equation is the following:

$$\varphi_j(x) = A_j e^{ik_j x} + A'_j e^{-ik_j x}, \qquad k_j = \sqrt{\frac{2mE}{\hbar^2}}, \quad j \in \{1, 3\}$$

In **Region 2**, the expression is depending on V_0. There are two cases:

1. $\mathbf{E < V_0}$: $\varphi_2 = B_2 e^{\delta_2 x} + B'_2 e^{-\delta_2 x}, \qquad \delta_2 = \sqrt{\frac{2m(V_0 - E)}{\hbar^2}}$
2. $\mathbf{E > V_0}$: $\varphi_2 = A_2 e^{ik_2 x} + A'_2 e^{-ik_2 x}, \qquad k_2 = \sqrt{\frac{2m(E - V_0)}{\hbar^2}}$

Apply **boundary conditions** at $x = -\ell/2$ and $x = \ell/2$ in order to determine all constants. If the wave is only traveling from left to right, then $A'_3 = 0$.

$$\varphi_1(-\ell/2) = \varphi_2(-\ell/2), \quad \varphi_2(\ell/2) = \varphi_3(\ell/2)$$
$$\frac{\partial}{\partial x}\varphi_1(-\ell/2) = \frac{\partial}{\partial x}\varphi_2(-\ell/2), \quad \frac{\partial}{\partial x}\varphi_2(\ell/2) = \frac{\partial}{\partial x}\varphi_3(\ell/2)$$

Then, the **transmission coefficient** T and the **reflection coefficient** R can be calculated as following:

$$R = \left(\frac{A_1}{A'_1}\right)^2, \qquad T = \left(\frac{A_3}{A_1}\right)^2$$

$\mathbf{E < V_0}$	$\mathbf{E > V_0}$
$T = \dfrac{4E(V_0 - E)}{4E(V_0 - E) + V_0^2 \sinh^2(\delta_2 \ell)}$	$T = \dfrac{4E(V_0 - E)}{4E(V_0 - E) + V_0^2 \sin^2(k_2 \ell)}$

If $\mathbf{E > V_0}$, the transmission coefficient has a maximum. If $k_2\ell = n\pi \Rightarrow T = 1$ (**resonance**). The minimum of T is at: $k_2\ell = \pi/2 + n\pi$.

4 Periodic Table of the Elements

1 2.20 1s **H** Hydrogen 1.00784–1.00811																	2 1s **He** Helium 4.002602(2)
3 0.98 2s **Li** Lithium 6.938–6.997	4 1.57 2s **Be** Beryllium 9.0121831(5)		Z eneg ss **Sy** Name saw	Z = atomic number; eneg = electronegativity; ss = subshell; Sy = Symbol, Name = element name, saw = standard atomic weight								5 2.04 2p **B** Boron 10.806–10.821	6 2.55 2p **C** Carbon 12.0096–12.0116	7 3.04 2p **N** Nitrogen 14.00643–14.00728	8 3.44 2p **O** Oxygen 15.99903–15.99977	9 3.98 2p **F** Fluorine 18.998403163(6)	10 2p **Ne** Neon 20.1797(6)
11 0.93 3s **Na** Sodium 22.98976928(2)	12 1.31 3s **Mg** Magnesium 24.304–24.307											13 1.61 3p **Al** Aluminium 26.9815385(7)	14 1.90 3p **Si** Silicon 28.084–28.086	15 2.19 3p **P** Phosphorus 30.973761998(5)	16 2.58 3p **S** Sulphur 32.059–32.076	17 3.16 3p **Cl** Chlorine 35.446–35.457	18 3p **Ar** Argon 39.948(1)
19 0.82 4s **K** Potassium 39.0983(1)	20 1.00 4s **Ca** Calcium 40.078(4)	21 1.36 3d **Sc** Scandium 44.955908(5)	22 1.54 3d **Ti** Titanium 47.867(1)	23 1.63 3d **V** Vanadium 50.9415(1)	24 1.66 3d* **Cr** Chromium 51.9961(6)	25 1.55 3d **Mn** Manganese 54.938044(3)	26 1.83 3d **Fe** Iron 55.845(2)	27 1.88 3d **Co** Cobalt 58.933194(4)	28 1.91 3d **Ni** Nickel 58.6934(4)	29 1.90 3d* **Cu** Copper 63.546(3)	30 1.65 3d **Zn** Zinc 65.38(2)	31 1.81 4p **Ga** Gallium 69.723(1)	32 2.01 4p **Ge** Germanium 72.630(8)	33 2.18 4p **As** Arsenic 74.921595(6)	34 2.55 4p **Se** Selenium 78.971(8)	35 2.96 4p **Br** Bromine 79.901–79.907	36 3.00 4p **Kr** Krypton 83.798(2)
37 0.82 5s **Rb** Rubidium 85.4678(3)	38 0.95 5s **Sr** Strontium 87.62(1)	39 1.22 4d **Y** Yttrium 88.90584(2)	40 1.33 4d **Zr** Zirconium 91.224(2)	41 1.6 4d* **Nb** Niobium 92.90637(2)	42 2.16 4d* **Mo** Molybdenum 95.95(1)	43 1.9 4d **Tc** Technetium (98)	44 2.2 4d* **Ru** Ruthenium 101.07(2)	45 2.28 4d* **Rh** Rhodium 102.90550(2)	46 2.20 4d* **Pd** Palladium 106.42(1)	47 1.93 4d* **Ag** Silver 107.8682(2)	48 1.69 4d **Cd** Cadmium 112.414(4)	49 1.78 5p **In** Indium 114.818(1)	50 1.96 5p **Sn** Tin 118.710(7)	51 2.05 5p **Sb** Antimony 121.760(1)	52 2.1 5p **Te** Tellurium 127.60(3)	53 2.66 5p **I** Iodine 126.90447(3)	54 2.60 5p **Xe** Xenon 131.293(6)
55 0.79 6s **Cs** Cesium 132.90545196(6)	56 0.89 6s **Ba** Barium 137.327(7)	57-71 ***** Lanthanides	72 1.3 5d **Hf** Halfnium 178.49(2)	73 1.5 5d **Ta** Tantalum 180.94788(2)	74 2.36 5d **W** Tungsten 183.84(1)	75 1.9 5d **Re** Rhenium 186.207(1)	76 2.2 5d **Os** Osmium 190.23(3)	77 2.20 5d **Ir** Iridium 192.217(3)	78 2.28 5d* **Pt** Platinum 195.084(9)	79 2.54 5d* **Au** Gold 196.966569(5)	80 2.00 5d **Hg** Mercury 200.592(3)	81 1.62 6p **Tl** Thallium 204.382–204.385	82 1.87 6p **Pb** Lead 207.2(1)	83 2.02 6p **Bi** Bismuth 208.98040(1)	84 2.0 6p **Po** Polonium (209)	85 2.2 6p **At** Astatine (210)	86 2.2 6p **Rn** Radon (222)
87 0.7 7s **Fr** Francium (223)	88 0.9 7s **Ra** Radium (226)	89-103 ****** Actinides	104 6d **Rf** Rutherfordium (261)	105 6d **Db** Dubnium (268)	106 6d **Sg** Seaborgium (269)	107 6d **Bh** Bohrium (270)	108 6d **Hs** Hassium (269)	109 6d **Mt** Meitnerium (278)	110 6d **Ds** Darmstadtium (281)	111 6d **Rg** Roentgenium (282)	112 6d **Cn** Copernicium (285)	113 7p **Nh** Nihonium (286)	114 7p **Fl** Flerovium (289)	115 7p **Mc** Moscovium (289)	116 7p **Lv** Livermorium (293)	117 7p **Ts** Tennessine (294)	118 7p **Og** Oganesson (294)

*	57 1.1 5d* **La** Lanthanum 138.90547(7)	58 1.12 4f* **Ce** Cerium 140.116(1)	59 1.13 4f **Pr** Praseodymium 140.90766(2)	60 1.14 4f **Nd** Neodymium 144.242(3)	61 1.13 4f **Pm** Promethium (145)	62 1.17 4f **Sm** Samarium 150.36(2)	63 1.2 4f **Eu** Europium 151.964(1)	64 1.2 4f* **Gd** Gadolinium 157.25(3)	65 1.1 4f **Tb** Terbium 158.92535(2)	66 1.22 4f **Dy** Dysprosium 162.500(1)	67 1.23 4f **Ho** Holmium 164.93033(2)	68 1.24 4f **Er** Erbium 167.259(3)	69 1.25 4f **Tm** Thulium 168.93422(2)	70 1.1 4f **Yb** Ytterbium 173.045(10)	71 1.27 4f **Lu** Lutetium 174.9668(1)
**	89 1.1 6d* **Ac** Actinium (227)	90 1.3 5f* **Th** Thorium 232.0377(4)	91 1.5 5f* **Pa** Protactinium 231.03588(2)	92 1.38 5f* **U** Uranium 238.02891(3)	93 1.36 5f* **Np** Neptunium (237)	94 1.28 5f **Pu** Plutonium (244)	95 1.13 5f **Am** Americium (243)	96 1.28 5f* **Cm** Curium (247)	97 1.3 5f **Bk** Berkelium (247)	98 1.3 5f **Cf** Californium (251)	99 1.3 5f **Es** Einsteinium (252)	100 1.3 5f **Fm** Fermium (257)	101 1.3 5f **Md** Mendelevium (258)	102 1.3 5f **No** Nobelium (259)	103 1.3 5f **Lr** Lawrencium (266)

Standard atomic weights taken from the Commission on Isotopic Abundances and Atomic Weights (ciaaw.org/atomic-weights.htm). Adapted from Ivan Griffin's LaTeX Periodic Table.

An asterisk (*) next to a subshell indicates an anomalous (Aufbau rule-breaking) ground state electron configuration.