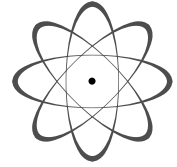


# Physics Formulæ



High School

Martin Ambauen

## 1 Units

### 1.1 Base units of the International System of Units (SI)

*1 second* is the SI unit of time. It is defined by taking the fixed numerical value of the caesium frequency  $\Delta\nu_{\text{Cs}}$ , the unperturbed ground-state hyperfine transition frequency of the caesium-133 atom, to be 9 192 631 770 when expressed in the unit Hz, which is equal to  $\text{s}^{-1}$ . (1967) **1 s**

*1 metre* is the SI unit of length. It is defined by taking the fixed numerical value of the speed of light in vacuum  $c$  to be 299 792 458 when expressed in the unit  $\text{m s}^{-1}$ . (1983) **1 m**

*1 kilogram* is the SI unit of mass. It is defined by taking the fixed numerical value of the Planck constant  $h$  to be  $6.626\,070\,15 \cdot 10^{-34}$  when expressed in the unit J s, which is equal to  $\text{kg m}^2 \text{s}^{-1}$ . (2019) **1 kg**

*1 ampere* is the SI unit of electric current. It is defined by taking the fixed numerical value of the elementary charge  $e$  to be  $1.602\,176\,634 \cdot 10^{-19}$  when expressed in the unit C, which is equal to A s. (2019) **1 A**

*1 kelvin* is the SI unit of thermodynamic temperature. It is defined by taking the fixed numerical value of the Boltzmann constant  $k$  to be  $1.380\,649 \cdot 10^{-23}$  when expressed in the unit  $\text{J K}^{-1}$ , which is equal to  $\text{kg m}^2 \text{s}^{-2} \text{K}^{-1}$ . (2019) **1 K**

*1 mole* is the SI unit of amount of substance. One mole contains exactly  $6.022\,140\,76 \cdot 10^{23}$  elementary entities. This number is the fixed numerical value of the Avogadro constant,  $N_{\text{A}}$ , when expressed in the unit  $\text{mol}^{-1}$  and is called the Avogadro number. The amount of substance, symbol  $n$ , of a system is a measure of the number of specified elementary entities. An elementary entity may be an atom, a molecule, an ion, an electron, any other particle or specified group of particles. (2019) **1 mol**

*1 candela* is the SI unit of luminous intensity in a given direction. It is defined by taking the fixed numerical value of the luminous efficacy of monochromatic radiation of frequency  $540 \cdot 10^{12}$  Hz,  $K_{\text{cd}}$ , to be 683 when expressed in the unit  $\text{lm W}^{-1}$ , which is equal to  $\text{cd sr W}^{-1}$ , or  $\text{cd sr kg}^{-1} \text{m}^{-2} \text{s}^3$ . (2019) **1 cd**

### 1.2 Multiples of units

Factor	Prefix	Symbol	Factor	Prefix	Symbol
$10^1$	deca	da	$10^{-1}$	deci	d
$10^2$	hecto	h	$10^{-2}$	centi	c
$10^3$	kilo	k	$10^{-3}$	milli	m
$10^6$	mega	M	$10^{-6}$	micro	$\mu$
$10^9$	giga	G	$10^{-9}$	nano	n
$10^{12}$	tera	T	$10^{-12}$	pico	p
$10^{15}$	peta	P	$10^{-15}$	femto	f
$10^{18}$	exa	E	$10^{-18}$	atto	a
$10^{21}$	zetta	Z	$10^{-21}$	zepto	z
$10^{24}$	yotta	Y	$10^{-24}$	yocto	y

Sources: DIN 1301, <https://www.bipm.org>

### 1.3 Greek alphabet

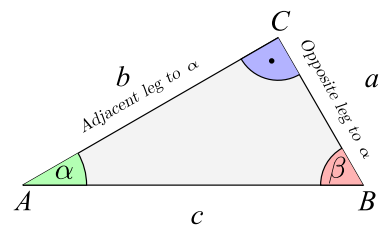
A	$\alpha$	Alpha	H	$\eta$	Eta	N	$\nu$	Nu	T	$\tau$	Tau
B	$\beta$	Beta	$\Theta$	$\theta, \vartheta$	Theta	$\Xi$	$\xi$	Xi	$\Upsilon$	$\upsilon$	Upsilon
$\Gamma$	$\gamma$	Gamma	I	$\iota$	Iota	O	$o$	Omicron	$\Phi$	$\phi, \varphi$	Phi
$\Delta$	$\delta$	Delta	K	$\kappa, \varkappa$	Kappa	$\Pi$	$\pi$	Pi	X	$\chi$	Chi
E	$\epsilon, \varepsilon$	Epsilon	$\Lambda$	$\lambda$	Lambda	P	$\rho, \varrho$	Rho	$\Psi$	$\psi$	Psi
Z	$\zeta$	Zeta	M	$\mu$	Mu	$\Sigma$	$\sigma, \varsigma$	Sigma	$\Omega$	$\omega$	Omega

## 2 Trigonometry

### 2.1 Right-angled triangle

$$\sin \alpha = \frac{a}{c} = \cos \beta \quad \cos \alpha = \frac{b}{c} = \sin \beta$$

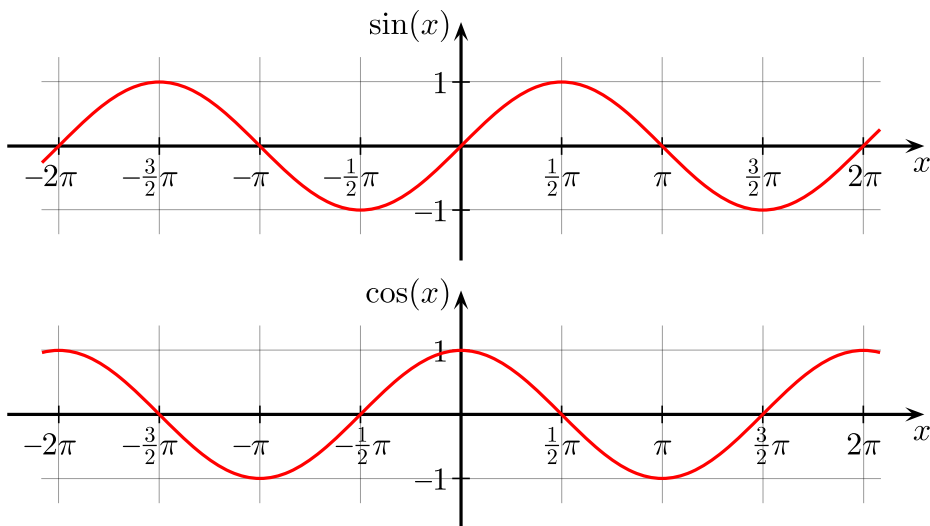
$$\tan \alpha = \frac{a}{b} = \cot \beta \quad \cot \alpha = \frac{b}{a} = \tan \beta$$



### 2.2 General triangle

Sine rule:  $\frac{a}{\sin \alpha} = \frac{b}{\sin \beta} = \frac{c}{\sin \gamma}$ ,      Cosine rule:  $a^2 = b^2 + c^2 - 2bc \cos(\alpha)$

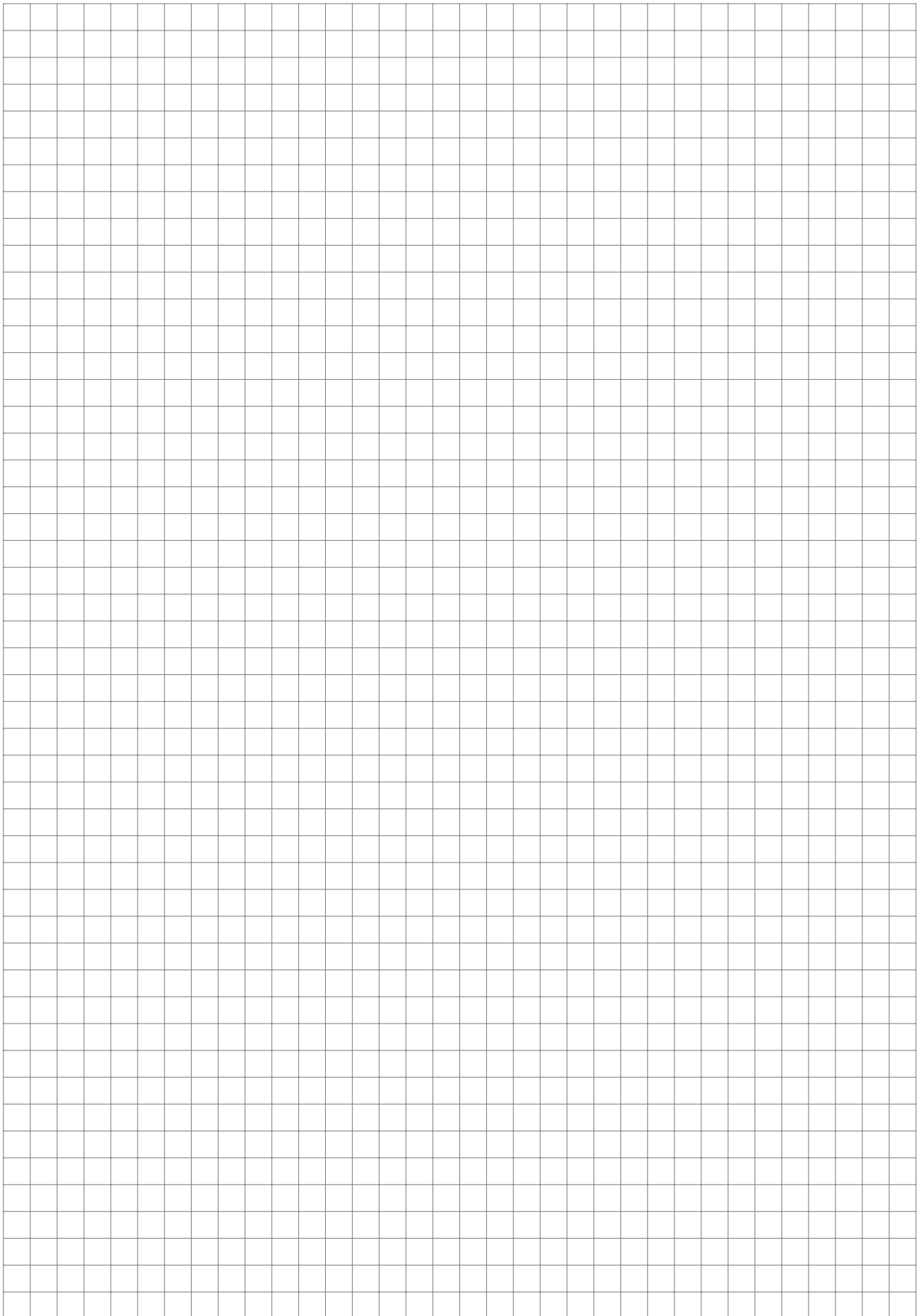
### 2.3 Trigonometric functions



### 2.4 Important relationships

$$\tan \alpha = \frac{\sin \alpha}{\cos \alpha}; \quad \sin^2 \alpha + \cos^2 \alpha = 1; \quad \sin(\alpha \pm \beta) = \sin \alpha \cos \beta \pm \cos \alpha \sin \beta$$

$$\cot \alpha = \frac{\cos \alpha}{\sin \alpha}; \quad \frac{1}{\cos^2 \alpha} = 1 + \tan^2 \alpha; \quad \cos(\alpha \pm \beta) = \cos \alpha \cos \beta \mp \sin \alpha \sin \beta$$



## 3 Mechanics

### 3.1 Kinematics

**Average and instantaneous velocity:**

$$\Delta \vec{s} = \vec{s}_2 - \vec{s}_1, \quad \Delta t = t_2 - t_1$$

$$\bar{\vec{v}} = \frac{\Delta \vec{s}}{\Delta t} = \vec{v}_{\text{average}} \quad (\text{Def.})$$

$$\vec{v} = \lim_{\Delta t \rightarrow 0} \frac{\Delta \vec{s}}{\Delta t} = \vec{v}_{\text{instantaneous}} \quad (\text{Def.})$$

**Magnitude of velocity (speed):**

$$|\vec{v}| = v$$

**Velocity conversion:**

$$v_{\text{km/h}} \xrightarrow{\cdot 3.6} v_{\text{m/s}} \xrightarrow{\cdot 3.6} v_{\text{km/h}}$$

**Uniform motion:**

$$\vec{s} = \vec{s}_0 + \vec{v} \cdot t$$

**Uniformly accelerated motion:**

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t} \quad (\text{Def.})$$

$$\vec{v} = \vec{v}_0 + \vec{a} t$$

$$\vec{s} = \vec{s}_0 + \vec{v}_0 t + \frac{1}{2} \vec{a} t^2$$

$$\vec{s} = \vec{s}_0 + \frac{1}{2} (\vec{v}_0 + \vec{v}) t$$

**Uniformly accelerated motion along a straight line:**

$$s = \frac{v^2 - v_0^2}{2a}, \quad s_0 = 0$$

**Free fall:**

$$\vec{a} = \vec{g}, \quad g_{\text{Earth}} \approx 9.81 \frac{\text{m}}{\text{s}^2}$$

**Projectile motion:**

$$v_{0x} = v_0 \cos \alpha, \quad v_{0y} = v_0 \sin \alpha$$

$$x = v_{0x} t, \quad y = v_{0y} t - \frac{1}{2} g t^2$$

$$v_x = v_{0x} = \text{const.}, \quad v_y = v_{0y} - g t$$

$$v = \sqrt{v_x^2 + v_y^2}$$

### 3.2 Forces

**Weight:**

$$\vec{F}_G = m \cdot \vec{g}$$

$$g_{\text{Earth}} \approx 9.81 \text{ N/kg}$$

(Reference value:  $g = 9.80665 \text{ N/kg}$ )

**Density:**

$$\rho = \frac{m}{V}, \quad [\rho] = \frac{\text{kg}}{\text{m}^3}$$

**Spring force:**

$$\vec{F}_{\text{spring}} = (-) D \cdot \vec{s}$$

**Friction:**

$$F_{\text{static}} \leq \mu_s \cdot F_N$$

$$F_{\text{kinetic}} = \mu_k \cdot F_N$$

$$F_{\text{rolling}} = \mu_r \cdot F_N$$

**Inclined plane:**

$$F_G^{\parallel} = F_G \cdot \sin \alpha = m g \sin \alpha$$

$$F_G^{\perp} = F_G \cdot \cos \alpha = m g \cos \alpha$$

**Air resistance (Drag):**

$$F \approx \frac{1}{2} c_w A \rho v^2$$

### 3.3 Newton's laws

**I. Law (Principle of inertia)**

$$v = \text{const.}, \quad \text{if } \vec{F}_{\text{res}} = \vec{0}$$

$\vec{F}_{\text{res}}$  : resultant force

**II. Law (Principle of motion)**

$$\vec{F}_{\text{res}} = m \cdot \vec{a}$$

**III. Law (“Actio = Reactio”)**

$$\vec{F}_{12} = -\vec{F}_{21}$$

**3.4 Energy and Power****Work:**

$$W = F_s \cdot s$$

$$W = F s \cos \alpha \quad (\text{Def.})$$

**Golden rule of mechanics:**

For frictionless simple machines:

“The product of force and distance (along the path) does not change.”

**Law of the lever:**

Measured from the fulcrum:

“Effort times effort-arm equals load times load-arm.”

**Forms of energy:**

$$E_{\text{pot}} = m g h$$

$$E_{\text{kin}} = \frac{1}{2} m v^2$$

$$E_{\text{spring}} = \frac{1}{2} D s^2$$

**Power:**

$$P = \lim_{\Delta t \rightarrow 0} \frac{\Delta E}{\Delta t} = P_{\text{instantaneous}} \quad (\text{Def.})$$

$$\bar{P} = \frac{\Delta E}{t} = \frac{W}{t} = P_{\text{average}}$$

$$P = F_s \cdot v = F v \cos \alpha$$

**Efficiency:**

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{W_{\text{out}}}{W_{\text{in}}} \quad (\text{Def.})$$

**3.5 Momentum****Momentum:**

$$\vec{p} = m \cdot \vec{v} \quad (\text{Def.})$$

**Impulse:**

$$\Delta \vec{p} = \vec{F} \Delta t \quad (\text{Force constant!})$$

**Inelastic collision:**

$$\vec{u} = \vec{v}_{\text{CM}} = \frac{m_1 \vec{v}_1 + m_2 \vec{v}_2}{m_1 + m_2}$$

**Elastic collision:**

$$\vec{v}_{\text{CM}} = \frac{m_1 \vec{v}_1 + m_2 \vec{v}_2}{m_1 + m_2}$$

$$\vec{v}'_1 = \vec{v}_1 - \vec{v}_{\text{CM}}$$

$$\vec{u}'_1 = -\vec{v}'_1$$

$$\begin{aligned} \vec{u}_1 &= \vec{u}'_1 + \vec{v}_{\text{CM}} = 2\vec{v}_{\text{CM}} - \vec{v}_1 \\ &= \frac{(m_1 - m_2) \vec{v}_1 + 2m_2 \vec{v}_2}{m_1 + m_2} \end{aligned}$$

( $\vec{v}'_2$ ,  $\vec{u}'_2$ , and  $\vec{u}_2$  analogously by swapping 1 and 2)

**3.6 Uniform circular motion****Frequency:**

$$f = \frac{1}{T} \quad (\text{Def.})$$

**Angular velocity:**

$$\omega = \frac{\Delta \varphi}{\Delta t} \quad (\text{Def.}), \quad [\omega] = \frac{\text{rad}}{\text{s}} = \frac{1}{\text{s}}$$

$$\omega = \frac{2\pi}{T} = 2\pi f, \quad [f] = \text{s}^{-1} = \text{Hz}$$

**Orbital velocity:**

$$v = \omega r$$

**Centripetal acceleration and resultant force:**

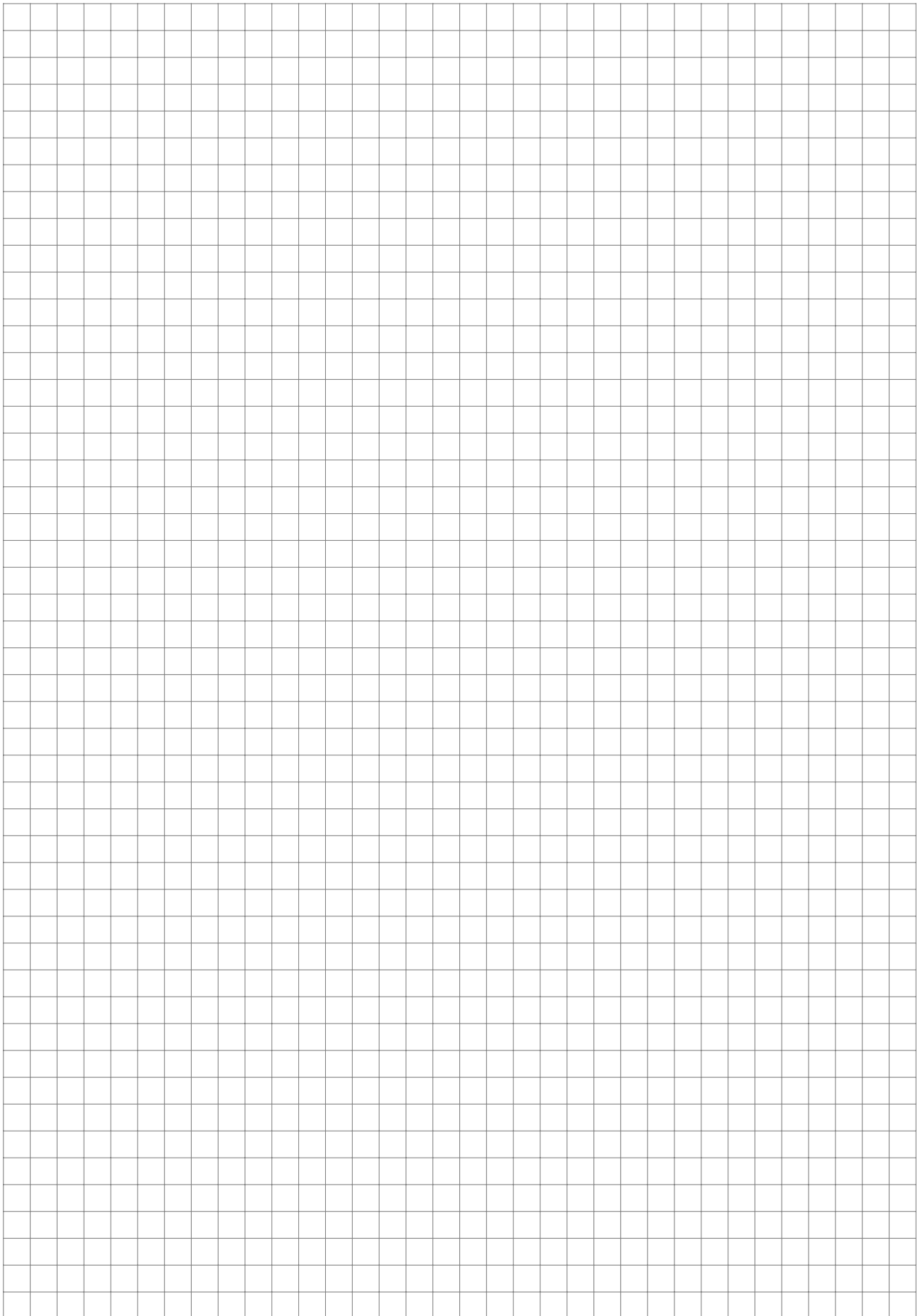
$$a_c = \omega^2 r = \frac{v^2}{r}$$

$$F_c = m a_c = m \omega^2 r$$

**3.7 Gravitation****Newton’s law of universal gravitation:**

$$F = G \frac{m_1 m_2}{r^2}$$

$$G = 6.67428(67) \cdot 10^{-11} \text{ Nm}^2 \text{ kg}^{-2}$$



## 4 Electricity and Magnetism

### 4.1 Electric Field

Electric field and voltage:

$$\vec{E} = \frac{\vec{F}}{Q} \quad (\text{Def.})$$

$$U = E_s \cdot s = E s \cos \alpha = \vec{E} \cdot \vec{s}$$

Elementary charge:

$$e = 1.6022 \cdot 10^{-19} \text{ C}$$

Coulomb's law:

$$F = \frac{1}{4\pi \varepsilon_0 \varepsilon_r} \cdot \frac{Q_1 Q_2}{r^2}, \quad \varepsilon_r = 1 \text{ (vacuum)}$$

$$\varepsilon_0 = 8.854 \cdot 10^{-12} \frac{\text{C}^2}{\text{Nm}^2}$$

Parallel-plate capacitor:

$$C = \varepsilon_0 \varepsilon_r \frac{A}{d}, \quad \varepsilon_r = 1 \text{ (vacuum)}$$

$\varepsilon_r$  : relative permittivity

E-field of a parallel-plate capacitor:

$$E = \frac{Q}{\varepsilon_0 \varepsilon_r A} = \frac{U}{d},$$

where  $d \ll \sqrt{A}$

Capacitance:

$$C = \frac{Q}{U} \quad (\text{Def.})$$

Parallel circuit:

$$C_{\text{eq}} = C_1 + C_2 + C_3 + \dots$$

Series circuit:

$$\frac{1}{C_{\text{eq}}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots$$

Electrical energy of the capacitor:

$$W = \frac{1}{2} C U^2$$

Surface charge density:

$$\sigma = \frac{Q}{A}$$

$$E = \frac{\sigma}{\varepsilon_0 \varepsilon_r}$$

### 4.2 Moving charge

Charge and current:

$$I = \frac{Q}{t}$$

Voltage and work:

$$U = \frac{W}{Q} \quad (\text{Def.})$$

$$= \frac{P}{I}$$

Resistance,  
resistivity:

$$R = \frac{U}{I} \quad (\text{Def.})$$

$$\rho_{\text{el.}} \cdot \frac{l}{A} = R \quad (\text{Def.})$$

Parallel circuit:

$$\frac{1}{R_{\text{eq}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$

Series circuit:

$$R_{\text{eq}} = R_1 + R_2 + R_3 + \dots$$

### 4.3 Electromagnetism

Magnetic flux density:

$$F = s I B \sin \alpha$$

$$\vec{F} = s (\vec{I} \times \vec{B}) \quad (\text{Def. of } \vec{B})$$

Right-hand rule (conventional current):

Middle finger = Thumb  $\times$  Index finger

Force = Current  $\times$  Magnetic field

**Lorentz force:**

$$\vec{F}_L = q (\vec{v} \times \vec{B}) = q |\vec{v}| |\vec{B}| \sin \alpha$$

**B-field in a long solenoid:**

$$B \approx \mu_0 \mu_r I \frac{n}{l}, \quad l \gg d$$

coil diameter  $d$ , length  $l$   
 $\mu_0 = 4\pi \cdot 10^{-7} \text{ T m A}^{-1}$

**B-field of a current-carrying infinitely long wire:**

$$B = \frac{\mu_0 \mu_r I}{2\pi r}$$

$r$ : distance from the wire axis

**Magnetic flux and induction:**

$$\Phi = \vec{B} \cdot \vec{A} = B A \cos \varphi$$

$$U_{\text{ind}} = -\frac{d\Phi}{dt} \approx -\frac{\Delta\Phi}{\Delta t}$$

## 5 Geometrical Optics

**Law of reflection:**

$$\alpha = \alpha'$$

**Magnification:**

$$M = \frac{h_i}{h_o} \quad (\text{Def.})$$

**Lateral magnification:**

$$\frac{h_i}{h_o} = \frac{v}{u}$$

**Thin lens equation:**

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

**Optical power:**

$$P = \frac{1}{f} \quad (\text{Def.})$$

**Self-induction:**

$$U_{\text{ind}} \approx L \cdot \frac{\Delta I}{\Delta t}$$

**Long solenoid:**

$$L = \mu_0 \mu_r n^2 \frac{A}{l}$$

$$W = \frac{1}{2} L I^2$$

**Alternating voltage (AC):**

$$U(t) = \hat{U} \cdot \sin \omega t$$

$$\omega = \frac{2\pi}{T} = 2\pi f$$

$$U_{\text{rms}} = \frac{\hat{U}}{\sqrt{2}}, \quad I_{\text{rms}} = \frac{\hat{I}}{\sqrt{2}}$$

$$\bar{P} = U_{\text{rms}} \cdot I_{\text{rms}}$$

**Transformer:**

$$\frac{U_1}{U_2} \approx \frac{n_1}{n_2}, \quad \frac{I_2}{I_1} \approx \frac{n_1}{n_2}$$

**Combination of lenses:**

$$P = P_1 + P_2$$

**Spherical concave mirror:**

$$f = \frac{r}{2}$$

**Speed of light in a vacuum:**

$$c_{\text{vac}} = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

$$c_{\text{vac}} = 299\,792\,458 \text{ m/s} \quad (\text{Def.})$$

**Refraction of light:**

$$n = \frac{c_{\text{vac}}}{c_{\text{medium}}} \quad (\text{Def.})$$

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{c_1}{c_2} = \frac{n_2}{n_1}$$

## 6 Hydrostatics and Aerostatics

**Pressure:**

$$p = \frac{F}{A} \quad (\text{Def.})$$

1 bar =  $10^5$  Pa,    1 Torr = 133.3 Pa,  
 1 atm =  $1.01325 \cdot 10^5$  Pa = 1.01325 bar  
 $\hat{=}$   $p_o$  (standard pressure)

**Hydrostatic pressure:**

$$p_{\text{total}} = p_o + \rho_{\text{fluid}} g h$$

**Buoyancy:**

$$F_B = V_{\text{displaced fluid}} \rho_{\text{fluid}} g$$

**Bernoulli's equation:**

$$\frac{1}{2} \rho v^2 + \rho g h + p = \text{const.}$$

## 7 Thermodynamics

### 7.1 Temperature

**Temperature conversion:**

$$\vartheta_{\text{Fahrenheit}} = 1.8 \frac{^\circ\text{F}}{^\circ\text{C}} \cdot \vartheta_{\text{Celsius}} + 32 \text{ } ^\circ\text{F}$$

$$T_{\text{Kelvin}} = \vartheta_{\text{Celsius}} + 273.15 \text{ K}$$

$$\Delta T = \Delta \vartheta_{\text{Celsius}}$$

**Linear expansion of solids:**

$$l = l_o + \Delta l \approx l_o (1 + \alpha \Delta T)$$

$$\Delta l \approx \alpha l_o \Delta T$$

**Volumetric expansion:**

$$V = V_o + \Delta V \approx V_o (1 + \gamma \Delta T)$$

$$\Delta V \approx \gamma V_o \Delta T$$

Solids:  $\gamma \approx 3\alpha$

**Ideal gas law:**

$$pV = nRT$$

$$= N k_B T = n N_A k_B T$$

**Simplified barometric formula:**

$$p(h) = p_o e^{-\frac{h}{8000 \text{ m}}}$$

$$e \approx 2.718\ 281\ 828\ 459$$

**Boyle's Law:**

$$p_1 \cdot V_1 = p_2 \cdot V_2 = \text{const.}$$

**Air resistance (Drag):**

$$F \approx \frac{1}{2} c_w A \rho v^2$$

with

$$R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$$

$$k_B = 1.38 \cdot 10^{-23} \text{ J K}^{-1}$$

$$N_A = 6.02 \cdot 10^{23} \text{ mol}^{-1}$$

**Root mean square velocity:**

$$v_{\text{rms}} = \sqrt{v^2} = \sqrt{\frac{3kT}{m}}$$

**Pressure of an ideal gas:**

$$p = \frac{1}{3} \frac{N}{V} m \overline{v^2}$$

### 7.2 Thermodynamics

**1st Law:**

$$\Delta U = W \checkmark + Q \checkmark \quad \checkmark : \text{'supplied'}$$

**Specific heat capacity:**

$$\Delta Q = c m \Delta T \quad (\text{Def.})$$

**Latent heat of fusion:**

$$Q = m \cdot L_{\text{solid-liquid}}$$

**Latent heat of vaporisation:**

$$Q = m \cdot L_{\text{liquid-gas}}$$

**Thermal conductivity  $\lambda$ :**

$$\frac{\Delta Q}{\Delta t} = (-)\lambda \cdot \frac{A}{\Delta x} \cdot \Delta T$$

Multiple layers:

$$\frac{\Delta Q}{\Delta t} = (-) \frac{A \Delta T}{\frac{\Delta x_1}{\lambda_1} + \frac{\Delta x_2}{\lambda_2} + \frac{\Delta x_3}{\lambda_3} + \dots}$$

**Thermal radiation:**

$$\lambda_{\text{max}} = \frac{2.898 \cdot 10^{-3} \text{ m} \cdot \text{K}}{T}$$

$$P_Q = \frac{Q}{\Delta t} = \sigma A T^4$$

$$\sigma = 5.67 \cdot 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$$

**Entropy:**

$$\Delta S = \frac{\Delta Q}{T} \quad (\text{reversible processes})$$

## 8 Constants and Units

**Proton mass:**

$$m_p = 1.6726 \cdot 10^{-27} \text{ kg}$$

**Neutron mass:**

$$m_n = 1.6749 \cdot 10^{-27} \text{ kg}$$

**Electron mass:**

$$m_e = 9.1095 \cdot 10^{-31} \text{ kg}$$

**Elementary charge:**

$$e = 1.6022 \cdot 10^{-19} \text{ C}$$

**Avogadro constant:**

$$N_A = 6.0221 \cdot 10^{23} \text{ mol}^{-1}$$

**Electronvolt:**

$$1 \text{ eV} = 1.6022 \cdot 10^{-19} \text{ J}$$

$$S = k_B \ln W$$

 $W$ : thermodynamic probability of the state**Carnot engines and entropy;****2nd Law:** ( $\geq$  and  $\leq$ : For idealised engine ' $=$ ')  
 $\eta_{\text{motor}} = \frac{W}{-Q_2} \leq \frac{T_2 - T_1}{T_2}$ 

$$Q_1 + Q_2 + W = 0$$

$$\Delta S = \frac{Q_1}{T_1} + \frac{Q_2}{T_2} \geq 0$$

$$\eta_{\text{motor}} = \frac{W}{-Q_2} \leq \frac{T_2 - T_1}{T_2}$$

$$\eta_{\text{heat pump}} = \frac{Q_2}{-W} \leq \frac{T_2}{T_2 - T_1}$$

$$\eta_{\text{refrigerator}} = \frac{-Q_1}{-W} \leq \frac{T_1}{T_2 - T_1}$$

**Atomic mass unit:**

$$1 \text{ u} = 1.6605 \cdot 10^{-27} \text{ kg}$$

$$\hat{=} 931.494 \text{ MeV}$$

**Astronomy:**

$$1 \text{ AU} = 1.496 \cdot 10^{11} \text{ m}$$

$$1 \text{ light year (ly)} = 9.4605 \cdot 10^{15} \text{ m}$$

$$1 \text{ mean solar day : } 1 \text{ d} = 24 \text{ h}$$

$$1 \text{ sidereal day : } 86 \text{ 164.09 s}$$

$$1 \text{ sidereal year : } 365.25636 \text{ d}$$

$$m_{\text{Earth}} = 5.98 \cdot 10^{24} \text{ kg}$$

$$r_{\text{Earth}} = 6371 \text{ km}$$

$$m_{\text{Moon}} = 7.35 \cdot 10^{22} \text{ kg}$$

$$r_{\text{Moon}} = 1738 \text{ km}$$

$$m_{\text{Sun}} = 1.99 \cdot 10^{30} \text{ kg}$$

$$r_{\text{Sun}} = 6.96 \cdot 10^8 \text{ m}$$

## 9 Tables

### Density of some substances:

Solids	Density at 20 °C $\rho$ or $\varrho$ in $\frac{\text{kg}}{\text{m}^3}$	Liquids	Density at 20 °C $\rho$ in $\frac{\text{kg}}{\text{m}^3}$	Gases at 0 °C (std. pressure $p_0$ )	Density $\rho$ in $\frac{\text{kg}}{\text{m}^3}$
Diamond	$3.51 \cdot 10^3$	Benzene	$0.879 \cdot 10^3$	Air	1.293
Ice (at 0 °C)	$0.917 \cdot 10^3$	Ethanol	$0.789 \cdot 10^3$	Carbon dioxide	1.977
Aluminium	$2.7 \cdot 10^3$	Glycerol	$1.261 \cdot 10^3$	Helium	0.1785
Gold	$19.29 \cdot 10^3$	Olive oil	$0.92 \cdot 10^3$	Freon 12	5.510
Iron	$7.86 \cdot 10^3$	Mercury	$13.546 \cdot 10^3$	Natural gas	0.83
Copper	$8.92 \cdot 10^3$	Water (H <sub>2</sub> O)	$0.998 \cdot 10^3$	Hydrogen	0.0899
Lead	$11.34 \cdot 10^3$	Water (D <sub>2</sub> O)	$1.105 \cdot 10^3$	Propane	2.010
Platinum	$21.45 \cdot 10^3$	Petroleum	$0.85 \cdot 10^3$	Nitrogen	1.250
Wood	$0.7 \cdot 10^3$	Sulphuric acid	$1.84 \cdot 10^3$	Xenon	5.897
Cork	$0.3 \cdot 10^3$	Toluene	$0.867 \cdot 10^3$	Ammonia	0.771

### Approximate values of some coefficients of friction:

Material combination	Kinetic friction $\mu_k$	Static friction $\mu_s$	Rolling friction $\mu_r$
Tyre on dry road	0.6	1.0	0.008
Tyre on wet road	0.4	0.7	Car tyre on loose sand: 0.3
Tyre on ice	0.15	0.2	Car tyre on gravel: 0.02
Waxed ski on snow (0 °C)	0.05	0.1	Bicycle tyre on asphalt: 0.007
Steel on steel	0.4	0.6	Railway wheel on rail: 0.0015
Teflon on Teflon	0.04	0.04	
Steel on ice	0.014	0.027	
Wood on wood	0.4	0.6	

### Absolute refractive indices (Vac. – Substance) of some substances for light of wavelength $\lambda = 589 \text{ nm}$ at 20 °C:

Solids	Refractive index $n$	Liquids	Refractive index $n$	Gases et al. (Gases: 0 °C, $p_0$ )	Refractive index $n$
Diamond	2.417	Benzene	1.501	Air	1.000292
Ice	1.309	Ethanol	1.360	Carbon dioxide	1.00449
Rock salt	1.544	Glycerol	1.473	Helium	1.000034
Fused quartz	1.458	Linseed oil	1.486	Plasma	$0 < n \leq 1$
Flint glass	1.612	Water	1.333	Vacuum	exactly 1
Crown glass	1.503	Toluene	1.496		

### Pressure and density of saturated water vapour:

$\vartheta$ in °C	$p_s$ in Pa	$\varrho_s$ in $\text{g m}^{-3}$	$\vartheta$ in °C	$p_s$ in Pa	$\varrho_s$ in $\text{g m}^{-3}$	$\vartheta$ in °C	$p_s$ in Pa	$\varrho_s$ in $\text{g m}^{-3}$
-10	285	2.36	15	1707	12.86	40	7378	50.17
-5	421	3.32	20	2337	17.32	45	9586	65.45
0	611	4.85	25	3172	23.10	50	12 340	83.00
5	874	6.82	30	4242	30.39	75	39 250	245.50
10	1227	9.41	35	5642	39.63	100	101 325	597.70

**Thermal data of some substances:**

<b>Solids</b>	$\alpha$ in $K^{-1}$	$\lambda$ in $\frac{W}{m \cdot K}$	$L_f$ in $\frac{J}{kg}$	$c$ in $\frac{J}{kg \cdot K}$	$\vartheta_f$ in $^{\circ}C$
Window glass	$7.6 \cdot 10^{-6}$	0.8		800	
Fused quartz	$0.45 \cdot 10^{-6}$	1.36		710	1610 <sup>1</sup>
Concrete	$6 - 14 \cdot 10^{-6}$	2.1			
Iron (pure)	$12 \cdot 10^{-6}$	80	$2.77 \cdot 10^5$	450	1535
Gold	$14.3 \cdot 10^{-6}$	312	$0.64 \cdot 10^5$	129	1063
Aluminium	$23.8 \cdot 10^{-6}$	239	$3.97 \cdot 10^5$	896	660.1
Glass-ceramic	$0.1 \cdot 10^{-6}$	1.46		800	
Diamond	$1.18 \cdot 10^{-6}$	2000	$1.05 \cdot 10^5$	510	3820
Invar: (64 % Fe, 36 % Ni)	$0.15 \cdot 10^{-6}$	11	5.15	460	1436
Aramid fibre	$-4.1 \cdot 10^{-6}$	0.04			
Ice (0 °C)	$37.0 \cdot 10^{-6}$	2.2	$3.338 \cdot 10^5$	2100	0
<b>Liquids</b>	$\gamma$ in $K^{-1}$	$\lambda$ in $\frac{W}{m \cdot K}$	$L_v$ in $\frac{J}{kg}$	$c$ in $\frac{J}{kg \cdot K}$	$\vartheta_f$ in $^{\circ}C$
Water	$0.21 \cdot 10^{-3}$	0.598	$22.56 \cdot 10^5$	4182	0
Ethanol	$1.10 \cdot 10^{-3}$	0.165	$8.40 \cdot 10^5$	2430	-114.5
Mercury	$0.182 \cdot 10^{-3}$	8.2	$2.86 \cdot 10^5$	139	-38.87
Glycerol	$0.50 \cdot 10^{-3}$	0.285	$8.54 \cdot 10^5$	2390	18.4
Sodium (400 °C)	$0.27 \cdot 10^{-3}$	84	$1.13 \cdot 10^5$	1280	97.8
<b>Gases</b>	$L_f$ in $\frac{J}{kg}$	$\lambda$ in $\frac{W}{m \cdot K}$	$L_v$ in $\frac{J}{kg}$	$c$ in $\frac{J}{kg \cdot K}$	$\vartheta_f$ in $^{\circ}C$
Nitrogen	$0.26 \cdot 10^5$	0.024	$1.98 \cdot 10^5$	1038	-210.00
Helium	$5 \cdot 10^5$	0.143	$20 \cdot 10^5$	5230	-272.2
Oxygen	$0.14 \cdot 10^5$	0.024	$2.13 \cdot 10^5$	917	-218.79
Methane	$0.59 \cdot 10^5$	0.030	$5.10 \cdot 10^5$	2219	-182.52
Hydrogen	$60 \cdot 10^5$	0.171	$450 \cdot 10^5$	14 320	-259.20

$\alpha$ : Coefficient of linear expansion at 20 °C,  $L_f$ : Specific latent heat of fusion,  $L_v$ : Spec. latent heat of vaporisation at  $p_0$ ,  $\lambda$ : Thermal conductivity at 20 °C,  $c$ : Spec. heat capacity at 20 °C and  $p_0$

**Electricity:** Electrical resistivity

Electrical resistivity	$[\rho] = \Omega m$	Electrical resistivity	$[\rho] = \Omega m$
Aluminium (20 °C)	$2.82 \cdot 10^{-8}$	Constantan (20 °C)	$49 \cdot 10^{-8}$
Copper (20 °C)	$1.68 \cdot 10^{-8}$	Tungsten (20 °C)	$5.3 \cdot 10^{-8}$
Tungsten (2500 °C)	$90 \cdot 10^{-8}$	Germanium (20 °C)	0.14
Silicon (pure, 20 °C)	640	Graphite (20 °C)	$300 \cdot 10^{-8}$
Gold (20 °C)	$2.2 \cdot 10^{-8}$	Zinc (20 °C)	$5.8 \cdot 10^{-8}$

**Conversion of mass and energy equivalents**

Atomic mass unit u  $\leftrightarrow$  kg  $\leftrightarrow$  megaelectronvolt  $\leftrightarrow$  kelvin  $\leftrightarrow$  joule

	u	kg	MeV	K	J
1 u	1	$1.6605 \cdot 10^{-27}$	$9.315 \cdot 10^2$	$1.0809 \cdot 10^{13}$	$1.4924 \cdot 10^{-10}$
1 kg	$6.0221 \cdot 10^{26}$	1	$5.6096 \cdot 10^{29}$	$6.5096 \cdot 10^{39}$	$8.9876 \cdot 10^{16}$
1 MeV	$1.0735 \cdot 10^{-3}$	$1.7827 \cdot 10^{-30}$	1	$1.1604 \cdot 10^{10}$	$1.6022 \cdot 10^{-13}$
1 K	$9.2511 \cdot 10^{-14}$	$1.5362 \cdot 10^{-40}$	$8.6174 \cdot 10^{-11}$	1	$1.3807 \cdot 10^{-23}$
1 J	$6.7005 \cdot 10^9$	$1.1126 \cdot 10^{-17}$	$6.2415 \cdot 10^{12}$	$7.2429 \cdot 10^{22}$	1

<sup>1</sup>Quartz crystal

## 10 Oscillations and Waves

### 10.1 Mechanical Oscillations

Frequency and angular frequency:

$$f = \frac{1}{T} \quad (\text{Def.})$$

$$\omega = \frac{2\pi}{T} = 2\pi f \quad (\text{Def.})$$

Harmonic oscillation:

$$s(t) = \hat{s} \sin \omega t$$

$$v(t) = \omega \hat{s} \cos \omega t$$

$$a(t) = -\omega^2 \hat{s} \sin \omega t$$

$$F(t) = m \cdot a = -m \omega^2 \hat{s} \sin \omega t$$

$$F(s) = -m \omega^2 s$$

Spring pendulum:

$$F = -D \cdot s$$

$$m \omega^2 = D, \quad \omega = \sqrt{\frac{D}{m}}$$

Simple pendulum:

$$\omega = \sqrt{\frac{g}{l}}$$

### 10.2 Mechanical Waves

Wavelength and propagation speed:

$$c = \frac{\lambda}{T} = f \cdot \lambda$$

Wavenumber:

$$k = \pm \frac{2\pi}{\lambda} = \pm \frac{\omega}{c} \quad (\text{Def.})$$

(+ to the right, - to the left)

Sinusoidal waves:

$$\begin{aligned} s(t, x) &= \hat{s} \sin \left( 2\pi \left( \frac{t}{T} \mp \frac{x}{\lambda} \right) + \delta \right) \\ &= \hat{s} \sin \left( \omega \left( t \mp \frac{x}{c} \right) + \delta \right) \\ &= \hat{s} \sin(\omega t - kx + \delta) \end{aligned}$$

Law of refraction:

$$\frac{\sin \alpha}{\sin \beta} = \frac{c_1}{c_2}$$

### 10.3 Electromagnetic Waves

LC circuit:

$$\omega = \frac{1}{\sqrt{LC}}$$

Speed of light in a vacuum:

$$c_{\text{vac}} = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

$$c_{\text{vac}} = 299\,792\,458 \text{ m/s} \quad (\text{Def.!!})$$

Refraction of light:

$$n = \frac{c_{\text{vac}}}{c_{\text{medium}}} \quad (\text{Def.})$$

$$\frac{\sin \alpha}{\sin \beta} = \frac{c_a}{c_b} = \frac{n_b}{n_a}$$

Diffraction grating:

$$\lambda = \frac{d}{k} \cdot \sin \alpha_k \quad (k = 1; 2; 3; \dots)$$

# 11 Nuclear Physics

Mass number:

$$A = Z + N$$

Mass defect:

$$\Delta m \approx Z(m_p + m_e) + Nm_n - m_a$$

Nuclear radius:

$$r \approx r_0 \sqrt[3]{A}$$

## 11.1 Radioactivity

Law of radioactive decay:

$$N = N_0 e^{-\lambda t}$$

Half-life:

$$T_{1/2} = \frac{\ln 2}{\lambda}$$

Activity:

$$A = -\frac{dN}{dt} = \lambda N$$

## 11.2 Radiological Quantities

Exposure:

$$X = \frac{\Delta Q}{\Delta m}, [X] = \text{C/kg}$$

Absorbed dose:

$$D = \frac{\Delta W}{\Delta m}, [D] = \text{J/kg} = \text{Gy}$$

Equivalent dose:

$$H = w_R D, [H] = \text{J/kg} = \text{Sv}$$

$w_R$ : radiation weighting factor

Effective dose:

$$E = \sum w_T H, [E] = \text{Sv}$$

$w_T$ : tissue weighting factor

## 11.3 Table of Nuclides

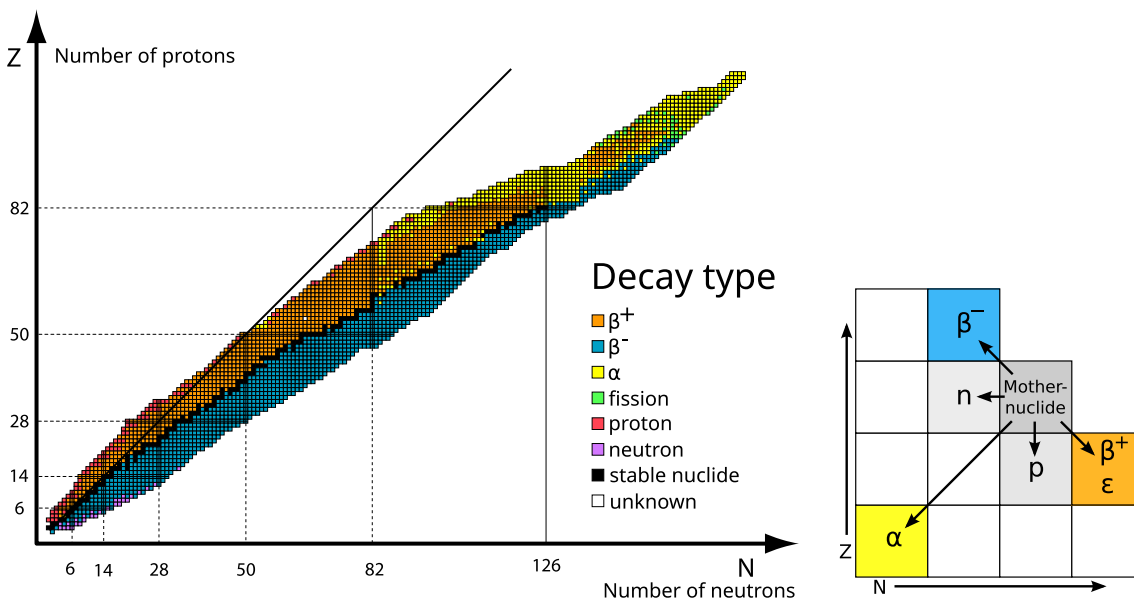


Chart of nuclides after SEGRÈ [Wikimedia Commons, File: Isotopentabelle\_Segrè]

## 12 Special Relativity

### Velocity transformations:

$$u' = u - v \quad (\text{classical}),$$

$$u' = \frac{u - v}{1 - \frac{uv}{c^2}} \quad (\text{relativistic})$$

$v$ : relative velocity between the moving frame  $S'$  and the rest frame  $S$  in one dimension.

### Length contraction:

$$l = \frac{l_0}{\gamma}, \quad \gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

$l_0$ : proper length measured in the rest frame of the object.

### Time dilation:

$$\Delta t = \gamma \Delta t_0$$

### Frequency:

$$f = f_0 \sqrt{\frac{c - v}{c + v}}$$

### Momentum:

$$\vec{p} = \gamma m \vec{v}$$

### Relativistic mass:

$$m_{\text{rel}} = \gamma m = \frac{p}{v}$$

### Force:

$$\vec{F} = \frac{d\vec{p}}{dt} = \dot{\vec{p}}$$

### Rest energy:

$$E_0 = mc^2$$

### Total energy:

$$E = \gamma E_0 = \sqrt{(mc^2)^2 + (pc)^2}$$

### Kinetic energy:

$$E_{\text{kin}} = E - E_0 = (\gamma - 1)mc^2$$

## 13 For the advanced in mathematics

### Displacement, velocity and acceleration:

$$\vec{v} = \lim_{\Delta t \rightarrow 0} \frac{\Delta \vec{s}}{\Delta t} = \dot{\vec{s}} \quad (\text{Def.})$$

$$\vec{a} = \lim_{\Delta t \rightarrow 0} \frac{\Delta \vec{v}}{\Delta t} = \dot{\vec{v}} = \ddot{\vec{s}} \quad (\text{Def.})$$

$$\vec{v}(t) = \vec{v}_0 + \int_{t_0}^t \vec{a}(t') dt'$$

$$\vec{s}(t) = \vec{s}_0 + \int_{t_0}^t \vec{v}(t') dt'$$

### Torque:

$$\vec{M} = \vec{r} \times \vec{F} \quad (\text{Def.})$$

### Work, power:

$$W = \vec{F} \cdot \vec{s} \quad (\text{Def.})$$

$$P = \dot{E}, \quad P = \dot{W} \quad (\text{Def.})$$

$$P = \vec{F} \cdot \vec{v}$$

### Circular motion:

$$\vec{v} = \vec{\omega} \times \vec{r}$$

$$\vec{a}_c = \vec{\omega} \times (\vec{\omega} \times \vec{r})$$

$$\vec{F}_c = m \vec{a}_c = m \vec{\omega} \times (\vec{\omega} \times \vec{r})$$

$$\vec{F}_C = 2m (\vec{v}_{\text{rel}} \times \vec{\omega})$$

18 VIIIA

1	1.0079	1 IA	1	1.0079	1 IA	1	4.0026	2	4.0026	18 VIIIA	2	He	Helium				
2	6.941	2 IIA	3	9.0122	2 IIA	4	9.0122	5	10.811	13 IIIA	6	12.011	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
3	11	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
4	37	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
5	55	57-71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
6	87	89-103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118
7	Fr	Ac-Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og

# Periodic Table of the Elements

57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Lanthanum	Cerium	Praseodymium	Neodymium	Promethium	Samarium	Europtium	Gadolinium	Terbium	Dysprosium	Holmium	Erbium	Thulium	Ytterbium	Lutetium

89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
Actinium	Thorium	Protactinium	Uranium	Neptunium	Plutonium	Americium	Curium	Berkelium	Californium	Einsteinium	Fermium	Mendelevium	Nobelium	Lawrencium

- Alkali Metal
- Alkaline Earth Metal
- Metal
- Metalloid
- Nonmetal
- Halogen
- Noble Gas
- Lanthanides/Actinides

z Mass  
**Symb.**  
 Name

Syn-  
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