

# **Formulas and Constants for College Physics**

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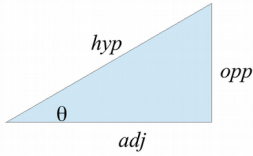
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# Math + Measurement

## Quadratic Equations

Quadratic Equation  $ax^2 + bx + c = 0 \rightarrow x_{1,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

## Trigonometry



Soh-Cah-Toa  
 $\sin(\theta) = \frac{opp}{hyp}$   
 $\cos(\theta) = \frac{adj}{hyp}$   
 $\tan(\theta) = \frac{opp}{adj} = \frac{\sin(\theta)}{\cos(\theta)}$

## Trigonometric Identities

Identities  $\sin(2\theta) = 2 \sin(\theta) \cos(\theta)$   
 $\sin^2(\theta) + \cos^2(\theta) = 1$   
 $\frac{1}{\cos^2(\theta)} = \tan^2(\theta) + 1$

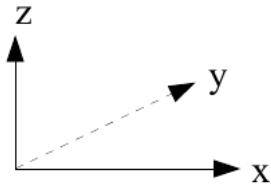
## Vectors

Dot-Product  $\vec{a} \cdot \vec{b} = a_x b_x + a_y b_y + a_z b_z = ab \cos(\theta)$

Cross-Product  $\vec{a} \times \vec{b} = \begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix} \times \begin{bmatrix} b_x \\ b_y \\ b_z \end{bmatrix} = \begin{bmatrix} a_y b_z - b_y a_z \\ a_z b_x - b_z a_x \\ a_x b_y - b_x a_y \end{bmatrix}$

$|\vec{a} \times \vec{b}| = ab \sin(\theta)$   
 (Applies to Right-Hand Coordinate Systems only)

Right hand coordinate system



Addition/Subtraction Head-to-Tail method or by components

## Logarithms

$\ln(x^s) = s \cdot \ln(x)$

$\ln(e^x) = x$

$\ln(xy) = \ln(x) + \ln(y)$

$\ln(x/y) = \ln(x) - \ln(y)$

## Linear Algebra

System of Equations

$a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + \dots = c_1$   
 $a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + \dots = c_2$   
 $a_{31}x_1 + a_{32}x_2 + a_{33}x_3 + \dots = c_3$   
 ...

$\rightarrow Ax = C \rightarrow x = A^{-1}C$

$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & \dots \\ a_{21} & a_{22} & a_{23} & \dots \\ a_{31} & a_{32} & a_{33} & \dots \\ \dots & \dots & \dots & \dots \end{bmatrix}$   $x = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \dots \end{bmatrix}$   $C = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ \dots \end{bmatrix}$

## Uncertainty

Absolute	$x = x_{avg} \pm \Delta x$	Uncertainty is obtained by: <ul style="list-style-type: none"> <li>- Estimation (at least, 1/2 the lowest increment)*</li> <li>- Statistics (mean deviation, standard deviation) **</li> </ul> * Usually much more (uncertainty of method, object, tool and observer add up) ** typically more than 10 measurements are needed
Relative	$x = x_{avg} \pm \frac{\Delta x}{x}$	
Addition/Subtraction	$(x_{avg} \pm \Delta x) + (y_{avg} \pm \Delta y) = (x_{avg} + y_{avg}) \pm (\Delta x + \Delta y)$	
Multiplication/Division	$(x_{avg} \pm \Delta x) * (y_{avg} \pm \Delta y) = x_{avg} * y_{avg} (1 \pm [\frac{\Delta x}{x_{avg}} + \frac{\Delta y}{y_{avg}}])$	
Min-Max Method	$x_{best} \pm \frac{x_{max} - x_{min}}{2}$	

Estimated Digit The last written digit of a number is estimated. Only one written digit should be affected by the uncertainty

Example:  $1.50 \pm 0.04$

## Excel / LibreOffice / OpenOffice

### General

Typing formulas and equations      Click on a cell and type =.....      Fixing a cell reference      Add a \$ in front of the row or column. Ex. \$C\$4

### Statistics

Average      AVERAGE(Range)      Highest, Lowest Value      MIN(Range) , MAX(Range)  
 Mean Deviation (Uncertainty)      AVEDEV(Range)      Standard Deviation      STDEV(Range)

### Slopes and Intercept

Slope      INDEX(LINEST(Y\_Values,X\_Values, TRUE,TRUE),1,1)      Intercept      INDEX(LINEST(Y\_Values,X\_Values, TRUE,TRUE),1,2)  
 Uncertainty of Slope      INDEX(LINEST(Y\_Values,X\_Values, TRUE,TRUE),2,1)      Uncertainty of Intercept      INDEX(LINEST(Y\_Values,X\_Values, TRUE,TRUE),2,2)

## Calculator Hints

### Equation

Model	Sharp	Casio
Quadratic Equation	EL-520X Mode → 2 → 2	EL-W516X Mode → 6 → 2
System of equations	Mode → 2 → 0 / 1	fx-991 ES Mode → 5 → 2

## Wolfram Alpha - <http://www.wolframalpha.com/>

### Equation

	Example
Quadratic Equation	$3x^2 - 2x - 2 = 0$ → Enter
System of equations	$3x+2y+7z=4, 3x+y=0, y+z=0$ → Enter

# Mechanics

## 1D Kinematics

Position  $\mathbf{s}=\mathbf{x}, \mathbf{s}=\mathbf{y}$  or  $\mathbf{s}=\mathbf{z}$  (sign gives direction)

Displacement  $\Delta s = s_f - s_i$

Average velocity  $\mathbf{v}_{av} = \frac{s_f - s_i}{\Delta t}$

Instantaneous velocity  $\mathbf{v} = \frac{ds}{dt}$  (slope of position)

Average acceleration  $\mathbf{a}_{av} = \frac{v_f - v_i}{\Delta t}$

Instantaneous acceleration  $\mathbf{a} = \frac{dv}{dt}$  (slope of velocity)

Five equations for **CONSTANT** acceleration  
 $\Delta v = at$   
 $\Delta s = 1/2(v_i + v_f)t$   
 $\Delta s = v_i t + 1/2 a t^2$   
 $\Delta s = v_f t - 1/2 a t^2$   
 $v_f^2 = v_i^2 + 2a \Delta s$

**Graphs**  
 $\mathbf{a}-t \rightarrow$  area  $\mathbf{v}-t \rightarrow$  area  
 slope  $\leftarrow$  slope  $\leftarrow$   $\mathbf{s}-t$

## Circular motion

Angular position (Consider CCW of +x as positive)  $\theta = \frac{s}{r}$  [rad]

Angular displacement\*  $\Delta \theta = \theta_f - \theta_i$  [rad]

Average angular velocity  $\omega_{av} = \frac{\theta_f - \theta_i}{\Delta t}$  [rad/s]

Instantaneous velocity  $\omega = \frac{d\theta}{dt}$  (slope of angular position)

Average angular acceleration  $\alpha_{av} = \frac{\omega_f - \omega_i}{\Delta t}$  [rad/s<sup>2</sup>]

Instantaneous acceleration  $\alpha = \frac{d\omega}{dt}$  (slope of velocity)

Five equations for **CONSTANT angular** acceleration  
 $\Delta \omega = \alpha t$   
 $\Delta \theta = 1/2(\omega_i + \omega_f)t$   
 $\Delta \theta = \omega_i t + 1/2 \alpha t^2$   
 $\Delta \theta = \omega_f t - 1/2 \alpha t^2$   
 $\omega_f^2 = \omega_i^2 + 2\alpha \Delta \theta$

**Graphs**  
 $\alpha-t \rightarrow$  area  $\omega-t \rightarrow$  area  
 slope  $\leftarrow$  slope  $\leftarrow$   $\theta-t$

\*While angular velocity and angular acceleration are vectors, angular displacement  $\Delta \theta$  is not. (Vector addition does not work)

## 2D/3D Kinematics

Position  $\vec{r} = (x, y, z)$

Displacement  $\Delta \vec{r} = \vec{r}_f - \vec{r}_i = (\Delta x, \Delta y, \Delta z)$

Average velocity  $\vec{v}_{av} = \frac{\vec{r}_f - \vec{r}_i}{\Delta t} = (\frac{\Delta x}{\Delta t}, \frac{\Delta y}{\Delta t}, \frac{\Delta z}{\Delta t})$

Instantaneous velocity  $\vec{v} = \frac{d\vec{r}}{dt} = (\frac{dx}{dt}, \frac{dy}{dt}, \frac{dz}{dt})$

Average acceleration  $\vec{a}_{av} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t} = (\frac{\Delta v_x}{\Delta t}, \frac{\Delta v_y}{\Delta t}, \frac{\Delta v_z}{\Delta t})$

Instantaneous acceleration  $\vec{a} = \frac{d\vec{v}}{dt} = (\frac{dv_x}{dt}, \frac{dv_y}{dt}, \frac{dv_z}{dt})$

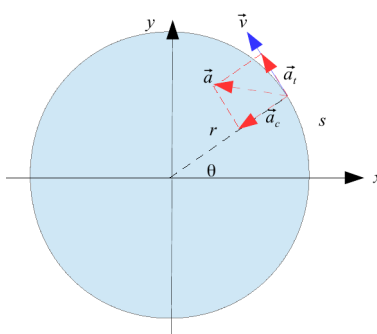
Five equations for **CONSTANT** acceleration  
 $\vec{v}_f = \vec{v}_i + \vec{a} t$   
 $\vec{r}_f = \vec{r}_i + 1/2(\vec{v}_i + \vec{v}_f)t$   
 $\vec{r}_f = \vec{r}_i + \vec{v}_i t + 1/2 \vec{a} t^2$   
 $\vec{r}_f = \vec{r}_i + \vec{v}_f t - 1/2 \vec{a} t^2$   
 $v_{fxyz}^2 = v_{ixyz}^2 + 2a_{xyz} \Delta r_{xyz}$

## Projectile Motion

Path  $\vec{r}(t) = \vec{r}_i + \vec{v}_i t + \frac{1}{2} \vec{a} t^2$

Trajectory for  $\vec{r}_i = 0$   
 $y = \tan(\Theta_i) x - \frac{g x^2}{2(v_i \cos(\Theta_i))^2}$

Range for  $\vec{r}_i = 0$   
 $\Delta x = \frac{v_i^2 \sin(2\Theta_i)}{g}$



### Conversion to linear entities

Distance travelled  $s = \Delta \theta r$

Speed  $v = \omega r$

Tangential acc.  $a_t = \alpha r$

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

Linear acceleration:  $\vec{a} = \vec{a}_t + \vec{a}_c$

### Uniform Circular Motion ( $\alpha=0$ )

Circumference:  $2\pi r$  Frequency:  $f$  [Hz]  $f = 1/T$   
 (how many cycles per second)

Period:  $T$  (time to go around once)

Speed  $v = \frac{2\pi r}{T} = \omega r$  Centripetal acc.  $a_c = \frac{v^2}{r} = \omega^2 r$

Velocity  $\vec{v} = -v \sin(\theta(t)) \hat{i} + v \cos(\theta(t)) \hat{j}$   $\theta(t) = \theta_i + \omega t$

Acceleration  $\vec{a} = \vec{v}' = -a_c \cos(\theta(t)) \hat{i} - a_c \sin(\theta(t)) \hat{j}$

### Classical (Galilean) Relativity

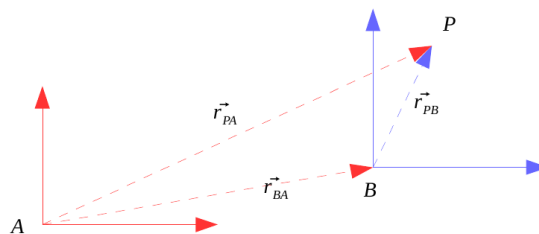
For two inertial\* reference frames A and B

Position of a point P:  $\vec{r}_{PA} = \vec{r}_{PB} + \vec{r}_{BA}$

Velocity of a point P:  $\vec{v}_{PA} = \vec{v}_{PB} + \vec{v}_{BA}$

Acceleration of a point P:  $\vec{a}_{PA} = \vec{a}_{BA}$

\* Inertial Reference frame : A reference frame in which all laws of physics hold (typically a reference frame that itself is not accelerated)



### Statics +Dynamics

	Linear	Rotational
Newton's 1st Law	$\vec{F}_{net} = 0 \Leftrightarrow \vec{a} = 0$	$\vec{\tau}_{net} = 0 \Leftrightarrow \vec{\alpha} = 0$
Newton's 2nd Law	$\vec{F}_{net} = m\vec{a}$	$\vec{\tau}_{net} = I\vec{\alpha}$
Newton's 3rd Law	$\vec{F}_{AB} = -\vec{F}_{BA}$	$\vec{\tau}_{AB} = -\vec{\tau}_{BA}$

Universal Law of Gravity  $F_G = G \frac{m_1 m_2}{r^2}$

Hooke's Law  $\vec{F} = -k\vec{x}$

Torque	$\tau = r F \sin(\alpha)$	$\vec{\tau} = \vec{r} \times \vec{F}$
Rotational Inertia in General	$I = \int x^2 dm$	
Parallel axis theorem	$I = I_{com} + m h^2$	
Mass - distance L from axis.	$I = m L^2$	
Beam, hinged at one side	$I = \frac{1}{3} m L^2$	
Thin rod – perpendicular central axis	$I = \frac{1}{12} m L^2$	
Solid sphere– central axis	$I = \frac{2}{5} m r^2$	
Spherical shell – central axis	$I = \frac{2}{3} m r^2$	
Solid cylinder – central axis	$I = \frac{1}{2} m r^2$	

### Work+Energy

Conservation of Energy	$E_{final} = E_{initial} + W_{by NCext}$
Work done by a force	$W = \vec{F} \cdot \vec{s} = F s \cos(\theta)$

NCext: Non Conservative External force

Potential gravitational Energy:	PE=mgh
Potential spring Energy	PE=1/2kx <sup>2</sup>
Linear Kinetic Energy	KE= 1/2mv <sup>2</sup>
Rotational Kinetic Energy	KE= 1/2Iω <sup>2</sup>
Mechanical Energy	ME=PE+KE

Power [Watt]  $P = \frac{\Delta W}{\Delta t} = \vec{F} \cdot \vec{v}$

### Momentum

	Linear	Rotational
Momentum	$\vec{p} = m\vec{v}$	$\vec{L} = \vec{r} \times \vec{p} = m(\vec{r} \times \vec{v}) = I\vec{\omega}$
Newton's 2 <sup>nd</sup> Law	$\vec{F}_{net} = \frac{\Delta \vec{p}}{\Delta t}$	$\vec{\tau}_{net} = \frac{\Delta \vec{L}}{\Delta t}$
Conservation of Momentum	$\vec{p}_f = \vec{p}_i + \vec{F}_{ext} \Delta t$	$\vec{L}_f = \vec{L}_i + \vec{\tau}_{ext} \Delta t$

Impulse	$\vec{J} = \Delta \vec{p}$
Inelastic collision :	Only momentum is conserved
Elastic Collision	Momentum and Mechanical energy is conserved

# Waves and Optics

## Simple Harmonic Motion

Frequency  $f$  [Hz]  $F=1/T=\omega/2\pi$

Angular Frequency  $\omega$  [rad/s]  $\omega=2\pi/T=2\pi f$

Period  $T$  [s]  $T=1/f=2\pi/\omega$

### Mass and Spring

$$\omega = \sqrt{\frac{k}{m}}, \quad T = 2\pi\sqrt{\frac{m}{k}}$$

restoring force  $F = m a(t) = -m \omega^2 x(t)$

Kinetic / Potential Energy  $K = \frac{1}{2} m v(t)^2, \quad U = \frac{1}{2} k x(t)^2$

## Simple Pendulum

restoring force  $\tau = -L F_g \sin(\Theta) = I \alpha$

... for small angles

$$\omega = \sqrt{\frac{g}{L}}, \quad T = 2\pi\sqrt{\frac{L}{g}}$$

## Mechanical Waves

Wavelength [m]  $\lambda = \frac{2\pi}{k}$

Angular wave number [1/m]  $k = \frac{2\pi}{\lambda}$

Soft reflection (free end, denser to less dense) No phase shift

### Transverse waves

$$f(x, t) = h(kx \pm \omega t)$$

$$f(x, t) = y_m \sin(kx \pm \omega t + \Phi)$$

+: moving left  
-: moving right

Particle velocity / acceleration:  $u = \frac{\delta y(x, t)}{\delta t}, \quad a = \frac{\delta u(x, t)}{\delta t}$

Wave speed:  $v = \sqrt{\frac{\tau}{\mu}} \quad \tau = \text{Tension}, \mu = \text{linear density}$

...Interference identical waves, shifted by  $\Phi(=\Delta x/\lambda)$ , traveling in the same direction

$$y'(x, t) = [2 y_m \cos(\frac{\Phi}{2})] \sin(kx - \omega t + \frac{\Phi}{2})$$

(for different amplitudes, use the Phasor-Diagram)

Constructive:  $\Phi = 2\pi m$  or  $\Delta x = m\lambda, m=0, 1, 2, \dots$

### ...Standing waves (identical waves traveling in opposite directions)

$$y'(x, t) = [2 y_m \sin(kx)] \cos(\omega t)$$

nodes: no amplitude  
antinodes: max amplitude

String, both ends fix  $\lambda_n = \frac{2L}{n}, n=1, 2, 3, 4, \dots$

Position:  $x(t) = x_m \cos(\omega t + \Phi)$

Velocity:  $v(t) = \frac{dx}{dt} = -v_m \sin(\omega t + \Phi)$

Acceleration:  $a(t) = \frac{dv}{dt} = -a_m \cos(\omega t + \Phi)$

### Torsion Pendulum

$$T = 2\pi\sqrt{\frac{I}{k}}$$

restoring force  $\tau = -\kappa \Theta$

## Physical Pendulum

restoring force  $\tau = -h_c F_g \sin(\Theta) = I \alpha$

... for small angles

$$\omega = \sqrt{\frac{mgh}{I}}, \quad T = 2\pi\sqrt{\frac{I}{mgh}}$$

Wave speed [m/s]  $v = \frac{\Delta x}{\Delta t} = \lambda f = \frac{\omega}{k} = \frac{\lambda}{T}$

Superposition principle  $y(x, t) = y_1(x, t) + y_2(x, t)$

Hard reflection (fixed end, less dens to denser medium)  $\pi$

### Longitudinal waves (Sound)

$$s(x, t) = s_m \cos(kx \pm \omega t + \Phi)$$

$$\Delta p(x, t) = \Delta p_m \sin(kx \pm \omega t + \Phi)$$

Sound Level (Decibel)  $I_0 = 10^{-12} W/m^2$

$$\beta = 10 \text{ dB} \cdot \log_{10}\left(\frac{I}{I_0}\right), \quad +1 \text{ dB} = \times 10$$

Intensity  $I$

$$I = \frac{P}{A}, \quad I = 10^{\frac{\beta}{10}} \cdot I_0$$

Wave speed:  $v = \sqrt{\frac{B}{\rho}}, \quad B: \text{Bulk modulus} \quad B = \frac{-\Delta p}{\Delta V/V}$

$$s'(x, t) = [2 s_m \cos(\frac{\Phi}{2})] \cos(kx \pm \omega t + \frac{\Phi}{2})$$

Deconstructive:  $\Phi = \pi m$  or  $\Delta x = m\lambda/2, m= 1, 3, 5, \dots$

Beats  $f_{\text{beat}} = f_1 - f_2$

Doppler Effect (classic)  $f' = f \frac{v \pm v_d}{v \mp v_s}$

Pipe, both ends open  $\lambda_n = \frac{2L}{n}, n=1, 2, 3, 4, \dots$

Pipe, open-closed  $\lambda_n = \frac{4L}{n}, n=1, 3, 5, \dots$

### Geometrical Optics

Snells Law (Law of refraction)  $n_1 \sin(\Theta_1) = n_2 \sin(\Theta_2)$  ,  $\frac{n_1}{n_2} = \frac{v_2}{v_1} = \frac{\lambda_2}{\lambda_1}$

Thin lens equation:  $\frac{1}{f} = \frac{1}{p} + \frac{1}{q} = (n-1) \left( \frac{1}{r_1} - \frac{1}{r_2} \right)$  ,  $m = \frac{h_i}{h_o} = \frac{-q}{p}$

Diopters  $D = 1/f$

p: Object distance  
 q: Image distance  
 (<0: Virtual, >0: Real)  
 f: focal distance (f<0: Diverging, f>0: Converging)

Law of reflection  $\Theta_i = \Theta_r$

Ray diagrams for Lenses:

Ray diagrams for curved mirrors:

1. Any ray reflects according to the law of reflection at the tangent to the curve
2. A ray parallel to the axis goes through the focal point.
3. A ray through the focal point becomes parallel to the axis.

$f = \text{radius}/2$

1. A ray through the center goes straight through.
2. A ray parallel to the axis goes through the focal point.
3. A ray through the focal point becomes parallel to the axis.

### Wave Optics

Phase difference due to path traveled in different medium (number of wavelengths)  $N_2 - N_1 = \frac{L}{\lambda_0} (n_2 - n_1)$

Thin film interference Add phase shift due to reflection and path difference to determine constructive and destructive interference.

Double Slit Interference

*Maxima:*  $d \cdot \sin(\Theta) = m \lambda$  ,  $m = 0, 1, 2, \dots$

Double Slit Diffraction

Complicated

*Minima*  $d \cdot \sin(\Theta) = (m + 0.5) \lambda$  ,  $m = 0, 1, 2, \dots$

*Maxima*

$a \cdot \sin(\Theta) = m \lambda$  ,  $m = 1, 2, 3, \dots$

Diffraction by a circular aperture  $\sin(\Theta) = 1.22 \frac{\lambda}{d}$

Diffraction Grating

Grating spacing:  $d = \text{width}/(\# \text{ of gratings } N)$

Rayleigh's Criterion for resolvability  $\Theta_R = \arcsin(1.22 \frac{\lambda}{d})$

*Maxima Lines*

$d \cdot \sin(\Theta) = m \lambda$  ,  $m = 0, 1, 2, \dots$

... *First minimum*

$N d \sin(\Delta \Theta) = \lambda$

... *Half line width*

$\Theta_{hw} = \frac{\lambda}{N d \cos(\Theta)}$

*Resolving power*

$R = \lambda_{avg} / \Delta \lambda = Nm$

# Modern Physics

## Nuclear Physics

${}^A_Z X$  A: Mass number (Protons+Neutrons)

Z: Atomic number (charge of the nucleus)

X: Chemical Symbol

Radius of the nucleus

$$r = r_0 A^{1/3} \quad r_0: 1.2 \text{ fm } (1.2 \times 10^{-15} \text{ m})$$

Nuclear Equation

Mass number and Charge is conserved (Mass is not)

**Binding Energy:**  $E_{BE} = \Delta m \cdot c^2 = [(Z \cdot (m_p + m_e) + N \cdot m_n) - m_{tot}] \cdot c^2$

Z:

Number of protons

N:

Number of neutrons

$m_{tot}$ :

Total mass of the isotope

$m_p + m_e = m_{H-1}$ :

Mass of a proton + an electron (1.007 825 u)

$m_n$ :

Mass of a neutron (1.008 665 u)

$c^2$ :

931.494013 MeV/u

## Radiation / Decay

	Event in Nucleus	Radiated particles
$\alpha$ -Decay	${}^4_2\text{He}$	${}^4_2\text{He}$
$\beta$ -Decay	${}^1_0n \rightarrow {}^1_1p + {}^0_{-1}e + \bar{\nu}_e$	${}^0_{-1}e + \bar{\nu}_e$
Positron-Decay	${}^1_1p \rightarrow {}^1_0n + {}^0_{+1}e + \nu_e$	${}^0_{+1}e + \nu_e$
$\gamma$ -Decay	Becomes stable	${}^0_0\gamma$
Number of radioactive nuclei:	$N(t) = N_0 e^{-\lambda t}$	Decay rate [Bq]: $R(t) = \lambda N(t) = R_0 e^{-\lambda t}$

## Units of radiation

Activity	Decay events per second	→ Becquerel [Bq] = disintegrations/ s	1 Curie = $3.7 \times 10^{10}$ Becquerel
Absorbed Dose	Absorbed energy	→ Gray [Gy] = Joules / kg	1 Gray = 100 rad
Biological Damage	Effect on humans	→ Sievert [Sv] = Gray x Factor	1 Sievert = 100 rem

## Quantum Physics

Energy of a photon

$$E = hf$$

Photoelectric Effect:

$$K_{max} = e V_{stop} \quad , \quad hf = K_{max} + \Phi \quad ,$$

Momentum of a photon

$$p = \frac{hf}{c} = \frac{h}{\lambda}$$

$$V_{stop} = \left(\frac{h}{e}\right)f - \frac{\Phi}{e}$$

De Broglie Wavelength

$$\lambda = \frac{h}{p}$$

Heisenbergs Uncertainty principle:

$$\Delta x \cdot \Delta p_x \geq \hbar$$

$$\Delta y \cdot \Delta p_y \geq \hbar$$

$$\Delta z \cdot \Delta p_z \geq \hbar$$

$$\hbar = h / (2\pi)$$



## Special Relativity

First postulate:

The laws of physics are the same for observers in all inertial reference frames. No one frame is preferred over any other.

Second postulate:

The speed of light in vacuum has the same value  $c$  in all directions and in all inertial reference frames.

**Proper time  $t_0$**  Time interval between two events occurring at the same location in an inertial reference frame.

**Proper length  $L_0$ :** The distance between two points measured in an inertial reference frame at rest relative to both points.

**Rest Mass** The mass of an object as measured in a reference frame not moving relative to the object (the only mass that is directly measurable)

Lorentz Transformation

A system  $x'y'z't'$  moving at a speed in x-direction relative to the system  $xyz$ .

$$x' = \gamma(x - vt)$$

$$y' = y$$

$$z' = z$$

$$t' = \gamma\left(t - \frac{v}{c^2}x\right)$$

Velocities

$$u' = \frac{u - v}{1 - \frac{uv}{c^2}}$$

Doppler Effect

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

$$f = f_0 \gamma \left(1 - \frac{v}{c}\right)$$

**Simultaneity is relative,** it depends on the motion of the observer

Two observers in relative motion will in general not agree whether two events are simultaneous or not.

Lorentz Factor:

$$\gamma = \frac{1}{\sqrt{1 - (v/c)^2}}$$

Time dilation:

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

Length contraction:

$$L = \frac{L_0}{\gamma}$$

Momentum:

$$p = m v \cdot \gamma$$

Kinetic Energy

$$KE = \gamma m c^2 - m c^2$$

Rest Energy

$$E_0 = m c^2$$

Minkowski Diagram

Graphical visualization of time dilation and length contraction

General Relativity

Generalization of the special relativity (allowing accelerations). Description of Gravity as a property of space-time

# Electricity

## Charge, Coulombs Force, Electric Field and Potential

Charge is quantized	$Q=N \cdot e$ [C]
Coulombs Law	$\vec{F} = k \frac{q_1 q_2}{(r)^2} \cdot \frac{\vec{r}}{(r)}$ [N] $\vec{F}_E = -\frac{\partial U}{\partial \vec{s}}$
Potential Energy of a conservative force	$\Delta U = U_{final} - U_{initial} = -W_{done\ by\ force}$ [J]
Electric Potential Energy	$\Delta U_{el} = q \Delta V = -W_{el} = -\int \vec{F}_{el} \cdot \vec{s} = -\int q \vec{E} \cdot d\vec{s}$ [J]
Electron Volt	$1eV = 1.6022 \cdot 10^{-19} J$

Current	$i = dQ/dt$ [A]
Electric Field	$\vec{E} = \frac{\vec{F}_e}{q_t} = k \frac{q_s}{r^2} \cdot \hat{r}$ [N/C] = [V/m] $\vec{E}_{tot} = \vec{E}_1 + \vec{E}_2 + \dots + \vec{E}_n$ $\vec{E} = -\frac{\partial V}{\partial \vec{s}}$
(Electric) Potential Difference	$\Delta V = \frac{\Delta U_{el}}{q} = -\int \vec{E} \cdot d\vec{s}$ [V]
Electric Potential due to a point charge	$V = k \frac{q}{r}$

## Capacitors

Capacitance	$C = \frac{Q}{V}$ [F] = Farad (Coulombs/Volt)
-------------	---



Parallel plate capacitor	Field: $E = \frac{\sigma}{\epsilon_0} = \frac{Q}{\epsilon_0 A}$ Potential: $ V  = E \cdot d$ Capacitance: $C = \frac{\epsilon_0 A}{d}$
--------------------------	--

Energy stored in a capacitor	$U = \frac{Q^2}{2C} = \frac{1}{2} Q V = \frac{1}{2} C V^2$
------------------------------	--

Capacitance in Series:	$\frac{1}{C_{eq}} = \sum \frac{1}{C_i}$ $Q = Q_1 = \dots = Q_n$ , $V = V_1 + \dots + V_n$
------------------------	--

Capacitance in Parallel:	$C_{eq} = \sum C_i$ $Q = Q_1 + \dots + Q_n$ , $V = V_1 = \dots = V_n$
--------------------------	--

Energy density in the field of a capacitor:	$u = \frac{1}{2} \epsilon_0 E^2 [J/m^3]$
---	--

## Current and Resistance

Current	$i = \frac{dq}{dt}$ [A]
Technical direction:	+ to -
Real direction of electrons in metals:	- to +

Resistance	$R = \frac{V}{I}$ Ohm [ $\Omega$ ] = [V/A]
------------	--



Power dissipated in a resistor	$P = IV = I^2 \cdot R = P = \frac{V^2}{R}$ Watt [W] = [J/s]
--------------------------------	---

Current density:	$J = \frac{i}{A} = n \cdot e \cdot v_d$ A: Cross section area n: Charges per Volume / free electron density e: Charge of an electron $v_d$ : Drift Speed: Speed of the charges in a wire
------------------	--

Resistivity	$\rho = \frac{E}{J}$ [ $\Omega m$ ] $R = \frac{\rho \cdot length}{area}$
-------------	---

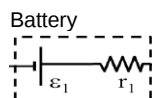
Conductivity	$\sigma = \frac{1}{\rho}$
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## Electromotive Force (EMF)

Ideal EMF	Can deliver as much current as required to maintain a fixed potential difference.
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Power delivered of an ideal EMF	$P = EMF \cdot I$
---------------------------------	-------------------



Has an internal resistance.  
As soon as current flows, the terminal Voltage is different from the EMF.  
Some Energy is lost (transformed to heat) in the internal resistance.

## Kirchoff's Rules

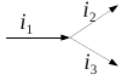
### Junction Rule

$$i_1 + i_2 + i_3 + \dots = 0$$

The sum of all currents at a junction is zero.

**Sign rules:**

Current entering the junction: +  
Current leaving the junction: -



### Loop Rule

$$\Delta V_1 + \Delta V_2 + \dots + \Delta V_n = 0$$

The sum of all voltages around a closed loop is zero.

**Sign rules:**

Going through a resistor in the same direction as the current : -  $\Delta V$   
Going through a resistor against the current : +  $\Delta V$   
Going through an EMF from - to + : +  $\Delta V$   
Going through an EMF from + to - : -  $\Delta V$

## RC-Circuits

### Charging

$$q(t) = Q_f (1 - e^{-t/\tau})$$

$$V(t) = \frac{q}{C} = V_f (1 - e^{-t/\tau})$$

$$i(t) = \frac{dq}{dt} = I_0 e^{-t/\tau}$$

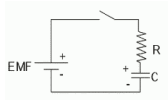
**with**

Final Charge:  $Q_f = C V_f$

Initial Current:  $I_0 = \frac{V_f}{R}$

Time constant:  $\tau = RC$

Final voltage: Depends on the circuit.



### Discharging

$$q(t) = Q_i e^{-t/\tau}$$

$$V(t) = \frac{q}{C} = V_i e^{-t/\tau}$$

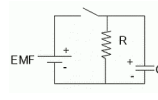
$$i(t) = \frac{dq}{dt} = -\left(\frac{Q_i}{\tau}\right) e^{-t/\tau} = I_i e^{-t/\tau}$$

**with**

Initial Charge:  $Q_i = C V_i$

Initial Current:  $I_i = \frac{V_i}{R}$

Time constant:  $\tau = RC$



# Magnetism

## Magnetic Fields and effect on moving charges

Tesla [T]	SI-Unit of the magnetic field $T = \frac{N \cdot s}{C \cdot m}$	Gauss [G]	Old unit of the magnetic field (not SI). 1 Gauss = Field strength of the magnetic field of the earth at the surface $1T = 10^4 G$
Lorentz Force	$\vec{F}_B = q \cdot \vec{v} \times \vec{B}$ $F_B =  q  \cdot v \cdot B \cdot \sin(\Phi)$	Charged particles circulating in a magnetic field	$ q  \cdot v \cdot B = m \frac{v^2}{R}$
Force on a current carrying wire	$\vec{F}_B = i(\vec{L} \times \vec{B})$ $F_B = i L B \sin(\Phi)$	Cyclotron	$ q  B = 2\pi m f_{osc}$
Magnetic Dipole Moment	Unit: [A m <sup>2</sup> ] or [J/T]  Magnetic Dipole Moment of a coil: $\mu = N i A$ N: Number of turns (Loops) i: Current A: Area of the loop	Velocity selector $\vec{E} \perp \vec{B}$	$ q  E =  q  v B \sin(90^\circ) \rightarrow v = E/B$
Torque on a Magnetic Dipole	$\vec{\tau} = \vec{\mu} \times \vec{B}$		
Potential Energy of a Magnetic Dipole	$U(\Theta) = -\vec{\mu} \cdot \vec{B}$ $U(\Theta) = -\mu \cdot B \cos(\Theta)$		

## Magnetic Fields due to currents

<b>Law of Biot-Savart</b>	<b>Vector Form:</b> $d\vec{B} = \frac{\mu_0}{4\pi} \cdot \frac{i d\vec{s} \times \hat{r}}{r^2}$ . $\hat{r} = \frac{\vec{r}}{ \vec{r} }$	<b>Magnitude Form:</b> $dB = \frac{\mu_0}{4\pi} \cdot \frac{i \cdot ds \cdot \sin(\theta)}{r^2}$
Magnetic field due to long straight wire at distance r	$B = \frac{\mu_0 i}{2\pi r}$	Magnetic field due to straight wire of finite length $B = \frac{\mu_0 i}{4\pi r} \cdot \sin(\alpha)$  Angle: Section of the wire seen from the point. Wire: Must start perpendicular to the point
Magnetic field due to circular arc of wire	$B = \frac{\mu_0 i \Phi}{4\pi r}$  Angle in <b>rad!</b>	Force between two parallel currents $F_{BA} = F_{AB} = i_B L B_A \sin(90^\circ) = \frac{\mu_0 L i_A i_B}{2\pi r}$
Magnetic Field of a solenoid	If $L \gg D$ $B = \frac{\mu_0 N i}{L} = \mu_0 n i$  otherwise $B = \frac{\mu_0 N i}{\sqrt{L^2 + D^2}}$  N= turns L= length n= turns per meter D= Diameter	

## Currents due to magnetic fields

Magnetic Flux	$\Phi = B \cdot A \cdot \cos(\Theta)$ Unit: [Tm <sup>2</sup> ] = [Wb]	Faraday's Law	$ EMF_{induced}  = N \frac{d\Phi}{dt}$ N= turns
Transformer	$V_s = \frac{N_s}{N_p} V_p$ , $I_s = \frac{N_p}{N_s} I_p$	Lenz's Law	The induced EMF creates a current I and a magnetic field B that oppose the change in magnetic flux

**Inductors**

Inductance L

$$[VsA^{-1}] = [H] \text{ (Henry)}$$

Self-Inductance of an inductor

$$EMF = -L \frac{dI}{dt}$$

Energy stored in an inductor.

$$E = \frac{1}{2} LI^2$$

RL-Circuit "turning on"

$$I(t) = I_0(1 - e^{-\frac{t}{\tau}}), \quad \tau = \frac{L}{R}$$

RL-Circuit "turning off"

$$I(t) = I_0 e^{-\frac{t}{\tau}}, \quad \tau = \frac{L}{R}$$

**AC Current**

Alternating current

$$V(t) = V_0 \sin(\omega t)$$

$$I(t) = I_0 \sin(\omega t - \phi)$$

 $\omega$  : Angular Frequency [rad/s]  $\omega = 2\pi f$  $\phi$  ; Phase shift (Delay of current behind voltage)

Root mean square values

$$V_{rms} = \frac{V_0}{\sqrt{2}}$$

$$I_{rms} = \frac{I_0}{\sqrt{2}}$$

**Average Power**

$$P_{avg} = V_{rms} I_{rms} \cos(\phi)$$

Instantaneous Power

$$P(t) = V(t)I(t)$$

**Impedance**

$$Z = \frac{V_0}{I_0} = \frac{V_{rms}}{I_{rms}} \quad \text{Ohm } [\Omega] = [V/A]$$

RCL Circuit - Series

$$Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2} \quad \tan(\phi) = \frac{(\omega L - \frac{1}{\omega C})}{R}$$

$$\text{Resonance frequency: } \omega = \frac{1}{\sqrt{LC}}$$

Inductor (Reactance  $X_L$ )

$$Z = \omega L, \quad \phi = \frac{\pi}{2} \quad (\text{V leads, I behind})$$

RCL Circuit – Parallel

$$\frac{1}{Z} = \sqrt{\frac{1}{R^2} + \left(\omega C - \frac{1}{\omega L}\right)^2} \quad \tan(\phi) = R\left(\frac{1}{\omega L} - \omega C\right)$$

Capacitor (Reactance  $X_C$ )

$$Z = \frac{1}{\omega C}, \quad \phi = -\frac{\pi}{2} \quad (\text{I leads, V behind})$$

Resistor (Impedance)

$$Z = R, \quad \phi = 0$$

# Physical Science

## Significant Figures + Measurement

**Measurements**      The last digit of a measurement is always estimated (meaning, it is not certain)      *Example :*      1.05 cm → meaning, it could have been 1.04 or 1.06 cm

<b>Significant Figures</b>	A number is significant when it is:	<i>Examples :</i>
	<ul style="list-style-type: none"> <li>- not a zero</li> <li>- a zero between non-zero digits</li> <li>- a zero after a non zero on the right of the decimal point or on the left of the decimal point</li> <li>- in the coefficient of a scientific number</li> </ul> <p>A zero is not significant when it is:</p> <ul style="list-style-type: none"> <li>- on the left of all non-zero digits</li> <li>- on the right of all non-zeros in a number without decimal point</li> </ul>	

123 → 3 significant figures  
 1001 → 4 significant figures  
 1.00 → 3 significant figures  
 100. → 3 significant figures  
  
 1.00 x 10<sup>3</sup> → 3 significant figures

*Examples:*  
 0.03 → 1 significant figure  
 100 → 1 significant figure

Exact numbers      Counted or definitions      Rounding Rules      >= 0.5 → round up, < 0.5 → round down

### Calculation rules for significant figures

Addition / Subtraction      Give the result with the fewest decimals      *Examples:*      1.00 + 2.3 = 3.3  
 5.5 - 0.50 = 5.0

Multiplication / Division      Give the result with the fewest significant figures.      *Examples:*      2.00 x 2.0 = 4.0  
 4 / 2.00 = 2

## Density + Matter

Density	Density = mass / Volume
Matter	Has space and occupies volume
Element	A collection of atoms of one type.
Compound	A combination of atoms of different types
Mixture	A mix of different element or compounds
Chemical Property	Ability to interact with other substances
Chemical Change	New substances with new properties are formed
Physical Property	Shape, State, ...
Physical Change	Change in shape and state, no new substances are formed

States	
Solid	Definite shape and volume
Liquid	Takes shape of the container, definite volume
Gas	Takes shape and volume of the container

*Heterogeneous*      Differences in the mixture are visible

*Homogenous*      No difference in the mixture is visible. It appears identical throughout.

*Signs:*      Color change, bubbles, heat produced or adsorbed

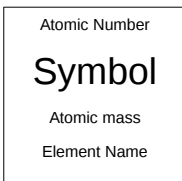
## Atoms

Dalton	Atoms are the smallest unit of matter. All atoms of one element are identical.	<i>Billiard Ball</i>
Thomson	Atoms are made of subatomic elements that are uniformly distributed	<i>Plum pudding</i>
Rutherford	Atoms are made of a small, dense, positive nucleus (protons and neutrons), and negative electrons orbiting the nucleus	<i>Planetary model</i>
Rutherford-Bohr	Like Rutherford, but the electrons are only found in distinct orbits.	<i>Planetary model with only few existing electron orbits corresponding to energy levels.</i>

Isotopes      Atoms of the same element but with a different mass number (= different number of neutrons)      Mass number      Number of Protons + Neutrons

**Periodic Table** (see Annex 1)

<b>Periodic Table</b>	Atoms are <ul style="list-style-type: none"> <li>ordered by ascending proton number (= atomic number)</li> <li>in groups (top down) of similar properties</li> <li>periods (horizontal)</li> </ul>
Alkali Metals (G1 excluding H)	Highly reactive, Soft with low melting point.
Alkaline Earth Metals (G2)	
Transition Elements (G3-12)	
Halogens (G7)	Highly reactive gases.
Noble gases (G8)	Do not react with any other elements.



**Atomic Number** : Number of protons  
**Symbol**: One or two letters. First letter is a capital letter  
**Atomic mass** : Average mass of all isotopes of the element (weighted by natural occurrence)  
 The unit of the number is amu/atom AND g/mol

Metals	<i>Left side of the Periodic Table</i>
Non-Metals	<i>Right side of the Periodic Table</i>
Metalloids	<i>Zig-Zag line between Metals and Non-Metals. Semiconductors</i>
<b>Diatomic Molecules</b>	Elements that in their elemental form come in pairs of two: H <sub>2</sub> , N <sub>2</sub> , O <sub>2</sub> , F <sub>2</sub> , Cl <sub>2</sub> , Br <sub>2</sub> , I <sub>2</sub> (Have N O Fear of Ice Cold Bear)

**Chemical Bonding**

Valence electrons      Electrons in the highest energy level of an atom (=Group Number for elements other than transition elements)      Lewis – Diagram      Shows the valence electrons of an element

<b>Octet Rule</b>	All elements want to achieve the valence electron configuration of the closest noble gas.	Metals	Achieve noble gas configuration by giving up valence electrons
		Non-Metals	Achieve noble gas configuration by increasing the number of valence electrons
		Metalloids	Can achieve noble gas configuration by increasing or decreasing the number of valence electrons

<b>Ionic Bond</b>	Transfer of electrons	→	Metal + Nonmetal, Polyatomic Ion + Nonmetal, Metal + Polyatomic Ion, Polyatomic Ion + Polyatomic Ion
<b>Covalent Bond</b>	Sharing of electrons	→	Non-metal + Non-metals
<b>Metallic Bond</b>	Transferring of electrons in an electron cloud	→	Metals (making them conducting)

**Nomenclature**

<b>Ionic Compounds</b>	Metal can only have one charge	→	Metal Name + Non-Metal Name + ide
	Metal can have different charges	→	Metal Name (Roman Numeral for charge) + Non-Metal name + ide
	Anion is a polyatomic Ion	→	As above, but without the -ide
<b>Polyatomic Ions</b>	Less oxygen	→	Name of first element + ite
	More oxygen	→	Name of first element + ate
	With hydrogen	→	Bi + Name
<b>Covalent Compounds</b>	Greek prefixes for numbers	→	Greek Prefix + Non-Metal + Greek Prefix + Non-Metal + .... + ide
<b>Acids</b>	See acid section		

**Moles and Chemical Reactions**

<b>Mol</b>	1 mol = $6.022 \times 10^{23}$ particles	Definition:	1 mol is the number of particles in 12.01 g of carbon.
<b>Molar mass</b>	Mass (in g) of one mol of a particles of a substance	For elements:	Mass given in periodic table (attention to diatomic substances!)
		For compounds:	Example $\text{CO}_2$ : Molarmass = $1 \times 12.01 \text{ g} + 2 \times 16.00 \text{ g}$
<b>Chemical Reactions</b>	Reactants $\rightarrow$ Products	- No atoms are gained or lost - No mass is gainer or lost	
Combustion reaction	Fuel + Oxygen $\rightarrow$ Water and $\text{CO}_2$		

**Solutions**

<b>Solution</b>	A homogenous mixture of two or more substances	Solute	Substance of a solution that is in the smaller amount
		Solvent	Substance of a solution that is in the larger amount
		Solubility	The maximum amount of solute that a solvent can dissolve
<b>Molarity</b>	$M = \frac{n}{V} = \frac{\text{mol of solute}}{\text{L of solution}}$	Dilution	$M_1 V_1 = M_2 V_2$
<b>Concentration (by mass)</b>	$C (\%m/m) = \frac{\text{g of solute}}{\text{g of solution}}$		

**Acids and Bases**

<b>Acid</b>	Generates $\text{H}^+$ ions in water (producing $\text{H}_3\text{O}^+$ )	Binary Acids ( $\text{H}^+ + \text{NM}^-$ )	Hydro + NM + ic + acid
		Oxy-Acids ( $(\text{H}^+ + \text{Ion}^-)$ )	Ion ends in -ate $\rightarrow$ ..... -ic acid (No hydro!) Ion ends in -ite $\rightarrow$ ..... -ous acid (No hydro!)
Reactions	Acid + Metal $\rightarrow$ $\text{H}_2$ + Salt Acid + Carbonate $\rightarrow$ $\text{CO}_2$ + Water + Salt		
<b>Base</b>	Generates $\text{OH}^-$ ions in water / Accepts $\text{H}^+$		
Reactions	Acid + Base $\rightarrow$ Water + Salt		
<b>pH</b>	$\text{pH} = -\log\left(\frac{\text{mol H}_3\text{O}}{\text{L}}\right), \quad \frac{\text{mol H}_3\text{O}}{\text{L}} = 1 \times 10^{-\text{pH}}$ # of decimal places of pH = # of sig. fig. of the coefficient	pH 0....7	Acidic
		pH 7....14	Basic
<b>pOH</b>	$\text{pOH} = -\log\left(\frac{\text{mol OH}}{\text{L}}\right), \quad \frac{\text{mol OH}}{\text{L}} = 1 \times 10^{-\text{pOH}}$	pH + pOH = 14	

**Radioactivity and Nuclear Physics**

$\rightarrow$  See Modern Physics



### Transformation of Energy

<b>Work</b>	$W = F_{  } \cdot s = F s \cos(\theta)$	Potential gravitational Energy:	$PE = mgh$	
Weight	$F_g = mg$	Linear Kinetic Energy	$KE = \frac{1}{2}mv^2$	
<b>Conservation of Energy</b>	The total amount of energy of a closed system is always constant.		Mechanical Energy	$ME = PE + KE$
<b>Endothermic</b>	Absorbing energy	Thermal Energy	Energy of random motion of atoms and molecules	
<b>Exothermic</b>	Releasing energy	Heat (transfer of Thermal Energy)	$Q = \Delta E_{th} = mc \Delta T$ c: Specific heat capacity	

### Electricity and Magnetism

→ See sections on Electricity and Magnetism

### Genetics

Genetics	The science of genes and heredity	Genotype	Genetic makeup
DNA	Deoxyribonucleic acid, blueprint of organisms	Phenotype	Visible traits (how the genotype is expressed)
Chromosomes	Organized structure of DNA	Mitosis	Normal cell division creating exact copies (full chromosome set)
Gene	Chunks of DNA containing the information for a character trait	Meiosis	Cell division for reproduction, half set of chromosomes
<b>Allele</b>	Variation of a gene.		
Dominant Allele	Hides the effect of another allele of the same gene	Homozygous	Having two identical alleles of a gene
Recessive Allele	Effect hidden when a dominant allele of the same gene is present	Heterozygous	Having two different alleles of a gene
Punnet Square	Diagram to predict the outcome of cross breeding	Law of segregation	Each parent only gives one allele to the offspring

## Constants and other properties

### Constants

Mechanics		Electricity and Magnetism		Modern Physics and Waves	
Universal Gravity constant G	$6.67 \cdot 10^{-11} \text{ Nm}^2/\text{kg}^2$	Unit charge e	$1.602 \cdot 10^{-19} \text{ C}$	Speed of light in vacuum c	299792458 m/s
g	9.8 m/s	k	$9.00 \cdot 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$	Planck Constant h	$6.63 \cdot 10^{-34} \text{ Js}$
		$\mu_0$	$4\pi \cdot 10^{-7} \text{ H/m}$	"h-bar"	$\hbar = h/(2\pi)$
		$\epsilon_0$	$8.85 \cdot 10^{-12} \text{ F/m}$		

### Mass

Proton	1.007276 u	H-1	1.007 825 u	He-4	4.002 603 u	Zr-97	96.9109531 u	U-238	238.0507882
Neutron	1.008 665 u	H-2				Te-109	108.92742 u	U-235	235.043929 u
Electron	0.0005485799 u	H-3	3.016 05 u			Xe-113	112.93334 u	Th-234	234.0436012
C-12	12.0 u					Cs-133	132.905429 u	Ce-140	139.905434 u
						Xe-133	132.9059107 u	Te-137	136.92532 u
								Nd-144	143.910083 u

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

### Half-life

U-238	$4.5 \times 10^9 \text{ y}$	C-14	5730 y	H-3	12.3 y	Ir-192	74 d	Tc-99m	6 h
K-40	$1.3 \times 10^9 \text{ y}$	Ra-226	1600 y			Fe-59	44 d		
Ra-226	$1.6 \times 10^3 \text{ y}$					Cr-51	28 d		
						I-131	8 d		

### Units

1 light year = $9.46 \times 10^{15} \text{ m}$	1 u = $1.6605 \cdot 10^{-27} \text{ kg}$	1 eV = $1.602 \times 10^{-19} \text{ J}$	1 mol = $6.022 \times 10^{23}$ particles
Kelvin	Celsius + 273	$1 \text{ u} \cdot c^2 = 931.494 \text{ MeV}$	1 cal = 4.184 J
Celsius	5/9 (Fahrenheit-32)	1 T = $10^4 \text{ G}$	1 Cal = 1 kcal = 1000 cal

### Prefixes

peta	P	$10^{15}$	deci	d	$10^{-1}$
tera	T	$10^{12}$	centi	c	$10^{-2}$
giga	G	$10^9$	milli	m	$10^{-3}$
mega	M	$10^6$	micro	$\mu$	$10^{-6}$
kilo	k	$10^3$	nano	n	$10^{-9}$
			pico	p	$10^{-12}$
			femto	f	$10^{-15}$

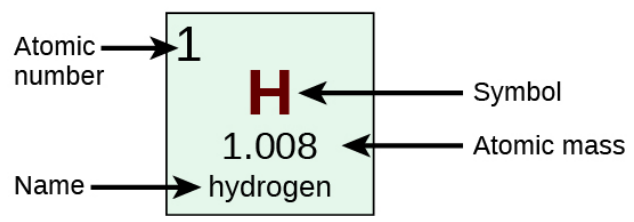
### Numbers (Greek, Latin)

1	Mono	I
2	Di	II
3	Tri	III
4	Tetra	IV
5	Penta	V
6	Hexa	VI
7	Hepta	VII
8	Octa	VIII
9	Nona	IX
10	Deca	X

# Annex 1 - Periodic Table

**Periodic Table of the Elements**

<b>1</b>																	<b>18</b>
<b>1</b>	<b>2</b>											<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>	<b>17</b>	<b>18</b>
1 <b>H</b> 1.008 hydrogen																	2 <b>He</b> 4.003 helium
2 <b>3</b> <b>Li</b> 6.94 lithium	<b>4</b> <b>Be</b> 9.012 beryllium											5 <b>B</b> 10.81 boron	6 <b>C</b> 12.01 carbon	7 <b>N</b> 14.01 nitrogen	8 <b>O</b> 16.00 oxygen	9 <b>F</b> 19.00 fluorine	10 <b>Ne</b> 20.18 neon
3 <b>11</b> <b>Na</b> 22.99 sodium	<b>12</b> <b>Mg</b> 24.31 magnesium											13 <b>Al</b> 26.98 aluminum	14 <b>Si</b> 28.09 silicon	15 <b>P</b> 30.97 phosphorus	16 <b>S</b> 32.06 sulfur	17 <b>Cl</b> 35.45 chlorine	18 <b>Ar</b> 39.95 argon
4 <b>19</b> <b>K</b> 39.10 potassium	<b>20</b> <b>Ca</b> 40.08 calcium	<b>21</b> <b>Sc</b> 44.96 scandium	<b>22</b> <b>Ti</b> 47.87 titanium	<b>23</b> <b>V</b> 50.94 vanadium	<b>24</b> <b>Cr</b> 52.00 chromium	<b>25</b> <b>Mn</b> 54.94 manganese	<b>26</b> <b>Fe</b> 55.85 iron	<b>27</b> <b>Co</b> 58.93 cobalt	<b>28</b> <b>Ni</b> 58.69 nickel	<b>29</b> <b>Cu</b> 63.55 copper	<b>30</b> <b>Zn</b> 65.38 zinc	<b>31</b> <b>Ga</b> 69.72 gallium	<b>32</b> <b>Ge</b> 72.63 germanium	<b>33</b> <b>As</b> 74.92 arsenic	<b>34</b> <b>Se</b> 78.97 selenium	<b>35</b> <b>Br</b> 79.90 bromine	<b>36</b> <b>Kr</b> 83.80 krypton
5 <b>37</b> <b>Rb</b> 85.47 rubidium	<b>38</b> <b>Sr</b> 87.62 strontium	<b>39</b> <b>Y</b> 88.91 yttrium	<b>40</b> <b>Zr</b> 91.22 zirconium	<b>41</b> <b>Nb</b> 92.91 niobium	<b>42</b> <b>Mo</b> 95.95 molybdenum	<b>43</b> <b>Tc</b> [97] technetium	<b>44</b> <b>Ru</b> 101.1 ruthenium	<b>45</b> <b>Rh</b> 102.9 rhodium	<b>46</b> <b>Pd</b> 106.4 palladium	<b>47</b> <b>Ag</b> 107.9 silver	<b>48</b> <b>Cd</b> 112.4 cadmium	<b>49</b> <b>In</b> 114.8 indium	<b>50</b> <b>Sn</b> 118.7 tin	<b>51</b> <b>Sb</b> 121.8 antimony	<b>52</b> <b>Te</b> 127.6 tellurium	<b>53</b> <b>I</b> 126.9 iodine	<b>54</b> <b>Xe</b> 131.3 xenon
6 <b>55</b> <b>Cs</b> 132.9 cesium	<b>56</b> <b>Ba</b> 137.3 barium	<b>57-71</b> <b>La-Lu</b> *	<b>72</b> <b>Hf</b> 178.5 hafnium	<b>73</b> <b>Ta</b> 180.9 tantalum	<b>74</b> <b>W</b> 183.8 tungsten	<b>75</b> <b>Re</b> 186.2 rhenium	<b>76</b> <b>Os</b> 190.2 osmium	<b>77</b> <b>Ir</b> 192.2 iridium	<b>78</b> <b>Pt</b> 195.1 platinum	<b>79</b> <b>Au</b> 197.0 gold	<b>80</b> <b>Hg</b> 200.6 mercury	<b>81</b> <b>Tl</b> 204.4 thallium	<b>82</b> <b>Pb</b> 207.2 lead	<b>83</b> <b>Bi</b> 209.0 bismuth	<b>84</b> <b>Po</b> [209] polonium	<b>85</b> <b>At</b> [210] astatine	<b>86</b> <b>Rn</b> [222] radon
7 <b>87</b> <b>Fr</b> [223] francium	<b>88</b> <b>Ra</b> [226] radium	<b>89-103</b> <b>Ac-Lr</b> **	<b>104</b> <b>Rf</b> [267] rutherfordium	<b>105</b> <b>Db</b> [270] dubnium	<b>106</b> <b>Sg</b> [271] seaborgium	<b>107</b> <b>Bh</b> [270] bohrium	<b>108</b> <b>Hs</b> [277] hassium	<b>109</b> <b>Mt</b> [276] meitnerium	<b>110</b> <b>Ds</b> [281] darmstadtium	<b>111</b> <b>Rg</b> [282] roentgenium	<b>112</b> <b>Cn</b> [285] copernicium	<b>113</b> <b>Uut</b> [285] ununtrium	<b>114</b> <b>Ff</b> [289] flerovium	<b>115</b> <b>Uup</b> [288] ununpentium	<b>116</b> <b>Lv</b> [293] livermorium	<b>117</b> <b>Uus</b> [294] ununseptium	<b>118</b> <b>Uuo</b> [294] ununoctium
		* <b>57</b> <b>La</b> 138.9 lanthanum	<b>58</b> <b>Ce</b> 140.1 cerium	<b>59</b> <b>Pr</b> 140.9 praseodymium	<b>60</b> <b>Nd</b> 144.2 neodymium	<b>61</b> <b>Pm</b> [145] promethium	<b>62</b> <b>Sm</b> 150.4 samarium	<b>63</b> <b>Eu</b> 152.0 europium	<b>64</b> <b>Gd</b> 157.3 gadolinium	<b>65</b> <b>Tb</b> 158.9 terbium	<b>66</b> <b>Dy</b> 162.5 dysprosium	<b>67</b> <b>Ho</b> 164.9 holmium	<b>68</b> <b>Er</b> 167.3 erbium	<b>69</b> <b>Tm</b> 168.9 thulium	<b>70</b> <b>Yb</b> 173.1 ytterbium	<b>71</b> <b>Lu</b> 175.0 lutetium	
		** <b>89</b> <b>Ac</b> [227] actinium	<b>90</b> <b>Th</b> 232.0 thorium	<b>91</b> <b>Pa</b> 231.0 protactinium	<b>92</b> <b>U</b> 238.0 uranium	<b>93</b> <b>Np</b> [237] neptunium	<b>94</b> <b>Pu</b> [244] plutonium	<b>95</b> <b>Am</b> [243] americium	<b>96</b> <b>Cm</b> [247] curium	<b>97</b> <b>Bk</b> [247] berkelium	<b>98</b> <b>Cf</b> [251] californium	<b>99</b> <b>Es</b> [252] einsteinium	<b>100</b> <b>Fm</b> [257] fermium	<b>101</b> <b>Md</b> [258] mendelevium	<b>102</b> <b>No</b> [259] nobelium	<b>103</b> <b>Lr</b> [262] lawrencium	



Color Code	
	Metal <b>Solid</b>
	Metalloid <b>Liquid</b>
	Nonmetal <b>Gas</b>

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