PHYSICS FORMULAS
2426

Electron = -1.602 19 × 10^{-19} C = 9.11 × 10^{-31} kg
Proton = 1.602 19 × 10^{-19} C = 1.67 × 10^{-27} kg
Neutron = 0 C = 1.67 × 10^{-27} kg
6.022 × 10^{23} atoms in one atomic mass unit
e is the elementary charge: 1.602 19 × 10^{-19} C
Potential Energy, velocity of electron: $\mathrm{PE} = eV = \frac{1}{2}mv^2$

1V = 1J/C 1N/C = 1V/m 1J = 1 N·m = 1 C·V
1 amp = 6.21 × 10^{18} electrons/second = 1 Coulomb/second
1 hp = 0.756 kW 1 N = 1 T·A·m 1 Pa = 1 N/m^2
Power = Joules/second = $I^2R = IV$ [watts *W*]

Quadratic Equation: $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$ Kinetic Energy [J] $KE = \frac{1}{2}mv^2$

[Natural Log: when $e^b = x$, $\ln x = b$]
m: 10^{-3} μ: 10^{-6} n: 10^{-9} p: 10^{-12} f: 10^{-15} a: 10^{-18}

Addition of Multiple Vectors:

$\vec{R} = \vec{A} + \vec{B} + \vec{C}$ Resultant = Sum of the vectors

$\vec{R}_x = \vec{A}_x + \vec{B}_x + \vec{C}_x$ *x*-component $A_x = A \cos\theta$

$\vec{R}_y = \vec{A}_y + \vec{B}_y + \vec{C}_y$ *y*-component $A_y = A \sin\theta$

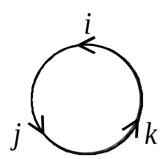
$R = \sqrt{R_x{}^2 + R_y{}^2}$ Magnitude (length) of *R*

$q_R = \tan^{-1}\dfrac{R_y}{R_x}$ *or* $\tan q_R = \dfrac{R_y}{R_x}$ Angle of the resultant

Multiplication of Vectors:

Cross Product or Vector Product:

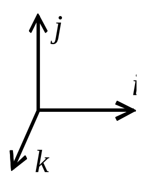
Positive direction:



$i \times j = k$ $j \times i = -k$

$i \times i = 0$

Dot Product or Scalar Product:



$i \cdot j = 0$ $i \cdot i = 1$

$\mathbf{a} \cdot \mathbf{b} = ab\cos q$

Derivative of Vectors:

Velocity is the derivative of position with respect to time:

$$\mathbf{v} = \frac{d}{dt}(x\mathbf{i} + y\mathbf{j} + z\mathbf{k}) = \frac{dx}{dt}\mathbf{i} + \frac{dy}{dt}\mathbf{j} + \frac{dz}{dt}\mathbf{k}$$

Acceleration is the derivative of velocity with respect to time:

$$\mathbf{a} = \frac{d}{dt}(v_x\mathbf{i} + v_y\mathbf{j} + v_z\mathbf{k}) = \frac{dv_x}{dt}\mathbf{i} + \frac{dv_y}{dt}\mathbf{j} + \frac{dv_z}{dt}\mathbf{k}$$

Rectangular Notation: $Z = R \pm jX$ where $+j$ represents inductive reactance and $-j$ represents capacitive reactance. For example, $Z = 8 + j6\Omega$ means that a resistor of 8Ω is in series with an inductive reactance of 6Ω.

Polar Notation: $Z = M \angle q$, where M is the magnitude of the reactance and q is the direction with respect to the horizontal (pure resistance) axis. For example, a resistor of 4Ω in series with a capacitor with a reactance of 3Ω would be expressed as 5 ∠-36.9° Ω.

In the descriptions above, impedance is used as an example. Rectangular and Polar Notation can also be used to express amperage, voltage, and power.

To convert from **rectangular to polar** notation:

Given: X - jY (careful with the sign before the "j")

Magnitude: $\sqrt{X^2 + Y^2} = M$

Angle: $\tan\theta = \dfrac{-Y}{X}$ (negative sign carried over from rectangular notation in this example)

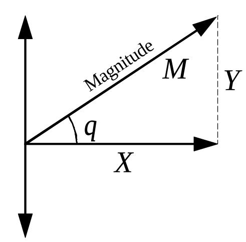
Note: Due to the way the calculator works, if X is negative, you must **add 180°** after taking the inverse tangent. If the result is greater than 180°, you may optionally subtract 360° to obtain the value closest to the reference angle.

To convert from **polar to rectangular** (j) notation:

Given: $M \angle q$

X Value: $M\cos\theta$

Y (j) Value: $M\sin\theta$



In conversions, the j value will have the same sign as the q value for angles having a magnitude < 180°.

Use rectangular notation when adding and subtracting.

Use polar notation for multiplication and division. Multiply in polar notation by multiplying the magnitudes and adding the angles. Divide in polar notation by dividing the magnitudes and subtracting the denominator angle from the numerator angle.

ELECTRIC CHARGES AND FIELDS

Coulomb's Law: [Newtons *N*]

$$F = k\frac{|q_1||q_2|}{r^2}$$

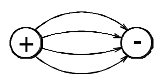
where:
F = force on one charge by the other[*N*]
k = 8.99 × 10^9 [$N{\cdot}m^2/C^2$]
q_1 = charge [*C*]
q_2 = charge [*C*]
r = distance [*m*]

Electric Field: [Newtons/Coulomb or Volts/Meter]

$$E = k\frac{|q|}{r^2} = \frac{|F|}{|q|}$$

where:
E = electric field [*N/C* or *V/m*]
k = 8.99 × 10^9 [$N{\cdot}m^2/C^2$]
q = charge [*C*]
r = distance [*m*]
F = force

Electric field lines radiate outward from positive charges. The electric field is zero inside a conductor.



Relationship of *k* to ϵ_0:

$$k = \frac{1}{4\pi\epsilon_0}$$

where:
k = 8.99 × 10^9 [$N{\cdot}m^2/C^2$]
ϵ_0 = permittivity of free space 8.85 × 10^{-12} [$C^2/N{\cdot}m^2$]

Electric Field due to an Infinite Line of Charge: [*N/C*]

$$E = \frac{\lambda}{2\pi\epsilon_0 r} = \frac{2k\lambda}{r}$$

E = electric field [*N/C*]
λ = charge per unit length [*C/m*}
ϵ_0 = permittivity of free space 8.85 × 10^{-12} [$C^2/N{\cdot}m^2$]
r = distance [*m*]
k = 8.99 × 10^9 [$N{\cdot}m^2/C^2$]

Electric Field due to ring of Charge: [*N/C*]

$$E = \frac{kqz}{(z^2 + R^2)^{3/2}}$$

or if z >> R, $E = \dfrac{kq}{z^2}$

E = electric field [*N/C*]
k = 8.99 × 10^9 [$N{\cdot}m^2/C^2$]
q = charge [*C*]
z = distance to the charge [*m*]
R = radius of the ring [*m*]

Electric Field due to a disk Charge: [*N/C*]

$$E = \frac{\sigma}{2\epsilon_0}\left(1 - \frac{z}{\sqrt{z^2 + R^2}}\right)$$

E = electric field [*N/C*]
σ = charge per unit area [*C/m*^{2}}
ϵ_0 = 8.85 × 10^{-12} [$C^2/N{\cdot}m^2$]
z = distance to charge [*m*]
R = radius of the ring [*m*]

Electric Field due to an infinite sheet: [*N/C*]

$$E = \frac{\sigma}{2\epsilon_0}$$

E = electric field [*N/C*]
σ = charge per unit area [*C/m*^{2}}
ϵ_0 = 8.85 × 10^{-12} [$C^2/N{\cdot}m^2$]

Electric Field inside a spherical shell: [*N/C*]

$$E = \frac{kqr}{R^3}$$

E = electric field [*N/C*]
q = charge [C]
r = distance from center of sphere to the charge [*m*]
R = radius of the sphere [*m*]

Electric Field outside a spherical shell: [*N/C*]

$$E = \frac{kq}{r^2}$$

E = electric field [*N/C*]
q = charge [C]
r = distance from center of sphere to the charge [*m*]

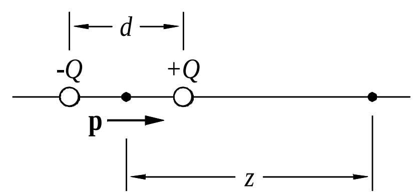
Average Power per unit area of an electric or magnetic field:

$$W/m^2 = \frac{E_m^{\,2}}{2\mu_0 c} = \frac{B_m^{\,2} c}{2\mu_0}$$

W = watts
E_m = max. electric field [*N/C*]
μ_0 = 4π × 10^{-7}
c = 2.99792 × 10^8 [*m/s*]
B_m = max. magnetic field [*T*]

A positive charge moving in the same direction as the electric field direction loses potential energy since the potential of the electric field diminishes in this direction.
Equipotential lines cross EF lines at right angles.

Electric Dipole: Two charges of equal magnitude and opposite polarity separated by a distance d.



$$E = \frac{2k\mathbf{p}}{z^3}$$

$$E = \frac{1}{2\pi\epsilon_0}\frac{\mathbf{p}}{z^3}$$

when $z \gg d$

E = electric field [*N/C*]
k = 8.99 × 10^9 [$N{\cdot}m^2/C^2$]
ϵ_0 = permittivity of free space 8.85 × 10^{-12} $C^2/N{\cdot}m^2$
$\mathbf{p}$ = *qd* [$C{\cdot}m$] "electric dipole moment" in the direction negative to positive
z = distance [m] from the dipole center to the point along the dipole axis where the electric field is to be measured

Deflection of a Particle in an Electric Field:

$$2ymv^2 = qEL^2$$

y = deflection [*m*]
m = mass of the particle [*kg*]
d = plate separation [*m*]
v = speed [*m/s*]
q = charge [*C*]
E = electric field [*N/C* or *V/m*
L = length of plates [*m*]

Potential Difference between two Points: [volts V]

$$\Delta V = V_B - V_A = \frac{\Delta PE}{q} = -Ed$$

ΔPE = work to move a charge from A to B [N·m or J]
q = charge [C]
V_B = potential at B [V]
V_A = potential at A [V]
E = electric field [N/C or V/m
d = plate separation [m]

Electric Potential due to a Point Charge: [volts V]

$$V = k\frac{q}{r}$$

V = potential [volts V]
$k = 8.99 \times 10^9$ [N·m^2/C^2]
q = charge [C]
r = distance [m]

Potential Energy of a Pair of Charges: [J, $N{\cdot}m$ or $C{\cdot}V$]

$$PE = q_2V_1 = k\frac{q_1q_2}{r}$$

V_1 is the electric potential due to q_1 at a point P
q_2V_1 is the work required to bring q_2 from infinity to point P

Work and Potential:

$$\Delta U = U_f - U_i = -W$$

$$U = -W_\infty$$

$$W = \mathbf{F}\cdot\mathbf{d} = Fd\cos q$$

$$W = q\int_i^f \mathbf{E}\cdot d\mathbf{s}$$

$$\Delta V = V_f - V_i = -\frac{W}{q}$$

$$V = -\int_i^f \mathbf{E}\cdot d\mathbf{s}$$

U = electric potential energy [J]
W = work done on a particle by a field [J]
$W_¥$ = work done on a particle brought from infinity (zero potential) to its present location [J]
$\mathbf{F}$ = is the force vector [N]
$\mathbf{d}$ = is the distance vector over which the force is applied[m]
F = is the force scalar [N]
d = is the distance scalar [m]
q = is the angle between the force and distance vectors
$d\mathbf{s}$ = differential displacement of the charge [m]
V = volts [V]
q = charge [C]

Flux: the rate of flow (of an electric field) [$N{\cdot}m^2/C$]

$$\Phi = \oint \mathbf{E}\cdot d\mathbf{A}$$

$$= \int E(\cos q)dA$$

Φ is the rate of flow of an electric field [$N{\cdot}m^2/C$]
$\oint$ integral over a closed surface
$\mathbf{E}$ is the electric field vector [N/C]
$\mathbf{A}$ is the area vector [m^2] pointing outward normal to the surface.

Gauss' Law:

$$\in_0 \Phi = q_{enc}$$

$$\in_0 \oint \mathbf{E}\cdot d\mathbf{A} = q_{enc}$$

$\in_0 = 8.85 \times 10^{-12}$ [C^2/N·m^2]
Φ is the rate of flow of an electric field [$N{\cdot}m^2/C$]
q_{enc} = charge within the gaussian surface [C]
$\oint$ integral over a closed surface
$\mathbf{E}$ is the electric field vector [J]
$\mathbf{A}$ is the area vector [m^2] pointing outward normal to the surface.

CAPACITANCE

Parallel-Plate Capacitor:

$$C = k \in_0 \frac{A}{d}$$

C = capacitance [farads F]
κ = the dielectric constant (1)
$\in_0$ = permittivity of free space 8.85×10^{-12} $C^2/N{\cdot}m^2$
A = area of one plate [m^2]
d = separation between plates [m]

Cylindrical Capacitor:

$$C = 2pk \in_0 \frac{L}{\ln(b/a)}$$

C = capacitance [farads F]
κ = dielectric constant (1)
$\in_0 = 8.85 \times 10^{-12}$ $C^2/N{\cdot}m^2$
L = length [m]
b = radius of the outer conductor [m]
a = radius of the inner conductor [m]

Spherical Capacitor:

$$C = 4pk \in_0 \frac{ab}{b-a}$$

C = capacitance [farads F]
κ = dielectric constant (1)
$\in_0 = 8.85 \times 10^{-12}$ $C^2/N{\cdot}m^2$
b = radius, outer conductor [m]
a = radius, inner conductor [m]

Maximum Charge on a Capacitor: [Coulombs C]

$$Q = VC$$

Q = Coulombs [C]
V = volts [V]
C = capacitance in farads [F]

For capacitors connected in series, the charge Q is equal for each capacitor as well as for the total equivalent. If the dielectric constant κ is changed, the capacitance is multiplied by κ, the voltage is divided by κ, and Q is unchanged. In a vacuum $\kappa = 1$, When dielectrics are used, replace $\in_0$ with $\kappa \in_0$.

Electrical Energy Stored in a Capacitor: [Joules J]

$$U_E = \frac{QV}{2} = \frac{CV^2}{2} = \frac{Q^2}{2C}$$

U = Potential Energy [J]
Q = Coulombs [C]
V = volts [V]
C = capacitance in farads [F]

Charge per unit Area: [C/m^2]

$$s = \frac{q}{A}$$

s = charge per unit area [C/m^2]
q = charge [C]
A = area [m^2]

Energy Density: (in a vacuum) [J/m^3]

$$u = \tfrac{1}{2}\epsilon_0 E^2$$

u = energy per unit volume [J/m^3]
ϵ_0 = permittivity of free space $8.85 \times 10^{-12}\ C^2/N{\cdot}m^2$
E = energy [J]

Capacitors in Series:

$$\frac{1}{C_{eff}} = \frac{1}{C_1} + \frac{1}{C_2} \ldots$$

Capacitors in Parallel:

$$C_{eff} = C_1 + C_2 \ldots$$

Capacitors connected in series all have the same charge q. For parallel capacitors the total q is equal to the sum of the charge on each capacitor.

Time Constant: [seconds]

$$\tau = RC$$

t = time it takes the capacitor to reach 63.2% of its maximum charge [seconds]
R = series resistance [ohms Ω]
C = capacitance [farads F]

Charge or Voltage after *t* Seconds: [coulombs C]

charging:

$$q = Q\left(1 - e^{-t/t}\right)$$

$$V = V_S\left(1 - e^{-t/t}\right)$$

discharging:

$$q = Qe^{-t/t}$$

$$V = V_S\, e^{-t/t}$$

q = charge after t seconds [coulombs C]
Q = maximum charge [coulombs C] $Q = CV$
e = natural log
t = time [seconds]
t = time constant RC [seconds]
V = volts [V]
V_S = supply volts [V]

[Natural Log: when $e^b = x$, $\ln x = b$]

Drift Speed:

$$I = \frac{\Delta Q}{\Delta t} = \left(nqv_d A\right)$$

ΔQ = # of carriers × charge/carrier
Δt = time in seconds
n = # of carriers
q = charge on each carrier
v_d = drift speed in meters/second
A = cross-sectional area in meters^2

RESISTANCE

Emf: A voltage source which can provide continuous current [volts]

$$\varepsilon = IR + Ir$$

ε = emf open-circuit voltage of the battery
I = current [amps]
R = load resistance [ohms]
r = internal battery resistance [ohms]

Resistivity: [Ohm Meters]

$$r = \frac{E}{J}$$

$$r = \frac{RA}{L}$$

r = resistivity [$W \cdot m$]
E = electric field [N/C]
J = current density [A/m^2]
R = resistance [W ohms]
A = area [m^2]
L = length of conductor [m]

Variation of Resistance with Temperature:

$$r - r_0 = r_0 a\,(T - T_0)$$

r = resistivity [$W \cdot m$]
r_0 = reference resistivity [$W \cdot m$]
a = temperature coefficient of resistivity [K^{-1}]
T_0 = reference temperature
$T - T_0$ = temperature difference [K or °C]

CURRENT

Current Density: [A/m^2]

$$i = \int \mathbf{J} \cdot d\mathbf{A}$$

if current is uniform and parallel to $d\mathbf{A}$, then: $i = JA$

$$J = (ne)V_d$$

i = current [A]
J = current density [A/m^2]
A = area [m^2]
L = length of conductor [m]
e = charge per carrier
ne = carrier charge density [C/m^3]
V_d = drift speed [m/s]

Rate of Change of Chemical Energy in a Battery:

$$P = ie$$

P = power [W]
i = current [A]
e = emf potential [V]

Kirchhoff's Rules

1. The sum of the currents entering a junctions is equal to the sum of the currents leaving the junction.
2. The sum of the potential differences across all the elements around a closed loop must be zero.

Evaluating Circuits Using Kirchhoff's Rules

1. Assign current variables and direction of flow to all branches of the circuit. If your choice of direction is incorrect, the result will be a negative number. Derive equation(s) for these currents based on the rule that currents entering a junction equal currents exiting the junction.
2. Apply Kirchhoff's loop rule in creating equations for different current paths in the circuit. For a current path beginning and ending at the same point, the sum of voltage drops/gains is zero. When evaluating a loop in the direction of current flow, resistances will cause drops (negatives); voltage sources will cause rises (positives) provided they are crossed negative to positive—otherwise they will be drops as well.
3. The number of equations should equal the number of variables. Solve the equations simultaneously.

MAGNETISM

André-Marie **Ampére** is credited with the discovery of electromagnetism, the relationship between electric currents and magnetic fields.

Heinrich **Hertz** was the first to generate and detect electromagnetic waves in the laboratory.

Magnetic Force acting on a charge *q*: [Newtons *N*]

$$F = qvB\sin\theta$$
$$F = q\mathbf{v}\times\mathbf{B}$$

F = force [*N*]
q = charge [*C*]
v = velocity [*m/s*]
B = magnetic field [*T*]
q = angle between *v* and *B*

Right-Hand Rule: Fingers represent the direction of the magnetic force *B*, thumb represents the direction of *v* (at any angle to *B*), and the force *F* on a **positive** charge emanates from the palm. The direction of a magnetic field is from **north to south**. Use the *left* hand for a *negative* charge.

Also, if a **wire** is grasped in the right hand with the thumb in the direction of current flow, the fingers will curl in the direction of the magnetic field.

In a **solenoid** with current flowing in the direction of curled fingers, the magnetic field is in the direction of the thumb.

When applied to electrical flow caused by a **changing magnetic field**, things get more complicated. Consider the north pole of a magnet moving toward a loop of wire (magnetic field increasing). The thumb represents the north pole of the magnet, the fingers *suggest* current flow in the loop. However, electrical activity will serve to balance the change in the magnetic field, so that current will actually flow in the opposite direction. If the magnet was being withdrawn, then the *suggested* current flow would be decreasing so that the actual current flow would be in the direction of the fingers in this case to oppose the *decrease*. Now consider a cylindrical area of magnetic field going *into* a page. With the thumb pointing into the page, this would *suggest* an electric field orbiting in a clockwise direction. If the magnetic field was increasing, the actual electric field would be CCW in opposition to the increase. An electron in the field would travel opposite the field direction (CW) and would experience a negative change in potential.

Force on a Wire in a Magnetic Field: [Newtons *N*]

$$F = BI\,\ell\sin q$$
$$F = I\,\ell\times B$$

F = force [*N*]
B = magnetic field [*T*]
I = amperage [*A*]
ℓ = length [*m*]
q = angle between *B* and the direction of the current

Torque on a Rectangular Loop: [Newton·meters *N·m*]

$$\tau = NBIA\sin\theta$$

N = number of turns
B = magnetic field [*T*]
I = amperage [*A*]
A = area [m^2]
q = angle between B and the plane of the loop

Charged Particle in a Magnetic Field:

$$r = \frac{mv}{qB}$$

r = radius of rotational path
m = mass [*kg*]
v = velocity [*m/s*]
q = charge [*C*]
B = magnetic field [*T*]

Magnetic Field Around a Wire: [T]

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

B = magnetic field [*T*]
m_0 = the permeability of free space $4\pi\times10^{-7}$ T·m/A
I = current [*A*]
r = distance from the center of the conductor

Magnetic Field at the center of an Arc: [T]

$$B = \frac{m_0 i f}{4pr}$$

B = magnetic field [*T*]
m_0 = the permeability of free space $4\pi\times10^{-7}$ T·m/A
i = current [*A*]
f = the arc in radians
r = distance from the center of the conductor

Hall Effect: Voltage across the width of a conducting ribbon due to a Magnetic Field:

$$(ne)V_w h = Bi$$
$$v_d Bw = V_w$$

ne = carrier charge density [C/m^3]
V_w = voltage across the width [*V*]
h = thickness of the conductor [*m*]
B = magnetic field [*T*]
i = current [*A*]
v_d = drift velocity [*m/s*]
w = width [*m*]

Force Between Two Conductors: The force is attractive if the currents are in the same direction.

$$\frac{F_1}{\ell} = \frac{m_0 I_1 I_2}{2pd}$$

F = force [*N*]
ℓ = length [*m*]
m_0 = the permeability of free space $4\pi\times10^{-7}$ T·m/A
I = current [*A*]
d = distance center to center [*m*]

Magnetic Field Inside of a Solenoid: [Teslas *T*]

$$B = \mu_0 nI$$

B = magnetic field [*T*]
m_0 = the permeability of free space $4\pi\times10^{-7}$ T·m/A
n = number of turns of wire per unit length [*#/m*]
I = current [*A*]

Magnetic Dipole Moment: [*J/T*]

$$m = NiA$$

m = the magnetic dipole moment [*J/T*]
N = number of turns of wire
i = current [*A*]
A = area [m^2]

Magnetic Flux through a closed loop: [$T{\cdot}M^2$ or Webers]

$$\Phi = BA\cos q$$

B = magnetic field [*T*]
A = area of loop [m^2]
q = angle between B and the perpen-dicular to the plane of the loop

Magnetic Flux for a changing magnetic field: [$T \cdot M^2$ or Webers]

$$\Phi = \int \mathbf{B} \cdot d\mathbf{A}$$

B = magnetic field [T]
A = area of loop [m^2]

A Cylindrical Changing Magnetic Field

$$\oint \mathbf{E} \cdot d\mathbf{s} = E2p\,r = \frac{d\Phi_B}{dt}$$

$$\Phi_B = BA = Bp\,r^2$$

$$\frac{d\Phi}{dt} = A\frac{dB}{dt}$$

$$e = -N\frac{d\Phi}{dt}$$

E = electric field [N/C]
r = radius [m]
t = time [s]
Φ = magnetic flux [$T \cdot m^2$ or Webers]
B = magnetic field [T]
A = area of magnetic field [m^2]
dB/dt = rate of change of the magnetic field [T/s]
e = potential [V]
N = number of orbits

Faraday's Law of Induction states that the instantaneous emf induced in a circuit equals the rate of change of magnetic flux through the circuit. Michael **Faraday** made fundamental discoveries in magnetism, electricity, and light.

$$e = -N\frac{\Delta\Phi}{\Delta t}$$

N = number of turns
Φ = magnetic flux [$T \cdot m^2$]
t = time [s]

Lenz's Law states that the polarity of the induced emf is such that it produces a current whose magnetic field opposes the change in magnetic flux through a circuit

Motional emf is induced when a conducting bar moves through a perpendicular magnetic field.

$$e = B\ell v$$

B = magnetic field [T]
ℓ = length of the bar [m]
v = speed of the bar [m/s]

emf Induced in a Rotating Coil:

$$e = NABw \sin wt$$

N = number of turns
A = area of loop [m^2]
B = magnetic field [T]
w = angular velocity [rad/s]
t = time [s]

Self-Induced emf in a Coil due to changing current:

$$e = -L\frac{\Delta I}{\Delta t}$$

L = inductance [H]
I = current [A]
t = time [s]

Inductance per unit length near the center of a solenoid:

$$\frac{L}{\ell} = m_0 n^2 A$$

L = inductance [H]
ℓ = length of the solenoid [m]
m_0 = the permeability of free space $4\pi\times10^{-7}$ T·m/A
n = number of turns of wire per unit length [$\#/m$]
A = area [m^2]

Amperes' Law:

$$\oint \mathbf{B} \cdot d\mathbf{s} = m_0 i_{enc}$$

B = magnetic field [T]
m_0 = the permeability of free space $4\pi\times10^{-7}$ T·m/A
i_{enc} = current encircled by the loop[A]

Joseph **Henry**, American physicist, made improvements to the electromagnet.
James Clerk **Maxwell** provided a theory showing the close relationship between electric and magnetic phenomena and predicted that electric and magnetic fields could move through space as waves.
J. J. **Thompson** is credited with the discovery of the electron in 1897.

INDUCTIVE & RCL CIRCUITS

Inductance of a Coil: [H]

$$L = \frac{N\Phi}{I}$$

N = number of turns
Φ = magnetic flux [$T \cdot m^2$]
I = current [A]

In an RL Circuit, after one time constant ($t = L/R$) the current in the circuit is 63.2% of its final value, ε/R.

RL Circuit:

current rise:

$$I = \frac{V}{R}\left(1 - e^{-t/t_L}\right)$$

current decay:

$$I = \frac{V}{R}e^{-t/t_L}$$

U_B = Potential Energy [J]
V = volts [V]
R = resistance [W]
e = natural log
t = time [seconds]
t_L = inductive time constant L/R [s]
I = current [A]

Magnetic Energy Stored in an Inductor:

$$U_B = \tfrac{1}{2}LI^2$$

U_B = Potential Energy [J]
L = inductance [H]
I = current [A]

Electrical Energy Stored in a Capacitor: [Joules J]

$$U_E = \frac{QV}{2} = \frac{CV^2}{2} = \frac{Q^2}{2C}$$

U_E = Potential Energy [J]
Q = Coulombs [C]
V = volts [V]
C = capacitance in farads [F]

Resonant Frequency: : The frequency at which $X_L = X_C$. In a **series**-resonant circuit, the impedance is at its minimum and the current is at its maximum. For a **parallel**-resonant circuit, the opposite is true.

$$f_R = \frac{1}{2p\sqrt{LC}}$$

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

f_R = Resonant Frequency [Hz]
L = inductance [H]
C = capacitance in farads [F]
w = angular frequency [rad/s]

Voltage, series circuits: [V]

$$V_C = \frac{q}{C} \quad V_R = IR$$

$$\frac{V_X}{X} = \frac{V_R}{R} = I$$

$$V^2 = V_R{}^2 + V_X{}^2$$

V_C = voltage across capacitor [*V*]
q = charge on capacitor [*C*]
f_R = Resonant Frequency [*Hz*]
L = inductance [*H*]
C = capacitance in farads [*F*]
R = resistance [*W*]
I = current [*A*]
V = supply voltage [*V*]
V_X = voltage across reactance [*V*]
V_R = voltage across resistor [*V*]

Phase Angle of a series RL or RC circuit: [degrees]

$$\tan f = \frac{X}{R} = \frac{V_X}{V_R}$$

$$\cos f = \frac{V_R}{V} = \frac{R}{Z}$$

(*f* would be negative in a capacitive circuit)

f = Phase Angle [degrees]
X = reactance [*W*]
R = resistance [*W*]
V = supply voltage [*V*]
V_X = voltage across reactance [*V*]
V_R = voltage across resistor [*V*]
Z = impedance [*W*]

Impedance of a series RL or RC circuit: [*W*]

$$Z^2 = R^2 + X^2$$

$$E = I\,Z$$

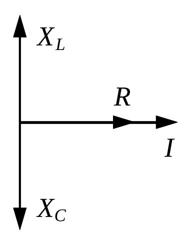
$$\frac{Z}{V} = \frac{X_C}{V_C} = \frac{R}{V_R}$$

$$Z = R \pm jX$$

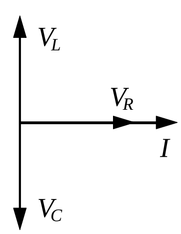
f = Phase Angle [degrees]
X = reactance [*W*]
R = resistance [*W*]
V = supply voltage [*V*]
V_X = voltage across reactance [*V*]
V_X = voltage across resistor [*V*]
Z = impedance [*W*]

Series RCL Circuits:

The Resultant Phasor $X = X_L - X_C$ is in the direction of the larger reactance and determines whether the circuit is inductive or capacitive. If X_L is larger than X_C, then the circuit is inductive and *X* is a vector in the upward direction.



In series circuits, the amperage is the reference (horizontal) vector. This is observed on the oscilloscope by looking at the voltage across the resistor. The two vector diagrams at right illustrate the phase relationship between voltage, resistance, reactance, and amperage.



Series RCL Impedance

$$Z^2 = R^2 + (X_L - X_C)^2 \qquad Z = \frac{R}{\cos f}$$

Impedance may be found by adding the components using vector algebra. By converting the result to polar notation, the phase angle is also found.

For multielement circuits, total each resistance and reactance before using the above formula.

Damped Oscillations in an RCL Series Circuit:

$$q = Qe^{-Rt/2L}\cos(w' t + f)$$

where

$$w' = \sqrt{w^2 - (R/2L)^2}$$

$$w = 1/\sqrt{LC}$$

When R is small and $\omega' \approx \omega$:

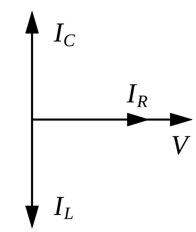
$$U = \frac{Q^2}{2C} e^{-Rt/L}$$

q = charge on capacitor [*C*]
Q = maximum charge [*C*]
e = natural log
R = resistance [*W*]
L = inductance [*H*]
w = angular frequency of the undamped oscillations [*rad/s*]
w = angular frequency of the damped oscillations [*rad/s*]
U = Potential Energy of the capacitor [*J*]
C = capacitance in farads [*F*]

Parallel RCL Circuits:

$$I_T = \sqrt{I_R{}^2 + (I_C - I_L)^2}$$

$$\tan f = \frac{I_C - I_L}{I_R}$$



To find total current and phase angle in multielement circuits, find *I* for each path and add vectorally. Note that when converting between current and resistance, a division will take place requiring the use of polar notation and resulting in a change of sign for the angle since it will be divided into (subtracted from) an angle of zero.

Equivalent Series Circuit: Given the *Z* in polar notation of a parallel circuit, the resistance and reactance of the equivalent series circuit is as follows:

$$R = Z_T \cos q \qquad X = Z_T \sin q$$

AC CIRCUITS

Instantaneous Voltage of a Sine Wave:

$$V = V_{\max} \sin 2\pi f t$$

V = voltage [*V*]
f = frequency [*Hz*]
t = time [s]

Maximum and rms Values:

$$I = \frac{I_m}{\sqrt{2}} \qquad V = \frac{V_m}{\sqrt{2}}$$

I = current [*A*]
V = voltage [*V*]

RLC Circuits:

$$V = \sqrt{V_R{}^2 + (V_L - V_C)^2}$$

$$\tan f = \frac{X_L - X_C}{R}$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

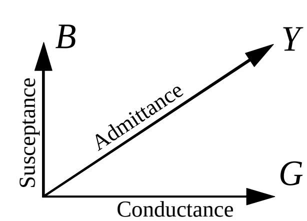
$$P_{avg} = IV\cos f$$

$$PF = \cos f$$

Conductance (G): The reciprocal of resistance in siemens (S).

Susceptance (B, B_L, B_C): The reciprocal of reactance in siemens (S).

Admittance (Y): The reciprocal of impedance in siemens (S).



ELECTROMAGNETICS

WAVELENGTH

$c = \lambda f$ $c = E / B$ $1\text{Å} = 10^{-10}\text{m}$	c = speed of light 2.998×10^8 m/s λ = wavelength [m] f = frequency [Hz] E = electric field [N/C] B = magnetic field [T] Å = (angstrom) unit of wavelength equal to 10^{-10} m m = (meters)

WAVELENGTH SPECTRUM

BAND	METERS	ANGSTROMS
Longwave radio	1 - 100 km	10^{13} - 10^{15}
Standard Broadcast	100 - 1000 m	10^{12} - 10^{13}
Shortwave radio	10 - 100 m	10^{11} - 10^{12}
TV, FM	0.1 - 10 m	10^{9} - 10^{11}
Microwave	1 - 100 mm	10^{7} - 10^{9}
Infrared light	0.8 - 1000 µm	8000 - 10^{7}
Visible light	360 - 690 nm	3600 - 6900
violet	360 nm	3600
blue	430 nm	4300
green	490 nm	4900
yellow	560 nm	5600
orange	600 nm	6000
red	690 nm	6900
Ultraviolet light	10 - 390 nm	100 - 3900
X-rays	5 - 10,000 pm	0.05 - 100
Gamma rays	100 - 5000 fm	0.001 - 0.05
Cosmic rays	< 100 fm	< 0.001

Intensity of Electromagnetic Radiation [watts/m^2]:

$$I = \frac{P_s}{4p r^2}$$

I = intensity [w/m^2]
P_s = power of source [watts]
r = distance [m]
$4pr^2$ = surface area of sphere

Force and Radiation Pressure on an object:

a) if the light is totally absorbed:

$$F = \frac{IA}{c} \qquad P_r = \frac{I}{c}$$

b) if the light is totally reflected back along the path:

$$F = \frac{2IA}{c} \qquad P_r = \frac{2I}{c}$$

F = force [N]
I = intensity [w/m^2]
A = area [m^2]
P_r = radiation pressure [N/m^2]
$c = 2.99792 \times 10^8$ [m/s]

Poynting Vector [watts/m^2]:

$$S = \frac{1}{m_0} EB = \frac{1}{m_0} E^2$$

$$cB = E$$

m_0 = the permeability of free space $4\pi \times 10^{-7}$ T·m/A
E = electric field [N/C or V/M]
B = magnetic field [T]
$c = 2.99792 \times 10^8$ [m/s]

LIGHT

Indices of Refraction:

Quartz:	1.458
Glass, crown	1.52
Glass, flint	1.66
Water	1.333
Air	1.000 293

Angle of Incidence: The angle measured from the perpendicular to the face or from the perpendicular to the tangent to the face

Index of Refraction: Materials of greater density have a higher index of refraction.

$$n \equiv \frac{c}{v}$$

n = index of refraction
c = speed of light in a vacuum 3×10^8 m/s
v = speed of light in the material [m/s]

$$n = \frac{\lambda_0}{\lambda_n}$$

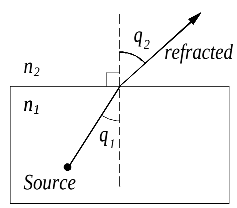
l_0 = wavelength of the light in a vacuum [m]
l_n = its wavelength in the material [m]

Law of Refraction: **Snell's Law**

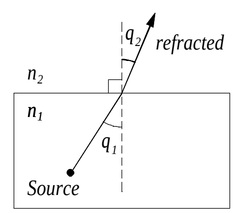
$$n_1 \sin q_1 = n_2 \sin q_2$$

n = index of refraction
q = angle of incidence

traveling to a region of lesser density: $q_2 > q_1$

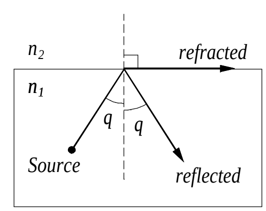


traveling to a region of greater density: $q_2 < q_1$



Critical Angle: The maximum angle of incidence for which light can move from n_1 to n_2

$$\sin \theta_c = \frac{n_2}{n_1} \quad \text{for } n_1 > n_2$$



Sign Conventions: When M is negative, the image is inverted. p is positive when the object is in front of the mirror, surface, or lens. Q is positive when the image is in front of the mirror or in back of the surface or lens. f and r are positive if the center of curvature is in front of the mirror or in back of the surface or lens.

Magnification by spherical mirror or thin lens. A negative m means that the image is inverted.

$$M = \frac{h'}{h} = -\frac{i}{p}$$

h' = image height [m]
h = object height [m]
i = image distance [m]
p = object distance [m]

Plane Refracting Surface:

plane refracting surface:

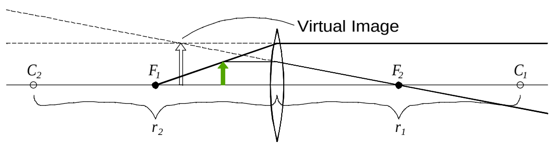
$$\frac{n_1}{p} = -\frac{n_2}{i}$$

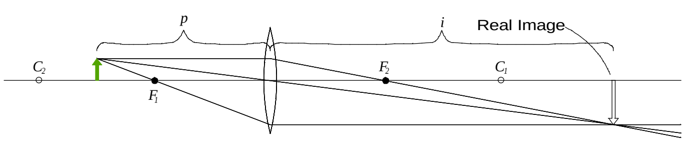
p = object distance
i = image distance [m]
n = index of refraction

Lensmaker's Equation for a thin lens in air:

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{i} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

f = focal length [m]
i = image distance [m]
p = object distance [m]
n = index of refraction
r_1 = radius of surface nearest the object[m]
r_2 = radius of surface nearest the image [m]





Thin Lens when the thickest part is thin compared to p.

i is negative on the left, positive on the right

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

f = focal length [m]
r = radius [m]

Converging Lens

f is positive (left)
r_1 and r_2 are positive in this example

Diverging Lens

f is negative (right)
r_1 and r_2 are negative in this example

Two-Lens System

Perform the calculation in steps. Calculate the image produced by the first lens, ignoring the presence of the second. Then use the image position relative to the second lens as the object for the second calculation ignoring the first lens.

Spherical Refracting Surface

This refers to two materials with a single refracting surface.

$$\frac{n_1}{p} + \frac{n_2}{i} = \frac{n_2 - n_1}{r}$$

$$M = \frac{h'}{h} = -\frac{n_1 i}{n_2 p}$$

p = object distance
i = image distance [m] (positive for real images)
f = focal point [m]
n = index of refraction
r = radius [m] (positive when facing a convex surface, unlike with mirrors)
M = magnification
h' = image height [m]
h = object height [m]

Constructive and Destructive Interference by Single and Double Slit Defraction and Circular Aperture

Young's double-slit experiment (bright fringes/dark fringes):

Double Slit

Constructive:

$$\Delta L = d \sin q = m l$$

Destructive:

$$\Delta L = d \sin q = (m + \tfrac{1}{2}) l$$

d = distance between the slits [m]
q = the angle between a normal line extending from midway between the slits and a line extending from the midway point to the point of ray intersection.
m = fringe order number [*integer*]
l = wavelength of the light [m]
a = width of the single-slit [m]
DL = the difference between the distance traveled of the two rays [m]
I = intensity @ q [W/m^2]
I_m = intensity @ q = 0 [W/m^2]
d = distance between the slits [m]

Intensity:

$$I = I_m (\cos^2 b)\left(\frac{\sin a}{a}\right)^2$$

$$b = \frac{p\, d}{l} \sin q$$

$$a = \frac{p\, a}{l} \sin q$$

Single-Slit

Destructive:

$$a \sin q = m l$$

Circular Aperture

1st Minimum:

$$\sin q = 1.22 \frac{g}{dia.}$$

In a circular aperture, the 1st minimum is the point at which an image can no longer be resolved.

A **reflected ray** undergoes a **phase shift** of 180°

when the reflecting material has a greater index of refraction n than the ambient medium. Relative to the same ray without phase shift, this constitutes a path difference of λ/2.

Interference between Reflected and Refracted rays

from a thin material **surrounded** by another medium:

Constructive:

$$2nt = (m + \tfrac{1}{2})\lambda$$

Destructive:

$$2nt = m\lambda$$

n = index of refraction
t = thickness of the material [m]
m = fringe order number [*integer*]
l = wavelength of the light [m]

If the thin material is between two different media, one with a higher n and the other lower, then the above constructive and destructive formulas are reversed.

Wavelength within a medium:

$$\lambda_n = \frac{\lambda}{n}$$

$$c = n\, l_n f$$

l = wavelength in free space [m]
l_n = wavelength in the medium [m]
n = index of refraction
c = the speed of light 3.00 × 10^8 [m/s]
f = frequency [Hz]

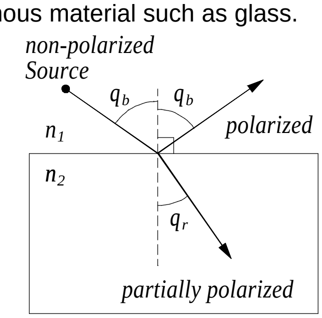
Polarizing Angle:

by **Brewster's Law**, the angle of incidence that produces complete polarization in the reflected light from an amorphous material such as glass.

$$\tan q_B = \frac{n_2}{n_1}$$

$$q_r + q_B = 90°$$

n = index of refraction
q_B = angle of incidence producing a 90° angle between reflected and refracted rays.
q_r = angle of incidence of the refracted ray.



Intensity of light passing through a polarizing lense:

[$Watts/m^2$]

initially unpolarized: $I = \frac{1}{2} I_0$

initially polarized:

$$I = I_0 \cos^2 q$$

I = intensity [W/m^2]
I_0 = intensity of source [W/m^2]
q = angle between the polarity of the source and the lens.

Formulae For DUAL NATURE AND RADIATION

By Mir Mohammed Abbas II PCMB 'A'

CHAPTER FORMULAS & NOTES

Important Terms, Definitions & Formulae

1 **Electric Discharge:** The passage of an electric current through a gas is called electric discharge.

2 **Discharge Tube:** A hard glass tube along with the necessary arrangement, which is used to study the passage of electric discharge through gases at low pressure, is called a discharge tube.

3 **Cathode Rays.** Cathode rays are the stream of negatively charged particles, electrons which are shot out at a high speed from the cathode of a discharge tube at pressure below 0.01 mm of Hg.

4 **Work Function.** The minimum amount of energy required by an electron to just escape from the metal surface is known as work function of the metal.

5 **Electron Emission.** The minimum amount of energy required by an electron to just escape from the metal surface is known as work function of the metal.

(i) **Thermionic emission.** Here electrons are emitted from the metal surface with the help of thermal energy.

(ii) **Field or cold cathode emission.** Electrons are emitted from a metal surface by subjecting it to a very high electric field.

(iii) **Photoelectric emission.** Electrons emitted from a metal surface with the help of suitable electromagnetic radiations.

(iv) **Secondary emission.** Electrons are ejected from a metal surface by striking over its fast moving electrons.

6 **Forces Experienced by an Electron in Electric and Magnetic Fields.**

(a) **Electric field:** The force F_E experienced by a electron e in an electric field of strength (intensity) E is given by

$$F_E = eE$$

(b) **Magnetic field**: The force experienced by an electron e in a magnetic field of strength B weber/m^2 is given by

$$F_B=Bev$$

where v is the velocity with which the electron moves in the electric field and the magnetic field, perpendicular to the direction of motion.

If the magnetic field is parallel to the direction of motion of electron, then, $F_B = 0$.

7 **Photoelectric Effect:** The phenomenon of emission of electrons from the surface of substances (mainly metals), when exposed to electromagnetic radiations of suitable frequency, is called photoelectric effect and the emitted electrons are called photoelectrons.

8 **Cut Off or Stopping Potential:** The value of the retarding potential at which the photoelectric current becomes zero is called cut off or stopping potential for the given frequency of the incident radiation.

9 **Threshold Frequency:** The minimum value of the frequency of incident radiation below which the photoelectric emission stops altogether is called threshold frequency.

10 **Laws of Photoelectric Effect.**

(i) For a given metal and a radiation of fixed frequency, the number of photoelectrons emitted is proportional to the intensity of incident radiation.

(ii) For every metal, there is a certain minimum frequency below which no photoelectrons are emitted, howsoever high is the intensity of incident radiation. This frequency is called *threshold frequency.*

(iii) For the radiation of frequency higher than the threshold frequency, the maximum kinetic energy of the photoelectrons is directly proportional to the frequency of incident radiation and is independent of the intensity of incident radiation.

(iv) The photoelectric emission is an *instantaneous* process.

11 **Einstein's Theory of Photoelectric Effect.** Einstein explained photoelectric effect with the help of Planck's quantum theory. When a radiation of frequency ν is incident on a metal surface, it is absorbed in the form of discrete packets of energy called quanta or photons.

A part of energy $h\nu$ of the photon is used in removing the electrons from the metal surface and remaining energy is used in giving kinetic energy to the photoelectron.

Einstein's photoelectric equation is

$$KE = \frac{1}{2}mv^2 = h\nu - w_o$$

where w_o is the work function of the metal.

If ν_0 is the threshold frequency, then $w_o = h\nu_o$

$$KE = \frac{1}{2}mv^2 = h\,(\nu - \nu_0)$$

All the experimental observations can be explained on the basis Einstein's photoelectric equation.

12 **Compton Scattering.** It is the phenomenon of increase in the wavelength of X-ray photons which occurs when these radiations are scattered on striking an electron. The difference in the wavelength of scattered and incident photons is called Compton shift, which is given by

$$\Delta\lambda = \frac{h}{m_0 c}(1 - \cos\phi)$$

where ϕ is the angle of scattering of the X-ray photon and m_0 is the rest mass of the electron.

13 **$\frac{e}{m}$ of an Electron by Thompson's Method.**

J. J. Thomson devised an experiment to determine the velocity (v) and the ratio of the charge (e) to the mass (m) i.e., $\frac{e}{m}$ of cathode rays. In this method electric field $\vec{E}$ and magnetic field $\vec{B}$ are applied on the cathode rays.

In the region where they are applied perpendicular to each other and to the direction of motion of cathode rays,

Force due to electric field, F_E = Force due to magnetic field F_B,

Or $$eE = Bev \Rightarrow v = \frac{E}{B}$$

Also $$\frac{e}{m} = \frac{E}{B^2 R} = \frac{V/d}{B^2 R} = \frac{Vx}{B^2 \ell L d}$$

where V = Potential difference between the two electrodes (i.e., P and Q)

d = distance between the two electrodes

R = radius of circular arc in the presence of magnetic field B

x = shift of the electron beam on the screen

ℓ = length of the field

L = distance between the centre of the field and the screen.

14 **Milliken's Oil Drop Method.** This determines the charge on the electron. Let ρ be the density of oil, σ is the density of the medium in which oil drop moves and η the coefficient of viscosity of the medium, then the radius r of the drop is

$$r = \sqrt{\frac{9}{2}\frac{\eta v_0}{(\rho - \sigma)g}}$$

where v_0 is the terminal velocity of the drop under the effect of gravity alone. At the terminal velocity v_0, the force due to viscosity becomes equal to the electric weight of the body. The charge on oil drop is

$$q = \frac{18\pi\eta(v_1 + v_0)}{E}\sqrt{\frac{\eta v_0}{2(\rho - \sigma)g}}$$

where v_1 is the terminal velocity of the drop under the influence of electric field and gravity and E is the applied electric field.

15 **Photocell.** It is an arrangement which converts light energy into electric energy. It works on the principle of photoelectric effect. It is used in cinematography for the reproduction of sound.

16 **Dual Nature of Radiation:** Light has dual nature. It manifests itself as a wave in diffraction, interference, polarization, etc.,

while it shows particle nature in photoelectric effect, Compton scattering, etc.

17 **Dual Nature of Matter:** As there is complete equivalence between matter (mass) and radiation (energy) and the principle of symmetry is always obeyed, de Broglie suggested that moving particles like protons, neutrons, electrons, etc., should be associated with waves known as de Broglie waves and their wavelength is called de Broglie wavelength. The de Broglie wavelength of a particle of mass m moving with velocity v is given by

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

where h is Planck's constant.

18 **Davison and Germer Experiment.** This experiment confirms the existence of de Broglie waves associated with electrons.

19 **de Broglie Wavelength of an Electron.** The wavelength associated with an electron bean accelerated through a potential

$$\lambda = \frac{h}{\sqrt{2meV}} = \frac{12.3}{\sqrt{V}} \mathring{A}$$

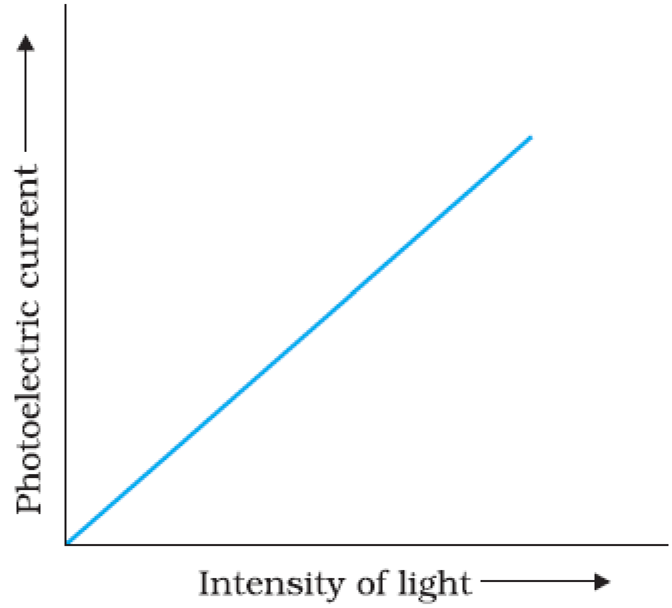
20 **Electron Microscope**: It is a device which makes use of accelerated electron beams to study very minute objects like viruses, microbes and the crystal structure of solids. It has a magnification of $\sim 10^5$.

TOP Formulae

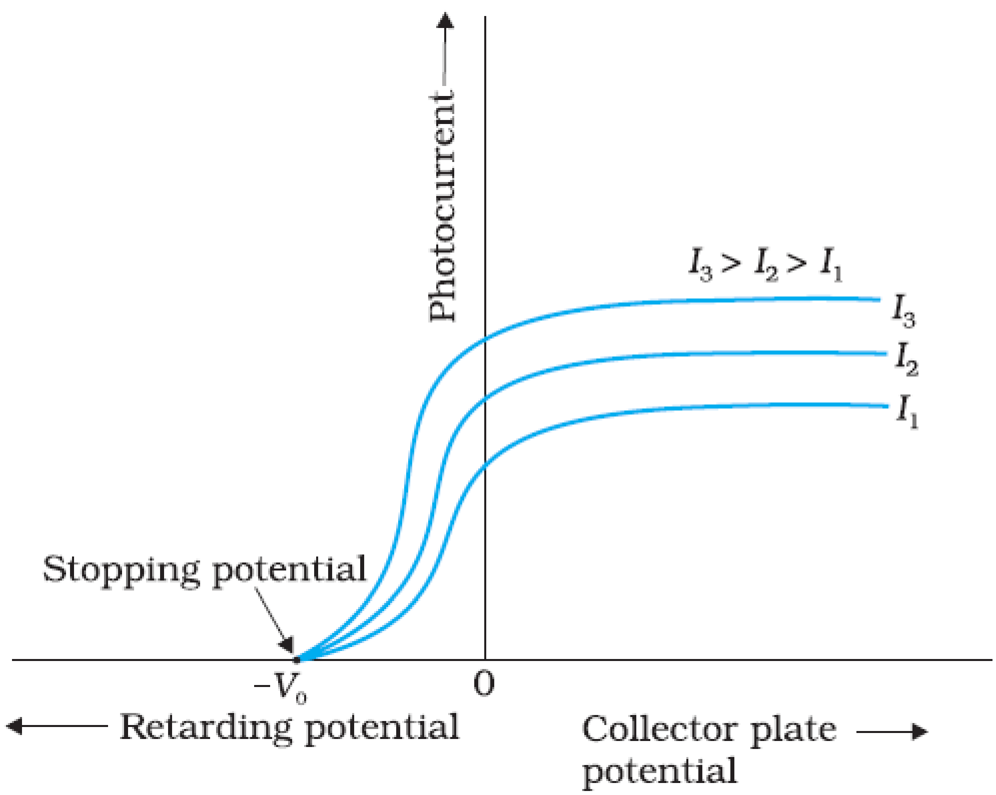
1. Maximum kinetic energy of the photoelectrons emitted from the metal surface: $K_{max} = eV_o = h\nu - \phi_o$ (Einstein's Photoelectric equation)
2. Work function of a metal surface:
   $w_o = \phi_o = h\nu_o$
3. de Broglie wavelength associated with the particle of momentum p is given as: $\lambda = \frac{h}{p} = \frac{h}{mv}$
   $\lambda = \frac{1.227}{\sqrt{V}}\,\text{nm}$, where V is the magnitude of accelerating potential
4. Heisenberg uncertainty principle:
   $\Delta x.\Delta p \approx h/2\pi$, where Δx is uncertainty in position & Δp is uncertainty in momentum

TOP Diagrams & Graphs:

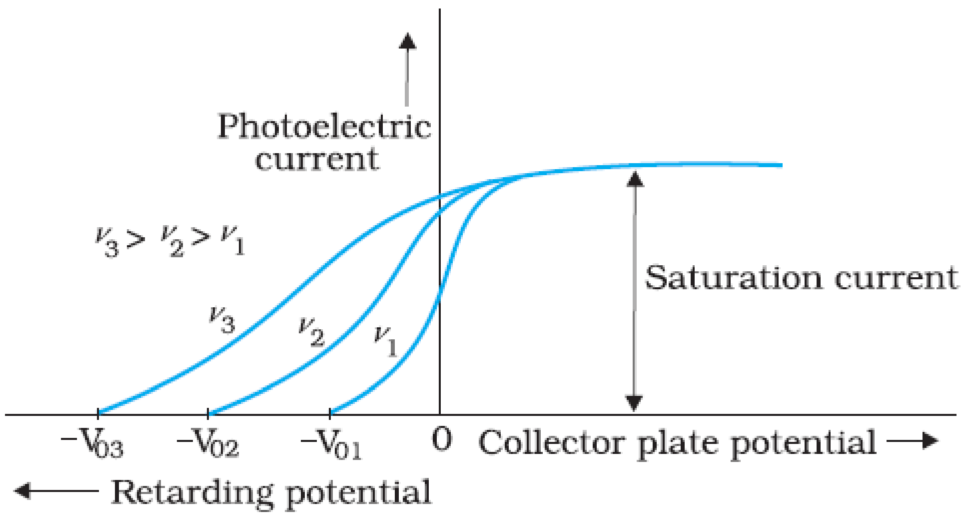
1. Variation of Photoelectron current with intensity of incident light:



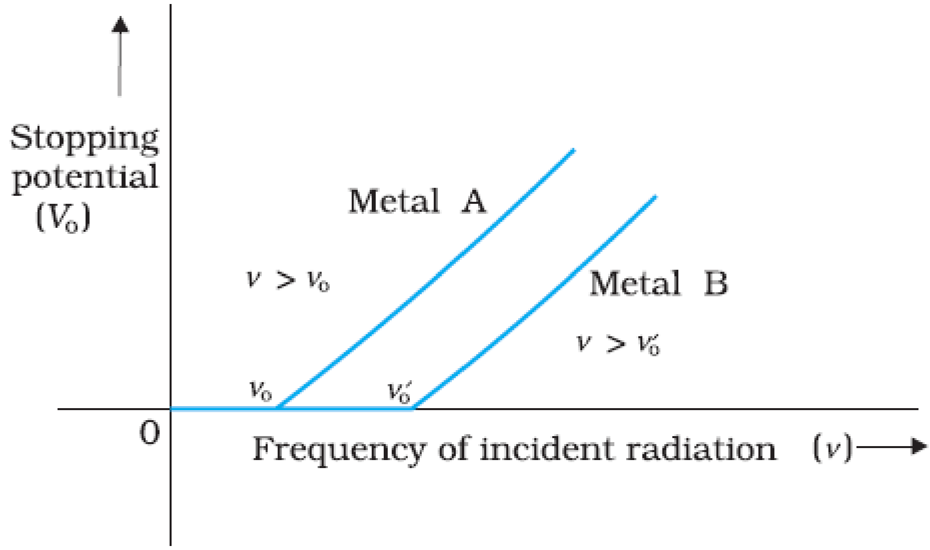
2. Variation of Photoelectron current with collector plate potential for different intensity of incident radiation



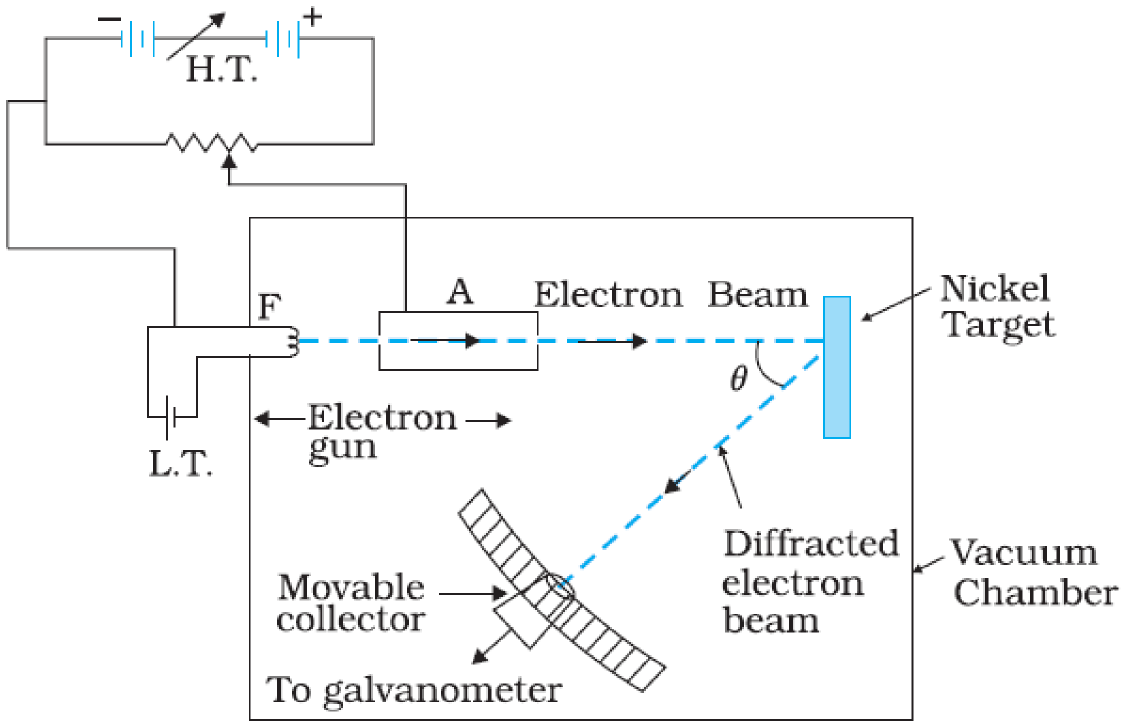
3. Variation of Photoelectron current with collector plate potential for different frequencies of incident radiation



4. Variation of stopping potential V_o with frequency ν of incident radiation for a given photosensitive material



5. David-Germar electron diffraction arrangement



H.T.
A
Electron Beam
Nickel Target
F
θ
Electron gun
L.T.
Diffracted electron beam
Vacuum Chamber
Movable collector
To galvanometer

PHYSICAL CONSTANTS & MATHEMATICAL FORMULAE

Physical Constants

electron charge	$e = 1.60\times10^{-19}$ C
electron mass	$m_e = 9.11\times10^{-31}$ kg $= 0.511$ MeV c^{-2}
proton mass	$m_p = 1.673\times10^{-27}$ kg $= 938.3$ MeV c^{-2}
neutron mass	$m_n = 1.675\times10^{-27}$ kg $= 939.6$ MeV c^{-2}
Planck's constant	$h = 6.63\times10^{-34}$ J s
Dirac's constant ($\hbar = h/2\pi$)	$\hbar = 1.05\times10^{-34}$ J s
Boltzmann's constant	$k_{\mathrm{B}} = 1.38\times10^{-23}$ J K^{-1} $= 8.62\times10^{-5}$ eV K^{-1}
speed of light in free space	$c = 299\,792\,458$ m s^{-1} $\approx 3.00\times10^{8}$ m s^{-1}
permittivity of free space	$\varepsilon_0 = 8.85\times10^{-12}$ F m^{-1}
permeability of free space	$\mu_0 = 4\pi\times10^{-7}$ H m^{-1}
Avogadro's constant	$N_{\mathrm{A}} = 6.02\times10^{23}$ mol^{-1}
gas constant	$R = 8.32$ J mol^{-1} K^{-1}
ideal gas volume (STP)	$V_0 = 22.4$ l mol^{-1}
gravitational constant	$G = 6.67\times10^{-11}$ N m^2 kg^{-2}
Rydberg constant	$R_\infty = 1.10\times10^{7}$ m^{-1}
Rydberg energy of hydrogen	$R_{\mathrm{H}} = 13.6$ eV
Bohr radius	$a_0 = 0.529\times10^{-10}$ m
Bohr magneton	$\mu_{\mathrm{B}} = 9.27\times10^{-24}$ J T^{-1}
fine structure constant	$\alpha \approx 1/137$
Wien displacement law constant	$b = 2.898\times10^{-3}$ m K
Stefan's constant	$\sigma = 5.67\times10^{-8}$ W m^{-2} K^{-4}
radiation density constant	$a = 7.55\times10^{-16}$ J m^{-3} K^{-4}
mass of the Sun	$M_\odot = 1.99\times10^{30}$ kg
radius of the Sun	$R_\odot = 6.96\times10^{8}$ m
luminosity of the Sun	$L_\odot = 3.85\times10^{26}$ W
mass of the Earth	$M_\oplus = 6.0\times10^{24}$ kg
radius of the Earth	$R_\oplus = 6.4\times10^{6}$ m

Conversion Factors

1 u (atomic mass unit) $= 1.66\times10^{-27}$ kg $= 931.5$ MeV c^{-2}	1 Å (angstrom) $= 10^{-10}$ m
1 astronomical unit $= 1.50\times10^{11}$ m	1 g (gravity) $= 9.81$ m s^{-2}
1 eV $= 1.60\times10^{-19}$ J	1 parsec $= 3.08\times10^{16}$ m
1 atmosphere $= 1.01\times10^{5}$ Pa	1 year $= 3.16\times10^{7}$ s

Polar Coordinates

$$x = r\cos\theta \qquad y = r\sin\theta \qquad \mathrm{d}A = r\ \mathrm{d}r\,\mathrm{d}\theta$$

$$\nabla^2 = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial}{\partial r}\right) + \frac{1}{r^2}\frac{\partial^2}{\partial\theta^2}$$

Spherical Coordinates

$$x = r\sin\theta\cos\phi \qquad y = r\sin\theta\sin\phi \qquad z = r\cos\theta \qquad \mathrm{d}V = r^2\sin\theta\ \mathrm{d}r\,\mathrm{d}\theta\,\mathrm{d}\phi$$

$$\nabla^2 = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial}{\partial r}\right) + \frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial}{\partial\theta}\right) + \frac{1}{r^2\sin^2\theta}\frac{\partial^2}{\partial\phi^2}$$

Calculus

$f(x)$	$f'(x)$	$f(x)$	$f'(x)$
x^n	nx^{n-1}	$\tan x$	$\sec^2 x$
e^x	e^x	$\sin^{-1}\left(\frac{x}{a}\right)$	$\frac{1}{\sqrt{a^2-x^2}}$
$\ln x = \log_e x$	$\frac{1}{x}$	$\cos^{-1}\left(\frac{x}{a}\right)$	$-\frac{1}{\sqrt{a^2-x^2}}$
$\sin x$	$\cos x$	$\tan^{-1}\left(\frac{x}{a}\right)$	$\frac{a}{a^2+x^2}$
$\cos x$	$-\sin x$	$\sinh^{-1}\left(\frac{x}{a}\right)$	$\frac{1}{\sqrt{x^2+a^2}}$
$\cosh x$	$\sinh x$	$\cosh^{-1}\left(\frac{x}{a}\right)$	$\frac{1}{\sqrt{x^2-a^2}}$
$\sinh x$	$\cosh x$	$\tanh^{-1}\left(\frac{x}{a}\right)$	$\frac{a}{a^2-x^2}$
$\mathrm{cosec}\, x$	$-\mathrm{cosec}\, x\ \cot x$	uv	$u'v + uv'$
$\sec x$	$\sec x\tan x$	u/v	$\frac{u'v-uv'}{v^2}$

Definite Integrals

$$\int_0^\infty x^n e^{-ax}\,\mathrm{d}x = \frac{n!}{a^{n+1}} \qquad (n \geq 0 \text{ and } a > 0)$$

$$\int_{-\infty}^{+\infty} e^{-ax^2}\,\mathrm{d}x = \sqrt{\frac{\pi}{a}}$$

$$\int_{-\infty}^{+\infty} x^2 e^{-ax^2}\,\mathrm{d}x = \frac{1}{2}\sqrt{\frac{\pi}{a^3}}$$

Integration by Parts: $$\int_a^b u(x)\frac{\mathrm{d}v(x)}{\mathrm{d}x}\,\mathrm{d}x = u(x)v(x)\Big|_a^b - \int_a^b \frac{\mathrm{d}u(x)}{\mathrm{d}x}v(x)\,\mathrm{d}x$$

Series Expansions

Taylor series: $f(x) = f(a) + \dfrac{(x-a)}{1!} f'(a) + \dfrac{(x-a)^2}{2!} f''(a) + \dfrac{(x-a)^3}{3!} f'''(a) + \cdots$

Binomial expansion: $(x+y)^n = \displaystyle\sum_{k=0}^{n} \binom{n}{k} x^{n-k} y^k$ and $\dbinom{n}{k} = \dfrac{n!}{(n-k)!k!}$

$(1+x)^n = 1 + nx + \dfrac{n(n-1)}{2!} x^2 + \cdots \qquad (|x| < 1)$

$e^x = 1 + x + \dfrac{x^2}{2!} + \dfrac{x^3}{3!} + \cdots\,,\quad \sin x = x - \dfrac{x^3}{3!} + \dfrac{x^5}{5!} - \cdots$ and $\cos x = 1 - \dfrac{x^2}{2!} + \dfrac{x^4}{4!} - \cdots$

$\ln(1+x) = \log_e(1+x) = x - \dfrac{x^2}{2} + \dfrac{x^3}{3} - \cdots \qquad (|x| < 1)$

Geometric series: $\displaystyle\sum_{k=0}^{n} r^k = \dfrac{1 - r^{n+1}}{1 - r}$

Stirling's formula: $\log_e N! = N \log_e N - N$ or $\ln N! = N \ln N - N$

Trigonometry

$\sin(a \pm b) = \sin a \;\cos b \pm \cos a \;\sin b$

$\cos(a \pm b) = \cos a \;\cos b \mp \sin a \;\sin b$

$\tan(a \pm b) = \dfrac{\tan a \pm \tan b}{1 \mp \tan a \;\tan b}$

$\sin 2a = 2 \sin a \;\cos a$

$\cos 2a = \cos^2 a - \sin^2 a = 2\cos^2 a - 1 = 1 - 2\sin^2 a$

$\sin a + \sin b = 2 \sin \tfrac{1}{2}(a+b) \cos \tfrac{1}{2}(a-b)$

$\sin a - \sin b = 2 \cos \tfrac{1}{2}(a+b) \sin \tfrac{1}{2}(a-b)$

$\cos a + \cos b = 2 \cos \tfrac{1}{2}(a+b) \cos \tfrac{1}{2}(a-b)$

$\cos a - \cos b = -2 \sin \tfrac{1}{2}(a+b) \sin \tfrac{1}{2}(a-b)$

$e^{\mathrm{i}\theta} = \cos\theta + \mathrm{i}\;\sin\theta$

$\cos\theta = \dfrac{1}{2}\left(e^{\mathrm{i}\theta} + e^{-\mathrm{i}\theta}\right)$ and $\sin\theta = \dfrac{1}{2\mathrm{i}}\left(e^{\mathrm{i}\theta} - e^{-\mathrm{i}\theta}\right)$

$\cosh\theta = \dfrac{1}{2}\left(e^{\theta} + e^{-\theta}\right)$ and $\sinh\theta = \dfrac{1}{2}\left(e^{\theta} - e^{-\theta}\right)$

Spherical geometry: $\dfrac{\sin a}{\sin A} = \dfrac{\sin b}{\sin B} = \dfrac{\sin c}{\sin C}$ and $\cos a = \cos b \;\cos c + \sin b \;\sin c \;\cos A$

Vector Calculus

$$\mathbf{A} \cdot \mathbf{B} = A_x B_x + A_y B_y + A_z B_z = A_j B_j$$

$$\mathbf{A} \times \mathbf{B} = (A_y B_z - A_z B_y)\, \hat{\mathbf{i}} + (A_z B_x - A_x B_z)\, \hat{\mathbf{j}} + (A_x B_y - A_y B_x)\, \hat{\mathbf{k}} = \epsilon_{ijk} A_j B_k$$

$$\mathbf{A} \times (\mathbf{B} \times \mathbf{C}) = (\mathbf{A} \cdot \mathbf{C})\mathbf{B} - (\mathbf{A} \cdot \mathbf{B})\mathbf{C}$$

$$\mathbf{A} \cdot (\mathbf{B} \times \mathbf{C}) = \mathbf{B} \cdot (\mathbf{C} \times \mathbf{A}) = \mathbf{C} \cdot (\mathbf{A} \times \mathbf{B})$$

$$\text{grad}\, \phi = \nabla \phi = \partial_j \phi = \frac{\partial \phi}{\partial x}\, \hat{\mathbf{i}} + \frac{\partial \phi}{\partial y}\, \hat{\mathbf{j}} + \frac{\partial \phi}{\partial z}\, \hat{\mathbf{k}}$$

$$\text{div}\, \mathbf{A} = \nabla \cdot \mathbf{A} = \partial_j A_j = \frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z}$$

$$\text{curl}\, \mathbf{A} = \nabla \times \mathbf{A} = \epsilon_{ijk} \partial_j A_k = \left(\frac{\partial A_z}{\partial y} - \frac{\partial A_y}{\partial z} \right) \hat{\mathbf{i}} + \left(\frac{\partial A_x}{\partial z} - \frac{\partial A_z}{\partial x} \right) \hat{\mathbf{j}} + \left(\frac{\partial A_y}{\partial x} - \frac{\partial A_x}{\partial y} \right) \hat{\mathbf{k}}$$

$$\nabla \cdot \nabla \phi = \nabla^2 \phi = \frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} + \frac{\partial^2 \phi}{\partial z^2}$$

$$\nabla \times (\nabla \phi) = 0 \qquad \text{and} \qquad \nabla \cdot (\nabla \times \mathbf{A}) = 0$$

$$\nabla \times (\nabla \times \mathbf{A}) = \nabla (\nabla \cdot \mathbf{A}) - \nabla^2 \mathbf{A}$$

Glossary Physics (*I-introduction*)

η - **Efficiency**: The percent of the work put into a machine that is converted into useful work output;

η = work done / energy used [-]. η = eta

In machines: The work output of any machine cannot exceed the work input (η<=100%); in an ideal machine, where no energy is transformed into heat: $work_{(input)} = work_{(output)}$, η=100%.

Energy: The property of a system that enables it to do work.

Conservation o. E.: Energy cannot be created or destroyed; it may be transformed from one form into another, but the total amount of energy never changes.

Equilibrium: The state of an object when not acted upon by a net force or net torque; an object in equilibrium may be at rest or moving at uniform velocity - not accelerating.

Mechanical E.: The state of an object or system of objects for which any impressed forces cancels to zero and no acceleration occurs.

Dynamic E.: Object is moving without experiencing acceleration.

Static E.: Object is at rest.F

Force: The influence that can cause an object to be accelerated or retarded; is always in the direction of the net force, hence a vector quantity; the four elementary forces are:

Electromagnetic F.: Is an attraction or repulsion between electric charges:

$F = 1/(4 \cdot \pi \cdot \varepsilon_0) \cdot (q_1 \cdot q_2/d^2)$ $[(C \cdot C/m^2) \cdot (N \cdot m^2/C^2)] = [N]$

Gravitational F.: Is a mutual attraction between all masses:

$F = G \cdot m \cdot M/d^2$ $[N \cdot m^2/kg^2 \cdot kg \cdot 1/m^2] = [N]$

Strong F.: (nuclear force) Acts within the nuclei of atoms:

$F = 1/(4 \cdot \pi \cdot \varepsilon_0) \cdot (e^2/d^2)$ $[(C \cdot C/m^2) \cdot (N \cdot m^2/C^2)] = [N]$

Weak F.: Manifests itself in special reactions among elementary particles, such as the reaction that occur in radioactive decay.

G, gravit. const.$\approx 6.672 \cdot E^{-11}[N \cdot m^2/kg^2]$	
d, distance	[m]
m,M, mass	[kg]
q, charge [A·s]	[C]
ε_0, dielectric constant	
$8.854 \cdot E^{-12}$ $[C^2/N \cdot m^2]$	[F/m]
π, 3.14	[-]
e, $1.602 \cdot 10\ E^{-19}$ [A·s]	[C]

Flux: The rate of flow of matter or energy across a unit area (see electromagnetism).

Horsepower: (*mechanics*) old unit for energy; 1 HP = 735,5W or approx. ¾ of a kW.

Inverse-Square Law: A law relating the intensity of an effect to the inverse square of the distance from the cause:

Intensity $\cong 1/distance^2$;

separating them: $F_G = G \cdot m \cdot M/d^2$ [N].

Spread of sound (see sound): $I_{S1} \cdot R_1 = I_{S2} \cdot R_2$ $[W/m^2]$

Electrostatic Force (see electromagnetics): $F = k_F \cdot q_1 \cdot q_2/d^2$ [N]

Light:I_L, light intensity (see optics): $I_{L1} \cdot R_1 = I_{L2} \cdot R_2$ $[Cd/m^2]$

G, gravit. const.$\approx 6.672 \cdot E^{-11}[N \cdot m^2/kg^2]$	
d, distance	[m]
m, M, mass	[kg]
I_S, sound intensity [J/s]	$[W/m^2]$
R, radius	[m]
k_F, coulomb c. $\approx 9 \cdot E^9$ $[N \cdot m^2/C^2]$	
q, charge [A·s]	[C]
I_L, light intensity	[Cd]

Mathematics - Graphs and Charts

Karthesian-; half-logarithmic-, double-logarithmic-; 3-D-charts

Slope: $y = m \cdot x + b$;

Circle: $(x-a)^2 + (y-b)^2 = r^2$; an orbit of negative energy, e.g. an orbit of a satellite ½·PE - (E<<0)

Ellipse: $x^2/a^2 + y^2/b^2 = 1$; orbit of negative energy - (E<0)

Hyperbola: $y = k \cdot x^2$; orbit of positive energy - extends to infinity - (E>0)

Parabola: $y = k/x$; orbit of almost 0 energy - extends to an ellipse; if E = 0 orbit extends to infinity;

Gradient: grad $\varphi = i \cdot \partial\varphi/\partial x + j \cdot \partial\varphi/\partial y + k \cdot \partial\varphi/\partial z$ = a vector quantity.

Divergenz: div$F = \partial F_x/\partial x + \partial F_y \partial/\partial y + \partial F_z/\partial z$ = a scalar quantity.

Right-Hand-Rule:

• (*mechanics*)	r, radius (middle finger) lever arm of screwdriver	[m]
product of force and lever arm	F, force (thumb)	[N]
τ = Fxr (maximum when F $\perp$ r)	τ, torque vector (index finger)	[N·m]
• (*mechanics*)	L, angular momentum (thumb)	$[kg \cdot m^2/s]$
Angular motion	I, momentum of inertia (p·v, index finger)	$[kg \cdot m^2]$
L = Ixω;	ω, angular speed (middle finger)	[1/s]
• (*magnetism*)	q·v, electrical current (index finger) [A·s·m/s]	[C·m/s]
magnetic force	B, magnetic field (middle finger) $[V \cdot s/m^2]$	[T]
$F_M = q \cdot vxB$	F, experienced force (thumb) $[kg \cdot m/s^2]$	[N]
• (*electromagnetism*)	EMW_P, wave propagation (thumb)	$[N^2 \cdot s/C^2]$
$EMW_P = ExB$	E, electrical field (index) [J/C] = [N·m/C]	[V/m]

Scalar: Independent of direction possesses only a scale, size; has nothing to doe with spatial orientation (such as length, temperature, time, mass, density, charge, volume etc.).
A vector quantity squared (see KE) will become a scalar quantity (compare vector).
S. **Quantity**: A quantity that has magnitude, but not direction. Examples are mass, volume, speed etc.
S. **Product**: Product of two vectors $A \cdot B = |A| \cdot |B| \cdot \cos(\theta)$ e.g., work $W = F \cdot d$; for $A \perp B$ $\cos(90) = 0$.

Vector: (*mechanics*) An arrow drawn to scale, used to represent a vector quantity (compare scalar); a vector quantity (velocity) multiplied with a scalar quantity (mass) will become a vector quantity (force).
V. **Quantity**: A quantity that has both magnitude and direction; e.g., force, velocity, acceleration, momentum, torque, electric-, magnetic fields etc.
Resultant V: The net result of a geometrical combination of two or more vectors found geometrically with the parallelogram-method or algebraically: $Ax + Bx = Cx$; $Ay + By = Cy$; $C = \sqrt{(Cx^2 + Cy^2)}$; $AxB = C$; $C = |A| \cdot |B| \cdot \sin(\theta)$; (see right-hand-rule).

SI - Base Units: (F. système international): Modern system of definitions and metric notation, now spreading throughout the academic, industrial, and commercial community; these are: ampere, area, joule, kelvin, kilogram, meter, mole, newton, rad, second, volume.

n **Amount of Substance** [mole]
The amount of substance that contains as many elementary entities (atoms, molecules, or other particles) as there are atoms in exactly 12 grams of ^{12}C isotope.

I **Electric Current** [ampere, A]
the flow of 1 coulomb (1C = 6.25 E^{18} electrons) of charge/s.

F **Force** [$kg \cdot m/s^2$] [newton, N]
the force that will give an object of 1 kg an acceleration of 1 m/s^2 = [kg m/s^2].

l **Lenght** [meter, m]
the length of the path traveled by light in vacuum during a time of 1/299792458 of a second. Area: [m^2]. Volume: [m^3] Quantity of space an object occupies.

L **Light Intensity** [N·m/(s·sr)] = [J/(s·sr)] = [W/sr] = [candela, Cd]
light intensity of a monochromatic radiation with a frequency of 540 E^{12} oscillations /s [Hz] with a power in the direction equal to 1/683 [Js or W/sterarian].

m,M **Mass** [kilogram, kg]
one kilogram is the amount of mass in 1 liter of water at 4°C.

rad **Radian**: The radian is the 2D plane angle between two radii of a circle which cut off on the circumference an arc equal in length to the radius: 1 rad = 57.3°; π rad = 180°;
sr - steradian: Is the solid 3D angle which, having its vertex in the center of a sphere, cuts off an area equal to that of a flat square with sides of length equal to the radius of the sphere.

T **Thermodynamic Temperature** [kelvin, K]
defined to be 1/273.15 the thermodynamic temperature of the triple point of water; ice melts therefore at 273.15 K and water boils at 373,15 K (both at atmospheric pressure).

T **Time**: Second [s]; the time taken by a ^{133} Cs-atom to make 9 192 631 770 vibrations.

W **Work** [N·m] [joule, J]
the specific heat of work at 15°C is given as 4185.5 J/kg·C done by a force of 1 newton acting over a distance of 1 meter.

SI-Derived Units:

ε_0	dielectric constant = $1/(\mu_0 \cdot c^2) = 8.8542 \cdot E^{-12}$	[$C^2/(N \cdot m^2)$] = [F/m]	in vacuum
γ	adiabatic exponent	[-]	
ρ	density	[kg/m^3]	
η	coefficient of efficiency	[-]	
η	viscosity index [$N \cdot s/m^2$]	[kg/s]	
λ	wavelength	[m]	
π	circle's constant = 3.14159	[-]	
Φ	magnetic flux [V·s]	[weber, Wb]	
μ	friction	[-]	
μ_0	permeability const. = $4 \cdot \pi \cdot 10^{-7}$	[T·m/A]=[V·s·m/(m^2·A)]=[N·s^2/C^2]=[N/A^2]	in vacuum
τ	torque	[N·m]	
ω	angular speed = $2\pi f = 2\pi/T$	[1/rad]	
$\Re$	gas constant = 8.314 510	[J/(mol·K)]	

a	acceleration	[m/s^2]	
A	area, cross-sectional area	[m^2]	
A	amplitude	[m]	
B	magn. field induction [V·s/m^2] = [J·s/(C·m^2)] = [tesla, T]		
c	speed of light 2.99792458·10^8 ≈ 3·10^8	[m/s]	sound 333 [m/s]
c	specific heat capacity	[N·m/(kg·K)]	[J/(kg·K)]
C	electric capacitance [C/V]	[farad, F]	
d	distance	[m]	
D	electric field	[V/m] = [J/(C·m)] = [N·m·C/m] = [N/C]	
e	charge of an electron = 1.602 177 3349·10^{-19}	[C]	
e	Euler's Constant 2.718 281 8 ≈ 2.718	[-]	
E	energy [kg·m^2/s^2] = [N·m]	[joule, J]	PE (potential e.), KE (kinetic e.)
E	electrical field [J/(C·m)] = [N·m/(C·m)]	[V/m]	
f	frequency [1/s]	[hertz, Hz]	
F	farad of capacity [A·s/V] = [A·s·C/J] = [C/V]	[F, farad]	
F	Faraday constant 9.649·E^4	[A·s/mol] = [C/mol]	
g	gravity on eart ≈ 9.81	[m/s^2]	
G	gravitational constant = 6.672 598 5·10^{-11}	[N·m^2/kg^2]	
h	plank's constant = 6.626 075 540·10^{-34}	[J·s]	
H	magnetic field= I/(2·π·d);	[A/m]	(see electromagnetics)
I	sound intensity	[W/m^2]	
I	unit; angular inertia	[kg·m^2]	
k_B	Boltzman's constant = 1,380 658 12·10^{-23}	[J/K]	
k_F	Coulomb's force constant = 8.987 551 79·10^9	[N·m^2/C^2] ≈ 9E^9 = 1/(4·π·ε_0)	
K	spring constant	[N/m]	
K_T	thermal conductivity	[W/(K·m)]	
l	length	[m]	
L	inductance [V·s/A]	[henry, H]	
L	angular momentum	[kg·m^2/s]	
m_e	mass of an electron = 9.109 389 754·E^{-31}	[kg]	
m_p	mass of a proton = 1.672 623 110·E^{-27}	[kg]	
m_n	mass of a neutron = 1.674 928 610·E^{-27}	[kg]	
n	index of refraction	[-]	
n_e	principle quantum number	[-]	
N	number of loops in an inductance	[-]	
N_A	Avogadro's constant = 6,022 136 736·E^{23}	[1/mol]	
p	linear momentum	[kg·m/s]	
p	pressure [N/m^2]	[pascal, Pa]	≈ 101300 [N/m^2] ≈ 10E^3 [kg/m^2]
P	power [J/s]	[watt, W]	
q	electric charge of an electron (see e) [A·s]	[coulomb, C]	
Q	heat capacity	[J]	1[eV] = 1.60E^{-19} [J]
r, R	radius	[m]	1[cal] = 4.178E^3 [J]
R	electric resistance [V/A] = [kg·m^2/(A^2·s^2)]	[ohm, Ω]	1[kWh] = 3.6E^3 [J]
S	conductance [A/V]	[siemens, S]	
S	entropy [kg·m/(s^2·K)] = [N·m/K]	[J/K]	
v	velocity	[m/s]	
V	electric potential [J/C]	[volt, V]	
V	volume	[m^3]	
X	reactance [V/A]	[ohm, Ω]	
y	height, elongation	[m]	
Z	impedance [V/A]	[ohm, Ω]	
	luminous flux [cd·sr]	[lumen, lm]	
	illuminance [cd·sr/m^2]	[lux, lx]	
	radioactivity [1/s]	[becquerel, Bq];	
	absorbed dose [J/kg]	[gray, Gy]	
	dose equivalent [J/kg]	[sievert, Sv]	

SI-Prefixes: E^{18} *exa*- E; E^{15} *peta*- P; E^{12} *tera*- T; E^9 *giga*- G; E^6 *mega*- M; E^3 *kilo*- k; E *deka*- d;
E^{-3} *milli*- m; E^{-6} *micro*- μ; E^{-9} *nano*- n; E^{-12} *pico*- p; E^{-15} *femto*- f; E^{-18} *atto*- a;

Glossary Physics *(II-mechanics)*

a - **Acceleration**: The rate at which velocity itself changes i.e. the rate at which an object's velocity changes with time; the change in velocity may be magnitude (speed), direction or both, therefore is a vector quantity: acceleration = change of velocity / time interval;
$a = v/t$ [m/s^2].
A. over a straight line:
Direction does not change a = change in speed / time interval

v, velocity	[m/s]	
t, time	[s]	

Collision: Momentum is conserved in collision, therefore changed in other forms of energy.
Elastic C.: A collision in which colliding objects rebound; no deformation or generation of heat.
Inelastic C.: The colliding objects become distorted and generates heat during the collision.

Energy: The property of a system that enables it to do work : KE + PE = constant!
Units in: [kg·m^2/s^2] = [N·m] = [J]
KE_A - **Angular Kinetic** E.:
Energy of motion; KE is proportional to the square of rotational velocity: $KE_A = ½·I·\omega^2$ [J]
KE_L **Linear Kinetic** E.: Energy of motion; KE is proportional to the square of velocity; $KE_L = ½·m·v^2$ [J]

I, angular inertia	[kg·m^2]
ω, angular velocity	[1/s]
m, mass	[kg]
v, linear velocity	[m/s]
g, grav. accelerat. 9.81	[m/s^2]
y, height	[m]

Net force times distance = work done in the change of KE;
PE **Potential** E.: The stored energy that a body possesses because of its position: $PE = m·g·y$ [J]

Equilibrium: It can be dynamic, static, mechanical, or rotational:
Mechanical E.: The state of an object or system of objects for which any impressed forces cancels to zero and no acceleration occurs.
Dynamic E.: Object is moving without experiencing acceleration.
Static E.: Object is at rest (stable, labile, indifferent, metastable).

Free Fall: Motion of an object, falling from high altitude under the influence of gravitational pull (see gravitation) friction of air neglected:
$v = g·t$ [m/s]
Distance traveled = ½ (the sum of the two speeds) x time;
$d = -½·g·t^2$ [m] (still without friction)
$v_T = \sqrt{(2·g·h)}$ [m/s]. (-"-, see terminal speed);

v, linear velocity	[m/s]
g, grav. accelerat. 9.81	[m/s^2]
y, elongation	[m]
t, time	[s]

F - **Force**: In classical mechanics it is the influence that can cause an object to be accelerated and is always in the direction of the net force, hence a vector quantity;
units in [kg·m/s^2] = [N]:
$F_L = m·a$ [N].
Centripetal F.: (L. petere, to seek) A center-seeking force that causes an object to follow a circular path.
$F_P = m·v^2/r = \omega·m·r$ [N].

m, mass	[kg]
a, acceleration	[m/s^2]
v, linear velocity	[m/s]
r, radis	[m]
ω, angular velocity	[1/s]

Centrifugal F.: (L. fugere, to flee) An outward force that is due to rotation; <u>in an inertial frame of reference</u>, it is fictions in the sense that it does not act on the rotating object but on whatever supplied the centripetal force; it is the reaction to centripetal force. <u>In a rotating frame of reference</u>, it does not act on the rotating body and is fictions in the sense that it is not an interaction with an agent or entity such as mass or charge but it is a force in itself that is solely a product of rotation; it has no reaction force counterpart.
<u>A fictitious force</u> arising in a rotating reference system. It points away from the center, in the direction opposite to the centripetal acceleration.
Coriolis F.: A fictitious force that occurs in rotating reference frames. It is responsible for the direction of the winds in hurricanes and water vortex.

F_F - **Friction**: The resistive forces that arise to oppose the motion or attempted motion of an object past another with which it is in contact
$F_F = \mu·F_N$ [N] $(\mu = \mu_r·\mu_0)$
(see matter - friction in liquids and gasses).

μ, friction coefficient	[-]
F_N, force ($F_F \perp F_N$)	[N]

g, G -**Gravitation**: Attraction between objects due to mass.

Acceleration due to G.: The acceleration of a freely falling object. Its value near the earth's surface is about 9.81 meters per second per second; constant on this planet, in average: $g = F/m = 9.81 [m/s^2]$ — F, force [N]; m, M mass [kg]

Center of Gravity: The average position of weight or the single point associated with an object where the force of gravity can be considered to act; usually identical with center of mass (compare weight).

G. **Field**: Gravitational forces interact, resulting in a reciprocal attraction of two or more objects; the field can be visualized as an up-side-down funnel and is considered a source field type: shielding of g-fields is not possible since only attracting forces have been observed: $g = F_G/m$ $[N/m^2]$

Law of universal G.: Every mass in the universe attracts every other mass with a force that for two masses is directly proportional to the product of the masses - and inversely proportional to the square of the distance separating them: $F_G = G \cdot m \cdot M/d^2$ [N]. — G, gravit. const. $6.672 \cdot 10^{-11}$ $[N \cdot m^2/kg^2]$; d, distance [m]

p - **Impulse**: Is the product of the force acting on an object and the time during which it acts; a vector quantity; (see also momentum); Relationship of Impulse and Momentum: Impulse is equal to the change in the momentum of the object that the impulse acts on

$p = F_{AV} \cdot t$ $(= m \cdot a \cdot \Delta t = m \cdot \Delta v \cdot \Delta t/\Delta t = m \cdot \Delta v)$ $[kg \cdot m/s]$

F, force	[N]
t, time	[s]
m, mass	[kg]
v, velocity	[m/s]

I - **Inertia**: (L. idleness) Is the tendency of an object to move forever without slowing down, in absence of retarding forces;

Linear I.: if at rest, the body tends to remain at rest; INERTIA = mass (see Newton's 1st law).

Angular (Rotational) I.: The property of an object to resist any change in its state of rotation: if rotating, it tends to remain rotating unless acted upon by a net external torque. $I = m \cdot r^2$ $[kg \cdot m^2]$. — r, radius [m]; m, mass [kg]

Inverse-Square Law: A law relating the intensity of an effect to the inverse square of the distance from the cause: Intensity $\cong 1/\text{distance}^2$:

gravitational force: $F_G = G \cdot m \cdot M/d^2$ [N]. (see gravitation)

Keppler's law of planetary motion:

1st law: Each planet moves in an <u>elliptical</u> orbit around the sun and with the sun at one focus.

2nd law: The line from the sun to any planet sweeps out <u>equal area</u> of space in <u>equal time</u> intervals — $A_1 = A_2$, area $[m^2]$

3rd law: The <u>squares</u> of the times of revolution (days, months, years) of the planets are proportional to the <u>cubes</u> of the average distances from the sun; $\underline{T^2 \approx R^3}$ for all planets. — R, radius [m]; T, period [s, h, min, d, mon, y]

m, M- **Mass**: The quantity of matter in a object, or concentrated energy ($E = m \cdot c^2$ see nuclear physics - mass). More specially the measurement of the inertia or sluggishness (drag) that an object exhibits in re-sponse to any effort made to start, stop, or change in any way its state of motion (see SI-units, weight).

Center o. M.: The average position of mass or the single point associated with an object where all the mass can be considered to be concentrated.

L - **Momentum**: (L. movere, to move) Inertia in motion; hence a vector quantity;

Angular (rotational) M.: A measure of an object's rotation about a particular axis; more specifically, the product of its rotation inertia and rotational velocity; for an object that is small compared to the radial distance, it is the product of mass, speed, and radial distance of rotation;

$L = I \cdot \omega = r x m \cdot v = r x p$ $[kg \cdot m^2 \cdot rad/s] = [kg \cdot m^2/s]$

$(r \perp p = r \perp m \cdot v)$; $\omega = v/r$

I, angular inertia	$[kg \cdot m^2]$
ω, angular speed	[rad/s]
m, mass	[kg]
r, radius	[m]
p, impulse	$[kg \cdot m/s]$

Conservation o. A. M.: When no external torque acts on an object or a system of objects, no change of angular momentum takes place. Hence, the angular momentum before an event involving only internal torques is equal to the angular momentum after the event.

Linear M.: The product of mass of an object and its velocity; proportional to velocity, (see impulse); $p = m \cdot v$ $(= F \cdot t)$ $[kg \cdot m/s]$

v, velocity	[m/s]
m, mass	[kg]
F, force $[kg \cdot m/s^2]$	[N]
t, time	[s]

Conservation o. L. M.: When no external net force acts o an object or a system of objects, no change of momentum takes place. Hence, the momentum before an event involving only internal forces is equal to the momentum after the event; $m \cdot v_{(\text{before event})} = m \cdot v_{(\text{after event})} = p$ (see collision).

N - **Newton**: The force that will give an object of 1 kg an acceleration of $1 m/s^2 = [kg \cdot m/s^2]$.(see SI-units).

1st law: Every material object continuous in its state of rest or uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it = LAW of INERTIA (a body in motion tends to stay in motion):
$F = 0; p = m \cdot v =$ constant

2nd law:. The acceleration of an object is directly proportional to the net force acting on the object, is in the direction of the net force and is inversely proportional to the mass of the object;
$F/m = a = v/t; F \cdot t = m \cdot v = p$ [kg·m/s] p changes with F.

F, force [N]
m, mass [kg]
p, impulse [kg·m/s]
t, time [s]
a, acceleration [m/s^2]

3rd law: Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first (conservation of linear momentum = actio est reactio).

N. **Cradle**: A little toy where a series of balls hooked onto thin threads exert an ideal example of an elastic colission and conservation of energy (PE + KE = constant).

P - **Power**: Equal the amount of work done per time unit it takes to do it;
1 watt of power is expended when 1 joule of work is done in 1 second;
$P = W/t$ [N·m/s] = [J/s] = [W]

W, work [N·m] [J]
t, time [s]

Projectile: Any object that is projected by some force and continues in motion by virtue of its own inertia.

Parabola P.: Any curved path followed by a projectile under the influence of gravitational attraction only.

v - **Speed**: Indicates how fast an object is;

Angular (Rotational) S.: The number of rotations or revolutions per unit of time; often RPM;
$v_A = r \cdot \omega = r \cdot \theta/t$ [m·rad/s] = [m/s]

Escape S.: The speed that a projectile, space probe, or similar object must reach to escape the gravitational influence of the earth or any other celestial body to which it is attracted:
$v_E = \sqrt{(2 \cdot G \cdot m/R)}$ [m/s].

r, R, radius [m]
ω, angular speed [rad/s]
θ, angle [rad]
t, time [s]
G, gravit. c. $6.672 \cdot 10^{-11}$ [$N \cdot m^2/kg^2$]
m, M mass [kg]
d, distance [m]

Linear S.: the time rate at which distance is covered by a moving object; (see velocity):
$v_L = d/t$ [m/s].

Average L. S.: Is the difference between total distance covered / total time interval:
$v_{AV} = (d_2 - d_1)/(t_2 - t_1)$ [m/s].

Orbital S.: $v_O = \sqrt{(G \cdot m/r^2)}$ [m/s]

Terminal S.: The speed at which the acceleration of a falling object terminates because friction balances the weight:
$v_T = \sqrt{(2 \cdot g \cdot y)}$ [m/s]

g, gravit. constant 9.81 [m/s^2]
y, height [m]

τ -**Torque**: The product of force and lever-arm distance, which tends to produce rotation:
$\tau = F \times r$ (for maximum yield: $F \perp r$; $F \cdot r \cdot \sin\theta$) [N·m] = [J]
the equivalent in linear mechanics is force (F).

F, force [N]
r, radius [m]
θ, angle [degree]

v -**Velocity**: Indicates how fast and in which *direction* an object moves; the specification of the speed of an object and its direction of motion, a vector quantity;
$v = d/t$ [m/s].

d, distance [m]
t, time [s]

Terminal V.: The speed and direction of a falling object at which acceleration reaches zero due to friction caused with air, balanced by weight:
$F = m \cdot a = -m \cdot g + m_B \cdot v^2$ (if $m \cdot g = m_B \cdot v^2$: $a = 0$)

a, acceleration [m/s^2]
$m_B = cw \cdot y \cdot A \cdot t/2$ (see friction - matter) =mass equivalent [kg]

w - **Weight**: The force due to gravity on an object (compare mass);
$w = m \cdot g = F$ (in the sense of gravitational force)

m, mass [kg]
g, grav. accelerat. 9.81 [m/s^2]

Weightlessness: A condition wherein gravitational pull appears to be lacking.

W -**Work**: Is the scalar product of the force and the distance through which the force moves; one joule of work is done when a force of 1 newton is exerted over a distance of 1 meter (compare power):
$W = F \cdot d$ [N·m] = [J].

F, force [N]
d, distance [m]

Glossary Physics (*III-properties of matter*)

Archimedes Principle.: An immersed body is buoyed up by a force equal to the weight of the fluid it displaces.
A.P. of **Flotation**: A floating object displaces a weight of fluid equal to its own weight.
A.P. of **Air**: An object surrounded by air is buoyed up with a force equal to the weight of displaced air.

Avogadro's Principle: Equal volumes of all gasses at the same temperature and pressure contain the same number of molecules (see Boyle-Mariott's law).

Barometer: Any device that measures atmospheric pressure.

Bernoulli's Effect: Any region in which the hydrostatic pressure ($\rho\cdot g\cdot y$) is constant; the pressure along any given streamline must decrease whenever the velocity of the fluid increases;
the all over pressure = hydrostatic + hydrodynamic pressure:
$p_0 = p_1 + ½\cdot\rho\cdot v_1^2 = p_2 + ½\cdot\rho\cdot v_2^2$ [Pa].
$p_1 + ½\cdot\rho\cdot v_1^2 + \rho\cdot g\cdot y_1 = \text{constant} = p_2 + ½\cdot\rho\cdot v_2^2 + \rho\cdot g\cdot y_2$
B. **Energy Effect**: A fluid that undergoes a pressure change undergoes an energy change
B. **Equation**: $\Delta W = \Delta KE\ (½\cdot m\cdot v^2) + PE\ (m\cdot g\cdot y)$
B. **Principle**: The pressure in a fluid decreases as fluid velocity increases.

ρ, density of liquid		[kg/m^3]
v, velocity of liquid		[m/s]
g, grav. accelerat.	9.81	[m/s^2]
y, height		[m]

Boyle-Marriot's Law: The product of pressure and volume is a constant for a given mass of a confined gas, regardless of changes in either pressure or volume individually, as long as the temperature remains unchanged; for ideal gases only:
$p \approx T$ (V = constant, isochor);
$p \approx 1/V$ (T = constant, isotherm);
$V \approx T$ (p = constant, isobar);
$p_1\cdot V_1 /T_1 = p_2\cdot V_2/T_2 = n\cdot\Re$
if $T_1 = T_2$: $p_1\cdot V_1 = \text{constant} = p_2\cdot V_2$

p, pressure [N/m^2]	[Pa]
V, volume	[m^3]
T, temperature	[K]
$\Re$ gas constant 8.3144	[J/mole·K]
n, amount o. substance	[mole]

Brownian Motion: The haphazard movement of tiny particles suspended in a gas or liquid resulting from bombardment by the fast-moving molecules of the gas or liquid (see heat - Maxwell-Boltzmann distribution); it ceases at absolute zero, i.e. 0 [K].
Consequences of the brownian motion are besides others, thermal-, and electrical background noise.

Capillary: The rise or fall of a liquid in a fine, hollow tube or in a narrow space.
Adhesion: Attraction between unlike substances; H_2O molecules are attracted to glass more than to H_2O;
Cohesion: The attraction between like substances.

ρ - **Density**: Mass of a substance per unit volume;
$\rho = m/V$ [kg/m^3]
Weight D.: Weight over volume
$\rho = m\cdot g/V$ [kg/m^3]

m, mass		[kg]
V, volume		[m^3]
g, accel. constat	9.81	[m/s^2]

Drag: The resistance to movement of an object through a medium, increasing with the viscosity and density of the medium and the surface area and shape of the object.

Displacement: A completely submerged object always displaces a volume of liquid equal to its own volume.

Elasticity: The property of a material wherein it changes shape when a deforming force acts on it, and returns to its original shape when the force is removed (see Hooke's law).

Flow: Motion of fluids in pipes show two distinct flow regimes (see viscosity and Reynolds principle):
Laminar F.: Turbulence-free flow of fluid in a vessel or past a moving object; a gradient (<u>parabolic</u> shape) of relative velocity exists in which the fluid layers closest to the wall or body have the lowest relative velocity (with maxim speed with the center of the circular tube and zero at the edges). Resistance (drop in pressure) of laminar flow rises linear with speed.
Turbulent F.: As the flow speed of real fluids increases; its ability to follow the contours of a solid obstacle decreases; it tears away of the surface and forms a wave of turbulence, that carries energy away (flow pattern doesn't follow a parabolic graph). Resistance of turbulent flow rises <u>nonlinear</u> with speed.

Force: It is the influence that cause an object to speed up or slow down, rise or sink; a vector quantity.
Buoyant F.: The net force (due to weight = m·g) that a fluid exerts on an immersed object.

F_F - **Friction**: The resistive forces that arise to oppose motion or of an object past another with which it is in contact;
Stoke's F.: Friction of a falling ball in a liquid:
$F_{FS} = 6 \cdot \pi \cdot \eta \cdot r \cdot v = 2 \cdot r \cdot \pi \cdot 3 \cdot \eta \cdot v$ [N]
Newton's F.: Friction of fast moving objects in gasses:
$F_{FN} = c_w \cdot \rho \cdot A \cdot v^2/2$ [N]

π, 3.14159 [-]
η, viscosity index [N·s/m²]
r, R radius [m]
v, velocity [m/s]
A, area [m²]
c_w, coeff. of resistance [N·s²/m²·m²]
ρ, density of medium [kg/m²]

Gas: Is the third state of matter (see state of matter).
Ideal G.: (see Boyle Mariott's law):
$p \cdot V = n \cdot \Re \cdot T$;
Real G.: $(p+p_I) \cdot (V-V_M) = n \cdot \Re \cdot T$ [m³·N/m²] = [N·m³].

n, amount o. substance [mole]
p, pressure [N/m²] [Pa]
p_I, internal gas pressure [Pa]

Hagen-Poiseuill's Law: In laminar flow, the flow is directly proportional to the driving pressure, and resistance is independent of flow; or the pressure difference required to maintain the flow, is directly proportional to the average speed of the flow rate of delivery:

$$\frac{V}{\Delta t} = \frac{\pi \cdot (p_2 - p_1) \cdot r^4}{8 \cdot \eta \cdot l} \quad [m^3/s] \quad \text{simplified: } V/t \approx r^4$$

a doubled radius result in a 16-fold increase of the rate of flow.

V, volume [m³]
V_M, volume o. molecule [m³]
T, temperature [K]
ℜ, gas constant 8.3144 [J/mole·K]
π, 3.14 [-]
η, viscosity index [kg/(s·m)]
l, length of tube [m]

Hooke's Law: The amount of a stretch or compression of an elastic material is directly proportional to the applied force e.g., spring;
Energy contained in a spring.: $ES = ½ \cdot K \cdot d^2$ [N·m/s] = [J/s] = [W]
Force of a Spring.: $F = - K \cdot d$ [N/m] = [N].

K, spring constant [N/m]
d, distance [m]

Hydrodynamic Paradox: A fluid escapes from a tube with a flattened end; if the end is positioned perpendicularly against a surface, the escaping liquid will actually press the tube against the surface; (see Bernoulli's principle for explanation).

Liquefaction: The critical point in isothermal compressed gasses; Under normal conditions a compressed gas will change into its liquid phase at a certain pressure (T constant); if, for example CO_2 is compressed below an isothermal temperature of 31.1°C , there will be an area where the gas won't be neither liquid nor gaseous, unless pressure rises further to pass beyond this area to reach definitely the liquid state.

Pascal's P.: The pressure applied to a fluid confined in a container is transmitted throughout the fluid and acts in all directions:
$F_1/A_1 = p = F_2/A_2$ [Pa]

F, force [N]
A, area [m²]
p, pressure [N/m²] [Pa]

Plasma: Hot matter beyond the gaseous state composed of electrically charged particles. The fourth state of matter, bare atomic nuclei and free electrons (see state of matter).

Pitot Tube: (also Prandt's -Tube) Device which allows the measurement of hydrodynamic pressures in liquids; it consists of a tube within a tube where the external tube with a tangential opening reads for the static pressure, and the central tube with a frontal opening reads for the dynamic pressure (used in airplanes):
$p_{total} = p_{static} + p_{dynamic}$ [Pa].

p - **Pressure**: The ratio of force to the area over which it is distributed:
$p = F/A$ [N/m²] = [Pa] (F ⊥ A);
Atmospheric P.: The pressure, exerted against bodies immersed in the atmosphere, that results from the weight and motion of molecules of atmospheric gases. At sea level, atmospheric pressure is about 101300 [N/m²] = [Pa] = $10 \cdot 10^3$ [kg/m²]
$p_y = p_0 \cdot e^{-y/H}$ [Pa].
Gas P.: Exerted momentum against the wall of the container x time;
$p_G = N_A \cdot k_B \cdot T/V$ [Pa]
Liquid P.: weight density x depth;
$p_L = m \cdot g/A$ = weight/area = $\rho \cdot V/A = \rho \cdot A \cdot y \cdot g/A = \rho \cdot y \cdot g$ [Pa].
Velocity of liquid leaking out of a jar caused by its own pressure:
$v_L = \sqrt{(2 \cdot g \cdot y)}$ [m/s];

p_0, pressure at sea level [Pa]
H, constant 8005 [m]
y, height [m]
k_B, Boltzmann c. $1.38 \cdot 10^{-23}$ [J/K]
N_A, Avogadro $6.02 \cdot 10^{23}$ [1/mole]
e, euler constant 2.718 [-]
V, volume [m³]
ρ, density [kg/m³]
m, mass [kg]
g, gravit. constant 9.81 [m/s²]

Reynold's Number: The tendency of a flowing gas or liquid to become turbulent is proportional to its velocity and density and inversely proportional to its viscosity; it indicates the change from laminar to turbulent flow; with an increase of speed, a laminar flow sooner or later will change into turbulent one:
$R_N = \rho \cdot v_{AV} \cdot d/\eta$ [-]

v_{AV}, average velocity [m/s]
η, viscosity index [kg/s]
d, diameter [m]
l, length [m]

Scaling: The study of how volume and shape (size) affect the relationship of weight, strength, and surface:
l : A : V = [m] : [m²] : [m³].

Surface Tension: The tendency of the surface of a liquid to contract in area and thus behave like a stretched rubber membrane.

State of Matter: solid, liquid, gaseous, plasma; (compare brownian motion).

Solid: Atoms and molecules vibrate about fixed positions in crystals, or amorphous arrays.

Liquid: If the rate of vibration is to increase (due to heat), molecules will shake apart and wander throughout the material - vibration about nonfixed positions - the shape of the material is no longer fixed but takes the shape of the container. - Melting Point: The lowest temperature at which a solid will begin to liquefy.

Gaseous: If more energy is put into the material, the molecules vibrate at even greater rates, they may break away from one another and assume gaseous state.

Plasma: Continuos heating causes the molecules to separate into atoms; if steam is heated to temperatures beyond ≈ 2000°C the atoms themselves will be shaken apart, making a gas of free electrons and bare nuclei, called plasma.

η - **Viscosity**: The internal resistance, or friction, offered to an object moving through a fluid $[N \cdot s/m^2] = [kg/(s \cdot m)]$

Glossary Physics (*IV-heat*)

Absolute Zero: The lowest possible temperature that a substance may have - the temperature at which molecules of a substance have their minimum kinetic energy; which is 0 [K] (compare matter - brownian motion).

Adiabatic Process: (Gk. adiabos, impassable) A process, usually of expansion or compression, wherein no heat enters or leaves a system. A gas which expands adiabatically does work, e.g., bicycle pump, sound propagation, etc.

A. **Expansion**: No heat enters the system; expansion therefore decreases internal available energy

A. **Compression**: No heat leaves the system; compression therefore increases internal energy.

A. **Equations**: Air has a low capacity to conduct heat, therefore can be viewed as adiabatically organized (not isothermal):

$T \cdot V^{\gamma-1}$ = constant	T, temperature	[K]
$T \cdot p^{(\gamma-1)/\gamma}$ = constant	V, volume	[m^3]
$p \cdot V^{\gamma}$ = constant	p, pressure [N/m^2]	[Pa]
γ = (possible axis of motion + 2)/(possible axis of motion)	γ, adiabatic exponent	[-]

Black Body: A body that absorbs all the radiation incident upon it (eye). Good absorbers (bad reflectors) are also good emitters e.g. a good transmission antenna is also a good receiver antenna; a black pot filled with hot water looses his heat (KE) faster than a white pot./ and v.v. (see radiation)

Boiling: A rapid state of evaporation that takes place within the liquid as well as at its surface. Water boils at 100 [°C], where the vapor pressure equals atmospheric pressure (it is the higher temperature that cooks food not the boiling process itself). As with evaporation, boiling is indeed a cooling process (boiling temperature does not exceed 100 [°C] at atmospheric condition until all the water molecules have been given the KE needed to liberate themselves. Boiling and freezing therefore can happen simultaneously in an under-pressurized chamber, as its done with freeze-dried coffee.

Calorie: Is defined as the amount of heat (KE) required to change the temperature of 1 gram of water by 1°C: 1 cal possesses a mechanical heat equivalent of $4.187 \cdot 10^3$ [J].

Clausius-Clapeyron's equation: The rise of the graph over increasing vapor pressure (gradient) reflects the specific energy of evaporation. The higher W_{EV} the steeper the slope:

	T, temperature	[K]
	p, pressure [N/m^2]	[Pa]
	V_V, spec. vol. of vapor	[m^3/kg]
$W_{EV} = T \cdot (V_V - V_L) \cdot dp/dT$ [N·m/kg] = [J/kg]	V_L, spec. vol. of liquid	[m^3/kg]

(see evaporation).

Condensation: The change of state from gas to liquid; opposed to evaporation. Warming of the liquid results.

Conductance: A quantity describing the ease with which heat flows by conduction under a temperature gradient across a substance or an object.

Convection: The mass transfer of heat due to mass movement of a gas or liquid.

η - **Efficiency**: The percent of the work put into a machine that is converted into useful work output; eta = η = work done / energy used [-];gas turbine 50% at 600K; car 25% at 350K (56% at 600k):

Thermal E.: Efficiency rises with increasing operation temperature:

$\eta = (T_{hot} - T_{cold})/T_{hot}$ [-] — T, temperature [K]

S - **Entropy**: A measure of the disorder of a system. Whenever energy freely transforms from one form to another, the direction of transformation is toward a state of greater disorder and therefore toward one of greater entropy:

$\Delta S = \Delta Q/T$ [N·m/K] = [J/K]	Q, inner heat energy [N·m] = [J]
e.g., crystals posses: order > entropy	T, temperature [K]
gas on the other hand: order < entropy	

Evaporation: The change of state at the surface of a liquid as it passes to the gaseous state. This is caused by the random motion of molecules (with higher KE) that occasionally escape from the liquid surface leaving behind a slightly cooler liquid. (see condensation).

Cooling of the liquid results as is proofed by a wetted cloth-	k_B, Boltzmann c. $1.38 \cdot 10^{-23}$ [J/K]
covered container (see also clausius equation):	T, temperature [K]
Such a liberated molecule possesses three levels of motion:	$\Re$ gas const.: 8.3144 [J/(mole·K)]
$E_{translation} + E_{rotation} + E_{oscillation}$	N_A, Avogadro const. 6.0221×10^{23} [1/mole]

$E_{EV} = 3 \cdot k_B \cdot T/2 = 3 \cdot \Re \cdot T/2 \cdot N_A = m \cdot v^2/2$ = KE [J]

the temperature of an ideal gas is proportional to the average translational KE of its molecules.

Fick's Law: Diffusion through a medium, in which the resulting motion of diffusion follows the least significant concentration (due to brownian motion) of the dissolved substance within the medium: $dn/dt = D\cdot\Delta n$ (laplace) $= D\cdot(\delta^2 n/\delta x^2 + \delta^2 n/\delta y^2 + \delta^2 n/\delta z^2)$; $n = N/V$
e.g.: ink dropped into a water filled jar will slowly diffuse throughout the solute.

D, coeff. of diffusion [m^2/s]
n = unit of substance [$1/m^3$]
N, number of units [-]
V, volume [m^3]

Greenhouse Effect: The heating effect of a medium such as glass or the earth's atmosphere that is transparent to the short-wavelength radiation of sunlight but opaque to long-wavelength terrestrial radiation. Energy of sunlight that enters the glass of a florist's greenhouse or the atmosphere of the earth is absorbed and reradiated at a longer wavelength that is consequently trapped, which produces heating.

Fourier's Law: The rate of flow of heat in a conducting body is proportional to its conductance to the temperature gradient.

Q -**Heat**: Energy in the form of molecular or atomic vibration that is transferred by conduction, convection, and radiation down a thermal gradient.
Matter doesn't contain heat but KE [J]; the kinetic energy that flows from a substance of higher temperature to a substance of lower temperature, commonly measured in calories or joules. Heat is the graveyard of useful energy:
heat transferred = mass x specific heat capacity x temperature change; $Q = m\cdot c\cdot\Delta T$ [J] (see below)
Heat added to as system = increase in internal energy + external work done by the system.
H. **Conduction**: The transfer and distribution of heat energy that moves from molecule to molecule within a substance.
H. **Convection**: The transfer of heat energy in a gas or liquid by means of currents in the heated fluid. The fluid moves, carrying energy with it. A fast moving molecule (warmer compared to others, hence higher in KE) tends to migrate towards the region of least obstruction - upward; warmer air rises.
Φ -H. **Current**: Occurs in bodies of different temperature, connected via a gaseous, liquid or solid medium following a source to sink pattern:
$\Phi = K_T\cdot A\cdot\Delta T/\Delta d$ [W]

K_T, thermal conductvty.[W/(K·m)]
A, area [m^2]
T, temperature [K]
d, distance [m]

H. **Radiation**: (see radiation).
H. **Wave**: Infrared (IR) light (see light - electromagnetic spectrum).
H. **Engine**: A changing internal energy to mechanical work, e.g. steam-, combustion-, jet-e, etc.
$W = \int p\cdot dV$ [N·m] = [J] - clockwise: engine does work; anti-clockwise.: engine needs work.
c - **Specific** H. **Capacity**: The quantity of heat per unit mass required to raise the temperature of a substance by 1 [°C];
$c = Q/(m\cdot\Delta T)$ [N·m/(kg·K)] = [J/(kg·K)]

Q, inner heat energy [N·m] = [J]
m, mass [kg]
T, temperature [K]

H. o. **Vaporization** of Water: 2.26 [MJ/kg] = 540 [cal/g]
H. o. **Fusion** of Water: 0.334 [MJ/kg] = 80 [cal/g]

Internal Energy: The total of all molecular energies, (KE + PE) internal to a substance. Changes in the internal energy are of principal concern in thermodynamics; the energy of being $E = m\cdot c^2$ [$kg\cdot m^2/s^2$].

Joule Thompson Effect: Compressed gasses undergo a "self"-heating effect; reciprocally when allowed to expand (through a choke-valve) cool off as used in fridges or bike-pump (see adiabatic):
$C_{JT} = \Delta T/\Delta p$ [K/Pa]

T, temperature [K]
p, pressure [N/m^2] [Pa]

Maxwell-Boltzmann Speed Distribution: Displays the most probable spectrum of molecular speeds available to the system at a particular temperature; e.g. molecular oxygen has an average speed of 200[m/s] at 73[K], whereas it increases to about 400[m/s] at 273[K] (compare Brownian motion); see chemistry - gas.

Newton's law of Cooling: The rate of the loss of heat with time from an object is proportional to the excess temperature of the substance over temperature of its surrounding.
Rate of cooling $\approx \Delta T$.

Perpetual motion machine: Hypothetical devices to extract energy from nowhere to do work.
1st kind: A device that supplies an endless output of work without any input of fuel or any other input of energy (violates the first law of thermodynamics)
2nd kind: A device that extracts thermal energy from some heat source, such as air or water , and converts it into mechanical energy (violates the 2nd law of thermodynamics).

Radiation: The transport of energy via electromagnetic waves (EMW) at the speed of light by means of electromagnetic waves without touching the hot object (don't mix up with radioactivity).
Low-temperature objects emit long waves, high-temperature objects emit shorter wavelengths.
Planck's law of Radiation of a Black Body: Emission of a

h, Planck con.:$6.63\cdot 10^{-34}$[J·s]
f, frequency [1/s] [Hz]

beam of single photons of a heated black body with the energy: c, speed o. light $3\cdot10^8$ [m/s]
$E = h\cdot f$ k_B, Boltzmann $1.38\cdot10^{-23}$ [J/K]
$I_V = 2\cdot h\cdot f^3/(c^2\cdot e^{h\cdot f/(k_B\cdot T)}-1)$ [J/(m²·sr)] T, temperature [K]

Thermal R.: A broad continous range of frequencies that arise out of the electromagnetic interactions among the atoms of solid, liquid and dense gases, mostly in infrared (IR), the higher the temperature the more energy (and usually the brighter) is irradiated per second (see black body).

Regelation: The process of melting under pressure and the subsequent refreezing when the pressure is removed. e, euler constant 2.718 [-]

Solar Constant: 1400 [J/m²] received from the sun each second at the top of the earth's atmosphere; 1400 [N·m/(s²·m²)] = [J/(s·m²)]; expressed in terms of power: 1.4 [kW/m²].

S. **Power**: Energy per unit time derived from the sun.

Temperature: The quantity that tells how warm an object is, with respect to some reference. A measure of the average kinetic energy per molecule in a substance, measured in [°C] or in [K].

T. **Inversion**: The condition wherein the upper regions of the atmosphere are warmer than the lower.

Thermodynamics: (Gk. therme, heat; dynamics, power) The study of heat (KE) and its transformation to other forms of energy.

1st Law of TD.: States that in all processes, the total energy of the universe remains constant (energy conservation - energy cannot be lost or gained, just transformed).
$E_{final} - E_{initial} = dE = Q+W$ [N·m] = [J]

2nd Law of TD.: States that the entropy, or degree of randomness, tends to increase. Heat will never spontaneously flow from a cold object to a hot object. Also, no machine can be completely efficient in converting energy to work ($\eta < 100\%$); some input energy is dissipated as heat. And finally, all systems tend to become more and more disordered as time goes by.
$W = F\cdot d\cdot\eta$ [kg·m/s²] = [N·m] = [J].

F, force [N]
d, distance [m]
η, efficiency [-]

3rd Law of TD.: Any entropy changes in an isothermal reversible process approach zero as the temperature approaches zero;
entropy of chemically pure perfect crystals is zero at temperature T= 0K,
$dS = S-S_0 = k_B\cdot\ln\Gamma$ S, entropy [J/K]
$\Gamma = W_{macrostate} / W_{microstate}$ k_B, Boltzmann $1.38\cdot10^{-23}$ [J/K]
e.g. a binary system has 4 micro- & 2 macrostates, thus Γ =0.5

Triple Point: The point at which the vapor, liquid, and solid states of a substance are in equilibrium; TP of water occurs at 0.01[°C] (273.16[K]) at 1/166 of atmospheric pressure or 608 [Pa].

Glossary *(V-sound and waves)*

Beat: A series of alternative reinforcements and cancellations produced by the interference of two sets of superimposed waves of different frequencies, heard as a throbbing effect in sound waves; periodic variations in the loudness of closely matched but still not identical frequencies (D.: schwebung).

Compression: Condensed region of the medium through which a longitudinal wave travels; in a standing wave pattern the antinodes (see refraction).

Doppler Effect: The change in frequency of wave motion resulting from motion of the sender or receiver; the pitch of sound increases (higher f) when the source moves toward the observer, and decreases (lower f) when the source moves away; in astronomic: a blue shift reads for an increase in f, and a red shift reads a decrease in shift; $f = f_0 \cdot (1 \pm v_O/c)/(1 \pm v_S/c)$ [Hz]

f_0, initial frequency [1/s] [Hz]
v_O, velocity of observer [m/s]
v_S, velocity of sender [m/s]
c, speed of light $\approx 3 \cdot 10^8$ [m/s]
or speed of sound 333 [m/s]
"-" receding, "+" approaching

Forced Vibration: The setting up of vibrations in an object by a vibrating force; usually the wooden or resonance body of an instrument or the box on which a tuning fork is mounted.

Fourier Analysis: A mathematical method that will resolve any periodic wave form into a series of simple sine waves = superposition of fundamentals + their multiple harmonics:
$y(t) = A_0 + \Sigma A_n \cdot \sin(n \cdot \omega \cdot t) = A_0 + \Sigma A_n \cdot \sin(n \cdot 2 \cdot \pi \cdot f \cdot t)$

f - **Frequency**: For a body undergoing simple harmonic motion (SHM), the number of vibrations it makes per unit time (vibrations per second)
$f = 1/T$ [1/s] = hertz, [Hz]
Fundamental F.: Lowest frequency of vibration - (1st harmonic).
Natural F.: A frequency at which an elastic object naturally tends to vibrate, so that minimum energy is required to produce a forced vibration or to continue vibration at that frequency; e.g. mass on a spring, pendulum, etc.
Resonance F.: The result of forced vibration in a body when an amplified frequency matches the natural frequency of the body.

A, amplitude [m]
A_n, amplitude of n^{th} harmonic [m]
n, integer; 1st, 2nd, 3rd harmonic [-]
ω, angular velocity [1/s]
t, time [s]
T, period [s]
π, 3.14 [-]

Harmonic: A partial tone that is an integer multiple of the fundamental frequency; examples listed below refer to the fixed or open ends: chord - both end fixed; tuning fork - one fixed one open; dipole antenna with both open ends;
1st H.: The fundamental frequency; e.g.: standing wave - chord: $\lambda/2$; tuning-fork: $\lambda/2$; antenna: $\lambda/2$;
2nd H.: Twice the fundamental frequency chord: $2 \cdot \lambda/2$; t.-fork: $2 \cdot 2 \cdot \lambda/2$; ant.: $2 \cdot 2 \cdot \lambda/2$;
3rd H.: Three times the fundamental frequency, etc. chord: $3 \cdot \lambda/2$; t.-fork: $3 \cdot 2 \cdot \lambda/2$; ant.: $3 \cdot 2 \cdot \lambda/2$;
Simple H. Motion (SHM) : A mass hooked onto a spring (see matter - Hooke's law)
$y = y_0 \cdot \sin(n \cdot \omega \cdot t)$ [m]
whereas: $\omega = 2 \cdot \pi \cdot f = 2 \cdot \pi / T$

y_0, amplitude [m]
π, 3.14 [-]
n, integer; 1st, 2nd, 3rd harmonic [-]

Inverse-Square Law: Law relating the intensity of an effect to the inverse square of the distance from the cause:
Intensity $\cong$ 1/distance^2;
Spread of sound: $I_{S1} \cdot R_1 = I_{S2} \cdot R_2$

f, frequency [1/s] [Hz]
T, period [s]
I_S, sound intensity [J/s] [W/m^2]
R, radius [m]

Interference Pattern: The pattern formed by superposition of different sets of waves that produces mutual reinforcement in some places and cancellation in others.
Constructive I.: Addition, resulting in a wave with increased amplitude.
Destructive I.: Addition, resulting in a wave with decreased or no amplitude or a so called out of phase effect.

Laplace's Eq: Sound is considered to be an adiabatic pressure wave; the pressure differences can not equalize each other; (see heat - adiabatic), hence speed of sound in gasses:
$v_{sound} = \sqrt{(c_{cp} \cdot p / c_{cv} \cdot \rho)}$ [m/s]

p, pressure [N/m^2] [Pa]
c; spec.heat capacity [N·m/(Kg·K)]
$_{cv}$ constant volume
$_{cp}$ constant pressure

Loudness: The physiological sensation directly related to sound intensity or volume. Relative loudness or soundlevel:
Intensity level $I_{S\,L} = 10 \cdot \log(I_S/I_{S0})$ [decibel, dB]

v, velocity [m/s]
ρ, density [kg/m^3]
I_S, I_{S0}, sound intensity [W/m^2]

Modulation: (L. modulare, to form) The process of impressing one wave system upon another of higher frequency.

Amplitude (AM)-M.: A type of modulation in which the amplitude of the carrier wave is varied above and below its normal value by an amount proportional to the amplitude of the impressed wave.

Frequency (FM)-M.: A type of modulation in which the frequency of the carrier wave varies above and below its normal frequency by an amount that is proportional to the amplitude of the impressed signal; in this case, the amplitude of the modulated carrier wave remains the same.

Oscillation: To and fro-vibratory motion (see also wave): SHM_O: $e^{i\varphi} = \cos\varphi + i\cdot\sin\varphi$;

The speed at which damping a SHM occurs can be written as:

$v = dy/dt = \omega\cdot y_0\cdot\cos(\omega\cdot t)$, resulting in a phase-shift of 90°, hence sin → cos:

$y(t) = y_0\cdot e^{-\delta t}\cdot\cos(\omega\cdot t)$ [m],

Damped O.: An oscillating system looses energy due to friction replacing the sinusoidal behavior of a SHM by a damped non-harmonic motion that gradually dies away.

Critically dampened.: (aperiodic) smooth stop y = 0:

$y(t) = y_0\cdot e^{-\delta t}$ [m]

$\delta\cdot t = 0$; $e^0 = 1$: undampened oscillation;

$\delta\cdot t < 0$; $e^{+\delta\cdot t} < 1$: dampened oscillation;

$\delta\cdot t > 0$; $e^{-\delta\cdot t} > 1$: feedback looped oscillation

Overdamp.: stops suddenly without returning to zero.

Underdamp.: slow stop, with many aftershakes,

experiencing a period-expansion (change in frequency):

$y(t) = y_0\cdot e^{-\delta t}\,(\omega_s\cdot\omega\cdot t)$ [m].

$\delta = \mu_K/(2\cdot m)$		
μ_K, friction const.	[-]
m, mass	[kg]
y_0, elongation	[m]
t, time	[s]
e, euler constant 2.178	[-]

Partial Tone: One of the frequencies present in a complex tone. When a partial tone is an integer multiple of the lowest frequency, it is a harmonic, and can be traced with the help of Fourier Analysis.

Pendulum: Mass hooked onto a string; Period of swing is determined by the length of the string and gravity (but not of mass):

$T = 2\cdot\pi\cdot\sqrt{(l/g)}$ [s].

π, 3.14	[-]
l, length	[m]
g, gravitat. const 9.81	[m/s^2]

T - **Period**: The time required for a vibration / wave to complete one cycle:

$T = 1/f$ [s]

f, frequency	[1/s]

Pitch: The "high-" or "lowness" of a tone, as on a musical scale, which is principally governed by frequency.

Refraction: Rarefied region, or region of lessened pressure, of the medium through which a longitudinal wave travels; in a standing wave pattern the nodes (see compression).

Resonance:(L. resonare, to resound) see frequency.

Acoustic R.: A struck tuning fork passes its frequency (through the medium of air) to another silent tuning fork with an identical tuning frequency its energy (coupled via air).

Sine curve: Characterized by an amplitude (y) and wavelength (λ) or frequency (f) (see wave).

Sound: A longitudinal wave phenomenon that consists of successive compression and refractions of the medium through which the wave travels (see Laplace).

Infrasonic: A sound of a frequency too low to be heard by the normal human ear - below 20 [Hz].

Ultrasonic: A sound of a frequency too high to be heard by the normal human ear - above 20[kHz].

Sonic Boom: The loud sound resulting from the incidence of a shock wave.

Speed of .S.: In a medium such as air sound is highly dependent upon temperature: 330 [m/s] at 0°C; 340[m/s] at 20°C, since hotter air has more KE, therefore molecules vibrate more vigorous, therefore conduct sound better; sound channeling occurs in layers of hot and cold air.

I_S - **Sound Intensity**: The average power radiating divided by the perpendicular area across which it is transported:

$I_S = P_{AV}/A$ [W/m^2].

P_{AV}, average power	[W]
A, area	[m^2]

Wave: also sine curve: A wave form traced by a simple harmonic motion that is uniformly moving in a perpendicular direction (amplitude), like the wavelike path traced on a moving conveyor belt by a pendulum swinging at right angles above a moving belt (time).

y, A - W. **Amplitude**: The maximum displacement on either side of the equilibrium (midpoint) position.

W. **Barrier**: When the speed of an object is as great as the speed of the waves in the medium it moves.

W. **Equation**: Describes the wave in time and space:

$\partial^2u/\partial x^2 + \partial^2u/\partial y^2 + \partial^2u/\partial z^2 = (1/v^2)\cdot\partial^2u/\partial t^2$

v, velocity	[m/s]
u (x,y,z,t), elongation in space & time	

W. **Motion**: The transfer of energy from a source to a distant receiver without the transfer of matter:

$E = h\cdot f = h\cdot c/\lambda$ [Js·m/s·1/m)] = [J]

Bow W.: The V-shaped 2D wave of a moving object across

f, frequency	[1/s]
h, Plank's constant $6.626\text{x}10^{-34}$	[J·s]
c, speed of light $\approx 3\cdot 10^8$	[m/s]
λ, wavelength	[m]

a liquid surface at a speed greater than the wave-speed; can
lead to a water boom (see sonic boom).
Carrier W.: The wave, usually of radio frequency, whose characteristics are modified in the process of modulation, used to transport information from any high frequency transmitter to a HF-receiver.
Group W.: A gravitational disturbance made by moving mass that propagates through space-time.
Longitudinal W.: A wave in which the individual particles of a medium vibrate back and forth in a direction parallel (longitudinal) to the direction in which the wave travels. Sound consists of longitudinal waves (see FM-modulation).
Shock W.: The 3D cone-shaped wave made by an object moving at supersonic speed through a fluid.
Standing W.: A stationary wave pattern formed in a medium when two sets of identical waves pass through the medium in opposite directions; e.g., a rope with partly stationary segments (nodes), whereas others oscillate vibrantly (antinodes - half way between successive nodes); or Cladnic figures.
Transverse W.: A wave in which the individual particles of a medium vibrate from side to side in a direction perpendicular (transverse) to the direction in which the wave travels; light consists of transverse waves (see AM-modulation).
λ- **Wavelength**: The distance between successive crests, throughs, or identical parts of a wave [m].
Wavespeed: The speed with which waves pass by a particular point; in water is usually slower than its frequency (group-wave velocity $\neq$ phase velocity)

$v = f \cdot \lambda$ [m/s]	f, frequency	[1/s]
	λ, wavelength	[m]

Glossary Physics *(VI-electricity and magnetics)*

Capacity: The ability of a capacitor or other body to store electric charge: The unit of measure is farad [F], which describes the proportionality between charge stored and potential for a given voltage: C = q/V [F]

C - **Capacitor**: An electrical device, in its simplest form a pair of parallel conducting plates separated by a small distance, that stores electric charge: $C = q/V = \varepsilon \cdot A/d$ [C/V] = [F] ($\varepsilon = \varepsilon_0 \cdot \varepsilon_r$)

q, charge [A·s] [C]
V, voltage [J/C] [V]
ε_0, dielectr. c. $8.85 \cdot 10^{-12}$ [$C^2/N \cdot m^2$]
A, area [m^2]
d. distance [m]

q - **Charge**: Is a whole number multiple of one electron and cannot be quantized below it (1e or 1p-net charge); no net charge has ever been found - it can't be created or destroyed, only transformed (compare 1st law of thermodynamics) $e = 1.602\ 18 \cdot 10^{-19}$ [As] = [C]. Like charges repel, opposite charges attract; electric charges can be isolated, magnet poles cannot.

Charging by contact: The transfer of charge from one substance to another by physical contact between substances; (see Van de Graaff's generator).

Charging by induction: The change in charge of a grounded object, caused by the electrical influence of electric charge close by, but not in contact; as it happens in a thunderstorm. either

V, voltage [J/C] [V]
I, current [C/s] [A]

Circuit: Network of electrical components connected in parallel, serial or mixed arrangement.

Parallel C.: An electric circuit with two or more electric elements (R, L, C) arranged in branches in such a way that any single one completes the circuit independently of all the others.
Equivalent capacity $C_E = C_1 + C_2 + C_N$ $V_1 = V_2 = V_N$ $I = I_1 + I_2 + I_N$
Equivalent resistor $R_E = 1/(1/R_1 + 1/R_2 + 1/R_N)$ $V_1 = V_2 = V_N$ $I = I_1 + I_2 + I_N$

Serial C.: An electric circuit with two or more electric elements (R, L, C) arranged in a sequential order, in such a way that any single follows a chain one after the other.
Equivalent capacity $C_E = 1/(1/C_1 + 1/C_2 + 1/C_N)$ $V = V_1 + V_2 + V_N$ $I_1 = I_2 = I_N$
Equivalent resistor $R_E = R_1 + R_2 + R_N$ $V = V_1 + V_2 + V_N$ $I_1 = I_2 = I_N$

RC-RL C.: A serial arrangement of a resistor and a capacity or inductance have a distinct charge- and discharge pattern, which follows an exponential graph:
C: charging: $V_C = V_0 \cdot (1-e^{-t/(R \cdot C)})$ discharging: $V_C = V_0 \cdot e^{-t/(R \cdot C)}$ [V]
L: charging: $I_L = I_0 \cdot (1-e^{-t/(R \cdot L)})$ discharging: $I_L = I_0 \cdot e^{-t/(R \cdot L)}$ [A]

t, time [s]
R, resistance [V/A] [Ω]
C, capacity [C/V] [F]
L, inductance [V·s/A] [H]
e, euler constant 2.718 [-]

C - **Coulomb**: The SI unit of electrical charge. One coulomb is equal to the total charge of $6.25 \cdot 10^{18}$ electrons transferred in 1[s] by 1[A].

Coulomb's law: The relationship among electrical force, charge, and distance:
$F = k_F \cdot q_1 \cdot q_2 / d^2$ [$Nm^2/C^2 \cdot C^2/m^2$] = [N]
If the charges are alike in sign, the force is repelling;
If the charges are unlike, the force is attractive.

k_F, coulomb c. $\approx 9 \cdot 10^9$ [$N \cdot m^2/C^2$]
q, charge [A·s] [C]
d, distance [m]

G - **Conductance**: A measure of the ease with which a conductor carries an electric current; the unit is the siemens [S] and is reciprocal to ohm [Ω].

Conductor: Any material through which charge easily flows (carries electric current) when subject an external electrical force; are also good heat conductors as well; electrons in the outer atomic shell are loose (valence shell).

Conductivity: The intrinsic property of a substance to conduct electric current; reciprocal to resistivity.

I - **Current**: By convention the energy transport or the flow of a positive electric charge (cation) from anode to cathode. Measured in amperes, where 1[A] is the flow of 6.25×10^{18} electrons per second.

Alternating current (AC): Electric current that repeatedly reverses its directions; the electric charges vibrate about relatively fixed points:
$I = I_{eff} = I_{peak}/\sqrt{2}$ [A]

I_{eff}, DC equivalent [A]
I_{peak}, AC peak, max [A]

Direct current (DC): An electric current flowing in one direction only.

Dielectric Constant: A measure of the degree to which a substance is able to store electric charge under an applied voltage; depends on charge distribution within molecules.

Electrically polarized: Term applied to an atom or molecule in which the charges are aligned so that one side is slightly more positive or negative than the opposite side; e.g. water, is an electrical dipole.

Electric Potential: Electrostatic pressure or potential difference (see potential, voltage).

Electrostatics: The study of electric charges at rest relative to one another

μ_0, permeability c. $4 \cdot \pi \cdot 10^{-7}$[T·m/A] (not in motion, as in currents). μ_r, rel. permeability [-]

Electromagnet: A magnet whose field is produced by an electric current. I, current [C/s] [A]

Usually in the form of a wire coil wrapped around a piece of iron: π, 3.14 [-]

$B = \mu \cdot I/(2 \cdot \pi \cdot r) = \mu \cdot H$ [N·s/(A·s·m)] = [N·s/(C·m)] = [T] r, radius [m]

$\mu = \mu_0 \cdot \mu_r$

Electromagnetic Induction: The induction of voltage when a magnetic field changes with time. If the magnetic field within a closed loop changes in any way, a voltage is induced in the loop (see Faraday's law): Voltage induced = - number of loops times mag. Field change/time:

$V_{ind} = -N \cdot d\phi/dt$ [V] N, number of loops [-]

It is a statement of Faraday's law. The induction of voltage is actually the result of a more fundamental phenomenon: the in- -duction of an electric field, as defined for the more general case.

$d\phi$,change of magn. flux [T/m^2]
dt, change of time [s]
V, voltage [J/C] [V]

eV – **Electron-volt**: The product of a fundamental unit of atomic charge and the unit of volt: e·V = energy: 1 eV = $1.6 \cdot 10^{-19}$ [A·s] ·1[V] = $1.6 \cdot 10^{-19}$ [A·s·V] = [C·V] = [J]

I, current [C/s] [A]
L, inductance [V·s/A] [H]
C, capacity [C/V] [F]

Energy: Stored energy after charging a capacitor, or inductance q, charge [A·s] [C]

PE in a capacity: $C_{PE} = \frac{1}{2} \cdot C \cdot V^2 = \frac{1}{2} \cdot q^2/C$ [J] B, mag. field induction [V·s/m^2] = [T]

KE in an inductance: $L_{PE} = \frac{1}{2} \cdot L \cdot I^2 = \frac{1}{2} \cdot B^2/\mu_0$ [J] μ_0, permeability c. $4 \cdot \pi \cdot 10^{-7}$[T·m/A]

Farad: Unit of capacity, two conductors share the same capacity of 1 [F] = [C/V] if the charges of 1 [C] induces a voltage of 1 [V] between them.

Faraday Cage: A box made of solid metal plates can shield external electric fields in a way that electrostatic field inside a charged conductor, anywhere beneath the surface, is zero (analogue to zero gravity in earth's center).

Faraday's law: The induced voltage in a coil is proportional to the product of the number of loops and the rate at which the magnetic field changes within these loops. An electric field is induced in any region of space in which a magnetic field is changing with time. The magnitude of the induced electric field is proportional to rate at which the magnetic field changes.

The direction of the induced field is at right angles to the changing magnetic field (see electromagnetic induction):

$V_{ind} = N \cdot d\Phi/dt$

N, number of loops [-]
$d\Phi$, change of magn. flux [V·s]
dt, change over time [s]

Field: The energetic region of space surrounding a charged object.

E - **Electric field**: About a charged point, the field decreases with distance according to the inverse-square law, like a gravitational field. Between appositely charged parallel plates, the electric field is uniform (condensator). A charged object placed in the region of an electric field experiences a force (electric field is a vector quantity since it possesses direction and strength.

Shielding of electrical field is possible since there are repelling and attracting forces); is a source field type (see faraday-cage):

$E = F/q$ [N/A·s] = [N/C]

F, force [kg·m/s^2] [N]
q, charge [A·s] [C]

B - **Magnetic field**: The space surrounding a magnetic object, where each location is assigned a value determined by the torque on a compass placed at that location, the direction of the field is in the direction of the N-pole of the compass:

$B = \mu \cdot H$ [N·s/(C·m)] = [N·m·s/(C·m^2] = [N/(A·m)] = [T]

$\mu = \mu_0 \cdot \mu_r$

μ_0, permeability c. $4 \cdot \pi \cdot 10^{-7}$ [N/A^2]
μ_r, rel. permeability [-]
H, magnetic field [A/m]

Flux: The rate of flow of matter or energy across a unit area e.g., magnetic flux ϕ;

F **- Force**: The energetic region of space exerts a force on a similar charged object.

Electrical F.: Causes the electrons to move, which are driven by the electrical field (see potential).

Electromotive Force (emf): The potential difference across the terminals of a battery or other source of electric energy.

Magnetic F.: The force resulting due to the motion of electric charges (compare electric field).

(1) Between magnets, it is the attraction of unlike magnetic poles for each other and the repulsion between like magnetic poles.

(2) Between a magnetic field and a moving charge, it is a deflecting force due to the motion of the charge: The deflecting force is perpendicular to the motion of the charge and perpendicular to the magnetic field lines. This force is greatest when the charge moves perpendicular to the field lines and is smallest (0) when moving parallel to the field lines i.e.: Lorentz force.

Lorentz F.: The force which acts on a charge when moving through a magnetic field (see right-hand rule):

$F_L = q \cdot v \times B$ [A·s · m/s · N/(A·m)] = [N]

if filed is not perpendicular to q·v: $F = q \cdot v \cdot B \cdot \sin\theta$

q, charge [A·s] [C]
v, velocity [m/s]
B, mag. field induction [V·s/m^2] = [T]

Generator: A device that produces electric current by rotating a coil within a stationary constant magnetic field using the reverse principle of the Lorentz force.
Van de Graaf's G.: A lightning machine; a motor driven rubber belt inside a support stand passes a metal brush kept at a certain voltage; the tips of the brush deposit a continuos supply of charge to the belt which is carried up into the hollow sphere connected via a 2nd brush (accumulated potential >1MV).
Hall Effect: Moving charges in a conductor are forced to one lateral edge under the influence of a magnetic field, generating a lateral, perpendicular detectable voltage.
Henry: Unit of inductance, two conductors have the same inductivity of 1[H] if the change of current of 1[A/s] induces a voltage of 1[V] in the other conductor.
Z - **Impedance**: A measure of the circuits entire ability to restrain alternating current by the geometrical addition of reactance and resistance:
$Z = \sqrt{(R^2 + X^2)}$ [Ω].
R, resistance [V/A] [Ω]
X, reactance [V/A] [Ω]
Inductor: An electrical device, in its simplest form a pair of loops wounded together to form a solenoid, that stores magnetic energy.
Inductance:
Self Inductance: Occurs in inductances, where each loop interacts with the same coil, retarding any change of the magnetic field (see Lenz' law).
Insulator: Any material that resists charge flow through it when subject an external electrical force; the valence shell is without free electrons.
Inverse-Square Law: A law relating the intensity of an effect to the inverse square of the distance from the cause:
Intensity ≅ 1/distance^2;
electrostatic: $F = k_F \cdot q_1 \cdot q_2/d^2$ $[N \cdot m^2/C^2 \cdot C^2/m^2] = [N]$
k_F, coulomb c. ≈ 9×10^9 $[Nm^2/C^2]$
q, charge [A·s] [C]
d, distance [m]
Ion: A charged particle formed when a neutral donor group or atoms gains or looses one or more electrons.
(+)Anion: An ion with a net positive charge.
(-)Cation: An ion with a net negative charge.
Kirchoff's Rules: Rules in determining voltages and currents in electrical networks
Loop R.: The sum of the potential charges encountered in any closed loop in a circuit is equal to zero: $\Sigma V_N = 0$.
Node R.: The sum of the currents entering a junction in a circuit equals he sum of the currents leaving the junction. $\Sigma I_N = 0$.
V, voltage [J/C] [V]
I, current [C/s] [A]
Lenz Law: The induced magnetic field in inductances, that will produce a current that always acts to oppose the change that originally caused it (see electromagnetic induction).
Magnet: In a magnet always both poles (S, N) are present, they cannot be separated (force-field type).
M.**Domains**: Clustered regions of aligned magnetic atoms. When these regions themselves are aligned with one another, the substance containing them is a magnet.
M. **Poles**: Like poles repel, opposite poles attract.
Magnetism: A materials ability to store magnetic energy after being magnetized describes 3 distinct classes (compare also chemistry-atom):
Diamag.: Any substance in which the magnetic flux inside is lower than outside (μ_r<1, slightly repelling when exposed to a magnetic field; temperature independent) - H_2, Cu, Hg....
Ferromag.: Any substance in which the magnetic flux inside is extremely high compared to outside; (μ_r>>1, the higher the temperature the less ferromagnetic will be the substance - see hysteresis) - Fe, Ni. Co...
Paramagnet.: Any substance in which the magnetic flux inside is higher than outside ($\mu_r \geq 1$, slightly attracting, the lower the temperature the more ferromagnetic the substance will become) - O_2, Cr, Pt....
Hysteresis: Ferromagnetic materials can be seen as conductors for magnetic field-lines, just as metal conductors for electric charges; if a permanent magnet is brought close to a never before magnetized ferromagnetic substance, many of the magnetic domains of this substance will be orientated along the field-lines (in a N-S direction), once removed, leaving behind a permanent magnetic material (H_R).
H. **Loop**: If the imprinted magnetic field acting upon the ferromagnetic material is changing constantly its direction (due to AC in the solenoid), the orientation of the field will alter with the frequency of the current, resulting in a periodic magnetization/demagnetization and magnetization in the reverse direction and so forth. along a distinct sigmoidal path; the area enclosed, reflecting the internal inefficiencies resulting in loss of energy as heat.
Magnetostriction: A ferromagnetic substance exposed to a magnetic field experiences tiny geometrical changes due to the alignment of the magnetic domains within it, i.e.: in-/decrease in length depending upon the direction of the imposed field.
Maxwell Equation: A set of equations that summarizes the behavior of electric and magnetic fields.

1^{st} EQ: divD = ρ; The law for electricity is based on Coloumb's law describing the forces of attraction (positive = source; negative = sink) and repulsion between stationary, like charges; opposite charges attract.
2^{nd} EQ: divB = 0; The law of magnetism asserts that there are no sources or sinks of magnetic field lines, hence magnetic field lines are always closed loops; magnetic poles cannot be separated.
3^{rd} EQ: rotE = -dB/dt; It describes the induction of an electric field by motion or by a changing magnetic field; a moving charge is surrounded by both an electric an a magnetic field; the induced current is always such as to oppose the change of flux that generated it (see lenz).
4^{th} EQ: rotH = dϕ/dt + j; It is based on the law of magnetic force between moving charges and it also contains the induction of a magnetic field by a changing electric field and vice versa.

Maxwell's counterpart to Faraday's law (4^{th} law): A magnetic field is induced in any region of space in which an electric field is changing with time. The magnitude of the induced magnetic field is proportional to the rate at which the electric field changes. The direction of the induced magnetic field is at right angles to the changing electric field (see optics - right hand rule for radio-waves).

Ω **Ohm's law**: The statement that the current in a circuit varies directly with the potential difference or voltage and inversely with resistance: A potential difference of 1[V] across a resistance of 1[Ω] produces a current of 1[A].
R = V/I [V/A] = [Ω]

V, voltage [J/C]	[V]
I, current [C/s]	[A]

V - **Potential** (voltage): The electric (pressure) potential energy per amount of charge, measured in volts, and often called voltage:
Voltage = electric energy/amount of charge
V = PE/q [J/(A·s)] = [J/C] = [V]
In DC-circuits: A pressure acting in one direction (fro +, to -)
In AC-circuits: Pressure repeatedly reverses direction
$V = V_{eff} = V_{peak}/\sqrt{2}$ [V]

PE, potential energy	[J]
q, charge [A·s]	[C]
V_{eff}, DC equivalent	[V]
V_{peak}, AC peak, max	[V]

P. **Energy**: The energy a charge possesses by virtue of its <u>location</u> in an electric field (PE).
P. **Difference**: The difference in voltage between two points, measured in volts. It can be compared to the difference in water pressure between two containers: If two containers having different water pressures are connected by a pipe, water will flow from the one with the higher pressure to the one with the lower pressure until the two pressures are equalized. Similarly, if two points with a difference in potential are connected by a conductor, charge will flow from the one with the greater potential to the one with the smaller potential until the potentials are equalized.

Peltier Effect. The reversed seeback-effect; in which a direct current cools one electrode pair, whereas the second is heated up.

Piezo effect: Deforming distinct crystals generate a lateral voltage, in the reversed process, an applied voltage causes the crystal slightly to deform, used in speakers, peepers, electronic mouse, antishockwavers....

P - **Power**: The rate of energy transfer, or the rate of doing work; equals the amount of energy per unit time, which electrically can be measured by the product of current and voltage:
Power = current x voltage
in DC-circuits: P = V·I [V·A] = [W]
in AC-circuits: P = V·I·cosθ [V·A] = [W]

V, voltage [J/C]	[V]
I, current [C/s]	[A]
θ, angle between V and I [degrees]	

Reactance: Is similar to resistance and reflects a delayed reaction due to changing of an electrical field in a capacitor or the field in a inductance.
$X = X_L - X_C$;
Inductive reactance: $X_L = \omega \cdot L = 2 \cdot \pi \cdot f \cdot L$ [Ω]
Capacitive Reactance: $X_C = 1/(\omega \cdot C) = 1/(2 \cdot \pi \cdot f \cdot C)$ [Ω]

Right -Hand-Rule:

- magnetic force (Lorentz) $F_L = q \cdot v x B$;
  q·v = electrical current (index finger);
  B = magnetic field (middle finger);
  F = experienced force (thumb);
- Right-hand-current rule for a solenoid:
  B = μ·H = μ·I·N/l [T]; I (thumb); B (four fingers).

ω, angular speed	[1/s]
L, inductance [V·s/A]	[H]
C, capacitor [C/V]	[F]
π, 3.14	[-]
f, frequency [1/s]	[Hz]
F, force [kg·m/s^2]	[N]
q·v, electrical current	[C·m/s]
B, field induction [V·s/m^2]	[T]
I, current [C/s]	[A]
μ, permeability of medium	
N, number of loops	[-]
l, length	[m]

R - **Resistance**: The property of a material that resists the flow of an electric current through it; in ohms:
R = V/I [V/A] = [Ω]
1[Ω] is defined as the resistance that allows 1[A] to flow when a potential of 1[V]across the resistance occurs:
R = ρ·l/A

V, voltage [J/C]	[V]
I, current [C/s]	[A]
ρ, density	[kg/m^3]
l, length	[m]
A, cross sectional area	[m^2]

Resonance: Where the capacitive and inductive reactances are equal: π, 3.14 [-]
$X_L = X_C$; (in AC-circuits only). L, inductance [V·s/A] [H]
R. **Frequency**: The frequency in which the: C, capacitor [C/V] [F]
$f_R = 1/(2\cdot\pi\sqrt{(L\cdot C)})$ [Hz]
Parallel R.: A parallel circuit of R, L, C; at f_r resonance of current (I_{LC}>) occurs with between L and C; Z is maximum, I minimum, V constant;
Serial R.: A serial circuit of R, L, C; at f_r resonance of voltage (V_{LC}>) between L and C occurs; Z is minimum, V constant, I maximum

Seeback Effect: A thermo-voltage between two contact-zones of two different metals will be generated, if both contact zones experience different temperature (see peltier effect).

Semiconductor: A poorly conducting material, such as crystalline silicon or germanium, that can be made a better-conducting material by the addition of certain impurities or energy the gap between the valence and the conductor-band of the outer electron shell is very narrow); thin layers of semiconducting materials (n, or p) are sandwiched together make up transistor, diodes, etc., which are used to control the flow of currents in electronic circuits, to detect and amplify radio signals, and to produce oscillation in transmitters; they also act as digital switches in integrated circuits (IC's).
n-layer: The impurity in the semiconductor possesses an excess electron, rendering it slightly negative e.g.: Si: 4e, As, 5e
p-layer: The impurities in the semiconductor lacks an electron (hole), rendering it slightly positive e.g.: Si: 4e, Al, 3e
Diode: Joining of a n- and a p-type altered semiconducting material; in neutral (no voltage applied), electrons in the junction area of the n-type crystal will diffuse across into the equivalent numbers of holes of the p-type material leaving the n-layer more positive than before; the resulting internal potential difference cuts off further transport of charges, leaving the central region depleted of carriers, depleted layer becomes an insulator.
If an external voltage is supplied - with the negative connected to the p-terminal and the positive to the n-terminal of the diode, the already depleted layer will be enlarged, rendering the diode more blocked. If, instead the polarity is reversed (plus on p, minus on n), than the external voltage will oppose the internal potential difference overflowing it by many electrons - the diode is forward biased, a current can flow - diodes are used in rectifiers to convert Ac into DC.
Transistor: Similar in principle as the diode, with one extra layer of semiconducting material added (npn or pnp); the middle layer is called base and is used to control the other layers to allow the passage of a controllable current between the other two layers (collector and the emiter-terminal).

Superconductor: A material in which the electrical resistance to the flow of electric current drops to near zero or zero under special circumstances that usually include low temperatures.

Skin Effect: A high-frequency voltage forces the current to flow in the outer layers of a conductor (like in a hollow tube) since the repelling forces in-between like charges become evident.

Transformer: A device for transferring electric power from one coil of wire to another by means of electromagnetic induction (transformers work only in AC-circuits)
$V_{prim}/V_{sec} = N_{prim}/N_{sec} = I_{sec}/I_{prim}$; $P_{prim} = P_{sec} = V\cdot I\cdot\cos\theta$
Tesla T.: A high frequency transformer, in which a capacity is added to combine a serial resonace circuit with the inductance of the primary coil ($N_{primary} >> N_{secundary}$); when the LC-combination is in resonance, f_r, (see above) usually in the MHz-band = resonance of voltage, the secondary open loop will emit a high frequency electromagnetic field, which can light a neon-bulb even though not connected to mains.

V, voltage [J/C] [V]
I, current [C/s] [A]
P, power [V·A] [W]
θ, angle b/w I & V [°]
N, loops [-]

Wheatstone Bridge: It is used for precise measurements of resistors; its operation is based on the principle that an unknown resistor in a serial arrangement with a known resistor is switched together to a parallel circuit; the comparison takes place at the cross-points of the two serial branches with an Amp-meter (current-meter); since one of the known resistors is adjustable, tuning is done until the A-meter indicates zero; at this stage the value of the unknown resistor can be read at the dial of the adjustable resistor: for I = 0: $R_x = R_2\cdot R_3/R_1$ R, resistor [V/A] [Ω]

Glossary Physics *(VII-optics)*

Absorption: Certain surfaces and colors absorb the visible spectrum of light (see also black body - matter) e.g. glass absorbs the UV-radiation, since glass atoms resonate with the UV-frequency, therefore glass is not transparent for UV (see reflection and selective transmission).

Additive Primary Colors: The three colors-red, blue, and green- that when added in certain proportions will produce any color in the spectrum.

Subtractive P.C.: The three colors of absorbing pigments-magenta ,yellow, and cyan-that when mixed in certain proportions will reflect any color in the spectrum.

Complementary C.: Any two colors that when added produce white light.

Critical angle: The minimum angle of incidence at which a light ray is totally reflected within a medium.

Diffraction: The deviation of light from rectilinear propagation. Like photons, electrons penetrate a screen as particles, but the pattern of arrival is wavelike, hence the typical defraction pattern of light (see wave-particle duality and holograms).

The bending of light around an obstacle or through a narrow slit occurs in such a way that fringes of light and dark or colored brands are produced, if the object is the size of the wavelength itself.

Single Slit D.: In the case of a single slit of width d, zeros of irradiance will occur on both sides of the broad central maximum when:

$d \cdot \sin\theta_n = n \cdot \lambda$

Maxima are regarded as the superposition of tiny secondary wavelets.

Double Slit D.: Similarly, when two parallel slits, each separated by a distance D, are present, narrow principal maxima will appear at the same locations and can be expressed mathematically:

$y_n = s/D \cdot n \cdot \lambda$ [m]

n, integer ±1, ±2, ±3,.... [-]
d, width of gap [m]
λ, wavelength [m]
θ, angle of refraction according to n [degree]
s, distance to screen [m]
D, distance between slits [m]
y_n, distance between maxima on screen from 0 [m]

Dispersion: The speed of light in a transparent medium depends on its frequency; violet travels about 1% slower in ordinary glass than does red light (higher frequencies face an increased absorption - UV absorption in glass); since white light is a mixture of many frequencies, which travel at slightly different speeds in transparent materials, hence refract differently, and bend by different amounts.

Eclipse: The partial or complete obscurence of a celestial body by another.

Solar E.: The event wherein the moon blocks light from the sun and casts its shadow on part of the earth.

Lunar E.: The event wherein the moon passes into the shadow of the earth.

EMW - **Electromagnetic wave**: An energy-carrying wave emitted by vibrating electrons that is composed of oscillating electric (with their charge) and magnetic fields (due to motion of charges) that regenerate one another (see Maxwell equations -electromagnetism).

E. **Spectrum**: The range of electromagnetic waves extending in frequency from radio waves to gamma rays - kHz-MHz, radio waves; MHz-GHz, microwaves; GHz-THz, infrared (IR); light, ultraviolet (UV), X-rays, gamma-rays (γ).

E. **Properties**: These are: appearance (color), behavior (reflection, refraction), nature of EMW (quantum theory).

Excitation: The process of boosting one or more electrons in an atom or molecule from a lower to a higher energy level. An atom in an excited state will usually decay (de-excite) rapidly into a lower state by the emission of radiation.

The energy of the radiation is proportional to its frequency:

$E \approx f$:

$E = h \cdot f$ [J]

h, plank's c. $6.63 \cdot 10^{-34}$ [J·s]
f, frequency [1/s] [Hz]

De-excitation: Occurs when the excited electron returns to its original shell-orbit; giving off the gained energy in form of an electromagnetic wave (light).

Fermat's Principle of least time: Light will take the path that requires the least time when it goes from one place to another.

Fluorescence: The property of absorbing radiant energy of one frequency and re-emitting radiant energy of lower frequency. Part of the absorbed radiant energy goes into heat and the other part into excitation; hence, the emitted radiant energy has a lower energy, and therefore a lower frequency, than the absorbed radiant energy; e.g. mercury-fluorescence lamp: emits after returning into the de-excited state UV-radiation, which is with the help of special dyes converted into visible light (lower energy level).

Frauenhofer Lines: Atoms will most strongly absorb light having the frequency to which it is tuned - the same frequency it emits; e.g. light of sun reveals absorption patterns identical to that emitted by helium, which means that helium at the sun's surface absorbs some light itself.

Hologram: (Gk. holo, whole; L. gram, message) A two-dimensional microscopic diffraction pattern that shows three-dimensional optical images.

Huygen's Principle: The theory by which light waves spreading out from a point source (circular wave on the surface of water, spherical wave in sound, light) can be regarded as the superposition of tiny secondary wavelets (see diffraction on a single-slit).

Image: Extrapolating reflected rays to the far side of a mirror or lens reveals that all rays seem to appear from a single point source of light placed beyond it (see mirror and lens).

Real I.: An image formed by the actual convergence of light rays which can be displayed on a screen.

Virtual I.: An illusionary image seen by the observer, through a mirror or lens that can't be projected onto a screen (but still be seen by the eye, because it is an optical device itself).

Incandescence: (L. incandescere, to glow) The state of glowing while at a high temperature, caused by electrons in vibrating atoms and molecules that are shaken in and out of their stable energy levels, emitting radiant energy in the process.

The peak frequency of radiant energy is proportional to the absolute temperature of a heated substance: $f_P \approx T \approx E^4$ doubling of the temperature corresponds to a doubling of frequency of the radiant energy, but a 16-fold increase in the rate of emission in radiant energy!

f_P, peak frequency [1/s] [Hz]
T, temperature [K]
E, energy [N·m] [J]

Interference: The superposition of waves producing regions of reinforcement and regions of cancellation.

I. **Colors**: The interference of selected wavelengths of light produces colors.

Constructive I.: Refers to regions of reinforcement.

Destructive I.: Refers to regions of cancellations.

Interferometer: An instrument which uses the principle of interference to measure small distances.

Fabry-Perot's I.: Consists of two parallel half-silvered mirrors.

A ray of light entering the space between the mirrors from an inclined angle, may pass straight through or be reflected once or several times by each mirror; constructive interference occurs when: $2 \cdot d \cdot \cos\theta = 0, \lambda, 2 \cdot \lambda, \ldots$

d, distance between mirrors [m]
θ, angle of incoming ray [degree]

Michelson's I.: A partially reflecting mirror (located at the center) splits an incoming monochromatic light-beam into two perpendicularly oriented sub-beams; both are reflected at mirrors, join at the center to finally reach the viewer; if one of the distant mirrors is moved in the axis of the beam, an interference pattern can be seen: movable distance: $d = n \cdot \lambda$

d, distance [m]
n, integer, 1,2,3.... [-]
λ, wavelength [m]

Inverse-Square Law: A law relating the intensity of an effect to the inverse square of the distance from the cause: Intensity $\cong$ 1/distance^2; Spread of light / electromagnetic wave: $I_{L1} \cdot R_1 = I_{L2} \cdot R_2$

I_L, light intensity [Cd]
R, radius [m]

Iridescence: The gradually increasing thickness of a transparent medium (soap film under gravitation) causes destructive interference for a specific color, allowing the complementary color spectrum to be reflected if watched under white light.

Lambert-Beer's Law: Describes capability of absorption in solutions: $I_x = I_0 \cdot e^{-C_c \cdot d}$

C_c, molar coeff. of absorption [1/m]
c, concentr. of solution [mole/l]
d, depth of penetration [m]

Laser: (acronym of: **l**ight **a**mplification by **s**timulated **e**mission of **r**adiation) An optical instrument that produces a beam of coherent monochromatic light; de-exciting gas-atoms emit a wave which is collected in-between a classical mirror and a partially reflecting mirror (= exit window of laser-beam); a laser commonly converts (is not a source of energy) about 1% of the stimulating energy into a beam (η <).

Lens: An optical instrument to focus or disperse incoming light waves (see images).

Converging L.: Convex Lens, a lens that is thicker in the middle than at the edges and refracts parallel rays passing through it to a focus.

Diverging L.: Concave lens, a lens that is thinner in the middle than at the edges, causing parallel rays passing through it to diverge:

L. **Equation**: $1/d + 1/d' = 1/f$ [m]

L. **Magnification**: $M_L = -d'/d$ [m]

d, distance of object [m]
d', distance of image [m]
f, distance of focus [m]

L. **Rays**: Three principle rays characterize the lens' behavior:

- The 1st incoming ray parallel to the lens' axis will be deflected to pass the focal point past the lens.

- The 2nd, center-seeking ray will straight pass through the center without a deflection.
- The 3rd incoming ray striking the focal point will be deflected to a parallel beam past the lens.

L. **Distortions**: Abnormalities of a lens refracting power or internal structures.

- **Astigmatism**: A defect caused when the radius of curvature is not uniformly the same throughout the lens; i.e.: the inability to focus simultaneously light-trays arriving in different planes.
- **Chromatic Aberration**: Chromatic distortion of an image produces by a lens or lens-system (red refracts more than blue light).
- **Spherical Aberration**: Parallel incoming rays at the edge of a lens do not meet at the focal point as do rays which are closer to the axis of lens.

Microscope: An instrument containing optical lenses (commonly an objective and an ocular) that reflect (bend) light rays magnifying the object; total magnification:
$M_T = M_{objective} \cdot M_{ocular}$ [-] M, magnification [-]
Electron M.: Instrument that uses beams of electrons with wavelengths shorter than light, allowing higher magnification; e.g. **SEM** (Scanning) used to observed outer surfaces with great depth of field rendering the objects three dimensional. **TEM** (Transmission) used to observed inner structures of thin, stained sections of cells. **TSEM** (Tunnel Scanning) for objects even smaller to be viewed with a SEM/TEM allowing images of atomic structures.

Mirage: A floating image that appears in the distance and is caused by refraction of light in the atmosphere.

Mirror: An optical instrument to focus or disperse incoming light waves, where in any point of the mirror the angle of the incoming ray is identical to that of the outgoing ray with respect to a perpendicular axis (see images): $\theta_{in} = \theta_{out}$;
M. **Equation**: $1/d + 1/d' = 1/f$; $f = ½ \cdot r$ [m]
M. **Magnification**: $M = -d/d'$ [-]

θ, angle (⊥ to mirror)	[degree]
d, distance of object	[m]
d', distance of image	[m]
f, distance of focus	[m]
r, radius of curvature	[m]

M. **Rays**: Three principal rays make sure that an reflected image may be predicted:

- The 1st ray passes through the center of the spherical surface;
- The 2nd ray, parallel to the axial line will pass through the focal point once reflected;
- The 3rd ray passes through the focal point and will be reflected as a parallel outgoing beam;

Convex M.: The reflecting area is the outer surface of a sphere.
Plane M.: A flat plane mirror where only a virtual image can be produced.
Spherical M.: A concave mirror with the surface curved like the inner surface of a sphere.

Opaque: The term applied to materials that absorb light with re-emission and thus through which light cannot pass.

Penumbra: A partial shadow that appears where some of the light is blocked and other light can fall.

Phase Rotation: Occur in certain crystals, cellophane etc. which cause a many-planed light-wave to travel faster through this medium in one plane than the perpendicular oriented elongation, resulting in rotation of an optical plane.

Phase Shift: When light in a medium is reflected at the surface of a 2nd medium in which the speed of transmitted light is lower than outside ($n_{inside} > n_{outside}$) there is a 180° phase shift; but no such shift occurs when the 2nd medium is one that transmits light at a higher speed (n<) - see speed of light.

Phosphorescence: A type of light emission that is the same as fluorescence except for a delay between excitation and de-excitation, which provides an afterglow. The delay is caused by atoms being excited to energy levels that do not decay rapidly. The afterglow may last from fractions of a second to hours, or even days, depending on the type of material, temperature, and other factors.

Photoelectric Effect: The emission of electrons from a metal surface when light shines on it; i.e.: light of low frequency does not emit electrons whereas light of high f. does (see X-rays - nuclear physics).

Photon: A light corpuscle, or the basic pocket of electromagnetic radiation; just as matter is composed of atoms (e,n,p) light is composed of photons (quanta).

h - **Planck's Constant**: A fundamental constant, which relates the energy of light quanta with their frequency:
$E = N \cdot h \cdot f$

N, number of quanta	[-]
f, frequency [1/s]	[Hz]
h, planks c. = $6.6 \cdot 10^{-34}$	[J·s]

Polarization: The alignment of the electric vectors that make up electromagnetic radiation. Such waves of aligned vibrations are said to be polarized.
Plane Polarized: Wave amplitude is oriented along on a plane (like a SHM); if 2 planes are involved (x, y with no phase-shift, and identical amplitude) the resulting wave is still single-planed but inclined by 45° (0), 135° (λ/2), 225° (0) or 315° (λ/2) with respect to the x-plane.
Circular Polarized: y-elongation is delayed by 90° (λ/4-right-circular p.) or -90° (λ/4-left circular p.).
Elliptically Polarized: In addition to circular polarized, the y, x- axis do not have the same amplitude.

Unpolirized: All planes are randomly present in a beam of sunlight; all elongational angles of a circular orientation.

Polarizer: They can filter out a single plane-oriented light-wave; it basically consists of a many-slited transparent plate; modern polarizers are made synthetically by molecular polymer-chains.

Quantum: Radiation of light is emitted in discrete bundles of energy; just as matter is quantified as a whole number of atoms, or electric charge is a whole number multiple of a single charge.

Q. **Mechanics**: (Also called quantum physics) The study of motion on the micro-world, just as mechanics is the study of motion in the macro-world.

Q. **Theory**: Energy is radiated in definite units called *quanta*, or photons. Just as matter is composed of atoms, radiant energy is composed of quanta. It further states that all material particles have wave properties..

Mass of a photon: $m = E/c^2$ [kg]

Rayleigh's Criterion: Decides whether two remote sources can be clearly distinguished with an optical instrument (also known as **resolution**): $360° = 2\cdot\pi$ / $1' = 2.909\cdot10^{-4}$ / $1'' = 4.848\cdot10^{-6}$ [rad]

$\theta_R = 1.22\cdot\lambda/2\cdot r$ [rad]

E, energy [N·m]	[J]
c, speed of light	$3\cdot10^8$ [m/s]
θ, angle of resolution	[rad]
λ, wavelength	[m]
2·r, diameter of object	[m]

Reflection: The <u>return</u> of light rays from a surface in such a way that the angle at which a given ray is returned is equal to the angle at which it strikes the surface; e.g. electrons of atoms in shiny materials are set in vibratory motion by light, which then re-emits by their own particular wave-length (see absorbtion)

Diffuse R.: The reflecting surface is irregular, light is returned in irregular directions.

Law of R.: The angle of an incidence equals the angle of reflection. The incident and reflected rays lie in a plane that is normal to the reflecting surface.

Total Internal R.: The total reflection of light traveling in a medium when it strikes on the surface of a less dense medium at an angle greater than the critical angle.

Refraction: The <u>bending</u> of an oblique ray of light when it passes from one transparent medium of one density to another with a different density, caused by a difference in the speed of light in those media. When the change in medium is abrupt (e.g., from air to water, the angle of incident is larger than the angle of refraction by an amount that depends on the relative speed of light in air and in water), the bending is abrupt; when the change in medium is gradual (from cool air to warm air), the bending is gradual, which accounts for mirages (compare speed of sound); the change from a dense medium to a denser medium (air-water line) bends light towards the perpendicular air-water line, whereas it is bent away from the perpendicular plane once light passes from a denser material to a less dense material (see critical angle)

R. **Index**: The refractive power of a medium compared with that of air, designated 1; $n_{diamond} = 2.4$; $n_{water} = 1.3$:

$n = c_{vacuum}/v_{\text{of light in medium}}$

$n_1\cdot\sin\theta_1 = n_2\cdot\sin\theta_2$ [-]

Right -Hand-Rule: electromagnetic propagation:

$EMW_P = E \times B$ [$N^2\cdot s/C^2$] $E_{\text{middle finger}}$; B_{thumb};

EMW_P = propagation of EM-wave (index finger);

n, index of refraction	[-]
f, frequency [1/s]	[Hz]
θ, angle (⊥ to surface)	[degree]
E, electric field	[V/m]
B, magn. field induct.	[T]
EMW, electromagn. wave	

Scattering of Light: Occurs when the scattering particles are much smaller than the wavelength of an incident light and have resonance at frequencies higher than the scattered light; the shorter the wavelength the more light is scattered, that's why daylight sky is blue (due to N_2, O_2-molecules). A red sunset on the other hand occurs when the sun is already low in the sky, therefore the path through the atmosphere is considerably longer than at midday; more blue is scattered, leaving more and more red; furthermore long-waves bend better than short waves, if the sun is about to vanish beyond the horizon, in reality its already past the horizon, just the bent red long waves give us this illusion that it might be still there.

Selective Transmission: Only a certain spectrum is allowed to pass through matter such as glass; in blue tinted glass only blue light penetrates, with a speed slightly lower than c; because excited electrons of glass-atoms pass their stimulated vibrations by means of "mechanical" transport to the neighboring atoms and so forth (see Newton's cradle - mechanics).

Shadow: A shaded region that appears where light rays are blocked by an object.

Spectrum: The splitting of white light into its distinct components.

Absorption S.: A continuous spectrum, like that of white light, interrupted by dark lines or bands that result from the absorption of certain frequencies of light by a substance through which the radiant energy passes (see Frauenhofer lines).

Emission S.: The distribution of wavelengths in the light from a luminous source; every element has its particular distinguishable pattern of <u>electron energy</u> level (distinguishes chemical properties as well) and therefore emits its own characteristic pattern of light frequency, after excitement, when de-excitation occurs

Spectroscope: An optical instrument that separates light into its constituent frequencies in the form of spectral lines.

c - **Speed of Light**: Recall from sound that:

$v = f \cdot \lambda$ [m/s] = c = constant in vacuum

but in media other than vacuum:

$v = c/n = \lambda \cdot n \cdot f$ [m/s]

n=1 in vacuum

$c = 1/\sqrt{(\varepsilon_0 \cdot \mu_0)}$

the speed of light decreases, which explains why light-rays seem to bend when penetrating clear water (see refraction and selective transmission).

f, frequency [1/s] [Hz]
λ, wavelength [m]
n, index of refraction [-]
c, speed of light $2.998 \cdot 10^8$ [m/s]
μ_0, permeability c. $4 \cdot \pi \cdot 10^{-7}$ [$N \cdot s^2/C^2$]
ε_0, dielectric c. $8.85 \cdot 10^{-12}$ [$C^2/(N \cdot m^2)$]

Fizeau's Reel: With the aid of an optical instrument , a light source, a reel with 720 teeth, and two mirrors (one partially reflective) it is possible to determine the running time of a light, being reflected at a far distant mirror (8630 [m]):

$c = 2 \cdot v \cdot l \cdot N$ [m/s]

v, turns of the reel [1/s]
d, distance to remote mirror [m]
N, number of teeth on the reel [1/m]

Transparent: The term applied to materials through which light can pass in straight lines.

Umbra: The darker part of a shadow where all the light is blocked.

Uncertainty Principle: The principle formulated by Heisenberg that states that the ultimate accuracy of measurement is given by the magnitude of Planck's constant, h. Further, it is not possible to measure exactly both the position and the momentum of a particle at the same time, nor the energy and the time during which the particle has that energy simultaneously, since the process of measurement alters the probe:

A short wavelength that can better see the tiny electron corresponds to a large quantum of energy, which greatly alters the electrons state of motion; if, on the other hand, we use a long wavelength that corresponds to a smaller quantum of energy, the change we induce to the electrons state of motion will be smaller, but the determination of its position by the coarser wave will be less accurate.

$\Delta p \cdot \Delta d \geq h/(2 \cdot \pi)$

$F \cdot \Delta t \cdot \Delta d \geq h/(2 \cdot \pi)$ $F \cdot d = E = W$

$E \cdot \Delta t \geq h/(2 \cdot \pi)$

Δp, uncertainty of momentum [kg·m/s]
Δd, uncertainty of position [m]

Wave: A wiggle in space and time; a disturbance propagated from one place to another with no actual transport of matter.

W. **Equation**: Describes the wave in time and space:

$\partial^2 u/\partial x^2 + \partial^2 u/\partial y^2 + \partial^2 u/\partial z^2 = (1/v^2) \cdot \partial^2 u/\partial t^2$

v, velocity [m/s]
u (x,y,z,t), elongation in space & time

Unpolarized W.: All oscillating directions (x,y,z) pass through a medium (see polarization).

W.-**Particle Duality**: (Also called De-Broglie wavelength)

Every particle will produce an interference or diffraction pattern; all bodies, therefore, (e, p, atoms, mice, you, planets, sun) have a wavelength that is related to the momentum by (see nuclear physics - wave):

$\lambda = h/(m \cdot v)$

h, Planck c.$6.63 \cdot 10^{-34}$ [J·s]
m, mass [kg]
v, velocity [m/s]

W.-**Particle Complementarity**: The principle enunciated by Niels Bohr that states that the wave and particle models of either matter or radiation complement each other and when combined provide a fuller description of either one.

Glossary Pysics *(VIII-nuclear physics)*

Atom: The smallest particle of an element that has all the element's properties; composed of a nucleus and a number of surrounding electrons ($2\cdot r = 1\cdot E^{-10}$ m). 2·r, diameter [m]

A. **Weight**: The weight of a representative atom of an element relative to the weight of an atom of ^{12}C, which has been assigned the value 12.

A. **Number**: the number associated with an atom, which is equal to the number of protons in the nucleus, or equivalently, to the number of electrons in the electric cloud of a neutral atom

A. **Mass Number**: The number associated with an atom, which is equal to the number of nucleons in the nucleus.

e - **Electron**: A subatomic particle with a negative electric charge equal in magnitude to the positive charge of the proton, but with a mass of 1/1837 of that of the proton. Electrons orbit the atom's positively charged nucleus and determine the atom's chemical properties; electron are considered waveicles since they both share properties of waves and particles.

Charge of an e.: $1.602\ 18\cdot E^{-19}$ [A·s] = [C]

Mass of an e.: $9.109\ 39\cdot E^{-31}$ [kg]

e-**Shell**: Energy levels od electrons surrounding the nucleus.

n - **Neutron**: (L. neuter, neither) An uncharged particle with a mass slightly greater than that of a proton, found in the atomic nucleus of all elements except hydrogen, in which the nucleus consists of a single proton; neutrons can also be seen as the glue, or cement in heavier atoms than H.

Mass of a n.: $1.674\ 929\cdot 10^{-27}$ [kg]

Radius of a n.: $1\cdot E^{-15}$ [m]

p - **Proton**: A subatomic or elementary, particle, with a single positive charge equal in magnitude to the charge of an electron and a mass of 1; the basic component of every atomic nucleus ($r = 1\cdot E^{-15}$ m).

Mass of a p.: $1.607\ 262\ 3\cdot E^{-27}$ [kg] which is approx. 2000 times heavier than an electron.

Radius of a p.: $1\cdot E^{-15}$ [m]

Carbon Dating: Because of cosmic bombardment, about 1% of carbon in the atmosphere is ^{14}C; both normal ^{12}C and the ^{14}C-isotope join with O_2, to become CO_2, hence all plants have a tiny little ^{14}C in them; since living things breath the decaying ^{14}C (splits up into ^{14}N + 1e) is accompanied by a replenishment of ^{14}C and a redroactive equilibrium is reached. When an organism dies, however, replenishment stops; the longer an organism is dead the less ^{14}C is conserved - ^{14}C-half life = 5730 years.

Chain Reaction: A self-sustaining reaction that, once started, steadily provides the energy and matter necessary to continue the reaction:

$^{1}n + {}^{235}U \rightarrow {}^{91}Kr + {}^{143}Ba + 3({}^{1}n)$

Correspondence Principle: The rule that a new theory is valid provided that, when it overlaps with the old, it agrees with the verified results of the old theory.

Critical Mass: the minimum mass of fissionable material in a reactor or nuclear bomb that will sustain a chain reaction; in natural ^{238}U there's only 0.7% of ^{235}U, too little to sustain a chain reaction.

Force: An influence that can cause an object to be accelerated or slowed down.

Strong Nuclear F.: Is an attracting force that acts between protons, neutrons and particles called mesons, all of which are classified as hadrons; The strong force acts only over a very short distance, it is very strong within the radius of a nucleus less than 10^{-15} m apart , but close to zero at greater separations, hence a larger nucleus is not as stable as a smaller nucleus - therefore most of the heavier elements need a large amount of neutrons (cement) to hold them together (see inverse square law).

Weak Nuclear F.: The force responsible for beta decay. This force occurs through the exchange of the W and Z^0 particles. All leptons and hadrons interact via this force.

Geiger-Mueller Counter: A device to detect radioactivity. It consists of a central wire in a hollow metal cylinder filled with gas; an electric voltage is applied across the cylinder and wire so that the wire is more positive than the cylinder; if radiation enters the tube and ionizes an atom in the gas chamber, the freed electron is attracted to the positively charged central wire. As this electron is accelerated towards the wire, it collides with other atoms and knocks out more electrons - this generates a short pulse of electric current, which activates a counting device connected to the tube.

Half-life: The time required for half the atoms of a radioactive element to decay.

Inverse-Square Law: A law relating the intensity of an effect to the inverse square of the distance from the cause:

Intensity ≅ 1/distance^2;

Electrostatic Force holding together the nucleus: $F = k_F\cdot q_1\cdot q_2/d^2$ [N]

k_F, coulomb c. ≈ $9\cdot E^{9}$ [N·m^2/C^2]
q, charge [A·s] [C]
d, distance [m]

Isotope: Atoms whose nuclei have the same number of protons but different numbers of neutrons. One of several possible forms of a chemical element that have same number of protons, differ from others in the number of neutrons in the atomic nucleus, but not in chemical properties e.g.: ^{21}Na, ^{22}Na, ^{23}Na.

Radioisot.: An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation; also called a radioactive isotope.

Mass: The quantity of matter in an object, the measurement of the inertia or sluggishness (drag) that an object exhibits in response to any effort made to start or stop it - a form of energy.

M. **Defect**: The binding energy of a typical nucleus is a rather large amount of energy - in average 8MeV for all nuclei; therefore a nucleus with a mass number "A" typically has a binding energy of about A·8MeV; the mass associated with the binding energy is BE/c^2; this mass is carried away by the energy released during the assembly of the nucleus from its consistent neutrons and protons - hence is considered to be 1% less than the sum of individual protons and neutrons.

Since this is the case especially in elements of the extreme end of the periodic table (H, U, etc) the most energy can be extracted if the lighter ones are fused to heavier elements (H to He) and the heavier elements be split up into lighter one (U to Kr and Ba).

Mass-energy equivalence: The relationship between mass and rest energy as giving by the equation: $E_0 = m \cdot c^2$ $[kg \cdot m^2/s^2] = [N \cdot m] = [J]$

Neutrino: Beta emissions are always accompanied by the emission of a neutral particle with almost no mass; it would take an 8 light-years thick lead block to stop ½ the neutrinos produced in a typical nuclear decay. 1000s of them fly through everything in each second, present speculation is that if neutrinos do have any mass they are so numerous that they make up 90% of the mass of the universe, enough to halt the present expansion and ultimately close the cycle from big bang to big crunch - neutrinos may be considered as the glue holding together the universe.

Nucleus: The positive charged core of an atom.

N. **Fission**: The splitting of the nucleus of a heavy atom, such as ^{235}U, into two main parts, accompanied by the release of energy (see mass defect): $^{1}n + {}^{235}U \rightarrow {}^{91}Kr + {}^{143}Ba + 3\,{}^{1}n$

N. **Fusion**: The combination of the nuclei of light atoms to form heavier nuclei, with the release of much energy (see mass defect): $^{2}H + {}^{3}H \rightarrow {}^{4}He + {}^{1}n$

Thermonuclear F.: Nuclear fusion produced by high temperature.

Nucleon: A nuclear proton or neutron; the collective name for either or both.

Particles: (see radioactive decay and rays)

Alpha P.: Two neutrons and two protons.

Beta P.: An electron, a proton and a antineutrino.

Quantum: An elemental unit of quantity (light).

Q. **Mechanics**: The branch of quantum physics that deals with finding the probability amplitudes of matter waves, organized principally by findings of Werner Heisenberg and Erwin Schrödinger.

Principle of Q. Number: There is a maximum capacity of electrons in an atom (each shell) can host: $n_e = 2 \cdot n^2$ n, number of orbit [-]

Quarks: Elementary constituent particles of building blocks of nuclear matter.

Radioactive Decay: Spontaneous chipping apart of the atomic nucleus. When a nucleus suffers alpha or beta decay, it is often left in an excited state, and if then eliminates the excitation energy in the form of a gamma ray; the emission of a gamma ray by a transition of a nucleon is similar to the emission of visible photons or of X-rays by a transition of an atomic electron.

α - **Alpha** D.: Regarded as the fission of the nucleus into two smaller nuclei; fission occurs spontaneously because of an instability in the original nucleus (see ray).

β - **Beta** D.: The simplest beta decay reaction is the decay of the neutron; the free neutron is unstable and it decays into a proton, an electron and an antineutrino (see beta ray).

Radioactivity: Emission of invisible rays of a radioactive substance like uranium (see ray);

α - **Alpha** R.: A stream of He- nuclei (2p+2n) ejected by certain radioactive nuclei and is *positively* charged ejected by certain radioactive nuclei; under the influence of a magnetic field (in the direction of the index finger;i.e.: right hand rule) are deflected towards the thumb, because of their positive electric charge. Alpha rays do not penetrate deeply e.g.: harmful when inhaled due to short distance penetration!

β - **Beta** R.: A stream of beta particles ejected by certain radioactive nuclei; have *negative* electric charge (electrons), hence are deflected towards the thumb under the influence of a magnetic field. Beta rays penetrate almost everything, but are stopped when encountering metal.

γ - **Gamma** R.: High-frequency electromagnetic radiation (photons)emitted by the nuclei of radioactive atoms and have *no charge* at all, hence not reflected by a magnetic field. These are the farthest reaching rays, and can only be shielded with a thick lead-block.

Ray: An electromagnetic propagation through space and time (see radioactivity).

α - **Alpha** R.: A stream of positively charged He- nuclei (2p+2n) ejected by radioactive nuclei.

β - **Beta** R.: A stream of negatively charged electrons ejected by certain radioactive nuclei.

γ - **Gamma** R.: High frequency (no charge) electromagnetic radiation emitted by radioactive atoms;.

X - or Roentgen R.: EMR lower in frequency and energy gamma-rays (see there) but higher than light.

Ritz combination Principle: the theory that the spectral lines of the elements have frequencies that are either the sums or the differences of the frequencies of two other lines.

Schrödinger wave equation: The fundamental equation of quantum mechanics, which interprets the wave nature of material particles in terms of probability wave amplitudes. It does not indicate where an electron can be found in an atom at any moment but only the likelihood of finding it there. It specifies the possible energy state the electron can occupy and identifies the corresponding wave function (ψ).$\Delta\psi+(8\cdot\pi^2\cdot m/h^2)\cdot(E\text{-}PE)\cdot\psi = 0$

$\Delta\psi$, LaPlace operator	[-1/m]
ψ, wave function	[m]
ψ^2, probability of density	[-]
PE, potential energy	[J]
E, total energy	[J]
m, mass	[kg]
h, Planck c. = $6.63\cdot10^{-34}$	[J·s]
π, circle's constant = 3.142	[-]

Transmutation: The conversion of an atomic nucleus of one element into an atomic nucleus of another element through a loss or gain in the number of protons.

When an alpha particle is ejected from ^{238}U which has 92 protons, it will loose the equivalent of 1 He atom (2p + 2n), therefore mutating to thorium ^{234}Th (see radioactive decay).

Artificial T.: Bombarding atoms with He-particles: $^{14}N + {}^{4}He \rightarrow {}^{17}O + {}^{1}H$

Natural T.: The normal process of decay of Uranium to mutate to Lead:

$^{238}U \rightarrow {}^{234}Th + {}^{4}He$, thronium is radioactive as well but emits beta particles instead, keeping an extra proton: $^{234}Th \rightarrow {}^{234}Pa + 1e$ to become protactinium and so forth until ^{206}Pb is formed.

(alpha emissions lower the atomic number, whereas beta emissions increase it).

Wave: A wiggle in space and time; a disturbance propagated from one place to another with no actual transport of matter.

de Broglie Matter W.: The standing wave of an orbiting electron around the nucleus in its shell - the associated wave properties of all particles of matter. The wavelength of a particle wave is related to its momentum and Planck's constant h, by the relationship;

Wavelength = h/momentum:

$\lambda = h/p = h/m\cdot v = 2\cdot\pi\cdot r/n$

h, plank c. $6.63\cdot E^{-34}$	[J·s]
p, linear momentum	[kg·m/s]
m, mass	[kg]
v, velocity	[m/s]
r, radius	[m]
n, number of oscillations in a particular orbit	

W. **Emissions in Matter**: An electromagnetic wave is emitted when electrons make a transition from a higher to a lower orbit: $\Delta E = h\cdot f$, hence the color of emitted light depends on the orbiting difference of the jump and whether the lower shell still accepts an electron - (see quantum number)

W-**Particle Duality**: (Also called De-Broglie wavelength) Every particle will produce an interference or diffraction pattern; by all bodies, therefore, (e, p, atoms, mice, you, planets, sun) have a wavelength that is related to the momentum

$\lambda = h/(m\cdot v)$

h, Planck c.$6.63\cdot E^{-34}$	[J·s]
m, mass	[kg]

X-ray: Electromagnetic radiation of higher frequencies than ultraviolet, emitted by innermost electron clouds of excited atoms (contrary to the outermost excitement of electrons in a florescence lamp).

Absorbtion of X-rays: An X-ray quantum penetrates a substance, looses part of its radiating intensity following an exponential graph:

The thicker the target the lower the remaining energy at the other end (materials of high density such as lead, with a concomitant high density of electrons, strongly absorb and block X-rays) and is characterized by four fundamental principles:

- **Elastic defraction**: Simple elastic defraction of the incoming X-ray by an atom; the energy contained in the X-ray quantum remains constant.
- **Photoelectric Effect**: The emission of electrons from a metal surface when light shines on it; i.e.: light of low frequency does not emit electrons whereas light of high f. does.
- **Compton Effect**: Scattered (deflected) X-rays have a wavelength somewhat longer than that of the original X-rays, since part of the energy has been given off to the excited electron.
- **Pair-building Effect**: Transformation of an X-ray quantum into an electron-positron-pair, which are at least double in energy equivalent; $E = h\cdot f > 1.02MeV$.

X-Ray Diffraction: Examination of crystalline structure using the pattern of scattered X rays.

Glossary Physics *(IX-relativity)*

Geodesic: The shortest path between points on any surface.
Gravitational red shift: The shift in wavelength toward the red end of the spectrum experienced by light leaving the surface of a massive object, as predicted by the general theory of relativity.
G. **Wave**: A gravitational disturbance made by moving mass that propagates through space-time.
Frame of Reference: A vantage point (usually a coordinate system with coordinate axes) from which position and motion may be measured.
Length contraction: The apparent shrinking of an object moving at relativistic speeds.
Mass-energy equivalence: The relationship between mass and rest energy as giving by the equation:
$E_0 = m \cdot c^2$ $[kg \cdot m^2/s^2] = [N \cdot m] = [J]$
Postulates of the special theory of relativity (1) All laws of nature are the same in all uniformly moving frames of reference. (2) The speed of light in free space will be found to have the same value regardless of the motion ofthe source or the motion ofthe observer; that is the speed of light is invariant.
Principle of equivalence: Local observations made in an accelerated frame of reference are indistinguishable from observations made in a Newtonian gravitation field.
Simultaneity: The condition wherein events occur or operate at the same time. Two events that are simultaneous in one frame of reference are not simultaneous in a frame moving relative to the first frame.
Space-time: the four-dimensions continuum in which all things exist; three dimensions are the coordinates of space and the fourth is of time.
Time dilation: The apparent slowing down of time for an object moving at relativistic speeds.