

Formula Sheet for Physics 113

speed of light in vacuum: $c = 3 \cdot 10^8 \frac{m}{s}$; conversion: $1 km = 1000 m$

1 nano – meter = $1 nm = 10^{-9} m$

speed of sound at room temperature (20°Celsius): $343 \frac{m}{s}$

mass of an electron: $m_e = 0.511 MeV/c^2 = 0.511 \times 10^6 eV/c^2 = 9.11 \times 10^{-31} kg$

mass of a positron = rest mass of an electron

mass of a proton: $m_p = 1.6726 \times 10^{-27} kg$

conversion: different units for energy $1 eV = 1.6 \times 10^{-19} J$

Planck's constant: $h = 6.626 \times 10^{-34} Js$

wave lengths of visible light: $400 nm - 700 nm$, $\lambda_{red} > \lambda_{green} > \lambda_{blue} > \lambda_{violet}$

constant velocity: $v = \frac{d}{t}$, d : distance, t : time

frequency: $f = \frac{1}{T}$, unit: $Hz = hertz = \frac{1}{s}$

Simple Harmonic Motion (SHM)

Hooke's Law in one dimension: $F = -kx$, displacement of the spring: x

position for SHM: $x = A \cos \omega t$, if stretched to maximum amplitude A at $t = 0$.

velocity for SHM: $v = -A\omega \sin \omega t$

acceleration for SHM: $a = -A\omega^2 \cos \omega t$

Elastic potential energy: $PE_{elastic} = \frac{1}{2} kx^2$

work done by the spring force: $W = \frac{1}{2} kx_0^2 - \frac{1}{2} kx^2$

period T , frequency f , angular frequency ω : $T = \frac{2\pi}{\omega} = \frac{1}{f}$

period of a spring + mass: $T = 2\pi \sqrt{\frac{m}{k}}$

period of a pendulum: $T = 2\pi \sqrt{\frac{L}{g}}$, L length of the string

Elastic deformation:

Stretch and compression: $F = Y \frac{\Delta L}{L_0} A$ with L_0 original length, A cross sectional area, Y Young's modulus

Shear deformation: $F = S \frac{\Delta X}{L_0} A$, with shear modulus S

Pressure: $P = \frac{F}{A}$

Pressure change implies volume change: $\Delta P = -B \frac{\Delta V}{V_0}$

Waves

wave velocity: $v = \lambda \cdot f$, λ is the wavelength

wave speed on a string of mass m and length L under tension F : $v = \sqrt{\frac{F}{m/L}}$

speed of sound in air: $v \approx (331 + 0.6T) \frac{m}{s}$, with T being the temperature in Celsius.

speed of sound in a solid bar: $v = \frac{Y}{\rho}$ with Young's modulus Y and density ρ .

intensity $I = \frac{\text{power}}{\text{area}}$, power = $\frac{\text{energy}}{\text{time}}$

intensity level: $\beta = 10 \log \frac{I}{I_0}$, threshold of human hearing $I_0 = 10^{-12} \frac{W}{m^2}$

energy of a wave: $E \propto A^2$, A : amplitude

Doppler effect: $f_o = f_s \frac{v \pm v_o}{v \mp v_s}$

upper signs: source and observer move toward each other

lower signs: source and observer move away from each other

v_o : speed of observer; v_s : speed of source

interference of waves

condition for constructive interference: $\Delta L = 0, \lambda, 2\lambda, 3\lambda, \dots$

condition for completely destructive interference: $\Delta L = \frac{1}{2}\lambda, \frac{3}{2}\lambda, \frac{5}{2}\lambda, \dots$

Beat frequency: $f_{beat} = |f_1 - f_2|$

$f_n = n f_1$, f_1 fundamental frequency or first harmonic, $n = 2, 3, 4, \dots$ correspond to the higher harmonics of a string

tubes with open ends: $f_n = \frac{v}{\lambda_n} = \frac{nv}{2L}$, any n

tubes with one closed end: $f_n = \frac{v}{\lambda} = \frac{nv}{4L}$, n odd

diffraction: diffraction with a single slit: $\sin \theta = \frac{\lambda}{D}$

circular opening: $\sin \theta = 1.22 \frac{\lambda}{D}$

θ is the direction of the first minimum

Light as a Wave

total energy density of an e.m. wave: $u = \frac{1}{2}\epsilon_0 E^2 + \frac{1}{2\mu_0} B^2$

electric and magnetic field of an e.m. wave: $E = cB$

intensity $S = cu$

average (rms) values: $E_{rms} = \frac{1}{\sqrt{2}}E_0$, $B_{rms} = \frac{1}{\sqrt{2}}B_0$

Doppler effect for electromagnetic waves: $f_o = f_s \left(1 \pm \frac{v_{rel}}{c}\right)$, for $v_{rel} \ll c$. The plus sign is used when source and observer move towards each other, the minus sign otherwise.

speed of light in a medium with refraction index n : $v = \frac{c}{n}$

wavelength of light in a medium $\lambda_n = \frac{\lambda}{n}$

Polarization: Unpolarized light falls onto a polarizer: $S = \frac{1}{2}S_0$, with initial intensity S_0

Polarized light falls on a polarizer: $S = S_0 \cos^2 \theta$, angle between electric field vector and polarizer axis: θ

Double Slit Experiment

maxima (bright fringes) at: $\sin \theta = m \frac{\lambda}{d}$, $m = 0, 1, 2, \dots$, separation of slits: d

minima (dark fringes) at: $\sin \theta = \left(m + \frac{1}{2}\right) \frac{\lambda}{d}$, $m = 0, 1, 2, \dots$

Thin-film interference: Light reflected from the front and rear surfaces of a thin film of transparent material can interfere. When light travels through a material with a larger index of refraction toward a material with a smaller index of refraction, there is no phase change upon reflection at the boundary. Otherwise, there is a phase change of $\lambda/2$.

A phase change of $\lambda/2$ occurs when the light reflects at a surface where the index of refraction increases.

Single Slit

Minima: $\sin \theta = m \frac{\lambda}{W}$, $m = 1, 2, \dots$, slit width: W

Resolving Power - Rayleigh criterion: Two objects can be resolved if they subtend an angle at least as large as θ_{min} : $\sin \theta_{min} = 1.22 \frac{\lambda}{D}$ where D is the diameter of the circular opening

reminder: angle in radians $\theta = \frac{s}{r}$, with arc length s and radius r

Diffraction Grating

Bright fringes (principal maxima): $\sin \theta = m \frac{\lambda}{d}$, $m = 0, 1, 2, \dots$, separation of slits: d ;

line density N : $N = 1/d$

Relativity

time dilation: $\Delta t = \frac{\Delta t_0}{\sqrt{1 - (v/c)^2}}$, Δt_0 is a proper time interval or "proper time"; Δt is the time measured by an observer with relative speed v .

length contraction: $\Delta L = \Delta L_0 \sqrt{1 - (v/c)^2}$, ΔL_0 is a proper length or rest length, measured by an observer in the rest frame of the object; ΔL is the length measured by an observer with relative speed v .

relativistic momentum: $p = \frac{mv}{\sqrt{1 - (v/c)^2}}$, m mass of an object

rest energy of an object: $E_0 = mc^2$

total energy of an object: $E = \frac{m}{\sqrt{1 - (v/c)^2}} c^2 = E_0 + KE$

$$E^2 = p^2 c^2 + m_0^2 c^4$$

photons: energy of a photon $E = hf$

photoelectric effect: $KE_{max} = hf - W_0$, W_0 : work function of the metal

photon momentum: $p = \frac{E}{c} = \frac{h}{\lambda}$

Compton effect shift in wave length: $\lambda' = \lambda + \frac{h}{m_{electron} c} (1 - \cos \phi)$

de Broglie **wave length of a particle**: $\lambda = \frac{h}{mv} = \frac{h}{p}$

momentum of a particle: $p = mv$

Bohr Model:

quantization condition imposed on angular momentum: $L = mvr_n = n \frac{h}{2\pi}$

radius of the n-th allowed orbit: $r_n = \frac{n^2}{Z} r_1$ with $r_1 = \frac{h^2}{4\pi^2 m k e^2}$

energy of the electron in the n-th allowed orbit:

$$E_n = \frac{Z^2}{n^2} \cdot E_1, \quad \text{with } E_1 = -13.6 eV, \text{ charge of the nucleus } Z$$

lowest energy state is the ground state

line spectrum of hydrogen: $\frac{1}{\lambda} = R \left(\frac{1}{n'^2} - \frac{1}{n^2} \right)$ with the Rydberg constant $R = 1.0974 \times 10^7 m^{-1}$;

$n = n' + 1, n' + 2, n' + 3 \dots$ $n' = 1$ Lyman series, $n' = 2$ Balmer series, $n' = 3$ Paschen series

Heisenberg's Uncertainty Relation: $(\Delta x)(\Delta p) \geq \frac{h}{4\pi}$ $(\Delta E)(\Delta t) \geq \frac{h}{4\pi}$

Mechanics

Equations for constant acceleration a in one dimension:

$$v_x = v_{0x} + a_x t \quad x = v_{0x} t + \frac{1}{2} a_x t^2$$

$$v_x^2 = 2a_x x + v_{0x}^2 \quad v_{x,avg} = \frac{1}{2}(v_{0x} + v_x) \quad v_{0x}: \text{initial velocity, i.e. velocity at } t = 0$$

acceleration due to gravity at Earth's surface: $g = 9.8m/s^2$

Newton's Second Law: $\sum \vec{F} = m\vec{a}$

Kinetic Energy: $KE = \frac{1}{2}mv^2$

Work - Kinetic Energy Theorem: $W_{net} = KE_f - KE_0 = \Delta KE$

Work: $W = F \cos \theta s$

gravitational potential energy: $GPE = mgh$

mechanical energy: $E_{mec} = KE + PE$ with $PE = GPE + EPE + PE_{elastic}$

$$W_{nc} = (KE_f + PE_f) - (PE_o + KE_o)$$

Power $P = \frac{W}{t}$

Geometry: area of a circle $A = \pi r^2$

surface area of a sphere: $S = 4\pi r^2$

Logarithms:

$$10^{\log x} = x$$

addition: $\log a + \log b = \log(ab)$

subtraction: $\log a - \log b = \log(\frac{a}{b})$

Quadratic equation: $ax^2 + bx + c = 0$, $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

Vector \vec{a} : $a_x = a \cos(\theta)$, $a_y = a \sin(\theta)$, $\tan(\theta) = \frac{a_y}{a_x}$

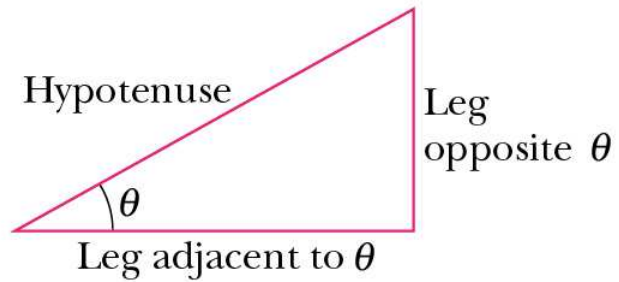
Trig and right triangle:

Units: On this page of the formula sheet, you will find relations between units. The table contains only **SI - units**.

$$\sin \theta = \frac{\text{leg opposite } \theta}{\text{hypotenuse}}$$

$$\cos \theta = \frac{\text{leg adjacent to } \theta}{\text{hypotenuse}}$$

$$\tan \theta = \frac{\text{leg opposite } \theta}{\text{leg adjacent to } \theta}$$



Note that once in a while, the same letter might either be the symbol for a physical quantity or the abbreviation for a unit, e.g. C may stand for capacitance, or for "Coulomb". This should always be clear from the context. If it is not clear to you, ask! Non SI-unit: the electron-volt, eV , is a unit for energy often used for elementary particles. $1eV = 1.6 \cdot 10^{-19}J$.

physical quantity	symbol	unit	abbreviation for unit
force	\vec{F}	Newton	$N = \frac{kgm}{s^2}$
energy, work	E, PE, KE, W	Joule	$J = Nm$
power	P	Watt	$W = \frac{J}{s} = VA = \frac{VC}{S}$
frequency	f	Hertz	$Hz = \frac{1}{s}$
pressure	P	Pascal	$Pa = \frac{N}{m^2}$
intensity	I	Watt/meter ²	$\frac{W}{m^2}$
sound intensity level	β	decibels	dB