

Physics 101 Formula Sheet

Last updated 3/3/2025. Please report any errors or accessibility issues to Prof. Gammie at gammie@illinois.edu

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Constants

$$g = 9.8 \text{ m/s}^2 \text{ (near Earth's surface)}$$

$$G = 6.7 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2 \text{ (Universal Gravitational Constant)}$$

$$\rho_{\text{water}} = 1000 \text{ kg/m}^3$$

$$v_{\text{sound,air}} = 343 \text{ m/s (speed of sound in air)}$$

$$v_{\text{light}} = 3 \times 10^8 \text{ m/s (speed of electromagnetic wave in vacuum)}$$

$$N_A = 6.022 \times 10^{23} \text{ molecules/mole (Avogadro's number)}$$

$$R = 8.31 \text{ J/(mol} \cdot \text{K)} \text{ (Ideal gas constant)}$$

$$k_B = \frac{R}{N_A} = 1.38 \times 10^{-23} \text{ J/K (Boltzmann constant)}$$

$$\sigma = 5.67 \times 10^{-8} \text{ J/(s} \cdot \text{m}^2 \cdot \text{K}^4) \text{ (Stefan-Boltzmann constant)}$$

Useful conversions

$$\text{Change of an arbitrary quantity } x: \Delta x = x_{\text{final}} - x_{\text{initial}}$$

$$\text{Period and frequency: } \omega = 2\pi f \quad T = 1/f$$

$$\text{Units of pressure: } 1 \text{ atm} = 1.01 \times 10^5 \text{ Pa} \quad 1 \text{ Pa} = 1 \text{ N/m}^2$$

$$\text{Units of volume: } 1 \text{ m}^3 = 1000 \text{ liters}$$

$$\text{Area of a circle of radius } r: A = \pi r^2$$

$$\text{Volume of a sphere of radius } r: V = \frac{4}{3}\pi r^3$$

$$\text{Surface area of a sphere of radius } r: A = 4\pi r^2$$

$$\text{Fahrenheit } (T_F) \text{ to Celsius } (T_C): T_C = \frac{5}{9}(T_F - 32^\circ)$$

$$\text{Celsius } (T_C) \text{ to Kelvin } (T_K): T_K = T_C + 273.15$$

Greek letter variable names

α – alpha (use: angular acceleration, linear expansion)

β – beta (use: volume expansion)

θ – theta (use: angle, angular displacement)

λ – lambda (use: wavelength)

μ – mu (use: coefficient of friction, linear density)

π – pi (use: as a constant)

ρ – rho (use: volume density)

τ – tau (use: torque)

ϕ – phi (use: angle)

ω – omega (use: angular speed, angular frequency)

Δ – delta (use: to represent change in a variable)

Σ – Sigma (use: the sum of the variable that follows)

σ – sigma (use: as a constant)

κ – kappa (use: as a constant)

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Linear Equations

Kinematics

$$v_{avg} \equiv \frac{\Delta x}{\Delta t} \quad a_{avg} \equiv \frac{\Delta v}{\Delta t}$$

$$v = v_0 + at$$

$$x = x_0 + v_0 t + \frac{1}{2}at^2$$

$$v^2 = v_0^2 + 2a\Delta x$$

Velocity of an object traveling in a moving medium: $\vec{v}_{object} = \vec{v}_{object \text{ in medium}} + \vec{v}_{medium}$

Centripetal acceleration around a circular path of radius R : $a_c = \frac{v^2}{R} = \omega^2 R$

Dynamics

Newton's 2nd Law: $\Sigma \vec{F} = m\vec{a}$ x direction: $\Sigma F_x = ma_x$ y direction: $\Sigma F_y = ma_y$

Force definitions (magnitudes):

Weight near the surface of Earth: $W = mg$ Spring force for a stretch x from equilibrium: $\vec{F}_s = -k\vec{x}$

Friction: $f_{s,max} = \mu_s F_N$ $f_k = \mu_k F_N$

Work and Energy

Work done by a force F across a distance d : $W \equiv Fd \cos \theta = F_{\parallel}d = Fd_{\parallel}$

Kinetic energy: $K \equiv \frac{1}{2}mv^2 = \frac{p^2}{2m}$

Gravitational potential energy near Earth's surface: $U_g = mgy$ Spring potential energy: $U_s = \frac{1}{2}kx^2$

Work-Kinetic Energy theorem: $W_{total} = \Delta K$

Definition of mechanical energy: $E = K + U$

Effect of non-conservative work on mechanical energy: $E_i + W_{nc} = E_f$

Definition of Power: $P \equiv \frac{W}{t}$

Impulse and Momentum

Definition of momentum: $\vec{p} \equiv m\vec{v}$

Impulse: $\vec{I} = \vec{F}_{avg}\Delta t$

$\Sigma \vec{F}_{ext}\Delta t = \Delta \vec{p}_{total}$ x direction: $p_{i,x} + \Sigma I_x = p_{f,x}$ y direction: $p_{i,y} + \Sigma I_y = p_{f,y}$

When $\Sigma \vec{F}_{ext} = 0$ momentum is conserved

Universal Gravitation - For celestial bodies and very far distances from Earth's surface

For two objects having masses m and M : $F_G = G \frac{mM}{R^2}$ $U_G = -G \frac{mM}{R}$

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Rotational Equations

Conversion between linear and rotational quantities

For rotating objects: x , v , and a describe translational values at some radius R

For objects rolling without slipping: x , v , and a describe center of mass values

$$\Delta x = R\Delta\theta \quad v = R\omega \quad a = R\alpha$$

$$1 \text{ revolution} = 2\pi \text{ radians}$$

$$\text{Location of center of mass: } x_{cm} = \frac{m_1\vec{x}_1 + m_2\vec{x}_2 + \dots}{m_1 + m_2 + \dots}$$

Rotational Kinematics

$$\omega_{avg} \equiv \frac{\Delta\theta}{\Delta t} \quad \alpha_{avg} \equiv \frac{\Delta\omega}{\Delta t}$$

$$\omega = \omega_0 + \alpha t$$

$$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$$

$$\omega^2 = \omega_0^2 + 2\alpha\Delta\theta$$

Rotation directions: Clockwise (CW) $\cup$ Counterclockwise (CCW) $\cap$

Rotational Statics and Dynamics

Newton's 2nd Law: $\Sigma \vec{\tau} = I\vec{\alpha}$ When $\Sigma \vec{\tau} = 0$ and $\Sigma \vec{F} = 0$ the object is in static equilibrium

Magnitude of torque: $\tau \equiv Fr \sin \theta = F_{\perp} r = Fr_{\perp}$

Work done by a torque: $W = \tau\Delta\theta$

Rotational Energy and Angular Momentum

$$\text{Rotational Kinetic energy: } K_{rot} \equiv \frac{1}{2}I\omega^2 = \frac{L^2}{2I}$$

$$\text{Total Kinetic energy: } K_{total} = K_{trans} + K_{rot} = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$$

Definition of angular momentum: $\vec{L} \equiv I\vec{\omega}$

$$\text{Impulse: } \vec{I} = \Delta\vec{p} = \vec{F}_{avg}\Delta t$$

$$\Sigma \vec{\tau}_{ext}\Delta t = \Delta\vec{L}_{total} \quad \text{When } \Sigma \vec{\tau}_{ext} = 0 \text{ angular momentum is conserved}$$

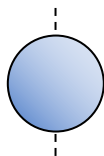
Moments of Inertia (I)

$$\text{Parallel axis theorem: } I = I_0 + Mh^2$$

$$I = \Sigma mr^2 \text{ (collection of point particles)}$$

$$I = \frac{2}{5}MR^2 \text{ (solid sphere or ball)}$$

$$I = \frac{2}{3}MR^2 \text{ (hollow sphere or ball)}$$

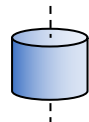


$$I = \frac{1}{2}MR^2 \text{ (solid disk or cylinder)}$$

$$I = MR^2 \text{ (hoop or hollow cylinder)}$$

$$I = \frac{1}{12}ML^2 \text{ (uniform rod about center)}$$

$$I = \frac{1}{3}ML^2 \text{ (uniform rod about one end)}$$



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Fluids

Definition of pressure: $P \equiv \frac{F}{A}$

Definition of density: $\rho \equiv \frac{m}{V}$

Pressure at a depth d below a point with pressure P_0 : $P = P_0 + \rho g d$

Force definition: Buoyant force (magnitude) $F_B = W_{displaced\ fluid} = \rho_{fluid} g V_{displaced}$

Volume flow rate: $Q = vA$

Flow continuity equation: $v_1 A_1 = v_2 A_2$

Bernoulli equation: $P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$

See [Constants](#) and [Conversions](#)

Heat and Thermodynamics

Temperature

Convert from degrees Fahrenheit (T_F) to degrees Celsius (T_C): $T_C = \frac{5}{9}(T_F - 32^\circ)$

Convert from degrees Celsius (T_C) to Kelvin (T_K): $T_K = T_C + 273.15$

Thermal expansion: $\Delta L = \alpha L_0 \Delta T$ $\Delta V = \beta V_0 \Delta T$ ($\beta = 3\alpha$)

Heat

First law of thermodynamics: $\Delta U = Q + W$

Specific heat capacity: $Q = cM\Delta T$

Latent heat of fusion (solid $\leftrightarrow$ liquid): $Q = L_f M$

Latent heat of vaporization (liquid $\leftrightarrow$ gas): $Q = L_v M$

Rate of heat transfer by conduction (magnitude): $H = \frac{Q}{t} = \frac{\kappa A (T_{hot} - T_{cold})}{L}$

Rate of heat transfer by radiation: $H = \frac{Q}{t} = e\sigma T^4 A$ $\sigma = 4.67 \times 10^{-8} \text{ J}/(\text{s} \cdot \text{m}^2 \cdot \text{K}^4)$

Net heat transfer rate by a radiating object in an environment with T_0 : $P_{net} = e\sigma A(T^4 - T_0^4)$

Ideal Gas Law and Kinetic Theory

$PV = nRT = Nk_B T$ (see [Constants](#))

For monatomic gases: $K_{avg} = \frac{3}{2}k_B T = \frac{1}{2}mv_{rms}^2$ $U = \frac{3}{2}Nk_B T = \frac{3}{2}nRT$

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Simple Harmonic Motion

Springs

Force exerted by a stretched spring (Hooke's Law): $\vec{F}_s = -k\vec{x}$

Potential energy stored in a stretched spring: $U_s = \frac{1}{2}kx^2$

Angular frequency: $\omega = \sqrt{\frac{k}{m}}$ Period: $T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{m}{k}}$

Equations of motion (depend on initial conditions):

Common option 1:

$$x(t) = A \cos(\omega t)$$

$$v(t) = -A\omega \sin(\omega t)$$

$$a(t) = -A\omega^2 \cos(\omega t)$$

Common option 2:

$$x(t) = A \sin(\omega t)$$

$$v(t) = A\omega \cos(\omega t)$$

$$a(t) = -A\omega^2 \sin(\omega t)$$

Maximum values: $x_{max} = A$

$v_{max} = A\omega$

$a_{max} = A\omega^2$

Simple Pendulums

Angular frequency: $\omega = \sqrt{\frac{g}{L}}$ Period: $T = 2\pi\sqrt{\frac{L}{g}}$

Waves and Sound

Speed of a wave on a string: $v = \sqrt{\frac{F_T}{m/L}}$

Relationship between speed, wavelength, and frequency: $v = \lambda f$

Resonator wavelengths:

Resonator with nodes at both ends: $\lambda_n = \frac{2}{n}L$ ($n = 1, 2, 3, \dots$)

Resonator with a node at one end, antinode on the other: $\lambda_n = \frac{4}{n}L$ ($n = 1, 3, 5, \dots$)

Sound intensity: $I = \frac{P}{4\pi r^2}$

Loudness: $\beta = (10 \text{ dB}) \log_{10} \left(\frac{I}{I_0} \right)$

Change in loudness: $\beta_2 - \beta_1 = (10 \text{ dB}) \log_{10} \left(\frac{I_2}{I_1} \right)$

[Converting with log base ten: $x = \log_{10}(y) \leftrightarrow y = 10^x$]

Frequency shift due to Doppler Effect:

$$f_{observer} = \left(\frac{v_{sound} \pm v_{observer}}{v_{sound} \mp v_{source}} \right) f_{source}$$

In the numerator:

Use + if the observer moves toward the source

Use – if the observer moves away from the source

In the denominator:

Use – if the source moves toward the observer

Use + if the source moves away from the observer

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