Physics 101 Formula Sheet

Last updated 3/4/2024. Please report any errors or accessibility issues to Prof. Ansell at ansellk@illinois.edu

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Constants

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

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

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

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

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

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

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

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

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

Useful conversions

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

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

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

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

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

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

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

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

Celsius (T_C) 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

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

$v = v_0 + at$

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

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

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: $W \equiv Fd\cos\theta$

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: $W_{nc} = \Delta E$

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

Impulse and Momentum

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

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

$\Sigma\vec{F}_{ext}\Delta t = \Delta\vec{P}_{total}$ x direction: $\Sigma\vec{F}_{ext,x}\Delta t = \Delta\vec{P}_{total,x}$ y direction: $\Sigma\vec{F}_{ext,y}\Delta t = \Delta\vec{P}_{total,y}$

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

Universal Gravitation

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

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

1 revolution = 2π radians

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

Rotational Kinematics

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

$\omega = \omega_0 + \alpha t$

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

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

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

Torque definition (magnitude): $\tau \equiv Fr\sin\theta$

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

Rotational Energy and Angular Momentum

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

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

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

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

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

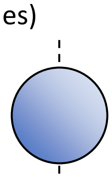
Moments of Inertia (I)

Parallel axis theorem: $I = I_0 + Mh^2$

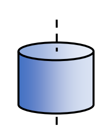
$I = \Sigma mr^2$ (collection of point particles)

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

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

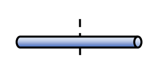


$I = \frac{1}{2}MR^2$ (solid disk or cylinder)

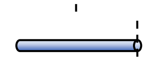


$I = MR^2$ (hoop or hollow cylinder)

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



$I = \frac{1}{3}ML^2$ (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): $T_C = \frac{5}{9}(T_F - 32°)$

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↔liquid): $Q = L_f M$ Latent heat of vaporization (liquid↔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: $H = \frac{Q}{t} = e\sigma T^4 A$ $\sigma = 4.67 \times 10^{-8}\ \mathrm{J/(s \cdot m^2 \cdot K^4)}$

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

Ideal Gas Law and Kinetic Theory

$PV = nRT = Nk_B T$ (see Constants)

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

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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: $\lambda_n = \frac{2}{n}L$ $(n = 1,2,3,\ldots)$

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

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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