

Linear uniform motion: $x_f = x_i + v_i \cdot \Delta t$

Linear motion with constant acceleration:

$$v_f = v_i + a \cdot \Delta t$$

$$x_f = x_i + v_i \cdot \Delta t + \frac{1}{2}a(\Delta t)^2$$

$$x_f = x_i + \frac{v_f^2 - v_i^2}{2a}$$

$$v_{avr} = \frac{x_f - x_i}{\Delta t} = \frac{v_f + v_i}{2}$$

Projectile motion:

$$v_{xf} = v_{xi}$$

$$v_{yf} = v_{yi} - g \cdot \Delta t$$

$$y_f = y_i + v_{yi} \cdot \Delta t - \frac{1}{2}g(\Delta t)^2$$

$$y_f = y_i - \frac{v_{yf}^2 - v_{yi}^2}{2g}$$

$$x_f = x_i + v_{xi} \cdot \Delta t$$

Angular uniform motion: $\theta_f = \theta_i + \omega_i \cdot \Delta t$

Angular motion with constant acceleration:

$$\omega_f = \omega_i + \alpha \cdot \Delta t$$

$$\theta_f = \theta_i + \omega_i \cdot \Delta t + \frac{1}{2}\alpha(\Delta t)^2$$

$$\theta_f = \theta_i + \frac{\omega_f^2 - \omega_i^2}{2\alpha}$$

$$\omega_{avr} = \frac{\theta_f - \theta_i}{\Delta t} = \frac{\omega_f + \omega_i}{2}$$

Connection between linear and angular variables: $s = \theta \cdot r$ $v = \omega \cdot r$ $a = \alpha \cdot r$ **Centripetal acceleration:** $a = \frac{v^2}{r} = \omega^2 r$

Newtons second law: **Linear** motion $\vec{F}_{net} = \sum_i \vec{F}_i = m\vec{a}$ **Angular** motion $\tau_{net} = \sum_i \tau_i = I \cdot \alpha$

Friction force: $f_s = \mu_s \cdot N$, $f_k = \mu_k \cdot N$ Hooks law: $f = -k \cdot \Delta x$ **Torque:** $\tau = F \cdot r \sin \theta = F \cdot r_{arm}$

Linear momentum: $\vec{p} = m \cdot \vec{v}$ Impulse: $\vec{I} = \vec{F} \cdot \Delta t$ Impulse-momentum: $\Delta \vec{p} = \vec{I}$ Angular momentum: $L = I \cdot \omega$

Conservation of momentum: **linear:** $\sum_k \vec{p}_{ki} = \sum_k \vec{p}_{kf}$ **angular:** $\sum_k L_{ki} = \sum_k L_{kf}$

Kinetic energy: **linear:** $K = \frac{mv^2}{2}$ **angular:** $K = \frac{I\omega^2}{2}$ **Work:** $W = F \cdot d \cos \theta$ or $W = \tau \cdot \theta$

Potential energy: **gravity:** $U = mgy$ **elastic:** $U = \frac{k(\Delta x)^2}{2}$ Power: $P = \frac{\Delta W}{\Delta t} = F \cdot v$

Conservation of energy: $\Delta K + \Delta U = K_f - K_i + U_f - U_i = W$ Work-Energy Theorem: $W_{net} = K_f - K_i = \Delta K$

Elastic Collision: $m_1 \vec{v}_{1i} + m_2 \vec{v}_{2i} = m_1 \vec{v}_{1f} + m_2 \vec{v}_{2f}$ $\frac{1}{2}m_1 v_{1i}^2 + \frac{1}{2}m_2 v_{2i}^2 = \frac{1}{2}m_1 v_{1f}^2 + \frac{1}{2}m_2 v_{2f}^2$ $v_{1i} - v_{2i} = -(v_{1f} - v_{2f})$

Moments of inertia:

Point-like object

Thin hoop, radius R

Solid cilinder, radius R

Hollow cilinder, inner radius R_1 , outer radius R_2

Uniform sphere, radius R

Thin spherical shell radius R

Long uniform rod, length L

Long uniform rod, length L

distance from axis R

axis through center

axis through center

axis through center

axis through center

axis through center

axis through center

axis through end

$$mR^2$$

$$mR^2$$

$$\frac{1}{2}mR^2$$

$$\frac{1}{2}m(R_1^2 + R_2^2)$$

$$\frac{2}{5}mR^2$$

$$\frac{3}{5}mR^2$$

$$\frac{1}{12}mL^2$$

$$\frac{1}{3}mL^2$$

Coefficient of Friction

	μ_s	μ_k
Steel on steel (dry)	0.8	0.6
Steel on steel (lubricated)	0.1	0.05
Aluminum on steel	0.61	0.47
Copper on steel	0.53	0.36
Rubber on concrete	1.0	0.8
Wood on wood	0.5	0.2
Wood on snow	0.12	0.06
Ice on ice	0.1	0.03
Synovial joints in humans	0.01	0.003

Center-of-mass: $x_{cm} = \frac{\sum_i m_i x_i}{M}$ **Gravity force:** $F = G \frac{m_1 m_2}{r^2}$ **Gravity potential energy:** $U = -G \frac{m_1 m_2}{r}$

Third Keplers Law: $T^2 = \left(\frac{4\pi^2}{GM_e} \right) a^3$ **Period** of rotation: $T = \frac{2\pi r}{v}$

Oscillations: $x(t) = A \cos(\omega t + \phi_0)$ $v(t) = -\omega A \sin(\omega t + \phi_0)$ $a(t) = -\omega^2 A \cos(\omega t + \phi_0)$

$$\omega = 2\pi f \quad f = \frac{1}{T} \quad E_{tot} = \frac{1}{2}kA^2 = \frac{1}{2}m\omega^2 A^2 = \frac{1}{2}mv_{max}^2 = \frac{1}{2}mv^2 + \frac{1}{2}kx^2 \quad \omega = \sqrt{\frac{k}{m}} \quad \omega = \sqrt{\frac{g}{L}}$$

Mass density: $\rho = \frac{m}{V}$ Pressure: $p = \frac{F}{A}$ Hydrostatic pressure: $p = p_0 + \rho gh$ Boyant force: $F_B = \rho_f g V_{submerged}$

Continuity: $v_i \cdot A_i = v_f \cdot A_f$ Bernoullis equation: $p_i + \frac{1}{2}\rho v_i^2 + \rho gy_i = p_f + \frac{1}{2}\rho v_f^2 + \rho gy_f$

Tensile stress= $\frac{F}{A}$ strain= $\frac{\Delta L}{L_0}$ $\frac{F}{A} = Y \frac{\Delta L}{L_0}$ Volume stress= $p = \frac{F}{A}$ $p = -B \frac{\Delta V}{V_0}$

Density:

Substance	$\rho(kg/m^3)$	Substance	$\rho(kg/m^3)$	Substance	$\rho(kg/m^3)$
Air	1.28	Aluminum	2700	Copper	8920
Ethyl alcohol	790	Gasoline	680	Glycerin	1260
Gold	19,300	Helium gas	0.18	Iron	7870
Lead	11,300	Mercury	13,600	Oil (typical)	900
Seawater	1030	Silicon	2330	Water (liquid)	1000
Water (solid)	920				

Specific heat:

Expansion coefficient:

Elastic properties:

Substance	$Y(N/m^2)$	$B(N/m^2)$
Aluminum	7×10^{10}	7×10^{10}
Concrete	3×10^{10}	
Copper	11×10^{10}	14×10^{10}
Mercury		3×10^{10}
Plastic	0.3×10^{10}	
Steel	20×10^{10}	16×10^{10}
Water		0.2×10^{10}
Wood	1×10^{10}	

Substance

Substance	$c(J/kg \cdot K)$	$c(cal/g \cdot K)$
Aluminum	900	0.22
Copper	390	0.093
Ethyl alcohol	2400	0.58
Iron/Steel	450	0.11
Silver	230	0.056
Lead	130	0.031
Mercury	140	0.033
Ice	2100	0.5
Water	4190	1
Wood	1700	0.4

Substance

Substance	$\alpha(C^\circ)^{-1}$	$\beta(C^\circ)^{-1}$
Aluminum	25×10^{-6}	75×10^{-6}
Brass	19×10^{-6}	56×10^{-6}
Copper	17×10^{-6}	50×10^{-6}
Ethyl alcohol		950×10^{-6}
Iron/Steel	12×10^{-6}	35×10^{-6}
Gold	14×10^{-6}	42×10^{-6}
Lead	29×10^{-6}	87×10^{-6}
Mercury		180×10^{-6}
Glass	9×10^{-6}	27×10^{-6}
Water		210×10^{-6}

Atomic mass number=number of protons + number of neutrons

Number of moles $n = \frac{N}{N_A} = \frac{M}{\mu}$ $k = \frac{R}{N_A}$ Temperature: $T_F = \frac{9}{5}T_C + 32^\circ$ $T = T_C + 273$

Ideal gas law: $pV = nRT = NkT$ $\frac{1}{2}m\bar{v}^2 = \frac{3}{2}kT$ $v_{rms} = \sqrt{\frac{3kT}{m}}$

Internal energy: monoatomic $U = \frac{3}{2}Nkt = \frac{3}{2}nRT$ diatomic $U = \frac{5}{2}Nkt = \frac{5}{2}nRT$

Work in ideal gas process: $W = - \int_{V_i}^{V_f} pdV$ =area under curve

For isobaric process: $W = -p(V_f - V_i)$ For isothermal process: $W = -nRT \ln \left(\frac{V_f}{V_i} \right)$ For isochoric process: $W = 0$

First law of thermodynamics: $\Delta U = Q + W = Q - W_g$ Efficiency of heat engine: $e = \frac{W_g}{Q_H} = 1 - \frac{Q_L}{Q_H}$

Carnot efficiency: $e = a - \frac{T_L}{T_H}$ COP(refrigerator)= $\frac{Q_L}{W}$ COP(heat pump)= $\frac{Q_H}{W}$

Specific heat: $c = \frac{Q}{m\Delta T}$ Latent heat: $Q = mL$ Thermal conductivity: $\frac{Q}{t} = kA \frac{T_f - T_i}{l}$

Thermal expansion: $\Delta L = \alpha L_0 \Delta T$ $\Delta V = \beta V_0 \Delta T$ $\beta = 3\alpha$ Radiation: $\frac{\Delta Q}{\Delta t} = e\sigma AT^4$

Monatomic gas: $c_V = \frac{3}{2}R$ Diatomic gas: $c_V = \frac{5}{2}R$ Specific heats of gases: $Q_V = nc_V\Delta T$ $Q_P = nc_P\Delta T$ $C_P = C_V + R$

Adiabatic process: $W = nc_V\Delta T$ $pV^\gamma = \text{const}$ $\gamma = \frac{c_P}{c_V}$

Melting/boiling temperatures and heats of transformation

Substance	$T_m(^{\circ}C)$	$L_f(J/kg)$	$T_b(^{\circ}C)$	$L_v(J/kg)$	Molar specific heats of gases (J/molK)		
Helium	-269.65	5.23×10^3	-268.93	2.09×10^4	Gas	c_V	c_P
Nitrogen (N ₂)	-210	0.26×10^5	-196	1.99×10^5	He	20.8	12.5
Oxygen	-218.79	1.38×10^4	-182.97	2.13×10^5	Ne	20.8	12.5
Ethyl alcohol	-114	1.09×10^5	78	8.79×10^5	Ar	20.8	12.5
Mercury	39	0.11×10^5	357	2.96×10^5	H ₂	28.7	20.4
Water	0	3.33×10^5	100	22.6×10^5	N ₂	29.1	20.8
Lead	328	0.25×10^5	1750	8.58×10^5	O ₂	29.1	20.9
Aluminum	660	3.97×10^5	2450	1.14×10^7			
Copper	1083	1.34×10^5	1187	5.06×10^6			

Constants

Free-fall acceleration $g=9.8$ m/s²

Gravitational constant $G=6.67 \times 10^{-11}$ Nm²/kg²

Gas constant $R=8.31$ J/(molK)

Boltzmanns constant $k=1.38 \times 10^{-23}$ J/K

Absolute zero $T_0 = -273^{\circ}C$

Avogadros number $N_A = 6.02 \times 10^{23}$ 1/mol

Speed of sound in the air $v=343$ m/s

Stefan-Boltzmann constant $= 5.67 \times 10^{-8}$ W/(m²K⁴)

Length	Time	Pressure	Power	Mass
1 in = 2.54 cm	1 day = 86400 s	1 Pa = 1 N/m ²		
1 mi = 1.609 km	1 year = 3.16×10^7 s	1 atm = 101,300 Pa	1 hp = 746 W = 550 ftlb/s	1 amu= 1.661×10^{-27} kg
1 m = 39.37 in	Force	1 atm = 760 mm of Hg	1 W = 1 J/s = 0.738 ftlb/s	Heat
1 km = 0.621 mi	1 lb = 4.45 N	= 1,013 bar	1 W = 3.42 Btu/h	1 cal = 4.186 J
		1 atm = 14.7 lb/in ² = 760 torr		

Astronomical Data

Planetary body	Mean distance from sun (m)	Period (years)	Mass (kg)	Mean radius (m)
Sun			1.99×10^{30}	6.96×10^8
Moon	3.84×10^8 *	27.3 days	7.36×10^{22}	1.74×10^6
Mercury	5.79×10^{10}	0.241	3.18×10^{23}	2.43×10^6
Venus	1.08×10^{11}	0.615	4.88×10^{24}	6.06×10^6
Earth	1.50×10^{11}	1.00	5.98×10^{24}	6.37×10^6
Mars	2.28×10^{11}	1.88	6.42×10^{23}	3.37×10^6
Jupiter	7.78×10^{11}	11.9	1.90×10^{27}	6.99×10^7
Saturn	1.43×10^{12}	29.5	5.68×10^{26}	5.85×10^7
Uranus	2.87×10^{12}	84.0	8.68×10^{25}	2.33×10^7
Neptune	4.50×10^{12}	165	1.06×10^{26}	2.21×10^7

* Distance from Earth

Thermal Expansion Coefficients

Material	Linear (1/ [°] C)	Material	Volume (1/ [°] C)
Aluminum	$24 \cdot 10^{-6}$	Acetone	$1.5 \cdot 10^{-4}$
Brass and bronze	$19 \cdot 10^{-6}$	Benzene	$1.24 \cdot 10^{-4}$
Concrete	$12 \cdot 10^{-6}$	Ethyl alcohol	$1.12 \cdot 10^{-4}$
Copper	$17 \cdot 10^{-6}$	Gasoline	$9.6 \cdot 10^{-4}$
Glass (ordinary)	$9 \cdot 10^{-6}$	Glycerin	$4.85 \cdot 10^{-4}$
Glass (Pyrex)	$3.2 \cdot 10^{-6}$	Mercury	$1.82 \cdot 10^{-4}$
Invar	$0.9 \cdot 10^{-6}$	Turpentine	$9.0 \cdot 10^{-4}$
Lead	$29 \cdot 10^{-6}$	Air at STP	$3.67 \cdot 10^{-5}$
Steel	$11 \cdot 10^{-6}$	Helium	$3.665 \cdot 10^{-5}$