

AP Physics 1 2027 Complete Formula Guide

Current exam-reference equations plus clearly labeled supplemental / derived study relationships

52 Exam-reference entries	86 Supplemental / derived relationships	138 Total guide entries
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How to use this guide. Entries labeled EXAM REFERENCE correspond to relationships/constants represented on the current AP Physics 1 exam reference material. Entries labeled SUPPLEMENTAL / DERIVED are useful relationships, rearrangements, definitions, or study tools included for problem solving. They are not a claim that College Board requires a separate list of 86 additional formulas to be memorized. Always understand the model, assumptions, signs, and variables.

Coverage

Constants & conversions - 4 entries (4 reference, 0 supplemental/derived)

Unit 1 · Kinematics - 3 entries (3 reference, 0 supplemental/derived)

Unit 2 · Force & Translational Dynamics - 6 entries (6 reference, 0 supplemental/derived)

Unit 3 · Work, Energy & Power - 8 entries (8 reference, 0 supplemental/derived)

Unit 4 · Linear Momentum - 4 entries (4 reference, 0 supplemental/derived)

Units 5-6 · Rotation & Rotating Systems - 15 entries (15 reference, 0 supplemental/derived)

Unit 7 · Oscillations - 5 entries (5 reference, 0 supplemental/derived)

Unit 8 · Fluids - 7 entries (7 reference, 0 supplemental/derived)

Math, vectors & SI relationships - 8 entries (0 reference, 8 supplemental/derived)

Unit 1 · Kinematics · essential derived formulas - 14 entries (0 reference, 14 supplemental/derived)

Unit 2 · Forces · essential derived formulas - 8 entries (0 reference, 8 supplemental/derived)

Unit 3 · Energy · essential derived formulas - 7 entries (0 reference, 7 supplemental/derived)

Unit 4 · Momentum · essential derived formulas - 6 entries (0 reference, 6 supplemental/derived)

Unit 5 · Torque & rotational dynamics · essential derived formulas - 15 entries (0 reference, 15 supplemental/derived)

Unit 6 · Energy & momentum of rotating systems · essential derived formulas - 8 entries (0 reference, 8 supplemental/derived)

Unit 7 · Oscillations · essential derived formulas - 9 entries (0 reference, 9 supplemental/derived)

Unit 8 · Fluids · essential derived formulas - 11 entries (0 reference, 11 supplemental/derived)

Constants & conversions

4 relationships in this section. Every entry includes its intended use, a caution, and variable meanings/units when applicable.

Universal gravitational constant

$$G = 6.67 \times 10^{-11} \text{ m}^3/(\text{kg s}^2) = 6.67 \times 10^{-11} \text{ N m}^2/\text{kg}^2$$

EXAM REFERENCE

Use: Universal gravitation and gravitational potential energy.

Watch: Use center-to-center separation r .

Variable	Meaning	SI unit
G	universal gravitational constant	$\text{N}\cdot\text{m}^2/\text{kg}^2$

Atmospheric pressure

$$1 \text{ atm} = 1.0 \times 10^5 \text{ N/m}^2 = 1.0 \times 10^5 \text{ Pa}$$

EXAM REFERENCE

Use: Pressure comparisons and fluid problems.

Watch: Keep absolute pressure and gauge pressure distinct.

Variable	Meaning	SI unit
atm	standard atmosphere	$1 \text{ atm} = 1.0 \times 10^5 \text{ Pa}$
Pa	pascal, SI pressure unit	N/m^2
N	newton, SI force unit	$\text{kg}\cdot\text{m/s}^2$

Acceleration due to gravity

$$g = 9.8 \text{ m/s}^2$$

EXAM REFERENCE

Use: Near-Earth mechanics.

Watch: Choose the axis before assigning a sign to g .

Variable	Meaning	SI unit
g	acceleration due to gravity	m/s^2

Gravitational field strength

$$g = 9.8 \text{ N/kg}$$

EXAM REFERENCE

Use: Weight and gravitational-field interpretation near Earth.

Watch: Same numerical magnitude as 9.8 m/s^2 , but different units and meaning.

Variable	Meaning	SI unit
g	gravitational field strength near Earth	N/kg

Unit 1 · Kinematics

3 relationships in this section. Every entry includes its intended use, a caution, and variable meanings/units when applicable.

Constant-acceleration velocity

$$v_x = v_{x0} + a_x t$$

EXAM REFERENCE

Use: Connect velocity, acceleration and time.

Watch: Only valid when a_x is constant.

Variable	Meaning	SI unit
v_{x0}	initial x-component of velocity	m/s
v_x	x-component of velocity	m/s
a_x	x-component of acceleration	m/s ²
t	time	s

Constant-acceleration position

$$x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$$

EXAM REFERENCE

Use: Connect position/displacement with time.

Watch: Keep x and y components separate in 2D motion.

Variable	Meaning	SI unit
v_{x0}	initial x-component of velocity	m/s
a_x	x-component of acceleration	m/s ²
x_0	initial x-coordinate	m
x	position coordinate	m
t	time	s

Time-free kinematics

$$v_x^2 = v_{x0}^2 + 2 a_x (x - x_0)$$

EXAM REFERENCE

Use: Use when time is absent from the useful known/unknown set.

Watch: Squaring can hide direction information; restore the physical sign afterward.

Variable	Meaning	SI unit
v_{x0}	initial x-component of velocity	m/s
v_x	x-component of velocity	m/s
a_x	x-component of acceleration	m/s ²
x_0	initial x-coordinate	m
x	position coordinate	m

Unit 2 • Force & Translational Dynamics

6 relationships in this section. Every entry includes its intended use, a caution, and variable meanings/units when applicable.

Center-of-mass position

$$\mathbf{x}_{\text{cm}}(\text{vector}) = \text{sum}(m_i \mathbf{x}_i(\text{vector})) / \text{sum}(m_i)$$

EXAM REFERENCE

Use: Locate the center of mass of a system.

Watch: All coordinates/vectors must use the same reference frame.

Variable	Meaning	SI unit
x_{cm}	center-of-mass position	m
x_i	position of object i	m
m_i	mass of object i	kg

System acceleration

$$\mathbf{a}_{\text{sys}}(\text{vector}) = \text{sum } \mathbf{F}(\text{vector}) / m_{\text{sys}} = \mathbf{F}_{\text{net}}(\text{vector}) / m_{\text{sys}}$$

EXAM REFERENCE

Use: Apply Newton's second law to a defined system.

Watch: Include only forces external to that chosen system.

Variable	Meaning	SI unit
a_{sys}	acceleration of the chosen system	m/s ²
$\Sigma \mathbf{F}$	vector sum of external forces	N
m_{sys}	total system mass	kg
$\mathbf{F}_{\text{net}}$	net external force	N

Universal gravitational force

$$|\mathbf{F}_g| = G m_1 m_2 / r^2$$

EXAM REFERENCE

Use: Find the gravitational interaction between separated masses.

Watch: r is center-to-center separation.

Variable	Meaning	SI unit
F_g	gravitational-force magnitude	N
G	universal gravitational constant	N·m ² /kg ²
m_1	mass of object 1	kg
m_2	mass of object 2	kg
r	center-to-center separation	m

Friction relationship

$$|\mathbf{F}_f| \leq |\mu \mathbf{F}_N|$$

EXAM REFERENCE

Use: Model static or kinetic friction with the appropriate coefficient.

Watch: Static friction is not automatically equal to $\mu_s F_N$.

Variable	Meaning	SI unit
F_f	friction force	N

Variable	Meaning	SI unit
F _N	normal force	N
μ	coefficient of friction	dimensionless

Ideal spring force

$$\mathbf{F}_s(\text{vector}) = -k \Delta \mathbf{x}(\text{vector})$$

EXAM REFERENCE

Use: Relate ideal-spring force to the change in spring length measured from relaxed length.

Watch: The sign gives force direction; the object-spring system equilibrium can differ from relaxed length when other forces such as gravity act.

Variable	Meaning	SI unit
Δx	change in spring length from relaxed length (extension/compression)	m
F _s	spring force	N
k	spring constant	N/m

Centripetal acceleration

$$a_c = v^2 / r$$

EXAM REFERENCE

Use: Find inward acceleration for curved or circular motion.

Watch: Centripetal force is not an extra force; identify the real inward net force.

Variable	Meaning	SI unit
a _c	centripetal acceleration	m/s ²
r	radius / separation	m
v	speed / velocity magnitude	m/s

Unit 3 · Work, Energy & Power

8 relationships in this section. Every entry includes its intended use, a caution, and variable meanings/units when applicable.

Translational kinetic energy

$$K = \frac{1}{2} m v^2$$

EXAM REFERENCE

Use: Energy associated with translational speed.

Watch: Kinetic energy is scalar and nonnegative.

Variable	Meaning	SI unit
m	mass	kg
v	speed / velocity magnitude	m/s
K	kinetic energy	J

Work by a constant force

$$W = F_{\text{parallel}} d = F d \cos(\theta)$$

EXAM REFERENCE

Use: Calculate energy transfer by a force through a displacement.

Watch: Use only the force component parallel to displacement.

Variable	Meaning	SI unit
F_{parallel}	force component parallel to displacement/velocity	N
θ	angle	rad
F	force magnitude	N
d	distance / displacement / axis separation	m
W	work	J

Work-energy theorem

$$\Delta K = \sum W_i = \sum F_{\text{parallel},i} d_i$$

EXAM REFERENCE

Use: Connect net work to change in kinetic energy.

Watch: Choose the system boundary consistently.

Variable	Meaning	SI unit
ΔK	change in kinetic energy	J
$\sum W_i$	net work / sum of works	J
$F_{\parallel,i}$	force component parallel to displacement for force i	N
d_i	displacement associated with force i	m

Elastic potential energy

$$U_s = \frac{1}{2} k (\Delta x)^2$$

EXAM REFERENCE

Use: Energy stored by an ideal spring as it is stretched or compressed from the spring's equilibrium/relaxed length used by the elastic-energy model.

Watch: Do not automatically equate this spring-length reference with the attached object-spring system equilibrium position when other forces shift the system equilibrium.

Variable	Meaning	SI unit
Δx	spring stretch/compression from the spring's equilibrium/relaxed length used by the elastic-energy model; do not confuse this with a shifted object-spring system equilibrium position	m
U_s	elastic potential energy	J
k	spring constant	N/m

Universal gravitational potential energy

$$U_G = -G m_1 m_2 / r$$

EXAM REFERENCE

Use: Use when gravitational field varies appreciably with r .

Watch: Zero reference is at infinite separation in this model.

Variable	Meaning	SI unit
U_G	gravitational potential energy	J
G	universal gravitational constant	$N \cdot m^2/kg^2$
m_1	mass of object 1	kg
m_2	mass of object 2	kg
r	center-to-center separation	m

Near-Earth gravitational potential change

$$\Delta U_g = m g \Delta y$$

EXAM REFERENCE

Use: Use for vertical changes where g is effectively constant.

Watch: Select the vertical coordinate consistently.

Variable	Meaning	SI unit
ΔU_g	change in gravitational potential energy	J
Δy	change in vertical position	m
g	gravitational acceleration / field strength	m/s^2 (equiv. N/kg)
m	mass	kg

Average power

$$P_{avg} = W / \Delta t = \Delta E / \Delta t$$

EXAM REFERENCE

Use: Rate of work or energy transfer over an interval.

Watch: Power is a rate, not an amount of energy.

Variable	Meaning	SI unit
Δt	elapsed time	s
ΔE	change in energy	J
P_{avg}	average power	W
W	work	J

Instantaneous mechanical power

$$P_{\text{inst}} = F_{\text{parallel}} v = F v \cos(\theta)$$

EXAM REFERENCE

Use: Find power at an instant from force and speed.

Watch: Use the force component parallel to velocity.

Variable	Meaning	SI unit
F_{parallel}	force component parallel to displacement/velocity	N
P_{inst}	instantaneous power	W
θ	angle	rad
F	force magnitude	N
v	speed / velocity magnitude	m/s

Unit 4 · Linear Momentum

4 relationships in this section. Every entry includes its intended use, a caution, and variable meanings/units when applicable.

Linear momentum

$$\mathbf{p}(\text{vector}) = m \mathbf{v}(\text{vector})$$

EXAM REFERENCE

Use: Describe translational momentum.

Watch: Momentum is a vector; retain direction.

Variable	Meaning	SI unit
m	mass	kg
v	speed / velocity magnitude	m/s
p	linear momentum	kg·m/s

Momentum form of Newton's second law

$$\mathbf{F}_{\text{net}}(\text{vector}) = \Delta \mathbf{p} / \Delta t = m \Delta \mathbf{v} / \Delta t = m \mathbf{a}$$

EXAM REFERENCE

Use: Connect net force to momentum change over time.

Watch: Use net external force for a chosen system.

Variable	Meaning	SI unit
Δv	change in velocity	m/s
Δt	elapsed time	s
Δp	change in momentum	kg·m/s
F_{net}	net force	N
m	mass	kg
a	acceleration	m/s ²

Impulse-momentum theorem

$$\mathbf{J}(\text{vector}) = \mathbf{F}_{\text{avg}}(\text{vector}) \Delta t = \Delta \mathbf{p}(\text{vector})$$

EXAM REFERENCE

Use: Connect force-time information to momentum change.

Watch: Area under a force-time graph is impulse.

Variable	Meaning	SI unit
Δt	elapsed time	s
Δp	change in momentum	kg·m/s
F_{avg}	average force	N
J	impulse	N·s (kg·m/s)

Center-of-mass velocity

$$\mathbf{v}_{\text{cm}}(\text{vector}) = \sum \mathbf{p}_i / \sum m_i = \sum (m_i \mathbf{v}_i) / \sum m_i$$

EXAM REFERENCE

Use: Find the velocity of a multi-object system's center of mass.

Watch: Vector velocities must retain direction/sign.

Variable	Meaning	SI unit
v_{cm}	center-of-mass velocity	m/s
m_i	mass of object i	kg
v_i	initial velocity	m/s
p_i	momentum of object i	kg·m/s

Units 5-6 • Rotation & Rotating Systems

15 relationships in this section. Every entry includes its intended use, a caution, and variable meanings/units when applicable.

Constant-angular-acceleration velocity

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

EXAM REFERENCE

Use: Rotational analogue of $v = v_0 + at$.

Watch: α must be constant.

Variable	Meaning	SI unit
ω_0	initial angular velocity	rad/s
ω	angular velocity / angular speed	rad/s
α	angular acceleration	rad/s ²
t	time	s

Constant-angular-acceleration position

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

EXAM REFERENCE

Use: Relate angular displacement to time.

Watch: Use radians when linking angular and linear quantities.

Variable	Meaning	SI unit
ω_0	initial angular velocity	rad/s
θ_0	initial angular position	rad
α	angular acceleration	rad/s ²
θ	angle	rad
t	time	s

Time-free rotational kinematics

$$\omega^2 = \omega_0^2 + 2 \alpha (\theta - \theta_0)$$

EXAM REFERENCE

Use: Use when time is not needed.

Watch: Sign convention still matters.

Variable	Meaning	SI unit
ω_0	initial angular velocity	rad/s
θ_0	initial angular position	rad
ω	angular velocity / angular speed	rad/s
α	angular acceleration	rad/s ²
θ	angle	rad

Tangential speed

$$v = r \omega$$

EXAM REFERENCE

Use: Connect linear speed to angular speed.

Watch: r is perpendicular distance from the rotation axis.

Variable	Meaning	SI unit
ω	angular velocity / angular speed	rad/s
r	radius / separation	m
v	speed / velocity magnitude	m/s

Tangential acceleration

$$a_T = r \alpha$$

EXAM REFERENCE

Use: Connect tangential and angular acceleration.

Watch: This does not include radial/centripetal acceleration.

Variable	Meaning	SI unit
α	angular acceleration	rad/s ²
a_T	tangential acceleration	m/s ²
r	radius / separation	m

Torque

$$\tau = r_{\perp} F = r F \sin(\theta)$$

EXAM REFERENCE

Use: Quantify a force's rotational effect about an axis.

Watch: θ is the angle between r and F ; line of action matters.

Variable	Meaning	SI unit
τ	torque magnitude	N·m
$r_{\perp}$	perpendicular lever arm	m
r	distance from axis to point of force application	m
F	force magnitude	N
θ	angle between position vector and force	rad

Rotational inertia

$$I = \sum m_i r_i^2$$

EXAM REFERENCE

Use: Compute rotational inertia for point masses.

Watch: Mass farther from the axis contributes with r^2 .

Variable	Meaning	SI unit
m_i	mass of object i	kg
r_i	distance of mass i from rotation axis	m
I	rotational inertia	kg·m ²

Parallel-axis theorem

$$I' = I_{cm} + M d^2$$

EXAM REFERENCE

Use: Shift rotational inertia to a parallel axis.

Watch: d is the separation between the center-of-mass axis and new axis.

Variable	Meaning	SI unit
I'	rotational inertia about shifted axis	$\text{kg}\cdot\text{m}^2$
I_{cm}	rotational inertia about parallel center-of-mass axis	$\text{kg}\cdot\text{m}^2$
M	total mass	kg
d	distance between the two parallel axes	m

Rotational Newton's second law

$$\alpha_{\text{sys}} = \sum \tau / I_{\text{sys}} = \tau_{\text{net}} / I_{\text{sys}}$$

EXAM REFERENCE

Use: Connect net external torque and angular acceleration.

Watch: Torque and rotational inertia must be evaluated about the same axis.

Variable	Meaning	SI unit
α_{sys}	angular acceleration of system	rad/s^2
$\sum \tau$	sum of external torques	$\text{N}\cdot\text{m}$
I_{sys}	rotational inertia of system	$\text{kg}\cdot\text{m}^2$
τ_{net}	net external torque	$\text{N}\cdot\text{m}$

Rotational kinetic energy

$$K_{\text{rot}} = \frac{1}{2} I \omega^2$$

EXAM REFERENCE

Use: Energy associated with rigid-body rotation.

Watch: Rolling can have translational and rotational kinetic energy simultaneously.

Variable	Meaning	SI unit
ω	angular velocity / angular speed	rad/s
K_{rot}	rotational kinetic energy	J
I	rotational inertia	$\text{kg}\cdot\text{m}^2$

Rotational work

$$W = \tau \Delta \theta$$

EXAM REFERENCE

Use: Work done by a constant torque through an angle.

Watch: Use $\Delta \theta$ in radians.

Variable	Meaning	SI unit
W	rotational work	J
τ	torque	$\text{N}\cdot\text{m}$
$\Delta \theta$	angular displacement	rad

Rigid-body angular momentum

$$L = I \omega$$

EXAM REFERENCE

Use: Angular momentum of a rigid rotating system about an axis.

Watch: Conservation requires negligible net external torque about that axis.

Variable	Meaning	SI unit
ω	angular velocity / angular speed	rad/s
L	angular momentum	$\text{kg}\cdot\text{m}^2/\text{s}$
I	rotational inertia	$\text{kg}\cdot\text{m}^2$

Particle angular momentum

$$L = r m v \sin(\theta)$$

EXAM REFERENCE

Use: Angular momentum of a moving particle about an origin/axis.

Watch: Use the component perpendicular to r .

Variable	Meaning	SI unit
θ	angle	rad
m	mass	kg
r	radius / separation	m
v	speed / velocity magnitude	m/s
L	angular momentum	$\text{kg}\cdot\text{m}^2/\text{s}$

Angular impulse

$$\Delta L = \tau \Delta t$$

EXAM REFERENCE

Use: Connect torque-time to angular-momentum change.

Watch: Use net external torque for a system.

Variable	Meaning	SI unit
ΔL	change in angular momentum	$\text{kg}\cdot\text{m}^2/\text{s}$
τ	net torque during interval	$\text{N}\cdot\text{m}$
Δt	time interval	s

Rolling displacement relation

$$\Delta x_{\text{cm}} = r \Delta \theta$$

EXAM REFERENCE

Use: Connect center-of-mass translation to rotation.

Watch: Requires rolling without slipping.

Variable	Meaning	SI unit
Δx_{cm}	center-of-mass displacement	m
r	rolling radius	m
$\Delta \theta$	angular displacement	rad

Unit 7 · Oscillations

5 relationships in this section. Every entry includes its intended use, a caution, and variable meanings/units when applicable.

Period-frequency relation

$$T = 1/f$$

EXAM REFERENCE

Use: Convert frequency to period or vice versa.

Watch: Do not confuse f with angular frequency.

Variable	Meaning	SI unit
T	period	s
f	frequency	Hz (s^{-1})

Mass-spring period

$$T_s = 2\pi \sqrt{m/k}$$

EXAM REFERENCE

Use: Ideal mass-spring SHM period.

Watch: Ideal period is independent of amplitude.

Variable	Meaning	SI unit
T_s	mass-spring period	s
π	pi, mathematical constant	dimensionless
m	mass	kg
k	spring constant	N/m

Simple-pendulum period

$$T_p = 2\pi \sqrt{l/g}$$

EXAM REFERENCE

Use: Small-angle pendulum SHM.

Watch: Large angles violate the small-angle approximation.

Variable	Meaning	SI unit
T_p	pendulum period	s
π	pi, mathematical constant	dimensionless
g	gravitational acceleration / field strength	m/s^2 (equiv. N/kg)
l	length	m

SHM position · cosine form

$$x = A \cos(2\pi f t)$$

EXAM REFERENCE

Use: Position versus time when the phase matches a cosine start.

Watch: Select the phase form that matches initial conditions.

Variable	Meaning	SI unit
x	displacement from equilibrium	m
A	amplitude	m
f	frequency	Hz (s^{-1})

Variable	Meaning	SI unit
t	time	s
π	pi, mathematical constant	dimensionless

SHM position - sine form

$$x = A \sin(2 \pi f t)$$

EXAM REFERENCE

Use: Position versus time for an alternate starting phase.

Watch: Sine and cosine forms differ by phase, not by physics.

Variable	Meaning	SI unit
x	displacement from equilibrium	m
A	amplitude	m
f	frequency	Hz (s^{-1})
t	time	s
π	pi, mathematical constant	dimensionless

Unit 8 • Fluids

7 relationships in this section. Every entry includes its intended use, a caution, and variable meanings/units when applicable.

Density

$$\rho = m/V$$

EXAM REFERENCE

Use: Mass per unit volume.

Watch: Track volume-unit conversions carefully.

Variable	Meaning	SI unit
ρ	density	kg/m^3
m	mass	kg
V	volume	m^3

Pressure

$$P = F_{\text{perp}}/A$$

EXAM REFERENCE

Use: Normal force distributed over an area.

Watch: Pressure is scalar even though force is vector.

Variable	Meaning	SI unit
P	pressure	Pa
$F_{\perp}$	force normal to the surface	N
A	surface area	m^2

Absolute hydrostatic pressure

$$P = P_0 + \rho g h$$

EXAM REFERENCE

Use: Pressure at a depth in a static fluid.

Watch: h is vertical depth.

Variable	Meaning	SI unit
P_0	reference/surface pressure	Pa
ρ	density	kg/m^3
g	gravitational acceleration / field strength	m/s^2 (equiv. N/kg)
h	height / depth	m
P	pressure	Pa

Gauge pressure

$$P_{\text{gauge}} = \rho g h$$

EXAM REFERENCE

Use: Pressure above a reference/surface pressure.

Watch: Do not add P_0 twice.

Variable	Meaning	SI unit
P_{gauge}	gauge pressure	Pa
ρ	density	kg/m^3

Variable	Meaning	SI unit
g	gravitational acceleration / field strength	m/s ² (equiv. N/kg)
h	height / depth	m

Buoyant force

$$F_b = \rho V g$$

EXAM REFERENCE

Use: Archimedes principle using displaced-fluid volume.

Watch: V is displaced-fluid volume, not automatically the whole object volume.

Variable	Meaning	SI unit
F _b	buoyant force	N
ρ	fluid density	kg/m ³
V	displaced fluid volume	m ³
g	gravitational acceleration magnitude	m/s ²

Continuity

$$A_1 v_1 = A_2 v_2$$

EXAM REFERENCE

Use: Steady incompressible flow through changing area.

Watch: Smaller cross-sectional area means greater speed under the model assumptions.

Variable	Meaning	SI unit
v ₁	flow speed at point 1	m/s
v ₂	flow speed at point 2	m/s
A ₁	cross-sectional area 1	m ²
A ₂	cross-sectional area 2	m ²

Bernoulli equation

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

EXAM REFERENCE

Use: Connect pressure, height and speed along a streamline.

Watch: Use only for the stated ideal-flow assumptions.

Variable	Meaning	SI unit
P ₁	pressure at point 1	Pa
P ₂	pressure at point 2	Pa
ρ	fluid density	kg/m ³
g	gravitational acceleration magnitude	m/s ²
y ₁	vertical position at point 1	m
y ₂	vertical position at point 2	m
v ₁	flow speed at point 1	m/s
v ₂	flow speed at point 2	m/s

Math, vectors & SI relationships

8 relationships in this section. Every entry includes its intended use, a caution, and variable meanings/units when applicable.

Newton in base SI units

$$1 \text{ N} = 1 \text{ kg m/s}^2$$

SUPPLEMENTAL / DERIVED

Use: Check force dimensions and unit conversions.

Watch: A newton is a derived unit, not a base unit.

Variable	Meaning	SI unit
N	newton	$\text{kg}\cdot\text{m/s}^2$
kg	kilogram	kg
m	metre	m
s	second	s

Joule relationship

$$1 \text{ J} = 1 \text{ N m}$$

SUPPLEMENTAL / DERIVED

Use: Connect work/energy to force-distance units.

Watch: N·m used for energy is called a joule; torque also has N·m dimensions but is not energy.

Variable	Meaning	SI unit
J	joule	N·m
N	newton	$\text{kg}\cdot\text{m/s}^2$
m	metre	m

Watt relationship

$$1 \text{ W} = 1 \text{ J/s}$$

SUPPLEMENTAL / DERIVED

Use: Connect power to energy transfer rate.

Watch: Power is energy per time, not total energy.

Variable	Meaning	SI unit
W	watt	J/s
J	joule	N·m
s	second	s

Pascal relationship

$$1 \text{ Pa} = 1 \text{ N/m}^2$$

SUPPLEMENTAL / DERIVED

Use: Convert pressure units.

Watch: Pressure uses force divided by area.

Variable	Meaning	SI unit
Pa	pascal	N/m^2
N	newton	$\text{kg}\cdot\text{m/s}^2$
m	metre	m

Degrees to radians

$$\theta_{\text{rad}} = \theta_{\text{deg}} \pi/180$$

SUPPLEMENTAL / DERIVED

Use: Convert angles before using arc-length and angular-motion relationships.

Watch: Rotational linear relations such as $s=r\theta$ require radians.

Variable	Meaning	SI unit
θ_{rad}	angle in radians	rad
θ_{deg}	angle in degrees	° (non-SI)
π	pi, mathematical constant	dimensionless

Revolution-radian conversion

$$1 \text{ rev} = 2 \pi \text{ rad}$$

SUPPLEMENTAL / DERIVED

Use: Convert cycles/revolutions to angular displacement.

Watch: Do not mix rev and rad inside $v=r\omega$.

Variable	Meaning	SI unit
rev	revolution	$2\pi \text{ rad}$
rad	radian	dimensionless SI angle unit
π	pi, mathematical constant	dimensionless

Vector x-component

$$A_x = A \cos(\theta)$$

SUPPLEMENTAL / DERIVED

Use: Resolve a vector when θ is measured from $+x$.

Watch: If the angle is measured from another axis, component assignment changes.

Variable	Meaning	SI unit
A_x	x-component of vector A	same unit as A
A	magnitude of vector A	context dependent
θ	angle measured from $+x$ direction	rad

Vector y-component

$$A_y = A \sin(\theta)$$

SUPPLEMENTAL / DERIVED

Use: Resolve a vector when θ is measured from $+x$.

Watch: Assign the sign from direction after finding the magnitude.

Variable	Meaning	SI unit
A_y	y-component of vector A	same unit as A
A	magnitude of vector A	context dependent
θ	angle measured from $+x$ direction	rad

Unit 1 · Kinematics · essential derived formulas

14 relationships in this section. Every entry includes its intended use, a caution, and variable meanings/units when applicable.

Average velocity

$$v_{\text{avg}} = \Delta x / \Delta t$$

SUPPLEMENTAL / DERIVED

Use: Definition from displacement over elapsed time.

Watch: Average velocity uses displacement, not total distance.

Variable	Meaning	SI unit
Δx	change in position / displacement	m
Δt	elapsed time	s
v_{avg}	average velocity	m/s

Average speed

$$\text{average speed} = \text{total distance} / \Delta t$$

SUPPLEMENTAL / DERIVED

Use: Scalar rate based on path length.

Watch: Do not replace distance with displacement if the object reverses direction.

Variable	Meaning	SI unit
$v_{\text{avg}}(\text{speed})$	average speed	m/s
distance	total distance traveled	m
Δt	elapsed time	s

Average acceleration

$$a_{\text{avg}} = \Delta v / \Delta t$$

SUPPLEMENTAL / DERIVED

Use: Definition from velocity change over time.

Watch: Velocity change is signed/vector; speed change alone is not enough.

Variable	Meaning	SI unit
Δv	change in velocity	m/s
Δt	elapsed time	s
a_{avg}	average acceleration	m/s ²

Average velocity for constant acceleration

$$v_{\text{avg}} = (v_i + v_f)/2 \text{ for constant acceleration}$$

SUPPLEMENTAL / DERIVED

Use: Shortcut when acceleration is constant.

Watch: Not valid for arbitrary nonconstant acceleration.

Variable	Meaning	SI unit
v_{avg}	average velocity	m/s
v_i	initial velocity	m/s
v_f	final velocity	m/s

Displacement from average velocity

$$\Delta x = v_{\text{avg}} \Delta t \text{ for constant acceleration}$$

SUPPLEMENTAL / DERIVED

Use: Combine with the constant-a average velocity relation.

Watch: Use only with the appropriate average velocity.

Variable	Meaning	SI unit
Δx	change in position / displacement	m
Δt	elapsed time	s
v_{avg}	average velocity	m/s

Projectile horizontal launch component

$$v_{0x} = v_0 \cos(\theta)$$

SUPPLEMENTAL / DERIVED

Use: Resolve launch velocity into x-component.

Watch: Angle convention matters.

Variable	Meaning	SI unit
θ	angle	rad
v_{0x}	initial horizontal velocity component	m/s
v_0	initial speed	m/s

Projectile vertical launch component

$$v_{0y} = v_0 \sin(\theta)$$

SUPPLEMENTAL / DERIVED

Use: Resolve launch velocity into y-component.

Watch: Assign the vertical sign from your axis choice.

Variable	Meaning	SI unit
θ	angle	rad
v_{0y}	initial vertical velocity component	m/s
v_0	initial speed	m/s

Horizontal projectile motion

$$x = x_0 + v_{0x} t \text{ when } a_x = 0$$

SUPPLEMENTAL / DERIVED

Use: Use when horizontal acceleration is negligible.

Watch: Horizontal and vertical motions share the same time.

Variable	Meaning	SI unit
v_{0x}	initial horizontal velocity component	m/s
a_x	x-component of acceleration	m/s ²
x_0	initial x-coordinate	m
x	position coordinate	m
t	time	s

Vertical projectile motion

$$y = y_0 + v_{0y} t - \frac{1}{2} g t^2$$

SUPPLEMENTAL / DERIVED

Use: Use with +y upward and negligible air resistance.

Watch: If you choose downward positive, signs change.

Variable	Meaning	SI unit
v_{0y}	initial vertical velocity component	m/s
y_0	initial y-coordinate	m
g	gravitational acceleration / field strength	m/s ² (equiv. N/kg)
y	vertical position	m
t	time	s

Projectile vertical velocity

$$v_y = v_{0y} - g t$$

SUPPLEMENTAL / DERIVED

Use: Use with +y upward.

Watch: At the top, $v_y=0$ but acceleration is still -g.

Variable	Meaning	SI unit
v_{0y}	initial vertical velocity component	m/s
v_y	vertical velocity component	m/s
g	gravitational acceleration / field strength	m/s ² (equiv. N/kg)
t	time	s

Relative velocity

$$v_{A/B} = v_{A/C} - v_{B/C}$$

SUPPLEMENTAL / DERIVED

Use: Connect velocities measured in different inertial frames.

Watch: Keep one sign convention for the whole chain.

Variable	Meaning	SI unit
$v_{A/B}$	velocity of A relative to B	m/s
$v_{A/C}$	velocity of A relative to C	m/s
$v_{B/C}$	velocity of B relative to C	m/s

Projectile time of flight

$$T = 2 v_0 \sin(\theta) / g \text{ for same launch and landing height}$$

SUPPLEMENTAL / DERIVED

Use: Shortcut for symmetric projectile motion.

Watch: Not valid when launch and landing heights differ.

Variable	Meaning	SI unit
T	time of flight	s
v_0	launch speed	m/s
θ	launch angle	rad
g	gravitational acceleration magnitude	m/s ²

Projectile range

$$R = v_0^2 \sin(2\theta)/g \text{ for same launch and landing height}$$

SUPPLEMENTAL / DERIVED

Use: Shortcut for ideal same-level launch/landing.

Watch: Not valid for different vertical endpoints or air resistance.

Variable	Meaning	SI unit
R	horizontal range	m
v_0	launch speed	m/s
θ	launch angle	rad
g	gravitational acceleration magnitude	m/s ²

Maximum height above launch point

$$h_{\max} = v_0^2 \sin^2(\theta)/(2g)$$

SUPPLEMENTAL / DERIVED

Use: Derived from v_y^2 relation at the top.

Watch: This is height above the launch level, not necessarily above the ground.

Variable	Meaning	SI unit
$h_{\max}$	maximum height above launch point	m
v_0	launch speed	m/s
θ	launch angle	rad
g	gravitational acceleration magnitude	m/s ²

Unit 2 · Forces · essential derived formulas

8 relationships in this section. Every entry includes its intended use, a caution, and variable meanings/units when applicable.

Newton's second law

$$\sum \mathbf{F}(\text{vector}) = m \mathbf{a}(\text{vector})$$

SUPPLEMENTAL / DERIVED

Use: Core force model for an object/system of constant mass.

Watch: Draw the free-body diagram before writing component equations.

Variable	Meaning	SI unit
$\Sigma \mathbf{F}$	vector sum of forces	N
m	mass	kg
$\mathbf{a}$	acceleration	m/s^2

Near-Earth weight magnitude

$$\mathbf{F}_g = m \mathbf{g}$$

SUPPLEMENTAL / DERIVED

Use: Weight near Earth when g is effectively constant.

Watch: Weight is a force; mass is not weight.

Variable	Meaning	SI unit
$\mathbf{F}_g$	weight / gravitational force magnitude	N
m	mass	kg
g	gravitational field strength	N/kg (equiv. m/s^2)

Kinetic friction magnitude

$$\mathbf{f}_k = \mu_k \mathbf{F}_N$$

SUPPLEMENTAL / DERIVED

Use: Sliding-contact friction model.

Watch: Direction opposes relative sliding motion.

Variable	Meaning	SI unit
$\mathbf{f}_k$	kinetic-friction force magnitude	N
μ_k	coefficient of kinetic friction	dimensionless
$\mathbf{F}_N$	normal force	N

Maximum static friction

$$\mathbf{f}_{s,\text{max}} = \mu_s \mathbf{F}_N$$

SUPPLEMENTAL / DERIVED

Use: Threshold before slipping begins.

Watch: Actual static friction can be anywhere from zero up to this maximum.

Variable	Meaning	SI unit
$\mathbf{f}_{s,\text{max}}$	maximum static-friction force	N
μ_s	coefficient of static friction	dimensionless
$\mathbf{F}_N$	normal force	N

Required inward net force

$$F_{\text{radial}} = m v^2/r$$

SUPPLEMENTAL / DERIVED

Use: Net radial force required for circular motion.

Watch: Do not add a separate “centripetal force” to the free-body diagram.

Variable	Meaning	SI unit
F_{radial}	net radial/inward force	N
m	mass	kg
r	radius / separation	m
v	speed / velocity magnitude	m/s

Gravitational field magnitude at radius r

$$g(r) = G M/r^2$$

SUPPLEMENTAL / DERIVED

Use: Field produced by a spherical mass M outside it.

Watch: r is measured from the center of the source mass.

Variable	Meaning	SI unit
$g(r)$	gravitational field magnitude at radius r	N/kg (equiv. m/s^2)
G	universal gravitational constant	$\text{N}\cdot\text{m}^2/\text{kg}^2$
M	source/central mass	kg
r	distance from source center	m

Speed in uniform circular motion

$$v = 2 \pi r/T$$

SUPPLEMENTAL / DERIVED

Use: Relate period to path length per revolution.

Watch: Use the radius of the circular path.

Variable	Meaning	SI unit
π	pi, mathematical constant	dimensionless
r	radius / separation	m
v	speed / velocity magnitude	m/s
T	period	s

Centripetal acceleration from period

$$a_c = 4 \pi^2 r/T^2$$

SUPPLEMENTAL / DERIVED

Use: Combine $v=2\pi r/T$ with $a_c=v^2/r$.

Watch: Only for uniform circular speed.

Variable	Meaning	SI unit
a_c	centripetal acceleration	m/s^2
π	pi, mathematical constant	dimensionless
r	radius / separation	m
T	period	s

Unit 3 · Energy · essential derived formulas

7 relationships in this section. Every entry includes its intended use, a caution, and variable meanings/units when applicable.

Mechanical energy

$$E_{\text{mech}} = K + U$$

SUPPLEMENTAL / DERIVED

Use: Combine kinetic and relevant potential energies.

Watch: Which potential energies belong depends on the chosen system.

Variable	Meaning	SI unit
E_{mech}	mechanical energy	J
K	kinetic energy	J
U	potential energy	J

Mechanical-energy conservation

$$K_i + U_i = K_f + U_f \text{ for an isolated mechanical model}$$

SUPPLEMENTAL / DERIVED

Use: Use when no energy is transferred out of the modeled mechanical system.

Watch: Friction can convert mechanical energy to thermal energy depending on system choice.

Variable	Meaning	SI unit
K_i	initial kinetic energy	J
U_i	initial potential energy	J
K_f	final kinetic energy	J
U_f	final potential energy	J

Mechanical energy with external work

$$K_i + U_i + W_{\text{ext}} = K_f + U_f$$

SUPPLEMENTAL / DERIVED

Use: Account for work transferring energy across the chosen system boundary.

Watch: Be explicit about what is inside the system.

Variable	Meaning	SI unit
W_{ext}	external work	J
K_i	initial kinetic energy	J
K_f	final kinetic energy	J
U_i	initial potential energy	J
U_f	final potential energy	J

Nonconservative work and mechanical energy

$$W_{\text{nc}} = \Delta E_{\text{mech}}$$

SUPPLEMENTAL / DERIVED

Use: Useful bookkeeping when nonconservative work changes mechanical energy.

Watch: Sign depends on whether nonconservative work adds or removes mechanical energy.

Variable	Meaning	SI unit
W_{nc}	nonconservative work	J

Variable	Meaning	SI unit
ΔE_{mech}	change in mechanical energy	J

Work done by an ideal spring

$$W_s = -\Delta U_s$$

SUPPLEMENTAL / DERIVED

Use: Conservative spring work is opposite the change in spring potential energy.

Watch: Distinguish work done by the spring from work done on the spring.

Variable	Meaning	SI unit
W_s	work done by ideal spring	J
ΔU_s	change in elastic potential energy	J

Work done by gravity

$$W_g = -\Delta U_g$$

SUPPLEMENTAL / DERIVED

Use: Conservative gravitational work is opposite gravitational potential-energy change.

Watch: The sign depends on initial and final vertical positions.

Variable	Meaning	SI unit
ΔU_g	change in gravitational potential energy	J
W_g	work done by gravity	J

Efficiency

$$\text{efficiency} = \text{useful energy output} / \text{energy input} \times 100\%$$

SUPPLEMENTAL / DERIVED

Use: Compare useful output to input energy (or power).

Watch: Efficiency cannot exceed 100% for an ordinary passive device.

Variable	Meaning	SI unit
η	efficiency	dimensionless (often %)
E_{useful}	useful output energy	J
E_{input}	input energy	J

Unit 4 · Momentum · essential derived formulas

6 relationships in this section. Every entry includes its intended use, a caution, and variable meanings/units when applicable.

System momentum

$$\mathbf{p}_{\text{sys}}(\text{vector}) = \sum \mathbf{p}_i(\text{vector})$$

SUPPLEMENTAL / DERIVED

Use: Add vector momenta of all objects in the chosen system.

Watch: Direction/sign matters.

Variable	Meaning	SI unit
p_{sys}	total system momentum	kg·m/s
p_i	momentum of object i	kg·m/s

Momentum conservation

$$\sum \mathbf{p}_{\text{initial}} = \sum \mathbf{p}_{\text{final}} \text{ when external impulse is negligible}$$

SUPPLEMENTAL / DERIVED

Use: Use when net external impulse on the system is negligible.

Watch: Momentum is conserved for the system, not necessarily each object.

Variable	Meaning	SI unit
$\Sigma p_{\text{initial}}$	total initial momentum	kg·m/s
Σp_{final}	total final momentum	kg·m/s

Impulse from a force-time graph

$$\mathbf{J} = \text{signed area under the force-time graph}$$

SUPPLEMENTAL / DERIVED

Use: Use graph area to find momentum change.

Watch: Area below the time axis contributes negative impulse.

Variable	Meaning	SI unit
J	impulse	N·s (kg·m/s)
F	force on graph	N
t	time on graph	s

Perfectly inelastic collision speed

$$\mathbf{v}_f = (\mathbf{m}_1 \mathbf{v}_{1i} + \mathbf{m}_2 \mathbf{v}_{2i}) / (\mathbf{m}_1 + \mathbf{m}_2) \text{ for a perfectly inelastic collision}$$

SUPPLEMENTAL / DERIVED

Use: Shortcut after two objects stick together.

Watch: This assumes external impulse is negligible.

Variable	Meaning	SI unit
v_f	common final velocity after sticking	m/s
m_1	mass of object 1	kg
v_{1i}	initial velocity of object 1	m/s
m_2	mass of object 2	kg
v_{2i}	initial velocity of object 2	m/s

Elastic-collision kinetic energy

total K_{initial} = total K_{final} for an elastic collision

SUPPLEMENTAL / DERIVED

Use: Use together with momentum conservation for ideal elastic collisions.

Watch: Momentum conservation alone does not imply kinetic-energy conservation.

Variable	Meaning	SI unit
K_{initial}	initial total kinetic energy	J
K_{final}	final total kinetic energy	J

Collision kinetic-energy change

Delta $K_{\text{collision}}$ = K_{f} - K_{i}

SUPPLEMENTAL / DERIVED

Use: Quantify kinetic-energy loss or gain during a collision.

Watch: Negative Delta K is common for inelastic collisions.

Variable	Meaning	SI unit
$\Delta K_{\text{collision}}$	collision kinetic-energy change	J
K_{i}	initial kinetic energy	J
K_{f}	final kinetic energy	J

Unit 5 · Torque & rotational dynamics · essential derived formulas

15 relationships in this section. Every entry includes its intended use, a caution, and variable meanings/units when applicable.

Angular displacement

$$\Delta\theta = \theta_f - \theta_i$$

SUPPLEMENTAL / DERIVED

Use: Rotational analogue of linear displacement.

Watch: Use radians in linear-angular conversions.

Variable	Meaning	SI unit
$\Delta\theta$	angular displacement	rad
θ_i	initial angular position	rad
θ_f	final angular position	rad

Average angular velocity

$$\omega_{\text{avg}} = \Delta\theta / \Delta t$$

SUPPLEMENTAL / DERIVED

Use: Angular displacement per time.

Watch: Angular direction/sign follows the chosen rotational convention.

Variable	Meaning	SI unit
$\Delta\theta$	angular displacement	rad
ω_{avg}	average angular velocity	rad/s
Δt	elapsed time	s

Average angular acceleration

$$\alpha_{\text{avg}} = \Delta\omega / \Delta t$$

SUPPLEMENTAL / DERIVED

Use: Angular-velocity change per time.

Watch: Positive/negative depends on rotational sign convention.

Variable	Meaning	SI unit
$\Delta\omega$	change in angular velocity	rad/s
α_{avg}	average angular acceleration	rad/s ²
Δt	elapsed time	s

Arc length

$$s = r\theta$$

SUPPLEMENTAL / DERIVED

Use: Connect angular displacement and distance along a circle.

Watch: theta must be in radians.

Variable	Meaning	SI unit
θ	angle	rad
r	radius / separation	m
s	arc length	m

Angular speed from frequency or period

$$\omega = 2\pi f = 2\pi/T$$

SUPPLEMENTAL / DERIVED

Use: Convert cycle rate to radians per second.

Watch: Do not confuse ordinary frequency f with angular speed ω .

Variable	Meaning	SI unit
ω	angular velocity / angular speed	rad/s
π	pi, mathematical constant	dimensionless
T	period	s
f	frequency	Hz (s^{-1})

Centripetal acceleration from angular speed

$$a_c = \omega^2 r$$

SUPPLEMENTAL / DERIVED

Use: Equivalent to v^2/r when $v = r\omega$.

Watch: This is radial, not tangential, acceleration.

Variable	Meaning	SI unit
ω	angular velocity / angular speed	rad/s
a_c	centripetal acceleration	m/s^2
r	radius / separation	m

Required radial net force from angular speed

$$F_{\text{radial}} = m\omega^2 r$$

SUPPLEMENTAL / DERIVED

Use: Net inward force for uniform circular motion.

Watch: Identify which real forces provide it.

Variable	Meaning	SI unit
F_{radial}	net radial/inward force	N
ω	angular velocity / angular speed	rad/s
m	mass	kg
r	radius / separation	m

Rotational equilibrium condition

$$\sum \tau = 0 \text{ for rotational equilibrium}$$

SUPPLEMENTAL / DERIVED

Use: Use when angular acceleration is zero.

Watch: Choose one axis and one sign convention for every torque.

Variable	Meaning	SI unit
$\sum \tau$	sum of torques about the chosen axis	N·m

Translational equilibrium condition

sum $\mathbf{F}(\text{vector}) = 0$ for translational equilibrium

SUPPLEMENTAL / DERIVED

Use: Use with torque equilibrium for a static rigid body.

Watch: Zero net force alone does not guarantee zero net torque.

Variable	Meaning	SI unit
$\Sigma \mathbf{F}$	vector sum of external forces	N

Thin hoop rotational inertia

$I_{\text{hoop}} = M R^2$

SUPPLEMENTAL / DERIVED

Use: Common ideal rigid-body model about its symmetry axis.

Watch: Use only for the stated hoop/ring geometry and axis.

Variable	Meaning	SI unit
I_{hoop}	rotational inertia of thin hoop	$\text{kg} \cdot \text{m}^2$
M	mass of body / central body	kg
R	radius / range	m

Solid disk/cylinder rotational inertia

$I_{\text{disk}} = \frac{1}{2} M R^2$

SUPPLEMENTAL / DERIVED

Use: Common ideal model about central symmetry axis.

Watch: Axis and mass distribution matter.

Variable	Meaning	SI unit
I_{disk}	rotational inertia of solid disk/cylinder	$\text{kg} \cdot \text{m}^2$
M	mass of body / central body	kg
R	radius / range	m

Solid sphere rotational inertia

$I_{\text{sphere}} = \frac{2}{5} M R^2$

SUPPLEMENTAL / DERIVED

Use: Common ideal model about a diameter.

Watch: Do not use for a hollow sphere.

Variable	Meaning	SI unit
I_{sphere}	rotational inertia of solid sphere	$\text{kg} \cdot \text{m}^2$
M	mass of body / central body	kg
R	radius / range	m

Thin spherical shell rotational inertia

$I_{\text{shell}} = \frac{2}{3} M R^2$

SUPPLEMENTAL / DERIVED

Use: Common ideal shell model about a diameter.

Watch: Use only for a thin shell.

Variable	Meaning	SI unit
I_{shell}	rotational inertia of thin spherical shell	$\text{kg} \cdot \text{m}^2$

Variable	Meaning	SI unit
M	mass of body / central body	kg
R	radius / range	m

Thin rod about center

$$I_{\text{rod,cm}} = \frac{1}{12} M L^2$$

SUPPLEMENTAL / DERIVED

Use: Common ideal rod model with axis through center perpendicular to rod.

Watch: Different axes require a different I or parallel-axis theorem.

Variable	Meaning	SI unit
$I_{\text{rod,cm}}$	rotational inertia of thin rod about center	$\text{kg}\cdot\text{m}^2$
M	rod mass	kg
L	rod length	m

Thin rod about one end

$$I_{\text{rod,end}} = \frac{1}{3} M L^2$$

SUPPLEMENTAL / DERIVED

Use: Common ideal rod model with axis through one end perpendicular to rod.

Watch: Do not confuse with the center-axis value.

Variable	Meaning	SI unit
$I_{\text{rod,end}}$	rotational inertia of thin rod about one end	$\text{kg}\cdot\text{m}^2$
M	rod mass	kg
L	rod length	m

Unit 6 · Energy & momentum of rotating systems · essential derived formulas

8 relationships in this section. Every entry includes its intended use, a caution, and variable meanings/units when applicable.

Total rolling kinetic energy

$$K_{\text{rolling}} = \frac{1}{2} M v_{\text{cm}}^2 + \frac{1}{2} I_{\text{cm}} \omega^2$$

SUPPLEMENTAL / DERIVED

Use: Add translational and rotational kinetic energy for a rolling rigid body.

Watch: Requires correct I about the center-of-mass axis.

Variable	Meaning	SI unit
K_{rolling}	total rolling kinetic energy	J
ω	angular velocity / angular speed	rad/s
v_{cm}	center-of-mass velocity	m/s
I_{cm}	rotational inertia about center-of-mass axis	kg·m ²
M	mass of body / central body	kg

Rolling speed condition

$$v_{\text{cm}} = R \omega \text{ for rolling without slipping}$$

SUPPLEMENTAL / DERIVED

Use: Link center-of-mass speed to angular speed.

Watch: Not valid during slipping.

Variable	Meaning	SI unit
v_{cm}	center-of-mass speed	m/s
R	rolling radius	m
ω	angular speed	rad/s

Rolling acceleration condition

$$a_{\text{cm}} = R \alpha \text{ for rolling without slipping}$$

SUPPLEMENTAL / DERIVED

Use: Link center-of-mass and angular acceleration.

Watch: Not valid during slipping.

Variable	Meaning	SI unit
a_{cm}	center-of-mass acceleration	m/s ²
R	rolling radius	m
α	angular acceleration	rad/s ²

Angular-momentum conservation

$$\sum L_{\text{initial}} = \sum L_{\text{final}} \text{ when external torque is negligible}$$

SUPPLEMENTAL / DERIVED

Use: Use about an axis where net external torque is negligible.

Watch: Angular momentum depends on the chosen origin/axis.

Variable	Meaning	SI unit
$\Sigma L_{\text{initial}}$	total initial angular momentum	kg·m ² /s

Variable	Meaning	SI unit
ΣL_{final}	total final angular momentum	$\text{kg}\cdot\text{m}^2/\text{s}$

Circular-orbit speed

$$v_{\text{orbit}} = \sqrt{G M/r}$$

SUPPLEMENTAL / DERIVED

Use: Speed for a small satellite in a circular orbit about mass M.

Watch: r is orbital radius from the center of M.

Variable	Meaning	SI unit
v_{orbit}	circular-orbit speed	m/s
G	universal gravitational constant	$\text{N}\cdot\text{m}^2/\text{kg}^2$
M	mass of body / central body	kg
r	radius / separation	m

Circular-orbit period

$$T_{\text{orbit}} = 2 \pi \sqrt{r^3/(G M)}$$

SUPPLEMENTAL / DERIVED

Use: Period of a circular orbit about mass M.

Watch: Derived for circular orbit.

Variable	Meaning	SI unit
T_{orbit}	orbital period	s
π	pi, mathematical constant	dimensionless
G	universal gravitational constant	$\text{N}\cdot\text{m}^2/\text{kg}^2$
M	mass of body / central body	kg
r	radius / separation	m

Circular-orbit kinetic energy

$$K_{\text{orbit}} = G M m/(2r)$$

SUPPLEMENTAL / DERIVED

Use: Kinetic energy in a circular gravitational orbit.

Watch: Specific to a circular orbit.

Variable	Meaning	SI unit
K_{orbit}	orbital kinetic energy	J
G	universal gravitational constant	$\text{N}\cdot\text{m}^2/\text{kg}^2$
M	mass of body / central body	kg
m	mass	kg

Circular-orbit total mechanical energy

$$E_{\text{orbit}} = -G M m/(2r)$$

SUPPLEMENTAL / DERIVED

Use: Total K+U for a circular gravitational orbit.

Watch: Negative total energy indicates a bound orbit.

Variable	Meaning	SI unit
E_{orbit}	total orbital mechanical energy	J
G	universal gravitational constant	$\text{N}\cdot\text{m}^2/\text{kg}^2$
M	mass of body / central body	kg
m	mass	kg

Unit 7 · Oscillations · essential derived formulas

9 relationships in this section. Every entry includes its intended use, a caution, and variable meanings/units when applicable.

Angular frequency

$$\omega_{\text{SHM}} = 2\pi f = 2\pi/T$$

SUPPLEMENTAL / DERIVED

Use: Convert between SHM period/frequency and angular frequency.

Watch: Angular frequency is not the same quantity as ordinary frequency.

Variable	Meaning	SI unit
ω_{SHM}	angular frequency of SHM	rad/s
π	pi, mathematical constant	dimensionless
T	period	s
f	frequency	Hz (s^{-1})

Mass-spring angular frequency

$$\omega_s = \sqrt{k/m}$$

SUPPLEMENTAL / DERIVED

Use: Ideal spring-mass oscillator.

Watch: Assumes ideal spring and SHM.

Variable	Meaning	SI unit
ω_s	mass-spring angular frequency	rad/s
m	mass	kg
k	spring constant	N/m

Small-angle pendulum angular frequency

$$\omega_p = \sqrt{g/l}$$

SUPPLEMENTAL / DERIVED

Use: Ideal small-angle pendulum.

Watch: Large amplitudes break the approximation.

Variable	Meaning	SI unit
ω_p	pendulum angular frequency	rad/s
g	gravitational acceleration / field strength	m/s^2 (equiv. N/kg)
l	length	m

SHM acceleration-position relation

$$a = -(k/m)x = -\omega^2 x$$

SUPPLEMENTAL / DERIVED

Use: Restoring acceleration is proportional and opposite to displacement.

Watch: x is measured from equilibrium.

Variable	Meaning	SI unit
ω	angular velocity / angular speed	rad/s
x	position coordinate	m
m	mass	kg

Variable	Meaning	SI unit
a	acceleration	m/s ²
k	spring constant	N/m

Maximum SHM speed

$$v_{\text{max}} = \omega A$$

SUPPLEMENTAL / DERIVED

Use: Maximum speed occurs at equilibrium.

Watch: A is amplitude from equilibrium.

Variable	Meaning	SI unit
v _{max}	maximum SHM speed	m/s
ω	angular frequency	rad/s
A	amplitude	m

Maximum SHM acceleration

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

SUPPLEMENTAL / DERIVED

Use: Maximum acceleration magnitude occurs at maximum displacement.

Watch: Direction is toward equilibrium.

Variable	Meaning	SI unit
a _{max}	maximum SHM acceleration	m/s ²
ω	angular frequency	rad/s
A	amplitude	m

Total ideal spring oscillator energy

$$E_{\text{SHM}} = \frac{1}{2} k A^2$$

SUPPLEMENTAL / DERIVED

Use: Total mechanical energy in ideal spring SHM.

Watch: Assumes no dissipative energy transfer.

Variable	Meaning	SI unit
E _{SHM}	total oscillator energy	J
k	spring constant	N/m
A	amplitude	m

SHM kinetic energy vs position

$$K = \frac{1}{2} k (A^2 - x^2)$$

SUPPLEMENTAL / DERIVED

Use: From total energy minus spring potential energy.

Watch: Works for the ideal spring oscillator model.

Variable	Meaning	SI unit
K	kinetic energy	J
k	spring constant	N/m
A	amplitude	m

Variable	Meaning	SI unit
x	displacement from equilibrium	m

SHM speed vs position

$$v = \omega \sqrt{A^2 - x^2}$$

SUPPLEMENTAL / DERIVED

Use: Relate speed to position without time.

Watch: This gives speed magnitude; direction requires motion context.

Variable	Meaning	SI unit
v	speed at displacement x	m/s
ω	angular frequency	rad/s
A	amplitude	m
x	displacement from equilibrium	m

Unit 8 · Fluids · essential derived formulas

11 relationships in this section. Every entry includes its intended use, a caution, and variable meanings/units when applicable.

Volume flow rate

$$Q = \Delta V / \Delta t$$

SUPPLEMENTAL / DERIVED

Use: Volume of fluid passing per unit time.

Watch: Do not confuse volume V with speed v.

Variable	Meaning	SI unit
Q	volume flow rate	m ³ /s
ΔV	volume transferred	m ³
Δt	elapsed time	s

Volume flow rate in a uniform cross section

$$Q = A v$$

SUPPLEMENTAL / DERIVED

Use: Connect cross-sectional area and average flow speed.

Watch: Use area perpendicular to flow.

Variable	Meaning	SI unit
Q	volume flow rate	m ³ /s
A	cross-sectional area	m ²
v	average flow speed	m/s

Force from uniform pressure

$$F = P A$$

SUPPLEMENTAL / DERIVED

Use: Rearrangement of $P = F_{\text{perp}}/A$.

Watch: Force is normal to the surface for pressure loading.

Variable	Meaning	SI unit
F	normal force	N
P	pressure	Pa
A	area	m ²

Pascal principle / hydraulic force

$$F_1/A_1 = F_2/A_2 \text{ in an ideal hydraulic system}$$

SUPPLEMENTAL / DERIVED

Use: Pressure transmitted through an ideal confined fluid.

Watch: Height differences or other pressure terms may need inclusion.

Variable	Meaning	SI unit
F ₁	force on piston 1	N
A ₁	piston area 1	m ²
F ₂	force on piston 2	N
A ₂	piston area 2	m ²

Apparent weight in a fluid

$$W_{\text{app}} = m g - F_b$$

SUPPLEMENTAL / DERIVED

Use: Scale/support reading when buoyant force acts upward.

Watch: Sign/direction depends on the force arrangement.

Variable	Meaning	SI unit
W_{app}	apparent weight / support reading	N
m	object mass	kg
g	gravitational acceleration magnitude	m/s^2
F_b	buoyant force	N

Floating condition

$$F_b = m g \text{ for floating equilibrium}$$

SUPPLEMENTAL / DERIVED

Use: Vertical equilibrium for a freely floating object.

Watch: Only the submerged portion displaces fluid.

Variable	Meaning	SI unit
F_b	buoyant force	N
m	object mass	kg
g	gravitational acceleration magnitude	m/s^2

Fraction submerged

$$V_{\text{sub}}/V_{\text{obj}} = \rho_{\text{obj}}/\rho_{\text{fluid}} \text{ for a floating object}$$

SUPPLEMENTAL / DERIVED

Use: Derived from buoyancy equilibrium for a uniform floating object.

Watch: Assumes the object floats without other vertical forces.

Variable	Meaning	SI unit
V_{sub}	submerged volume	m^3
V_{obj}	total object volume	m^3
ρ_{obj}	object density	kg/m^3
ρ_{fluid}	fluid density	kg/m^3

Hydrostatic pressure difference

$$\Delta P = \rho g \Delta h$$

SUPPLEMENTAL / DERIVED

Use: Pressure change between two depths in the same static fluid.

Watch: Use vertical depth difference.

Variable	Meaning	SI unit
ΔP	pressure difference	Pa
ρ	fluid density	kg/m^3
g	gravitational acceleration magnitude	m/s^2
Δh	vertical depth difference	m

Mass flow rate

$$\text{mass flow rate} = \rho Q = \rho A v$$

SUPPLEMENTAL / DERIVED

Use: Convert volume flow rate to mass per time for constant density.

Watch: Density must be consistent with the flow model.

Variable	Meaning	SI unit
$\dot{m}$	mass flow rate	kg/s
ρ	fluid density	kg/m ³
Q	volume flow rate	m ³ /s
A	cross-sectional area	m ²
v	flow speed	m/s

Torricelli outflow speed

$$v = \sqrt{2 g \Delta h} \text{ for ideal Torricelli outflow}$$

SUPPLEMENTAL / DERIVED

Use: Derived from Bernoulli for a large reservoir and small outlet.

Watch: Requires the ideal assumptions and appropriate pressure endpoints.

Variable	Meaning	SI unit
v	ideal outflow speed	m/s
g	gravitational acceleration magnitude	m/s ²
Δh	height difference between surface and outlet	m

Continuity at a junction

$$\sum Q_{\text{in}} = \sum Q_{\text{out}} \text{ for steady incompressible flow}$$

SUPPLEMENTAL / DERIVED

Use: Apply conservation of volume flow across multiple branches.

Watch: For compressible flow, mass conservation is the safer general statement.

Variable	Meaning	SI unit
Q_{in}	incoming branch flow rate	m ³ /s
Q_{out}	outgoing branch flow rate	m ³ /s

Final checks before using a formula

- Identify the physical model first; do not choose an equation only because the variables look familiar.
- Choose a coordinate system and keep vector signs consistent.
- Check that the equation assumptions match the situation (for example, constant acceleration or ideal-spring behavior).
- Use SI units consistently and perform a dimensional check when practical.
- For spring questions, distinguish spring deformation measured from the spring's relaxed length from the equilibrium position of the complete object-spring system; they need not coincide.
- For graph questions, remember that slopes and signed areas can encode physical quantities even when no single plug-in formula is appropriate.