Essential Physics Formulas: Grade 9

A concise school reference guide

Kinematics, dynamics, momentum, energy, oscillations, waves and atomic physics

1. Uniform motion

Average speed:

$$v_{\text{avg}} = \frac{s_{\text{total}}}{t_{\text{total}}}.$$

For uniform rectilinear motion:

$$x = x_0 + v_x t.$$

Displacement along the x-axis:

$$s_x = v_x t.$$

If only the magnitude of velocity and the distance travelled are considered:

$$s = vt.$$

2. Acceleration

The x-component of acceleration is:

$$a_x = \frac{v_x - v_{0x}}{t}.$$

Therefore:

$$v_x = v_{0x} + a_x t.$$

Here v_{0x} is the initial x-component of velocity and v_x is the x-component of velocity after time t.
The SI unit of acceleration is:

$$[a] = \frac{\text{m}}{\text{s}^2}.$$

3. Motion with constant acceleration

The x-component of displacement is:

$$s_x = v_{0x} t + \frac{a_x t^2}{2}.$$

Using the initial and final x-components of velocity:

$$s_x = \frac{v_{0x} + v_x}{2}\, t.$$

Relation between velocity and displacement:

$$v_x^2 - v_{0x}^2 = 2 a_x s_x.$$

The coordinate of the body is:

$$x = x_0 + v_{0x} t + \frac{a_x t^2}{2}.$$

Here x_0 is the initial coordinate and x is the coordinate after time t.

4. Free fall

Neglecting air resistance, a body moves with the acceleration due to gravity g.
If the body starts falling from rest:

$$v = gt,$$

$$h = \frac{gt^2}{2},$$

$$v^2 = 2gh.$$

For upward motion or motion with a non-zero initial velocity, first choose the positive direction of the axis and then consistently use the signs of the velocity and acceleration components.

5. Circular motion

Linear speed:

$$v = \frac{2\pi R}{T} = 2\pi R\nu.$$

Frequency and period are related by:

$$\nu = \frac{1}{T}.$$

Angular velocity:

$$\omega = \frac{2\pi}{T} = 2\pi\nu.$$

Centripetal acceleration:

$$a_{\mathrm{c}} = \frac{v^2}{R} = \omega^2 R.$$

6. Newton's first and second laws

Newton's first law.
In an inertial reference frame, if the resultant force acting on a body is zero:

$$\vec{F}_{\mathrm{res}} = 0,$$

then the acceleration of the body is zero:

$$\vec{a} = 0.$$

Therefore, the body remains at rest or continues to move with constant velocity in a straight line.
Newton's second law.
In an inertial reference frame, the acceleration of a body is determined by the resultant force:

$$\vec{F}_{\mathrm{res}} = m\vec{a}.$$

In projection onto the x-axis:

$$\sum F_x = ma_x.$$

Thus, the first law describes the case of zero resultant force, while the second law relates force and acceleration in the general case.

7. Gravity and universal gravitation

The gravitational force near Earth's surface:

$$F_g = mg.$$

Newton's law of universal gravitation:

$$F = G\frac{m_1 m_2}{r^2}.$$

The acceleration due to gravity near the surface of a celestial body is:

$$g = G\frac{M}{R^2}.$$

8. Friction

For kinetic friction:

$$F_{\mathrm{fr}} = \mu N.$$

Here μ is the coefficient of friction and N is the normal force.
On a horizontal surface with no other vertical forces:

$$N = mg.$$

Static friction varies from zero up to a maximum value required to prevent slipping.

9. Momentum

Momentum of a body:

$$\vec{p} = m\vec{v}.$$

Impulse of a force:

$$\vec{F}\,\Delta t = \Delta\vec{p}.$$

In a closed system, momentum is conserved:

$$\sum \vec{p}_{\mathrm{before}} = \sum \vec{p}_{\mathrm{after}}.$$

10. Work and energy

Mechanical work:

$$A = Fs\cos\alpha.$$

Kinetic energy:

$$E_k = \frac{mv^2}{2}.$$

Gravitational potential energy:

$$E_p = mgh.$$

The work done by the resultant force equals the change in kinetic energy:

$$A_{\text{res}} = \Delta E_k.$$

When only conservative forces act, mechanical energy is conserved:

$$E_k + E_p = \text{const}.$$

11. Power

Average power:

$$P = \frac{A}{t}.$$

For motion in the direction of the force:

$$P = Fv.$$

12. Harmonic oscillations

The coordinate in harmonic motion is:

$$x = A\cos(\omega t + \varphi_0).$$

Here A is the amplitude and φ_0 is the initial phase.
Period and frequency:

$$T = \frac{1}{\nu}.$$

Angular frequency:

$$\omega = 2\pi\nu = \frac{2\pi}{T}.$$

Period of a mass–spring oscillator:

$$T = 2\pi\sqrt{\frac{m}{k}}.$$

Period of a simple pendulum for small oscillations:

$$T = 2\pi\sqrt{\frac{l}{g}}.$$

13. Waves

The relation between wave speed, wavelength and frequency is:

$$v = \lambda\nu.$$

Since

$$\nu = \frac{1}{T},$$

we also have:

$$v = \frac{\lambda}{T}.$$

During one period, a wave travels one wavelength:

$$\lambda = vT.$$

14. Electromagnetic induction

Magnetic flux:

$$\Phi = BS\cos\alpha.$$

Here α is the angle between the magnetic field vector and the normal to the surface.
The induced electromotive force is:

$$\mathcal{E}_i = -\frac{\Delta\Phi}{\Delta t}.$$

The minus sign expresses Lenz's law: the induced current is directed so that it opposes the change in magnetic flux that produced it.

15. Transformer

For an ideal transformer:

$$\frac{U_2}{U_1} = \frac{N_2}{N_1}.$$

Here N_1 and N_2 are the numbers of turns in the primary and secondary windings.
For an ideal transformer, the input and output powers are equal:

$$U_1 I_1 = U_2 I_2.$$

For a real transformer, this equality is only approximate because of energy losses.

16. Photons

Photon energy:

$$E = h\nu = \frac{hc}{\lambda}.$$

Photon momentum:

$$p = \frac{E}{c} = \frac{h}{\lambda}.$$

Here h is Planck's constant and c is the speed of light in vacuum.

17. Radioactive decay

Let T be the half-life.
After n half-lives, the number of undecayed nuclei is:

$$N = N_0 \left(\frac{1}{2}\right)^n.$$

Here:

$$n = \frac{t}{T}.$$

Therefore, after time t:

$$N = N_0\, 2^{-t/T}.$$

Here N_0 is the initial number of nuclei and N is the number of undecayed nuclei after time t.

18. Rest energy and binding energy

The rest energy of a body is:

$$E_0 = mc^2.$$

Here m is the mass of the body and c is the speed of light in vacuum.
The nuclear binding energy is:

$$E_\mathrm{b} = \Delta m\, c^2.$$

Here Δm is the mass defect.

Motion graphs

The slope of a position–time graph $x(t)$ gives the x-component of velocity:

$$v_x = \frac{\Delta x}{\Delta t}.$$

The slope of a velocity–time graph $v_x(t)$ gives the x-component of acceleration:

$$a_x = \frac{\Delta v_x}{\Delta t}.$$

The area under the $v_x(t)$ graph over a chosen time interval gives the x-component of displacement s_x.

This reference sheet is intended for quick review. Before using a formula, check the conditions under which it applies and the units of all quantities.