AP Physics 2: Algebra-Based

AP Physics

> *Every AP physics exam supplies a table of equations, so the useful question is not what exists but what the table leaves you to remember. Anything not marked GIVEN is one to carry in your head. Compiled by GioPhysics from the published syllabus. This is an independent study aid, not a College Board document; the official syllabus is the authority.*

9 Thermodynamics

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Ideal gas law

$$PV = nRT = N k_B T$$

- P — pressure (Pa)
- V — volume (m^3)
- n — amount of gas (mol)
- N — number of molecules
- T — absolute temperature (K)

The same law counted two ways, by moles or by molecules. T must be in kelvin.

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Average kinetic energy of a molecule

$$K_{avg} = (3/2)\, k_B T$$

- K_{avg} — mean translational kinetic energy of one molecule (J)
- k_B — Boltzmann's constant (J/K)
- T — absolute temperature (K)

What temperature actually measures. It does not depend on which gas.

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Root-mean-square speed

$$v_{rms} = \sqrt{3 k_B T / m} = \sqrt{3RT / M}$$

- v_{rms} — root-mean-square molecular speed (m/s)
- m — mass of one molecule (kg)
- M — molar mass (kg/mol)

Heavier molecules move more slowly at the same temperature.

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First law of thermodynamics

$$\Delta U = Q + W$$

- ΔU — change in the internal energy of the gas (J)
- Q — energy added by heating (J)
- W — work done on the gas (J)

AP takes W as the work done on the gas, so compressing it is positive. Signs are where marks are lost here.

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Work done on a gas

$$W = -P\,\Delta V$$

- W — work done on the gas (J)
- P — pressure, held constant (Pa)
- ΔV — change in volume (m^3)

At constant pressure. In general it is minus the area under the process on a PV diagram.

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Heating a substance

$$Q = m\ c\ \Delta T$$

- Q — energy transferred by heating (J)
- m — mass (kg)
- c — specific heat capacity (J/(kg K))
- ΔT — temperature change (K)

10

Electric Force, Field, and Potential

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Coulomb's law

$$F_E = (1 / 4\pi\varepsilon_0)\ q_1 q_2 / r^2$$

- F_E — force on each charge, along the line joining them (N)
- q_1, q_2 — the two charges (C)
- r — separation (m)
- ε_0 — permittivity of free space ($C^2/(N\ m^2)$)

$1 / 4\pi\varepsilon_0$ is the constant written $k = 9.0 \times 10^9\ N\ m^2/C^2$. Like charges repel, so signs tell you direction, not magnitude.

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Electric field

$$E = F_E / q$$

- E — electric field, a vector (N/C or V/m)
- F_E — force on the test charge (N)
- q — test charge (C)

The definition. Field points along the force on a positive charge.

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Field of a point charge

$$E = (1 / 4\pi\varepsilon_0)\ q / r^2$$

- E — field strength at distance r (N/C)
- q — charge producing the field (C)
- r — distance from it (m)

Away from a positive charge, towards a negative one. Fields from several charges add as vectors.

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Uniform field between parallel plates

$$E = \Delta V / d$$

- E — field strength, uniform between the plates (V/m)
- ΔV — potential difference across the gap (V)
- d — separation of the plates (m)

The field points from high potential to low.

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Electric potential of a point charge

$$V = (1 / 4\pi\varepsilon_0)\ q / r$$

- V — potential at that point (V)
- q — charge producing it, sign included (C)
- r — distance from it (m)

A scalar: potentials from several charges add by ordinary arithmetic, with their signs.

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Electric potential energy of two charges

$$U_E = (1 / 4\pi\varepsilon_0)\ q_1 q_2 / r$$

- U_E — potential energy of the pair (J)
- q_1, q_2 — the two charges, signs included (C)

Zero at infinite separation. Negative for opposite charges, which is why they are bound.

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Energy change of a charge moved through a potential difference

$$\Delta U_E = q\,\Delta V$$

ΔU_E — change in electric potential energy (J)
q — charge moved (C)
ΔV — potential difference it moves through (V)

The definition of the electronvolt, and the way accelerated-charge questions are set.

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A conductor in electrostatic equilibrium

E = 0 inside · excess charge sits on the surface · the whole conductor is one equipotential

E — field within the conducting material (N/C)
V — the same everywhere on and in the conductor (V)

Not formulae, but the facts every conductor question turns on. Any field inside would move the free charges, so it cannot persist.

11 Electric Circuits

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Electric current

$$I = \Delta Q / \Delta t$$

I — current (A)
ΔQ — charge passing a point (C)
Δt — time taken (s)

Conventional current is the direction positive charge would move.

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Resistance of a wire

$$R = \rho L / A$$

R — resistance (Ω)
ρ — resistivity of the material (Ω m)
L — length (m)
A — cross-sectional area (m^2)

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Ohm's law

$$I = \Delta V / R$$

$\Delta V = IR$ · $R = \Delta V / I$

ΔV — potential difference across the component (V)
I — current through it (A)
R — resistance (Ω)

A property of ohmic components only; a filament lamp or a diode does not obey it.

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Electrical power

$$P = I\,\Delta V = I^2R = (\Delta V)^2 / R$$

P — power delivered (W)
I — current (A)
ΔV — potential difference (V)

The last two forms hold only where $\Delta V = IR$ does.

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Resistors in series

$$R_s = R_1 + R_2 + \ldots$$

R_s — equivalent resistance (Ω)

Same current through each; the potential differences add.

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Resistors in parallel

$$1 / R_p = 1 / R_1 + 1 / R_2 + \ldots$$

R_p — equivalent resistance (Ω)

Same potential difference across each; the currents add. The result is always smaller than the smallest resistor.

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Kirchhoff's rules

$$\Sigma I \text{ into a junction} = \Sigma I \text{ out of it} \cdot \Sigma \Delta V \text{ round any loop} = 0$$

- I — current at a junction (A)
- ΔV — potential change across each element in the loop (V)

Conservation of charge and conservation of energy. Stated as rules rather than printed as formulae, and needed for any circuit that will not reduce to series and parallel.

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Capacitance

$$C = Q / \Delta V$$

- C — capacitance (F)
- Q — charge on either plate (C)
- ΔV — potential difference between the plates (V)

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Parallel-plate capacitor

$$C = \kappa \varepsilon_0 A / d$$

- κ — dielectric constant of the material between the plates
- A — plate area (m^2)
- d — plate separation (m)

$\kappa = 1$ for a vacuum and is greater than 1 for any dielectric, so a dielectric always raises the capacitance.

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Energy stored in a capacitor

$$U_C = \tfrac{1}{2} Q \Delta V = \tfrac{1}{2} C (\Delta V)^2$$

- U_C — energy stored (J)
- Q — charge stored (C)
- C — capacitance (F)

The half is there because the potential difference grows as the charge arrives.

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Capacitors in series and parallel

$$1 / C_s = 1 / C_1 + 1 / C_2 + \ldots \cdot C_p = C_1 + C_2 + \ldots$$

- C — equivalent capacitance (F)

The opposite way round from resistors, which is the mistake this pair exists to catch.

12 Magnetism and Electromagnetism

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Force on a moving charge

$$F_M = q v B \sin\theta$$

- F_M — magnetic force (N)
- q — charge (C)
- v — speed (m/s)
- B — magnetic flux density (T)
- θ — angle between v and B (°)

The force is perpendicular to both v and B, found with the right hand, so it does no work and only changes direction.

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Force on a current-carrying wire

$$F_M = B I L \sin\theta$$

- I — current (A)
- L — length of wire in the field (m)
- θ — angle between the wire and the field (°)

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Field of a long straight wire

$$B = \mu_0 I / (2\pi r)$$

- B — flux density at distance r (T)
- μ_0 — permeability of free space (T m/A)
- r — perpendicular distance from the wire (m)

The field circles the wire; grip it with the right hand, thumb along the current.

ALGEBRA

Magnetic flux

$$\Phi B = B A \cos \theta$$

- ΦB — magnetic flux through the loop (Wb)
- A — area of the loop (m^2)
- θ — angle between the field and the normal to the loop (°)

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Faraday's law of induction

$$\varepsilon = - \Delta\Phi B / \Delta t$$

- ε — induced emf (V)
- $\Delta\Phi B$ — change in flux through the loop (Wb)
- Δt — time it takes (s)

The minus sign is Lenz's law: the induced current opposes the change that caused it. For N turns, multiply by N.

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Motional emf

$$\varepsilon = B L v$$

- L — length of the moving conductor (m)
- v — speed across the field (m/s)

Faraday's law for a bar sliding on rails, where the area of the circuit changes at Lv. Worth being able to rebuild rather than recall.

13 Geometric Optics

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Index of refraction

$$n = c / v$$

- n — index of refraction of the medium
- c — speed of light in a vacuum (m/s)
- v — speed of light in the medium (m/s)

n is never less than 1. The frequency does not change when light crosses a boundary; the wavelength does.

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Snell's law

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

- n_1, n_2 — indices either side of the boundary
- θ_1, θ_2 — angles to the normal (°)

Angles are measured from the normal, not the surface.

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Critical angle

$$\sin \theta c = n_2 / n_1$$

- θc — critical angle (°)
- n_1 — index of the denser medium the light is in
- n_2 — index of the medium beyond

Snell's law with the refracted ray at 90°. Only possible when n_1 is greater than n_2; beyond θc the light is totally internally reflected.

ALGEBRA

Mirror and thin lens equation

$$1 / s_o + 1 / s_i = 1 / f$$

- s_o — object distance (m)
- s_i — image distance, negative for a virtual image (m)
- f — focal length, negative for a diverging lens or convex mirror (m)

The sign convention carries the physics: get it wrong and a virtual image comes out real.

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Magnification

$$M = h_i / h_o = - s_i / s_o$$

- M — magnification
- h_i, h_o — image and object height (m)

A negative M means the image is inverted.

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Focal length of a spherical mirror

$$f = R / 2$$

- f — focal length (m)
- R — radius of curvature (m)

14 Waves, Sound, and Physical Optics

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Wave speed

$$v = f \lambda$$

$f = v / \lambda$ · $\lambda = v / f$

- v — wave speed, set by the medium (m/s)
- f — frequency, set by the source (Hz)
- λ — wavelength (m)

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Standing waves with two matching ends

$$\lambda_n = 2L / n, \quad n = 1, 2, 3 \ldots$$

- L — length of the string or pipe (m)
- n — harmonic number

A string fixed at both ends, or a pipe open at both ends. Read off the boundary conditions rather than recalled — draw the pattern and count.

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Standing waves in a pipe closed at one end

$$\lambda_n = 4L / n, \quad n = 1, 3, 5 \ldots$$

- L — length of the pipe (m)
- n — odd harmonics only

A node at the closed end and an antinode at the open one, which is why the even harmonics are missing.

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Double-slit and grating maxima

$$d \sin \theta = m \lambda$$

- d — slit separation, or grating spacing (m)
- θ — angle of the bright fringe from the centre (°)
- m — order of the fringe, 0, 1, 2 …

Constructive interference, where the path difference is a whole number of wavelengths.

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Fringe spacing on a distant screen

$$\Delta y = \lambda L / d$$

- Δy — distance between neighbouring bright fringes (m)
- L — distance from the slits to the screen (m)
- d — slit separation (m)

For small angles, with L much greater than d.

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Single-slit minima

$$a \sin \theta = m \lambda, \quad m = 1, 2, 3 \ldots$$

- a — width of the single slit (m)
- θ — angle of the dark fringe (°)

The same-looking equation as the two-slit one but locating dark fringes, not bright. Note which it is before substituting.

15 Modern Physics

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Photon energy

$$E = h f = h c / \lambda$$

- E — energy of one photon (J or eV)
- h — Planck's constant (J s)
- f — frequency of the light (Hz)

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Photoelectric effect

$$K_{max} = h f - \varphi$$

- K_{max} — maximum kinetic energy of an emitted electron (J or eV)
- φ — work function of the surface (J or eV)

Below the threshold frequency nothing is emitted however bright the light — the observation that made the photon necessary.

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de Broglie wavelength

$$\lambda = h / p$$

- λ — wavelength associated with the particle (m)
- p — momentum (kg m/s)

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Photon emitted between energy levels

$$h f = |\Delta E|$$

- ΔE — difference between the two levels (J or eV)
- f — frequency of the photon (Hz)

Levels are discrete, so the emitted frequencies are too. That is what a line spectrum is.

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Mass-energy equivalence

$$E = m c^2$$

- E — energy equivalent of the mass (J)
- m — mass (kg)
- c — speed of light in a vacuum (m/s)

Used as $\Delta E = \Delta m\, c^2$ for the mass defect of a nucleus and the energy released in a decay.

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What a nuclear reaction conserves

$$\Sigma A \text{ unchanged} \cdot \Sigma Z \text{ unchanged}$$

- A — mass number, the count of nucleons
- Z — atomic number, the count of protons

Charge and nucleon number balance across the arrow; energy and momentum are conserved as well. Not a formula, but it is what the equations are checked against.