ADVANCED PLACEMENT PHYSICS 2 TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS	
Avogadro's number,	$N_0 = 6.02 \times 10^{23}\ \text{mol}^{-1}$
Universal gas constant,	$R = 8.31\ \text{J}/(\text{mol} \cdot \text{K})$
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}\ \text{J/K}$
1 atmosphere of pressure,	$1\ \text{atm} = 1.0 \times 10^5\ \text{N/m}^2 = 1.0 \times 10^5\ \text{Pa}$
Coulomb constant,	$k = \dfrac{1}{4\pi\varepsilon_0} = 9.0 \times 10^9\ \dfrac{\text{N} \cdot \text{m}^2}{\text{C}^2}$
Proton mass,	$m_p = 1.67 \times 10^{-27}\ \text{kg}$
Neutron mass,	$m_n = 1.67 \times 10^{-27}\ \text{kg}$
Electron mass,	$m_e = 9.11 \times 10^{-31}\ \text{kg}$
Elementary charge,	$e = 1.60 \times 10^{-19}\ \text{C}$
Vacuum permittivity,	$\varepsilon_0 = 8.85 \times 10^{-12}\ \text{C}^2/(\text{N} \cdot \text{m}^2)$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\ (\text{T} \cdot \text{m})/\text{A}$
1 electron volt,	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$
Planck's constant,	$h = 6.63 \times 10^{-34}\ \text{J} \cdot \text{s} = 4.14 \times 10^{-15}\ \text{eV} \cdot \text{s}$
	$hc = 1.99 \times 10^{-25}\ \text{J} \cdot \text{m} = 1240\ \text{eV} \cdot \text{nm}$
Speed of light,	$c = 3.00 \times 10^8\ \text{m/s}$
Wien's constant,	$b = 2.90 \times 10^{-3}\ \text{m} \cdot \text{K}$
Stefan-Boltzmann constant,	$\sigma = 5.67 \times 10^{-8}\ \text{W}/(\text{m}^2 \cdot \text{K}^4)$
1 unified atomic mass unit,	$1\ \text{u} = 1.66 \times 10^{-27}\ \text{kg} = 931\ \text{MeV}/c^2$

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

Magnitude of the acceleration due to gravity at Earth's surface, $g = 9.8\ \text{m/s}^2$

Magnitude of the gravitational field strength at Earth's surface, $g = 9.8\ \text{N/kg}$

UNIT SYMBOLS	
ampere,	A
coulomb,	C
degree Celsius,	°C
electron volt,	eV
farad,	F
hertz,	Hz
joule,	J
kelvin,	K
kilogram,	kg
meter,	m
mole,	mol
newton,	N
ohm,	Ω
pascal,	Pa
second,	s
tesla,	T
volt,	V
watt,	W

PREFIXES		
Factor	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	$1/2$	$3/5$	$\sqrt{2}/2$	$4/5$	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	$4/5$	$\sqrt{2}/2$	$3/5$	$1/2$	0
$\tan\theta$	0	$\sqrt{3}/3$	$3/4$	1	$4/3$	$\sqrt{3}$	∞

The following conventions are used in this exam unless otherwise stated:

- The frame of reference is inertial.
- Frictional forces are negligible.
- Strings, springs, batteries, wires, and meters are ideal.
- Resistors and lightbulbs are ohmic.
- Ideal gases are monatomic.
- The electric potential is zero at an infinite distance from an isolated point charge.
- Current is conventional current.
- Capacitors are air-filled $(\kappa = 1.0)$.
- The small angle approximation is valid for single- and double-slit diffraction.

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Equations

ELECTRICITY

Equation name	Equation
Coulomb's law (electric force)	$\left\|\vec{F}_E\right\| = \frac{1}{4\pi\varepsilon_0}\frac{\left\|q_1 q_2\right\|}{r^2} = k\frac{\left\|q_1 q_2\right\|}{r^2}$
Electric field (force on test charge)	$\vec{E} = \frac{\vec{F}_E}{q}$
Electric field (around point charge)	$\left\|\vec{E}\right\| = \frac{1}{4\pi\varepsilon_0}\frac{\left\|q\right\|}{r^2} = k\frac{\left\|q\right\|}{r^2}$
Electric potential energy (system of 2 charges)	$U_E = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r} = k\frac{q_1 q_2}{r}$
Difference in potential energy	$\Delta U_E = q\Delta V$
Electric potential (from multiple point charges)	$V = \frac{1}{4\pi\varepsilon_0}\sum_i \frac{q_i}{r_i}$
Average electric field	$\left\|\vec{E}\right\| = \left\|\frac{\Delta V}{\Delta r}\right\|$
Capacitance	$C = \frac{Q}{\Delta V}$
Capacitance (parallel-plate capacitor)	$C = \kappa\varepsilon_0\frac{A}{d}$
Electric field (parallel-plate capacitor)	$E_C = \frac{Q}{\kappa\varepsilon_0 A}$
Electric potential energy (capacitor)	$U_C = \frac{1}{2}Q\Delta V$
Current	$I = \frac{\Delta q}{\Delta t}$
Resistance	$R = \frac{\rho\ell}{A}$
Electric power	$P = I\Delta V$
Ohm's law	$I = \frac{\Delta V}{R}$
Equivalent resistance (resistors in series)	$R_{\mathrm{eq},s} = \sum_i R_i$
Equivalent resistance (resistors in parallel)	$\frac{1}{R_{\mathrm{eq},p}} = \sum_i \frac{1}{R_i}$
Equivalent capacitance (capacitors in series)	$\frac{1}{C_{\mathrm{eq},s}} = \sum_i \frac{1}{C_i}$
Equivalent capacitance (capacitors in parallel)	$C_{\mathrm{eq},p} = \sum_i C_i$
Time constant (RC circuit)	$\tau = R_{\mathrm{eq}}C_{\mathrm{eq}}$

Units

Variable	Units
A = area	m²
C = capacitance	F = C/V
d = distance	m
E = electric field	N/C = V/m
F = force	N = kg·m/s²
I = current	A
ℓ = length	m
P = power	W = J/s = N·m/s
q = charge	C
Q = charge	C
r = distance, radius, or position	m
R = resistance	Ω
t = time	s
U = potential energy	J = kg·m²/s²
V = electric potential	V = J/C
κ = dielectric constant	(no unit)
ρ = resistivity	Ω·m
τ = time constant	s

MAGNETISM

Equations		Variable	Units
Magnetic force (moving charge)	$F_B = qvB\sin\theta$	A = area	m²
Magnetic field (current-carrying wire)	$B = \frac{\mu_0 I}{2\pi r}$	B = magnetic field	T = N/(A·m)
Magnetic force (on wire)	$F_B = I\ell B\sin\theta$	F = force	N = kg·m/s²
Magnetic flux	$\Phi_B = \vec{B}\cdot\vec{A}$	I = current	A
	$\Phi_B = \lvert\vec{B}\rvert\cos\theta\lvert\vec{A}\rvert$	ℓ = length	m
Faraday's law (induced emf)	$\lvert\mathcal{E}\rvert = \left\lvert\frac{\Delta\Phi_B}{\Delta t}\right\rvert$	q = charge	C
Induced emf (moving rod loop)	$\mathcal{E} = B\ell v$	r = distance, radius, or position	m
		t = time	s
		v = velocity or speed	m/s
		$\mathcal{E}$ = emf	V = J/C
		θ = angle	deg
		Φ = flux	T·m² = V·s = Wb

THERMAL PHYSICS

Equations		Variable	Units
Pressure	$P = \frac{F_\perp}{A}$	A = area	m²
Average kinetic energy (gas particles)	$K_{avg} = \frac{3}{2}k_B T = \frac{1}{2}mv_{rms}^2$	c = specific heat	J/(kg·K)
Heat transfer rate (conduction)	$\frac{Q}{\Delta t} = \frac{kA\Delta T}{L}$	F = force	N = kg·m/s²
Ideal gas law	$PV = nRT = Nk_B T$	k = thermal conductivity	W/(m·K)
Internal energy (ideal monatomic gas)	$U = \frac{3}{2}nRT = \frac{3}{2}Nk_B T$	K = kinetic energy	J
Work done on a system	$W = -P\Delta V$	L = length	m
1st law of thermodynamics	$\Delta U = Q + W$	m = mass	kg
Energy to change temperature	$Q = mc\Delta T$	n = number of moles	mol
		N = number of atoms	(no unit)
		P = pressure	Pa = N/m²
		Q = energy transferred to a system by heating	J
		t = time	s
		T = temperature	K
		U = internal energy	J
		v = velocity or speed	m/s
		V = volume	m³
		W = work done on a system	J = N·m

WAVES, SOUND, AND OPTICS

Equations	
Wavelength	$\lambda = \frac{v}{f}$
Index of refraction	$n = \frac{c}{v}$
Snell's law (refraction)	$n_1 \sin\theta_1 = n_2 \sin\theta_2$
Thin lens or mirror	$\frac{1}{s_i} + \frac{1}{s_o} = \frac{1}{f}$
Magnification	$\lvert M \rvert = \left\lvert \frac{h_i}{h_o} \right\rvert = \left\lvert \frac{s_i}{s_o} \right\rvert$
Path length diff. (bright fringes)	$\Delta D = m\lambda$
Path length diff. (single-slit)	$\Delta D = a\sin\theta$
Single-slit diffraction (minima, dark fringes)	$a\left(\frac{y_{\text{min}}}{L}\right) \approx m\lambda$
Path length diff. (double-slit)	$\Delta D = d\sin\theta$
Double-slit interference (maxima, bright fringes)	$d\left(\frac{y_{\text{max}}}{L}\right) \approx m\lambda$
Wave speed (in a string)	$v_{\text{string}} = \sqrt{\frac{F_T}{m/\ell}}$
Period	$T = \frac{1}{f}$
Wave (displacement vs time)	$x(t) = A\cos(\omega t) = A\cos(2\pi ft)$
Wave (displacement vs position)	$y(x) = A\cos\left(2\pi \frac{x}{\lambda}\right)$
Beat frequency	$\lvert f_{\text{beat}} \rvert = \lvert f_1 - f_2 \rvert$

Variable	Units
a = width	m
A = amplitude	m
d = separation	m
D = path length	m
f = frequency or focal length	Hz = 1/s or m
F = force	N = kg·m/s²
h = height	m
ℓ = length	m
L = distance	m
m = order or mass	(no unit) or kg
M = magnification	(no unit)
n = index of refraction	(no unit)
s = position	m
t = time	s
T = period	s
v = speed	m/s
x = position	m
y = position	m
λ = wavelength	m
θ = angle	deg
ω = angular frequency	rad/s

MODERN PHYSICS

Equations	
Energy (photon)	$E = hf$
de Broglie wavelength (particles)	$\lambda = \dfrac{h}{p}$
Wavelength (photon)	$\lambda = \dfrac{c}{f}$
Wien's law (blackbody radiation)	$\lambda_{max} = \dfrac{b}{T}$
S-B law (blackbody radiation)	$P = A\sigma T^4$
Photoelectric effect	$K_{max} = hf - \phi$
Compton scattering	$\Delta\lambda = \dfrac{h}{m_e c}(1 - \cos\theta)$
Mass-energy equivalence	$E = mc^2$
Radioactive decay	$N = N_0 e^{-\lambda t}$
Decay constant (half-life)	$\lambda = \dfrac{\ln 2}{t_{1/2}}$

	Units
A = area	m²
E = energy	J
f = frequency	Hz = 1/s
K = kinetic energy	J or eV
m = mass	kg
N = number of particles	(no unit)
p = momentum	kg·m/s
P = power	W = J/s
t = time	s
T = absolute temperature	K
θ = angle	deg
λ = wavelength or decay constant	m or 1/s
ϕ = work function	J or eV

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

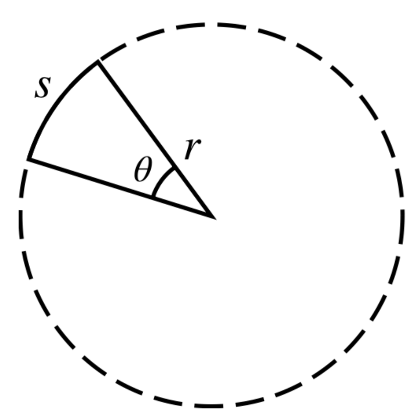
Triangle
$A = \frac{1}{2}bh$

Circle
$A = \pi r^2$
$C = 2\pi r$
$s = r\theta$

Rectangular Solid
$V = \ell wh$

Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$

Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$



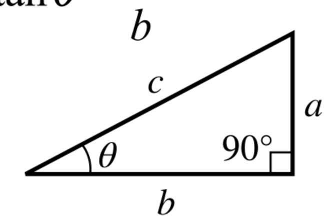
A = area
b = base
C = circumference
h = height
ℓ = length
r = radius
s = arc length
S = surface area
V = volume
w = width
θ = angle

Right Triangle
$a^2 + b^2 = c^2$

$\sin\theta = \frac{a}{c}$

$\cos\theta = \frac{b}{c}$

$\tan\theta = \frac{a}{b}$



Equations

MECHANICS AND FLUIDS

Linear kinematics	$v_x = v_{x0} + a_x t$ $x = x_0 + v_{x0}t + \frac{1}{2}a_x t^2$ $v_x^2 = v_{x0}^2 + 2a_x\left(x - x_0\right)$
Center of mass	$\vec{x}_{\text{cm}} = \frac{\sum m_i \vec{x}_i}{\sum m_i}$
Newton's 2nd law	$\vec{a}_{\text{sys}} = \frac{\sum \vec{F}}{m_{\text{sys}}} = \frac{\vec{F}_{\text{net}}}{m_{\text{sys}}}$
Gravitational force	$\left\|\vec{F}_g\right\| = G\frac{m_1 m_2}{r^2}$
Friction force	$\left\|\vec{F}_f\right\| \le \left\|\mu \vec{F}_N\right\|$
Spring force (Hooke's law)	$\vec{F}_s = -k\Delta\vec{x}$
Centripetal acceleration	$a_c = \frac{v^2}{r}$
Translational kinetic energy	$K = \frac{1}{2}mv^2$
Work	$W = F_{\|\|}d = Fd\cos\theta$
Work-energy theorem	$\Delta K = \sum W_i = \sum F_{\|\|,i}d_i$
Spring potential energy	$U_s = \frac{1}{2}k(\Delta x)^2$
Gravitational potential energy	$U_G = -\frac{Gm_1m_2}{r}$ $\Delta U_g = mg\Delta y$
Power	$P_{\text{avg}} = \frac{W}{\Delta t} = \frac{\Delta E}{\Delta t}$ $P_{\text{inst}} = F_{\|\|}v = Fv\cos\theta$
Linear momentum	$\vec{p} = m\vec{v}$
Impulse	$\vec{F}_{\text{net}} = \frac{\Delta\vec{p}}{\Delta t} = m\frac{\Delta\vec{v}}{\Delta t} = m\vec{a}$ $\vec{J} = \vec{F}_{\text{avg}}\Delta t = \Delta\vec{p}$
Velocity of center of mass	$\vec{v}_{\text{cm}} = \frac{\sum \vec{p}_i}{\sum m_i} = \frac{\sum m_i\vec{v}_i}{\sum m_i}$

Units

a = acceleration	m/s²
d = distance	m
E = energy	J
F = force	N
J = impulse	kg·m/s = N·s
k = spring constant	N/m
K = kinetic energy	J
m = mass	kg
p = momentum	kg·m/s
P = power	W = J/s = N·m/s
r = radius or distance	m
t = time	s
U = potential energy	J
v = velocity or speed	m/s
W = work	J = N·m
x = position	m
y = vertical position	m
θ = angle	deg or rad
μ = coefficient of friction	(no unit)

MECHANICS AND FLUIDS

Equations

Rotational kinematics	$\omega = \omega_0 + \alpha t$ $\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$ $\omega^2 = \omega_0^2 + 2\alpha\left(\theta - \theta_0\right)$
Linear / rotational kinematics conversions	$v = r\omega$ $a_T = r\alpha$
Torque	$\tau = r_\perp F = rF\sin\theta$
Rotational inertia	$I = \sum m_i r_i^2$
Parallel axis theorem	$I' = I_{\text{cm}} + Md^2$
Newton's 2nd law (rotation)	$\alpha_{\text{sys}} = \frac{\Sigma\tau}{I_{\text{sys}}} = \frac{\tau_{\text{net}}}{I_{\text{sys}}}$
Rotational kinetic energy	$K = \frac{1}{2}I\omega^2$
Work (rotation)	$W = \tau\Delta\theta$
Angular momentum	$L = I\omega$ $L = rmv\sin\theta$
Angular impulse	$\Delta L = \tau\Delta t$
Center of mass (rolling)	$\Delta x_{\text{cm}} = r\Delta\theta$
Period	$T = \frac{1}{f}$
Mass-spring period	$T_s = 2\pi\sqrt{\frac{m}{k}}$
Pendulum period	$T_p = 2\pi\sqrt{\frac{\ell}{g}}$
Simple harmonic motion	$x = A\cos(2\pi ft)$ $x = A\sin(2\pi ft)$
Density	$\rho = \frac{m}{V}$
Pressure	$P = \frac{F_\perp}{A}$ $P = P_0 + \rho gh$ $P_{\text{gauge}} = \rho gh$
Buoyant force	$F_b = \rho Vg$
Conservation of flow rate	$A_1 v_1 = A_2 v_2$
Bernoulli's equation	$P_1 + \rho g y_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho v_2^2$

Units

	Units
a = acceleration	m/s²
A = amplitude or area	m or m²
d = distance	m
f = frequency	Hz = 1/s
F = force	N
h = height	m
I = rotational inertia	kg·m²
k = spring constant	N/m
K = kinetic energy	J
ℓ = length	m
L = angular momentum	kg·m²/s
m = mass	kg
M = mass	kg
P = pressure	Pa = N/m²
r = radius or distance	m
t = time	s
T = period	s
v = velocity or speed	m/s
V = volume	m³
W = work	J = N·m
x = position	m
y = vertical position	m
α = angular acceleration	rad/s²
θ = angle or angular position	rad or deg
ρ = density	kg/m³
τ = torque	N·m
ω = angular speed	rad/s

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