Physics 211 Formula Sheet

E1

$$|\vec{F}_e| = k\frac{|q_1 q_2|}{r^2}$$

$\vec{F}_e$ electrostatic force vector
$k = 8.99 \times 10^9\ \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}$
q_1, q_2 charge of particles
r distance between particles

$$\vec{F}_e = q\vec{E}$$

$\vec{F}_e$ electrostatic force vector
q charge of test particle
$\vec{E}$ electric field vector

$$\vec{E} = k\frac{Q}{|\vec{r}_{PS}|^2}\hat{r}_{PS}$$

$\vec{E}$ Electric field vector at a point P due to a **single particle**
$k = 8.99 \times 10^9\ \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}$
Q charge of source particle
$\vec{r}_{PS}$ position of P relative to source particle
$\hat{r}_{PS}$ unit vector in the direction of $\vec{r}_{PS}$

E2

$$\vec{E} = k\frac{2\vec{p}_e}{|\vec{r}_{PD}|^3}$$

$\vec{E}$ Electric field vector at a distant point P along a **dipole**'s axis
$k = 8.99 \times 10^9\ \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}$
$\vec{p}_e$ dipole moment vector
$\vec{r}_{DP}$ position of P relative to dipole's center

$$|\vec{p}_e| = qs$$

$\vec{p}_e$ dipole moment vector
q charge of diploe's positive particle
s particle's separation

$$\vec{E} = 2k\frac{\lambda}{|\vec{r}_{PN}|}\hat{r}_{PN}$$

$\vec{E}$ Electric field vector at a point P by an infinite **linear charge dist.**
$k = 8.99 \times 10^9\ \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}$
λ linear charge density
$\vec{r}_{PN}$ position of P relative to the nearest point on the line
$\hat{r}_{PN}$ unit vector in the direction of $\vec{r}_{PN}$, perpendicularly away from the line

$$\vec{E} = (2\pi k)\sigma\hat{r}_{PN} = \frac{\sigma}{2\epsilon_0}\hat{r}_{PN}$$

$\vec{E}$ Electric field vector at a point P by an infinite **planar charge dist.**
$k = 8.99 \times 10^9\ \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}$
σ charge per unit area
$\hat{r}_{PN}$ unit vector points perpendicularly away from the plane, at P
$\epsilon_0 = 8.85 \times 10^{-12} \frac{\mathrm{C^2}}{\mathrm{N \cdot m^2}}$

E3

$$\phi(x,y,z) = \frac{V_e(x,y,z)}{q}$$

ϕ electric potential at a point with coordinates x, y, z

V_e total electrostatic potential energy

q charge of test particle

$$\phi = k\frac{Q}{|\vec{r}_{PS}|}$$

ϕ electric potential

$k = 8.99 \times 10^9 \ \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}$

Q charge of fixed particle

$\vec{r}_{ps}$ position of the observation point, P, relative to the fixed particle

$$\Delta\phi = -\int \vec{E} \cdot d\vec{r}$$

$\Delta\phi$ difference in potential between two points

$\vec{E}$ Electric field vector

$d\vec{r}$ step between the two points

$$\vec{E}(x,y,z) = \begin{bmatrix} E_x \\ E_y \\ E_z \end{bmatrix} = \begin{bmatrix} -\partial\phi/\partial x \\ -\partial\phi/\partial y \\ -\partial\phi/\partial z \end{bmatrix} = -\vec{\nabla}\phi$$

$\vec{E}$ Electric field vector at a point with coordinates x, y, z

ϕ electric potential at a point with coordinates x, y, z

E4

$$C \equiv \left|\frac{Q}{\Delta\phi}\right| = \epsilon_0\frac{A}{S}$$

C Capacitance

Q charge of either plate of a capacitor

$\Delta\phi$ difference in potential between the two plates

A Area of one plate

s separation of the plates

$\epsilon_0 = 8.85 \times 10^{-12}$

$$u_E = \frac{1}{2}\epsilon_0|\vec{E}|^2 = \frac{1}{8\pi k}|\vec{E}|^2$$

u_E energy density of an electric field

$\epsilon_0 = 8.85 \times 10^{-12} \ \frac{\mathrm{C^2}}{\mathrm{N \cdot m^2}}$

$k = 8.99 \times 10^9 \ \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}$

$\vec{E}$ Electric field vector

$$U = \frac{1}{2}C(\Delta\phi)^2$$

U energy stored in the electric field of a capacitor

C capacitance of the capacitor

$\Delta\phi$ difference in potential between the two plates

E5

$\vec{v}_d = -\frac{e}{m_e}\vec{E}\tau$	$\vec{v}_d$ drift velocity of an electron e elementary charge m_e mass of an electron $\vec{E}$ Electric field vector τ time between collisions
$\vec{J} = \rho\vec{v}_d = nq\vec{v}_d$	$\vec{J}$ current density in the neighborhood of a point in a conductor ρ charge per unit volume $\vec{v}_d$ drift velocity n number density (number of carriers per unit volume) q charge of each carrier
$\vec{J} = \sigma_c\vec{E}$	$\vec{J}$ current density in the neighborhood of a point in a conductor σ_c conductivity $\vec{E}$ Electric field at that point
$\sigma_c = \frac{nq^2\tau}{m}$	σ_c conductivity n number density q charge of each carrier τ time between collisions m mass of a carrier
$n = N_1\rho_m\frac{N_A}{M_A}$	n number density N_1 number of electrons per one atom ρ_m metal's mass density N_A Avagadro's number, 6.02×10^{23} M_A atomic weight
$\vec{J}_N = n\vec{v}$	$\vec{J}_N$ number current density $\vec{v}$ velocity n number density
$\frac{\Delta N}{\Delta t} = \vec{J}_N \cdot \vec{A}$	ΔN change in the number of particles Δt change in time $\vec{J}_N$ number current density $\vec{A}$ area Vector
$i \equiv \int_S \vec{J} \cdot d\vec{A}$	i current S surface $\vec{J}$ current density $\vec{A}$ tile vector

E6

$$|\Delta\phi_{\text{wire}}| = |\vec{E}|L$$

$\Delta\phi_{\text{wire}}$ potential difference between the ends of a wire
$\vec{E}$ Electric field inside the wire
L Length of wire

$$R = \frac{|\Delta\phi|}{I}$$

R Resistance
$|\Delta\phi|$ potential difference
I current

$$R = \frac{L}{\sigma_c A}$$

R Resistance of wire
$|L$ length of wire
A Cross sectional area
σ_c resistivity of wire

$$P = I|\Delta\phi| = \frac{|\Delta\phi|^2}{R} = I^2R$$

P Power dissipated, R Resistance
$|\Delta\phi|$ potential difference, I current

$$I(t) = I_0 e^{-t/RC}$$

$$|\Delta\phi(t)| = |\Delta\phi_0|e^{-t/RC}$$

$$Q(t) = Q_0 e^{-t/RC}$$

I current flowing through the circuit
$|\Delta\phi|$ potential difference between the plates
Q charge on the capacitor's positive plate
$I_0 = I(0)$, $Q_0 = Q(0)$, $|\Delta\phi_0| = |\Delta\phi(0)|$
e euler's constant ≈ 2.7183, t time
R Resistance
C Capacitance of capacitor

E7

$$R_{\text{set}} = R_1 + R_2 + \ldots$$

R_{set} equivalent resistance of a set of resistors in series
R_n resistance of the nth resistor

$$\frac{1}{R_{\text{set}}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$$

R_{set} equivalent resistance of a set of resistors in parallel
R_n resistance of the nth resistor

E8

$$\vec{F}_m = q(\vec{v} \times \vec{B})$$

$\vec{F}_m$ magnetic force on a charged particle
q charge of particle
$\vec{v}$ velocity of particle
$\vec{B}$ magnetic field

$$R = \frac{|\vec{p}_\perp|}{|q||\vec{B}|}$$

R radius of helical motion
$\vec{p}_\perp$ component of the particle's momentum perpendicular to $\vec{B}$
q charge of particle
$\vec{B}$ magnetic field

$$T = \frac{2\pi m}{|q||\vec{B}|}$$

T period of helical motion
m mass of particle
$\vec{B}$ magnetic field
q charge of particle

E9

$$\vec{F}_{m,seg} = L\vec{I} \times \vec{B}$$

$\vec{F}_{m,seg}$ force on a segment of wire
L length of segment of wire
$\vec{I}$ current vector
$\vec{B}$ magnetic field

$$\vec{\mu} = NI\vec{A}$$

$\vec{\mu}$ magnetic moment vector
N number of turns
I current
$\vec{A}$ tile vector of loop

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

$\vec{\tau}$ torque on a loop
$\vec{\mu}$ magnetic moment vector
$\vec{B}$ magnetic field

$$V_m = -\vec{\mu} \cdot \vec{B}$$

V_m magnetic potential energy
$\vec{\mu}$ magnetic moment vector
$\vec{B}$ magnetic field

$$P = 4|\vec{\mu}||\vec{B}|f$$

P power output of an electric motor
$\vec{\mu}$ magnetic moment vector
$\vec{B}$ magnetic field
f frequency of motor (turns per second)

$$|\Delta\phi| = |\vec{v}||\vec{B}|L$$

$\Delta\phi$ potential difference between a bar's ends
$\vec{v}$ velocity of bar
$\vec{B}$ magnetic field
L length of bar

$$\frac{W}{q} = |\vec{v}||\Delta\vec{B}|L$$

W Work by a spacially changing magnetic field on a charge carrier in a loop
q charge of a carrier
$\vec{v}$ velocity of bar
$\Delta\vec{B}$ change in magnetic field
L length of leg of loop

E10

$$\vec{B} = \frac{\mu_0}{4\pi}\frac{q}{|\vec{r}_{PS}|^2}(\vec{v} \times \hat{r}_{PS})$$

$\vec{B}$ magnetic field vector created at point P by a moving charged particle
μ_0 magnetic permeability, $\mu_0/4\pi = 10^{-7}$ Tsm/C
q charge of particle
$\vec{v}$ velocity of the particle
$\vec{r}_{PS}$ position vector of P relative to the charged particle
$\hat{r}_{PS}$ unit vector of the in the direction of $\vec{r}_{PS}$

$$\vec{B} = \frac{\mu_0}{4\pi}\sum_{\text{all i}}\frac{dL}{|\vec{r}_{Pi}|^2}(\vec{I}_i \times \hat{r}_{Pi})$$

$\vec{B}$ magnetic field vector created at point P by a uniform, arbitrarily shaped wire
μ_0 magnetic permeability, $\mu_0/4\pi = 10^{-7}$ Tsm/C
dL length of the ith segment of wire
$\vec{I}_i$ Current flowing through the ith segment of wire
$\vec{r}_{Pi}$ position vector of P relative to the charged particle
$\hat{r}_{Pi}$ unit vector of the in the direction of $\vec{r}_{Pi}$

$$|\vec{B}| = \frac{\mu_0 I r}{4\pi}\frac{2}{r^2} = \frac{\mu_0 I}{2\pi r}$$

$\vec{B}$ Magnetic field produced by an infinite, straight wire (with cst. current)
μ_0 magnetic permeability, $\mu_0/4\pi = 10^{-7}$ Tsm/C
I constant current
r distance to the nearest point of the wire

$$|\vec{B}| = \frac{\mu_0 I}{2R}$$

$\vec{B}$ Magnetic field produced at the center of a circular loop (with cst. current)
μ_0 magnetic permeability, $\mu_0/4\pi = 10^{-7}$ Tsm/C
I constant current
R Radius of loop

E11

$$\vec{F}_{em} = q(\vec{E} + \vec{v} \times \vec{B})$$

$\vec{F}_{em}$ Electromagnetic force
q charge of moving particle
$\vec{E}$ Electromagnetic field
$\vec{v}$ velocity of moving particle
$\vec{B}$ magnetic field

$$\begin{bmatrix} E'_x \\ E'_y \\ E'_z \end{bmatrix} = \begin{bmatrix} E_x \\ \gamma(E_y - \beta \not{B}_z) \\ \gamma(E_z + \beta \not{B}_y) \end{bmatrix}$$

$$\begin{bmatrix} \not{B}'_x \\ \not{B}'_y \\ \not{B}'_z \end{bmatrix} = \begin{bmatrix} \not{B}_x \\ \gamma(\not{B}_y + \beta E_z) \\ \gamma(\not{B}_z - \beta E_y) \end{bmatrix}$$

$\vec{E}$ Electric field in the home frame
$\vec{B}$ Magnetic field in the home frame
$\vec{E}'$ Electric field in the prime frame
$\vec{B}'$ Magnetic field in the prime frame
βc velocity of prime frame relative to home frame
$\gamma \equiv (1-\beta^2)^{-1/2}$

$\vec{\not{B}} = c\vec{B}$

E12

$$\vec{\nabla}\cdot\vec{E} \equiv \frac{\partial E_x}{\partial x} + \frac{\partial E_y}{\partial y} + \frac{\partial E_z}{\partial z}$$

$\vec{\nabla}\cdot\vec{E}$ divergence of the electric field
$\vec{\nabla} = \begin{bmatrix} \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \end{bmatrix}$
$\vec{E}$ Electric field

$$\vec{\nabla}\cdot\vec{E} = \frac{\rho}{\epsilon_0}$$

$\vec{\nabla}\cdot\vec{E}$ divergence of the electric field
$\vec{\nabla} = \begin{bmatrix} \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \end{bmatrix}$
$\vec{E}$ Electric field
ρ charge density
$\epsilon_0 = 8.85 \times 10^{-12} \frac{\mathrm{C}^2}{\mathrm{N\cdot m^2}}$

E13

$$\vec{\nabla}\cdot\vec{E} = \begin{cases} \frac{\partial E_z}{\partial z} & \text{for a unidirectional field} \\ \frac{1}{s}\frac{d}{ds}(sE_s) & \text{for an axial field} \\ \frac{1}{r^2}\frac{d}{dr}(r^2E_r) & \text{for an radial field} \end{cases}$$

$\vec{\nabla}\cdot\vec{E}$ divergence of the electric field
E_s Electric field component away from the central axis
s distance from central axis
E_r Electric field component away from the center point
r distance from center point

$$\vec{\nabla}\times\vec{B} \equiv \begin{bmatrix} \frac{\partial}{\partial y}B_z - \frac{\partial}{\partial z}B_y \\ \frac{\partial}{\partial z}B_x - \frac{\partial}{\partial x}B_z \\ \frac{\partial}{\partial x}B_y - \frac{\partial}{\partial y}B_x \end{bmatrix}$$

$\vec{\nabla}\times\vec{B}$ curl of the magnetic field
$\vec{B}$ magnetic field
$\vec{\nabla} = \begin{bmatrix} \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \end{bmatrix}$

$$\vec{\nabla}\times\vec{B} = \mu_0\vec{J}$$

$\vec{\nabla}\times\vec{B}$ curl of the magnetic field
$\vec{\nabla} = \begin{bmatrix} \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \end{bmatrix}$
$\vec{B}$ Magnetic field
$\vec{J}$ current density
μ_0 magnetic permeability, $\mu_0/4\pi = 10^{-7}$ Tsm/C

$$\vec{\nabla}\times\vec{B} = \begin{bmatrix} (\vec{\nabla}\times\vec{B})_x \\ (\vec{\nabla}\times\vec{B})_y \\ (\vec{\nabla}\times\vec{B})_z \end{bmatrix} = \underset{\text{if } \vec{B} = B_x\hat{x}}{\begin{bmatrix} 0 \\ \frac{\partial B_x}{\partial z} \\ \frac{-\partial B_x}{\partial y} \end{bmatrix}} \text{ or } \underset{\text{if } \vec{B} = B_y\hat{y}}{\begin{bmatrix} \frac{-\partial B_y}{\partial z} \\ 0 \\ \frac{\partial B_y}{\partial x} \end{bmatrix}} \text{ or } \underset{\text{if } \vec{B} = B_z\hat{z}}{\begin{bmatrix} \frac{\partial B_z}{\partial y} \\ \frac{-\partial B_z}{\partial x} \\ 0 \end{bmatrix}} \quad \text{for a unidirectional field}$$

$$\vec{\nabla}\times\vec{B} = \begin{bmatrix} (\vec{\nabla}\times\vec{B})_u \\ (\vec{\nabla}\times\vec{B})_\phi \\ (\vec{\nabla}\times\vec{B})_z \end{bmatrix} = \begin{bmatrix} \frac{-\partial B_\phi}{\partial z} \\ 0 \\ \frac{1}{u}\frac{\partial}{\partial u}(uB_\phi) \end{bmatrix} \text{for a circular field}$$

E14

$$\oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{enc}}}{\epsilon_0}$$

$\vec{E}$ Electric field
$d\vec{A}$ tile vector
q_{enc} net charge enclosed
$\epsilon_0 = 8.85 \times 10^{-12} \frac{\text{C}^2}{\text{N}\cdot\text{m}^2}$

$$\oint \vec{B} \cdot d\vec{S} = \mu_0 i_{\text{enc}}$$

$\vec{B}$ Magnetic field
$d\vec{S}$ tile vector
i_{enc} signed current that flows through gaussian surface
μ_0 magnetic permeability, $\mu_0/4\pi = 10^{-7}$ Tsm/C

E15

Maxwell's Equations

$\vec{\nabla} \cdot \vec{E} = \frac{\rho}{\epsilon_0}$	$\vec{\nabla} \cdot \vec{E} = \frac{\rho}{\epsilon_0}$
$\vec{\nabla} \times \vec{B} - \epsilon_0 \mu_0 \frac{\partial \vec{E}}{\partial t} = \mu_0 \vec{J}$	$\vec{\nabla} \times \not{\vec{B}} - \frac{1}{c} \frac{\partial \vec{E}}{\partial t} = \frac{1}{\epsilon_0} \left(\frac{\vec{J}}{c} \right)$
$\vec{\nabla} \cdot \vec{B} = 0$	$\vec{\nabla} \cdot \not{\vec{B}} = 0$
$\vec{\nabla} \times \vec{E} + \frac{\partial \vec{B}}{\partial t} = 0$	$\vec{\nabla} \times \vec{E} + \frac{1}{c} \frac{\partial \not{\vec{B}}}{\partial t} = 0$

$\vec{\nabla} \cdot \vec{E}$ divergence of the electric field
$\vec{\nabla} \times \vec{B}$ curl of the magnetic field
$\vec{\nabla} = \begin{bmatrix} \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \end{bmatrix}$
$\vec{B}$ Magnetic field
ρ charge density
$c = 3.00 \times 10^8 \ \frac{\text{m}}{\text{s}}$
$\epsilon_0 = 8.85 \times 10^{-12} \frac{\text{C}^2}{\text{N}\cdot\text{m}^2}$

$\vec{\nabla} \cdot \vec{B}$ divergence of the magnetic field
$\vec{\nabla} \times \vec{E}$ curl of the electric field
$\vec{E}$ Electric field
$\not{\vec{B}} = c\vec{B}$
$\vec{J}$ current density
μ_0 magnetic permeability, $\mu_0/4\pi = 10^{-7}$ Tsm/C

E16

$$E_\phi = \begin{cases} \frac{-1}{2} \frac{\partial B_z}{\partial t} u & \text{for } u < R \\ \frac{-1}{2} \frac{\partial B_z}{\partial t} \frac{R^2}{u} & \text{for } u > R \end{cases}$$

u distance from the solenoids axis
B_z Magnetic field along axis direction
R radius of solenoid
E_ϕ Electric field in the counterclockwise ϕ direction

$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

$\mathcal{E} = \oint \vec{E} \cdot d\vec{r}$ emf induced in a closed loop
$\Phi_B = \int \vec{B} \cdot d\vec{A}$ magnetic flux

E17

$$|\mathcal{E}| = L\left|\frac{dI}{dt}\right|$$

$\mathcal{E} = \oint \vec{E} \cdot d\vec{r}$ self-induced emf in a coil or loop
L inductance
I current flowing through the loop

$$L = \mu_0 \pi r^2 \frac{N^2}{\ell}$$

L inductance of a long solenoid
μ_0 magnetic permeability, $\mu_0/4\pi = 10^{-7}$ Tsm/C
r radius of solenoid
N number of turns
ℓ length of solenoid

$$I(t) = I_0 e^{-(R/L)t}$$

I current in an inductor whose $\mathcal{E}$ pushes this current through a resister
$I_0 = I(0)$
R resistance of the resistance
L inductance of the inductor

$$U^{\text{th}} = \frac{1}{2} L I_0^2$$

U^{th} Energy dissipated by a resistor in an LR circuit
L inductance
I_0 initial current

$$U_0^B = \frac{\pi r^2 \ell}{2\mu_0} |\vec{B}_0|^2$$

U_0^B magnetic field's energy inside a long solenoid at $t = 0$
r radius of solenoid, ℓ length of solenoid
$\vec{B}_0$ initial magnetic field

$$u_{EM} = \frac{1}{2}\left(\epsilon_0 |\vec{E}|^2 + \frac{|\vec{B}|^2}{\mu_0}\right)$$
$$= \frac{\epsilon_0}{2}\left(|\vec{E}|^2 + |\vec{\cancel{B}}|^2\right)$$

u_{EM} energy density of an electromagnetic field
$\epsilon_0 = 8.85 \times 10^{-12} \frac{\text{C}^2}{\text{N}\cdot\text{m}^2}$
$\vec{E}$ Electric field
$\vec{B}$ Magnetic Field
$\vec{\cancel{B}} = c\vec{B}$

$$i = \frac{-dQ}{dt}$$

i current in an LC circuit
Q positive charge on one of the capacitor's plates

$$Q(t) = Q_0 \cos(\omega t)$$

Q positive charge on one of the capacitor's plates
$\omega = 1/\sqrt{LC}$
L inductance, C capacitance

$$\mathcal{E}_{\text{src}}(t) = \mathcal{E}_0 \sin(\omega t)$$

$\mathcal{E}_{\text{src}}$ emf that the source imposes on the primary coil

$$\mathcal{E}_2 = \left(\frac{N_2}{N_1}\right)\mathcal{E}_1$$

$\mathcal{E}_1$, $\mathcal{E}_2$ emf in coil 1,2
N_1, N_2 number of turns in coil 1,2

$$i_1(t) = \frac{\mathcal{E}_0}{L\omega} \sin(\omega t - \tfrac{1}{2}\pi)$$

i_1 current flowing in the primary coil

E18

avg EM wave intensity $= c\epsilon_0\left[|\vec{E}|^2\right]_{\text{avg}}$

$= \frac{1}{A}\frac{\Delta U_{\text{EM}}}{\Delta t} = c\left[u_{\text{EM}}\right]_{\text{avg}}$

c speed of light
$[|\vec{E}|^2]_{\text{avg}}$ average of the electric field's squared magnitude
$\Delta U_{\text{EM}}/\Delta t$ Average power per unit time
A area that the EM wave deposits energy onto
u_{EM} energy density of EM wave

$$u_{\text{EM}} = \epsilon_0|\vec{E}|^2$$

u_{EM} energy density of EM wave
$\vec{E}$ Electric field

$$|\vec{E}_w| = c|\vec{B}_w| = \frac{1}{4\pi\epsilon_0}\frac{|q||\vec{a}|\sin\theta}{c^2R}$$

$\vec{E}_w$, $\vec{B}_w$ Electric, Magnetic field of the EM wave at at a point P, caused by an accelerating particle
q charge of particle
$\vec{a}$ acceleration of particle
R distance from the accelerating particle to P
θ angle between $\vec{a}$ and $\vec{P}$

$$U_{\text{EM}} = \frac{|q|^2|\vec{a}|^2[\sin^2\theta]_{\text{avg}}\tau}{4\pi\epsilon_0 c^3}$$

U_{EM} Energy contained in an EM wave
q charge of particle
$\vec{a}$ acceleration of particle
τ brief time
R distance from the accelerating particle to P
θ angle between $\vec{a}$ and $\vec{P}$
c speed of light

$$P = \frac{q^2|\vec{a}|^2}{6\pi\epsilon_0 c^3}$$

P power that a particle radiates in the form of an EM wave
q charge of particle
$\vec{a}$ acceleration of particle
c speed of light

Some Physical Constants

Speed of light	c	3.00×10^{8} m/s
Gravitational constant	G	6.67×10^{-11} N·m²/kg²
Coulomb's constant	$1/4\pi\varepsilon_0$	8.99×10^{9} N·m²/C²
Permittivity constant	ε_0	8.85×10^{-12} C²/(N·m²)
Permeability constant	μ_0	$4\pi \times 10^{-7}$ N/A²
Planck's constant	h	6.63×10^{-34} J·s
Boltzmann's constant	k_B	1.38×10^{-23} J/K
Elementary charge	e	1.602×10^{-19} C
Electron mass	m_e	9.11×10^{-31} kg
Proton mass	m_p	1.673×10^{-27} kg
Neutron mass	m_n	1.675×10^{-27} kg
Avogadro's number	N_A	6.02×10^{23}

Standard Metric Prefixes (for powers of 10)

Power	Prefix	Symbol
10^{18}	exa	E
10^{15}	peta	P
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
10^{-15}	femto	f
10^{-18}	atto	a

Commonly Used Physical Data

Gravitational field strength $g = \lvert\vec{g}\rvert$ (near the earth's surface)	9.80 N/kg = 9.80 m/s²
Mass of the earth M_e	5.98×10^{24} kg
Radius of the earth R_e	6380 km (equatorial)
Mass of the sun $M_\odot$	1.99×10^{30} kg
Radius of the sun $R_\odot$	696,000 km
Mass of the moon	7.36×10^{22} kg
Radius of the moon	1740 km
Distance to the moon	3.84×10^{8} m
Distance to the sun	1.50×10^{11} m
Density of water†	1000 kg/m³ = 1 g/cm³
Density of air†	1.2 kg/m³
Absolute zero	0 K = −273.15°C = −459.67°F
Freezing point of water‡	273.15 K = 0°C = 32°F
Boiling point of water‡	373.15 K = 100°C = 212°F
Normal atmospheric pressure	101.3 kPa

†At normal atmospheric pressure and 20°C.
‡At normal atmospheric pressure.

Useful Conversion Factors

1 meter = 1 m = 100 cm = 39.4 in = 3.28 ft
1 mile = 1 mi = 1609 m = 1.609 km = 5280 ft
1 inch = 1 in = 2.54 cm
1 light-year = 1 ly = 9.46 Pm = 0.946×10^{16} m
1 minute = 1 min = 60 s
1 hour = 1 h = 60 min = 3600 s
1 day = 1 d = 24 h = 86.4 ks = 86,400 s
1 year = 1 y = 365.25 d = 31.6 Ms = 3.16×10^{7} s
1 newton = 1 N = 1 kg·m/s² = 0.225 lb
1 joule = 1 J = 1 N·m = 1 kg·m²/s² = 0.239 cal
1 watt = 1 W = 1 J/s
1 pascal = 1 Pa = 1 N/m² = 1.45×10^{-4} psi
1 kelvin (temperature difference) = 1 K = 1°C = 1.8°F
1 radian = 1 rad = 57.3° = 0.1592 rev
1 revolution = 1 rev = 2π rad = 360°
1 cycle = 2π rad
1 hertz = 1 Hz = 1 cycle/s

1 m/s = 2.24 mi/h = 3.28 ft/s
1 mi/h = 1.61 km/h = 0.447 m/s = 1.47 ft/s
1 liter = 1 l = (10 cm)³ = 10^{-3} m³ = 0.0353 ft³
1 ft³ = 1728 in³ = 0.0283 m³
1 gallon = 1 gal = 0.00379 m³ = 3.79 l ≈ 3.8 kg H_2O
Weight of 1-kg object near the earth = 9.8 N = 2.2 lb

1 pound = 1 lb = 4.45 N
1 calorie = energy needed to raise the temperature of 1 g of H_2O by 1 K = 4.186 J
1 horsepower = 1 hp = 746 W
1 pound per square inch = 6895 Pa
1 food calorie = 1 Cal = 1 kcal = 1000 cal = 4186 J
1 electron volt = 1 eV = 1.602×10^{-19} J

$$T = \left(\frac{1\text{K}}{1^\circ\text{C}}\right)(T_{[\text{C}]} + 273.15^\circ\text{C}) \qquad T_{[\text{C}]} = \left(\frac{5^\circ\text{C}}{9^\circ\text{F}}\right)(T_{[\text{F}]} - 32^\circ\text{F})$$

$$T = \left(\frac{5\text{K}}{9^\circ\text{F}}\right)(T_{[\text{F}]} + 459.67^\circ\text{F}) \qquad T_{[\text{F}]} = 32^\circ\text{F} + \left(\frac{9^\circ\text{F}}{5^\circ\text{C}}\right)T_{[\text{C}]}$$

Electromagnetic Units and Conversion Factors

1 coulomb = 1 C = unit of charge = total charge of 6.242×10^{18} protons
1 N/C = unit of electric field strength = 1 V/m
1 volt = 1 V = unit of energy per unit charge = 1 V = 1 J/C = 1 N·m/C = 1 kg·m^2/(C·s^2)
1 ampere = 1 A = unit of current = 1 C/s
1 ohm = 1 Ω = unit of resistance = 1 V/A = 1 J·s/C^2 = 1 kg·m^2/(C^{2}s)
1 farad = 1 F = unit of capacitance = 1 C/V = 1 s/Ω = 1 C^2/J = C^{2}s^2/(kg·m^2)
1 watt = 1 W = unit of power (rate of energy conversion) = 1 J/s = 1 V·A = 1 V^2/Ω
1 tesla = 1 T = unit of magnetic field strength = 1 N·s/(C·m) = 1 kg/(C·s)
1 gauss = 1 G = unit of magnetic field strength = 10^{-4} T
1 henry = 1 H = unit of inductance = V·s/A = 1 Ω·s = kg·m^2/C^2
units of conductivity = (Ω·m)$^{-1}$
units of current density = A/m^2
$\vec{\mathbb{B}} = c\vec{B}$ = represents the magnetic field expressed N/C (same units as electric field)
$(\mu_0 \varepsilon_0)^{-1} = c^2 \quad \Rightarrow \quad 1/(4\pi\varepsilon_0) = \mu_0 c^2/4\pi$
$(c\varepsilon_0)^{-1} = 377\ \Omega$

Some Useful Indefinite Integrals

$$\int x^n dx = \frac{1}{n+1}x^{n+1} \quad (n \neq -1) \qquad \int \frac{dx}{(x^2+a^2)^{1/2}} = \ln[x + (x^2+a^2)^{1/2}] \qquad \int \frac{x\,dx}{(x^2+a^2)^{1/2}} = (x^2+a^2)^{1/2}$$

$$\int \frac{dx}{x} = \ln|x| \qquad \int \frac{dx}{x^2+a^2} = \frac{1}{a}\tan^{-1}\left(\frac{x}{a}\right) \qquad \int \frac{x\,dx}{(x^2+a^2)^{3/2}} = \frac{-1}{(x^2+a^2)^{1/2}}$$

$$\int e^{ax}dx = \frac{1}{a}e^{ax} \qquad \int \frac{dx}{(x^2+a^2)^{3/2}} = \frac{1}{a^2}\frac{x}{(x^2+a^2)^{1/2}} \qquad \int \frac{x^2dx}{(x^2+a^2)^{3/2}} = \frac{-x}{(x^2+a^2)^{1/2}} + \ln[x + (x^2+a^2)^{1/2}]$$

Standard Electric and Magnetic Field Patterns

Field pattern ($\vec{F} = \vec{E}$ or $\vec{B}$)	**Created by**	**Divergence**	**Curl**	**Gaussian Surface (GS)** **Amperian Loop (AL)**
General	(anything)	$\vec{\nabla}\cdot\vec{F} = \frac{\partial F_x}{\partial x} + \frac{\partial F_y}{\partial y} + \frac{\partial F_z}{\partial z}$	$\vec{\nabla}\times\vec{F} = \begin{bmatrix} \frac{\partial F_z}{\partial y} - \frac{\partial F_y}{\partial z} \\ \frac{\partial F_x}{\partial z} - \frac{\partial F_z}{\partial x} \\ \frac{\partial F_y}{\partial x} - \frac{\partial F_x}{\partial y} \end{bmatrix}$	(not applicable)
Unidirectional ($\vec{F} = F_z\hat{z}$)	infinite flat plate (both $\vec{E}$ and $\vec{B}$) infinite solenoid ($\vec{B}$)	$\vec{\nabla}\cdot\vec{F} = \frac{\partial F_z}{\partial z}$	$\vec{\nabla}\times\vec{F} = \begin{bmatrix} \frac{\partial F_z}{\partial y} \\ -\frac{\partial F_z}{\partial x} \\ 0 \end{bmatrix}$	GS: rectangular solid AL: rectangle
Axial ($\vec{F} = F_s\hat{s}$)	infinite cylindrically symmetric object ($\vec{E}$)	$\vec{\nabla}\cdot\vec{F} = \frac{1}{s}\frac{\partial}{\partial s}(sF_s)$	$\vec{\nabla}\times\vec{F} = 0$ (identically)	GS: cylindrical can AL: (not applicable)
Radial ($\vec{F} = F_r\hat{r}$)	spherically symmetric object ($\vec{E}$)	$\vec{\nabla}\cdot\vec{F} = \frac{1}{r^2}\frac{\partial}{\partial r}(r^2F_r)$	$\vec{\nabla}\times\vec{F} = 0$ (identically)	GS: sphere AL: (not applicable)
Circular ($\vec{F} = F_\phi\hat{\phi}$)	infinite cylindrically symmetric situation where current flows parallel to its axis ($\vec{B}$) or where $\partial\vec{B}/\partial t$ is parallel to the axis ($\vec{E}$)	$\vec{\nabla}\cdot\vec{F} = 0$ (identically)	$\vec{\nabla}\times\vec{F} = \begin{bmatrix} [\vec{\nabla}\times\vec{F}]_u \\ [\vec{\nabla}\times\vec{F}]_\phi \\ [\vec{\nabla}\times\vec{F}]_z \end{bmatrix} = \begin{bmatrix} -\frac{\partial F_\phi}{\partial z} \\ 0 \\ \frac{1}{u}\frac{\partial}{\partial u}(uF_\phi) \end{bmatrix}$	GS: (not applicable) AL: circle

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