1. Charges, Forces, & Fields

$$\vec{F}_{12} = \frac{kq_1q_2}{(r_{12})^2}\hat{r}_{12}$$
$$\vec{F} = q\vec{E}$$
$$\vec{E} = k\int\frac{dQ}{r^2}\hat{r}$$
$$\vec{a} = \frac{q\vec{E}}{m}$$
$$E = Vq$$
$$|\vec{p}_{_D}| = qd$$

Charge densities

$$Q = \rho V$$
$$Q = \sigma A$$
$$Q = \lambda \ell$$

$\vec{F}_{ij}$: Force from i on j, N
q_i : Charge of particle i, C
Q : Charge of source particle, C
r_{ij} : Distance from i to j, m
$\hat{r}_{ij}$: Unit vector in direction from i to j
$\vec{E}$: Electric field, NC^{-1}
E : Energy, J
$\vec{a}$: Acceleration, ms^{-2}
k : Coulomb's constant
$\vec{p}_{_D}$: Dipole moment
d : Distance separating charges on dipole

2. Electric flux and Potential

- The net **flux** through any closed surface surrounding a point charge q is given by q_{in}/ϵ_o and is independent of the shape of the surface.
- A conductor in **electrostatic equilibrium** has the following properties :
  · Electric field is zero everywhere inside the conductor
  · Any net charge on a conductor must reside on its surface
  · Surface charge density is greatest where curvature is smallest

$$\Phi_E = \frac{q_{encl}}{\varepsilon_o}$$
$$\Phi_E = \oint_{G.S.} \vec{E}\cdot d\vec{A}$$
$$\Delta V_{AB} = kq\left(\frac{1}{r_A} - \frac{1}{r_B}\right) = -\int_A^B \vec{E}\cdot d\vec{r}$$
$$\Delta E_p = q\Delta V$$
$$V = k\int\frac{dq}{r}$$
$$\vec{E} = \frac{kq}{r^2}$$
$$\vec{E}_{\{x,y,z\}} = -\frac{\partial V}{\partial\{x,y,z\}}$$

Φ_E : Electric flux, Nm^2C^{-1}
ΔV_{AB} : Change in voltage from A to B
ε_o : Permittivity constant of free space
E_p : Potential energy, J

Electric fields

rod of infinite length : $2k\lambda/r$
sheet of infinite surface : $\sigma/2\epsilon_o$

3. Capacitance

working voltage : Maximum safe capacitor potential difference before dielectric breakdown
dielectric : A nonconducting material whose presence between capacitor plates increases capacitance

$$V = Ed = \frac{Qd}{\varepsilon_o A}$$
$$E_p = \frac{1}{2}CV^2 \qquad \text{(for PPC)}$$
$$Q = CV \qquad \text{(for PPC)}$$
$$C = \kappa\frac{\varepsilon_o A}{d} \qquad \text{(for PPC)}$$
$$E_{p_E} = \frac{1}{2}\varepsilon_o E^2$$
$$E_p = \frac{\varepsilon_o}{2}\int E^2 dV$$
$$V_C = \mathcal{E}(I - e^{-t/RC}) \qquad \text{(when charging)}$$
$$V_C = V_o e^{-t/RC} \qquad \text{(when discharging)}$$

Dipole shit

$$\vec{p} = \vec{\ell}q$$
$$\tau = p \times \vec{E}$$
$$E_p = -\vec{p}\cdot\vec{E}$$

V : Voltage, V
d : Distance between plates of PPC, m
A : Surface area of one plate of PPC, m^2
E_p : Potential energy, J
C : Capacitance, $F = CV^{-1}$
κ : Dielectric constant
E_{p_E} : Electric energy density, Jm^{-3}
$\vec{p}$: Electric dipole moment for two charges of equal and opposite magnitude separated by distance ℓ in direction from $+$ to $-$
τ : Torque

4. Electric current

Kirchoff's rules :
· The sum of the currents entering any junction in a circuit must equal the sum of the currents leaving that junction.
· The sum of the potential differences across all elements around any closed circuit loop must be zero.

$$I = \frac{dQ}{dt}$$
$$= nqvA$$
$$V = IR$$
$$R = \frac{\rho\ell}{A}$$
$$J = \frac{I}{A} = \sigma\vec{E}$$
$$\rho = \frac{1}{\sigma}$$
$$P = IV$$
$$\tau = RC$$

I : Current, A
n : Number of charge carriers with charge q and velocity v passing through area A
R : Resistance, Ω
ρ : Resistivity
σ : Conductivity
ℓ : Length of resistor, m
A : Surface area, m^2
J : Current density
τ : Time constant
P : Power, W

5. Magnetism

ferromagnet : Metal whose atoms' magnetic moments are all aligned in same direction
paramagnet : Substance with atoms having permanent magnetic dipole moments
diamagnet : Substance whose atoms' dipole moments are in reverse direction of field

$$\vec{F}_B = q\vec{v} \times \vec{B}$$
$$\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$$
$$r = \frac{mv^2}{q\vec{v} \times \vec{B}}$$
$$f_c = \frac{qB}{2\pi m}$$
$$\vec{F} = I\vec{\ell} \times \vec{B}$$
$$V_H = \frac{IB}{nqt} = H_c \frac{IB}{t}$$
$$\vec{B} = \frac{\mu_o I}{4\pi} \int \frac{d\vec{\ell} \times \vec{r}}{r^2}$$
$$\vec{\mu} = NI\vec{A}$$
$$\tau_{max} = NI\vec{A} \cdot \vec{B}$$
$$\vec{\tau} = \vec{\mu} \times \vec{B}$$
$$E_p = -\vec{\mu} \cdot \vec{E}$$
$$v_s = E/B$$
$$F_w = \frac{\mu_0 I_1 I_2 \ell}{2\pi d}$$
$$\oint \vec{B} \cdot d\vec{r} = \mu_o I$$
$$\vec{B}_s = \frac{\mu_o NI}{L}$$
$$\vec{B}_t = \frac{\mu_o NI}{2\pi r}$$

$\vec{B}$: Magnetic field, T
r : Radius of path in magnetic field
f_c : Cyclotron frequency
$\vec{\ell}$: Conductor length current direction vector
V_H : Hall potential
n : Number of charges per unit volume
H_c : Hall coefficient
μ_o : Permeability of free space
τ : Torque in a current-carrying loop
$\vec{\mu}$: Magnetic dipole moment
v_s : Velocity selector velocity
F_w : Force on wire carrying I_1 parallel to wire carrying I_2 distance d apart
$\vec{B}_s$: Solenoid magnetic field
$\vec{B}_t$: Toroid magnetic field
N : Number of turns in coil

Maxwell's equations

$$\oint_S \vec{E} \cdot d\vec{A} = \frac{q}{\varepsilon_o}$$
$$\oint_S \vec{B} \cdot d\vec{A} = 0$$
$$\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt}$$
$$\oint \vec{B} \cdot d\vec{s} = \mu_o I + \varepsilon_o \mu_o \frac{d\Phi_E}{dt}$$

6. Induction

Lenz's law : The direction of an induced emf or current is such that the magnetic field created by the induced current opposes the change in magnetic flux that created the current.

$$L = \frac{N\Phi_B}{I}$$
$$L = \frac{V}{dI/dt}$$
$$\Phi_B = \int \vec{B} \cdot d\vec{A}$$
$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$
$$I = \varepsilon_o \frac{d\Phi_E}{dt}$$
$$E_p = \frac{1}{2} L I^2$$

L : Inductance, VsA^{-1}
Φ_B : Magnetic flux density, $T = kgs^{-2}A^{-1}$
$\mathcal{E}$: Induced emf, V