NJIT Physics 121 Formula Sheet

Fundamentals

Electron: $e = -1.6 \times 10^{-19}$ C, $m_e = 9.11 \times 10^{-31}$ kg
Proton: $m_p = 1.67 \times 10^{-27}$ kg
Number of excess electrons $N = |Q|/e$
Electromagnetic constants: $\epsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C^2/(N{\cdot}m^2)}$
$1/(4\pi\epsilon_0) = k = 9 \times 10^9\ \mathrm{(N{\cdot}m^2)/C^2}$
$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{T{\cdot}m/A}$
Acceleration due to gravity: $g = 9.8\ \mathrm{m/s^2}$

Preliminaries: Vectors, General Mathematics

Vector magnitude: $|\vec{A}| = \sqrt{A_x^2 + A_y^2}$ or $\sqrt{A_x^2 + A_y^2 + A_z^2}$
Vector direction: $\tan\theta = \frac{A_y}{A_x}$
Dot product: $\vec{A} \cdot \vec{B} = A_x B_x + A_y B_y + A_z B_z = |\vec{A}||\vec{B}|\cos\theta$
Cross product: $\hat{\imath} \times \hat{\jmath} = \hat{k} \quad \hat{\jmath} \times \hat{k} = \hat{\imath} \quad \hat{k} \times \hat{\imath} = \hat{\jmath}$
$\hat{\imath} \times \hat{\imath} = \hat{\jmath} \times \hat{\jmath} = \hat{k} \times \hat{k} = 0$
$\vec{A} \times \vec{B} = (A_y B_z - A_z B_y)\,\hat{\imath} + (A_z B_x - A_x B_z)\,\hat{\jmath}$
$+ (A_x B_y - A_y B_x)\,\hat{k}$
$|\vec{A} \times \vec{B}| = |\vec{A}||\vec{B}|\sin\theta$
Quadratic formula: $ax^2 + bx + c = 0,\ x = \left(-b \pm \sqrt{b^2 - 4ac}\right)/(2a)$
Integrals: $\int dx/x = \ln x$; $\int dx/\sqrt{a^2 + x^2} = \ln(x + \sqrt{a^2 + x^2})$
$\int dx\,\left(a^2 + x^2\right)^{-\frac{3}{2}} = x/\left(a^2\sqrt{a^2 + x^2}\right)$
$\int x\left(a^2 + x^2\right)^{-\frac{3}{2}}\ dx = -1/\sqrt{a^2 + x^2}$
Circumference: $C = 2\pi R$
Sphere area, volume: $A = 4\pi R^2$, $V = \frac{4}{3}\pi R^3$
Cylinder and cone volume: $V = \pi R^2 h$ (cylinder), $V = \frac{1}{3}\pi R^2 h$ (cone)

Physics 111

Kinematics: $v_f = v_0 + at$
$\Delta x = v_0 t + \frac{1}{2}at^2$
$v_f^2 = v_0^2 + 2a\Delta x$
$v_f + v_0 = 2\Delta x/t$
Newton's Laws: $\vec{F}_{\text{net}} = 0 \longleftrightarrow \vec{v} = \text{constant}$
$\vec{F}_{\text{net}} = m\vec{a}$
$\vec{F}_{12} = -\vec{F}_{21}$
Uniform circular motion $\omega = v/R$, $a_c = v^2/R = \omega^2 R$
Work and power: $W = \int_a^b \vec{F} \cdot d\vec{r}$, $P = W/t = \vec{F} \cdot \vec{v}$
Kinetic energy: $K = \frac{1}{2}mv^2$
Work-Energy Theorem $\Delta K = W_{\text{net}}$
Potential energy (conservative forces): $W_{ab} = U_a - U_b = -\Delta U$

Chapter 21: Electric Charge and the Electric Field

Coulomb's Law: $\vec{F} = \dfrac{1}{4\pi\epsilon_0}\dfrac{q_1 q_2}{r^2}\hat{r}$
Force on a test charge q_0: $\vec{F} = q_0\vec{E}$
Field of a point charge: $\vec{E} = \dfrac{1}{4\pi\epsilon_0}\dfrac{q}{r^2}\hat{r}$
Charge density: $\lambda = Q/L$ (linear)
$\sigma = Q/A$ (area)
$\rho = Q/V$ (volume)
Field of an infinite line of charge: $E = \dfrac{\lambda}{2\pi\epsilon_0 r}$
Field of an infinite nonconducting plane of charge: $E = \dfrac{\sigma}{2\epsilon_0}$

Chapter 22: Gauss's Law

Flux of a uniform field through a flat surface: $\Phi_E = EA\cos\phi$
Flux of a nonuniform field: $\Phi_E = \oint \vec{E} \cdot d\vec{A}$
Gauss's Law: $\oint \vec{E} \cdot d\vec{A} = \dfrac{Q_{\text{enc}}}{\epsilon_0}$
Field at the surface of a conductor: $E = \dfrac{\sigma}{\epsilon_0}$
Solid insulating sphere, radius R, with charge Q distributed uniformly throughout volume: $E = \dfrac{1}{4\pi\epsilon_0}\dfrac{Q}{r^2}$ (outside, $r > R$)
$E = \dfrac{1}{4\pi\epsilon_0}\dfrac{Qr}{R^3}$ (inside, $r < R$)

23: Electric Potential

Potential energy, two charges: $U = \dfrac{1}{4\pi\epsilon_0}\dfrac{qq_0}{r}$
Electric potential: $V = U/q_0$
Potential of a point charge: $V = \dfrac{1}{4\pi\epsilon_0}\dfrac{q}{r}$
Superposition: $V = \dfrac{1}{4\pi\epsilon_0}\displaystyle\sum_i \dfrac{q_i}{r_i}$
Charge distribution: $V = \dfrac{1}{4\pi\epsilon_0}\displaystyle\int \dfrac{dq}{r}$
Work: $W_{\text{ab}} = U_{\text{a}} - U_{\text{b}} = -q\Delta V$
Potential from field: $V_a - V_b = \int_a^b \vec{E} \cdot d\vec{l}$
Constant field: $\Delta V = -Ed$
Field from potential: $E_x = -\partial V/\partial x$, $E_y = -\partial V/\partial y$, $E_z = -\partial V/\partial z$
Conducting sphere, radius R and charge Q: $V(r) = kQ/r\ (r > R)$
$V(r) = kQ/R\ (r \le R)$

Chapter 24: Capacitance and Dielectrics

Field at a conductor: $E = \sigma/\epsilon_0$

Field between two oppositely charged plates (σ and $-\sigma$): $E = \sigma/\epsilon_0$

Parallel-plate capacitor: $C = Q/V = K\epsilon_0 A/d$

Energy in a capacitor: $U = \frac{1}{2}CV^2 = \frac{1}{2}Q^2/C = \frac{1}{2}QV$

Capacitors in parallel: $C_{\text{eq}} = C_1 + C_2 + \ldots$

Capacitors in series: $1/C_{\text{eq}} = 1/C_1 + 1/C_2 + \ldots$

Total charge: $Q = C_{\text{eq}}V$

Chapter 25: Current, Resistance, and Electromotive Force

Electric current: $I = dq/dt$ or $\Delta q/\Delta t$

Current density: $J = I/A = nqv_{\text{d}}$

Resistivity: $\rho = E/J$

Resistance (cylindrical conductor): $R = \rho L/A$

Ohm's Law: $V = IR$

Source with internal resistance: $V_{ab} = \mathcal{E} - Ir$

Power (general): $P = V_{ab}\,I$

Power delivered to a resistor: $P = VI = I^2R = V^2/R$

Chapter 26: DC Circuits

Resistors in series: $R_{\text{eq}} = R_1 + R_2 + \ldots$

Resistors in parallel: $1/R_{\text{eq}} = 1/R_1 + 1/R_2 + \ldots$

Kirchoff's Rules: $\Sigma I = 0$ (node), $\Sigma V = 0$ (loop)

RC circuit, time constant: $\tau = RC$

RC circuit, capacitor charging:
$$q(t) = \mathcal{E}C\left(1 - e^{-t/\tau}\right)$$
$$= q_F\left(1 - e^{-t/\tau}\right)$$
$$V(t) = q(t)/C = \mathcal{E}\left(1 - e^{-t/\tau}\right)$$
$$i(t) = i_{\max}e^{-t/\tau},\ i_{\max} = \mathcal{E}/R$$

RC circuit, capacitor discharging:
$$q(t) = Q_0\,e^{-t/\tau}$$
$$V(t) = V_0\,e^{-t/\tau},\ V_0 = Q_0/C$$
$$i(t) = I_0\,e^{-t/\tau},\ I_0 = Q_0/\tau$$

Chapter 27: Magnetic Fields and Magnetic Forces

Magnetic force: $\vec{F} = q\vec{v} \times \vec{B}$

Motion in a magnetic field: $R = \dfrac{mv}{|q|B}$, $T = \dfrac{2\pi m}{|q|B}$

Magnetic flux: $\Phi_B = \int \vec{B} \cdot d\vec{A}$ or $\Phi_B = BA$

Force on a current-carrying segment: $d\vec{F} = Id\vec{l} \times \vec{B}$

Force on a current-carrying wire: $\vec{F} = I\vec{L} \times \vec{B}$

Magnetic moment of a loop: $\vec{\mu} = I\vec{A}$

Torque on a current-carrying loop: $\tau = IBA\sin\phi$

Potential energy of a loop: $U = -\vec{\mu} \cdot \vec{B}$

Chapter 28: Sources of Magnetic Field

Field of a moving charge: $\vec{B} = \dfrac{\mu_0}{4\pi}\dfrac{q\vec{v} \times \hat{r}}{r^2}$

Field of a current-carrying element: $d\vec{B} = \dfrac{\mu_0}{4\pi}\dfrac{Id\vec{l} \times \hat{r}}{r^2}$

Field of a current-carrying wire: $B = \dfrac{\mu_0 I}{2\pi r}$

Force between wires: $\dfrac{F}{L} = \dfrac{\mu_0 I_1 I_2}{2\pi r}$

Field at the center of a loop: $B = \dfrac{\mu_0 I}{2a}$

Field on the axis of a solenoid: $B = \mu_0 nI$, $n =$ turns per unit length

Ampere's Law: $\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{encl}}$

Chapter 29: Electromagnetic Induction

Faraday's Law:
$$\mathcal{E} = -d\Phi_B/dt$$
$= -A\,dB/dt$ (constant area, varying field)
$= -B\,dA/dt$ (constant field, varying area)

Induced current: $I_{\text{ind}} = \mathcal{E}/R$

Motional EMF: $\mathcal{E} = vBL$ (constant field)
$= \oint(\vec{v} \times \vec{B}) \cdot d\vec{l}$ (if $\vec{B} = B(\vec{r})$)

Induced electric fields: $\oint \vec{E} \cdot d\vec{l} = -d\Phi_B/dt$

Chapter 30: Inductance

Inductance of a loop: $L = \Phi_B/i$

Solenoid (length l, area A, density n): $L/l = \mu_0 An^2$

Induced emf: $\mathcal{E} = -L\,di/dt$

Magnetic field energy: $U = \frac{1}{2}LI^2$

RL circuit time constant: $\tau = L/R$

RL circuit current: $i(t) = \mathcal{E}/R\left(1 - e^{-t/\tau}\right)$

LC circuit: $\omega = 2\pi f = 1/\sqrt{LC}$

LC circuit energy: $\frac{1}{2}Q_{\max}^2/C = \frac{1}{2}LI_{\max}^2$

LRC circuit: $\omega' = \sqrt{\dfrac{1}{LC} - \dfrac{R^2}{4L^2}}$

Chapter 31: Alternating Current

rms current, voltage: $I_{\text{rms}} = I/\sqrt{2}$, $V_{\text{rms}} = V/\sqrt{2}$

Inductive and capacative reactance: $X_L = \omega L$, $X_C = 1/\omega C$

Impedance: $Z = \sqrt{R^2 + (X_L - X_C)^2}$

Current amplitude: $I = \mathcal{E}/Z$

Phase angle: $\tan\phi = (X_L - X_C)/R$

Resonance: $\omega_d = \omega_0 = 1/\sqrt{LC}$
$X_L = X_C$ and $Z = R =$ minimum
current $=$ maximum

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