

Learn these by heart before the exam.

Electric Charges, Fields, and Gauss's Law

$$\vec{F} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} \hat{r}, \quad \frac{1}{4\pi\epsilon_0} = 9.0 \times 10^9$$

$$\vec{E} = \frac{\vec{F}}{q}, \quad \vec{E} = \frac{1}{4\pi\epsilon_0} \int \frac{dq}{r^2} \hat{r} \quad \text{exploit symmetry: cancel the components that pair off before integrating}$$

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

$$E_{\text{sheet}} = \frac{\sigma}{2\epsilon_0}, \quad E_{\text{line}} = \frac{\lambda}{2\pi\epsilon_0 r}, \quad E_{\text{sphere}} = \frac{Q}{4\pi\epsilon_0 r^2}$$

Gauss only gives E easily with spherical, cylindrical or planar symmetry. Choose the surface so E is constant and parallel to $d\vec{A}$.

Inside a conductor in electrostatic equilibrium $E = 0$; all excess charge sits on the surface.

Electric Potential

$$V = \frac{1}{4\pi\epsilon_0} \frac{q}{r}, \quad V = \frac{1}{4\pi\epsilon_0} \int \frac{dq}{r} \quad \text{a SCALAR integral, so no components: usually easier than finding } E \text{ directly}$$

$$\Delta V = - \int \vec{E} \cdot d\vec{l}, \quad \vec{E} = -\nabla V \quad E_x = -\partial V / \partial x: \text{field points down the steepest potential drop}$$

$$U = qV, \quad U = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

Route: charge distribution to V by integration, then E by differentiation. It beats the vector integral nearly every time.

Equipotential surfaces are perpendicular to $\vec{E}$; no work is done moving along one.

Conductors and Capacitors

$$C = \frac{Q}{V}, \quad C_{\text{plate}} = \frac{\kappa\epsilon_0 A}{d}$$

$$U_C = \frac{1}{2} QV = \frac{1}{2} CV^2 = \frac{Q^2}{2C}, \quad u_E = \frac{1}{2} \epsilon_0 E^2$$

$$C_p = \sum C_i, \quad \frac{1}{C_s} = \sum \frac{1}{C_i}$$

A dielectric κ raises C . At constant Q it lowers V and E ; at constant V it raises Q .

Electric Circuits

$$I = \frac{dq}{dt}, \quad V = IR, \quad P = IV, \quad R = \frac{\rho L}{A}$$

$$\tau = RC, \quad q(t) = Q_f (1 - e^{-t/RC}), \quad q(t) = Q_0 e^{-t/RC}$$

at $t = 0$ an uncharged capacitor acts as a wire; at $t \rightarrow \infty$ as a break RC

$$\tau = \frac{L}{R}, \quad I(t) = \frac{\mathcal{E}}{R} (1 - e^{-Rt/L}) \quad \text{an inductor is the}$$

opposite: a break at $t = 0$, a wire at $t \rightarrow \infty$ RL

Kirchhoff: $\sum I_{\text{in}} = \sum I_{\text{out}}$ at a junction, $\sum \Delta V = 0$ round a loop. Assign directions and let a negative answer fix them.

Magnetic Fields and Electromagnetism

$$\vec{F} = q\vec{v} \times \vec{B}, \quad \vec{F} = I\vec{L} \times \vec{B}$$

$$r = \frac{mv}{qB}, \quad T = \frac{2\pi m}{qB} \quad \text{the period does NOT depend on speed: the cyclotron principle}$$

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I d\vec{l} \times \hat{r}}{r^2}$$

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{enc}}$$

$$B_{\text{wire}} = \frac{\mu_0 I}{2\pi r}, \quad B_{\text{solenoid}} = \mu_0 n I, \quad B_{\text{loop, centre}} = \frac{\mu_0 I}{2R}$$

A magnetic force never does work: $\vec{F} \perp \vec{v}$ always.

Electromagnetic Induction

$$\Phi_B = \int \vec{B} \cdot d\vec{A}, \quad \mathcal{E} = -\frac{d\Phi_B}{dt}$$

$\mathcal{E} = BLv$ for a rod of length L sliding at v perpendicular to B

$$L = \frac{N\Phi_B}{I}, \quad \mathcal{E}_L = -L \frac{dI}{dt}, \quad U_L = \frac{1}{2} LI^2$$

Lenz's law is energy conservation. The induced current opposes the CHANGE, so pushing a magnet in meets resistance.

Flux changes three ways: B changes, area changes, or the angle changes. Say which one when you justify.

Exam technique

Say WHY the symmetry lets you use Gauss or Ampere before you use it. The justification carries marks.

For RC and RL, describe the two limits ($t = 0$ and $t \rightarrow \infty$) first; they anchor the exponential.

Derive symbolically and substitute once. Check a limiting case (large r , small t) and state the check.