FREE NOTES · NCERT + JEE/NEET LEVEL

Electrostatic Potential & Capacitance

Potential, potential energy, equipotential surfaces, conductors, dielectrics, capacitor, series-parallel combination aur stored energy. Har topic ke saath formula box aur solved numericals.

01 Electric potential
02 Point charge ka potential
03 Dipole aur system of charges ka potential
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01 Electric potential

Unit positive charge ko **infinity se kisi point tak** (bina acceleration ke) laane me jitna work lage, wo us point ka potential hai.

$$V = W / q$$

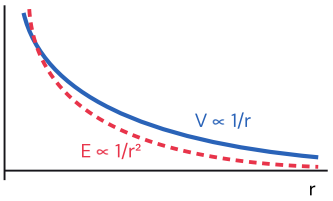
Unit volt (V) = J/C. Scalar. Potential difference: $V_B - V_A = W_{AB}/q$. Positive charge high potential se low ki taraf jaata (paani upar se neeche jaisa).

Electrostatic force conservative hai, isliye work sirf start aur end point pe depend karta, raaste pe nahi.

02 Point charge ka potential

$$V = k\,q / r$$

+q ke liye positive, -q ke liye negative. $V \propto 1/r$ (field $\propto$ $1/r^2$). Infinity pe V = 0.



Potential dheere girta, field tezi se

Charged conducting sphere (R, q): bahar $V = kq/r$, surface aur andar har jagah $V = kq/R$ (constant).

03 Dipole aur system of charges ka potential

DIPOLE (R ≫ A)

$$V = k\,p\cos\theta\,/\,r^2$$

Axial line (θ = 0): kp/r². Equatorial line (θ = 90°): **V = 0** (par field 0 nahi!). $V \propto 1/r^2$.

KAI CHARGES

$$V = k\,(q_1/r_1 + q_2/r_2 + \ldots)$$

Seedha algebraic sum (scalar), direction ki tension nahi. Sign ke saath jodo.

EXAMPLE

Square ke chaaron kono pe +q, centre pe: V = 4kq/(a/√2), field = 0. +q, −q, +q, −q ho toh V = 0 aur field bhi 0.

04 Equipotential surfaces

Aisi surface jis pe har point ka potential same. Is pe charge ko ghumane me **work = 0**.

- Field lines hamesha equipotential ke ⊥.
- Do equipotentials kabhi nahi katati.
- Point charge: concentric spheres. Uniform field: field ke ⊥ planes.
- Jahan equipotentials paas-paas, wahan field tez.
- Conductor ki surface ek equipotential hai.

05 E aur V ka rishta

$$E = -dV/dr$$

Field us direction me jahan potential sabse tezi se ghatta. Uniform field: $E = V/d$. Isliye E ki unit V/m bhi.

DHYAN DO

V = 0 ka matlab E = 0 nahi (dipole ka equatorial point). E = 0 ka matlab V = 0 nahi (charged shell ke andar V constant, non-zero).

06 Potential energy

DO CHARGES

$$U = k\, q_1\, q_2 / r$$

Same sign: U positive (repulsion, paas laane me work lagta). Ulte sign: negative (bound).

TEEN YA ZYADA

$$U = k(q_1q_2/r_{12} + q_2q_3/r_{23} + q_1q_3/r_{13})$$

Har pair ek baar.

External field me charge q ki PE: $U = qV$. Dipole ki: $U = -pE\cos\theta$.

ELECTRON VOLT

1 V potential difference se electron ko mili energy: $1\ eV = 1.6 \times 10^{-19}$ J. Speed nikaalne ke liye: $qV = ½mv^2$.

07 Conductors (electrostatics)

Gun	Kyun
Andar E = 0	Free electrons tab tak hilte jab tak field khatam na ho
Surface pe E surface ke ⊥	Parallel hissa hota toh charge behta
Saara charge surface pe	Gauss's law se, andar net charge 0
Poora conductor equipotential	E = 0 ⇒ V constant
Nukeele hisse pe charge density zyada	σ ∝ 1/R (curvature zyada ⇒ σ zyada)

Nukeele kone pe σ bahut zyada ⇒ field itna tez ki hawa ionize ho jaati: **corona discharge**. **Lightning conductor** isi pe kaam karta.

08 Dielectrics & polarisation

Dielectric = insulator jo electric field me **polarise** ho jaata (andar ke charges thoda khisak ke chhote dipoles bana lete).

Type	Bina field ke	Example
Polar	Molecules me pehle se dipole moment (random)	H_2O, HCl
Non-polar	Dipole moment 0, field se induce	O_2, N_2, CO_2

Andar ka field ghatta: $E = E_0/K$

Dielectric constant $K = \varepsilon/\varepsilon_0 = \varepsilon_r$ (vacuum $= 1$, metal $= \infty$)

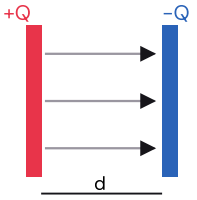
Polarisation $P = \chi_e E$, $K = 1 + \chi$ (χ = susceptibility).

09 Capacitor

Do conductors (plates) jinke beech insulator. Charge aur energy store karta hai.

$$C = Q / V$$

Unit farad (F) = C/V. 1 F bahut bada, aam taur pe µF, pF. C sirf **shape, size aur beech ke medium** pe depend karta, Q ya V pe nahi.



Beech me uniform field $E = \sigma/\varepsilon_0$

PARALLEL PLATE CAPACITOR

$$C = \varepsilon_0 A / d$$

Area badhao ⇒ C badhe; doori badhao ⇒ C ghate. Isolated sphere: $C = 4\pi\varepsilon_0 R$ (Earth ≈ 711 µF).

10 Dielectric ke saath capacitor

Poora bhara: $C = K\,\varepsilon_0\,A\,/\,d = K\,C_0$

Thickness t ka slab: $C = \varepsilon_0 A\,/\,(d - t + t/K)$

Metal slab ($K = \infty$): $C = \varepsilon_0 A/(d - t)$

Dielectric daala jab	Q	V	E	C	Energy U
Battery judi hai (V fix)	K guna	Same	Same	K guna	K guna
Battery hata di (Q fix)	Same	1/K	1/K	K guna	1/K

11 Series & parallel

SERIES

$$1/C = 1/C_1 + 1/C_2 + \ldots$$

Har capacitor pe **same charge**. Voltage baant-ta: chhote C pe zyada V. Total C sabse chhote se bhi kam.

PARALLEL

$$C = C_1 + C_2 + \ldots$$

Har capacitor pe **same V**. Charge baant-ta: bade C pe zyada Q.

YAAD RAKHO

Capacitor ka combination resistor ka **ulta**: series me 1/C judte, parallel me C seedhe. n barabar capacitors: series C/n, parallel nC.

12 Stored energy

$$U = \tfrac{1}{2} C V^2 = Q^2/(2C) = \tfrac{1}{2} Q V$$

Energy density $u = \tfrac{1}{2} \varepsilon_0 E^2$ (J/m^3)

Energy plates ke beech ke field me store hoti hai.

CHARGE SHARING (DO CAPACITORS JODNA)

Common potential: $V = (C_1V_1 + C_2V_2)/(C_1 + C_2)$. Energy loss: $\Delta U = C_1C_2(V_1 - V_2)^2/(2(C_1 + C_2))$.

Energy heat aur radiation me jaati, hamesha loss hota.

Battery se capacitor charge karo toh battery QV energy deti, capacitor me ½QV store, aadhi heat ban jaati.

13 JEE Extra + Tricks

JEE LEVEL

- Dielectric slab (moti t) ke saath: $C = \varepsilon_0 A/(d - t + t/K)$; metal slab: $C = \varepsilon_0 A/(d - t)$.
- Do charged capacitors jodne pe energy loss: $\Delta U = \frac{1}{2} \cdot C_1C_2/(C_1 + C_2) \cdot (V_1 - V_2)^2$ (garmi).
- Plates ke beech force $F = Q^2/(2\varepsilon_0 A)$; energy density $u = \frac{1}{2}\varepsilon_0 E^2$.
- Battery judi (V constant) vs hati (Q constant): dielectric daalne pe C × K; V constant to Q, U × K; Q constant to V, U ÷ K.
- Conducting sphere ke andar har jagah potential = kQ/R.

14 Solved numericals ($k = 9 \times 10^9$)

Q1. 4 µC charge se 9 cm door potential?
$V = 9 \times 10^9 \times 4 \times 10^{-6}/0.09 = 4 \times 10^5$ V. **Ans: 4×10^5 V**

Q2. 2 µC charge ko 100 V se 300 V wale point tak le jaane me work?
$W = q(V_B - V_A) = 2 \times 10^{-6} \times 200 = 4 \times 10^{-4}$ J. **Ans: 4×10^{-4} J**

Q3. 2 µC aur −3 µC, 10 cm door. System ki PE?
$U = 9 \times 10^9 \times (-6 \times 10^{-12})/0.1 = -0.54$ J. **Ans: −0.54 J**

Q4. Parallel plate: A = 100 cm², d = 1 mm. C? ($\varepsilon_0 = 8.85 \times 10^{-12}$)
$C = 8.85 \times 10^{-12} \times 0.01/0.001 = 8.85 \times 10^{-11}$ F ≈ 88.5 pF. **Ans: ≈ 88.5 pF**

Q5. 2, 3, 6 µF series me, 12 V battery. Total C aur har ek pe charge?
$1/C = 1/2 + 1/3 + 1/6 = 1 \Rightarrow C = 1$ µF. Q = 12 µC (sab pe same). **Ans: 1 µF, 12 µC**

Q6. 10 µF capacitor 200 V tak charge. Energy?
$U = \frac{1}{2} \times 10^{-5} \times 4 \times 10^4 = 0.2$ J. **Ans: 0.2 J**

Q7. 4 µF (50 V) ko uncharged 6 µF se joda. Common V aur energy loss?
$V = 4 \times 50/10 = 20$ V. Pehle $\frac{1}{2} \times 4 \times 10^{-6} \times 2500 = 5$ mJ, baad $\frac{1}{2} \times 10 \times 10^{-6} \times 400 = 2$ mJ ⇒ loss 3 mJ.
Ans: 20 V, 3 mJ

15 Common mistakes

- Potential me vector sum karna. V scalar hai, sign ke saath jodo.
- Capacitor ke series/parallel ko resistor jaisa lagana (ulta hai).
- Dielectric daalte waqt battery judi hai ya nahi, ye dekhe bina answer dena.
- V = 0 ⇒ E = 0 maan lena.
- Conductor ke andar potential 0 maan lena (constant hota, surface jitna).
- pF = 10^{-12}, µF = 10^{-6} ka confusion.

16 Formula sheet

Potential	$V = W/q,\ V = kq/r$
Dipole	$V = kp\cos\theta/r^2$
Field from V	$E = -dV/dr,\ E = V/d$
PE	$U = kq_1q_2/r,\ U = qV$
Capacitance	$C = Q/V$
Parallel plate	$C = K\varepsilon_0 A/d$
Partial slab	$C = \varepsilon_0 A/(d - t + t/K)$
Sphere	$C = 4\pi\varepsilon_0 R$
Series / parallel	$1/C = \Sigma 1/C_i\ /\ C = \Sigma C_i$
Energy	$\frac{1}{2}CV^2 = Q^2/2C,\ u = \frac{1}{2}\varepsilon_0 E^2$
Common potential	$(C_1V_1 + C_2V_2)/(C_1 + C_2)$

17 Practice questions

1. Parallel plate capacitor ki doori 2 guna aur area aadha. C?
2. Battery hata ke K = 5 ka dielectric daala. V aur U?
3. Teen 3 µF capacitors: series aur parallel me C?
4. Electron ko 100 V se accelerate kiya. Energy (eV aur J)?
5. Dipole ki equatorial line pe V aur E?

ANSWERS

1) C/4 · 2) V/5, U/5 · 3) 1 µF, 9 µF · 4) 100 eV = 1.6×10^{-17} J · 5) V = 0, E = kp/r^3 (0 nahi)

18 Quick revision: exam se pehle 5 minute

POTENTIAL

- V = kq/r (scalar).
- Dipole equatorial: V = 0.
- E = -dV/dr; E ⊥ equipotential.
- Conductor: andar E = 0, V constant.

ENERGY

- U = kq_1q_2/r; har pair.
- 1 eV = 1.6×10^{-19} J.
- Capacitor $\frac{1}{2}CV^2$, u = $\frac{1}{2}\varepsilon_0 E^2$.

CAPACITOR

- C = $K\varepsilon_0 A/d$.
- Series: Q same; parallel: V same.
- Battery judi: V fix; hati: Q fix.

DIELECTRIC

- E andar = E_0/K.
- Polar (H_2O) vs non-polar (O_2).
- Charge sharing me energy loss.

Doubt hai? padhaiadda.netlify.app pe AI Doubt Solver se poocho, ya is chapter ka mock test do.