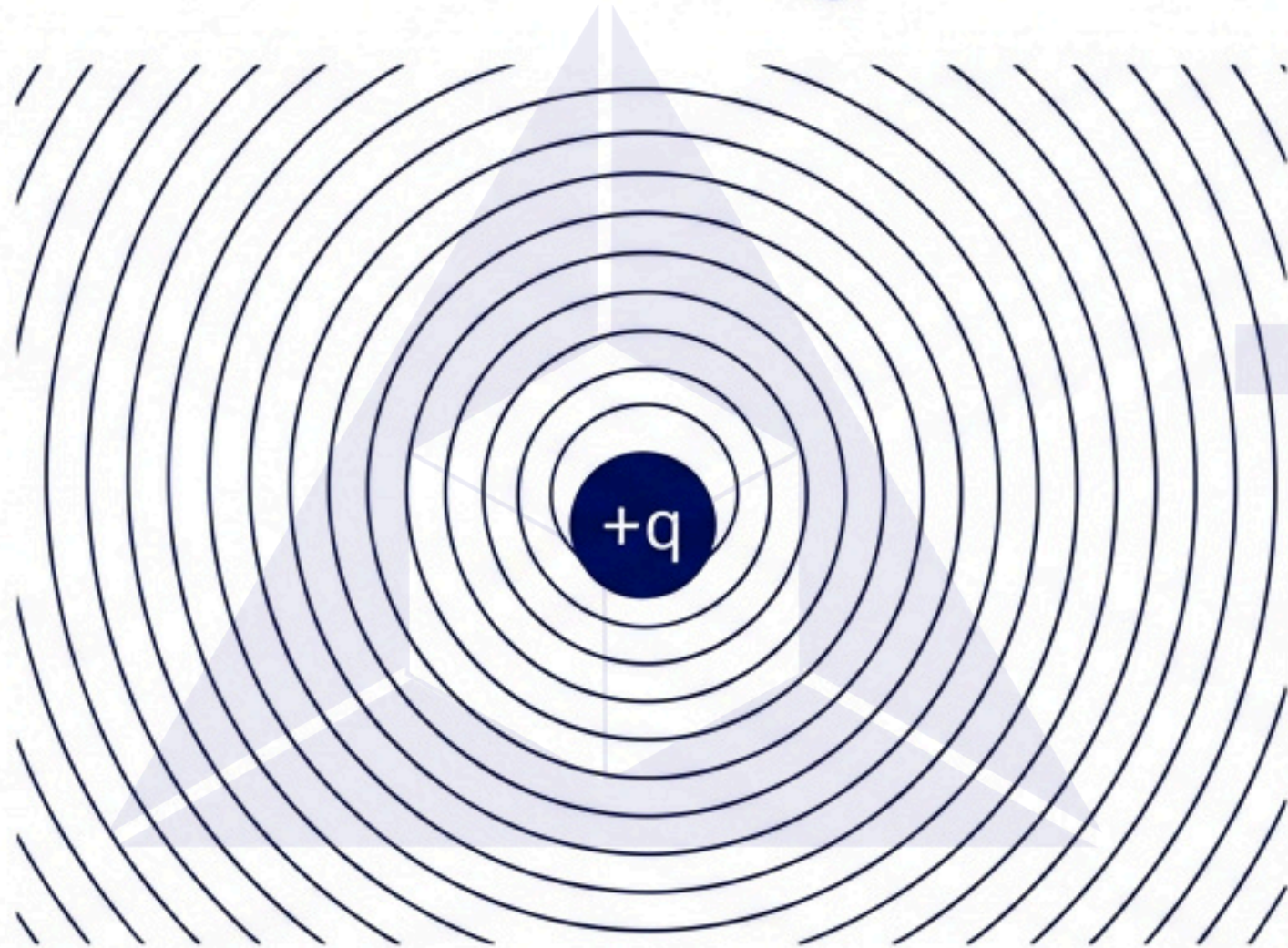


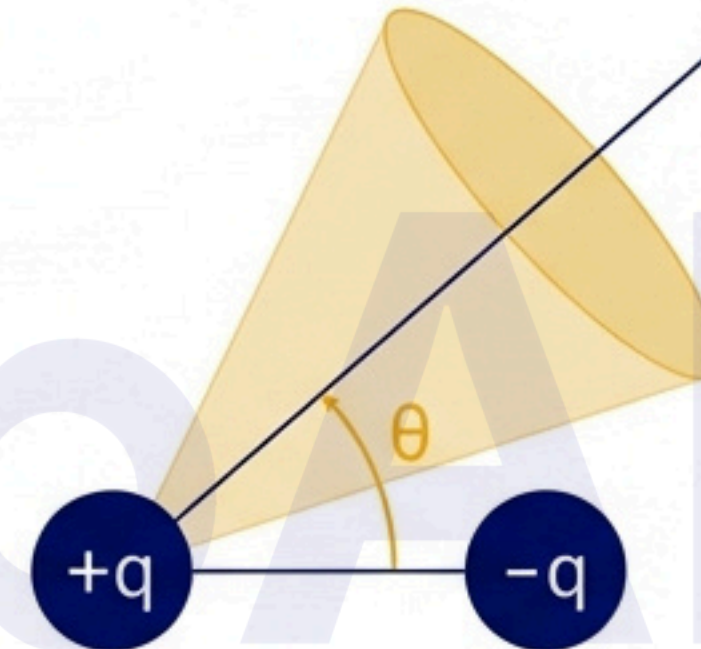
A dipole's potential depends on direction too.

Point Charge

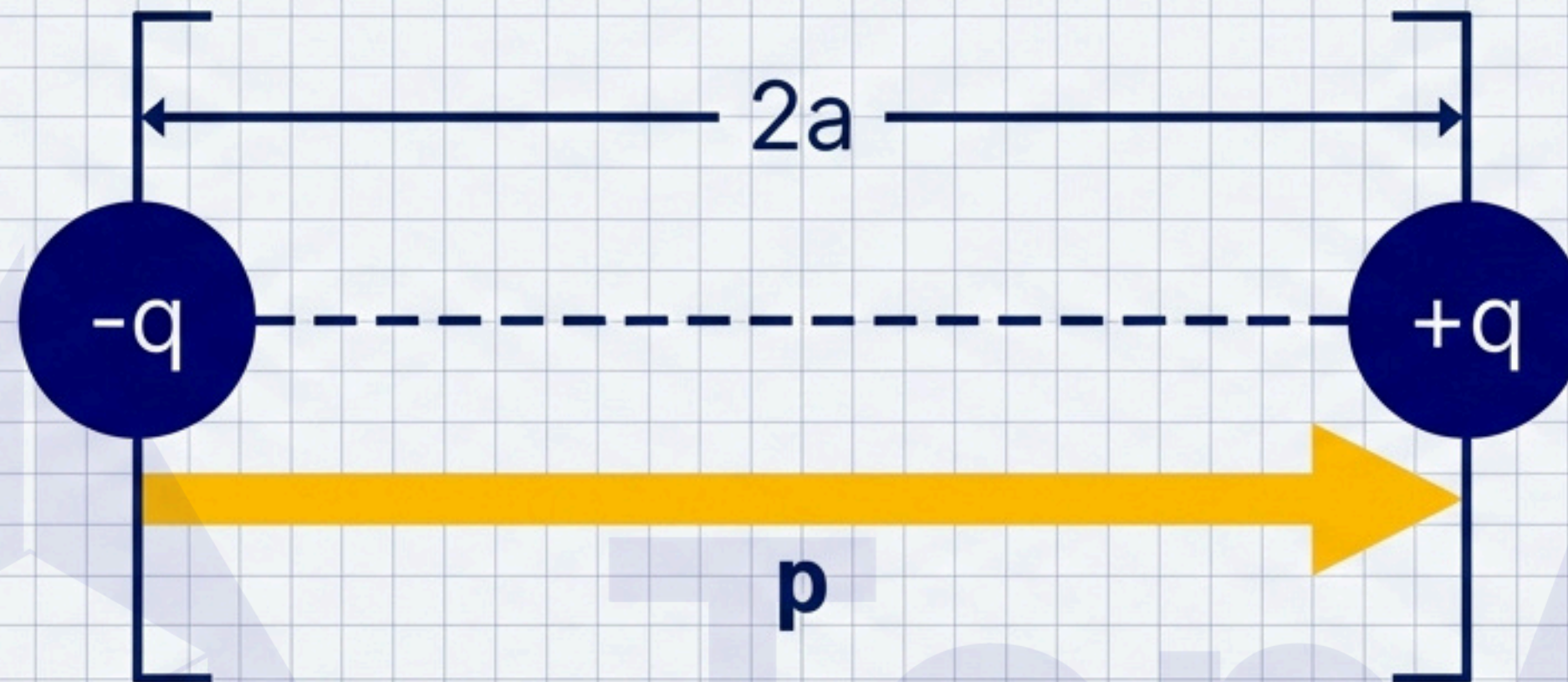


Spherically symmetric.
Depends ONLY on distance (r).

Electric Dipole



Directionally dependent. Depends
on distance (r) AND angle (θ).

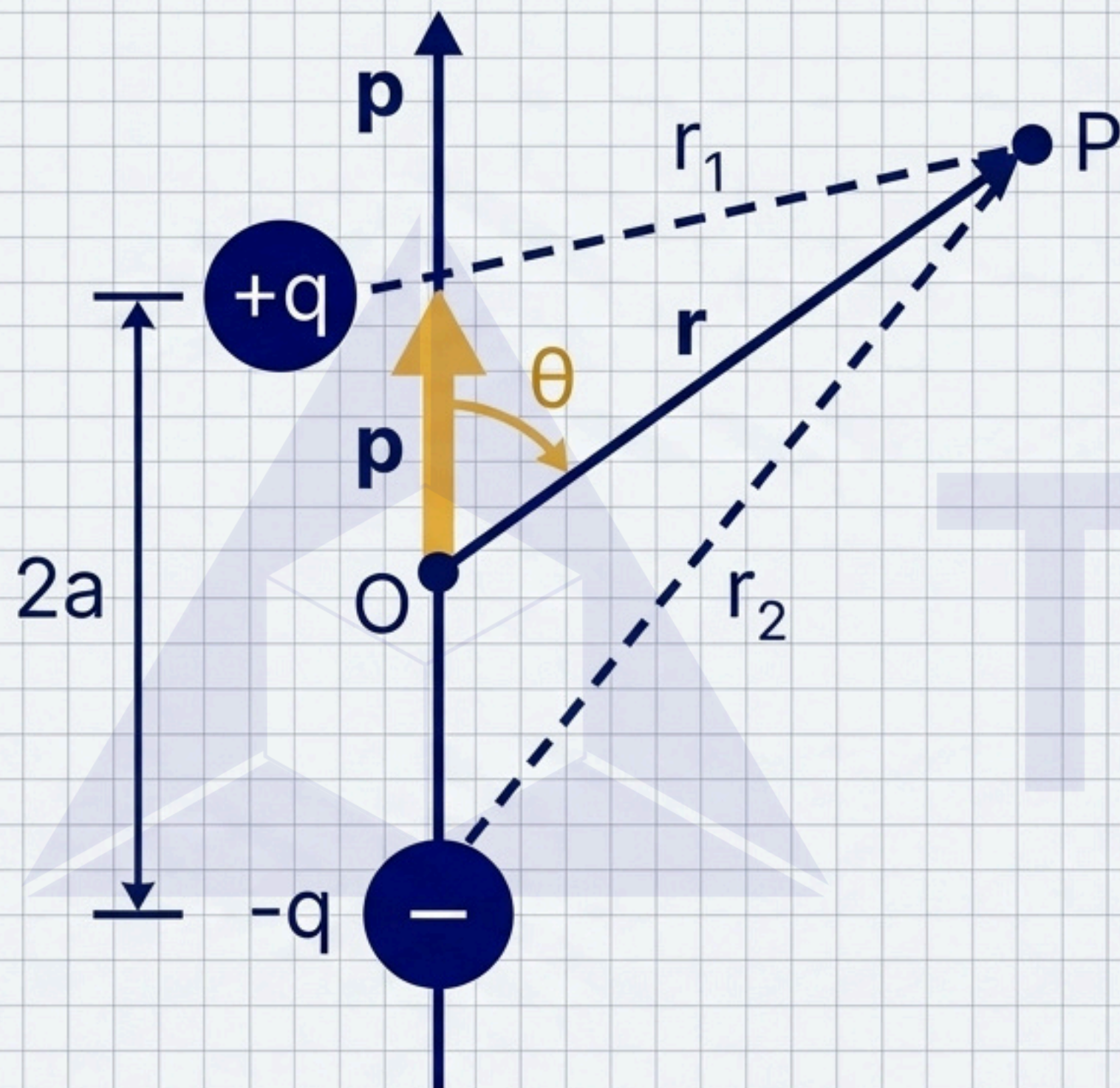


The System

- Two charges, $+q$ and $-q$.
- Separated by a small distance $2a$.
- Total net charge is zero.

The Dipole Moment (p)

- Magnitude: $p = q \times 2a$
- Direction: Points from $-q$ to $+q$.



Mapping Distances to Point P

O = Origin at dipole center

P = Observation point at position vector $\mathbf{r}$

r_1 = Distance from $+q$ to P

r_2 = Distance from $-q$ to P

θ = Angle between $\mathbf{r}$ and $\mathbf{p}$



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Superposition & The Binomial Approximation

Step 1: Superposition (Eq 2.9)

Sum the individual potentials:

$$V = \frac{1}{4\pi\epsilon_0} \left(\frac{q}{r_1} - \frac{q}{r_2} \right)$$



Step 2: Geometric Relations (Eq 2.10)

Apply the cosine rule from the triangle:

$$r_1^2 = r^2 + a^2 - 2ar \cos\theta$$

$$r_2^2 = r^2 + a^2 + 2ar \cos\theta$$



Step 3: The Approximation (Eq 2.13)

$r \gg a$

Retain terms up to first order in a/r using Binomial theorem:

$$1/r_1 \cong (1/r) * (1 + (a/r) * \cos\theta)$$

$$1/r_2 \cong (1/r) * (1 - (a/r) * \cos\theta)$$

The Dipole Potential Formula

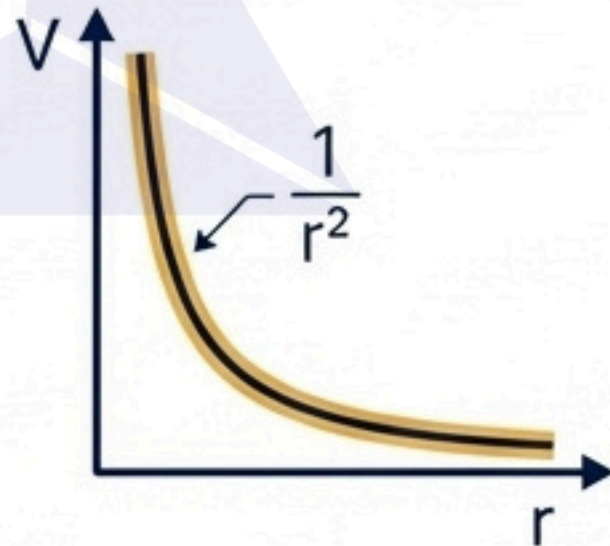
$$V = \frac{1}{4\pi\epsilon_0} \frac{\mathbf{p} \cos\theta}{r^2}$$

Vector form: $V = \frac{1}{4\pi\epsilon_0} \frac{\mathbf{p} \cdot \hat{\mathbf{r}}}{r^2}$ [for $r \gg a$]

Depends on Distance (r)

Potential falls off as $1/r^2$.

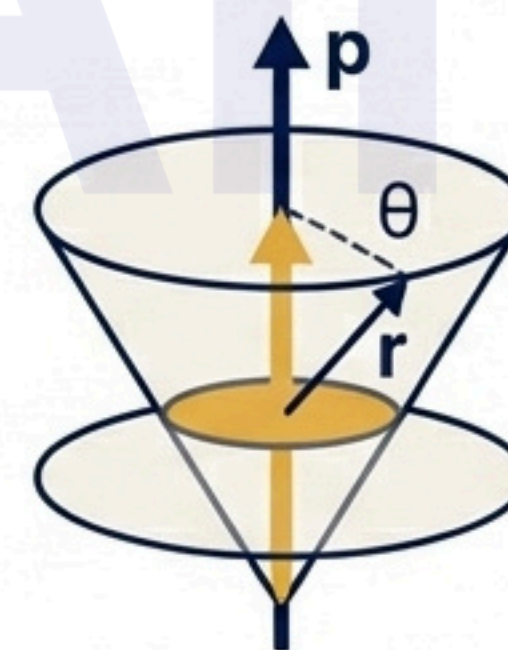
Insight: Fades faster than a point charge (which is $1/r$).



Depends on Angle (θ)

Dot product ($\mathbf{p} \cdot \hat{\mathbf{r}}$) creates the $\cos\theta$ term.

Features axial symmetry about $\mathbf{p}$.



Axial vs. Equatorial Plane

Axial Line (Eq 2.16)

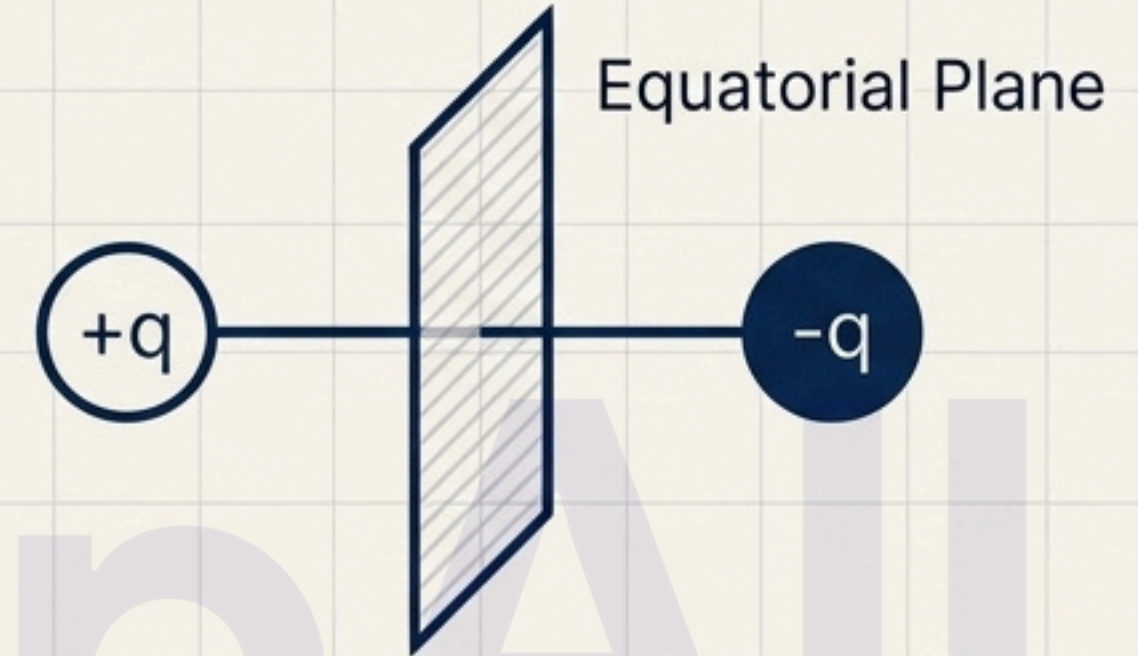


Angle: $\theta = 0$ or π

$$V = \pm \frac{1}{4\pi\epsilon_0} \frac{p}{r^2}$$

Maximum magnitude potential

Equatorial Plane



Angle: $\theta = \pi/2$

$$V = 0$$

Zero potential everywhere on this plane

✓ Key Takeaways

- Depends on both distance (r) and angle (θ) between r and p .
- Scales as $1/r^2$ at large distances (falls off faster than point charge).
- Features axial symmetry around the dipole moment vector.

⚠ Exam Traps

- **Warning 1:** Do NOT confuse point charge potential ($V \propto 1/r$) with dipole potential ($V \propto 1/r^2$). The faster drop-off is a frequent trick question.
- **Warning 2:** The formula $V = (kp \cos\theta) / r^2$ is an approximation strictly valid only when $r \gg a$.



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