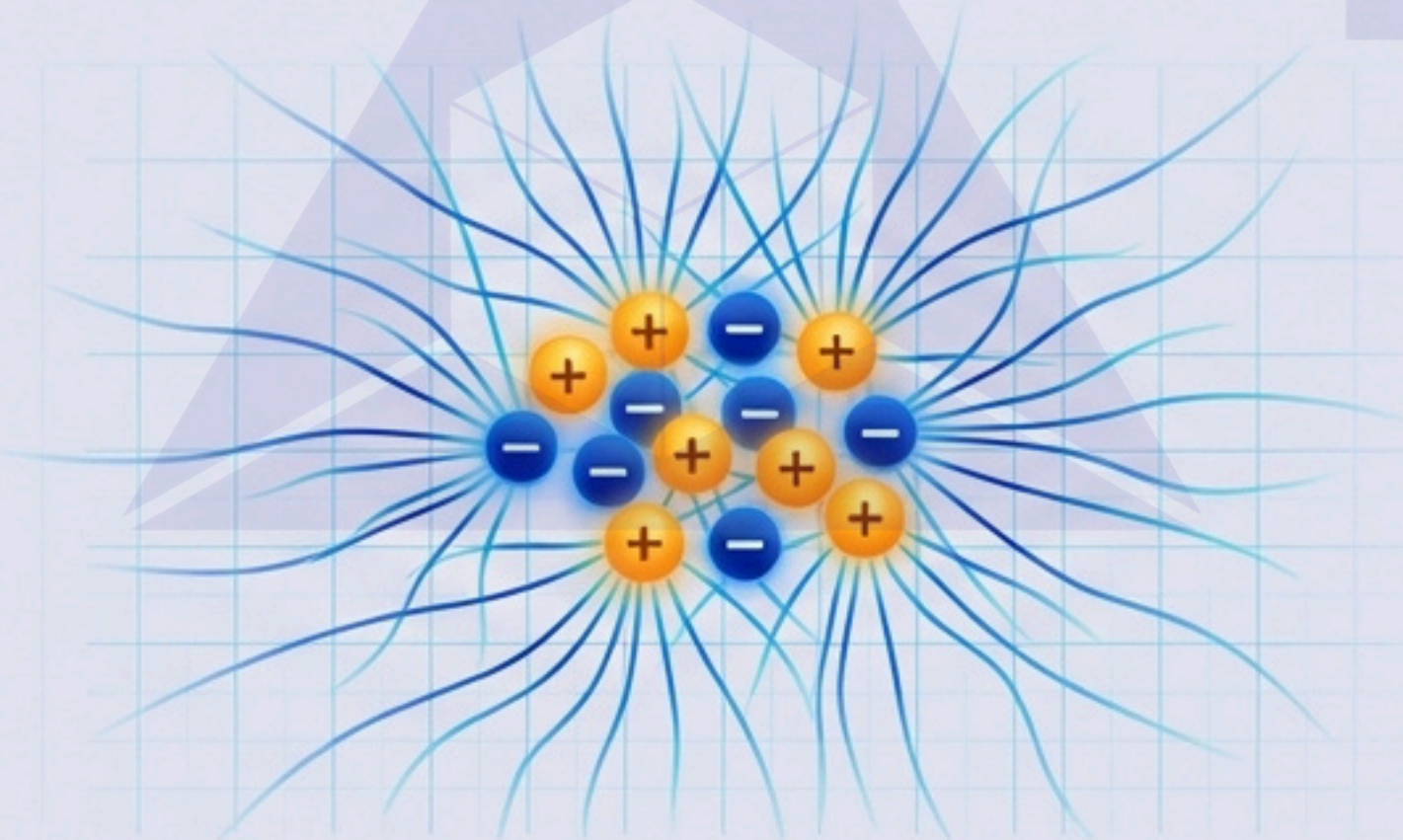


What changes when the field is external?

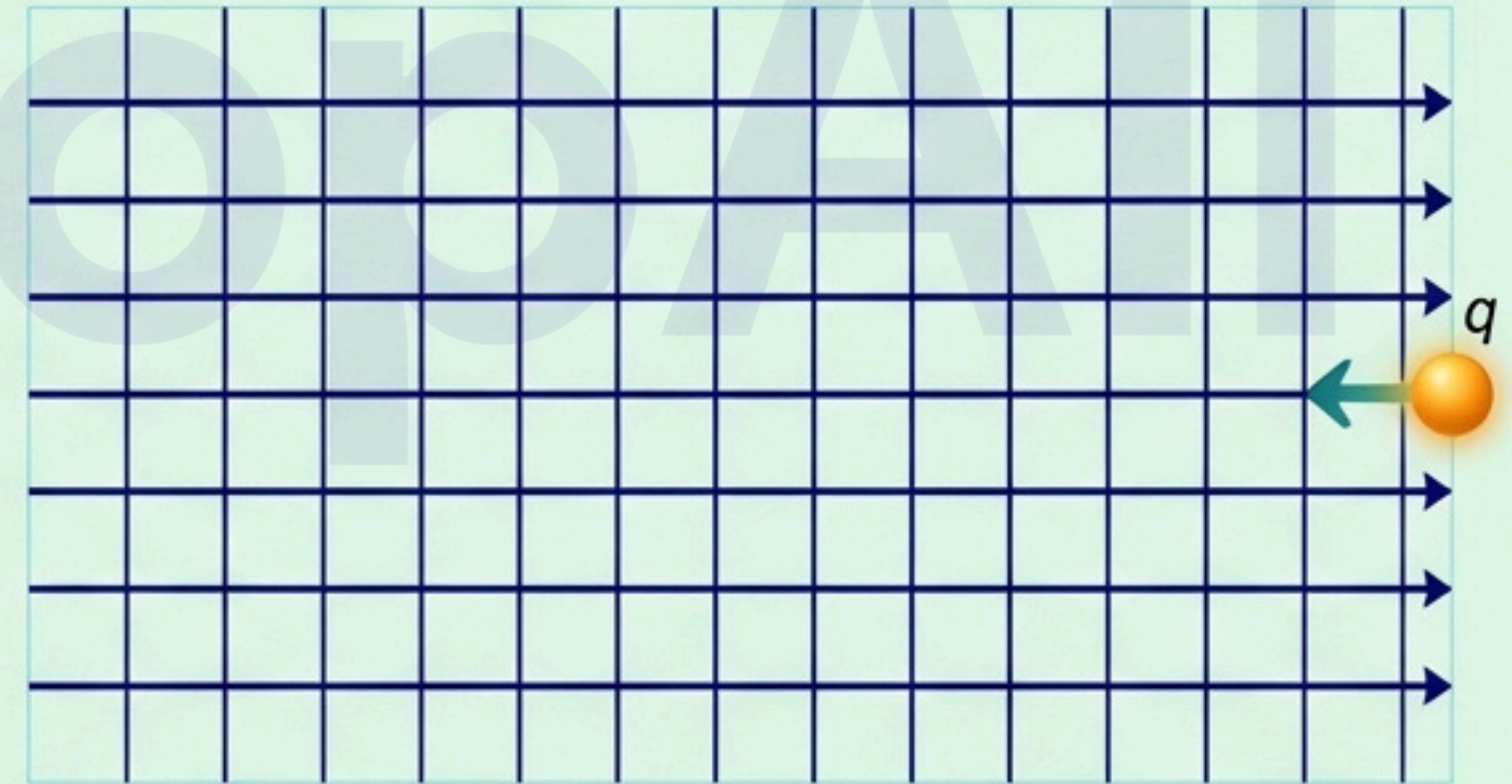
The Previous Paradigm

- We calculated the energy of building a system from scratch.
- The charges WERE the source of the field.



The New Paradigm

- The field (E) already exists, created by unknown external sources.
- We only care about the energy of a new charge (q) placed INTO this existing field.

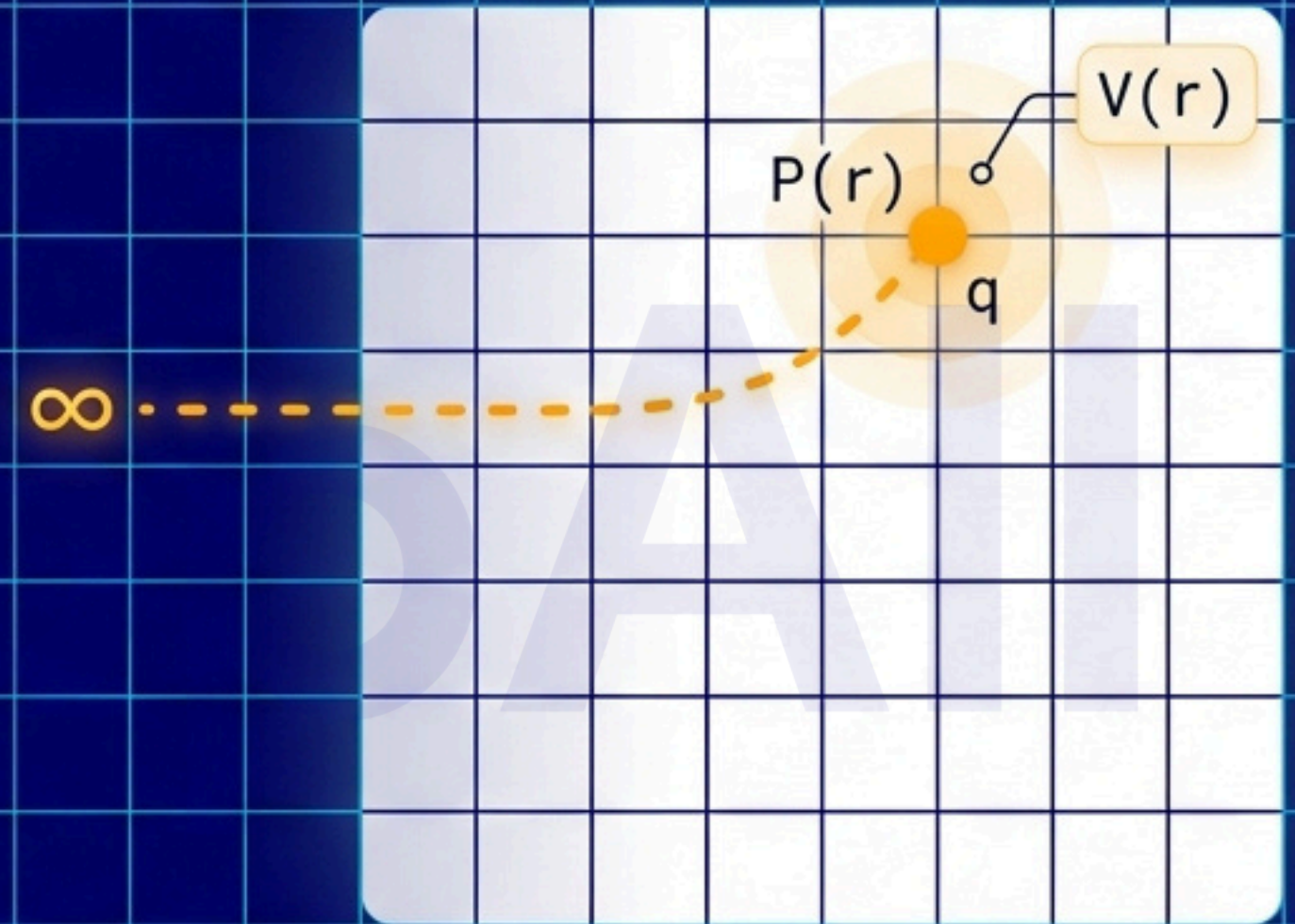


A Single Charge Enters the Grid

The Setup

- External field (E) and potential (V) vary from point to point.
- Test charge (q) is too small to affect external sources.

1. Potential V at point P is the work done bringing a unit positive charge from infinity.
2. Therefore, bringing charge q from infinity to point P requires work: $q \times V$.



Practice more, score more

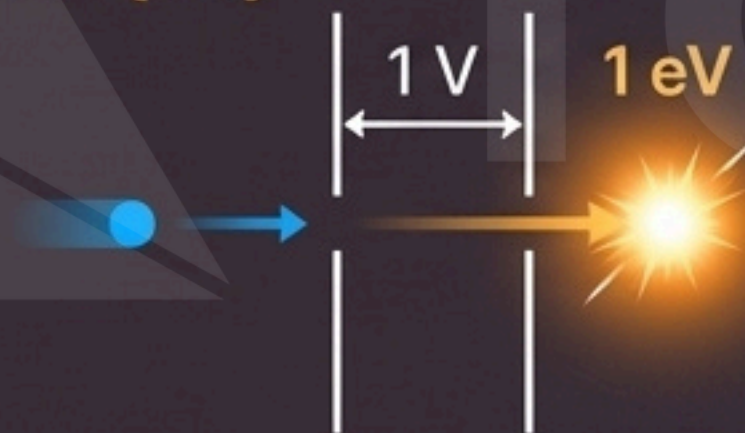
The Energy of Position: $U = qV(r)$

Potential energy of q at r in an external field $= qV(r)$

Exam Focus: The Electron Volt (eV)

If an electron is accelerated by a potential difference of 1 V, it gains energy of 1 eV.

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$



⚠ Mistake Prevention

Do not confuse $V(r)$ with the potential created BY q . $V(r)$ is strictly the external environment!

Practice more, score more



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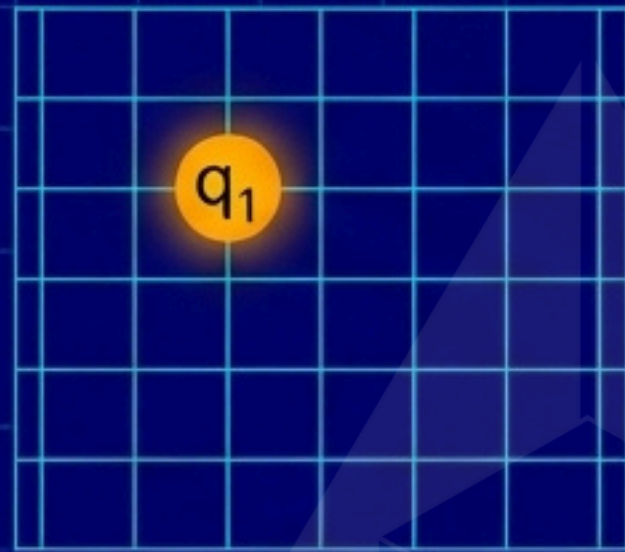
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- » Track Your Performance Smarter

Two Charges: The Triple Interaction

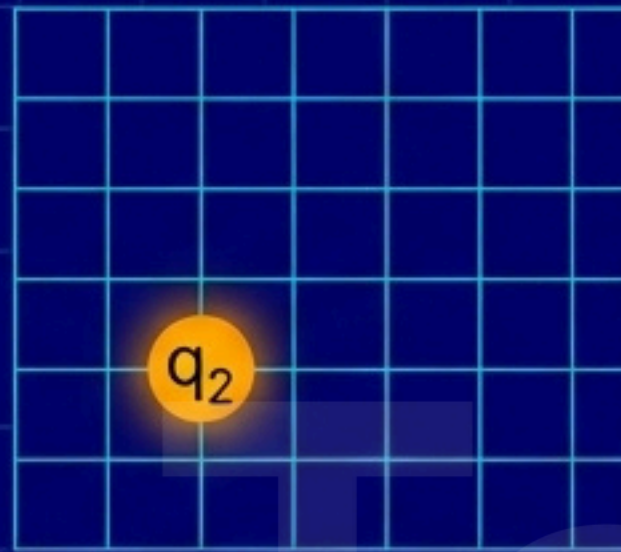
Total Energy = External Work + Internal Work



Step 1: Bring q_1 against external field

$$\rightarrow q_1 V(r_1)$$

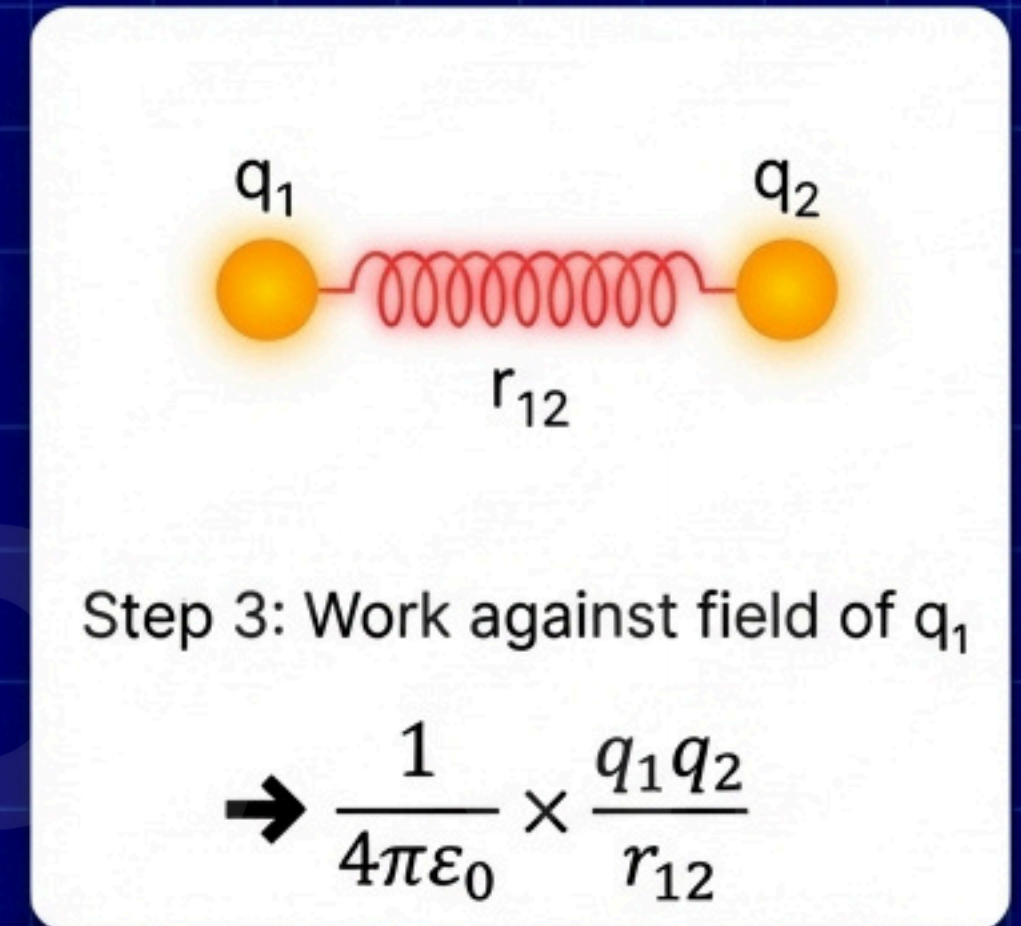
+



Step 2: Bring q_2 against external field

$$\rightarrow q_2 V(r_2)$$

+



$$U = q_1 V(r_1) + q_2 V(r_2) + \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r_{12}}$$

Dipoles in a Uniform External Field

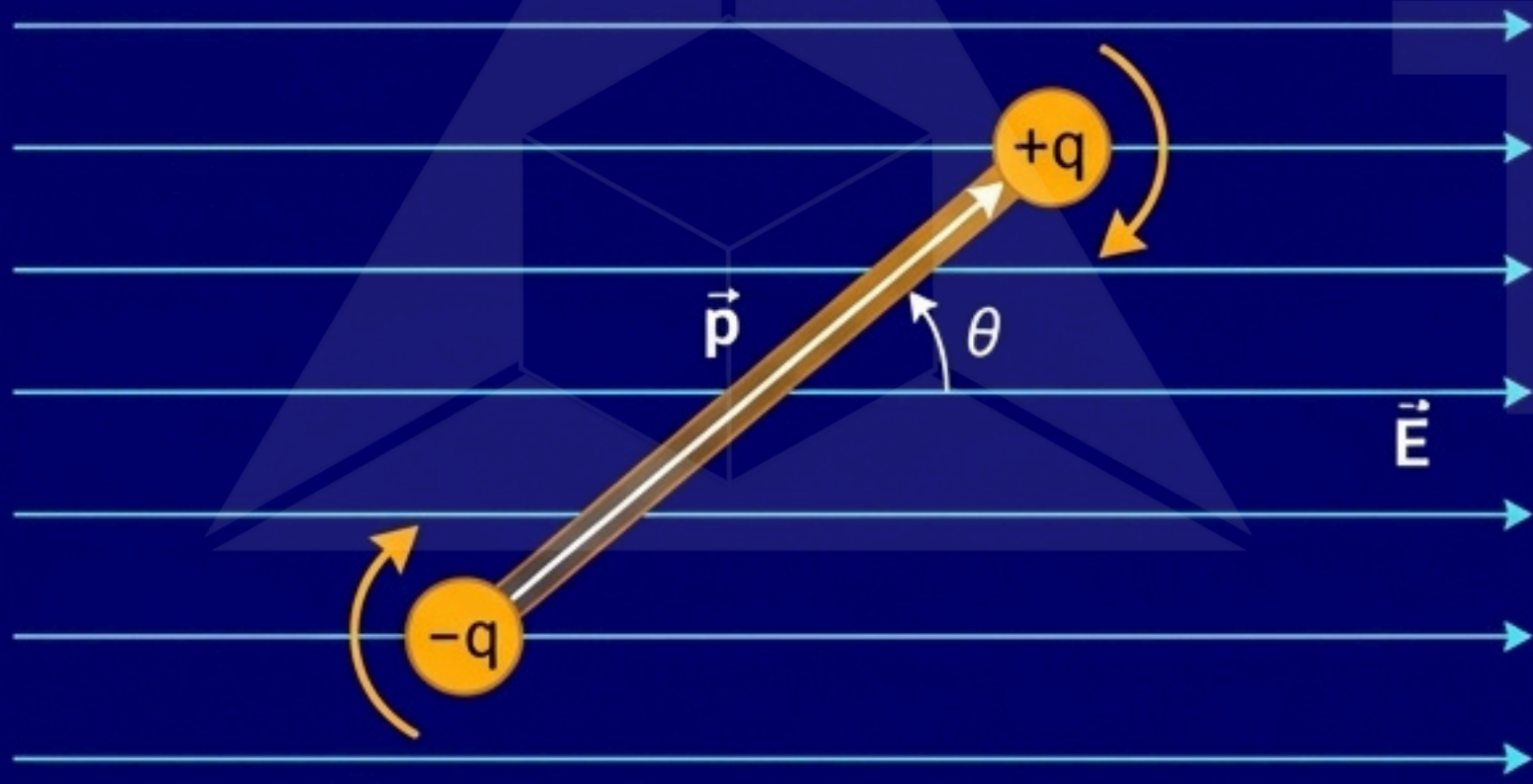
The Physics

- Net force is zero, but field applies a torque ($\tau = \vec{p} \times \vec{E}$).
- Torque tries to rotate the dipole to align with the field $\vec{E}$.

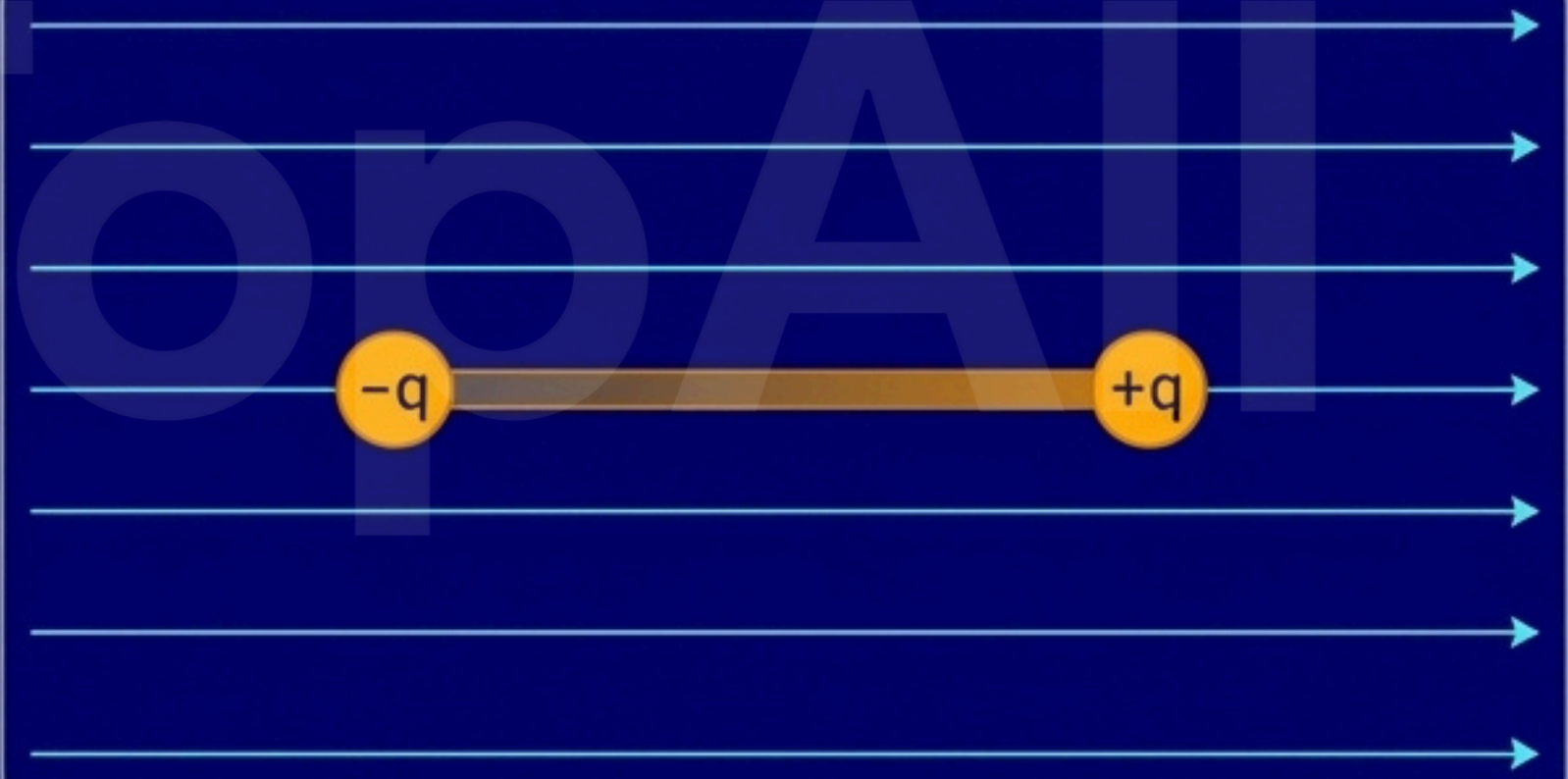
The Work Done

- Rotating against this torque from θ_0 to θ_1 requires external work.
- This work is stored as potential energy.

Before Alignment



After Alignment



Alignment & Energy: $U = -\mathbf{p} \cdot \mathbf{E}$

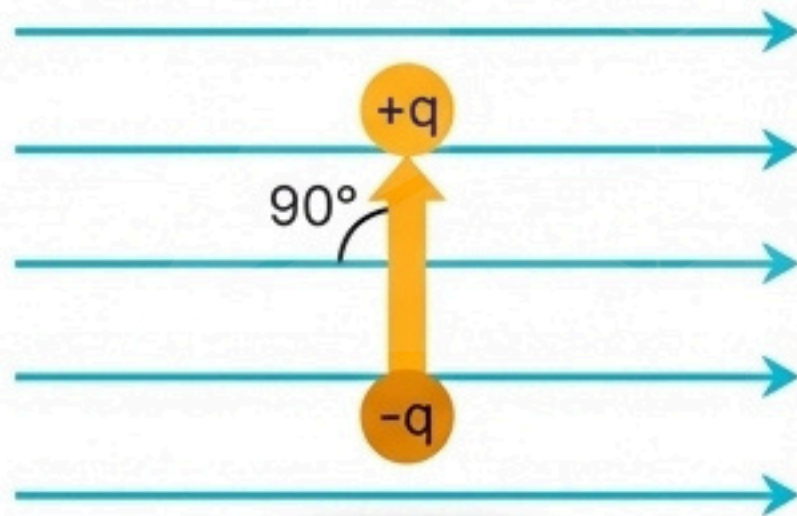
$$U = -pE \cos\theta$$

$$U = -\mathbf{p} \cdot \mathbf{E}$$

Setting the Zero Point:

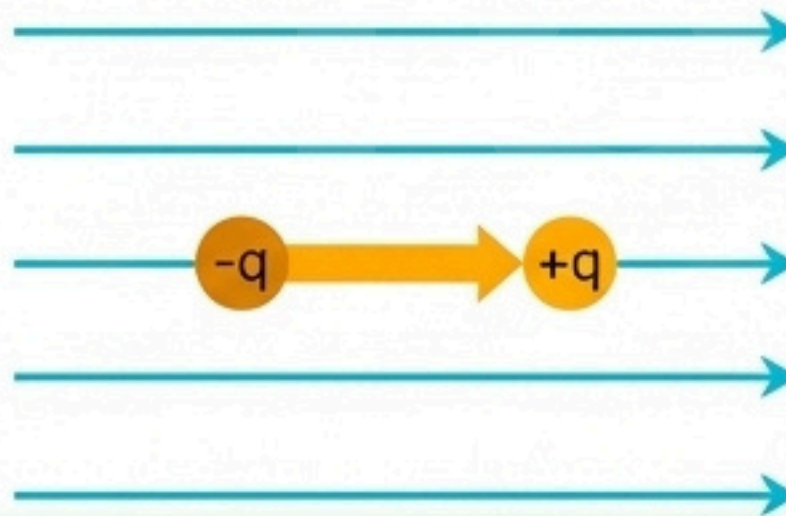
- We choose $U = 0$ at $\theta_0 = \pi/2$ (perpendicular).
- Here, work done against field for $+q$ and $-q$ cancel out.

90°



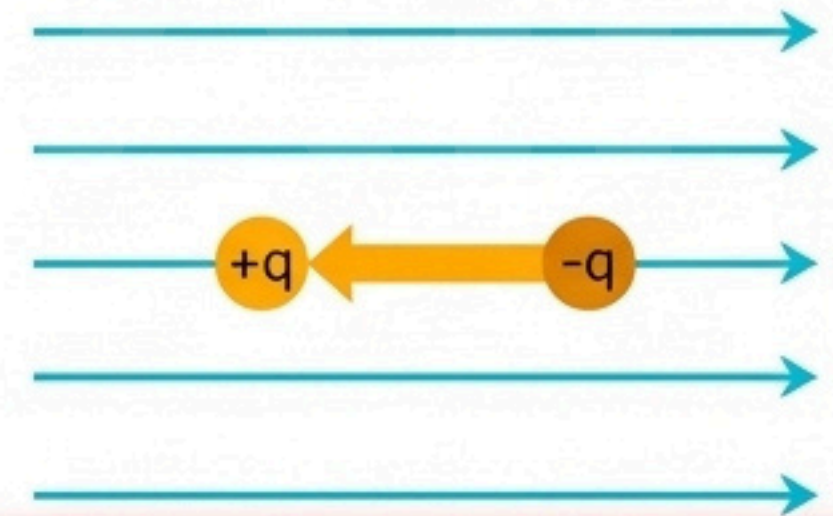
Zero U

0°



Stable Equilibrium (Min Energy)

180°



Unstable Equilibrium (Max Energy)

Key Takeaways: External Fields



Key Takeaways

- ✓ **DISTINGUISH** the external field $\mathbf{E}$ from the fields created by the test charges.
- ✓ **CALCULATE** single charge energy as $U = qV(r)$.
- ✓ **COMBINE** external potential energy with internal interaction energy for multi-charge systems.
- ✓ **DEFINE** 1 Electron Volt (eV) as $1.6 \times 10^{-19} \text{ J}$.
- ✓ **EVALUATE** dipole energy based on its alignment angle: $U = -\mathbf{p} \cdot \mathbf{E}$.

$$U = qV$$

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

$$U_{\text{sys}} = q_1 V_1 + q_2 V_2 + \frac{kq_1 q_2}{r_{12}}$$

$$U_{\text{dipole}} = -\mathbf{p} \cdot \mathbf{E}$$



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