

Building a charge system stores energy

The Big Idea

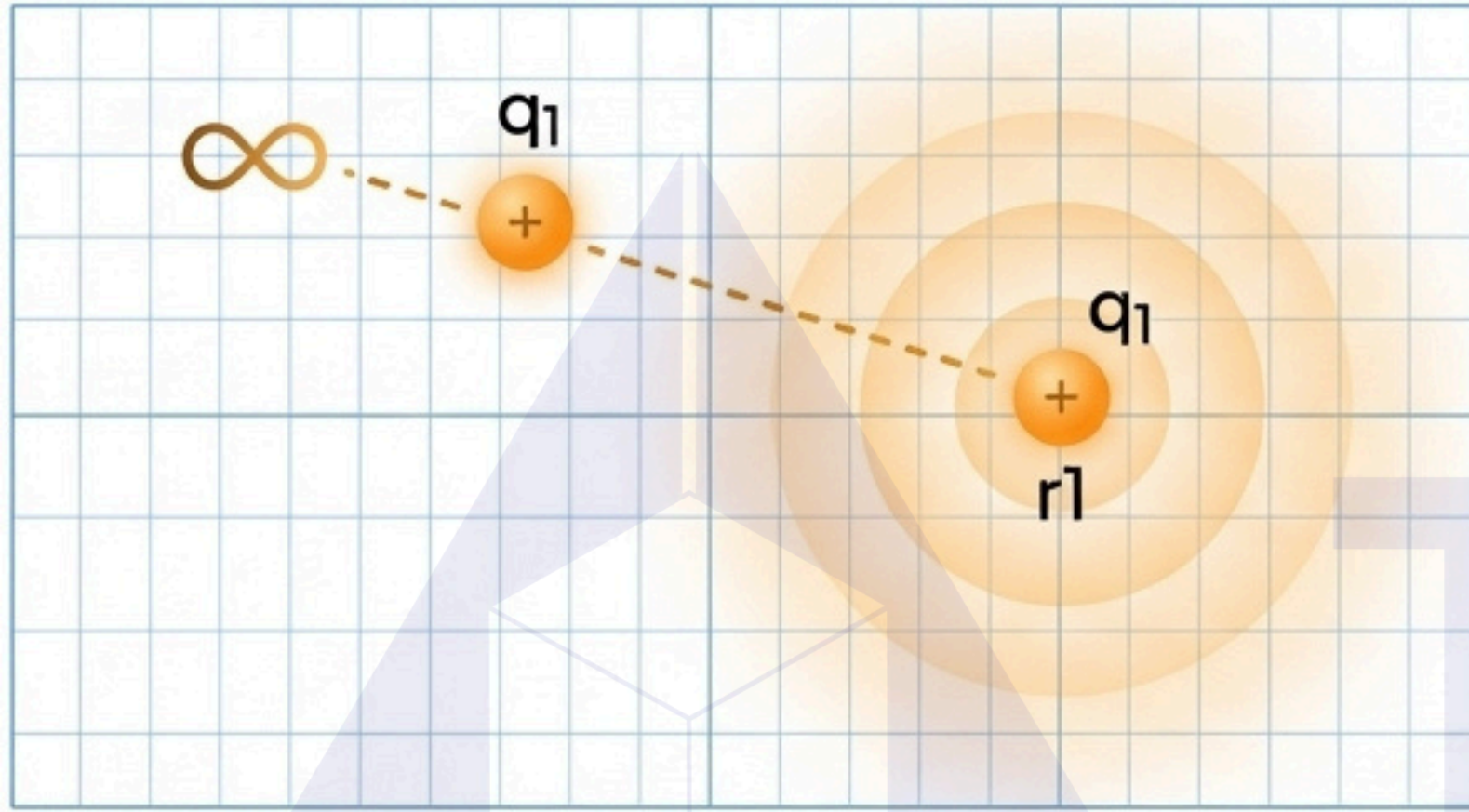
Imagine an empty universe. Bringing charges together from infinity is like compressing a spring or lifting a heavy block.

The Physics Translation

- Electrostatic forces push or pull against you.
- You must do External Work to force them into a specific arrangement.
- That work gets locked inside the system as Electrostatic Potential Energy (U).



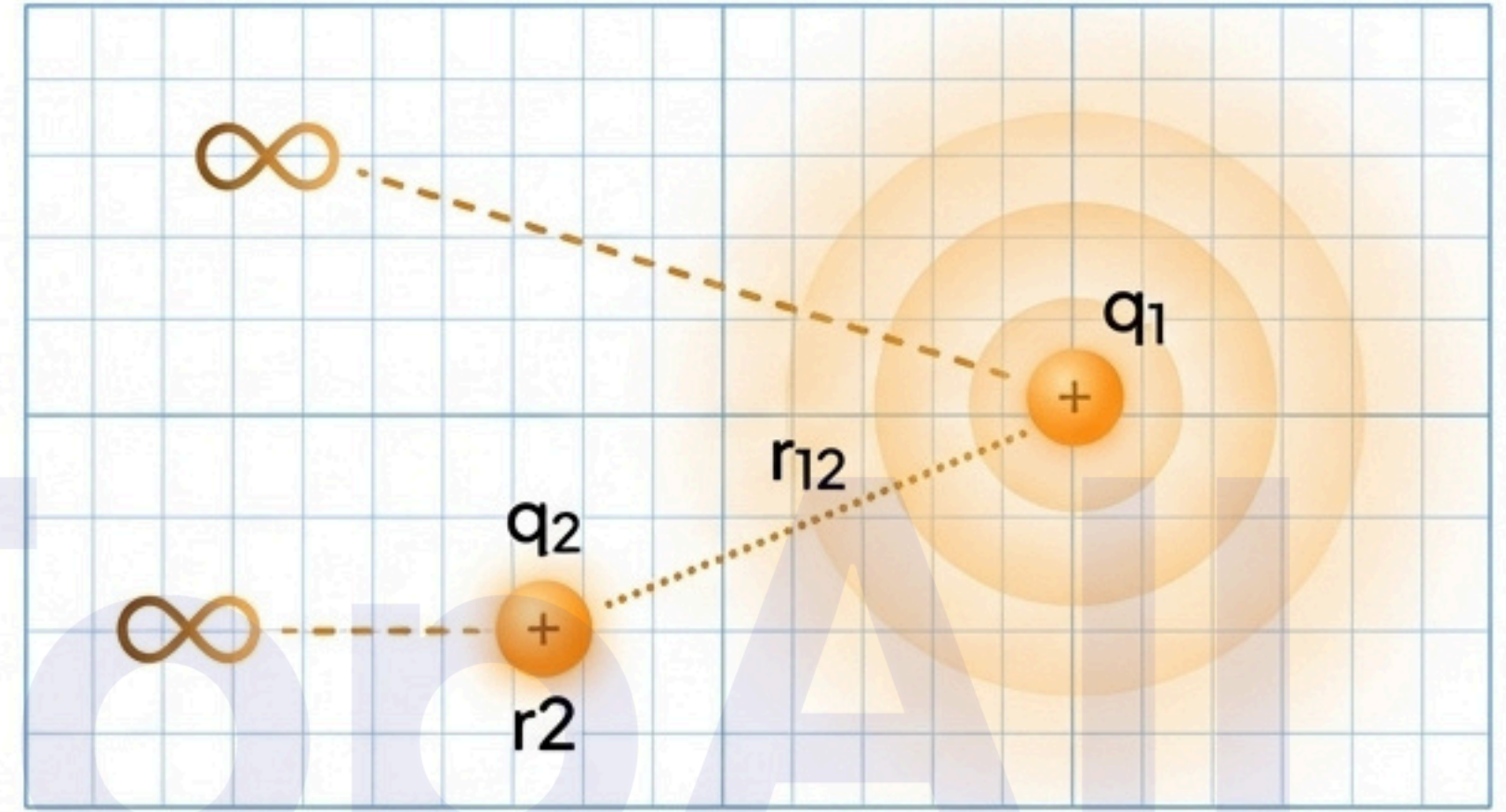
The Assembly Process: Charges Arriving from Infinity



Step 1: Bring the First Charge (q_1)

Brought to position r_1 . The space is completely empty; no external field exists.

$$\text{Work done} = 0$$



Step 2: Bring the Second Charge (q_2)

Brought to position r_2 . Must fight against the electric field already created by q_1 .

$$\text{Work done on } q_2 = q_2 \times V_1$$

Potential Energy of a Two-Charge System

The interacting
pair of charges

$$U = \frac{1}{4\pi\epsilon_0} \times \frac{q_1 q_2}{r_{12}}$$

Inverse distance
relationship

Like Charges ($q_1 q_2 > 0$)



Repulsive force. You must do positive work against it to push them together.

→ **U is Positive**

Unlike Charges ($q_1 q_2 < 0$)



Attractive force. You do negative work (holding them back) as they pull together.

→ **U is Negative**



**You've Learned the Theory.
Let's Test Them Now.**

$$E=mc^2$$



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Scaling Up: Systems of Three or More Charges

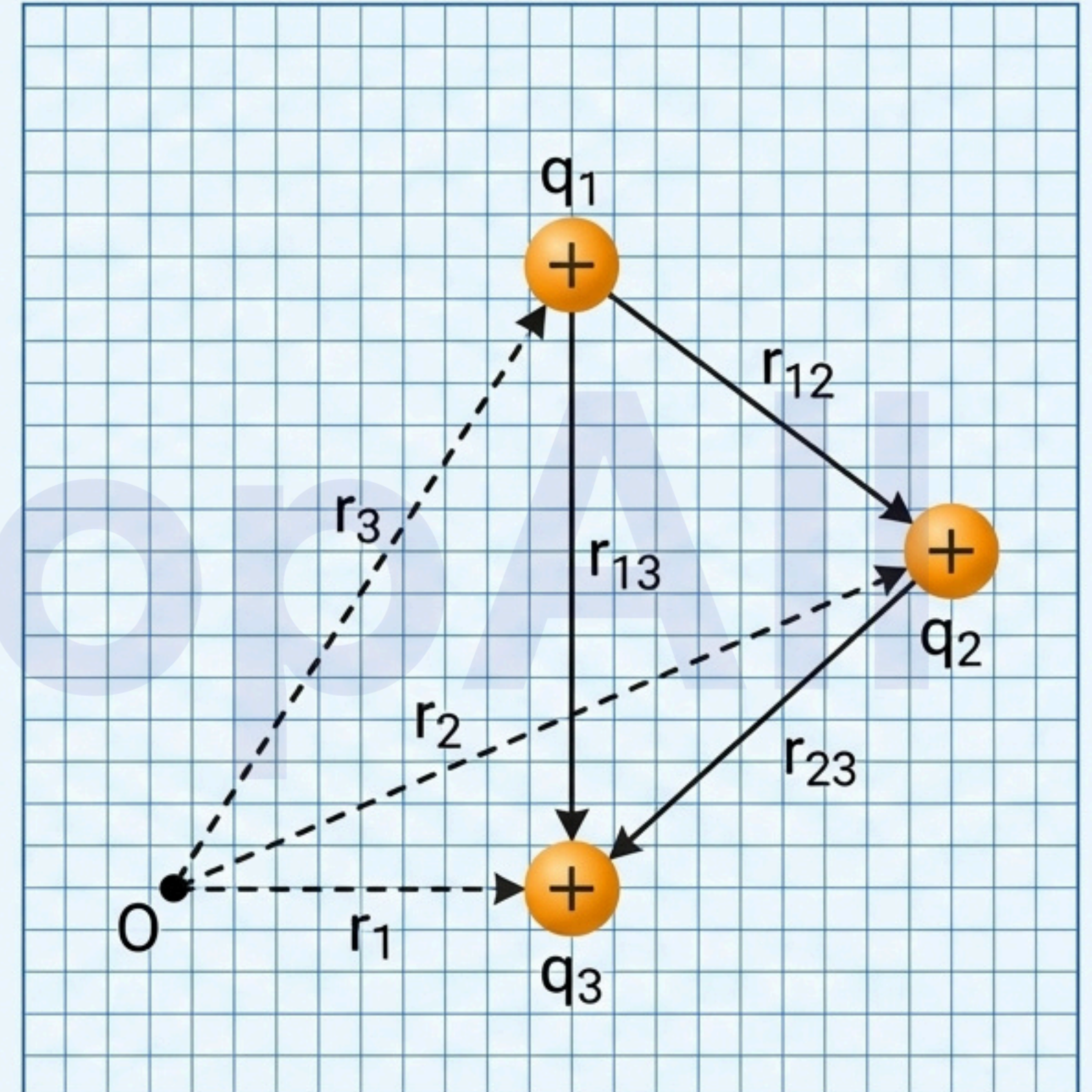
Block 1 Bring the Third Charge (q_3)

Now, q_3 must do work against both q_1 and q_2 .
Work done = $q_3 \times V_{1,2}$

Block 2 Total System Energy

Add the work from all steps.
 U equals the sum of energy from every unique pair.

$$U = \frac{1}{4\pi\epsilon_0} \left[\frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}} \right]$$



Final Energy Depends on Arrangement, Not Path

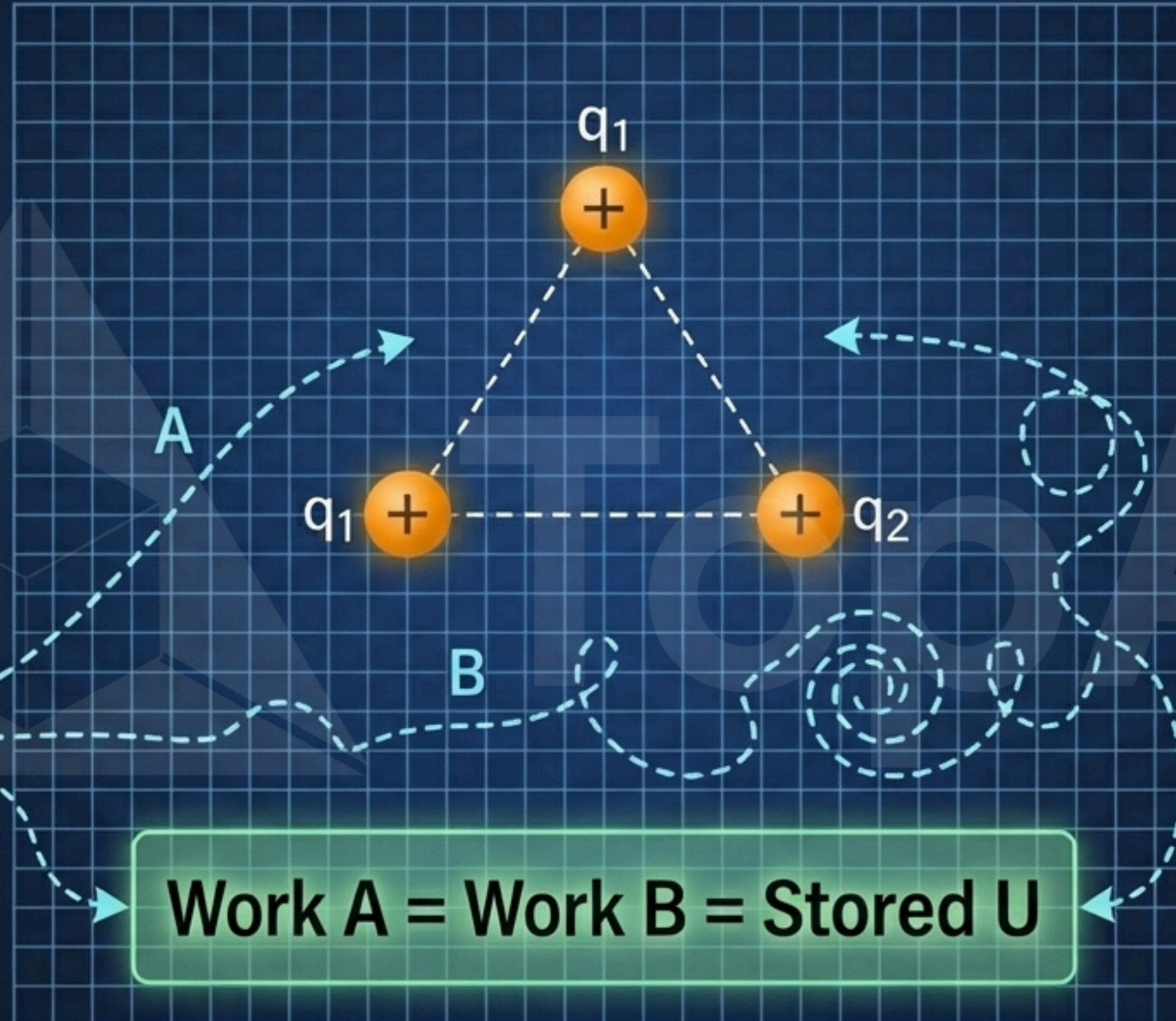
The Order
Doesn't Matter

If we brought q_2 first and q_1 second, the total calculated U would be exactly the same.

The Path
Doesn't Matter

Electrostatic force is a Conservative Force.

Work done is path-independent; U characterizes only the present state of the arrangement.



Synthesis slide: Key Takeaways & Exam Traps

Key Takeaways

- **Remember:** First charge brought from infinity requires ZERO work.
- **Calculate:** For N charges, energy is the algebraic sum of all unique pair combinations.
- **Define:** U is the external work done against electrostatic forces to build the configuration.

Common Mistakes

- **Ignoring the signs:** Always include the $\pm$ signs of the charges in your pair calculations. Negative U means a bound, stable system.
- **Double-counting pairs:** q_1q_2 is the mathematically same pair as q_2q_1 . Only count each pair once!
- **Mixing up r and r^2 :** Potential energy depends on $1/r$, NOT $1/r^2$ (which is exclusively for force and electric fields).



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