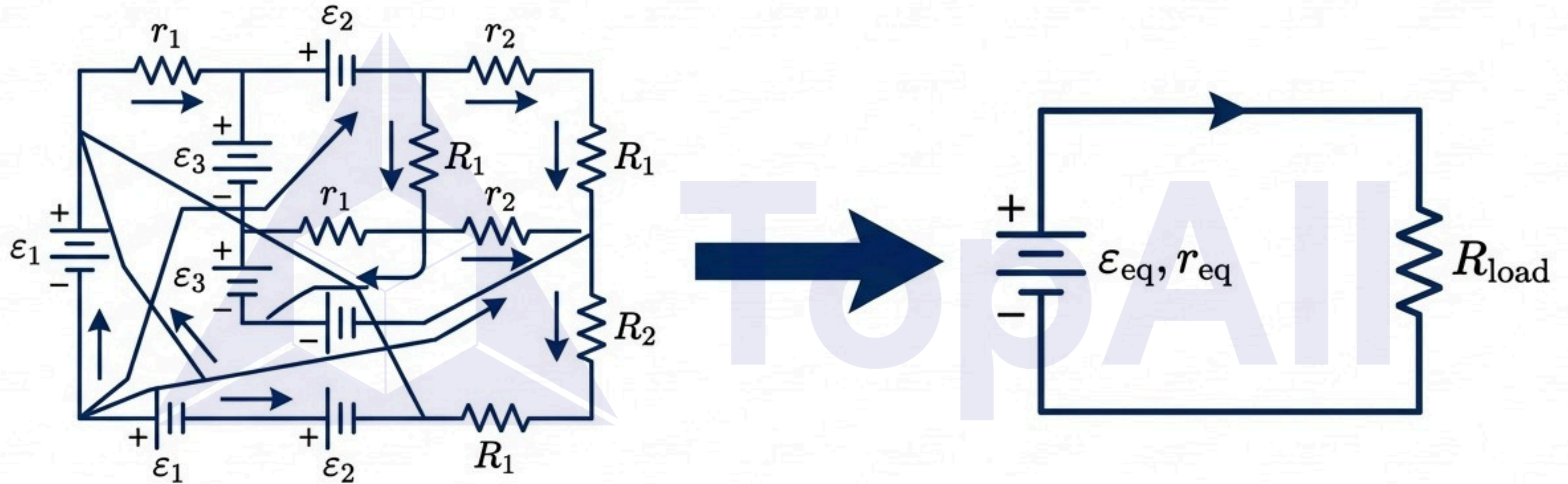


CELLS IN SERIES AND PARALLEL

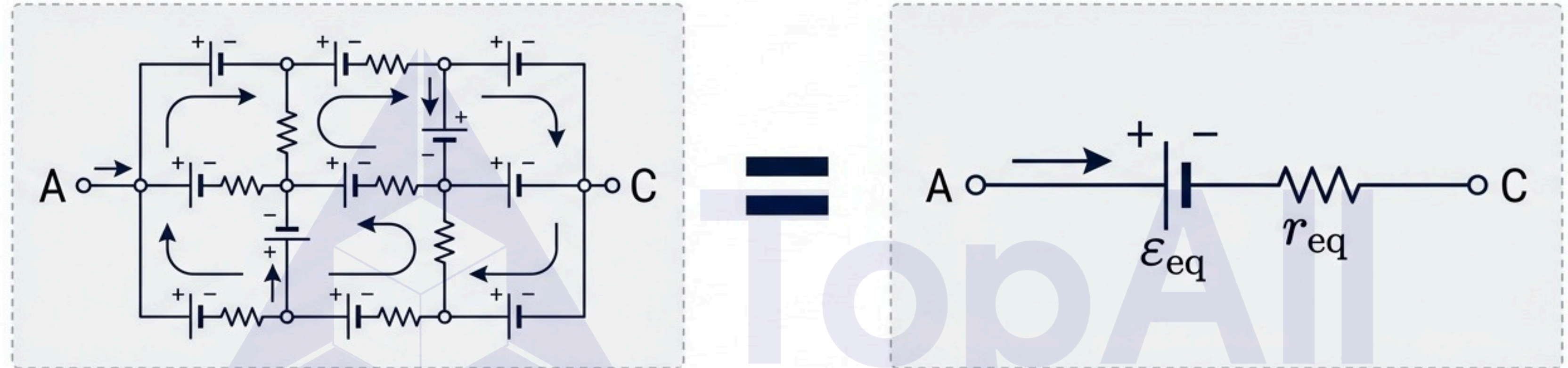
Circuit Simplification and Equivalent EMFs



Overview: Mastering the reduction of complex battery networks into a single equivalent cell (ϵ_{eq} , r_{eq}) to accelerate circuit analysis and master Kirchhoff's Rules.

THE EQUIVALENT CELL CONCEPT

Simplifying the Complex



The Conceptual Model: Any combination of cells—no matter how complex—can be replaced by a single equivalent cell for calculations.

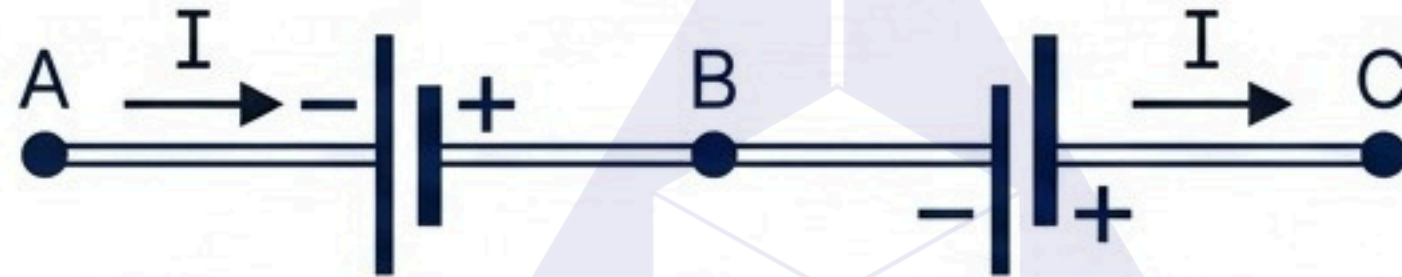
The Goal: Find the equivalent electromotive force (ϵ_{eq}) and equivalent internal resistance (r_{eq}) that produce the exact same potential difference and current in the external circuit.

Simplification allows us to bypass complex, multi-loop Kirchhoff equations and solve for external current instantly.

SERIES COMBINATIONS: POLARITY MATTERS

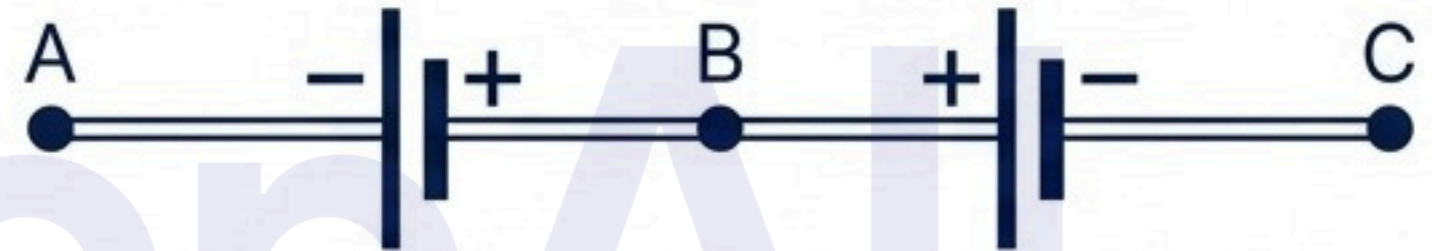
Stacking Potentials

AIDING POLARITY



Aiding Polarity: Cells push current in the same direction. Potentials stack additively.

OPPOSING POLARITY



Opposing Polarity: Cells 'fight' each other. The cell with the larger EMF dictates the direction of the current.

Internal resistance acts like a **physical tollbooth**. Regardless of polarity (aiding or opposing), the internal resistances ALWAYS add up.



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SERIES FORMULA BANK

Rules for Series Equivalency

When cells assist each other:

$$\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2$$

When cells oppose each other (assuming $\varepsilon_1 > \varepsilon_2$):

$$\varepsilon_{eq} = \varepsilon_1 - \varepsilon_2$$

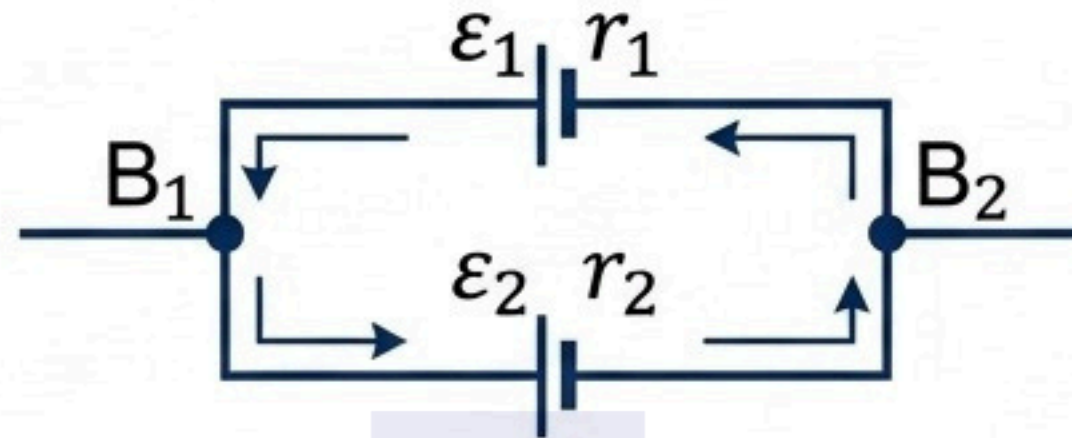
Internal resistance always adds in series:

$$r_{eq} = r_1 + r_2$$

Note: Can be extended to n cells: $\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2 + \dots + \varepsilon_n$

PARALLEL FORMULA BANK

Rules for Parallel Equivalency



Conductances add up in parallel:

$$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2}$$

The EMF ratio is the sum of individual ratios:

$$\frac{\epsilon_{eq}}{r_{eq}} = \frac{\epsilon_1}{r_1} + \frac{\epsilon_2}{r_2}$$

Rule of Thumb: If the polarity of a cell is reversed in the parallel branches, simply plug a negative sign into its ϵ value in the formula.

JEE TRAP ALERT

The Parallel EMF Misconception

~~$$\epsilon_{eq} = \epsilon_1 + \epsilon_2$$
$$\epsilon_{eq} = \frac{\epsilon_1 + \epsilon_2}{2}$$~~

The Trap: Students intuitively try to add parallel EMFs together, or assume that two identical cells in parallel double the voltage.

The Reality: Parallel EMF is a weighted average, weighted by the inverse of their internal resistances!

The Proof: $\epsilon_{eq} = (\epsilon_1 * r_2 + \epsilon_2 * r_1) / (r_1 + r_2)$

Pro-Tip: If you connect **n** identical cells of EMF **ϵ** and resistance **r** in parallel, the equivalent EMF is **STILL ϵ** , not **$n\epsilon$** . Only the internal resistance drops to **r/n** , allowing you to draw a much higher maximum current!

REVISION CHEAT SHEET

Cell Combinations at a Glance

Feature	Series Combination	Parallel Combination
Circuit Setup	Single path for current	Multiple paths for current
Equivalent EMF	$\mathcal{E}_{eq} = \mathcal{E}_1 \pm \mathcal{E}_2$	$\frac{\mathcal{E}_{eq}}{r_{eq}} = \frac{\mathcal{E}_1}{r_1} \pm \frac{\mathcal{E}_2}{r_2}$
Equivalent Resistance	$r_{eq} = r_1 + r_2$	$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2}$

The Golden Rules:

1. Internal resistance ALWAYS increases in series, and ALWAYS decreases in parallel.
2. EMF magnitude depends entirely on polarity. (Watch your signs!)



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