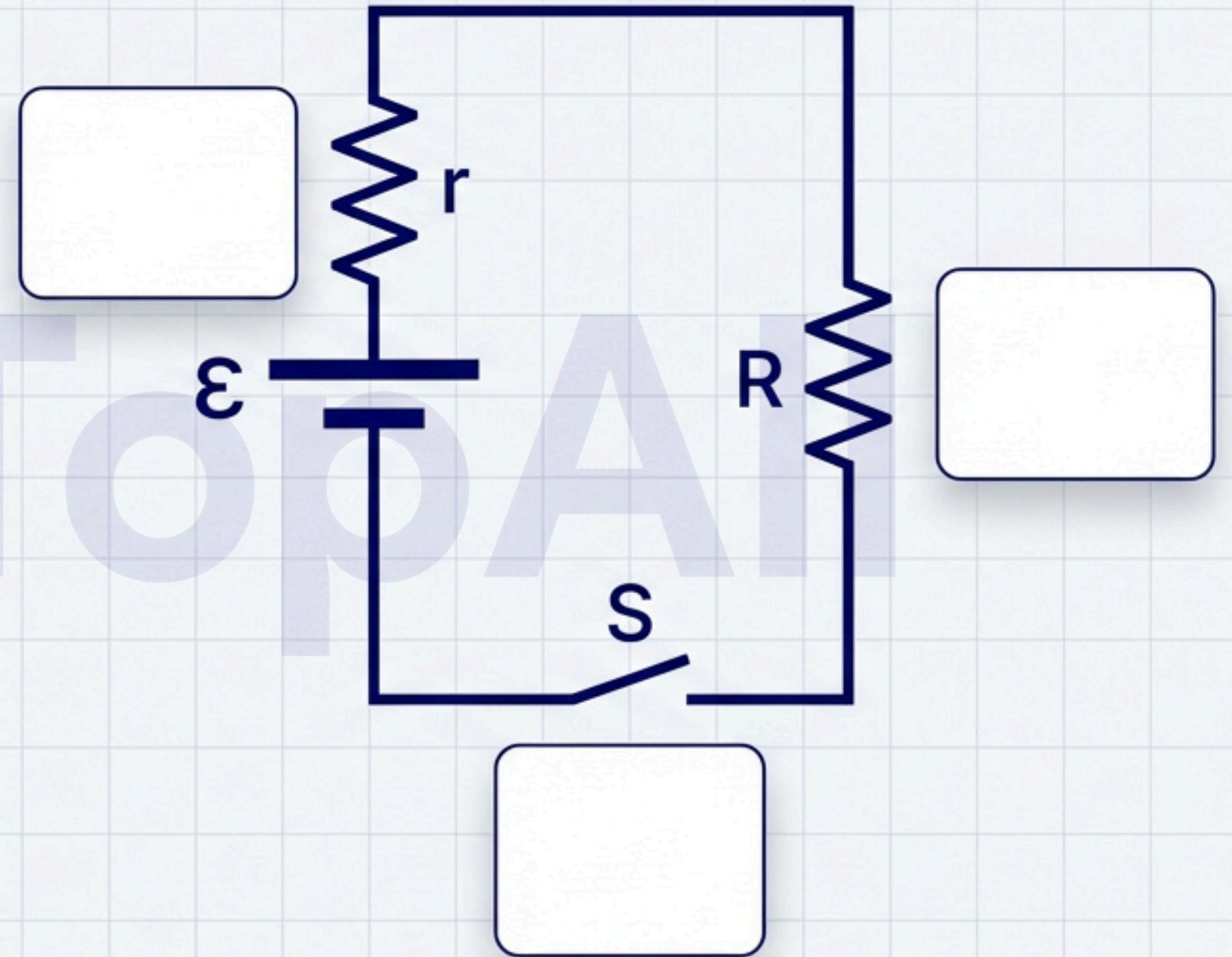


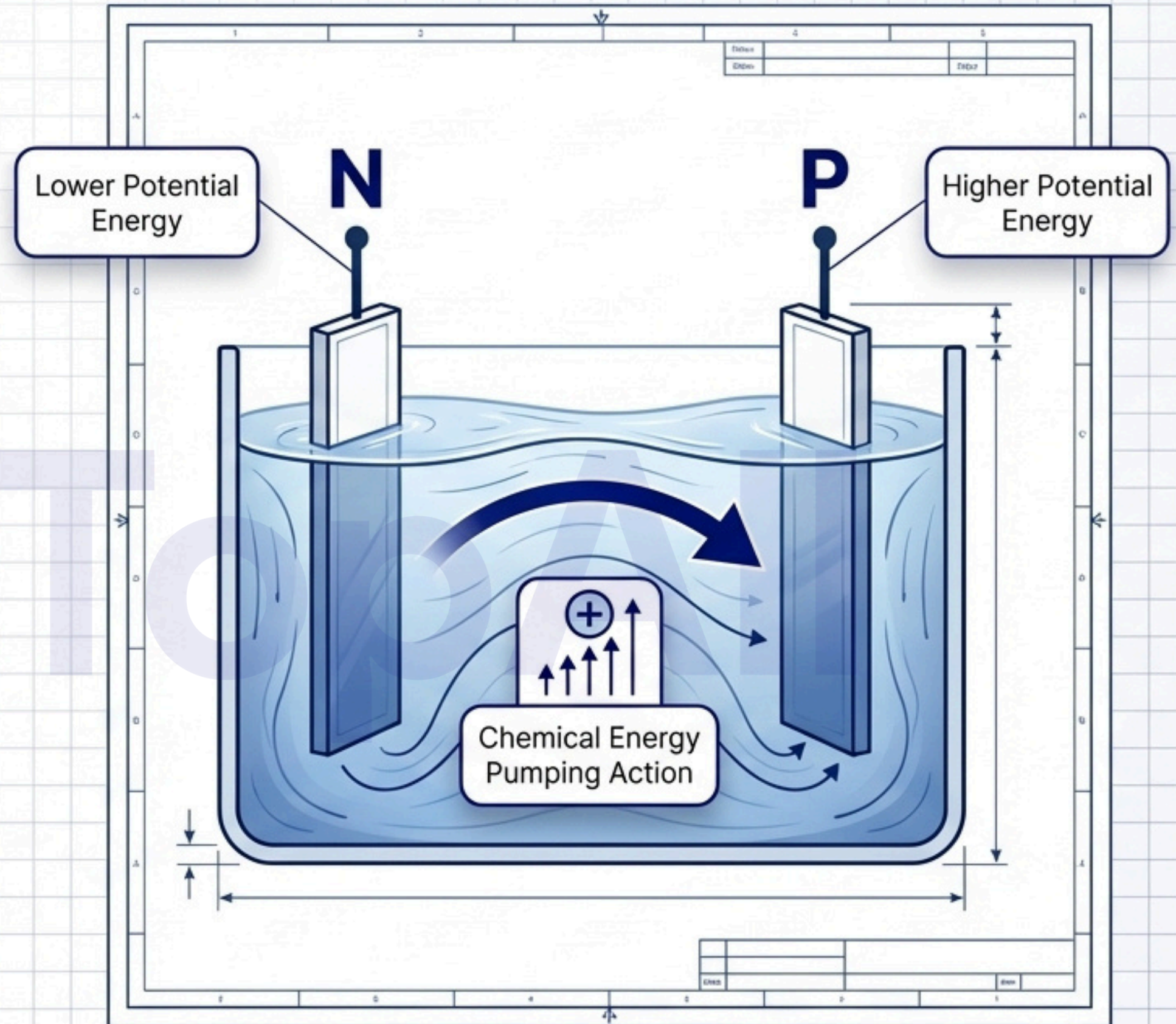
# Cells, emf, and Internal Resistance

Deriving the circuit current relation:  $I = \varepsilon / (R + r)$



# THE ENGINE OF A CIRCUIT

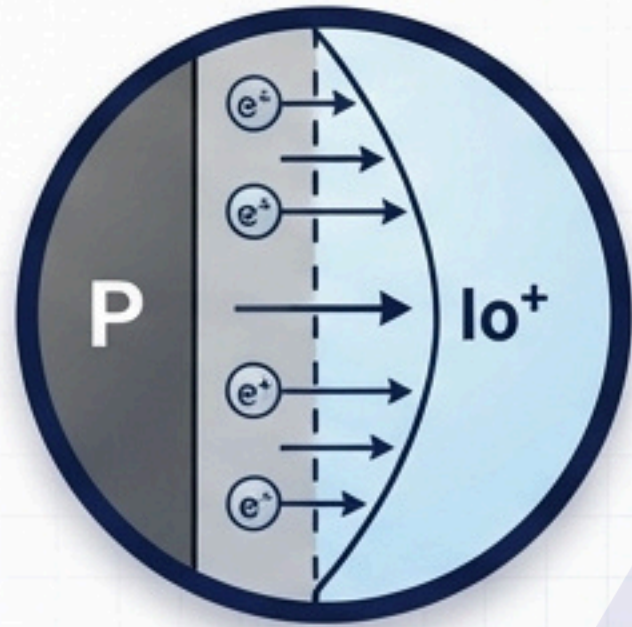
A cell does not supply charge; it supplies energy. It uses chemical energy to move electric charge from a lower to a higher potential, maintaining a steady current.



# OPEN CIRCUIT: DEFINING emf ( $\epsilon$ )

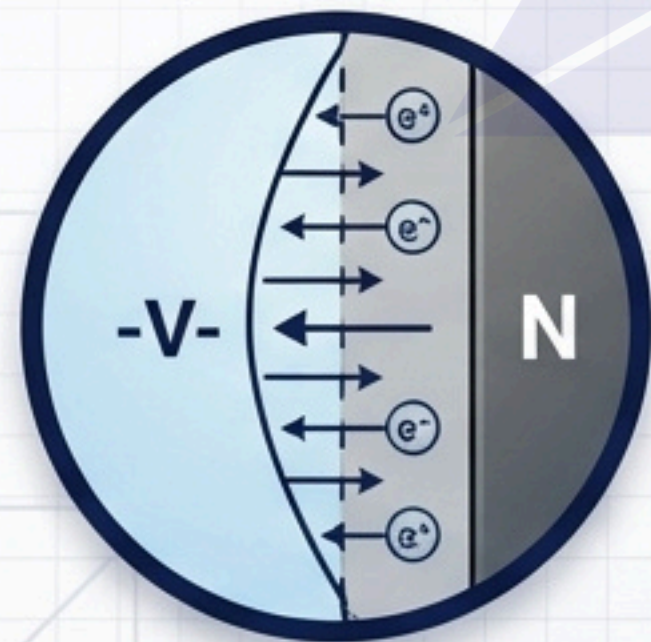
When no current flows, the potential difference across the cell is at its theoretical maximum.

At Positive Electrode (A)



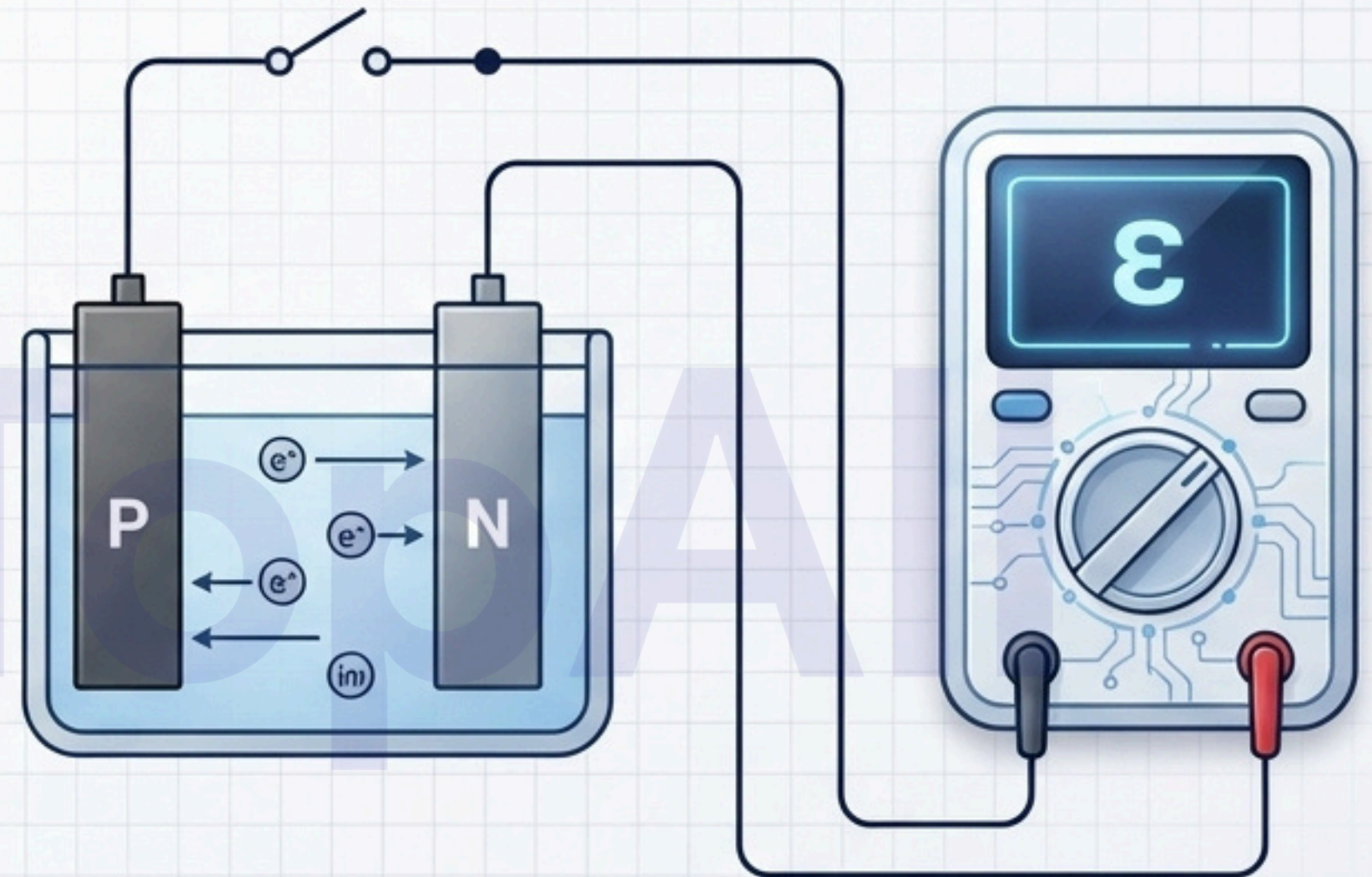
$$V^+ (V^+ > 0)$$

At Negative Electrode (B)



$$-V^- (V^- \geq 0)$$

$$\text{Electromotive Force } (\epsilon) = V_+ - (-V^-) = V_+ + V^-$$



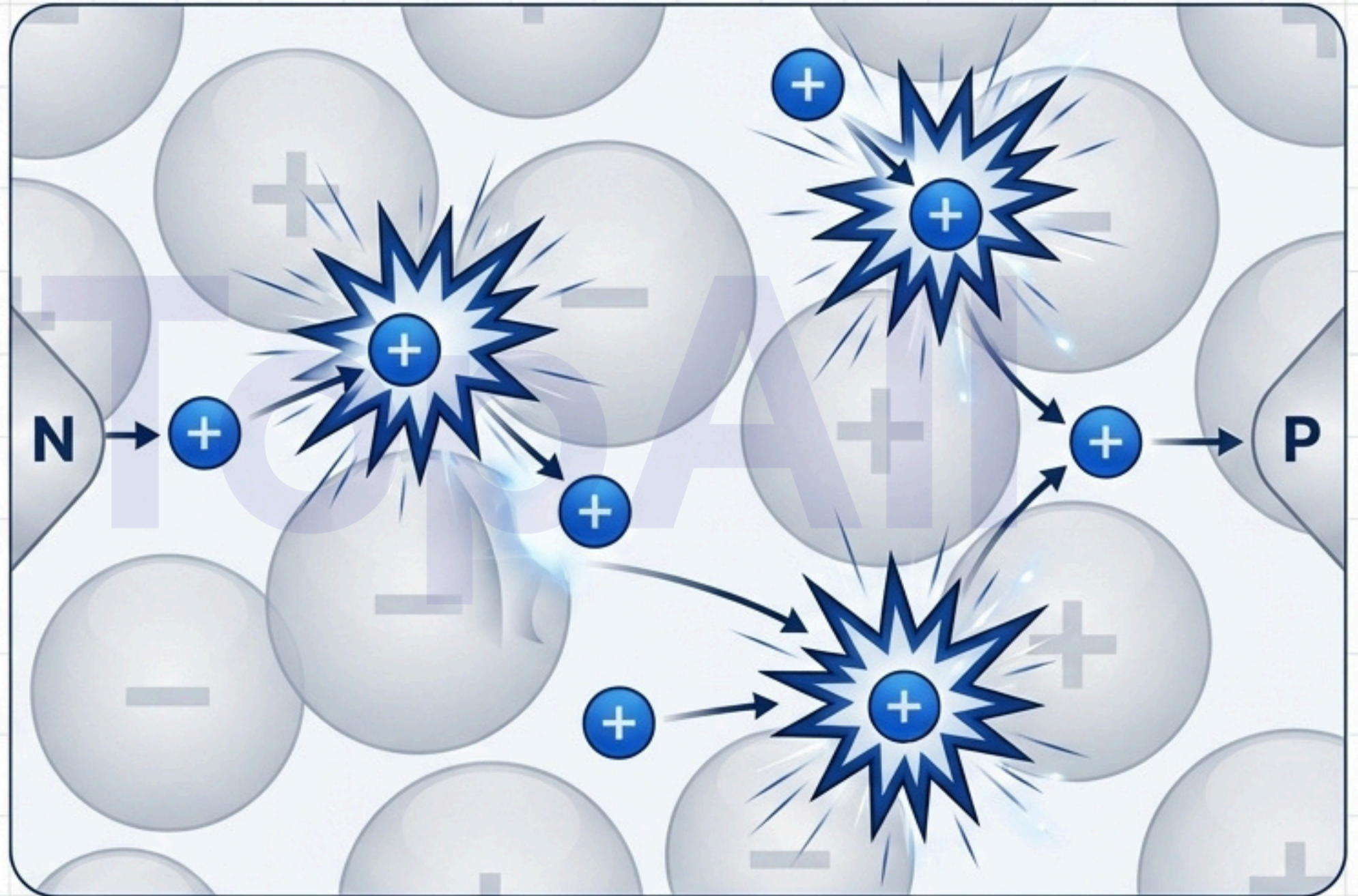
**Historical Misnomer:**  
emf is a potential difference  
(Joules/Coulomb),  
NOT a force (Newtons).

# THE REAL-WORLD CONSTRAINT: INTERNAL RESISTANCE ( $r$ )

The electrolyte itself opposes the flow of current. The ideal  $\mathcal{E}$  is never fully available in a closed circuit.

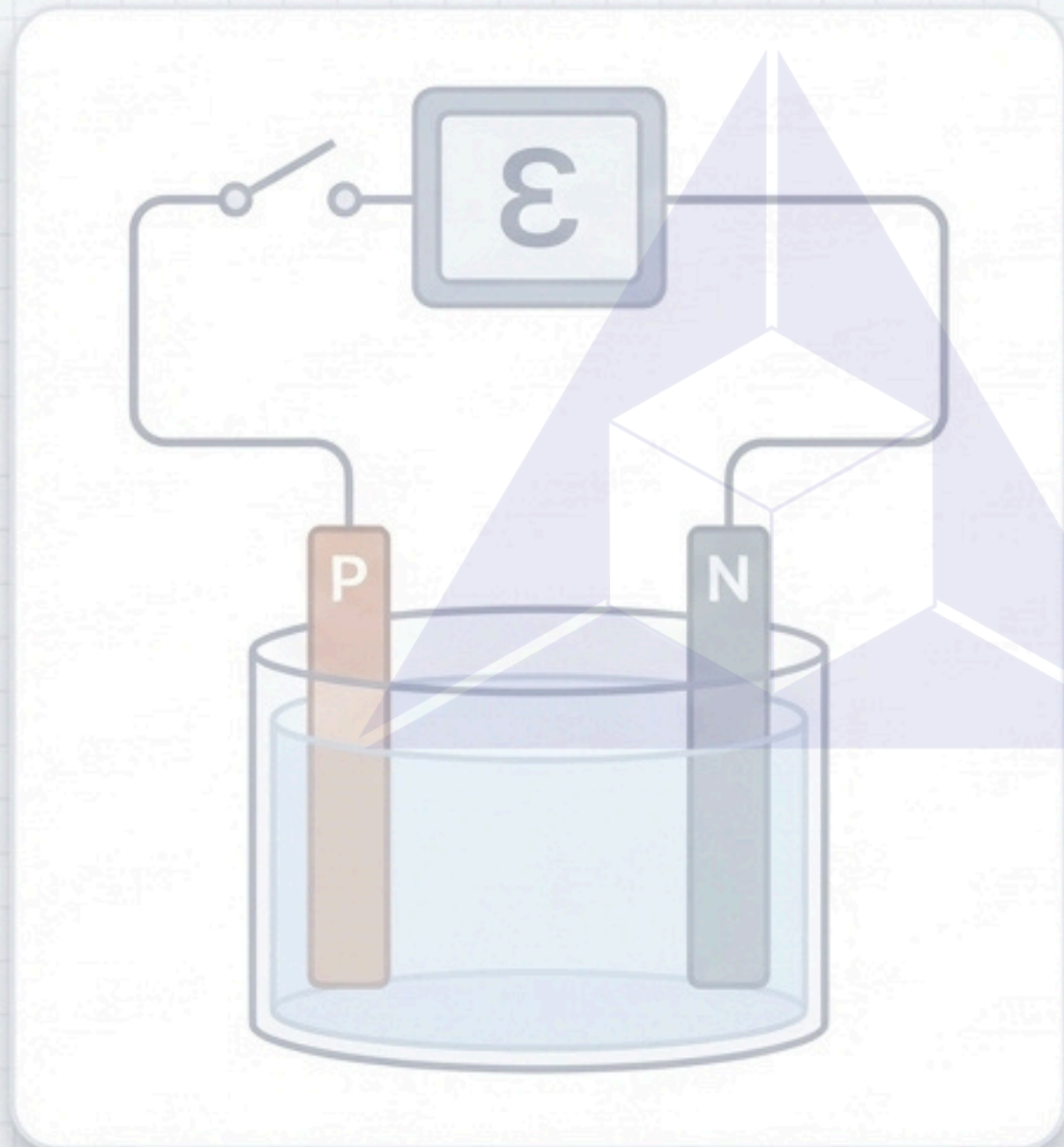
## Internal Resistance ( $r$ )

The finite resistance offered by the electrolyte to the flow of current inside the cell.

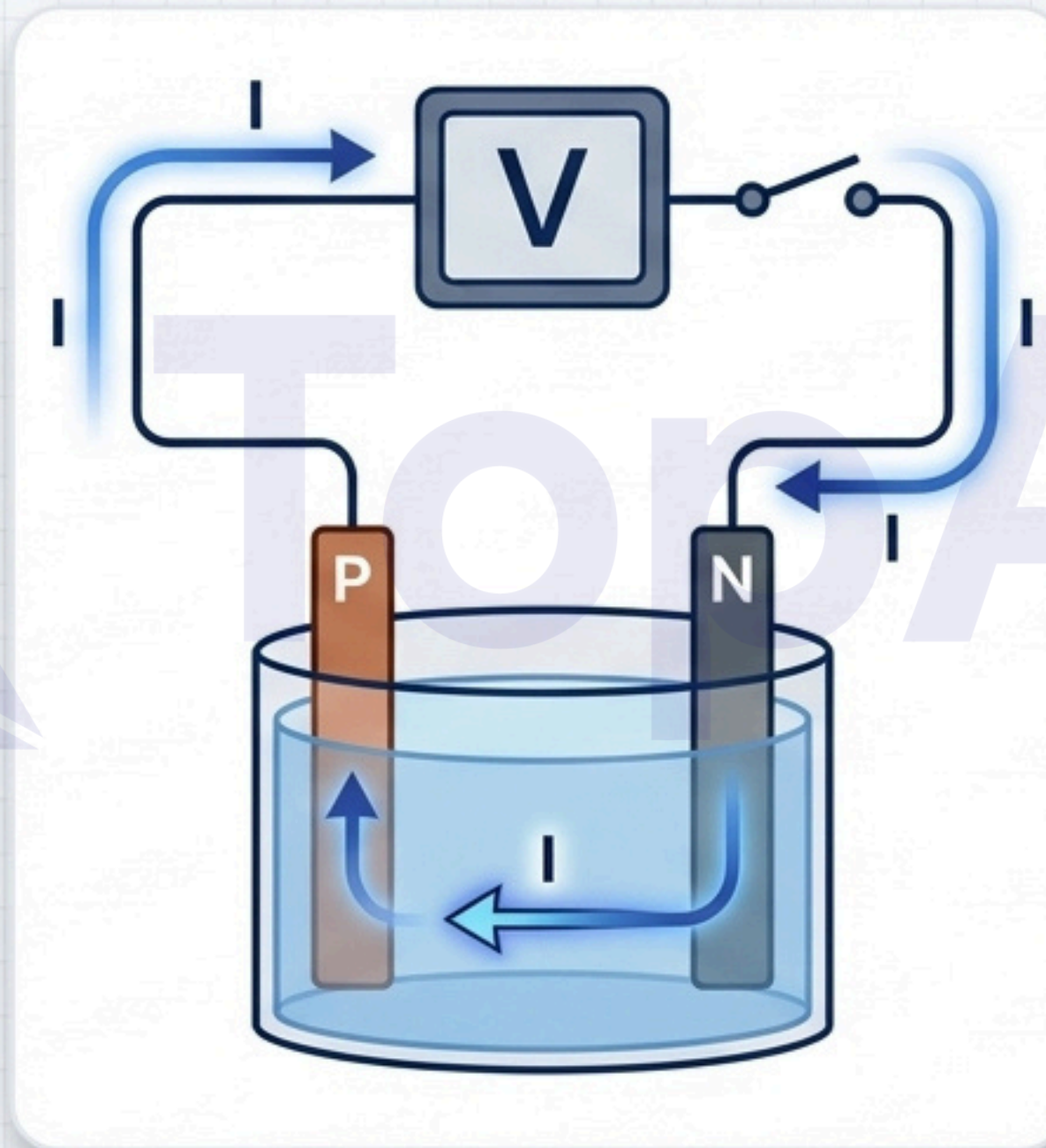


# LOADED CIRCUIT: TERMINAL VOLTAGE (V)

Open



Loaded



DERIVATION FLOW

**Current  $I$**  flows through electrolyte (N to P).



It encounters internal resistance  $r$ .

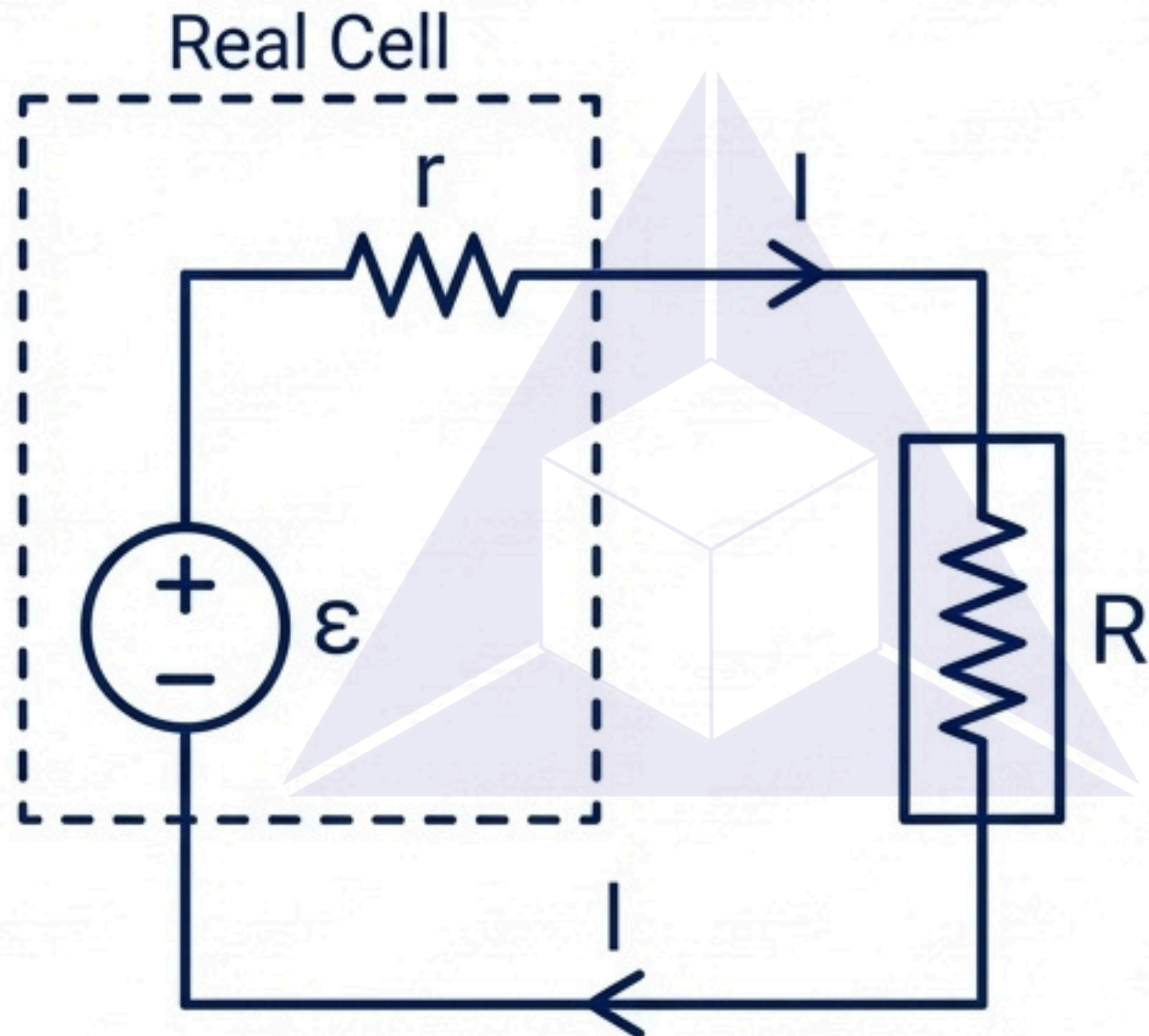


**Voltage** drops by  $-Ir$ .



$$V = \mathcal{E} - Ir$$

# SYNTHESIZING THE CURRENT EQUATION



Terminal Voltage:  $V = \epsilon - Ir$

Ohm's Law (External):  $V = IR$

Equating the two:  $IR = \epsilon - Ir$

Rearranging:  
 $IR + Ir = \epsilon \rightarrow I(R + r) = \epsilon$

$$I = \frac{\epsilon}{R + r}$$

# KEY TAKEAWAYS



## CORE VARIABLES

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- $\varepsilon$  = emf (Open circuit potential difference)
- $V$  = Terminal Voltage (Loaded potential difference)
- $r$  = Internal resistance of electrolyte

## THE MASTER FORMULA

$$I = \frac{\varepsilon}{R + r}$$

Connects internal cell mechanics to external circuit loads.

## EXAM EDGE CASES

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**Open Circuit:**

$$I = 0 \Rightarrow V = \varepsilon$$

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**Short Circuit  
(Max Current):**

$$R = 0 \Rightarrow I_{\max} = \frac{\varepsilon}{r}$$

(Note: May cause permanent cell damage)