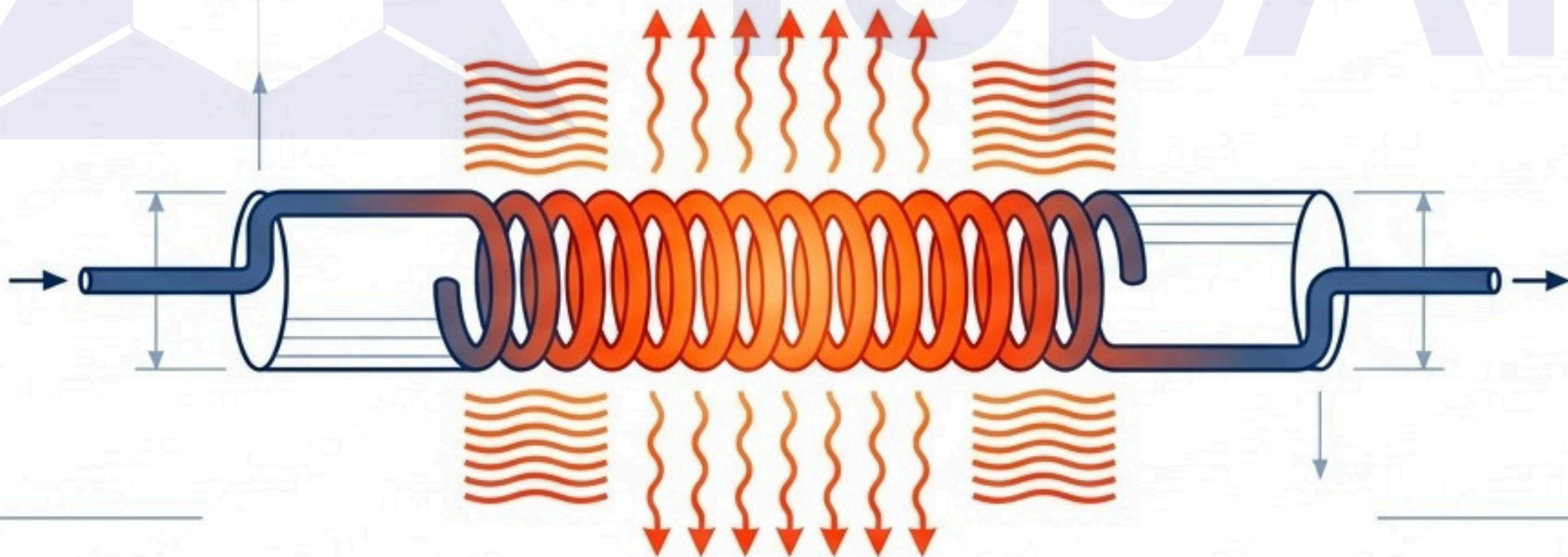


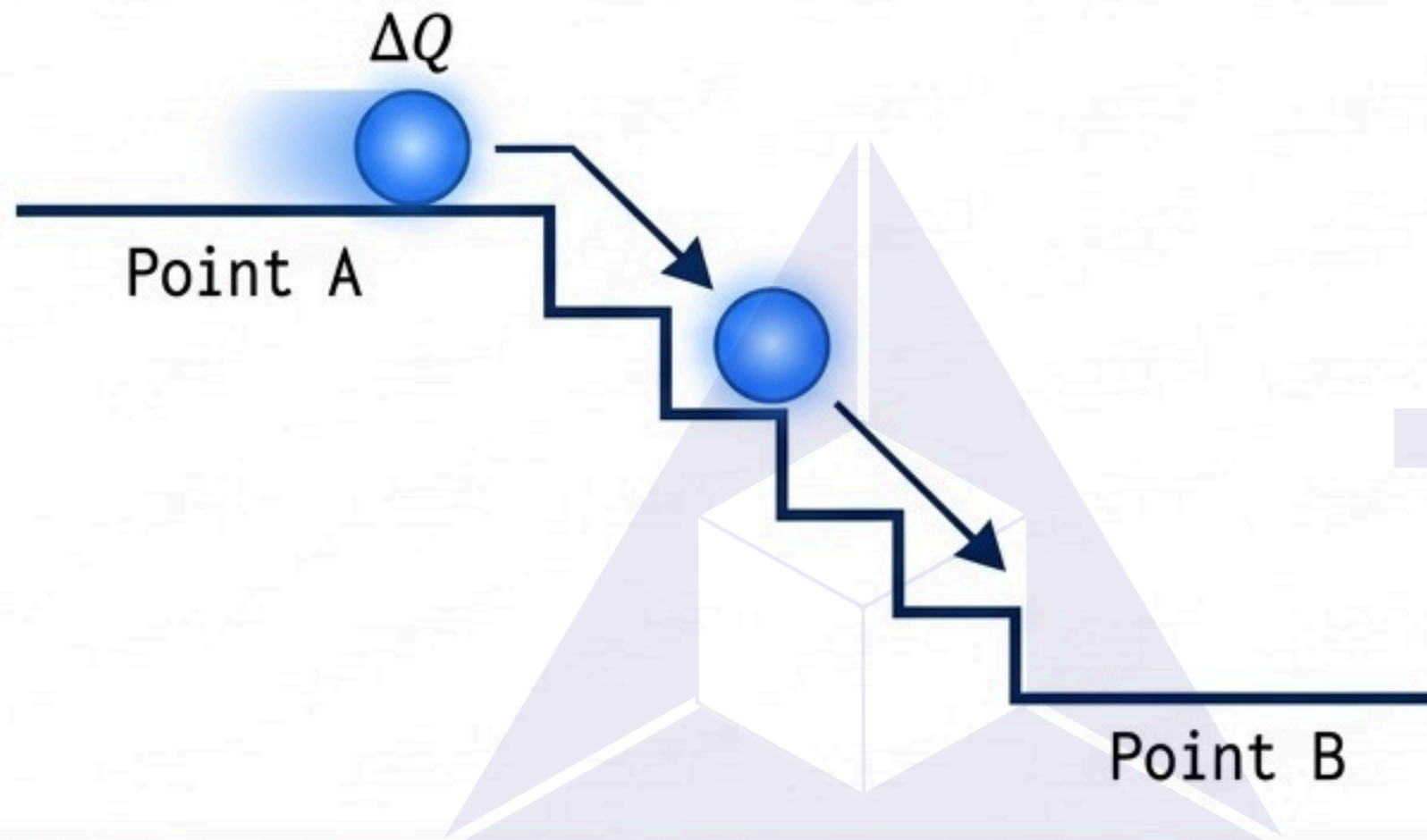
Electrical Energy, Power and Transmission Loss

From microscopic lattice collisions to macroscopic power grids.



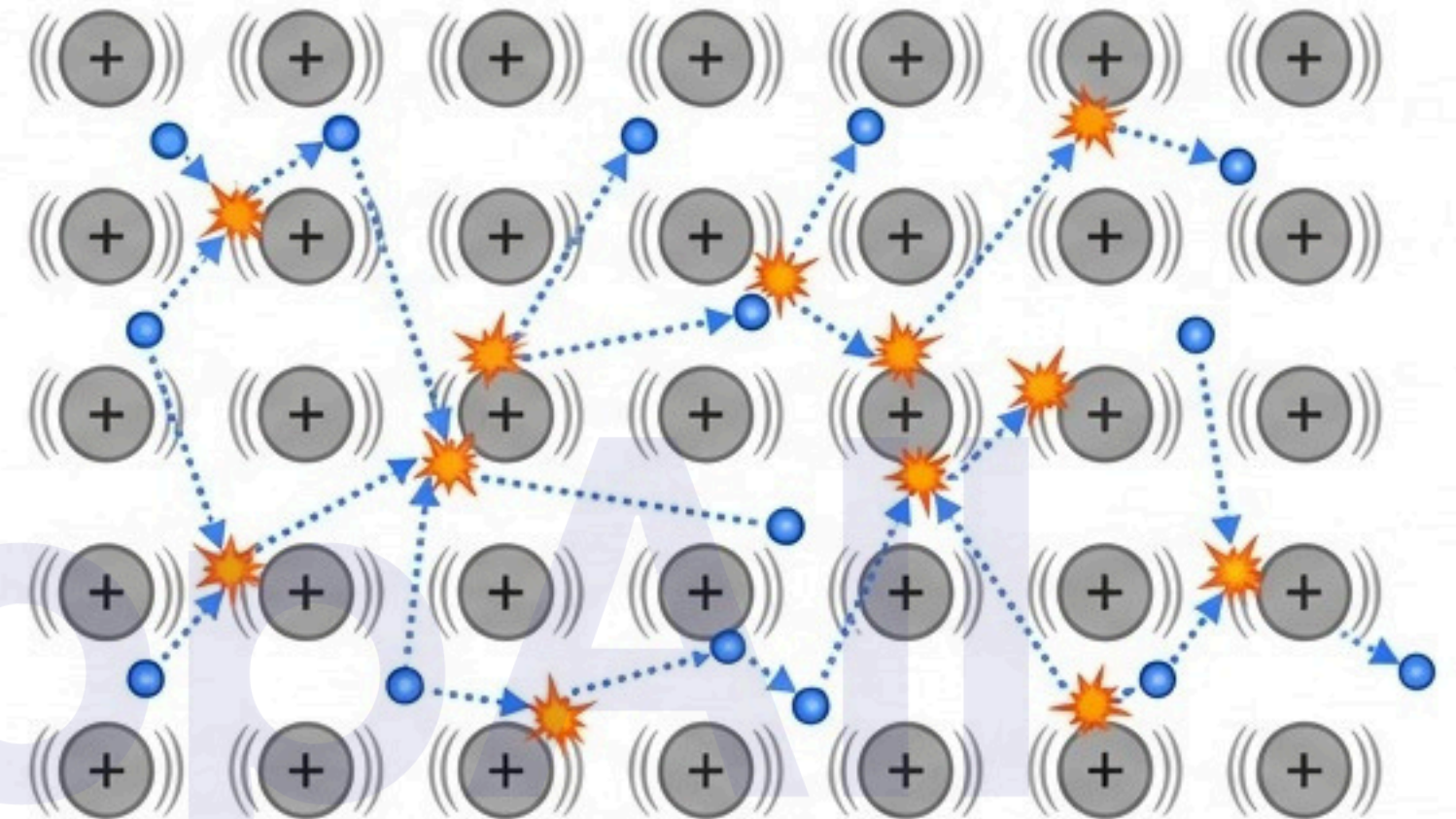
THE PRECISION BLUEPRINT: OHMIC HEAT GENERATION

MACRO: The Potential Drop



Potential energy drops: $\Delta U_{pot} = -IV\Delta t < 0$.
By conservation of energy, kinetic energy *should* increase ($\Delta K = IV\Delta t > 0$).

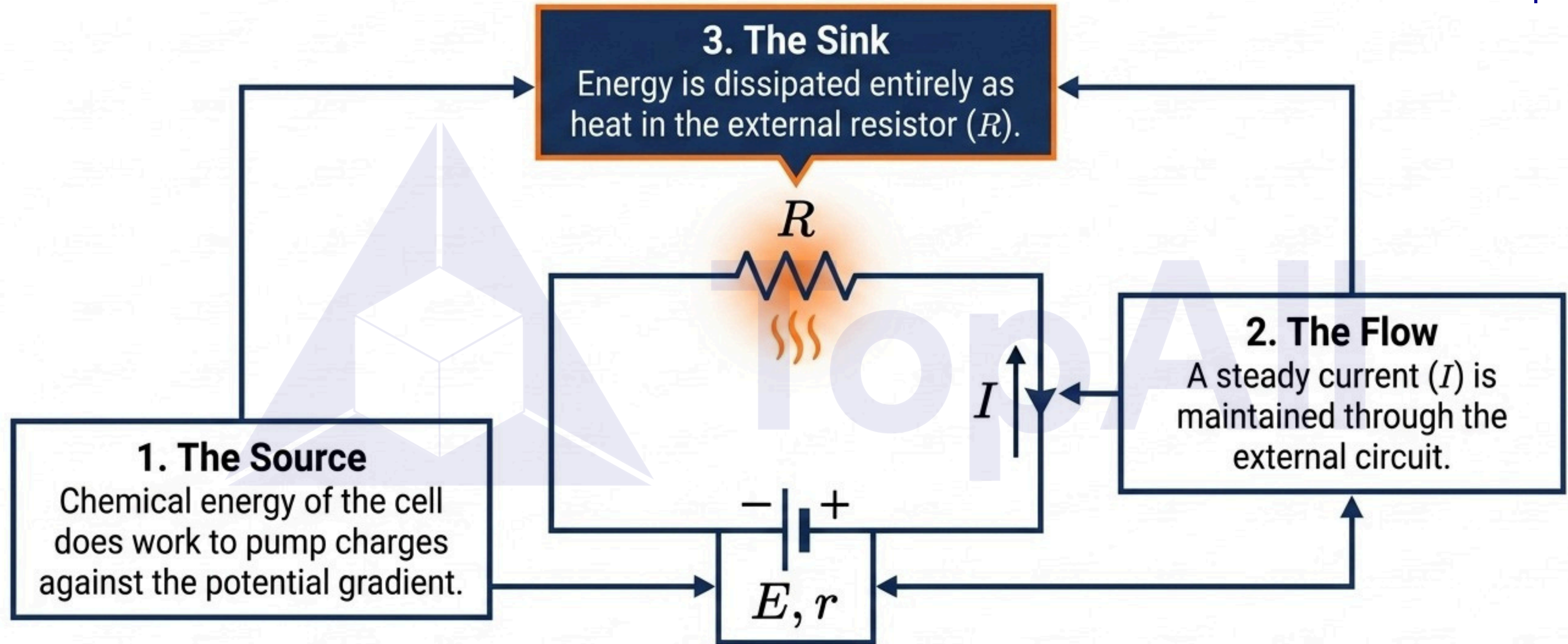
MICRO: The Lattice Collision



Electrons do *not* accelerate freely. Energy gained from the electric field is shared with the atoms during constant collisions, causing vigorous lattice vibrations.

SYNTHESIS: The 'lost' potential energy transfers to the lattice as vibrational kinetic energy, manifesting macroscopically as **Ohmic Heat** ($\Delta W = IV\Delta t$).

THE CIRCUIT MODEL OF HEAT DISSIPATION



Key Insight: The exact amount of work done by the cell is dissipated as heat in the resistor.



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$$E=mc^2$$



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The Mathematical Toolkit

General Power

$$P = IV$$

Energy dissipated per unit time in ANY device.

Ohmic Power

$$P = I^2 R = \frac{V^2}{R}$$

Specific to resistors.
Derived by substituting
Ohm's Law ($V=IR$).

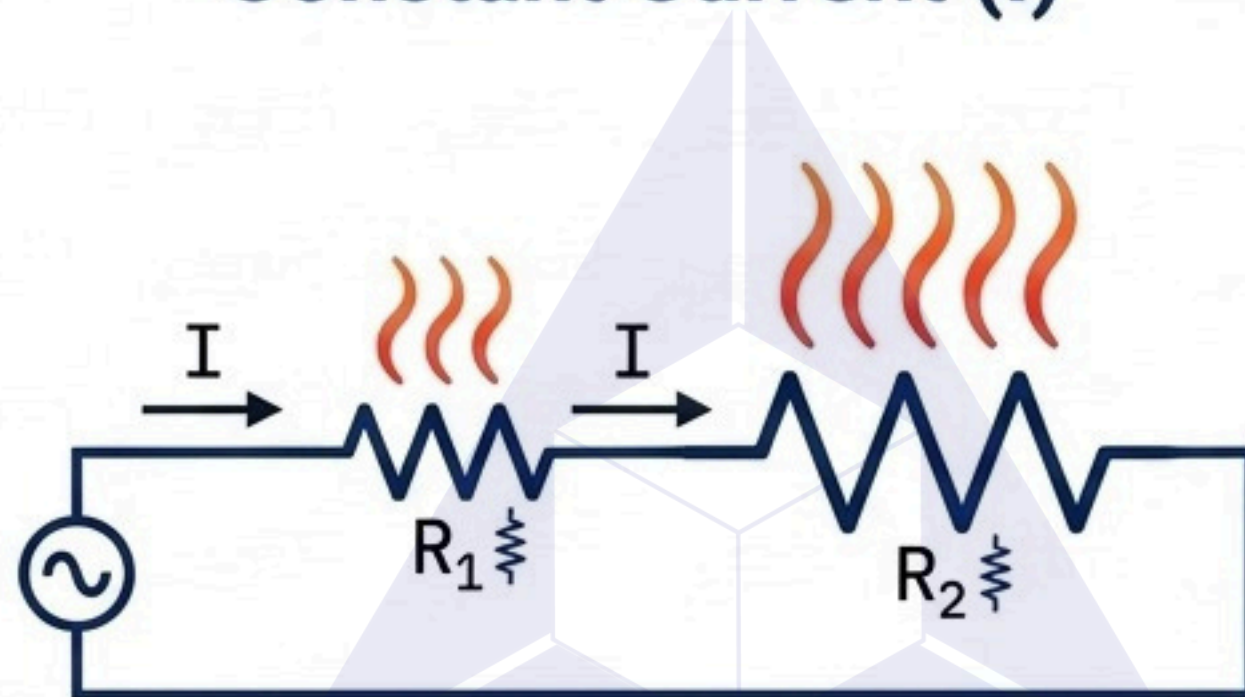
Transmission Loss

$$P_c = I^2 R_c = \left(\frac{P}{V} \right)^2 R_c$$

Cable loss for transmitted
power P across
wires of resistance R_c .
(Substitute $I = P/V$).

TRAP ALERT: Does Power increase or decrease with Resistance?

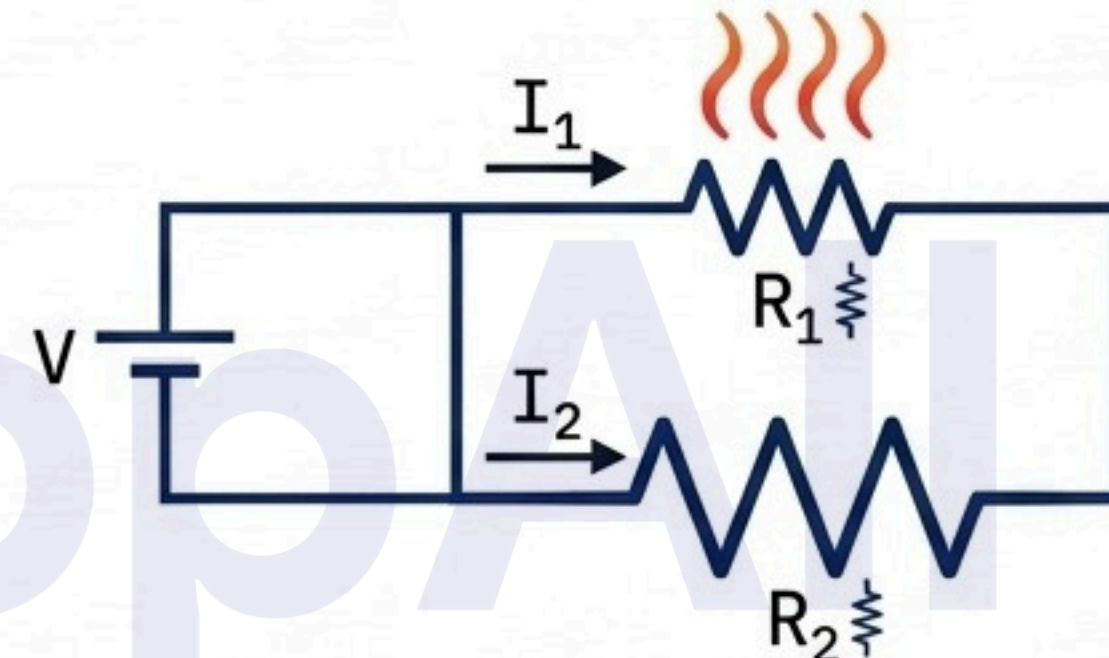
Constant Current (I)



$$P = I^2 R$$

$P \propto R$. (In series, the HIGHER resistance dissipates more heat).

Constant Voltage (V)

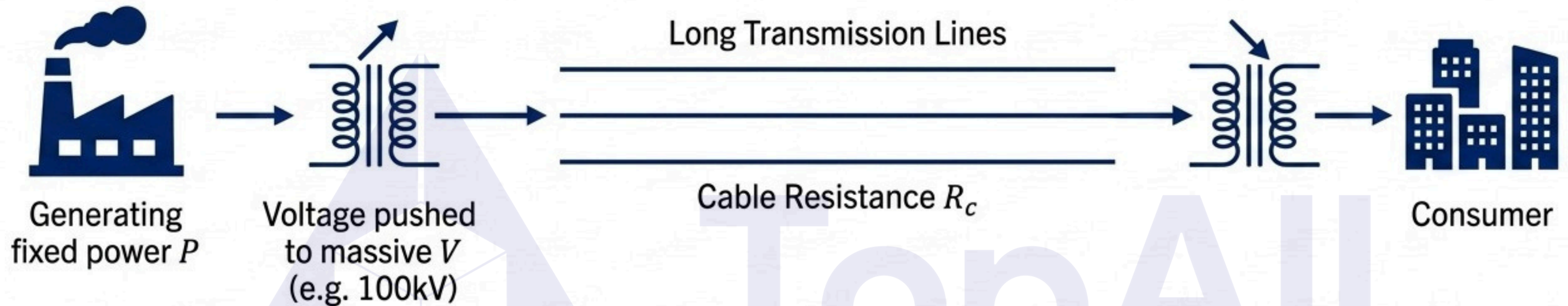


$$P = V^2 / R$$

$P \propto 1/R$. (In parallel, the LOWER resistance dissipates more heat).

Never guess the relationship. The formula you choose must always rely on the variable that remains **CONSTANT** in that specific circuit architecture.

Macro Application: The Power Grid



- **The Problem:** Transmitting power across hundreds of miles means high cable resistance (R_c). Cable loss is $P_c = I^2 R_c$.
- **The Solution:** To deliver a massive fixed power P without melting the wires, you must reduce the current I .
- **The Math:** Because $I = P/V$, stepping up the voltage ($V \uparrow$) shrinks the current ($I \downarrow$) to a tiny fraction, practically eliminating the Ohmic loss.

For a fixed transmitted power,

cable loss

$$P_c \propto \frac{1}{V^2}$$

- Doubling the transmission voltage cuts the wasted energy by a factor of 4.
- Increasing voltage by 10x cuts wasted energy by a factor of 100.
- *This single mathematical truth dictates the architecture of the modern global electrical grid.*



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