Why a 12 V Battery Gives Only 10 V

Physics | JEE Main & Advanced

Don't Memorize. Visualize.

Every battery has a small resistance r inside it. When the battery drives a current I, a voltage Ir is used up across r, so the voltage across its ends is $V = E - Ir$, less than its emf E. The two are equal only when no current flows.

EMF, E

The voltage a battery gives when no current flows: what an ideal voltmeter reads across it on its own. The 12 V marked on a battery is its emf.

It does not change with the current.

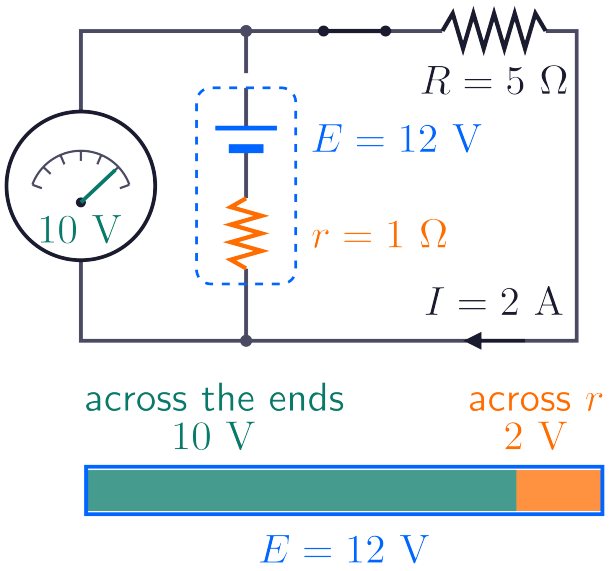
TERMINAL VOLTAGE, V

The voltage across the battery's two ends while it drives a current I: $V = E - Ir$.

It falls as the current grows.

Where the 2 V goes: one circuit

A battery of emf $E = 12$ V with internal resistance $r = 1\ \Omega$ drives a current through $R = 5\ \Omega$.
The same current flows through R and r, which are in series: $I = \dfrac{E}{R + r} = \dfrac{12}{5 + 1} = 2$ A.
Across r, inside the battery: $Ir = 2 \times 1 = 2$ V, used up as heat in the battery.
Left across the ends: $V = 12 - 2 = 10$ V. This is also $IR = 2 \times 5$, the voltage across R, and it is what the voltmeter reads.

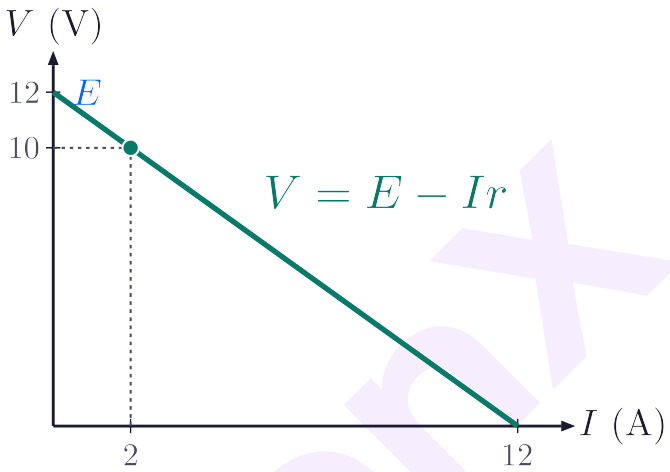


Open the switch

With the switch open, $I = 0$, so $Ir = 0$ and the voltmeter reads $V = E = 12$ V. This is why the emf is the reading with no current.

The voltage against the current

$V = E - Ir$ is a straight line on a graph of V against I.
It meets the V-axis at E (no current) and falls by r for every ampere: its slope is $-r$. At $I = 2$ A it gives 10 V.
It reaches $V = 0$ at $I = \dfrac{E}{r} = 12$ A, the largest current the battery can drive: its ends joined by a thick wire (a short circuit).



CAREFUL

The label is not the voltage you get. A battery marked 12 V gives 12 V across its ends only when no current flows. The more current it drives, the less it gives.
$V = E - Ir$ **is for a battery driving the current.** When another source pushes current into it (charging), the current goes the other way through r and $V = E + Ir$.

Solved example

A cell of emf 3 V and internal resistance $1\ \Omega$ is joined to a $5\ \Omega$ resistor. Find the current and the voltage across the cell's ends.

Current. $I = \dfrac{E}{R + r} = \dfrac{3}{5 + 1} = 0.5$ A.

Ends. $V = E - Ir = 3 - 0.5 \times 1 = 2.5$ V. Check: $IR = 0.5 \times 5 = 2.5$ V.

0.5 A; 2.5 V

Key formulas

$$\text{current in the circuit} = \frac{E}{R + r}$$

$$\text{voltage across the ends (driving the current)} = E - Ir = IR$$

$$\text{voltage across the ends (being charged)} = E + Ir$$

$$\text{short-circuit current} = \frac{E}{r}$$

Practice set

Easy to hard. The voltmeter is ideal (it draws no current). The answers start on the next page.

Q1. Quiz from the Short. A battery has $E = 6$ V and $r = 0.5\ \Omega$, and the current is 2 A. What does a voltmeter across its ends read? (A) 6 V (B) 5 V (C) 1 V.

Q2. A cell of emf 1.5 V and internal resistance $0.5\ \Omega$ is joined to a $2.5\ \Omega$ resistor. Find the current and the voltage across the cell's ends.

Q3. A voltmeter reads 9 V across a battery on its own and 8 V when the battery drives a current of 0.5 A. Find the emf and the internal resistance.

Q4. A battery has $E = 12$ V and $r = 2\ \Omega$. What resistance must be joined to it so that the voltage across its ends is 9 V?

Q5. A battery of emf 12 V and internal resistance $0.5\ \Omega$ has its ends joined by a thick wire of negligible resistance. Find the current and the voltage across its ends.

Q6. A battery of emf 12 V and internal resistance $1\ \Omega$ is being charged by a current of 2 A. Find the voltage across its ends.

Watch the animated lesson on YouTube

Why a 12 V Battery Gives Only 10 V (Short)

Scan the code to open the JEEVisionX channel on YouTube. This lesson is in the JEE Concepts Visualization Shorts playlist.

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Answers

Q1

(B) 5 V

The voltage used up inside is $Ir = 2 \times 0.5 = 1$ V, so $V = E - Ir = 6 - 1 = 5$ V. 6 V forgets r; 1 V is Ir alone.

Q2

0.5 A; 1.25 V

$I = \dfrac{1.5}{2.5 + 0.5} = 0.5$ A;
$V = 1.5 - 0.5 \times 0.5 = 1.25$ V $= 0.5 \times 2.5$.

Q3

$E = 9$ V; $r = 2\ \Omega$

With no current the voltmeter reads E. Then $8 = 9 - 0.5\,r$, so $r = 2\ \Omega$.

Q4

$6\ \Omega$

$Ir = 12 - 9 = 3$ V, so $I = \dfrac{3}{2} = 1.5$ A and $R = \dfrac{9}{1.5} = 6\ \Omega$.

Q5

24 A; 0 V

$I = \dfrac{E}{r} = \dfrac{12}{0.5} = 24$ A. All 12 V is used up inside: $Ir = 12$ V, so $V = 0$.

Q6

14 V

While being charged, the current enters at the $+$ end, so $V = E + Ir = 12 + 2 \times 1 = 14$ V.

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