

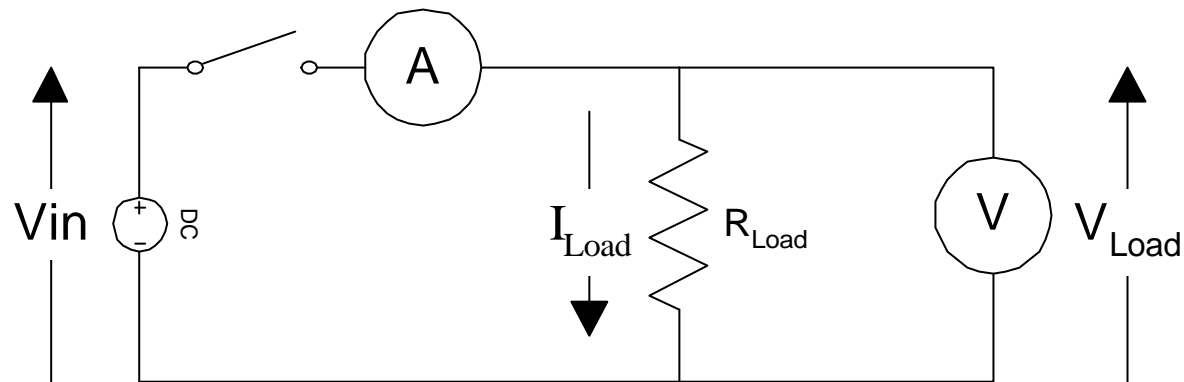


Voltage and Current Meters

- Voltage is always measured between two points.
 - That is, the *voltmeter* is connected in *parallel* with the circuit.
 - This means that voltage can be conveniently measured without breaking the circuit and interrupting the current.
- Current is measured by passing all the current through the meter.
 - That is, the ammeter is connected in *series* with the circuit.
 - This means that the circuit must be broken and reconnected via the *ammeter* so that all the current flows through the meter.
 - In circuit troubleshooting and testing, it is often inconvenient to break the circuit to perform measurements, so voltage measurements are preferred.



Connecting Ammeters and Voltmeters



To avoid measurement errors due to connecting ammeters and voltmeters

- Voltmeters should have high internal resistance
- Ammeters should have low internal resistance



Open and Closed Circuits

- A circuit is said to be *closed* when there is a complete path available for the passage of current, as occurs when the switch is closed in the previous circuit
- A circuit is said to be *open* (or open-circuit) if current is unable to flow, as occurs when a switch is open. When a fuse blows, sometimes we say it has gone *open-circuit*.



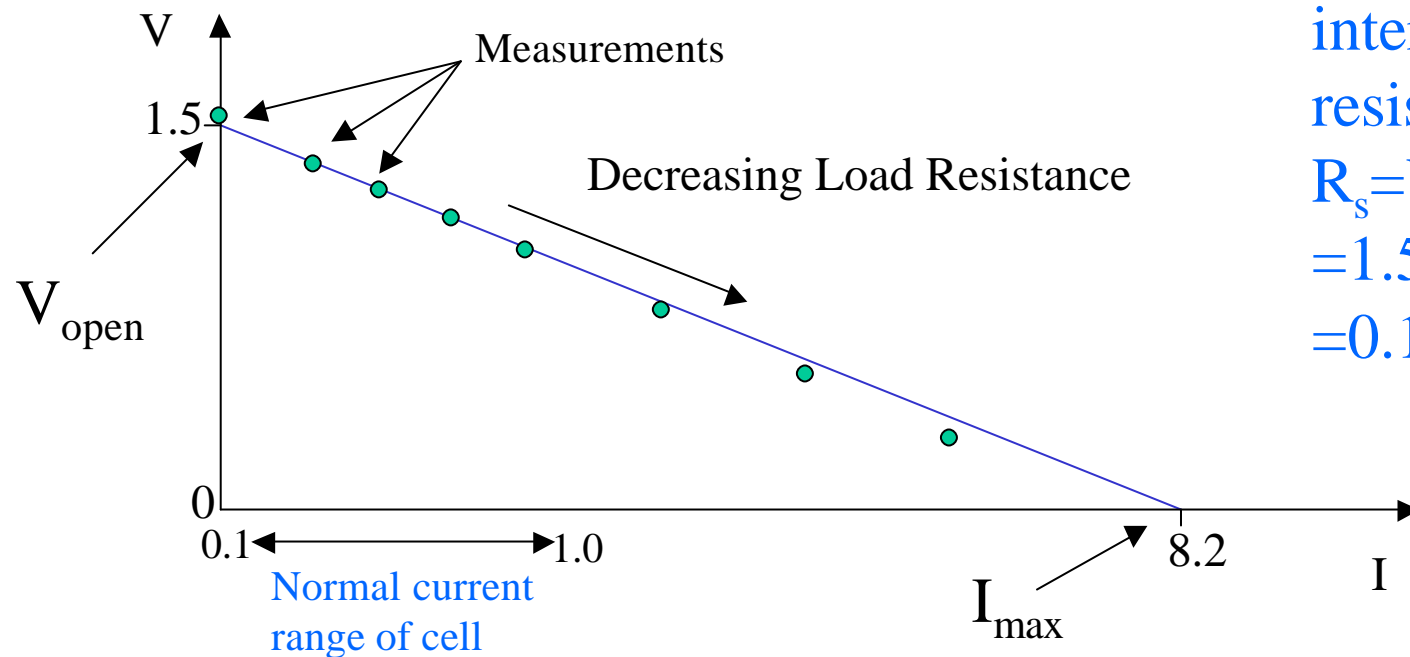
Ideal Sources

- We are all familiar with batteries to supply DC at a reasonably constant voltage. For example, a fresh Alkaline “D” (electrochemical) cell will provide 1.5V under light current load.
- But what happens as we increase the load from say 10Ω to 1Ω and even down to $.0001\Omega$?
- From Ohm’s Law
 - Current = $1.5/10 = 150\text{mA}$ into 10Ω
 - Current = $1.5/1 = 1.5\text{A}$ into 1Ω
 - Current = $1.5/0.0001 = 15,000\text{A}$ into 0.0001Ω
- There is no way this cell can provide 15,000A, so the voltage must fall below 1.5V under this heavy load.



Ideal Voltage Source

- If we plot cell voltage versus current for a fresh cell, the plot might look something like this.



From graph
internal cell
resistance

$$R_s = V_{open} / I_{max} \\ = 1.5 / 8.2 \\ = 0.183 \Omega$$



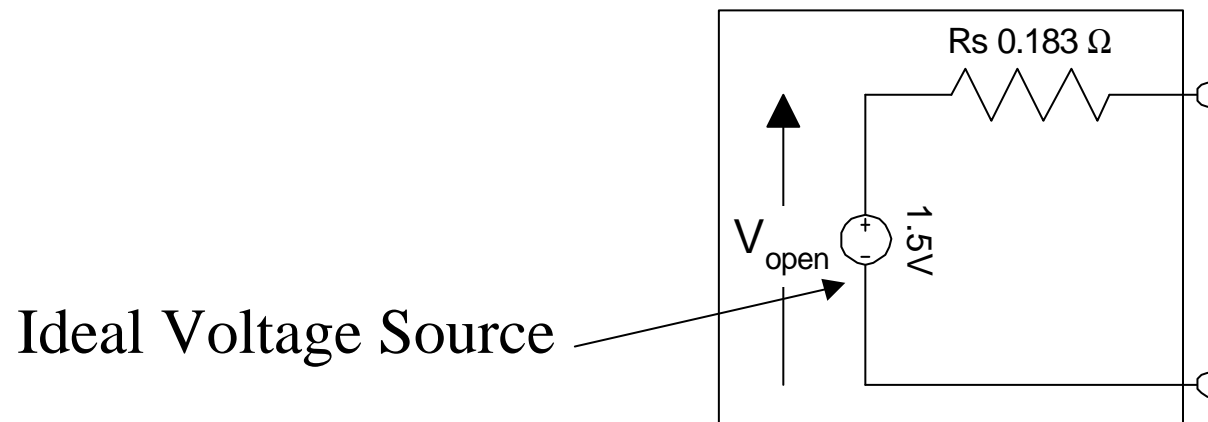
Comments

- Notice how the measured currents under heavy load tend to fall below the regression line (called the *load line*) established by the measurements performed under light load
 - This could be due to the onset of some limiting process such as hydrogen formation or heating in the cell which does not occur in normal operation.
- The open circuit measurement may also be slightly higher than the trend line
- Therefore the load line should always be drawn through measurement points in the normal current range of the device.



Thevenin Model

- A real cell can be modelled as an *ideal voltage source* in series with an internal resistance, R_s
- The ideal voltage source maintains a constant voltage regardless of the load
- The diagram below shows the *Thevenin model* for the cell.





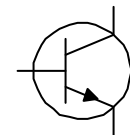
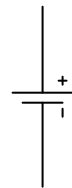
Comments

- All practical voltage sources are non-ideal, but when they are used within the working range for which they are designed, their behaviour is close to ideal.
- Although real sources are not ideal, we generally assume that the sources will be used sensibly and draw our circuits using ideal models.
- The ideal voltage source maintains a constant voltage at its output terminals and has zero internal resistance.



Current Sources

- An ideal voltage source maintains a constant voltage across the output terminals. Unlike real sources, It will deliver whatever current is required to maintain the voltage despite variations in load resistance. A cell or battery (set of cells collected in series) is an example of a real constant voltage source.
- An ideal current source, on the other hand, maintains a constant output current out of the output terminals. It will deliver whatever voltage is required to force the current through the load resistance. Practical constant current sources are easy to build using semiconductor devices such as transistors.

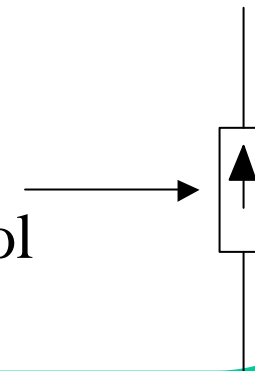




Ideal Current Source

- The internal resistance of an ideal current source is infinite whereas the internal resistance of an ideal voltage source is zero.
- This means that with no load (i.e., infinite load resistance), the voltage on the output terminals of an ideal current source will rise towards infinity, just as the current from an ideal voltage source will rise towards infinity as the load approaches 0Ω .

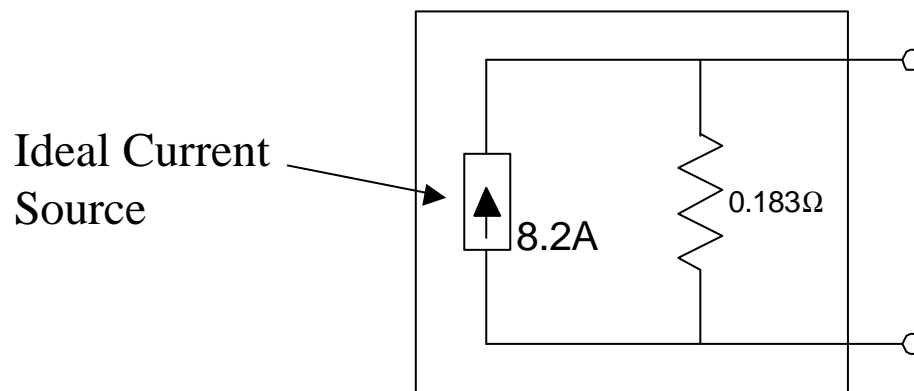
Ideal Current
Source Symbol





Norton Model

- A real cell can also be modelled as an *ideal current source* in parallel with an internal resistance, R_s .
- The ideal current source maintains a constant current regardless of the load.
- The diagram below shows the *Norton model* for the previous cell example.



Note: Open Circuit
Voltage is
 $V=IR=8.2 \times 0.183=1.5V$



Comments

- Real sources can be simply modelled by either the Thevenin (voltage) or Norton (current) equivalent circuits.
- Both models behave identically electrically (same VI characteristics), so either model can be chosen depending on the application.
- In a real cell or battery, the equivalent model will vary as the battery becomes discharged or aged.
- The charge carrying capacity of a battery is usually expressed in amp hours. For example, a 1 Ahr cell will nominally deliver 1A for one hour, 0.5 A for 2 hours etc. (Q: how many coulombs is this?)

A:3600



Power and Energy

- Electric Power (P) is measured in watts (W).
- You will frequently see kilowatts (kW), megawatts (MW), and milliwatts (mW)
- The amount of power consumed by an electrical device is the rate at which it dissipates energy
- In a flashlight, chemical potential energy in the battery is converted to electrical energy which is passed to the bulb and dissipated in light and heat.
- Energy (E) or work is measured in joules (J), so watts are joules per second, and joules are watt-seconds.



Power and Energy

- Using this notation we can say

$$P = \frac{dE}{dT} \quad \text{and} \quad E = \int P dt$$

where the units are watts, joules, and seconds.

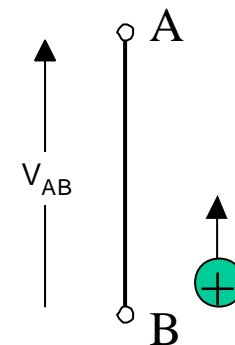
- In order to express power and energy in terms of voltage and current, we need to look at the formal definition of voltage.



Equation for Power

- The potential difference between two points A and B is defined as the work done in moving a unit positive charge from B to A. Denote this V_{AB} .
- Thus if we move one coulomb of charge from B to A, we perform V_{AB} joules of work.
- Further, if we continuously move 1 coulomb per second, 1 Ampere, from B to A, we require a power of V_{AB} joule per second, or watts.
- This yields the equation for Power

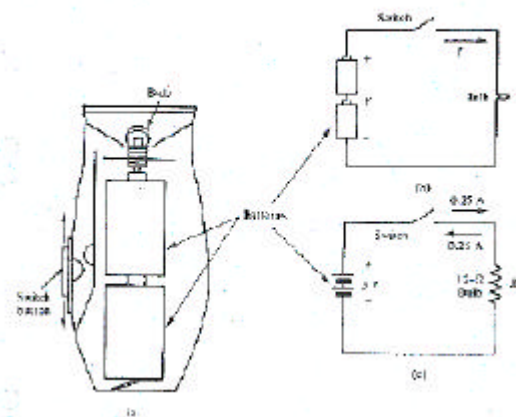
$$P=IV$$





Example

- Consider the flashlight example
- We had a 3V battery delivering 250 mA, so the power dissipated in the bulb is $3 \times 250 = 750 \text{ mW}$.
- Power supplied by the battery must equal the power dissipated in the bulb by conservation of power



Combining $P=VI$ with $V=IR$ yields
 $P = V^2/R$ and $P = I^2R$

In this example,
 $P = V^2/R = 3^2/12 = 750 \text{ mW}$
as above



Biomedical Example

This is a real life example.



- A nurse in the neonatal intensive care ward needs to transport a ventilated baby to the operating theatre, but the baby cannot be removed from the ventilator. The ventilator has a NiCd rechargeable battery backup.
- Will the battery pack be able to supply the required current?
- How long will fully charged batteries last?

Drager Babylog 8000 Plus Ventilator





Biomedical Example

- Available Information from operating manuals:
 - The batteries are 48V and rated at 17 Ahr
 - The ventilator draws 0.6A at 230V and the heater (to keep the baby warm) draws 680W at 230V
 - The output of the inverter which converts the battery voltage to 230VAC is rated at 7.2A at 230V with 90% conversion efficiency.
- Ventilator requires current of $0.6 + (680/230) = 0.6 + 2.96 = 3.56A$
- Inverter can supply up to 7.2A at 230V, so 3.56A is well within the rated output, but can the battery supply the necessary current?



Biomedical Example

- Required battery current is $3.56 \times (230/48)/0.9 = 19A$
- This current is reasonable for a 17 Ahr battery and the battery would discharge in $17/19 = 0.89$ hr, or 54 minutes Note: trialed 4/99 and operated for 1 hr on batteries.
- So the ventilator should be able to be moved to the operating theatre under battery backup. For added safety, the battery would last longer if the baby were wrapped up and the heaters turned off.
- Q: Why would the ambulance and helicopter 230V supply be limited to just 1A and be unable to run the ventilator and heater?
- A: Probably because it is converted from a 12V supply. A current of 1A at 240V becomes 20A at 12V (240W), which is a heavy load equivalent to another set of car headlights.