Circuits and Capacitors

I. Current, Power, **Resistance**
   - resistivity
   - internal resistance

II. Circuit Analysis
   - series and parallel
   - nodes, loops, switches

III. Capacitance
   - parallel plate capacitor
   - capacitors in circuits

	The student will be able to:	HW:
1	Define electric current and the ampere and solve problems relating current to charge and time and to power and voltage.	✓ 1 – 3
2	Define resistance, resistivity, and the ohm and Ohm's Law and solve related problems.	4 – 10
3	Define and apply the concepts of internal resistance and emf to solve related problems with the standard model of the terminal voltage of voltaic cells.	11 – 14
4	Determine resistance for series or parallel combinations of resistors, state and apply Kirchoff's node and loop rules and solve related problems, including analysis circuits with multiple batteries, resistors, and switches.	15 – 20
5	Define capacitance and relate to charge, voltage and energy to solve related problems involving capacitors in circuits at steady states of charge or discharge and qualitatively describe transitions of such states.	21 – 29
6	State the relation between capacitance, area, separation, and dielectric constant for parallel plate capacitors and solve related problems.	30 – 35

Definition of Resistance

For most materials it requires greater electric potential to produce greater current.

However, the resulting current also depends on resistance. The greater the resistance, the greater the potential required to produce a *certain level* of current.

Resistance is defined as the ratio of potential difference to current.

Definition of Resistance

$$R = \frac{\Delta V}{I}$$

where: R = resistance

ΔV = electric potential "across"

I = electric current "through"

More commonly written as: $$V = IR$$

(often referred to as Ohm's Law)

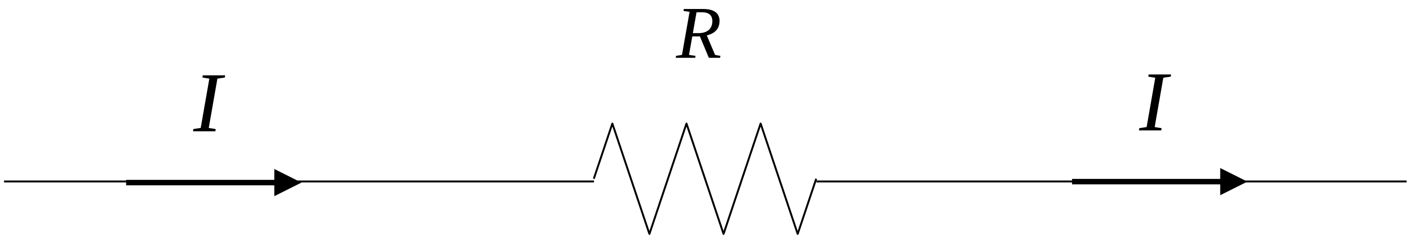
Units of Resistance

- The SI unit for electric resistance is the **ohm**.
- One ohm is equal to one volt per one ampere:

$$1\ \Omega = 1\ \mathrm{V/A}$$

- The greater the number of ohms, the more volts it takes to achieve one ampere of current – *i.e.* "More volts per ampere means more resistance and therefore more ohms".

Which side of the resistor is at a higher potential?



This side is at a higher potential!

+ ΔV –

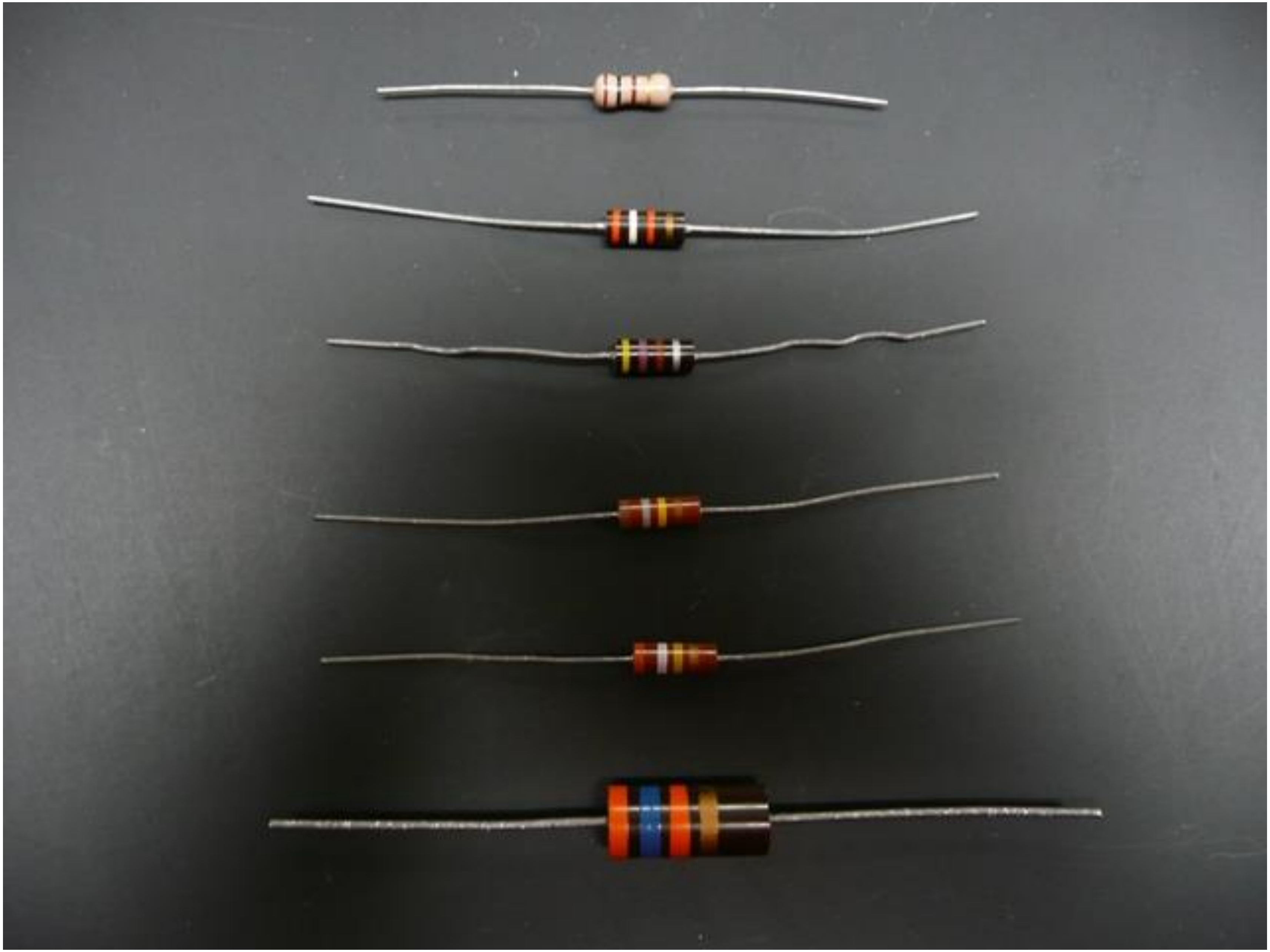
The potential difference ΔV across a resistor (one side relative to the other) is often described as a potential drop because charge is losing energy that is dissipated by the resistor in the form of heat.

Ohm’s Law

In the 1820’s, Georg Ohm found that the ratio of voltage to current is constant over a wide range of conditions for metals and many other substances.

Such a substance has a **constant resistance** and is said to be **ohmic**.

However, there are materials and devices that do not have a constant resistance. These are said to be **nonohmic**.



Resistors

- A resistor is a device designed to have a particular amount of resistance.
- A resistor is designed to be ohmic and therefore has the same resistance over a wide range of operating conditions.

What determines the amount of resistance?

The type of substance has a great influence on resistance. In particular, electron orbitals and atomic bonding affect the potential difference required to produce a certain level of current.

The physical dimensions of an object will also greatly influence resistance.

Greater length and/or lesser cross sectional area will result in greater resistance (because there is less current for a given voltage).

Modeling Resistance in Ohmic Materials

$$R = \rho \frac{L}{A}$$

where: R = resistance of wire (or other object)

ρ = resistivity of the substance from which the wire is made

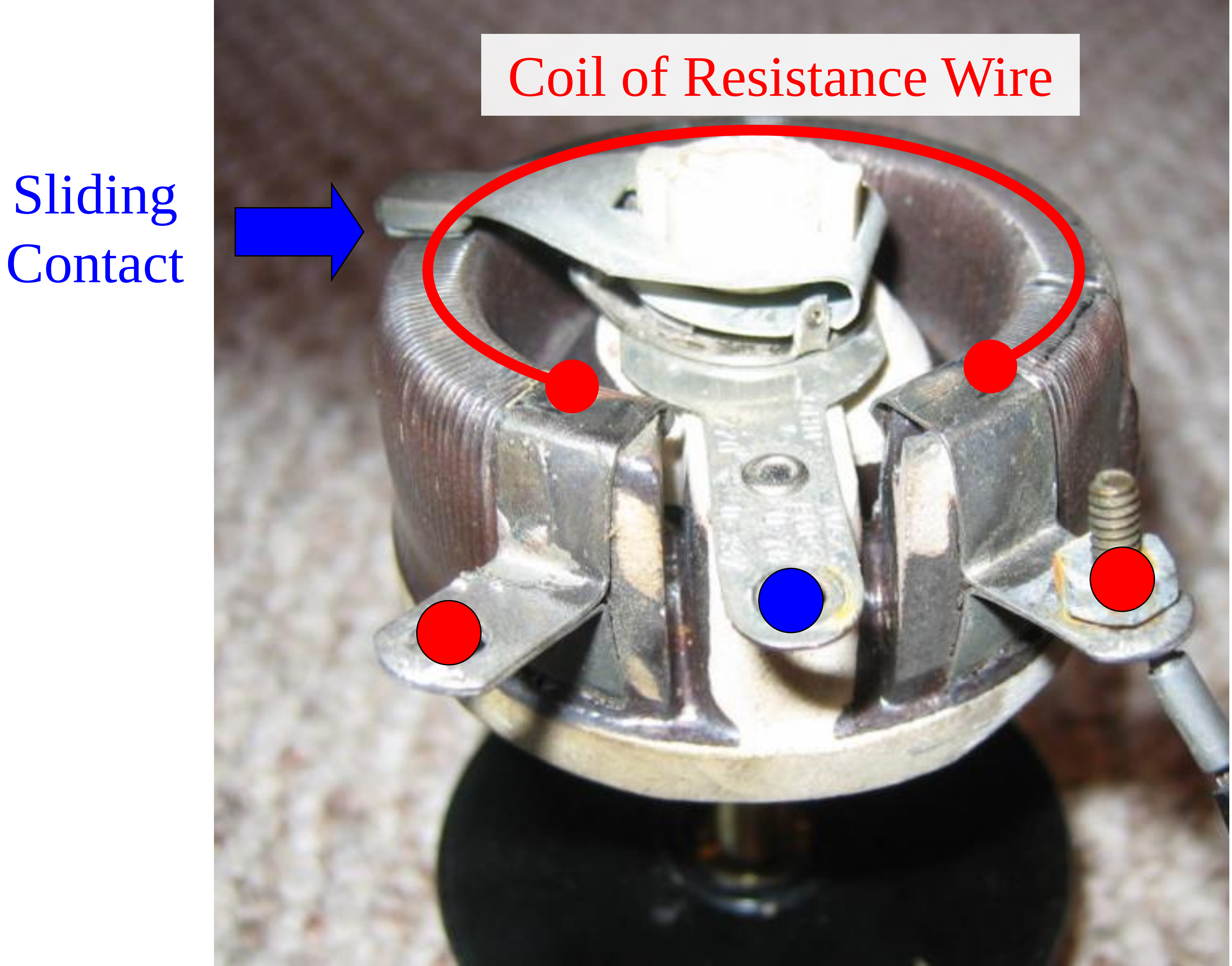
L = length of wire

A = cross-sectional area of wire

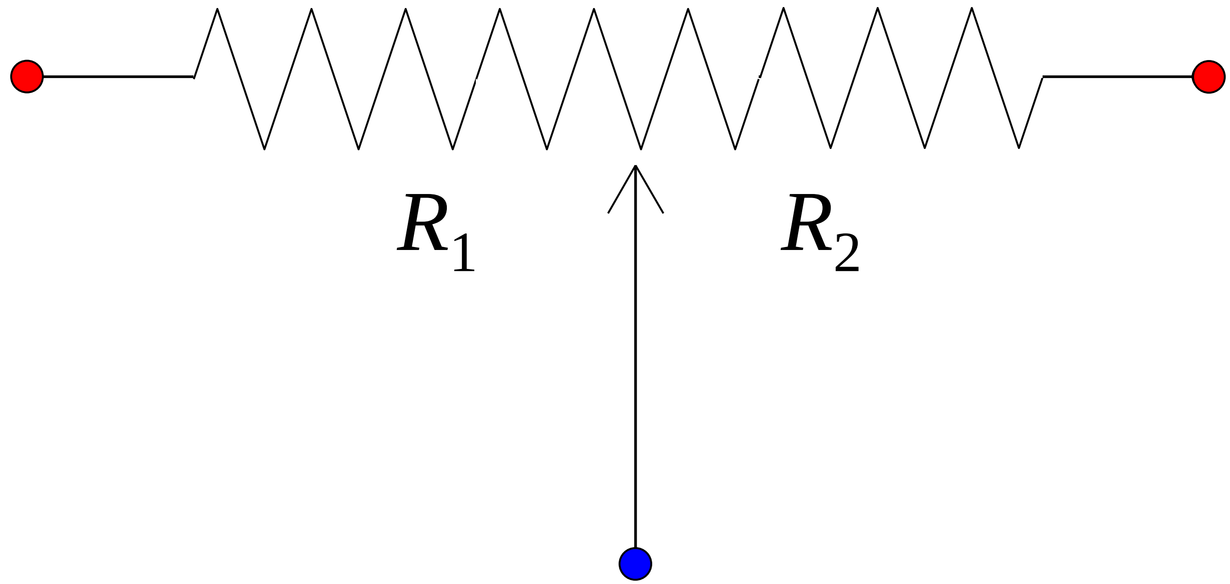
Material	Resistivity ($\Omega \cdot m$)	Temp. Coeff. (K^{-1})
Silver	1.59×10^{-8}	3.8×10^{-3}
Copper	1.68×10^{-8}	6.8×10^{-3}
Aluminum	2.65×10^{-8}	4.29×10^{-3}
Tungsten	5.60×10^{-8}	4.25×10^{-3}
Nickel	6.84×10^{-8}	6.9×10^{-3}
Iron	9.71×10^{-8}	6.51×10^{-3}
Platinum	1.06×10^{-7}	3.93×10^{-3}
Nichrome	1.00×10^{-6}	4×10^{-4}
Carbon	3.5×10^{-5}	-5×10^{-4}
Silicon	2.5×10^{3}	-7×10^{-2}
Wood	$10^{8} - 10^{11}$	
Glass	$10^{10} - 10^{14}$	

Dependence on Temperature

- Generally speaking resistance will increase as temperature increases.
- For the filament of an incandescent bulb this is a dramatic effect – the brighter the bulb, the higher the temperature of the filament, and the greater its resistance.
- Decreasing temperature in some materials results in resistance dropping to essentially zero. A material with zero resistance is called a **superconductor**.


Sliding Contact
Coil of Resistance Wire

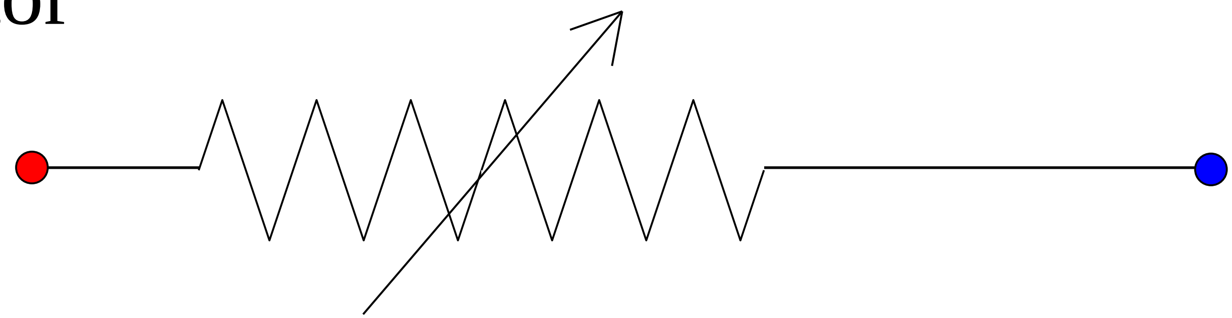
Potentiometer



$$R = \rho \frac{L}{A}$$

The total resistance (R_1 + R_2) between the two ends (red terminals) is constant. A certain part (R_1 <u>or</u> R_2) of the total resistance exists between either end and the point of contact (blue terminal) depending on the length of wire between.

Variable Resistor



If only the blue and one of the red terminals are connected the device becomes simply a variable resistor that can be controlled by turning a knob or otherwise sliding the point of contact along the resistance wire.

Potentiometers and variable resistors are useful for controlling current and/or voltage and are found in many different types of circuits.

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Cells & Batteries

- A voltaic (or galvanic) cell is a single container of chemicals with two electrodes: an anode and a cathode.
- Properly speaking a “battery” is a collection of multiple cells connected in series.
- Energy is “stored” in chemical form until a current is drawn from the battery, at which point oxidation occurs at the anode and reduction occurs at the cathode.

EMF

- The energy associated with the chemical reaction can be quantified by *EMF* ("electromotive force"), which is a measure of energy per charge.
- For a given chemical reaction there is a characteristic *EMF*, which is independent of the quantity of reactants and can be determined by standard electric potentials of the corresponding half-reactions.

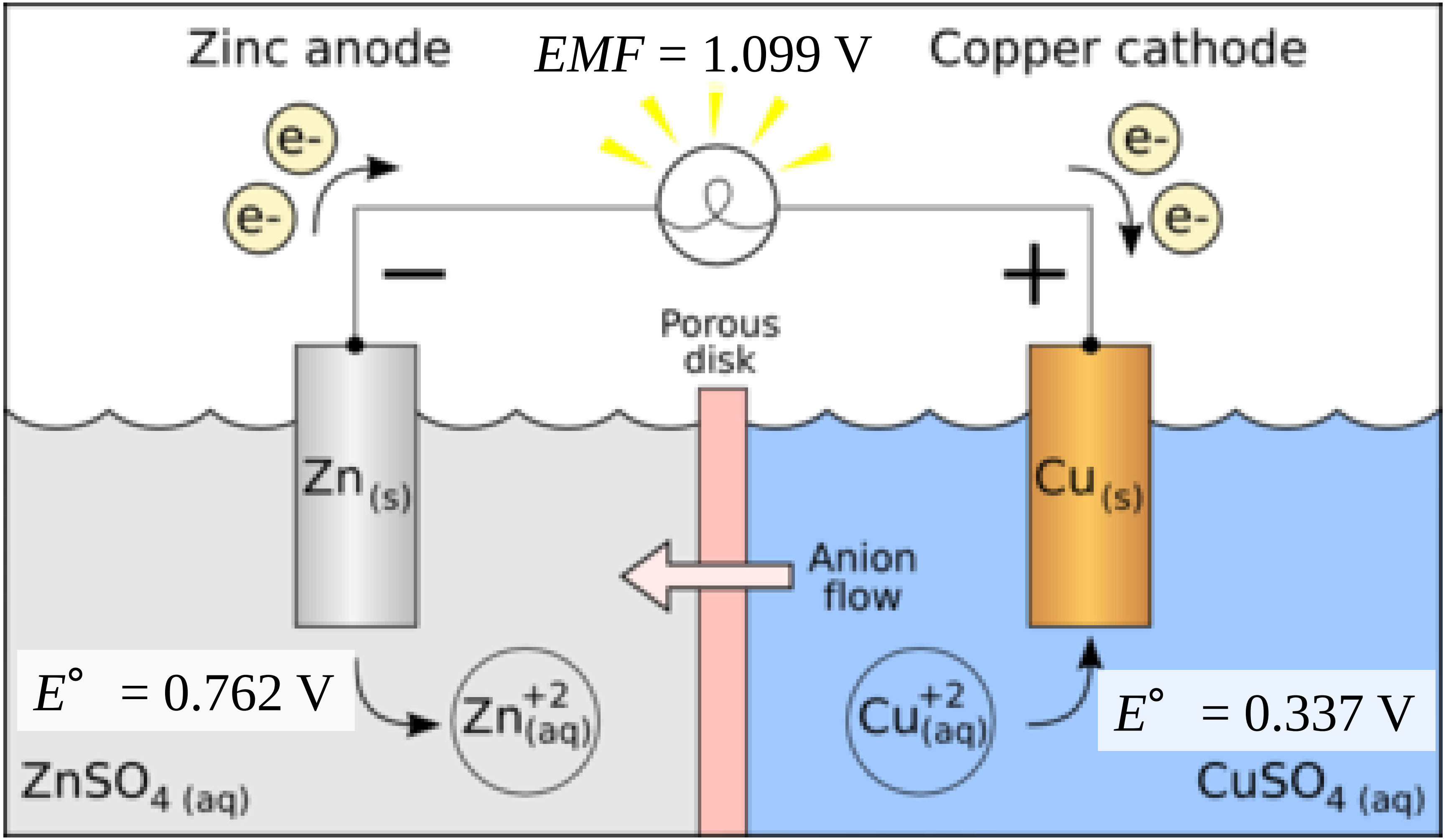


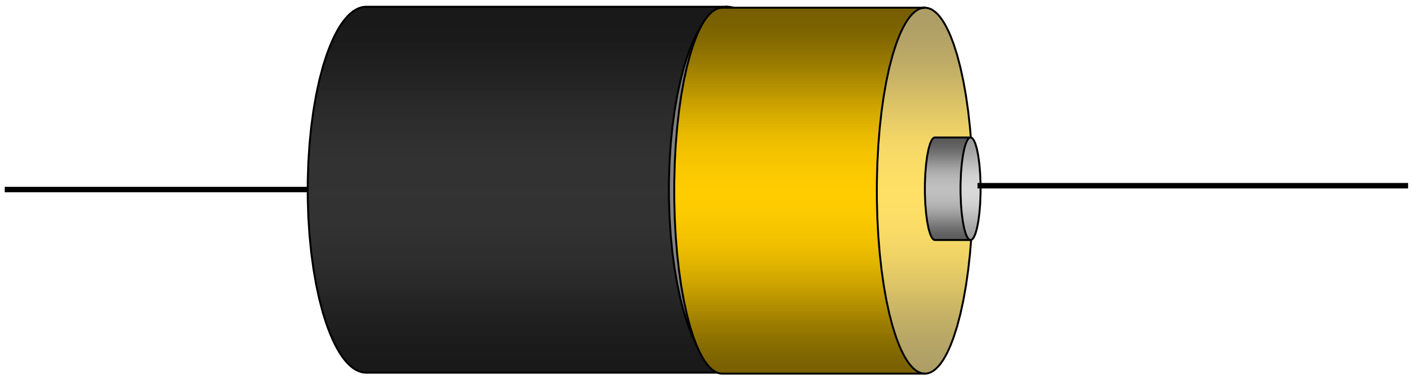
image credit: Wikipedia, Ohiostandard

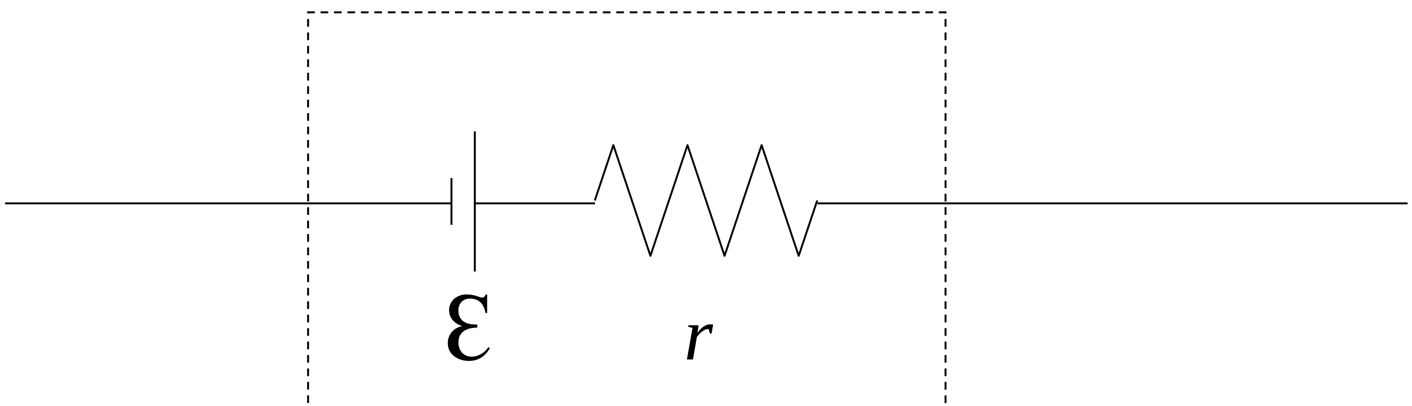
The potential or *EMF* (electromotive force) is the sum of the half-potentials of the reactions taking place – 0.762 + 0.337 = 1.099V in this particular example.

Terminal Voltage and Internal Resistance

- A battery's voltage has a *tendency* to be *relatively constant*. However it is the EMF of the chemical reaction that should be constant.
- The voltage measured at the terminals of the battery is variable depending on the current. The greater the current, the less the terminal voltage.
- The variance in terminal voltage is a result of internal resistance associated with the flow of charge through the battery.

Modeling the Behavior of a Cell or Battery

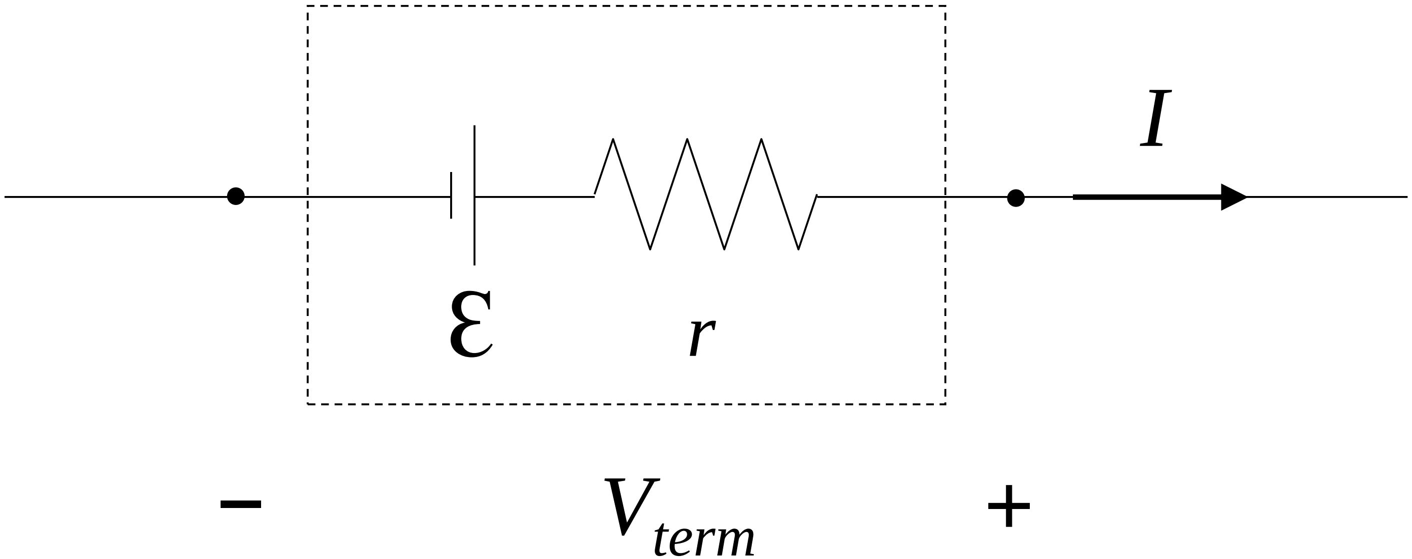




where: $\mathcal{E}$ = emf

r = internal resistance

Modeling the Behavior of a Cell or Battery



The terminal voltage is the “useable” potential difference between the positive and negative terminals of the battery.

$$V_{term} = \varepsilon - Ir$$