Science A Physics

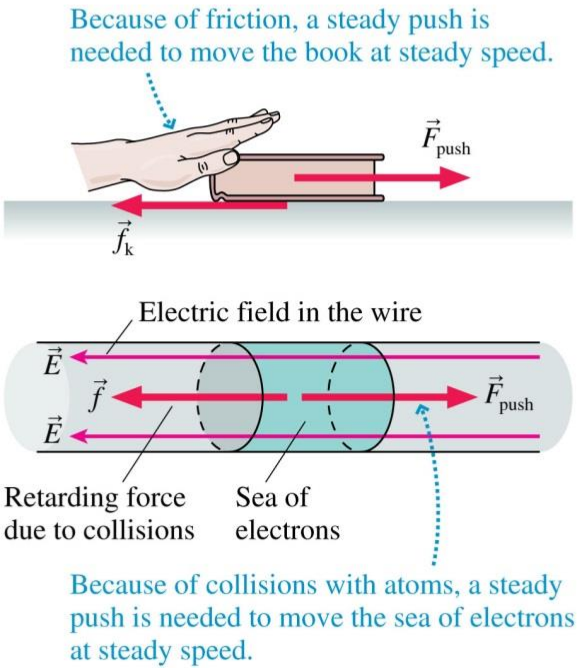
Lecture 13:

Electric Current, and Resistance; Part 1

Aims of today's lecture

1. The Electric Battery
2. Electric Current
3. Electric Potential
4. Resistance
5. Resistivity

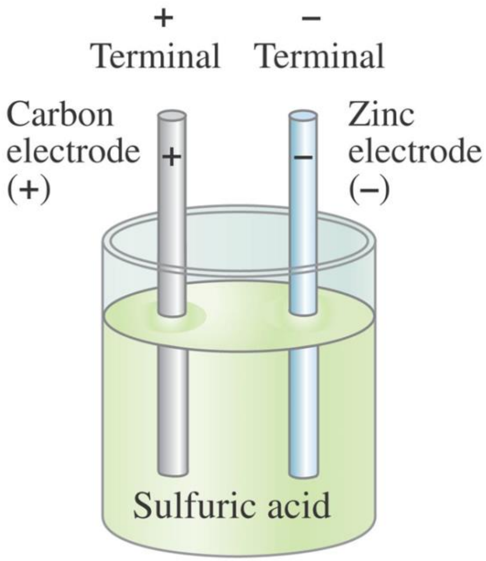
Moving Charges

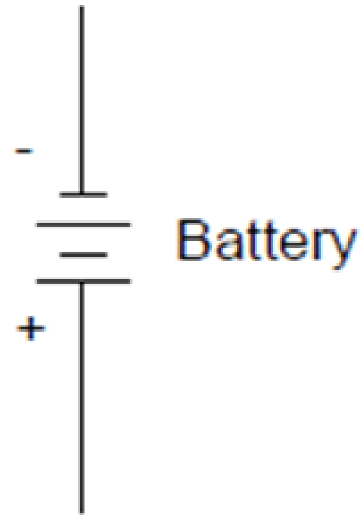


- As we've seen in previous lectures, in electrostatic situations, the electric field must be zero inside a conductor (if it were not, the charges would move).
- But when charges are moving in a conductor, an electric field (which in turn creates a potential difference) is needed.
- This **potential difference** can be provided by a **battery**.

1. The Electric Battery

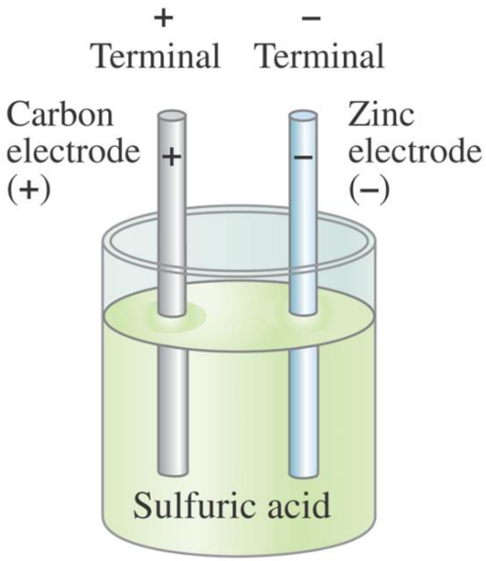
The Electric Battery

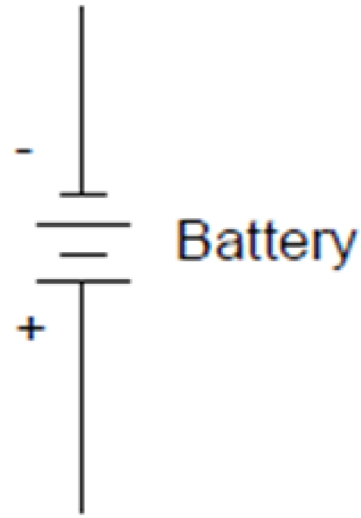




- A battery produces a potential difference due to a series of chemical reactions which take place inside it.
- In Semester 2, if you study **Foundation Science B Chemistry**, you will study in more detail how exactly these chemical reactions create such a potential difference.

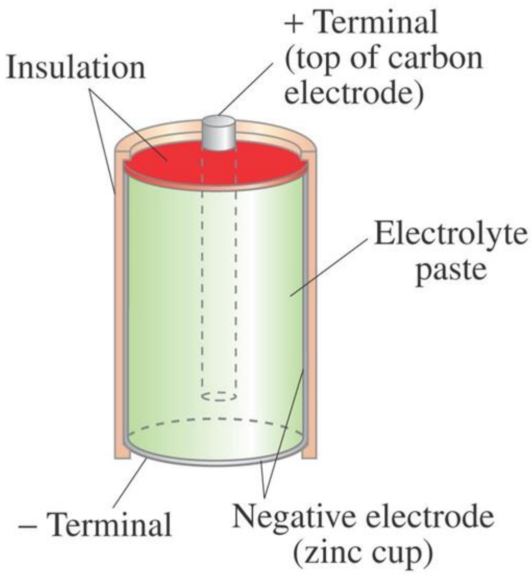
The Electric Battery



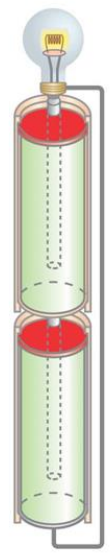


- For now, all you need to know is that because there is an opposite charge on the two electrodes, there is a potential difference between the two terminals.
- If a wire joins these terminals, forming a circuit, then charge can flow from the negative terminal to the positive terminal, creating an electric current.

The Electric Battery



(a) One D-cell

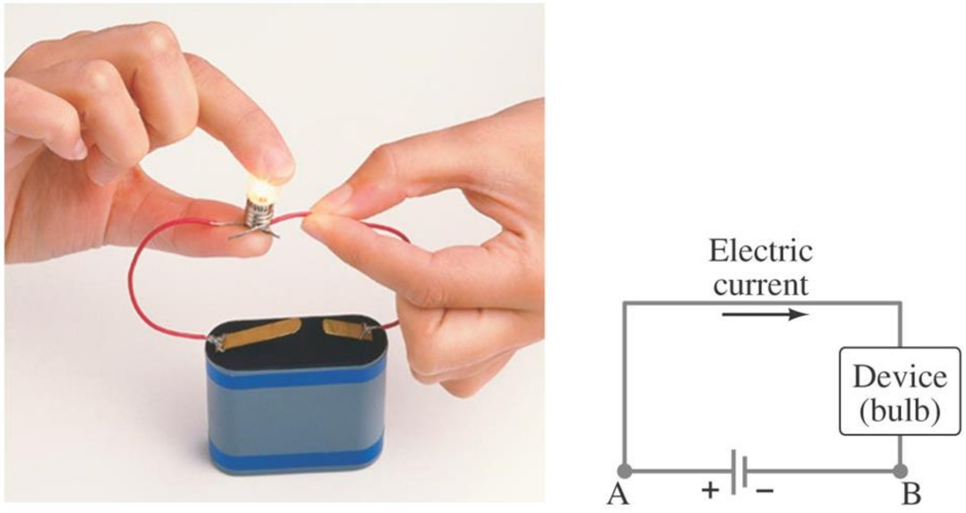


(b) Two AA batteries

- When two or more cells (which form batteries) are connected so that the positive terminal of one is connected to the negative terminal of the next, they are said to be connected in series and their voltages add up.
- A bigger voltage can cause a bigger electric current to flow. Let’s have a look at electric current in more detail.

2. Electric Current

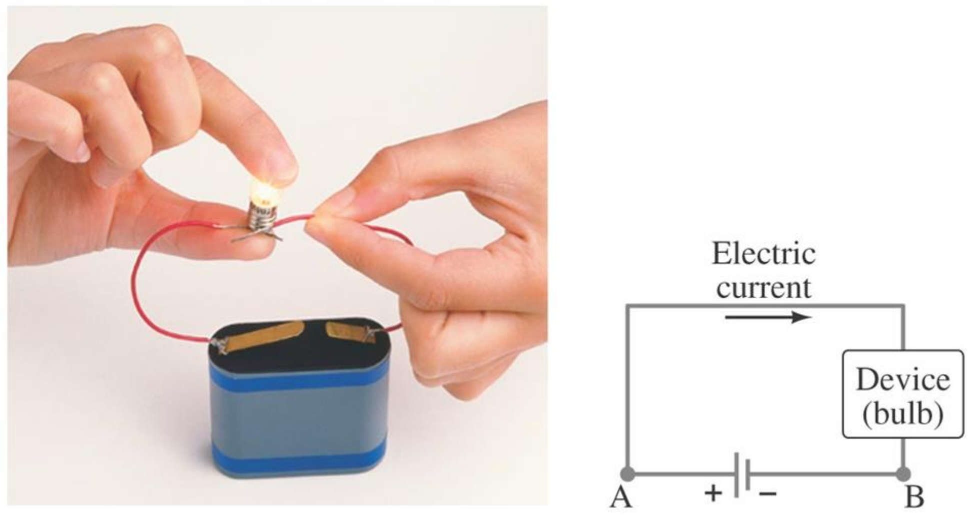
Electric Current



(a) (b)

- As we have seen, the purpose of a battery is to produce a potential difference, which can then make charges move.
- When a continuous conducting path is connected between the terminals of a battery, we have an electric circuit, as shown above.

Electric Current



(a) (b)

- The device connected to the battery could be a lightbulb, a heater, a radio, or whatever.
- When such a circuit is formed, charge can flow through the wires of the circuit, from one terminal of the battery to the other, as long as the conducting path is continuous.
- A flow of charge such as this is called an **electric current**.

A Traditional (Conventional) View of Current

- Before our modern understanding of current, the old view of current was to think of it in terms of charge flow $\boldsymbol{Q}$**.**
- **If $\boldsymbol{Q}$ (whatever this $\boldsymbol{Q}$ is)** is the total amount of charge that has moved past a point in a wire, we can define the current $\boldsymbol{I}$ in the wire to be the rate of charge flow:

$$I = \frac{dQ}{dt}$$

N.B. Current is the **rate** at which charge flows.

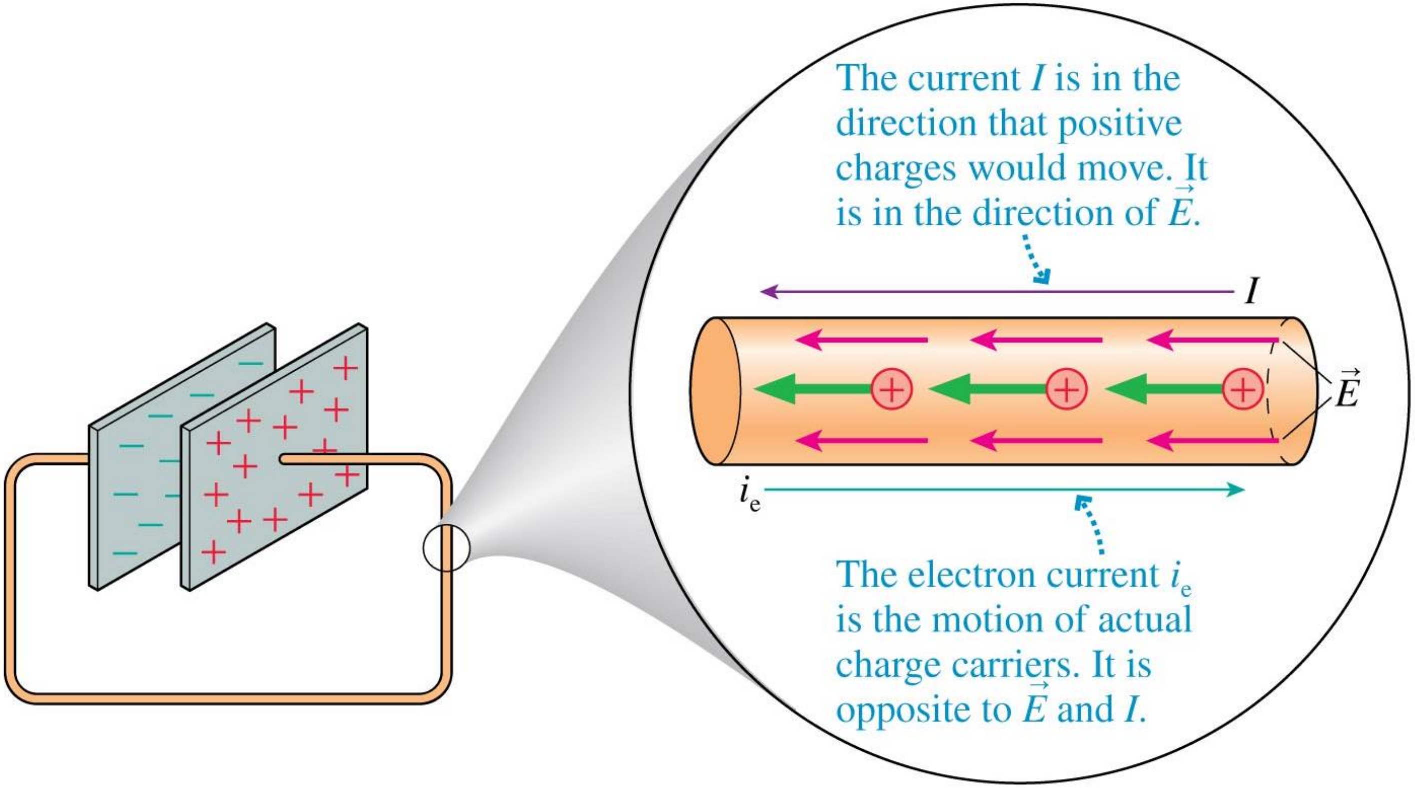
A Conventional View of Current

$$I = \frac{dQ}{dt}$$

Andre M. Ampère, 1776-1836

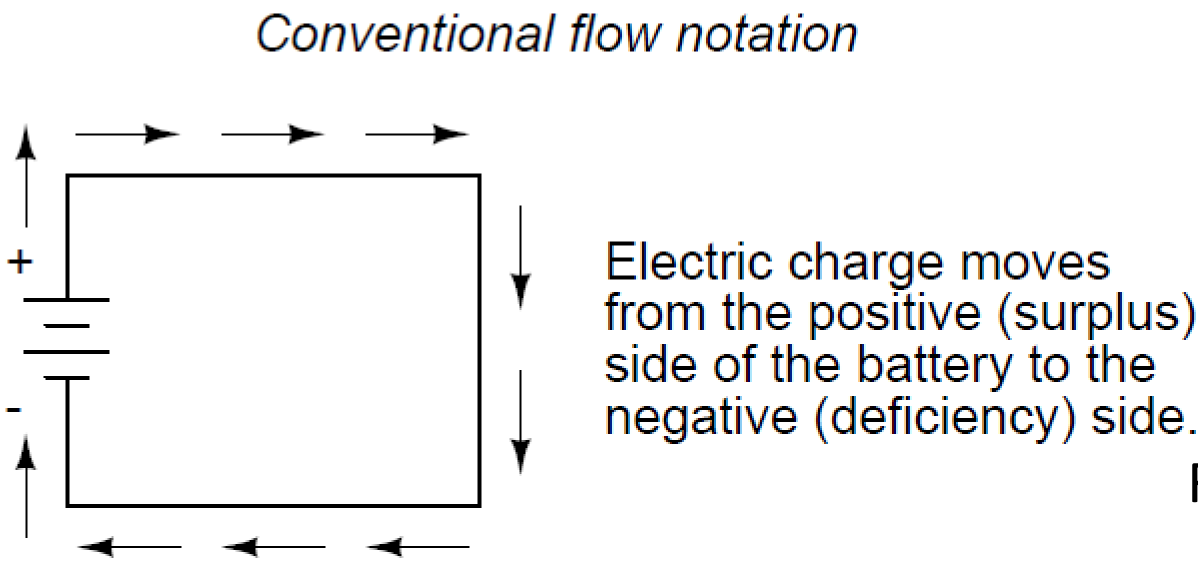
- The SI unit for current, I, is the Coulomb per second, which is called the **ampere.**
- $1 \text{ ampere} = 1 \text{ A} = 1 \text{ C/s}.$
- The conventional view considered the current to be the movement of positive charge carriers.

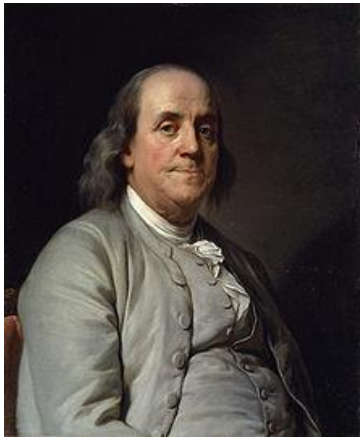
Conventional Current versus Electron Current



- Note that the direction of the **conventional current, I, *(or conventional charge flow)*** in a metal is opposite to the actual direction of the **electron current i_e**.

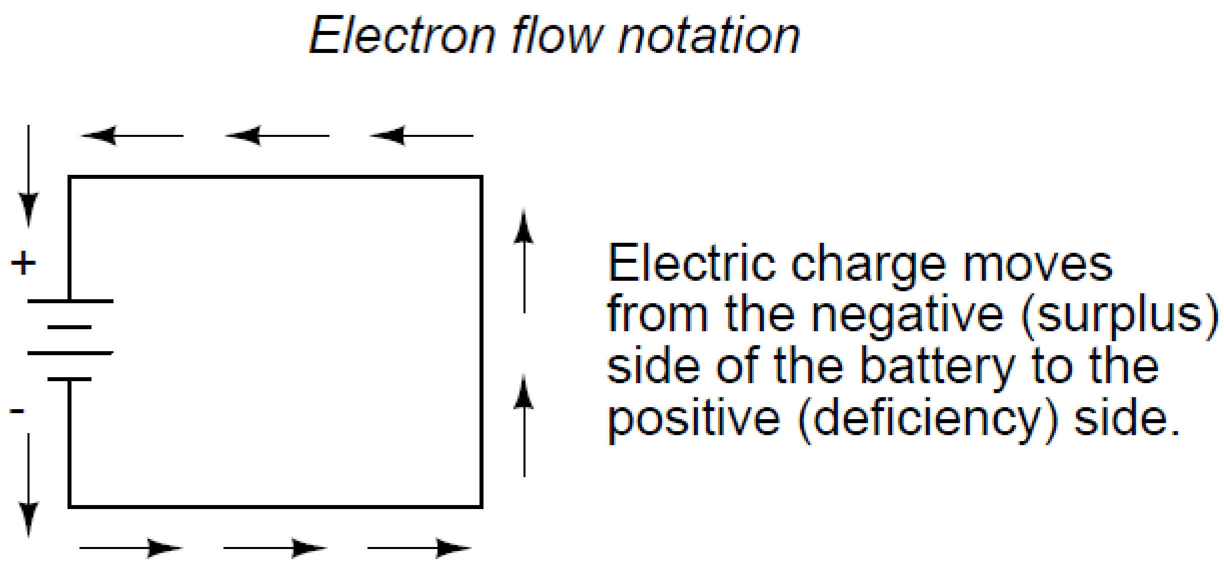
Conventional Current versus Electron Current




Franklin, 1706-1790

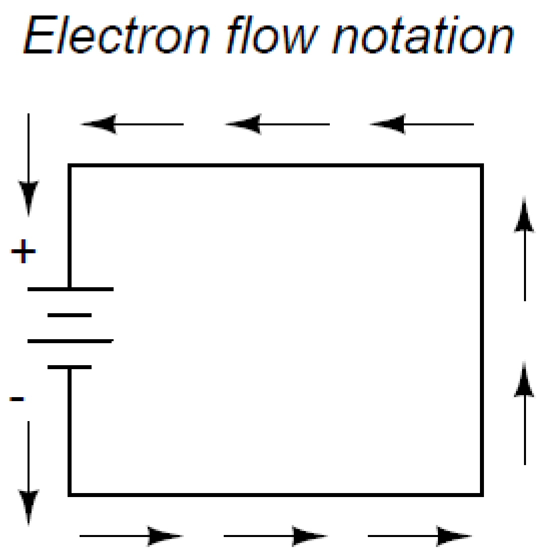
- **Remember Franklin:** he incorrectly thought that electric charge moved in the opposite direction than it actually does, and so objects he called negative (representing a deficiency of charge) actually have a surplus of electrons.

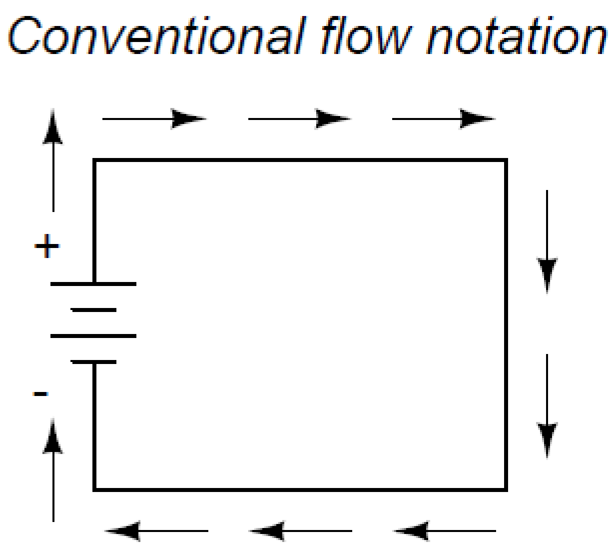
Conventional Current versus Electron Current



- By the time the true nature of charge flow (electron flow) was discovered, the terms positive and negative had been so well established in the scientific community that no effort was made to change it.
- The scientific community can sometimes be lazy!

Actual Electron Flow versus Conventional Flow





Q. Does it really matter how we designate charge flow in a circuit?

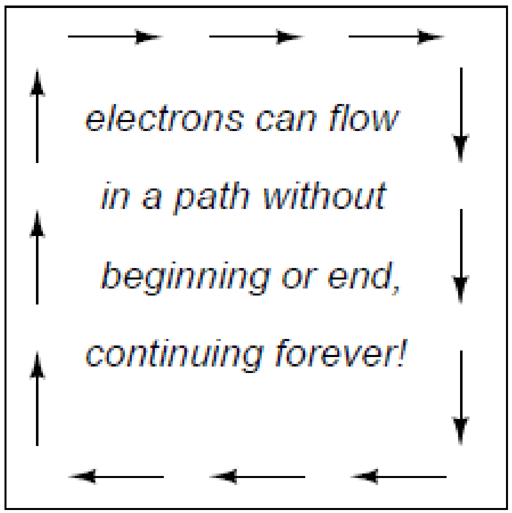
A. Not really, so long as we're consistent in the use of our symbols.

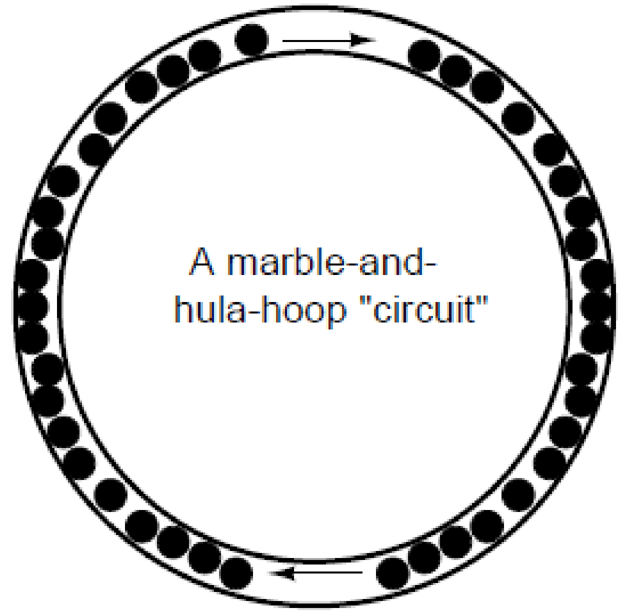
Electric Current—A Consequence of an Electric Field

- For electric current, the continuous flow of electrons requires there to be an unbroken path (usually in the form of wires) to permit that flow, denoted as follows:

- However, there will never be a continuous or uniform flow of electrons within the above wire unless they have a place to come from and a place to go.

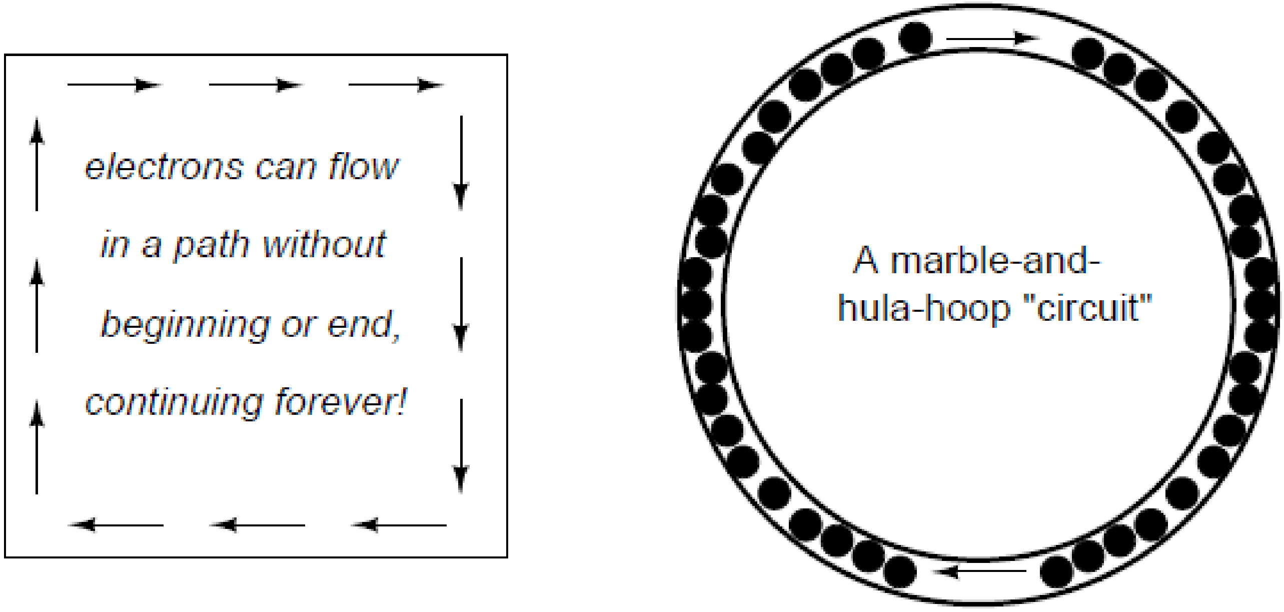
Electric Current





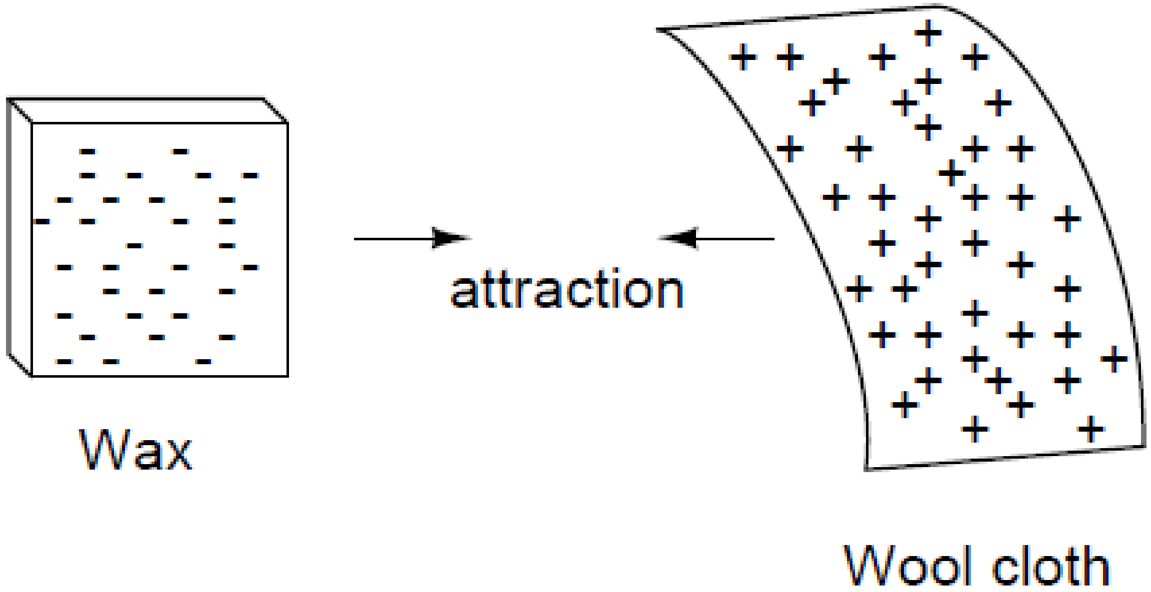
- A circuit is an unbroken loop of conductive material that allows electrons to flow through continuously without beginning or end.

Electric Current



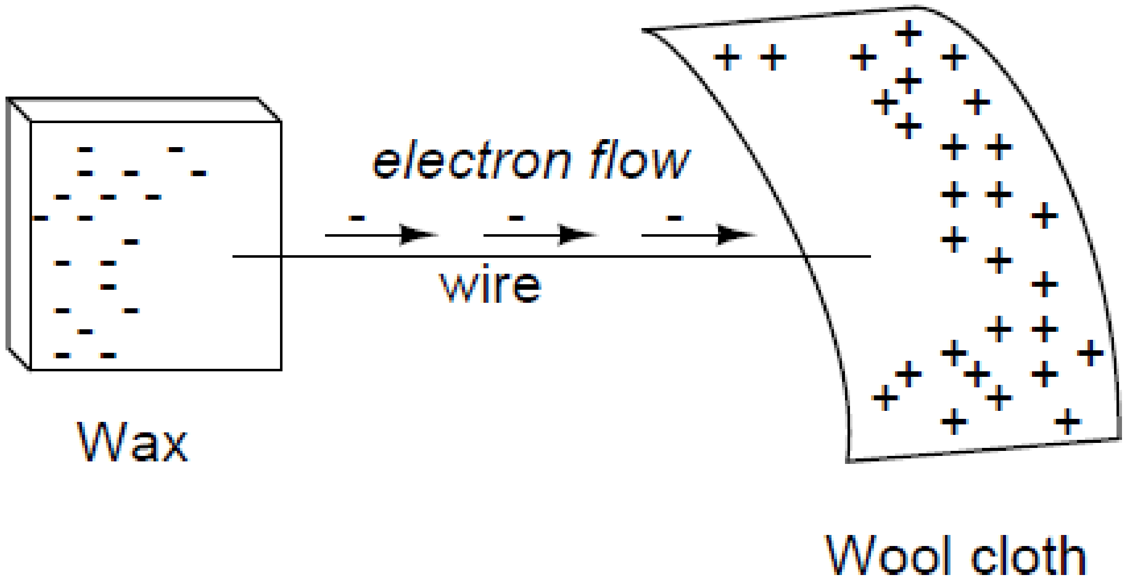
- Just like marbles in a tube or water in a pipe, it takes some kind of influencing force to start charge/electron flow. With electrons, this force is **the force produced by an imbalance of electric charge – an electric field, which we can say creates an electric potential.**

Electric Current



- The imbalance of electrons between the atoms in the wax and the atoms in the wool creates a force (in the form of an **electric field**) between the two materials. With no path for electrons to flow from the wax to the wool, however, the wax and the wool will remain stationary—**static electricity**.

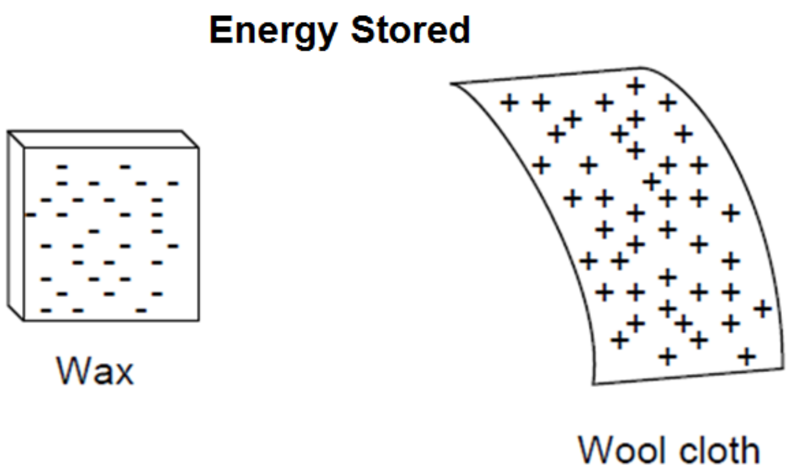
Electric Current

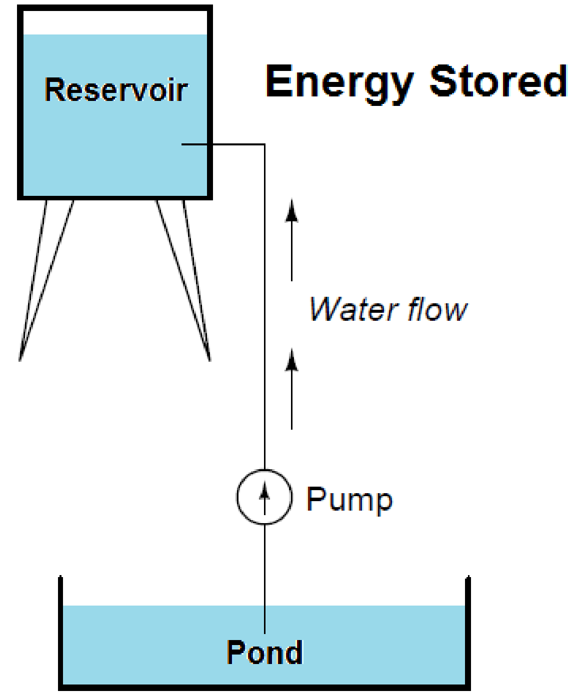


- When a conductor bridges the insulating gap, however, the force can cause electrons to flow in a uniform direction through the wire, if only for a while, until the charge in that area neutralises, and the force between the wax and the wool does not exist anymore—**dynamic electricity**.
- As we've seen in previous lectures, another name for the force that causes the electrons to flow is the '**electric potential'/'voltage'.**

3. ‘Electric Potential’/ ‘Voltage’

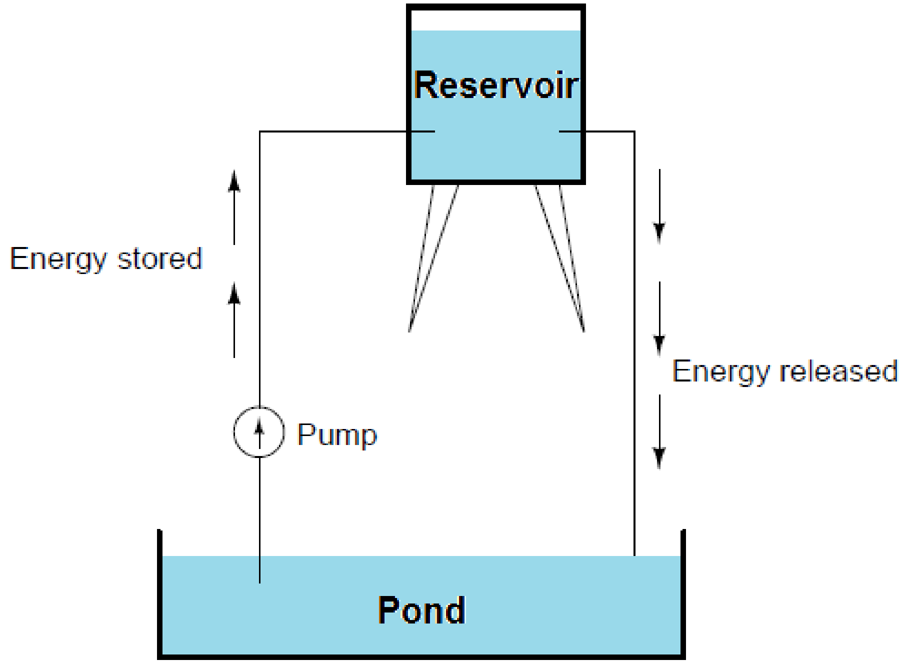
‘Electric Potential’/‘Voltage’





- The electric charge formed between these two materials by rubbing them together creates an electric field, and you can think of this electric field as having a certain amount of energy called **electric potential** or **voltage**. To use an analogy, this stored energy is like the energy stored in a high reservoir of water that has been pumped from a lower-level pond.

‘Electric Potential’/‘Voltage’



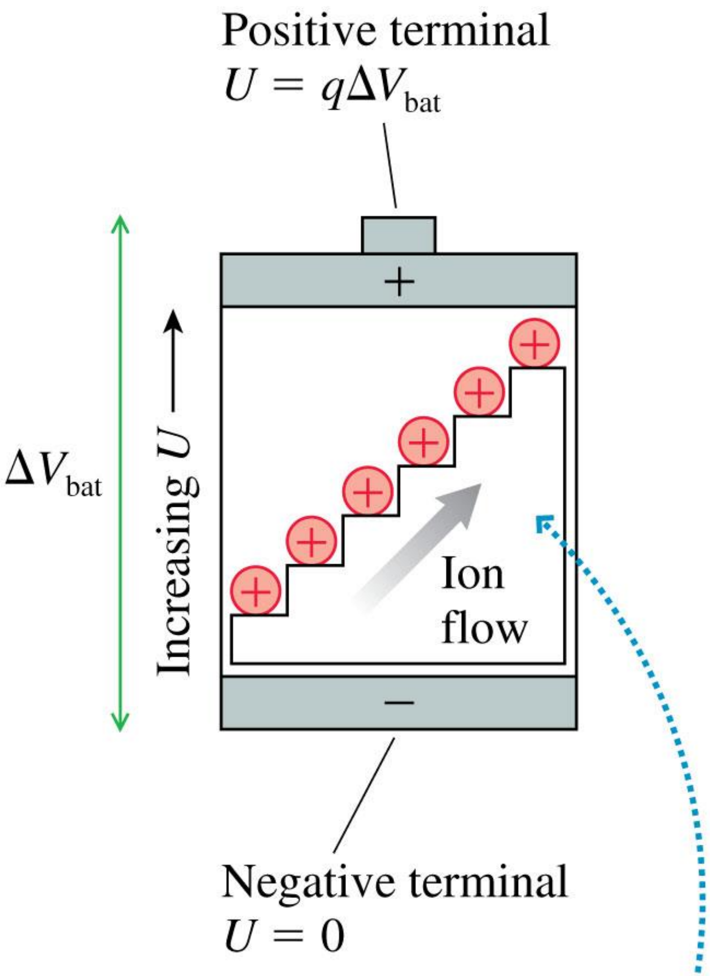
- It takes energy (**what we call electromotive force**) to pump the water from the low-level pond to the high-level reservoir, and the movement of water through the piping back down to its original level is equal to the releasing of this stored energy.

‘Electric Potential’/‘Voltage’

- An electric circuit must contain a battery or other device that does work on electric charges to bring them to a position of higher electric potential energy so that they can flow through the circuit to a lower potential energy.

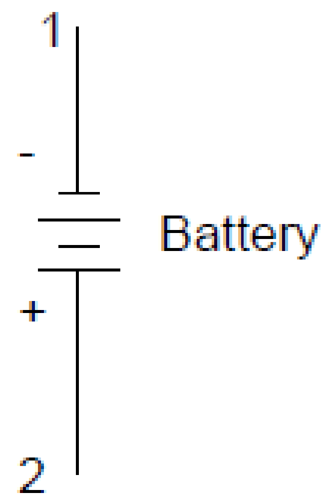
‘Electric Potential’/‘Voltage’

- The most common source of ‘electric potential’/ ‘voltage’ is a **battery**.
- The figure shows the **charge escalator model** of a battery.
- Lifting positive charges to a positive terminal requires that work be done, and the chemical reactions within the battery provide the energy to do this work. We call this process **electromotive force**.



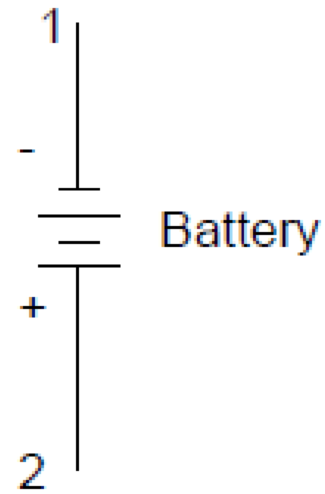
The charge escalator “lifts” charge from the negative side to the positive side. Charge q gains energy $\Delta U = q\Delta V_{bat}$.

‘Electric Potential’/‘Voltage’



- Any source of voltage, including batteries, have two points for electrical contact, such as point 1 and point 2 in the above diagram.
- The horizontal lines represent metallic plates immersed in a liquid or semi-solid material that not only conducts electrons, but also generates the voltage (electric field) to push/pump the electrons along by interacting with the plates.

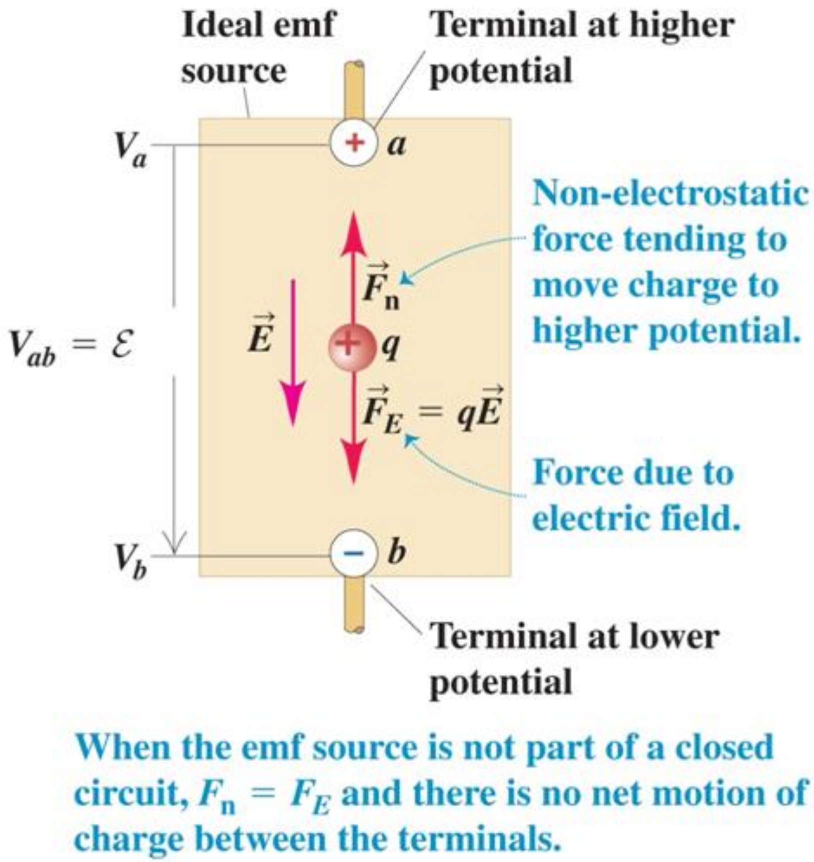
‘Electric Potential’/‘Voltage’



- The negative (-) end of the battery is always the end with the shortest dash, and the positive (+) end of the battery is always the end with the longest dash.

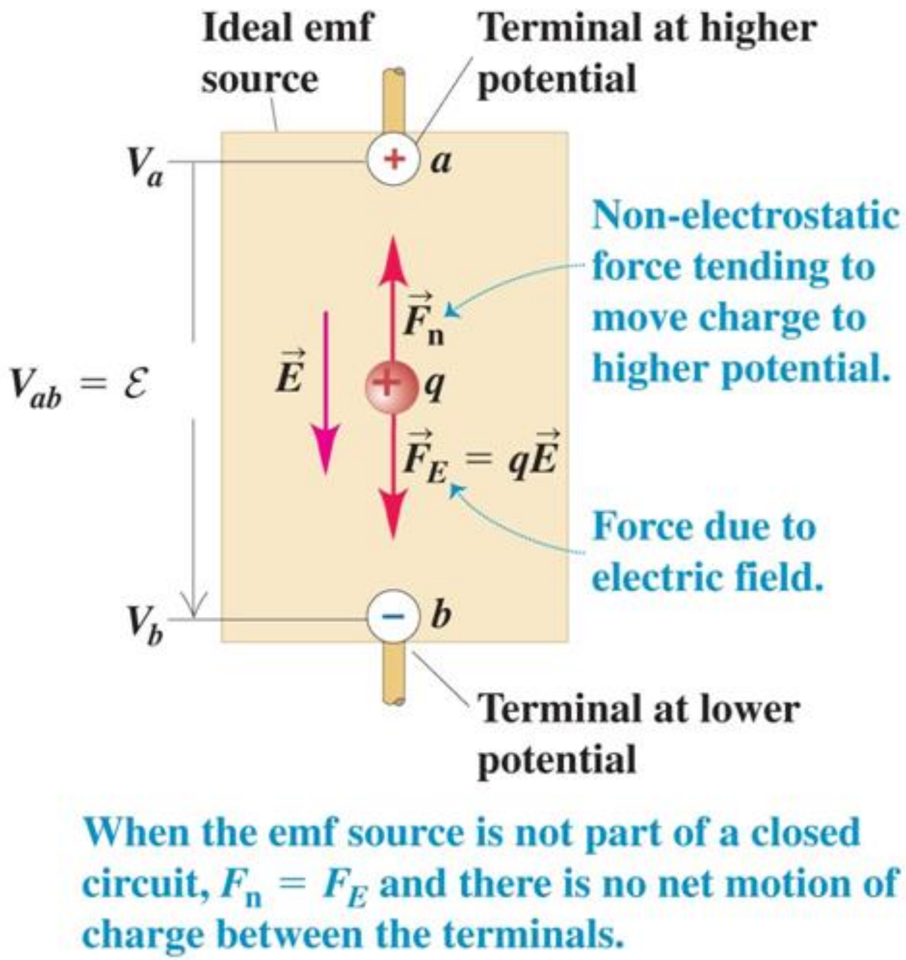
- Since we have decided to call electrons negatively charged, the negative end of a battery is that end which tries to push electrons out of it. Likewise, the positive end is that end which tries to attract electrons.

‘Electric Potential’/‘Voltage’



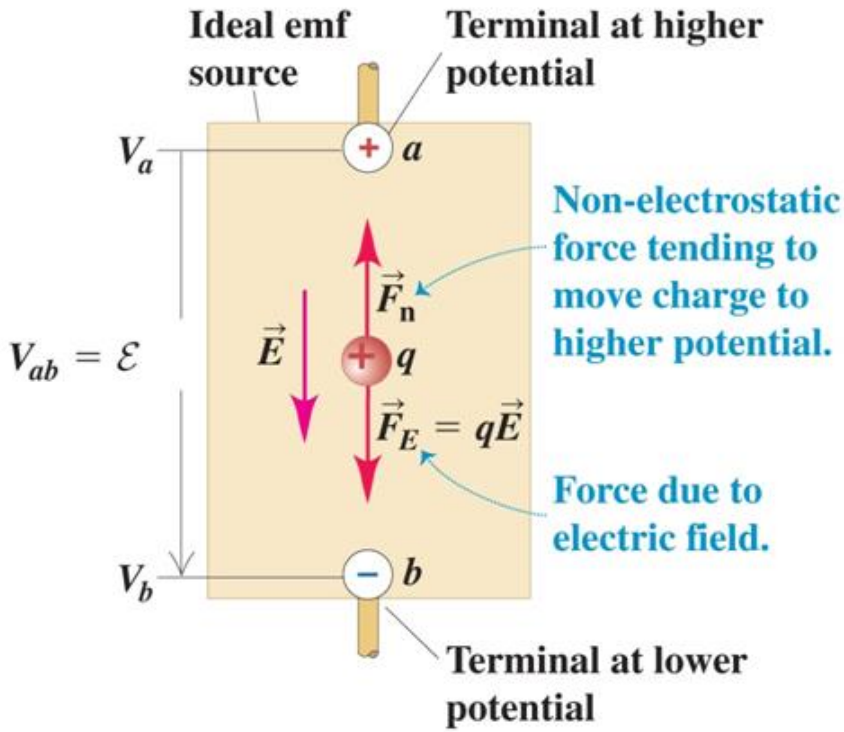
- **Electromotive force:** the influence that moves charges from lower to higher potential despite electric field forces in the opposite direction.

'Electric Potential'/'Voltage'



- $\boldsymbol{Emf}$**:** not a force, but an energy per unit charge, J/C.

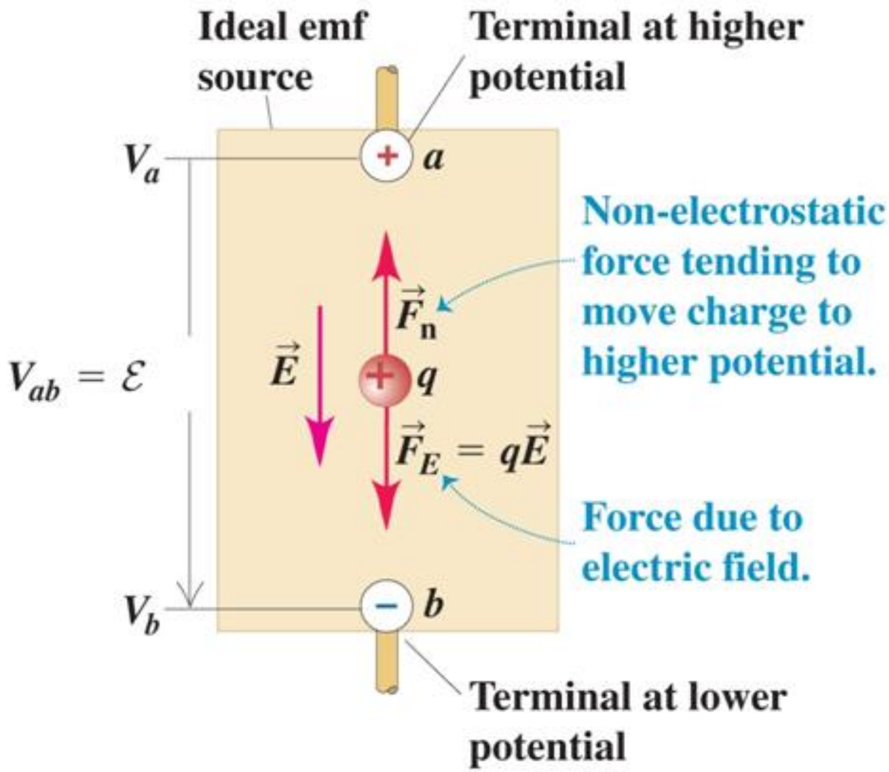
‘Electric Potential’/‘Voltage’



When the emf source is not part of a closed circuit, $F_n = F_E$ and there is no net motion of charge between the terminals.

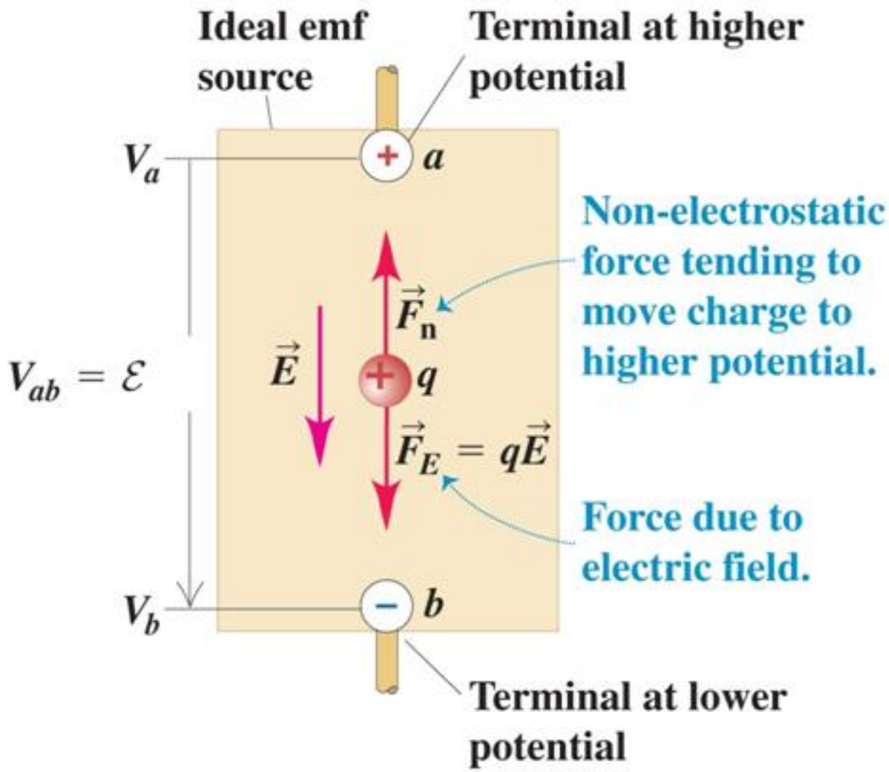
- **Electromotive force:** an ideal source of emf maintains a constant potential difference between its terminals, independently of the current through it.

‘Electric Potential’/‘Voltage’



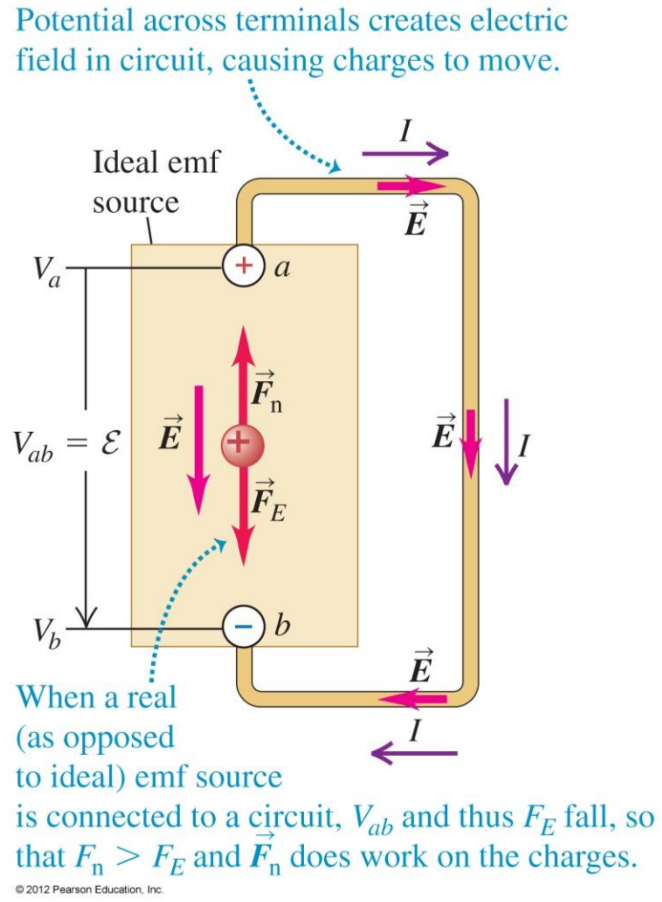
- ***Emf*** **source**: in the above diagram, the emf source has to provide some influence (a non-electrostatic force) that pushes charge from $\boldsymbol{b}$ to $\boldsymbol{a}$ (opposite to the electrical field force), and maintains the potential difference.

‘Electric Potential’/‘Voltage’



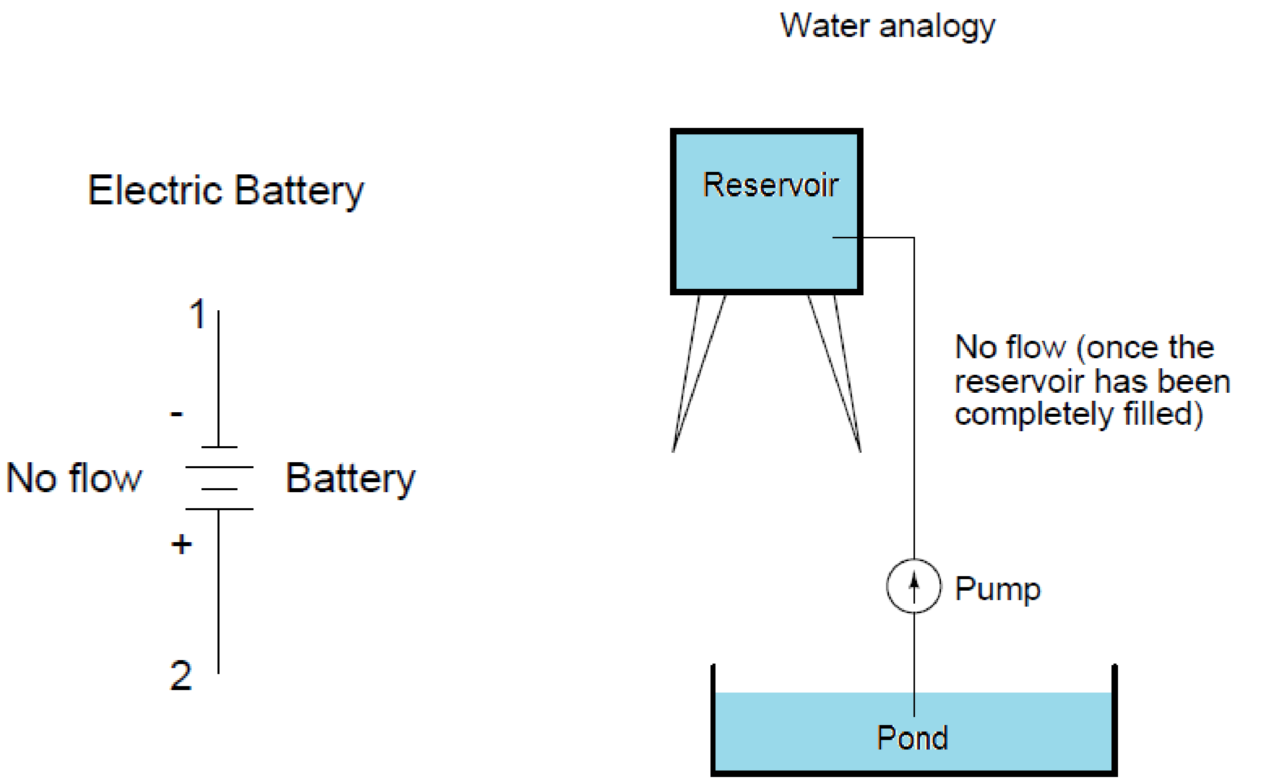
- ***Emf*** **source influence**: this influence depends on the source. In a battery, it is due to chemical processes; in an electric generator, as we will see in later lectures, it results from magnetic forces.

'Electric Potential'/'Voltage'

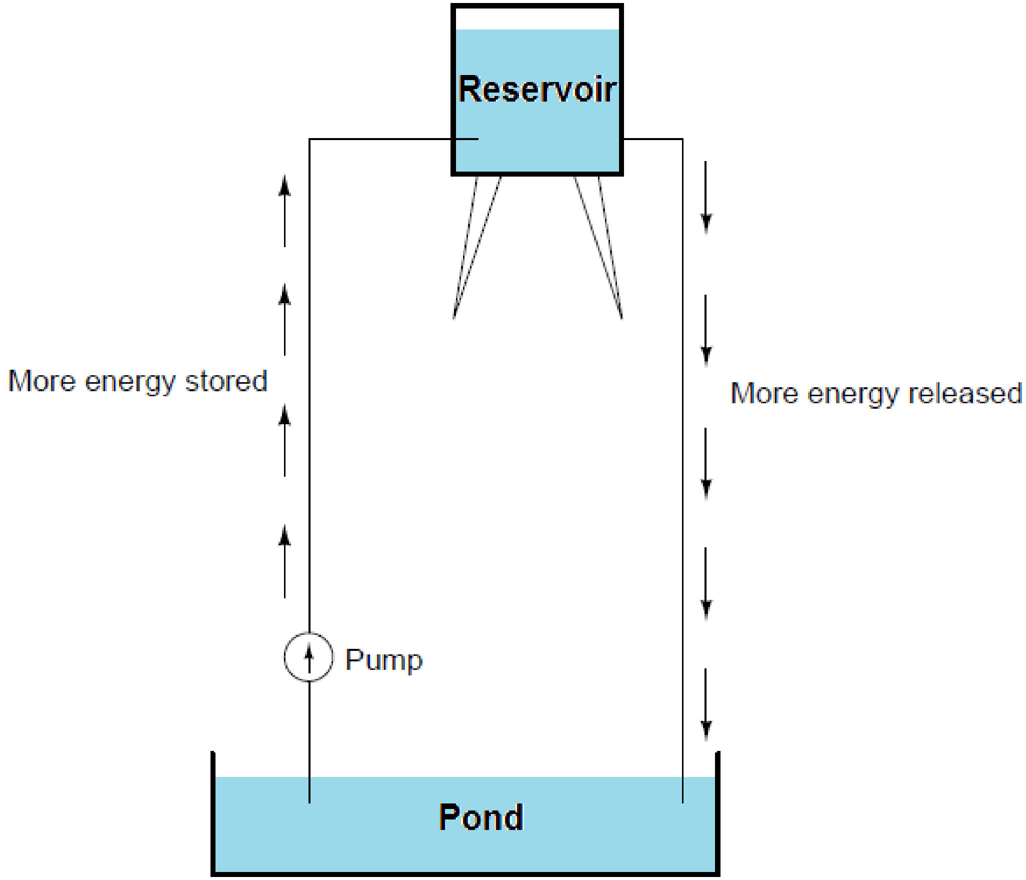


- When a charge q flows around the circuit, the potential rise ε as it passes through the source is equal to the potential drop from a to b as it passes through the wire or resistor.

‘Electric Potential’/‘Voltage’

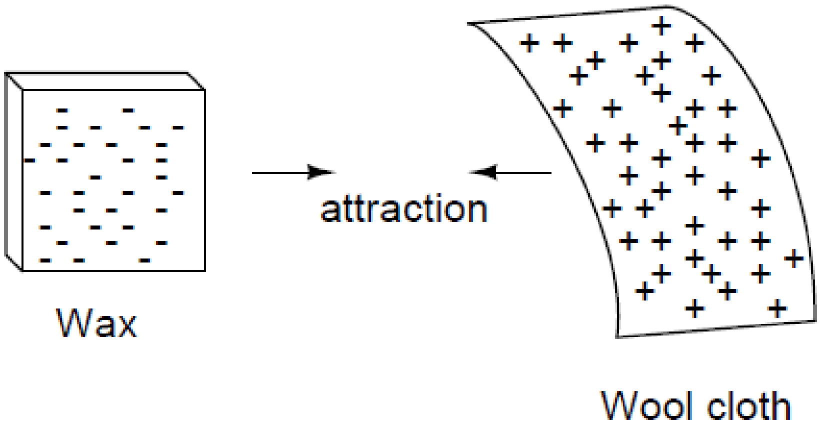


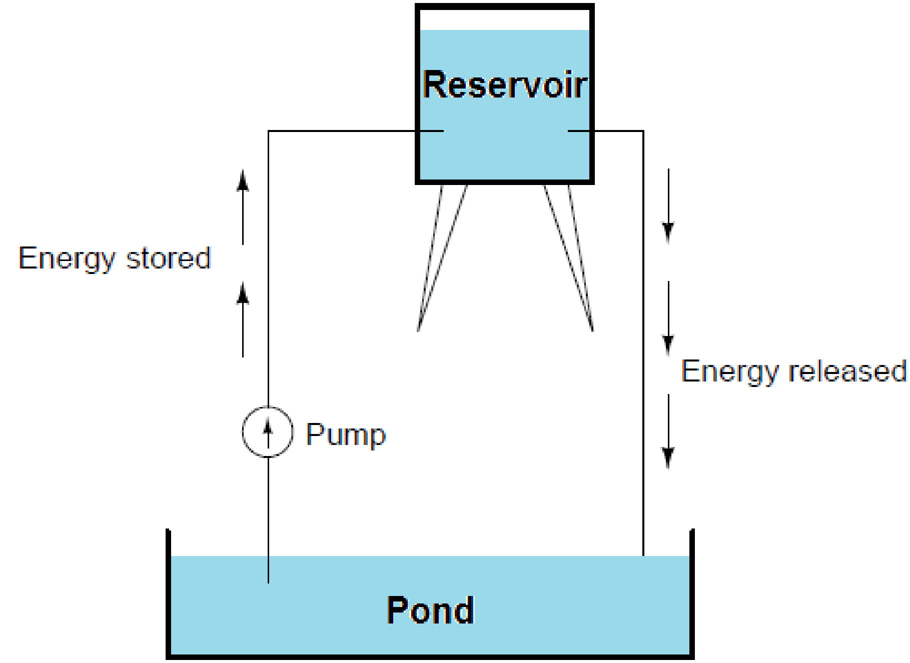
- With the ‘+’ and ‘-’ ends of the battery not connected to anything, there will be voltage between those two points, but there will be no flow of electrons through the battery, because there is no continuous path for the electrons to move.



- If water is pumped to an even higher level, it will take even more energy to do so: thus, more energy will be stored, and more energy will be released if the water is allowed to flow through a pipe back down again. In terms of a battery, we would say it has a '**bigger voltage**'/ '**bigger electric potential**'.

‘Electric Potential’/‘Voltage’

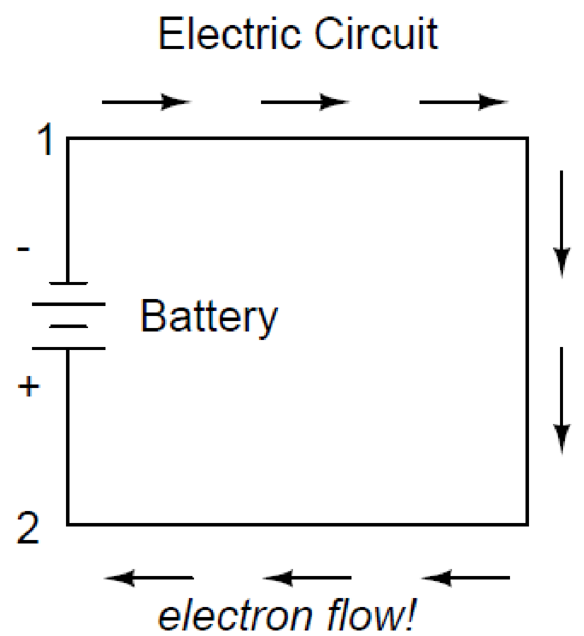




N.B. This **electric potential energy**, stored in the form of an electric charge imbalance (**an electric field**) and capable of making electrons flow through a conductor, can be called **voltage, a measure of the electric potential energy per unit charge of electrons, with units of J/C.**

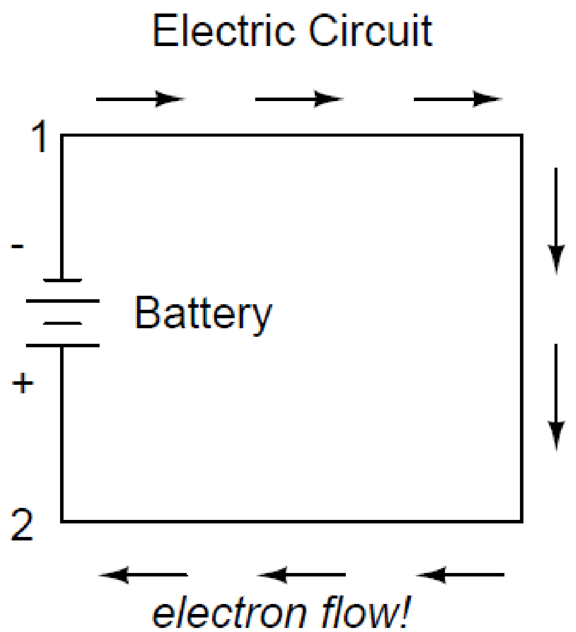
4. Resistance

Resistance



- To produce an electric current in a circuit, a difference in potential is required. As we’ve seen, one way of producing a potential difference along a wire is to connect its ends to the opposite terminals of a battery.

Resistance



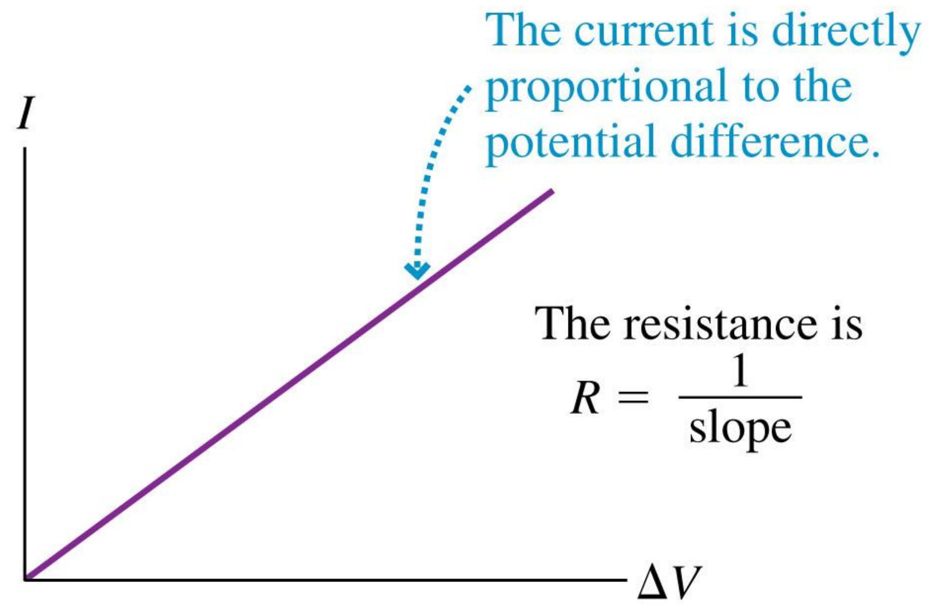
George Simon Ohm,
1787-1854

- It was Georg Simon Ohm who established experimentally that the current in a metal wire is proportional to the potential difference, V, applied to its two ends:

$$I \propto V$$

Resistance

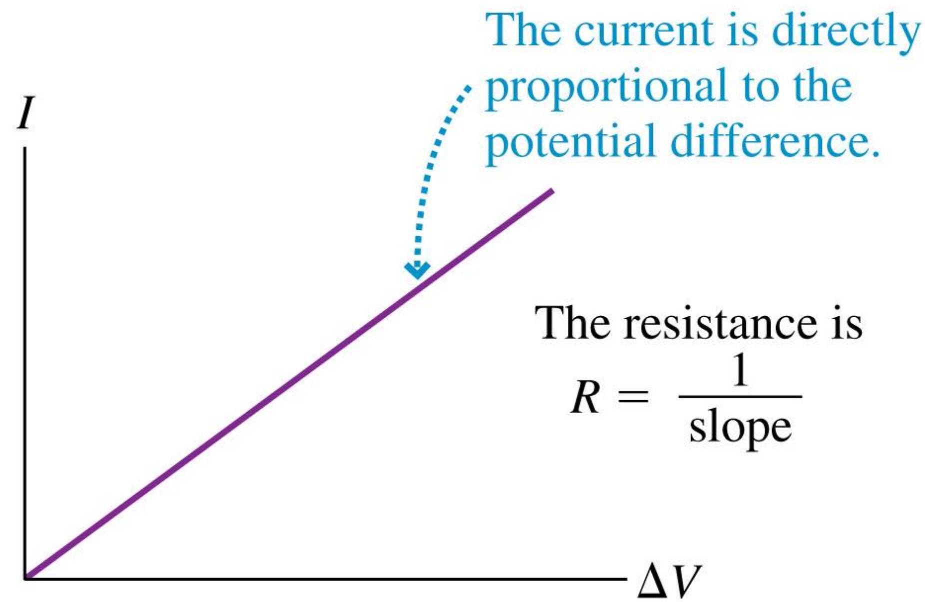
George Simon Ohm, 1789-1854



- Discovered in 1827, Ohm’s principal discovery was that the amount of electric current through a metal conductor between two points in a circuit is **directly proportional** to the voltage across it, for a given temperature.

Resistance

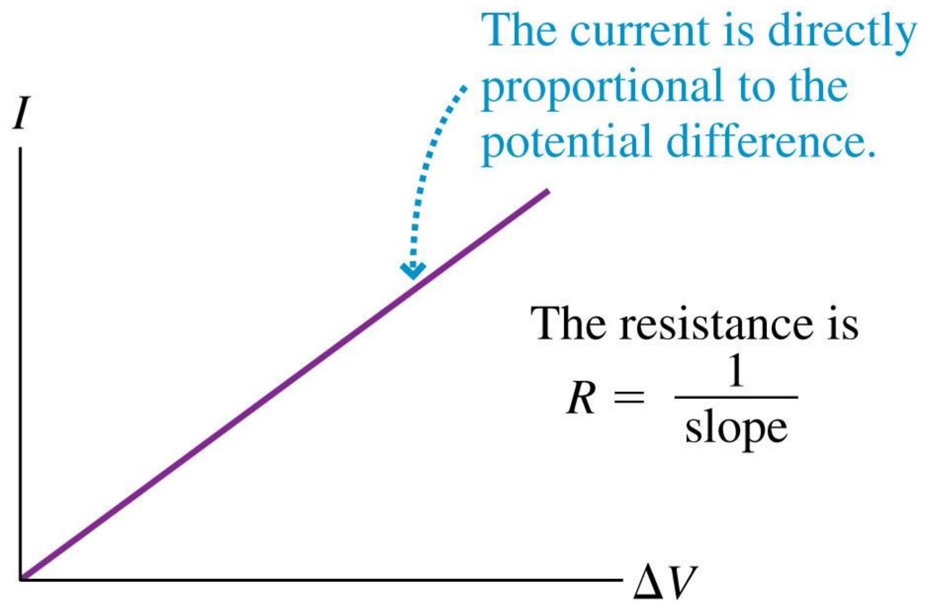
George Simon Ohm,
1789-1854



- The electron flow (which makes up the current) is resisted because of interactions with the atoms of the wire.
- To quantify this **resistance**, we look at the **ratio** of the voltage drop (ΔV) between two points on the wire to the current (I) that flows between those two points: $V{:}\,I$

Resistance

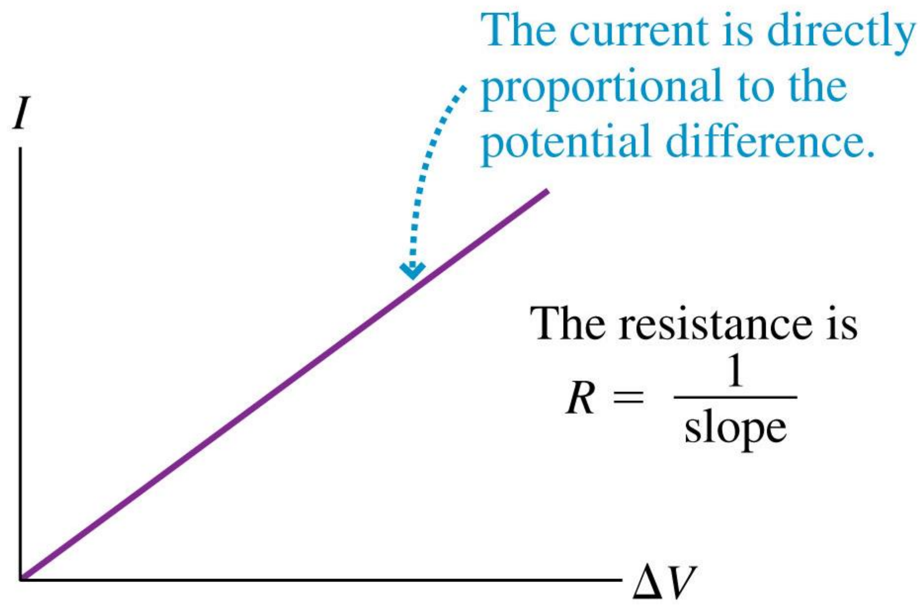
George Simon Ohm,
1789-1854



- To quantify this **resistance**, we look at the **ratio** of the voltage drop (ΔV or V) between two points on the wire to the current (I) that flows between those two points: $V : I$
- This ratio is called resistance ($\boldsymbol{R = \frac{V}{I}}$), and it is different for different materials.

Resistance

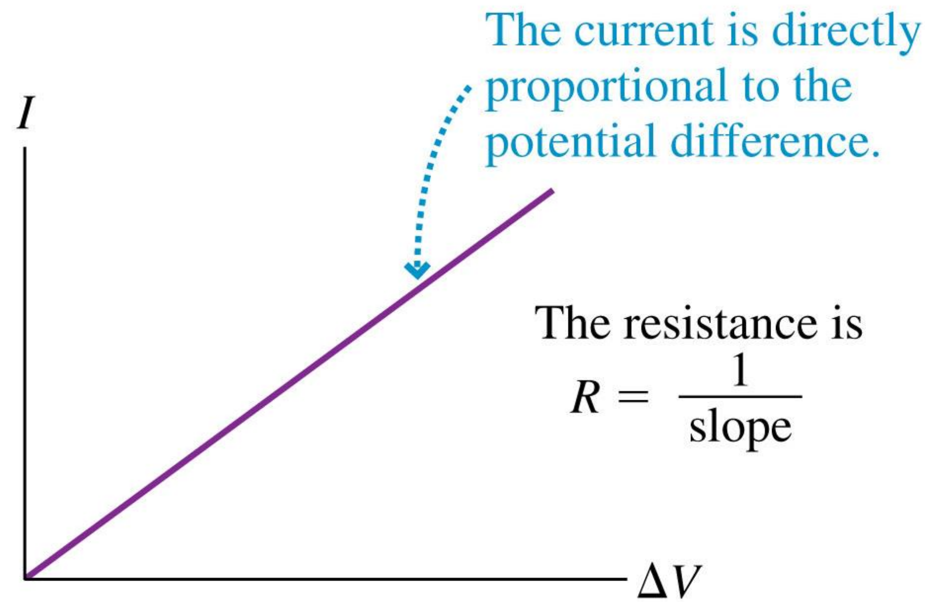
George Simon Ohm, 1789-1854



- This ratio is called resistance ($\boldsymbol{R = \frac{V}{I}}$), and it is different for different materials. We can also call this ratio and the equation that represents it ($\boldsymbol{V = IR}$) **Ohm's law**.
- Ohm's law is only valid though for materials where R is constant; we will see later that R can vary.

Resistance

George Simon Ohm,
1789-1854



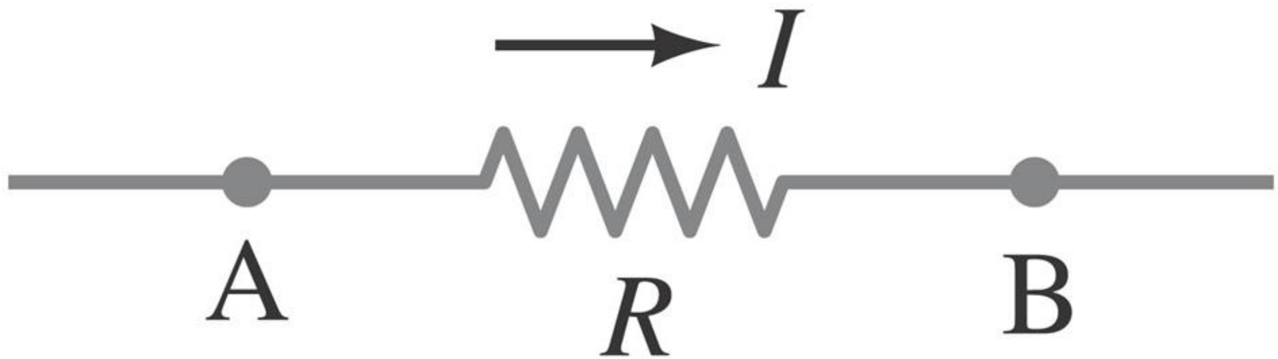
- The unit for resistance is called the ohm and is abbreviated Ω.
- Because $R = V/I$, we see that 1.0 Ω is equivalent to $1.0\ \mathrm{V/A}$.

N.B.

Every part of a circuit offers some resistance to current. Parts of the circuit which offer the most resistance are referred to as **resistors**; we will study some resistors in our next lecture

5. Resistivity

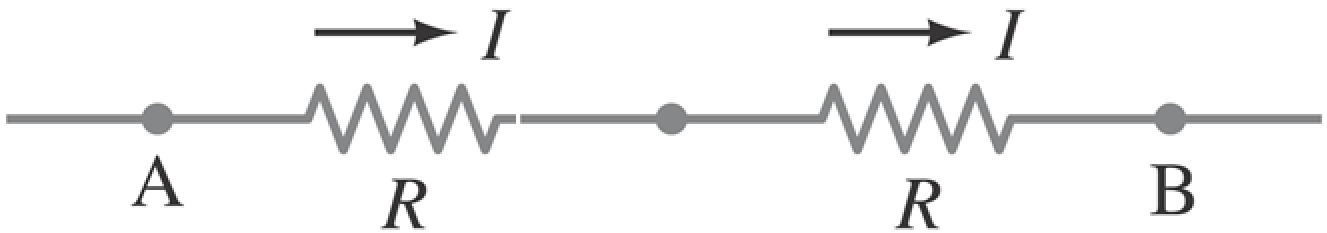
What does Resistance Depend on?



- So far, we've said that the ratio of the voltage drop (V) between two points, to the current (I) that flows between those two points, for a wire (or resistor), is a measure of the resistance (R), for that particular wire, which is made from a particular material.

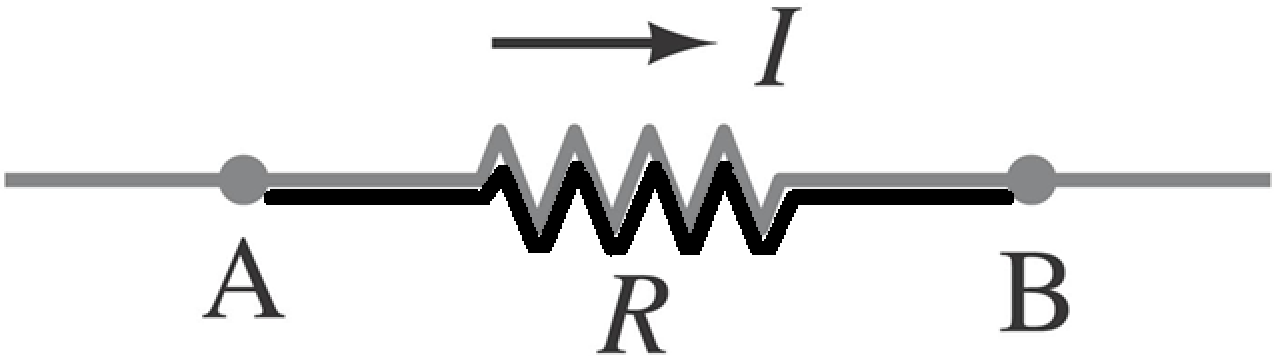
- A natural question to ask, however, is 'does the resistance of a wire depend on anything else'?

What does Resistance Depend on?



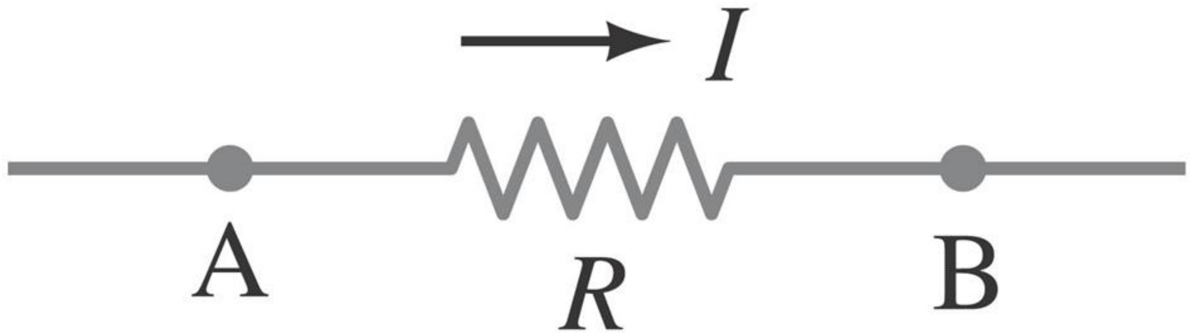
- Well, if we double the length of the wire/resistor, the voltage drop (V) between points A and B will double, but the current (I) will stay the same; therefore, the resistance (R) will double.
- Thus, $R \propto l$,
  where l is the length of the wire/resistor.

What does Resistance Depend on?



- If, on the other hand, we only double the cross-sectional area (A) of the wire, then the voltage (V) will stay the same, but the current (I) will double; therefore, the resistance (R) will be halved.
- Thus, $R \propto \frac{1}{A}$,
  where A is the cross-sectional area of the wire/resistor.

What does Resistance Depend on?



- In summary, it is found experimentally that the resistance (R) of any wire is directly proportional to its length (l) and inversely proportional to its cross-sectional area A. That is,

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

where ρ, the constant of proportionality, is called the **resistivity** and depends on the material used. Its unit is the $\Omega \cdot \mathrm{m}$.

Resistivity

TABLE 25–1 Resistivity and Temperature Coefficients (at 20°C)

Material	Resistivity, ρ ($\Omega \cdot$ m)	Temperature Coefficient, α $(C°)^{-1}$
Conductors		
Silver	1.59×10^{-8}	0.0061
Copper	1.68×10^{-8}	0.0068
Gold	2.44×10^{-8}	0.0034
Aluminum	2.65×10^{-8}	0.00429
Tungsten	5.60×10^{-8}	0.0045
Iron	9.71×10^{-8}	0.00651
Platinum	10.60×10^{-8}	0.003927
Mercury	98.00×10^{-8}	0.0009
Nichrome (Ni, Fe, Cr alloy)	100.00×10^{-8}	0.0004
Semiconductors†		
Carbon (graphite)	$(3-60) \times 10^{-5}$	−0.0005
Germanium	$(1-500) \times 10^{-3}$	−0.05
Silicon	0.1 – 60	−0.07
Insulators		
Glass	$10^{9} - 10^{12}$	
Hard rubber	$10^{13} - 10^{15}$	

† Values depend strongly on the presence of even slight amounts of impurities.

- A low resistivity value means that a material is a good conductor. We can see that silver is the best conductor, but yet, we use copper for most wiring; we do so because it is cheaper.

Resistivity

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† Values depend strongly on the presence of even slight amounts of impurities.

- Aluminum, although it has a higher resistivity than copper, is much less dense than it. It is thus preferable to copper in some situations, such as for transmission lines, because its resistance for the same weight is less than that for copper.

Temperature Dependence of Resistivity

TABLE 25–1 Resistivity and Temperature Coefficients (at 20°C)

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- The resistivity of a material depends somewhat on temperature.
- The resistance of metals generally increases with temperature. If the temperature change is not too great, the resistivity of metals usually increases nearly linearly with temperature. That is,

$$\rho_T = \rho_0[1 + \alpha(T - T_0)]$$

Temperature Dependence of Resistivity

TABLE 25–1 Resistivity and Temperature Coefficients (at 20°C)

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$$\rho_T = \rho_0[1 + \alpha(T - T_0)]$$

- Where ρ_0 is the resistivity at some reference temperature T_0 (such as 0°C or 20°C), ρ_T is the resistivity at a temperature T, and α is the **temperature coefficient of resistivity**.

Summary of today's Lecture

1. The Electric Battery
2. Electric Current
3. Electric Potential
4. Resistance
5. Resistivity

Lecture 13: Optional Reading

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

- **Ch. 25.1**, The Electric Battery; p.756-757.
- **Ch. 25.2**, Electric Current; p.758-759.
- **Ch. 25.3**, Ohm's Law: Resistance and Resistors; p.759-761.
- **Ch. 25.4**, Resistivity; p.762-763.

Home Work

Do not forget to attempt the **Additional Problems** for this lecture before logging in to **Mastering Physics** to complete your assignments.