IDC102:Hands-on Electronics
Lecture - 4

Lab Equipments

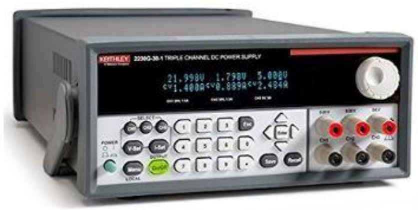
IISER

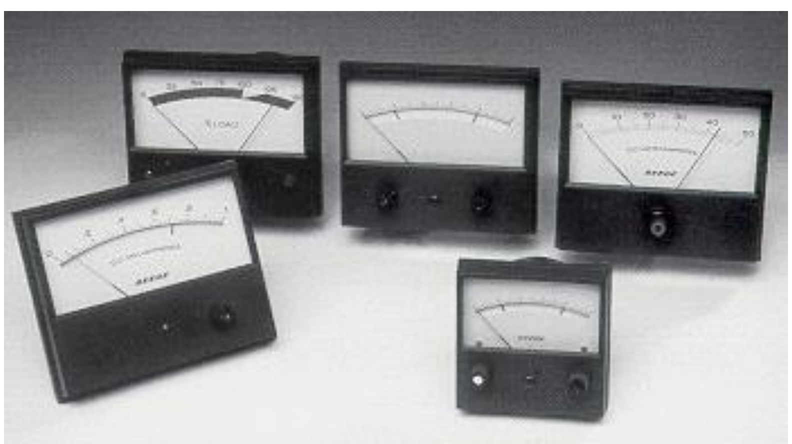
Satyajit Jena, 09/05/2022

Measurements

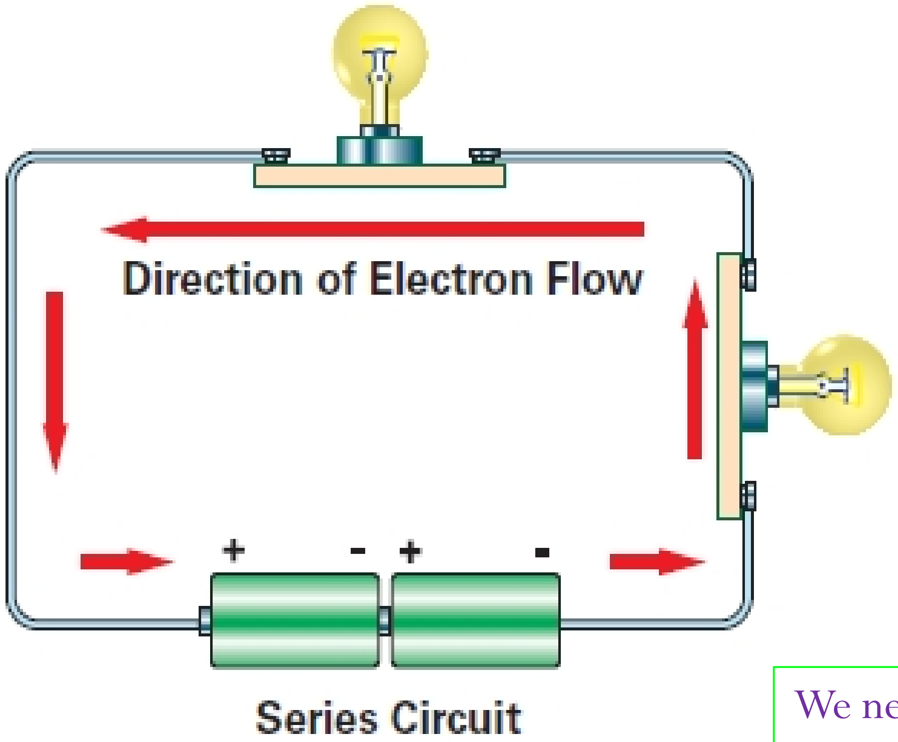
- We need to understand the instrument/device which measures the magnitude of an electrical quantity at the time when it is being measured

Digital Multimeters
Tektronix DMM4020 Datasheet





Measuring Device: what to measure?



We know that a circuit is established when there is a continuous path for electricity to travel from one end of the energy source to the other end.

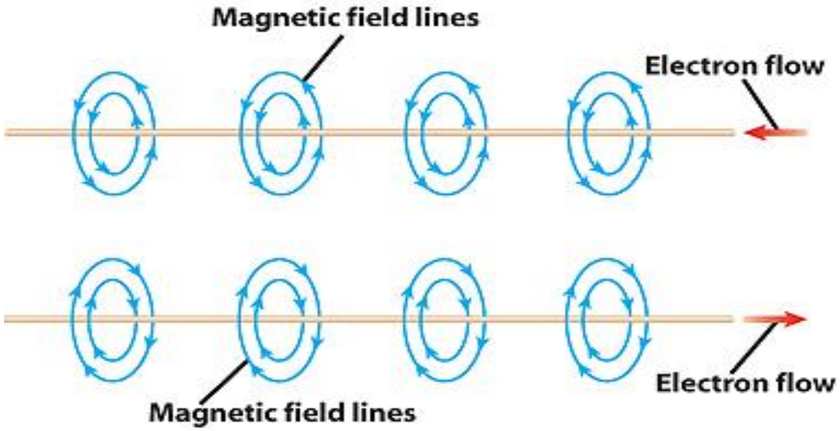
All circuits need three basic parts: an energy source, wires, and the object that is going to change the electrical energy into another form of energy (load).

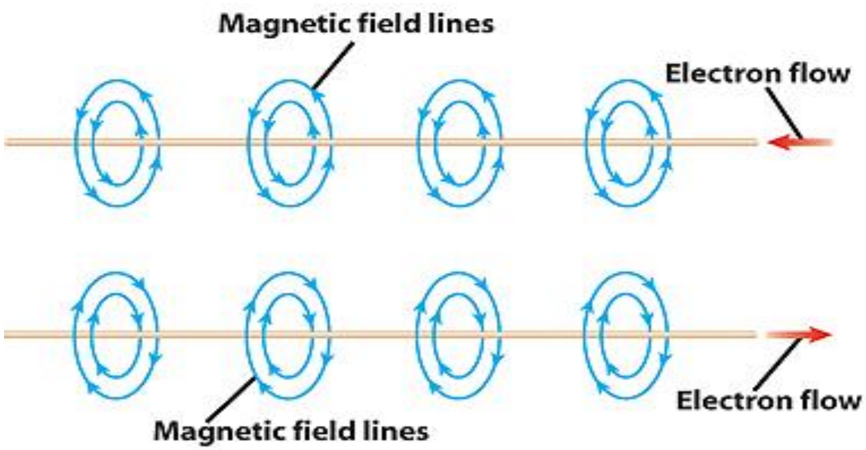
We need to quantify the strength of source (like voltage)
We need to know the flow of current (measuring current)
We need to know what is the amount of power consume
We need to know what is the opposition force (resistance)

We need the devices for these quantities to measure
How do we measure them?

Moving Charges

- Moving charges, like those in an electric current, produce magnetic fields.
  - The magnetic field around a current-carrying wire forms a circular pattern around the wire
  - The direction of the field depends on the direction of the current.
  - The strength of the magnetic field depends on the amount of current flowing in the wire.



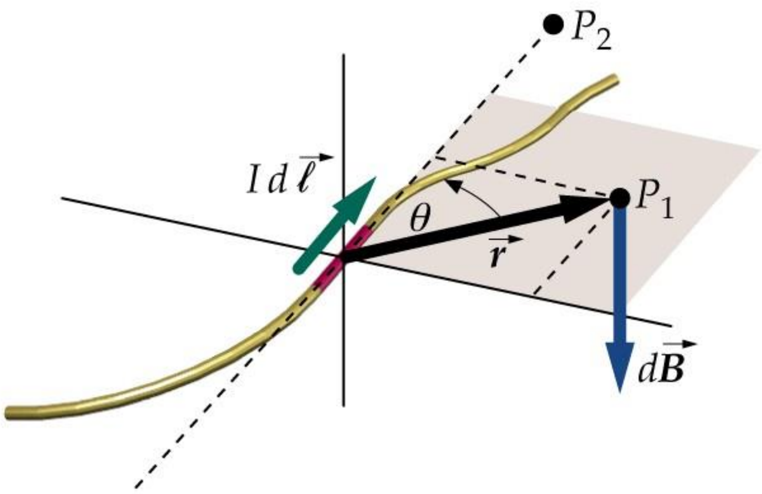


Question is what is the strength and how to determine the direction?

Biot-Savart Law

- Biot and Savart recognized that a conductor carrying a steady current produces a force on a magnet.
- Biot and Savart produced an equation that gives the magnetic field at some point in space in terms of the current that produces the field.

- Biot-Savart law says that if a wire carries a steady current I, the magnetic field dB at some point P associated with an element of conductor length ds has the following properties:
  - The vector dB is perpendicular to both ds (the direction of the current I) and to the unit vector r_{hat} directed from the element ds to the point P.

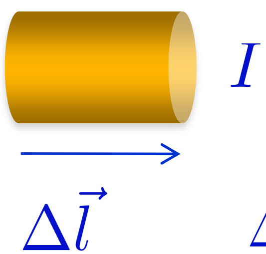


Biot-Savart Law

Quantitative rule for computing the magnetic field from any electric current

$$\vec{B} = \left(\frac{\mu_o}{4\pi}\right)\frac{q\vec{v} \times \hat{r}}{|r|^2}$$

point charge



$$\Delta\vec{B} = \left(\frac{\mu_o}{4\pi}\right)\frac{I\Delta\vec{l} \times \hat{r}}{|r|^2}$$

current in a segment of wire

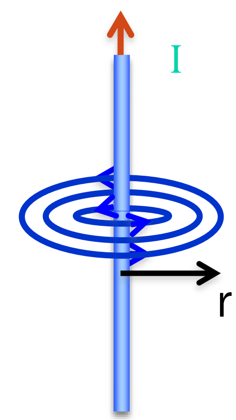
$\Delta\vec{l}$ = length of this chunk of wire

An infinitely long straight wire carries a current ***i*.**

$$\boxed{\vec{B} = \left(\frac{\mu_o}{4\pi}\right)\frac{IL}{r\sqrt{r^2 + (L/2)^2}}\hat{\theta}}$$

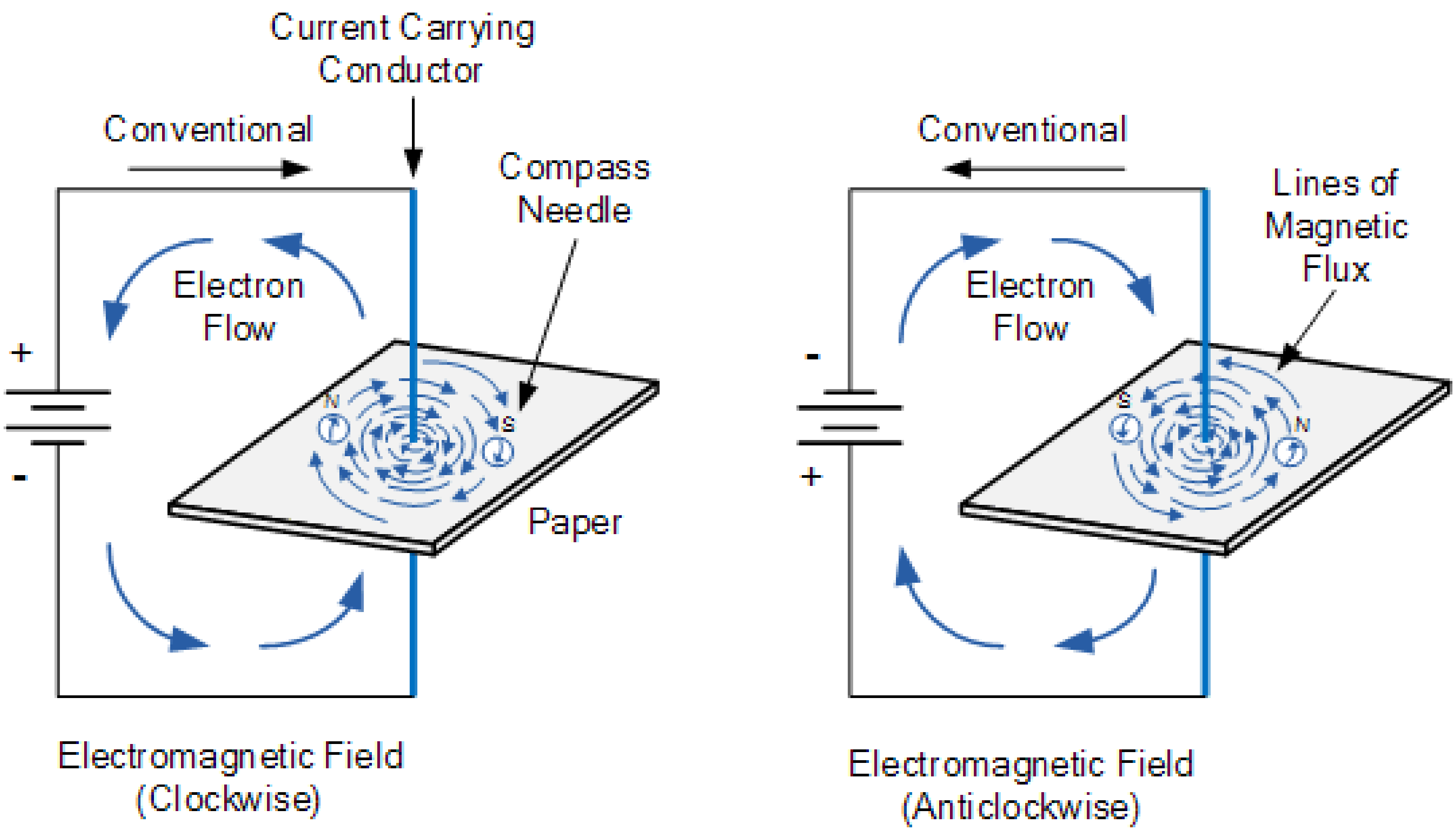
B of a Long Straight Wire

(Cylindrical Coordinates)



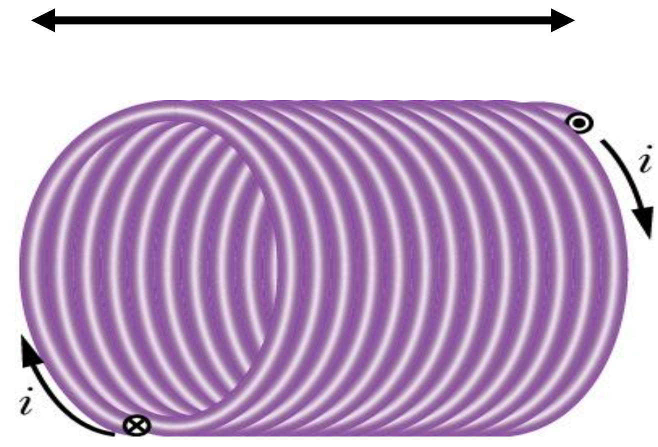
Cylindrical Coordinates

Magnetic Field around a Conductor



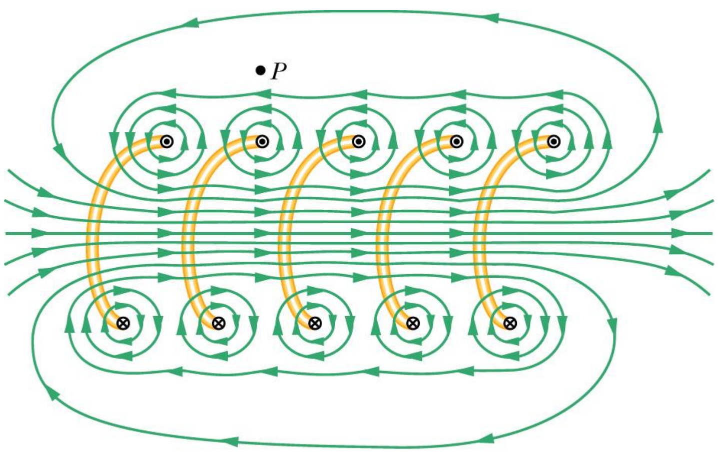
Magnetic field of a solenoid

• A constant magnetic field could be produced by an infinite sheet of current. In practice, however, it is easier and more convenient to use a ***solenoid***.



• A ***solenoid*** is defined by a current I flowing through a wire that is wrapped n turns per unit length on a cylinder of radius R and length L.

$$B_x = \mu_0 n I$$



• ***Long*** *solenoid (R<<L):*

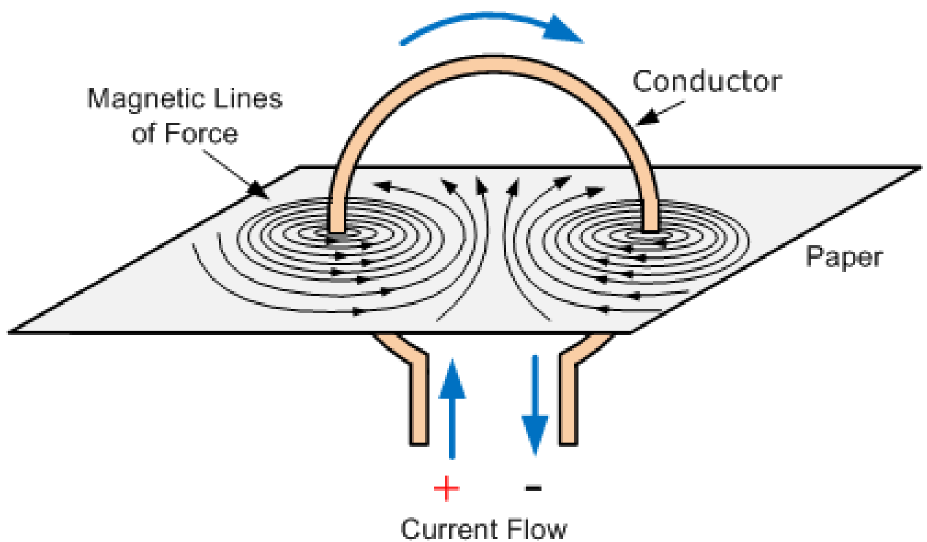
B inside solenoid ➡ ***// to axis***

B outside solenoid ➡ ***nearly zero***

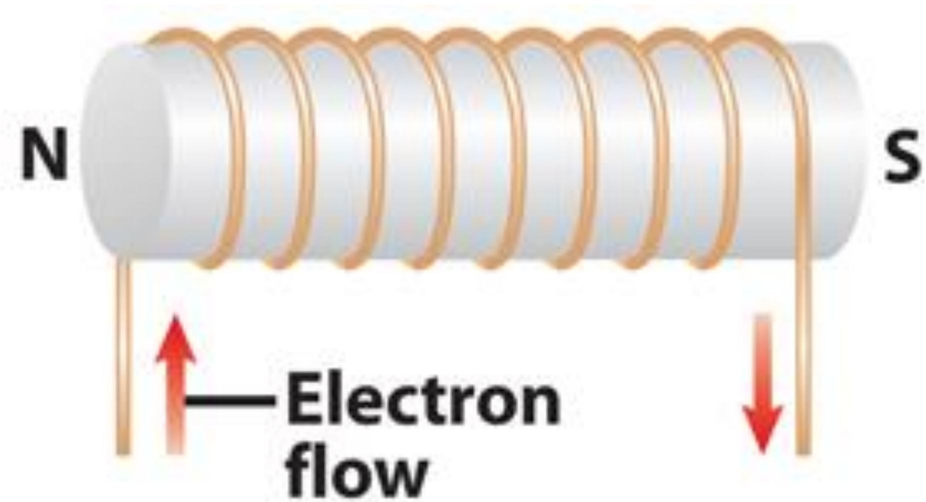
(not very close to the ends or wires)

Magnetic field of a solenoid: electromagnet

- The current flowing through the two parallel conductors of the loop are in opposite directions as the current through the loop exits the left-hand side and returns on the right-hand side.

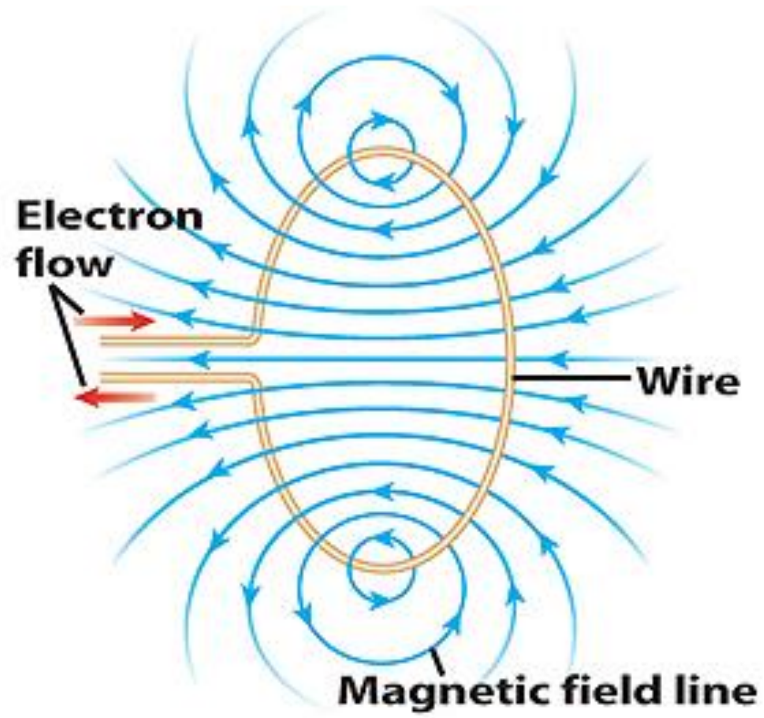


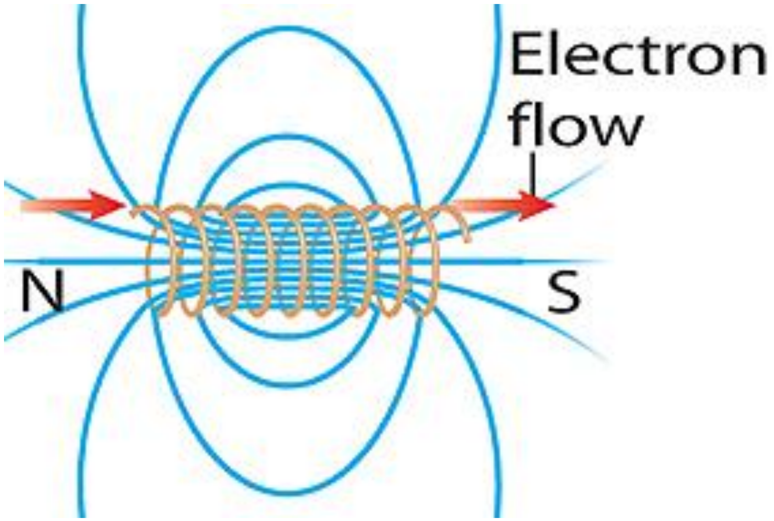
- If the wire is wrapped around an iron core, an electromagnet is formed.



Electromagnet

- **Electromagnet:** a temporary magnet made by placing a piece of iron inside a current-carrying coil of wire.
- Magnetic field is present only when current is flowing in the wire coil.



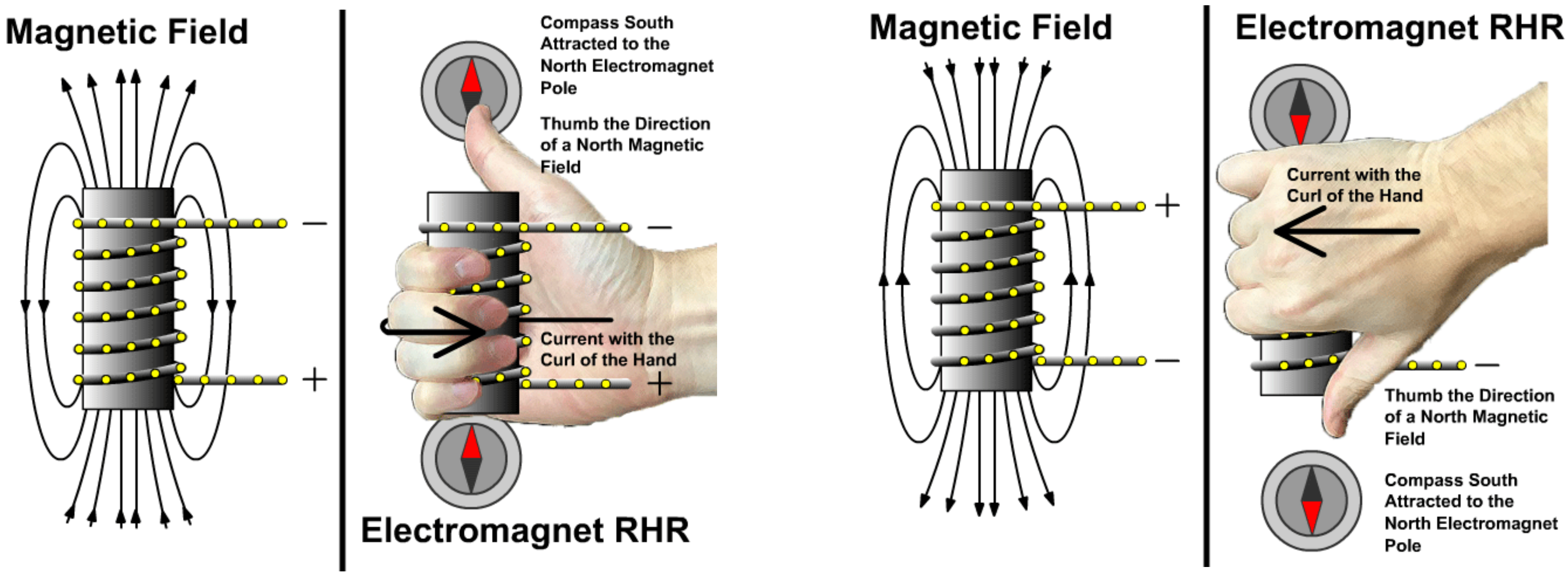


- Increase strength of the magnetic field by adding more turns to the wire coil or increasing the current passing through the wire.

Electromagnet

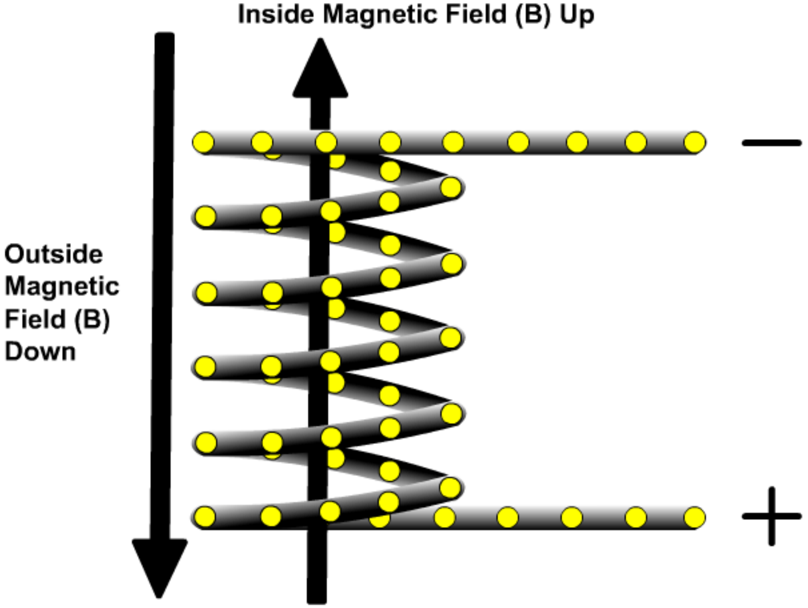
- Magnetic properties of electromagnets can be controlled by changing the electric current flowing through the wire coil.
  - When no current is flowing, the electromagnet loses its magnetic properties.
  - Strength can be increased by adding more turns of wire or by increasing the current.
- Converts electrical energy into mechanical energy to do work!
  - The forces exerted on an electromagnet by another magnet can be used to make the electromagnet rotate.

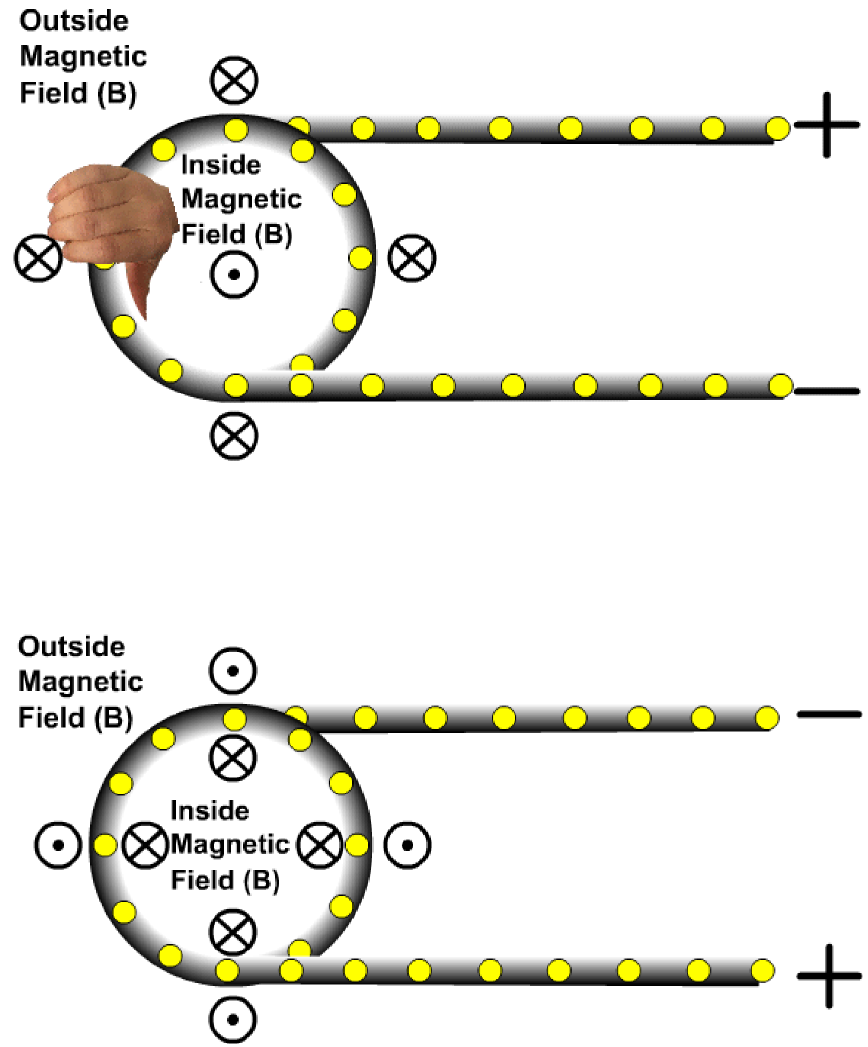
Electromagnet



The direction of moving changes decides the direction of magnetic field

Electromagnet

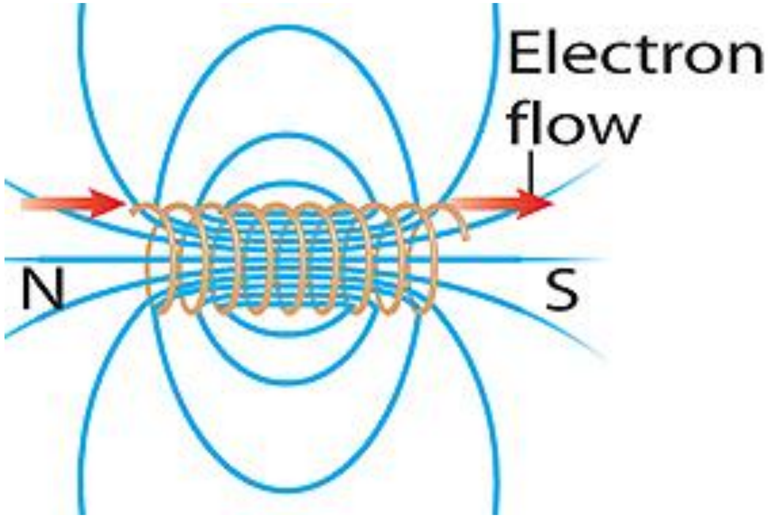


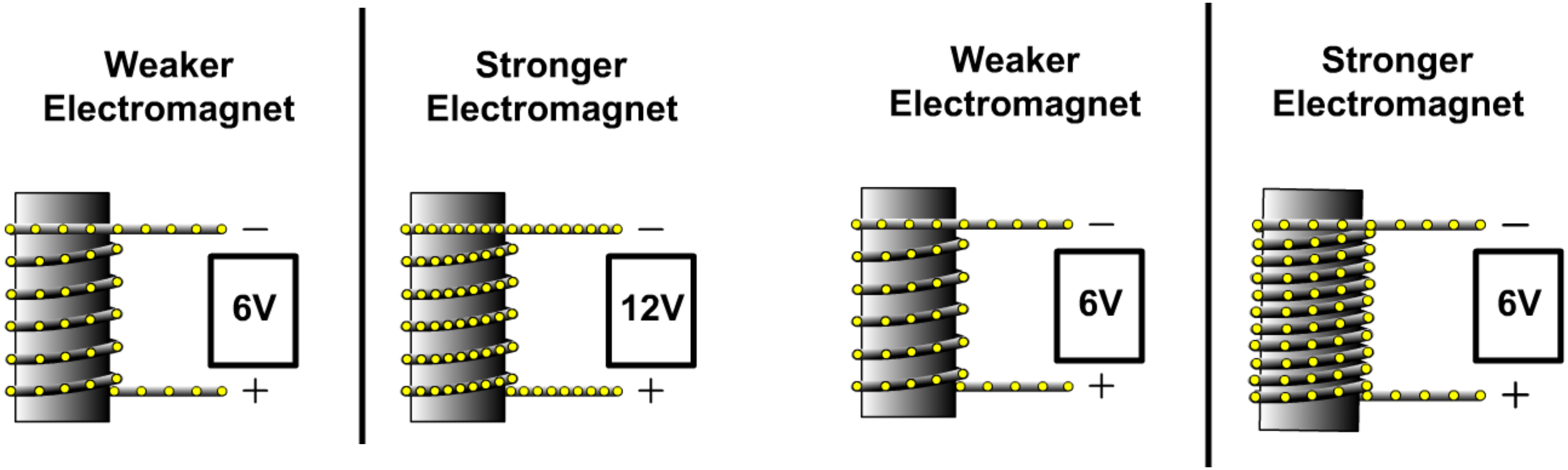


Field lines outside and inside of the loop

Electromagnet

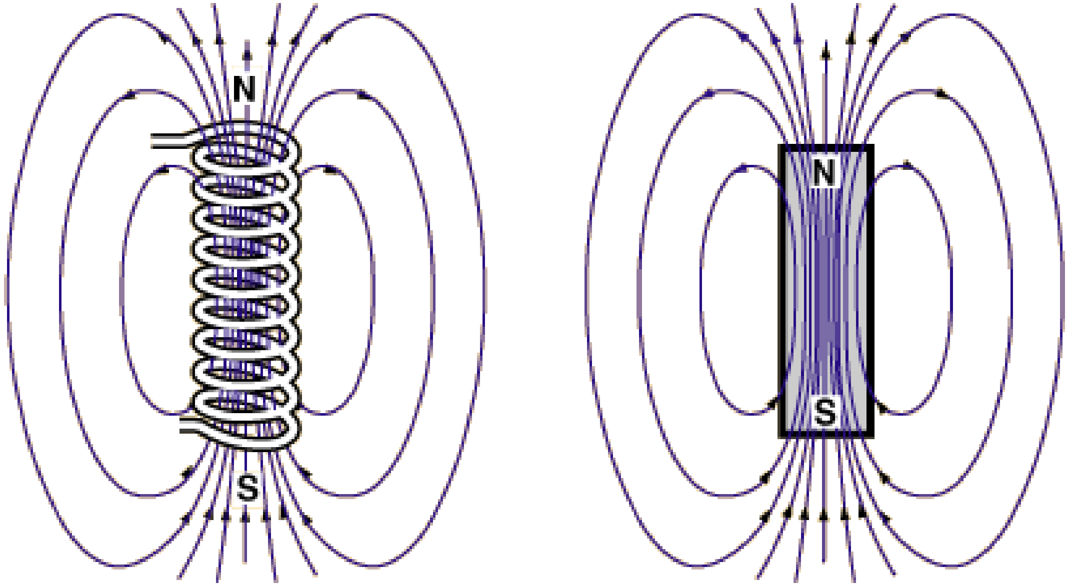
- Increase strength of the magnetic field by adding more turns to the wire coil or increasing the current passing through the wire.

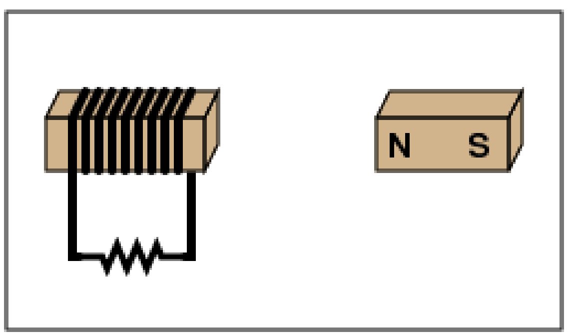




Magnet and Electromagnet

The magnetic field of a coil is identical to the field of a disk-shaped permanent magnet.





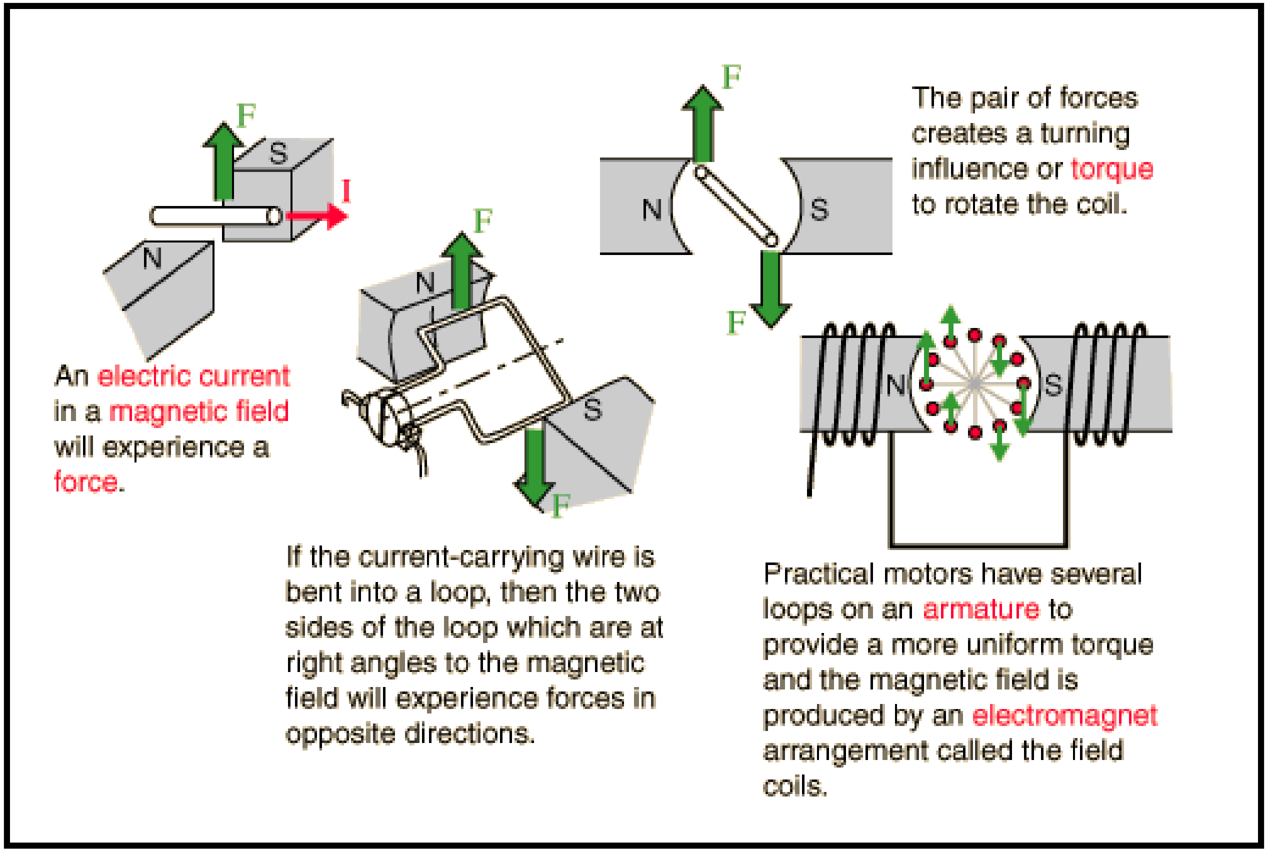
A stationary magnet can push or pull on the assembly of this electromagnet.

Larger field will have large push or pull, how you get larger field? => give more current or more voltage to have more current.

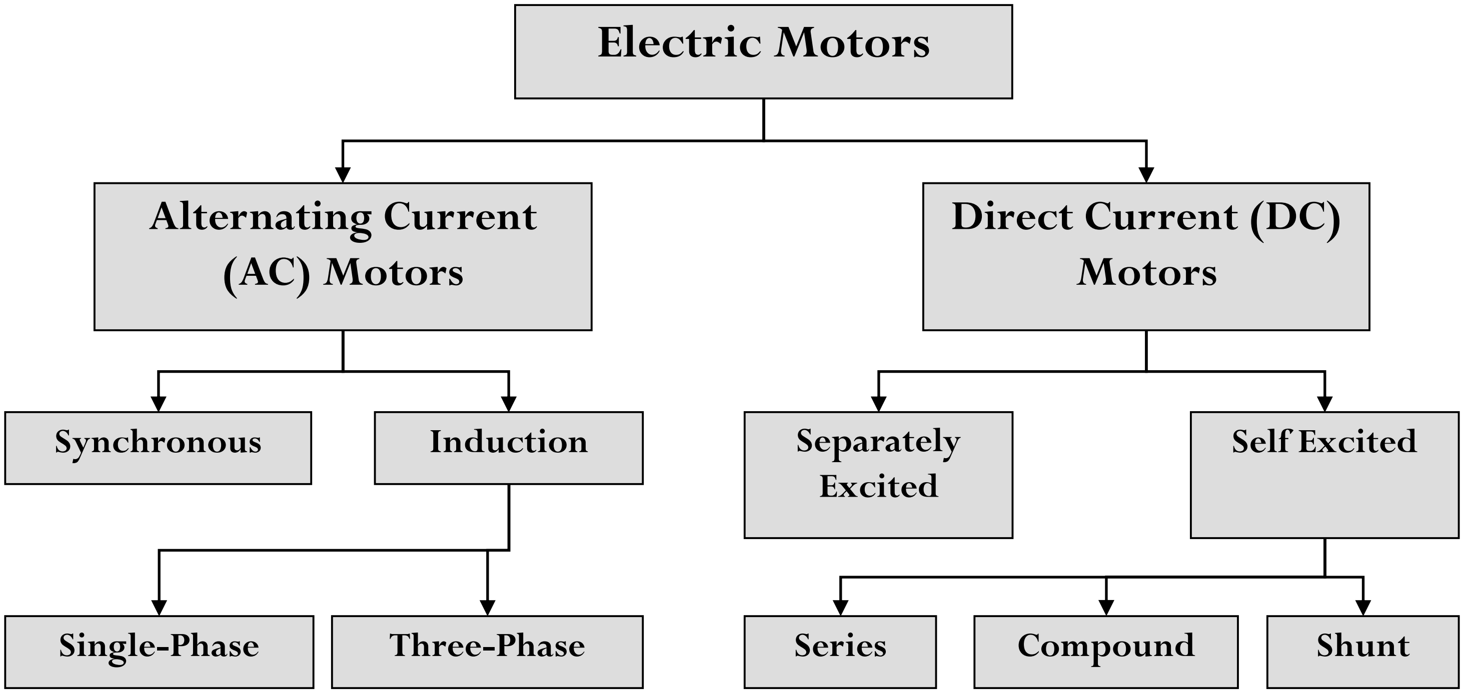
Let's use these concept to build something to measure

Motors

- **Electromechanical device that converts electrical energy to mechanical energy**



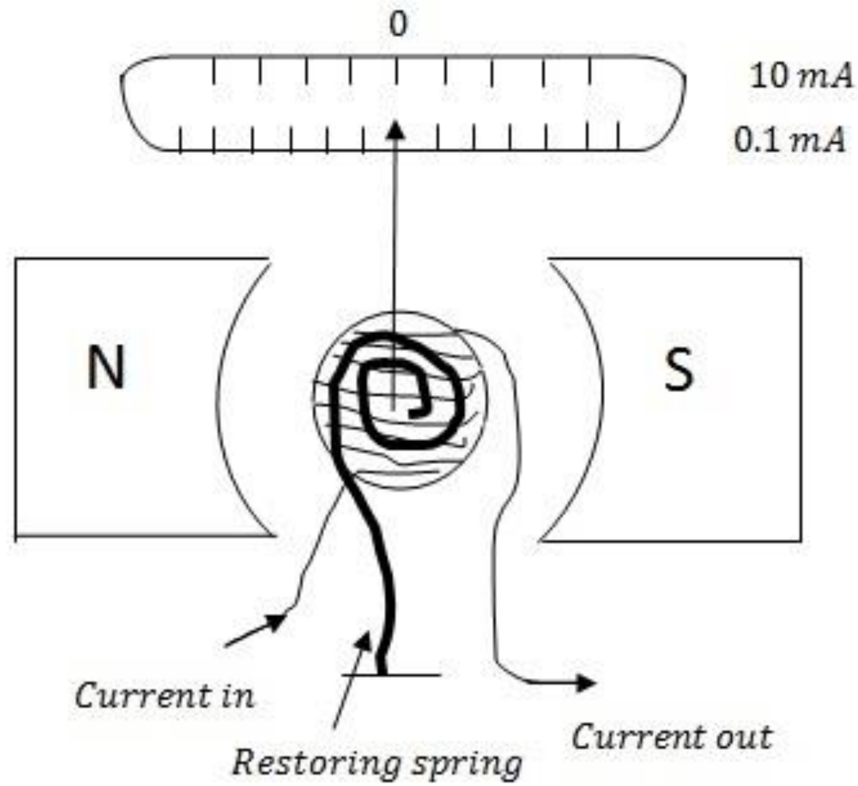
Type of Electric Motors



Beyond our scope to discuss each of them.

Let's make a device

A wire can be wrapped around a piece of iron, and placed between two magnets whereby opposite ends of the magnets face each other. The ends of the wire can be connected to terminals of power



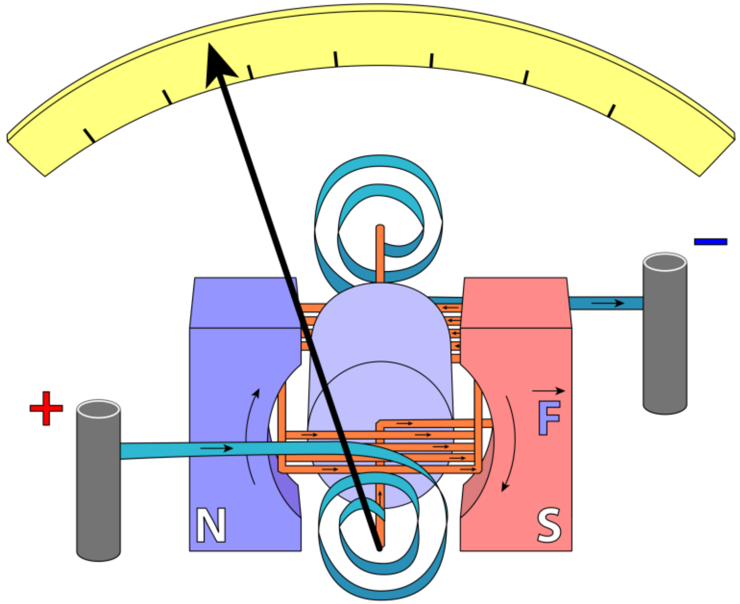
When electric current passes through the coil, a torque is applied to the wire-wrapped core twisting it.

The amount of twisting is proportional to the current through the wire. The needle stops when the torque due to the electromagnetic force is equal to the torque provided by the spring. When the current is turned off, the spring returns the needle to 0.

This was the exact idea of Galvanometer

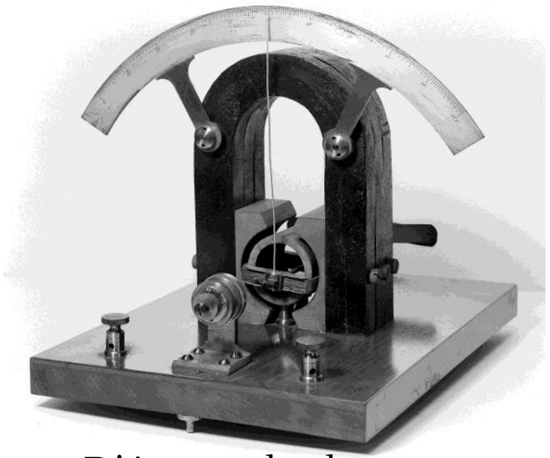
Galvanometer

- **Galvanometer:** a device that uses an electromagnet to measure electric current.
- Galvanometers were the first instruments used to determine the presence, direction, and strength of an electric current in a conductor.



Central Scientific Tangent Galvanometer utilizing compass (1941)

Thomson mirror galvanometer, patented in 1858.



D'Arsonval galvanometer

Galvanometer

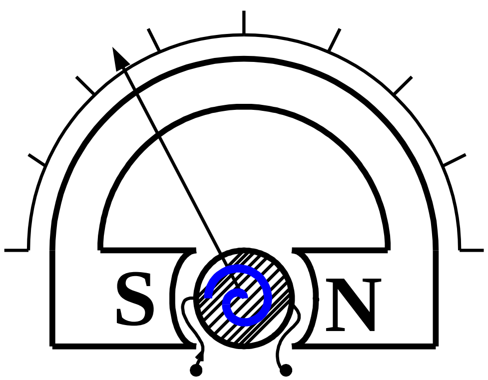
André-Marie Ampère, (1775-1836), is credited with the invention of the galvanometer in 1824. The earliest galvanometers were literally constructed of a compass surrounded by a coil of wire => called *tangent* galvanometers

The early moving-magnet form of galvanometer had the disadvantage that it was affected by any magnets or iron masses near it, and its deflection was not linearly proportional to the current. In 1882 Jacques-Arsène d'Arsonval and Marcel Deprez developed a form with a stationary permanent magnet and a moving coil of wire,

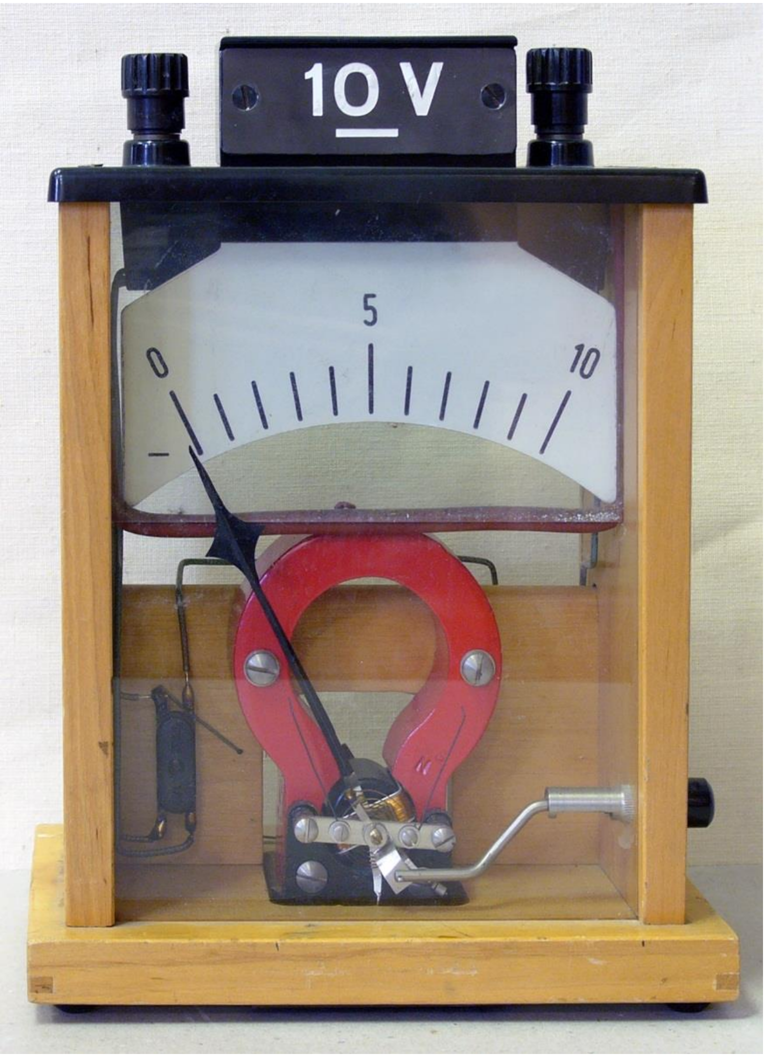
Source: wiki

D'Arsonval Meter Movement

- Permanent Magnet Frame
- Torque on rotor proportional to coil current
- Restraint spring opposes electric torque
- Angular deflection of indicator proportional to rotor coil current



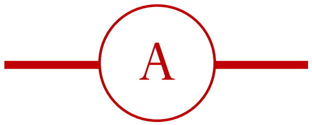
Let's see how the measuring is done



A D'Arsonval Voltmeter

Measuring Devices

When we measure **voltage** or **current** in a circuit, we want to make sure to minimize an effect that our tool has on the circuit so that we get the most accurate results



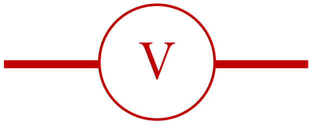
Ammeter

Ammeter: measures current I

Voltmeter: measures voltage difference ΔV

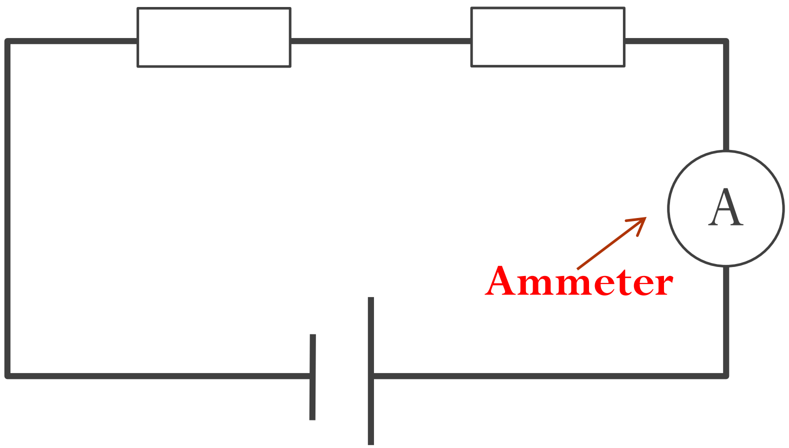
Ohmmeter: measures resistance R

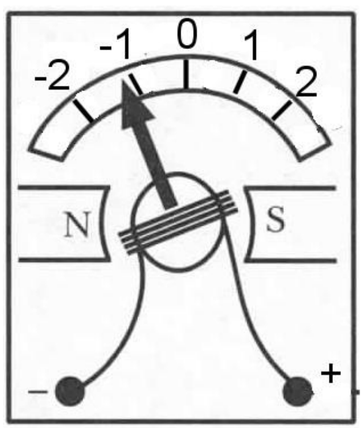
Voltmeter



Measuring Instruments: Ammeter

- Ammeters, Hooked up in **series** with the component being measured

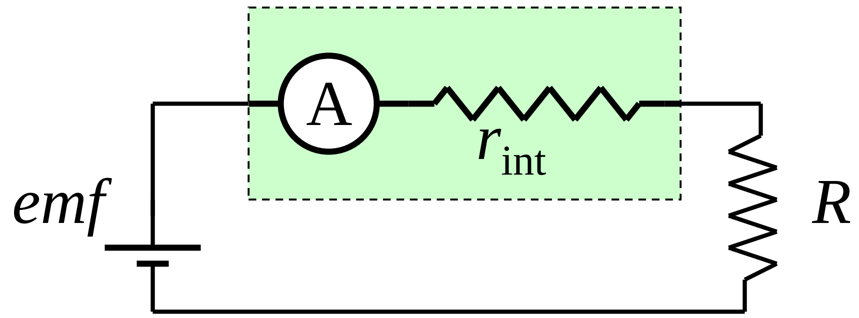




Simple commercial ammeter

Ammeter Design

Ammeter is inserted in series into a circuit – measured current flows through it.



Process of measuring requires charges to do some work:
Internal resistance

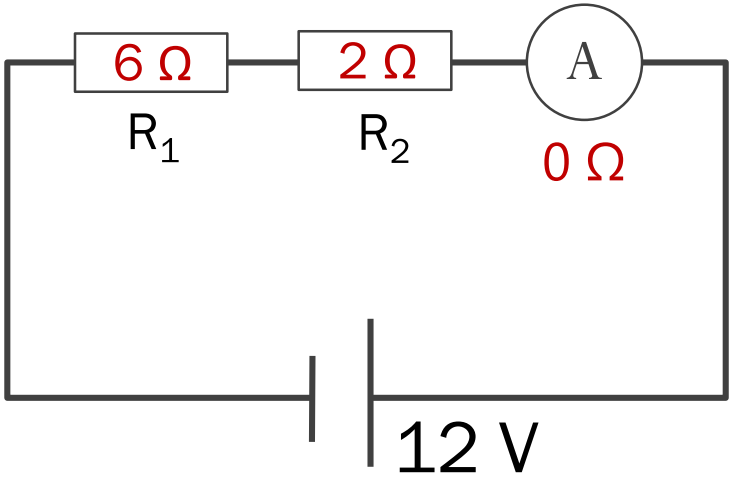
No ammeter: $emf - RI = 0 \longrightarrow I = \dfrac{emf}{R}$

With ammeter: $emf - r_{int}I - RI = 0 \longrightarrow I = \dfrac{emf}{R + r_{int}}$

Internal resistance of an ammeter must be very small

Measuring Current: Idea Situation =

What is the reading for the current flowing through this ideal ammeter?



$$R_T = 8\ \Omega$$

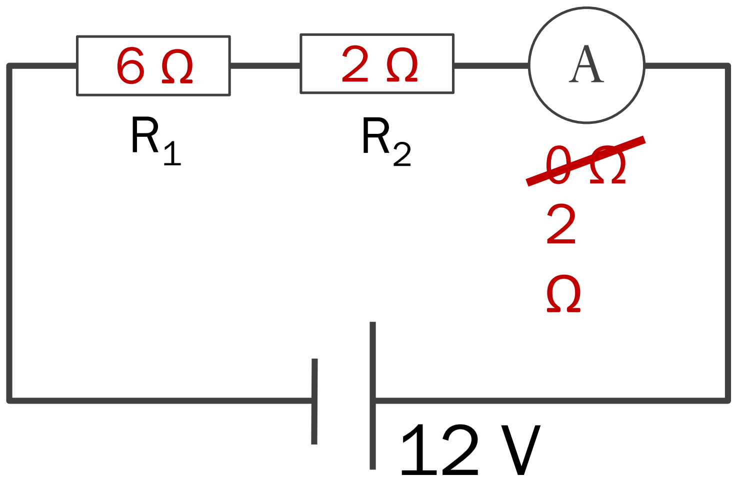
$$I = \frac{V}{R} = \frac{12}{8} = \mathbf{1.5\ A}$$

The ammeter has no effect on the current that it's measuring

An ideal Ammeter will have ZERO resistance

What if Ammeter isn't ideal?

What is the reading for the current flowing through this ~~ideal~~ 2 Ω ammeter?



$$R_T = \cancel{8\,\Omega}\ 10\,\Omega$$

$$I = \frac{V}{R} = \frac{12}{\cancel{8}\ 10} = \cancel{1.5\ \mathbf{A}}\ 1.2\ \mathbf{A}$$

The non-ideal ammeter's resistance slows down the current that it's measuring

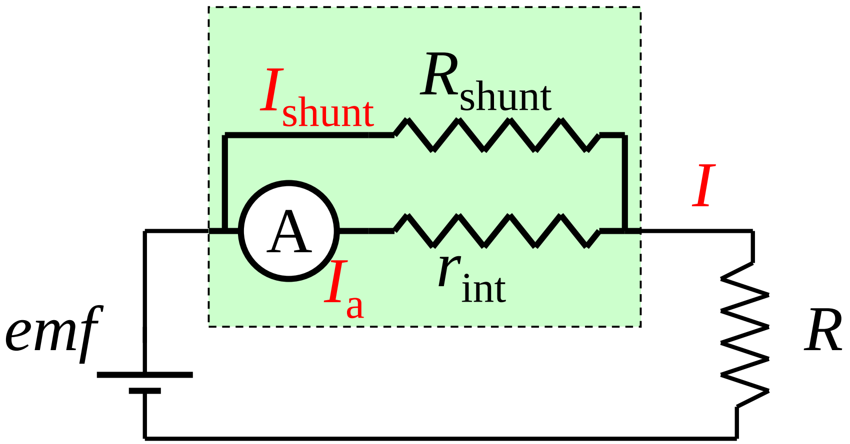
$$r_{\text{int}} I_a - R_{shunt} I_{shunt} = 0$$

$$I = I_a + I_{shunt}$$

$$r_{\text{int}} I_a - R_{shunt}(I - I_a) = 0$$

$$I_a(r_{\text{int}} + R_{shunt}) - R_{shunt} I = 0$$

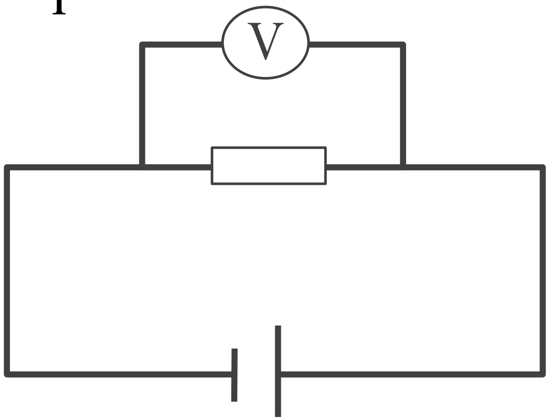
$$\boxed{I_a = \frac{R_{shunt}}{r_{\text{int}} + R_{shunt}} I}$$



Using a shunt resistor one can reduce sensitivity of an ammeter

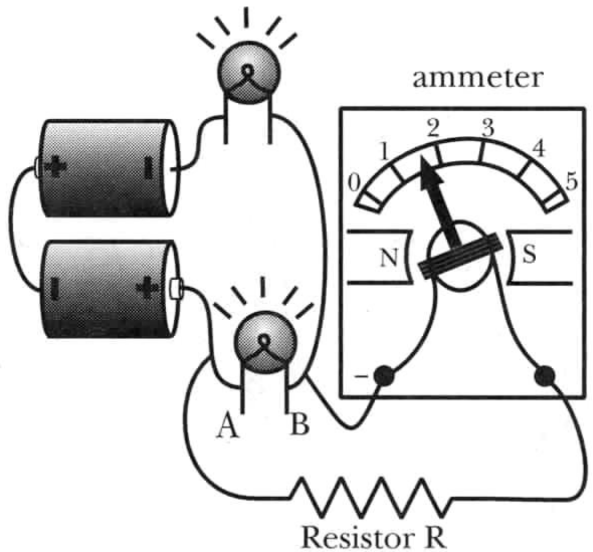
Measuring Instruments: Voltmeter

- Voltmeters are connected in parallel across the points between which potential difference is to be measured.



Connecting Voltmeter:

Higher potential must be connected to the '+' socket and lower one to the '-' socket to result in positive reading.

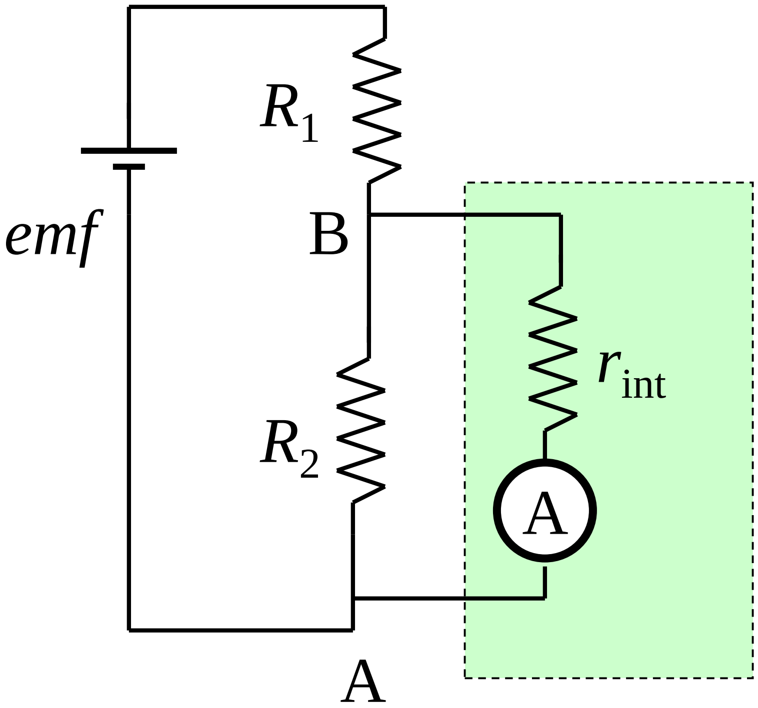


ΔV_{AB} – add a series resistor to ammeter

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

Measure I and convert to $\Delta V_{AB} = IR$

Voltmeter Internal Resistance



ΔV_{AB} in absence of a voltmeter

$$\Delta V_{AB} = \frac{R_2}{R_1 + R_2} emf$$

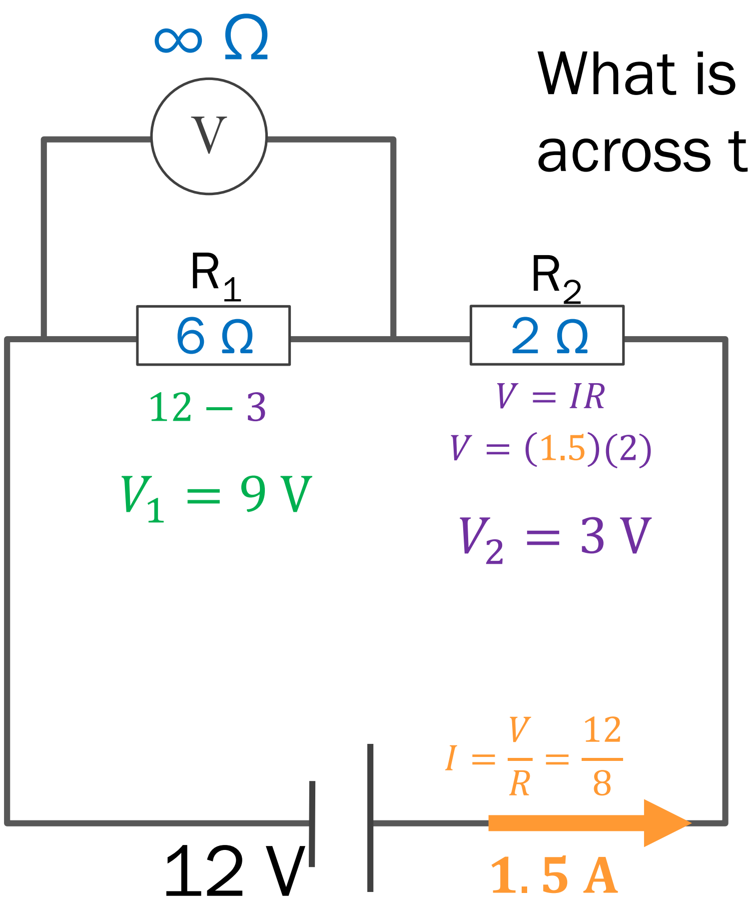
ΔV_{AB} in presence of a voltmeter

$$\Delta V_{AB} = \frac{R_{2\|\text{int}}}{R_1 + R_{2\|\text{int}}} emf$$

$$R_{2\|\text{int}} = \frac{R_2 r_{\text{int}}}{R_2 + r_{\text{int}}}$$

Internal resistance of a voltmeter must be very large

Measuring Voltage: Ideal



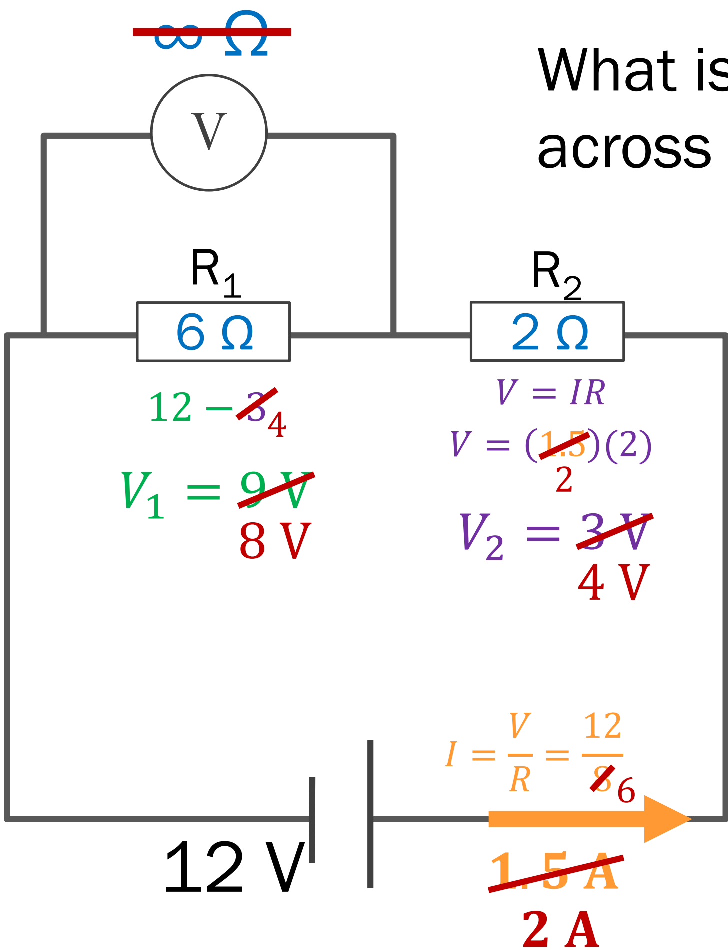
What is the reading for the ideal voltmeter across the resistor R_1?

$$R_T = \frac{1}{\frac{1}{6} + \frac{1}{\infty}} + 2$$

0

$$R_T = 6 + 2 = \mathbf{8\ \Omega}$$

Voltage: Non-ideal



What is the reading for the ~~ideal~~ 12 Ω voltmeter across the resistor R_1?

$$R_T = \frac{1}{\frac{1}{6}+\frac{1}{\cancel{\infty}\ 12}} + 2$$

$$R_T = \cancel{6}\ 4 + 2 = \cancel{8\ \Omega}\ 6\ \Omega$$

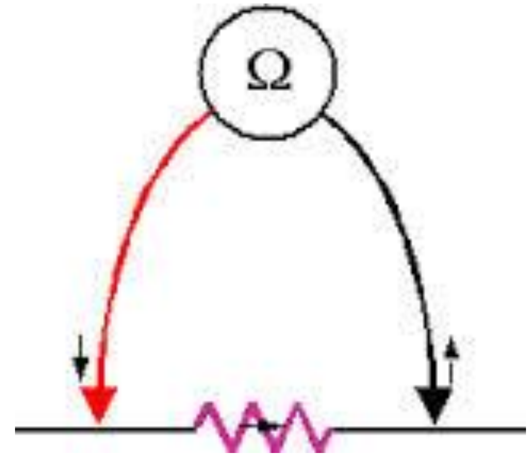
Indirect

- Measure Voltage across Resistor
- Measure Current through Resistor
- Calculate Resistance (Inaccurate)

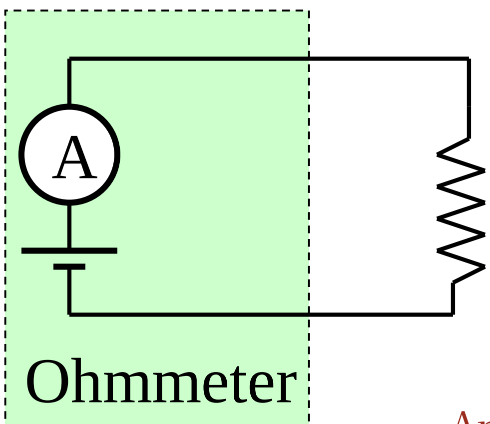
d'Arsonval Ohmmeter

- Very Simple
- Inaccurate

Wheatstone Bridge (Most Accurate)



How would you measure R?



$$R = \frac{emf}{I}$$

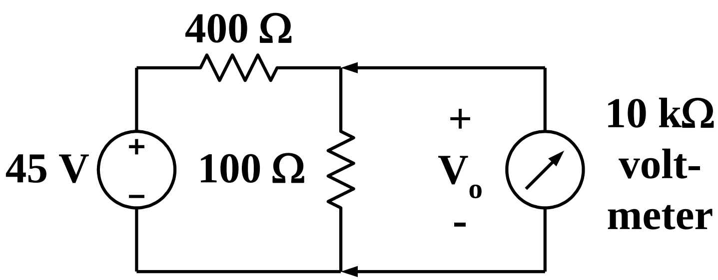
$$\boxed{I = \frac{emf}{R}}$$

Ammeter with a small voltage source

Measurement Errors

- Inherent Instrument Error
- Poor Calibration
- Improper Use of Instrument
- Application of Instrument Changes What was to be Measured
  - Ideal Voltmeters have Infinite Resistance
  - Ideal Ammeters have Zero Resistance

Voltmeter Measurement



True Voltage:

$$V_o = 45V \frac{100\Omega}{500\Omega} = 9V$$

(If voltmeter removed)

$$V_o = 45V \frac{100\Omega}{400\Omega\left(1+\dfrac{100\Omega}{10k\Omega}\right)+100\Omega} = 8.9286$$

$$\%Error = \left(\frac{8.9286V}{9.0V} - 1\right)100\% = -0.794\%$$

Current Measurement

Measured Current: $$I_o = 5\,A\frac{25\Omega}{125.05\Omega} = 0.9996\,A$$

$$\%Error = \left(\frac{0.9996\,A}{1.0\,A} - 1\right)100\% = -.04\%$$

$$I_o = 5\,A\frac{25\Omega}{125.05\Omega} = 0.9996\,A$$

$$\%Error = \left(\frac{0.9996\,A}{1.0\,A} - 1\right)100\% = -.04\%$$

Multimeter

- Multimeter or a multitester is a measurement instrument used in electronics, which is designed to perform tasks of several measuring instruments.
- The voltage, current, and resistance measurements can be made using different options available in a common Multimeter. Therefore, it is also called VOM (Volt Ohm meter).
- There are two types of multimeters ;analog and digital based on their measurement and display method.
- There are Analog and Digital Multimeter

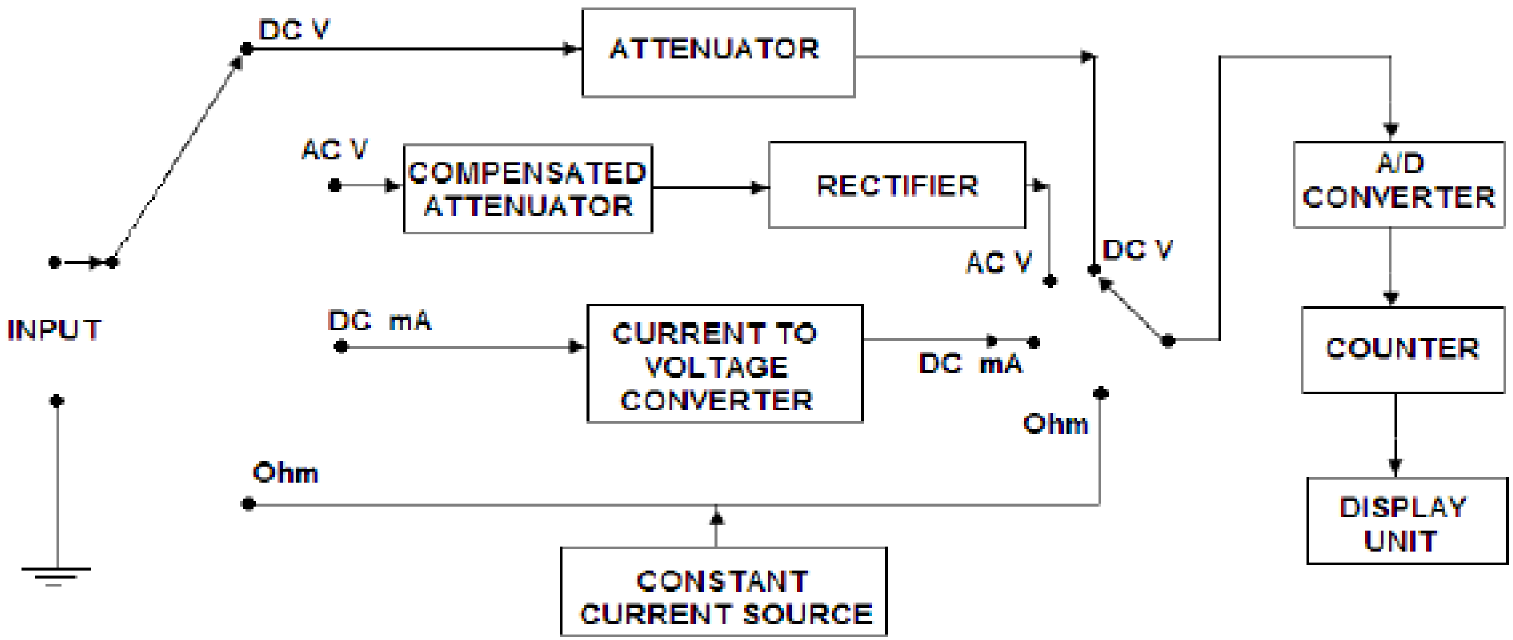
Analog Multimeter

- In Analog Multimeter, continuous deflection of a pointer over a scale represents the value of quantity being measured.
- Analog meters require no power supply, they give a better visual indication of changes and suffer less from electrical noise and isolation problems.
- These meters are simple and inexpensive.

Digital Multimeter

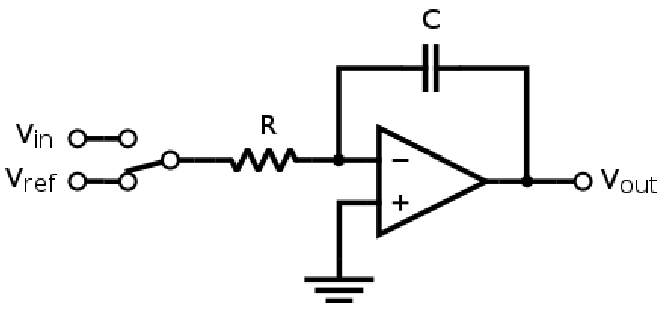
- Digital multimeters display a numerical value as the output which has a higher accuracy than the analog multimeters.
- Digital multimeter is basically a digital voltmeter and may be used for the measurement of voltage ,current (D.C or A.C) and resistance. All quantities other than D.C voltage are first converted into an equivalent D.C voltage by some device.

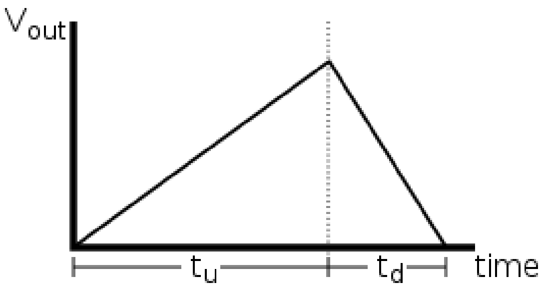
How Digital Multimeter works



- Integrating Converter
- Dependent on V_{ref}
- Dependent on Temperature
- Independent of RC

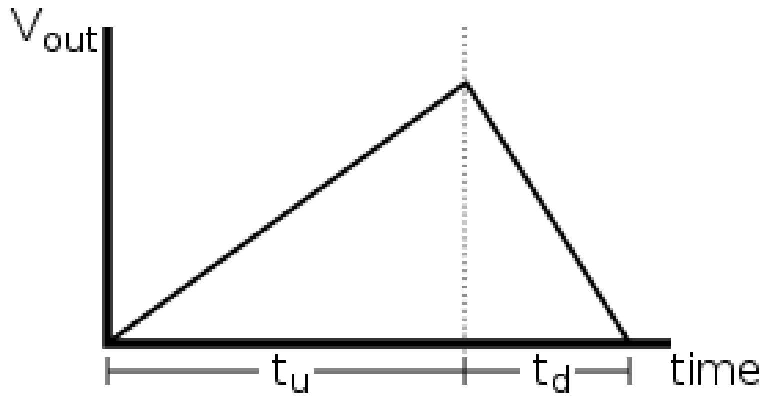
Example Voltmeter





How the DVM Works

$$V_{out-up} = -\frac{V_{in}}{RC} t_u$$



$$V_{out-down} = 0 = -\frac{V_{ref}}{RC} t_d + V_{out-up}$$

$$\frac{V_{ref}}{RC} t_d = -\frac{V_{in}}{RC} t_u$$

$$V_{in} = -V_{ref} \frac{t_d}{t_u}$$

If

$$V_{ref} = -5V \qquad R = 10k\Omega$$

$$C = 10\mu F \qquad t_u = 100ms$$

$$t_d = 50ms$$

$$V_{in} = -(-5V)\frac{50ms}{100ms} = 2.5V$$

Measuring Instruments: Multimeter

- Digital Multimeter (DMM) facilities
  - While the facilities that a digital multi-meter can offer are much greater than their analogue predecessors, the cost of DMMs is relatively low. DMMs are able to offer as standard the basic measurements that would typically include:
  - Current (DC)
  - Current (AC)
  - Voltage (DC)
  - Voltage (AC)
  - Resistance

- However, using integrated circuit technology, most DMMs are able to offer additional test capabilities. These may include some of the following:
  - Capacitance
  - Temperature
  - Frequency
  - Transistor test - hfe, etc
  - Continuity (buzzer)

Measuring Instruments: Multimeter

Analog Vs Digital Multimeters

- Analog multimeters give the output as a reading on a scale against a pointer, while digital multimeter output is in numerical form displayed on a LCD.
- Digital multimeters are more accurate than analog multimeters.
- Digital multimeters have a better range of measurements than analog multimeters.
- Digital multimeters offer additional features such as capacitance, temperature, frequency, sound level measurements and detection of semiconductor device pins (transistor / diode).
- Analog multimeters have to be calibrated manually, while most digital multimeters are calibrated automatically before every measurement.
- Analog multimeters are less costly while digital multimeters are expensive.

DMM

Used to measure Voltage, Current, and Resistance

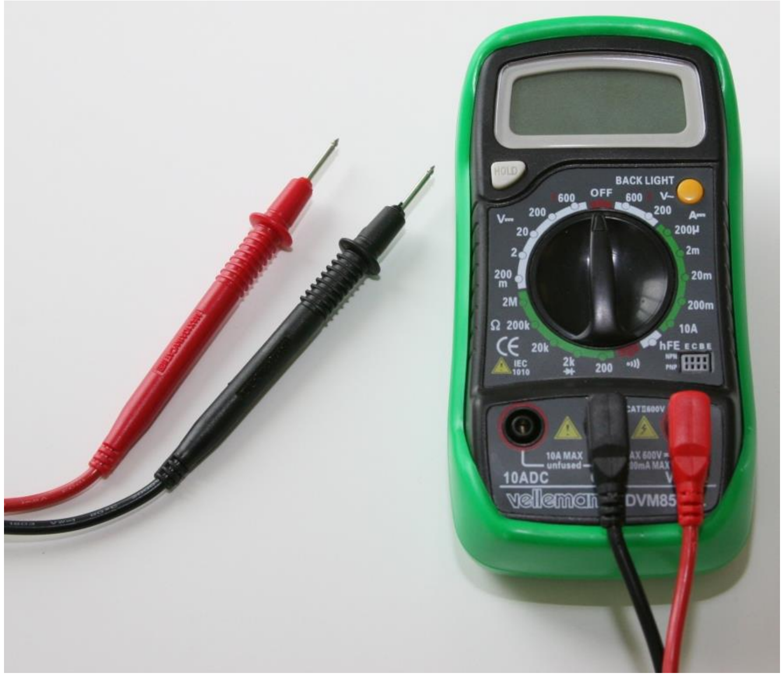
Symbol

(V ---) Voltage Direct Current

(V ~) Voltage Alternating Current

(A ---) Current

(Ω) Resistance



Traditional Digital Multimeter (DMM)

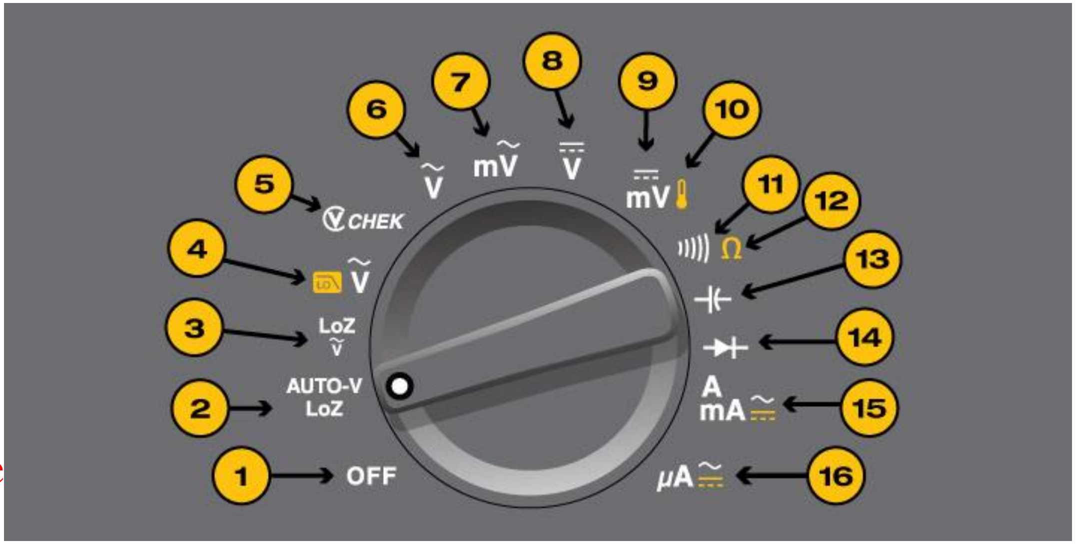
In this activity you will learn how to measure voltage.

DMM Display

- Multimeter consists of:
- Display
  - (1) Digits
  - (6) Negative indicator
  - (15) Measurement units
  - (3) Continuity beeper
- Selection Knob
- Ports

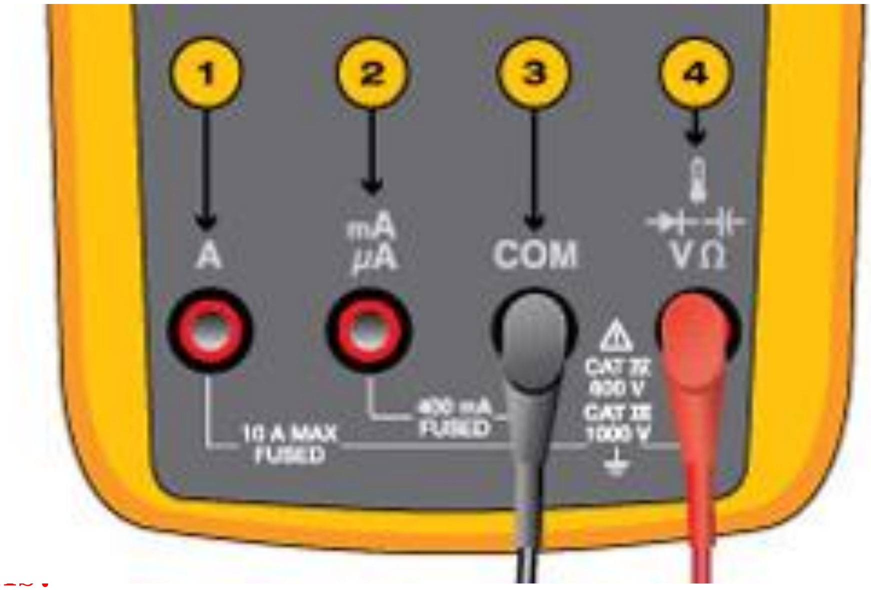
DMM Selection Dial

- Multimeter consists of:
- Display
- Selection Knob
  - (1) ON/OFF
  - (6, 7) AC voltages
  - (8, 9) DC voltages
  - (12) Resistance
  - (14) Diode
  - (15, 16) Current (move le
- Ports



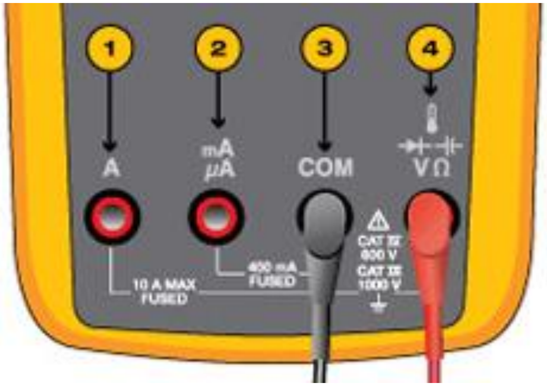
DMM Ports

- Multimeter consists of:
- Display
- Selection Knob
- Ports
  - Common
  - Voltage
  - Current (A , mA/**μ**A)
  - Read carefully! Meters ha
    different port configurati



DMM Measurements: Continuity

- **Measure Continuity:**
- Test fuses
- Open or completed electrical connections
- *Ring out* a wire to identify
- Connect to *Com* and *V* ports, and set selector switch to:
-

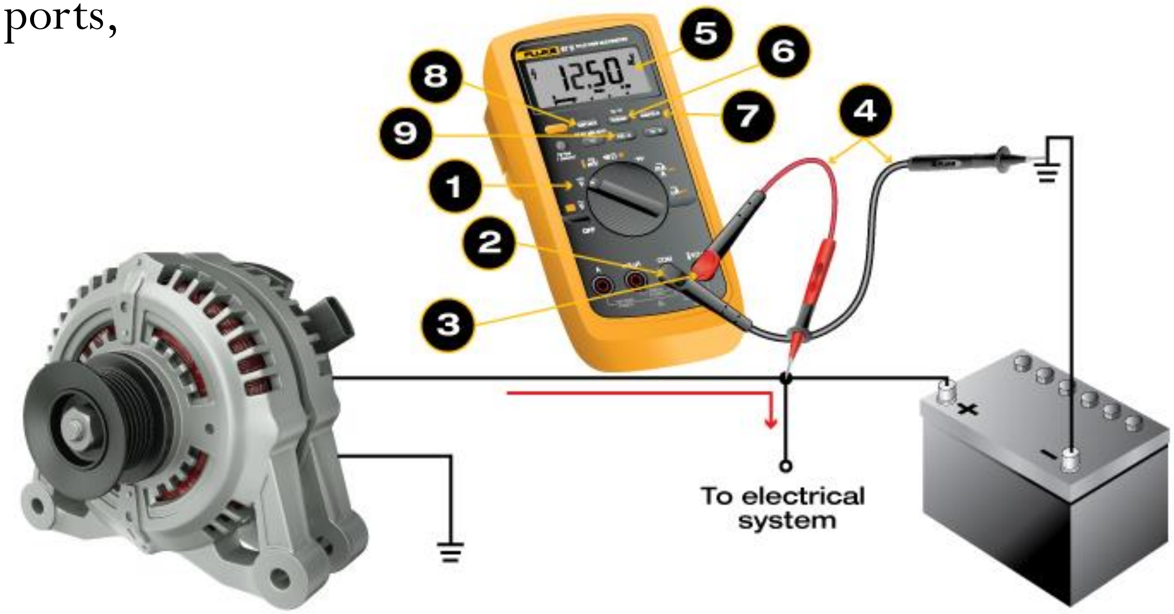


DMM Measurements: Resistance (Ω)

- Deenergized circuits only!
- Check resistor values
- Check for open circuits
- Check for adequate ground connection

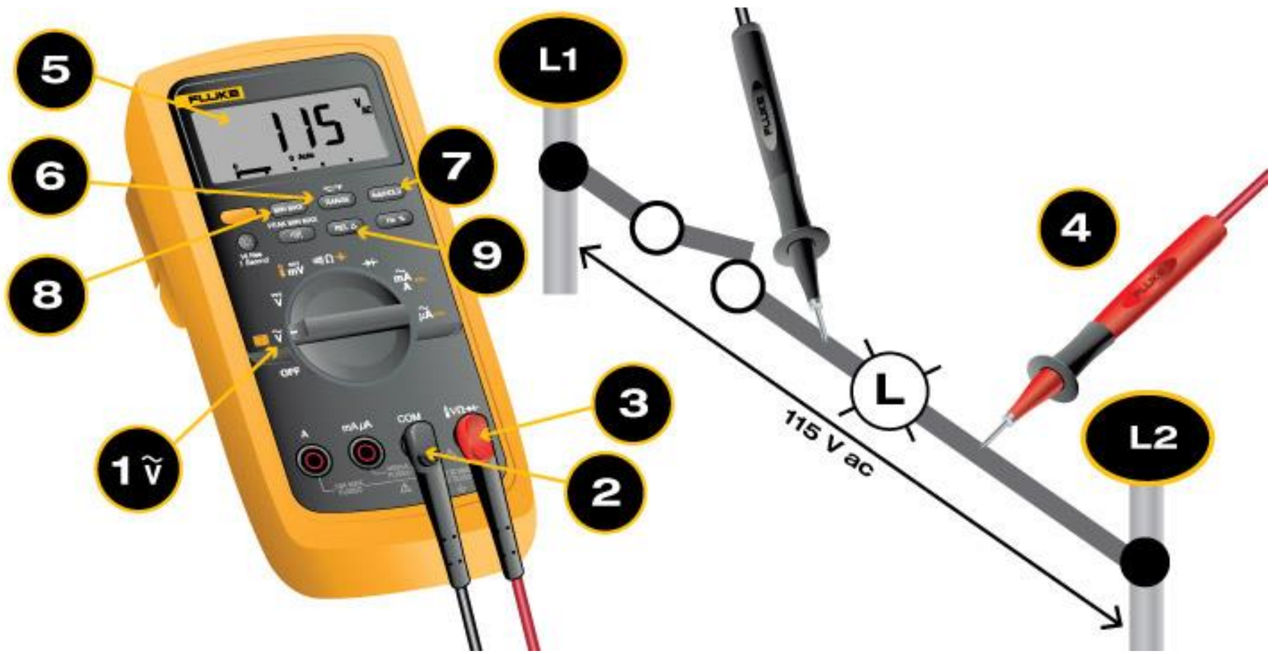
DMM Measurements: DC Voltage

- Check for Voltage within a circuit
- Leads are in parallel with circuit
- Connect to "*Com*" and "*V*" ports, and set selector switch to: or mV
-



DMM Measurements: AC Voltage

- Leads are in parallel with circuit
- Connect to *Com* and *V* ports, and set selector switch to : or mV
-



DMM Measurements: Current

Note: If a meter includes fused current terminals, verify that its fuses are good.

- Check for Current within a circuit or branch
- Leads are in series with circuit
- Current flows through the meter!

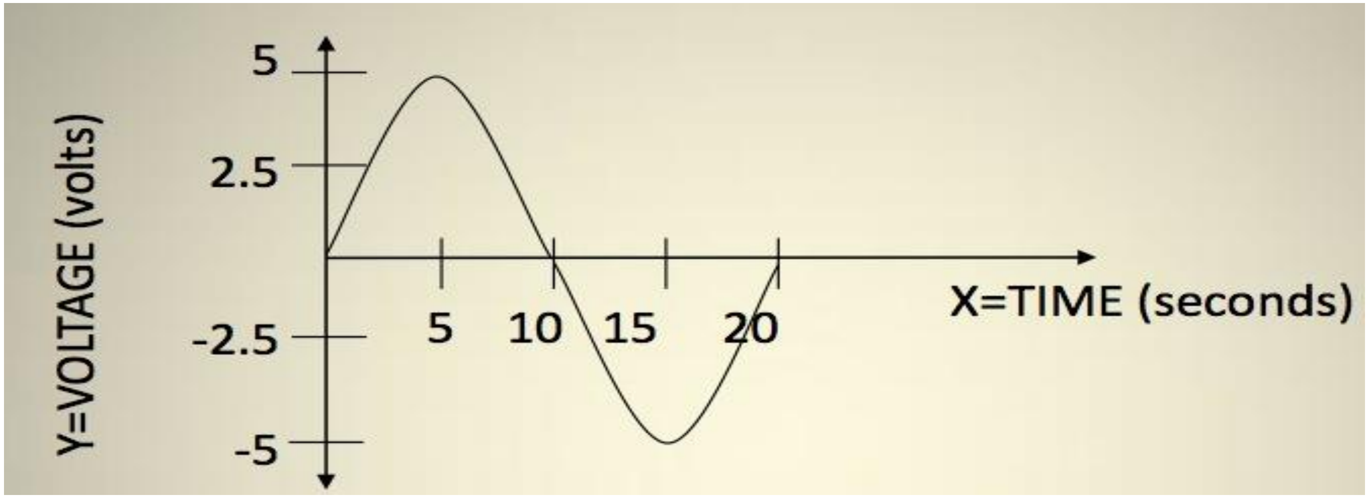
Connect to *Com* and (10A/A*)* ports. Set selector switch to mÃ/Ã for AC amps;   or mADC for DC amps.

Time Series Measurement

- You measure Voltage or Current at a particular instant of time
- What if I ask to measure these quantities with respect to time??

Time	T0	T1	T2	T3	T4	T5	T6	T7	…
Voltage	V1	V2	V3	V4	V5	V6	V7	V8	…
Current	I1	I2	I3	I4	I5	I6	I7	I8	…

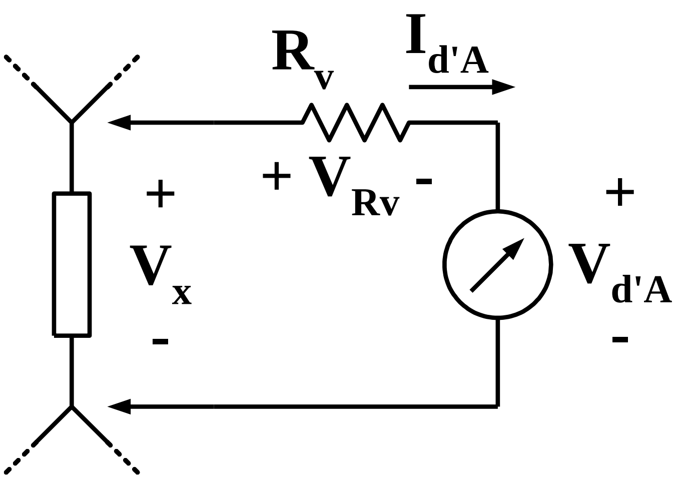
- Plot Time vs Voltage and Time vs Current => **Waveforms**

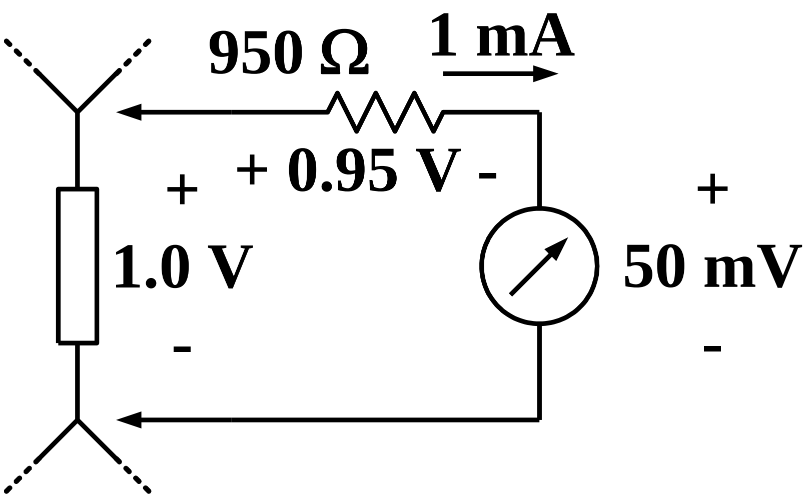


Extra Slides

D'Arsonval Voltmeter

- Small voltage rating on movement (~50 mV)
- Small current rating on movement (~1 mA)
- Must use voltage dropping resistor, R_v



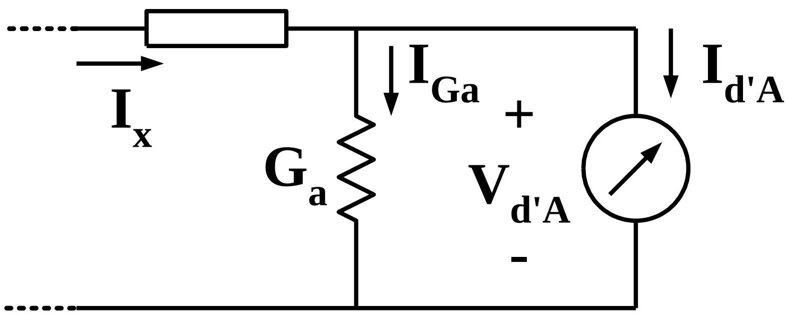


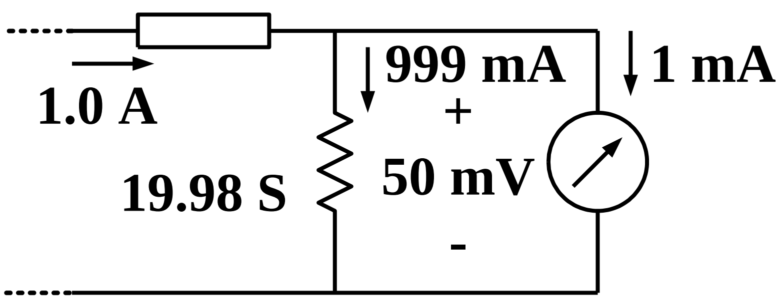
Note: d'Arsonval movement has resistance of 50 Ω

Scale chosen for 1.0 volt full deflection.

D'Arsonval Ammeter

- Small voltage rating on movement (~50 mV)
- Small current rating on movement (~1 mA)
- Must use current bypass conductor, G_a



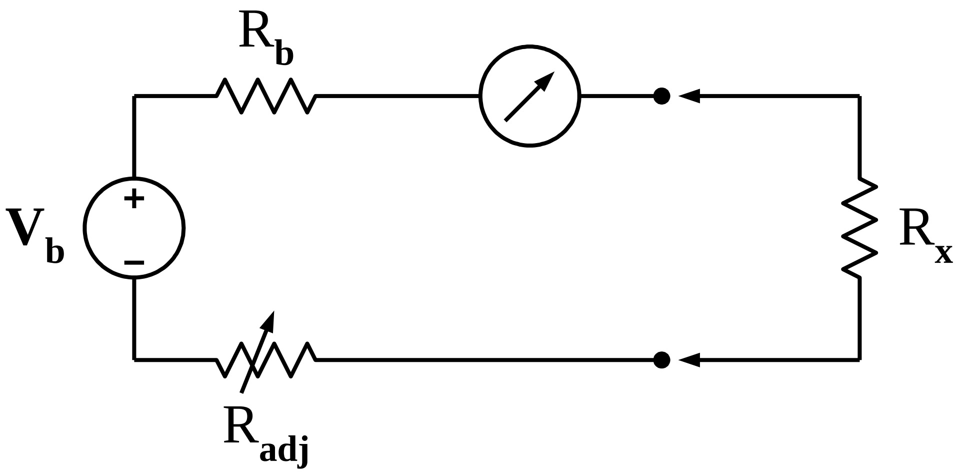


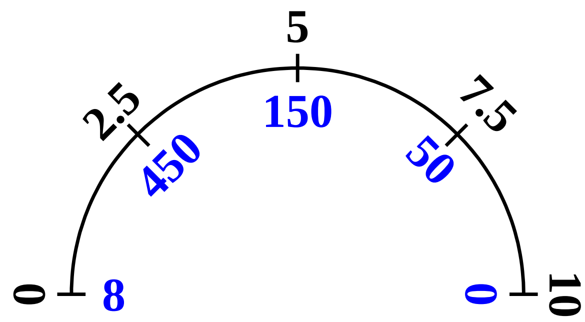
Note: d'Arsonval movement has conductance of 0.02 S

G_a = 19.98 S has ~50.050 mΩ resistance.

Scale chosen for 1.0 amp full deflection.

D'Arsonval Ohmmeter





10 mA Full Scale (Outer Numbers)

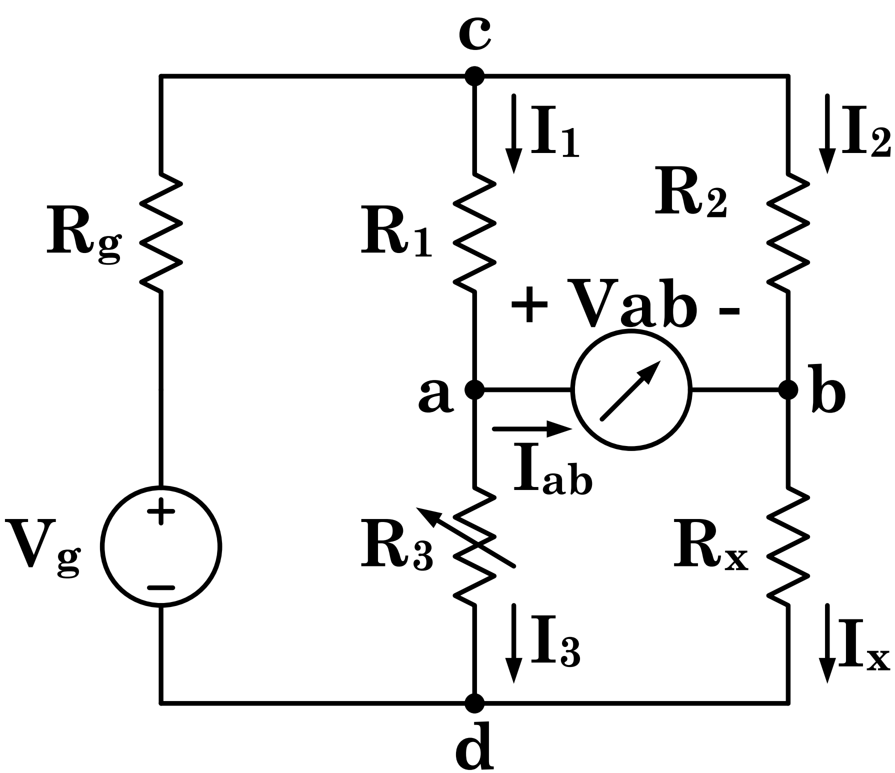
Need to adjust R_{adj} and zero setting each scale change.

$R_b + R_{adj} + R_{d'A} = 150\ \Omega$

Inner (Nonlinear) Scale in Ohms

$V_b = 1.5$ V

Wheatstone Bridge



$V_{ab} = 0$ and $I_{ab} = 0$

$V_{ad} = V_{bd}$

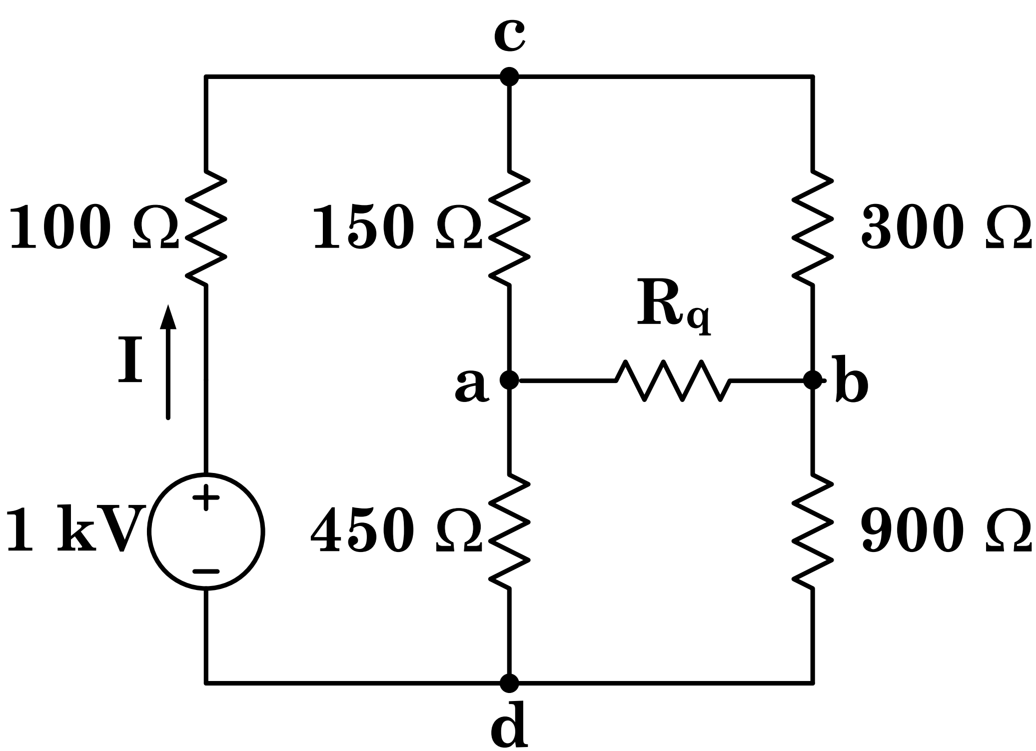
$I_1 = I_3$ $\quad$ $I_2 = I_x$

$R_1 I_1 = R_2 I_2$

$R_3 I_3 = R_x I_x$

$$R_x = \frac{R_2 \cdot R_3}{R_1}$$

Example: Wheatstone Bridge



$$\frac{150\,\Omega}{450\,\Omega} = \frac{300\,\Omega}{900\,\Omega}$$

I = 2 A