## Electrical Current Flow

Electron Flow - From excess to deficient

Conventional Current Flow
- Internal to Source (Battery)
  - Negative to Positive
- External from Source (Battery)
  - Positive to Negative

Voltage Drop - Across a Resistor + to -

"*Negative Current*" - Assumed Direction Reversed

## Electrical Theory

Ohm's Law
- $I = V/R$ (DC)    $I = V/Z$ (AC)

Joule's Law
- $P = IE = I^2R$ (I Squared R Loss)

Kirchoff's Law
- Sum of Loop Voltages = 0
- Sum of Node Currents = 0

## Electrical Theory

| Quantity | Symbol | Unit | Equation |
|---|---|---|---|
| Charge | Q | coulomb | $Q = \int idt$    $Q = CV$ |
| Current | I | ampere | $I = dQ/dt$ |
| Voltage | V | volt | $V = dW/dQ$ |
| Energy | W | joule | $W = \int VdQ = \int Pdt$ |
| Power | P | watt | $P = dW/dt = IV$ |

**Power and Voltage Ratios Expressed in Decibels (dB's)**

1 Bel = $\log(Power_2 / Power_1)$

1 decibel = 1 dB = 0.1 Bel, hence 10 dB = 1 Bel

To express a Power Ratio in dB's, use dB = $10 \log(Power_2 / Power_1)$

Let $Power_2 = 2\ Power_1$
Power Ratio in dB's = $10 \log(2\ Power_1 / Power_1) = 10 \log(2) = 3.01$

Let $Power_2$ = 0.5 Power1
Power Ratio in dB's = $10 \log(0.5\ Power_1 / Power_1) = 10 \log(0.5) = -3.01$

-3 dB is often expressed as "3 dB Down" which is the half power point ($Power_2 = 1/2\ Power_1$)

Let $Power_2 = Power_1$
Power Ratio in dB's = $10 \log(Power_1 / Power_1) = 10 \log(1) = 0$

dB = 0 does not imply zero power but rather a power ratio of one-to-one
dB = 0 can be used as a zero reference; that is to say, set your reference level to a particular value and then use the dB scale to refer all other values to that reference level.

Examples: Reference Level = 400 watts.
200 watts = -3 dB
800 watts = +3 dB
400 watts = 0 dB
4000 watts = +10 dB
40 watts = -10 dB
650 watts = +2.1 dB
65 watts = -7.9 dB
100 watts = -6 dB
2,500,000 watts = +64 dB

Note: A reference of 1 milliwatts is used for dBm's
1 milliwatts = 10 log(1 / 1) = 0 dBm
5 milliwatts = 10 log(5 / 1) = +7 dBm
500 milliwatts = +27 dBm
0.001 milliwatts = -30 dBm

For Voltage, Power = $IE = (E/R)E = E^2/R$

To express a Voltage Ratio in dB's, use dB = $10 \log(Power_2 / Power_1) = 10 \log[(E_2^2/R) / E_1^2/R)]$
$10 \log[(E_2^2/R) / E_1^2/R)] = 10 \log(E_2^2 / E_1^2) = 20 \log(E_2 / E_1)$

Let Power Ratio dB = -3, then $20 \log(E_2 / E_1) = -3$
$\log (E_2 / E_1) = -0.15$
$E_2 / E_1 = 0.707 = 0.5$ SQRT(2)

**DMM Resolution and Accuracy**

Resolution (3½ Digits or 1999)
3 Full Digits (Left-Hand Digit Max Value = 1)
Maximum Reading 1999

Resistor Measurement Accuracy
± (2.5% Reading + 5 Units Last Digit)

Always use lowest range that provides maximum digits

**Resistor Measurement Accuracy Example #1**

Nominal 4700 Ohm Resistor

Reading on the 20K Ω Range = 4.58 = 4580 ohms

2.5% x 4580 = 115

Last digit represents 50 ohms

Accuracy = ± (115 + 50) = ± 165 (165 / 4580 = 3.60%)

Resistor Value: 4580 ± 165 = 4415 to 4745

Note: 5% of Nominal Value = 0.05 x 4700 = 235 (4465 to 4935)

**Resistor Measurement Accuracy Example #2**

Nominal 1.5M Ohm Resistor

Reading on the 2000K Ω Range = 1462 = 1, 462,000 ohms

2.5% x 1, 462,000 = 36,550

Last digit represents 5000 ohms

Accuracy = ± (36,550 + 5,000) = ± 41,550 41,550 / 1,462,000 = 2.84%

Resistor Value: 1, 462,000 ± 41,550 = 1,420,450 to 1,503,550

Note: 5% of Nominal Value = 0.05 x 1,500, 000 = 75,000 (1,425,000 to 1,575,000)

## DMM Resolution and Accuracy

Resolution (3½ Digits or 1999)
    3 Full Digits (Left-Hand Digit Max Value = 1)
    Maximum Reading 1999

Resistor Measurement Accuracy
    ± (2.5% Reading + 5 Units Last Digit)

What does *5 Units Last Digit* really mean?

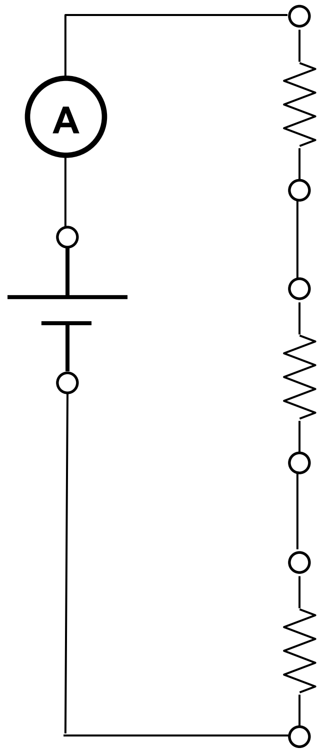
```
DMM Resistance Scale         Max Readout    Mental Conversion
2K  =  2000 Ohms             1.999          2000
       abcx                  a bcx          abcx
where
 a = 1000
 b =  100
 c =   10
 x =    1  5 units of last digit = 5 x 1 = 5 ohms
```

```
DMM Resistance Scale         Max Readout    Mental Conversion
20K =  20000 Ohms            1.999          20000
       abcx                  a bcx          abcx
where
 a = 10000
 b =  1000
 c =   100
 x =    10  5 units of last digit = 5 x 10 = 50 ohms
```

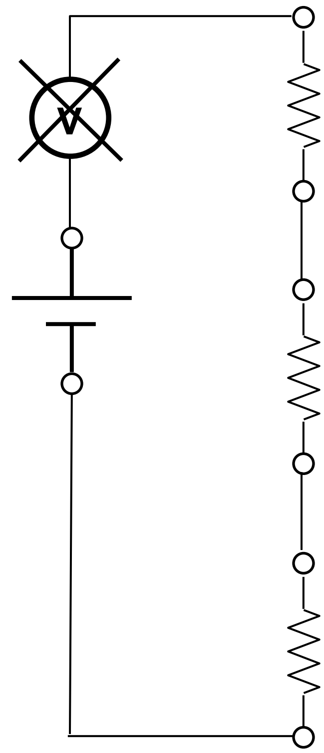
```
DMM Resistance Scale         Max Readout    Mental Conversion
2M =  2,000,000 Ohms         1.999          2,000,000
      a bcx                  a bcx          a bcx
where
 a = 1,000,000
 b =   100,000
 c =    10,000
 x =     1,000  5 units of last digit = 5 x 1000 = 5000 ohms
```

**DMM Connections**

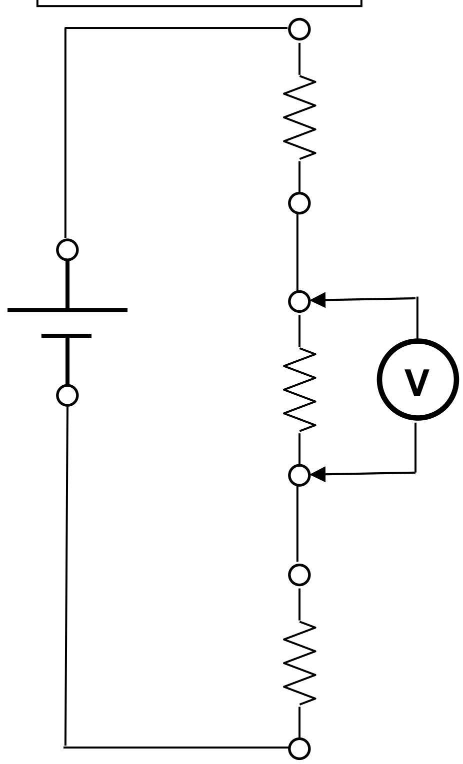
Ammeter in Series
OKAY




Voltmeter in Series
Prohibited




Voltmeter in Parallel
OKAY




Ammeter in Parallel
Prohibited