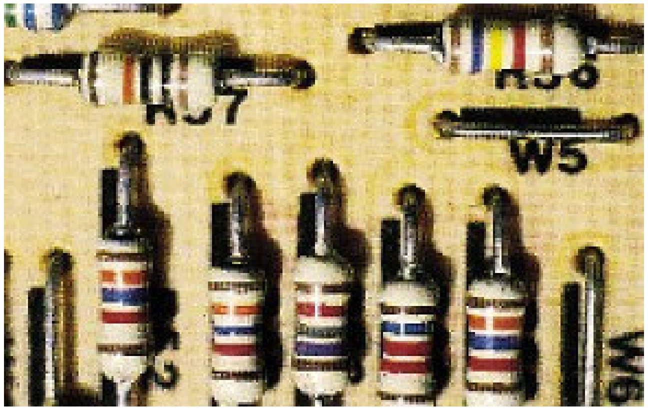
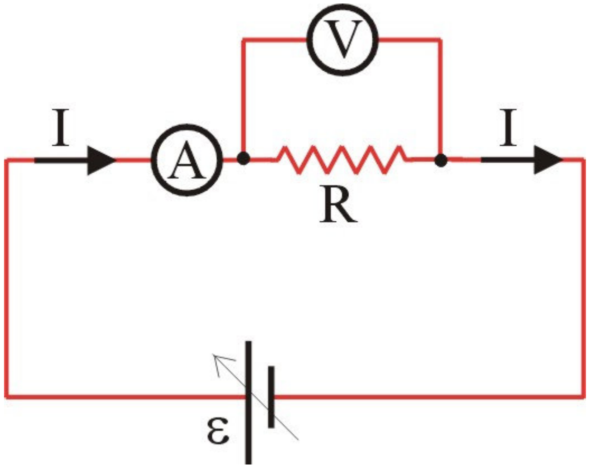
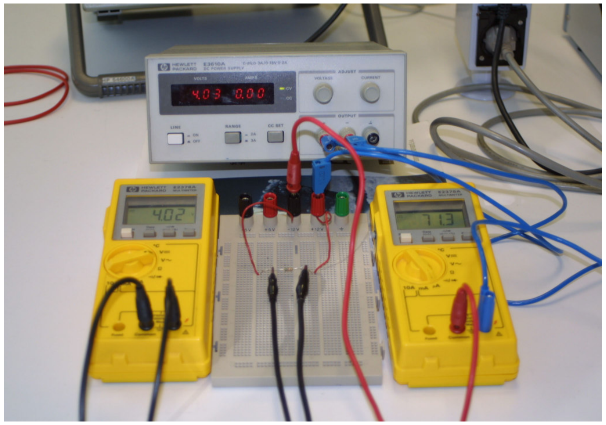
Experiment # 1:
DC Measurements

- **Multimeter:**
  - Measurements of DC voltage and current, and resistance
  - Errors introduced by the multimeter
- **Omh's Law for Direct Current:**
  - experiment: 'short' and 'long' arrangement
- **Maximum Power Transfer Theorem**







Multimeter (1/2)

Used as an ohmmeter (it measures Ω), voltmeter (V), ammeter (I)

-Ammeter: current measurement
(in series)

-Voltmeter: voltage measurement
(in parallel)

-Ohmmeter: resistance measurement
resistor must be isolated from the rest of the circuit

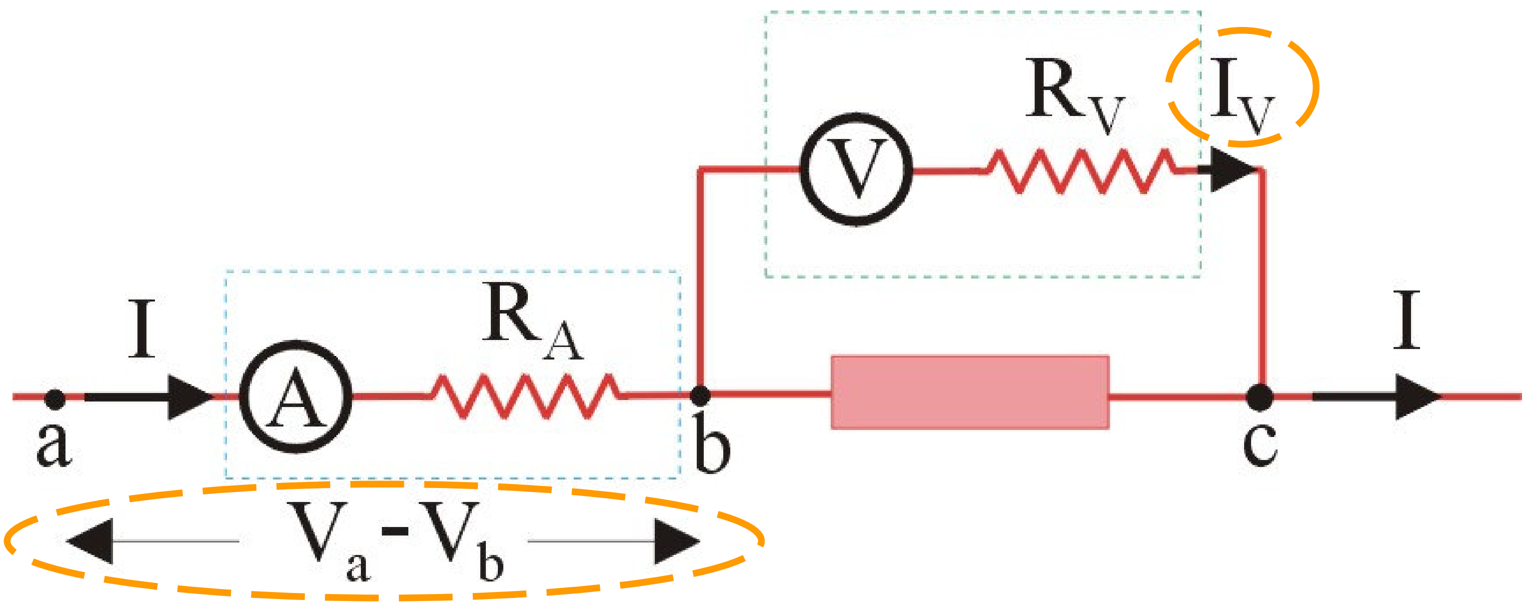
Please, pay attention to input terminals (“jacks”) and to the range selected!!!

Multimeter (2/2)

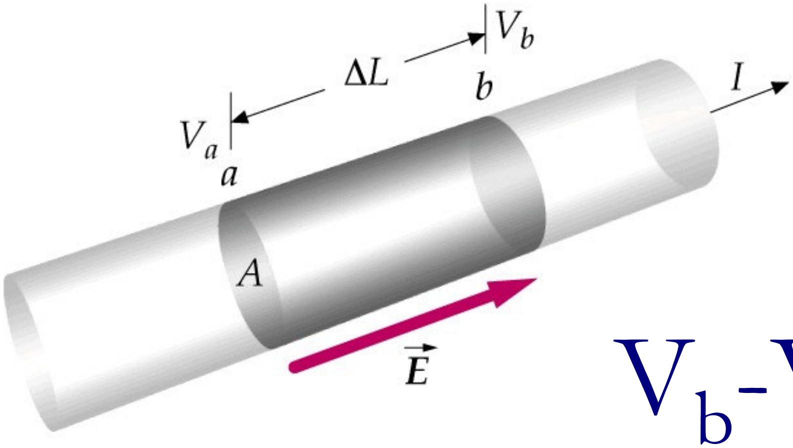
Errors when using a multimeter:

- uncertainty of the device: digitising error and precision
- perturbations introduced in the circuit by the instrument

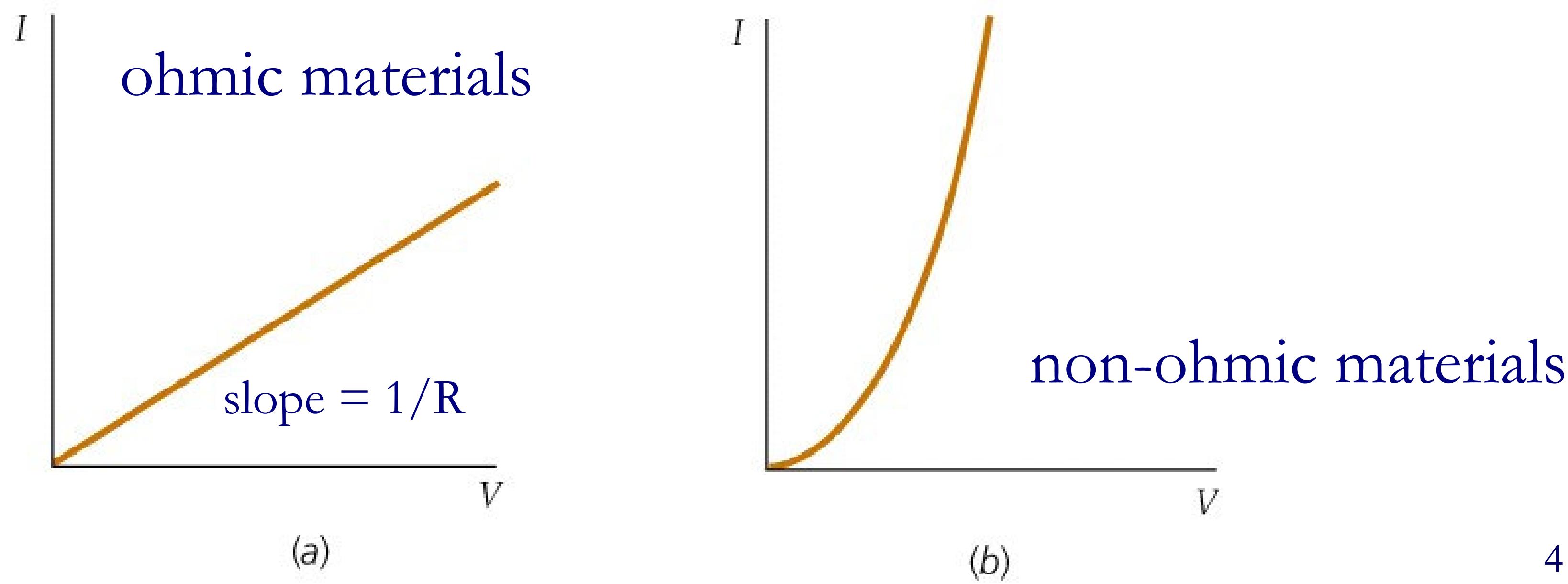
Ideal ($R_V = \infty$, $R_A = 0$) and **real** multimeters:



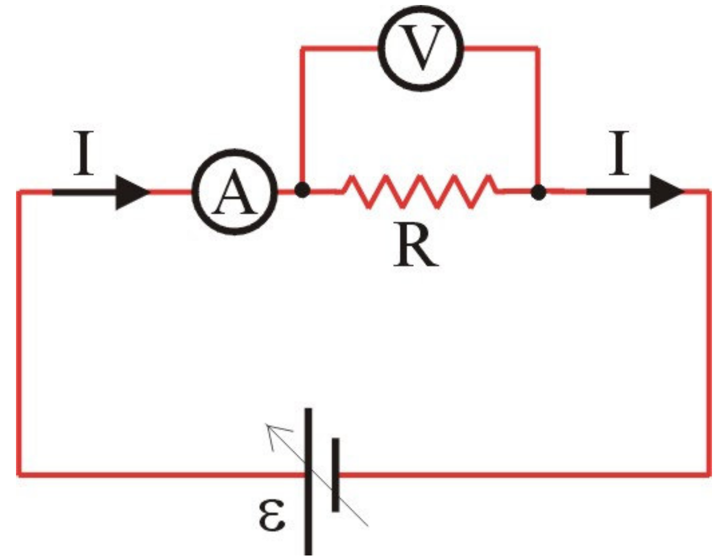
Ohm’s Law



$$V_b - V_a = I \cdot R$$

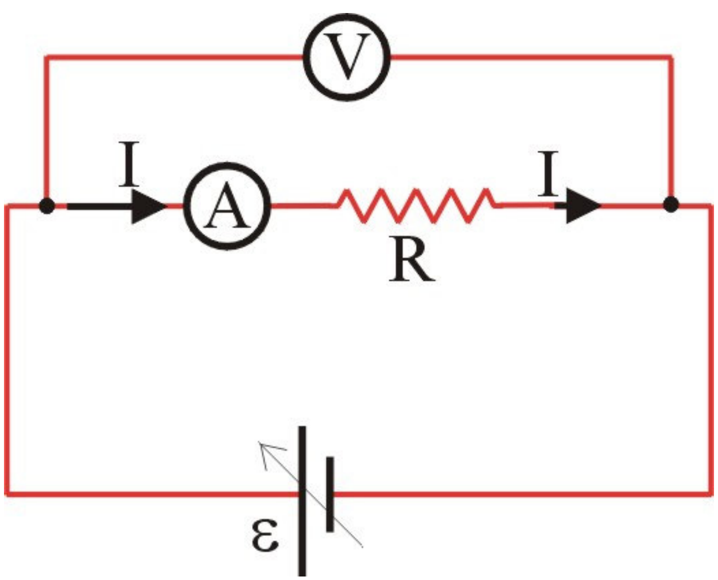


Resistance measurement from Ohm's Law



"Short" arrangement:

$$\frac{1}{R_{short}} = \frac{1}{R} + \frac{1}{R_V}$$



"Long" arrangement:

$$R_{long} = R + R_A$$

V=I ·R

Same value for R only if $R_V=\infty$, $R_A=0$

Maximum Power Transfer Theorem (Jacobi's Theorem) (1/2)

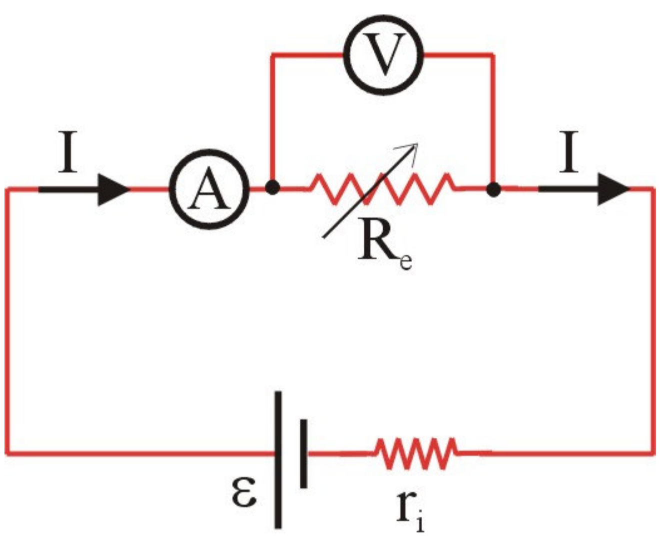
Work done by the electrostatic field, change in electrostatic potential energy:

$$W = q\left(V_b - V_c\right)$$

$$W = I\left(V_b - V_c\right)t$$

Following Ohm's Law: $W = I^2 R t$

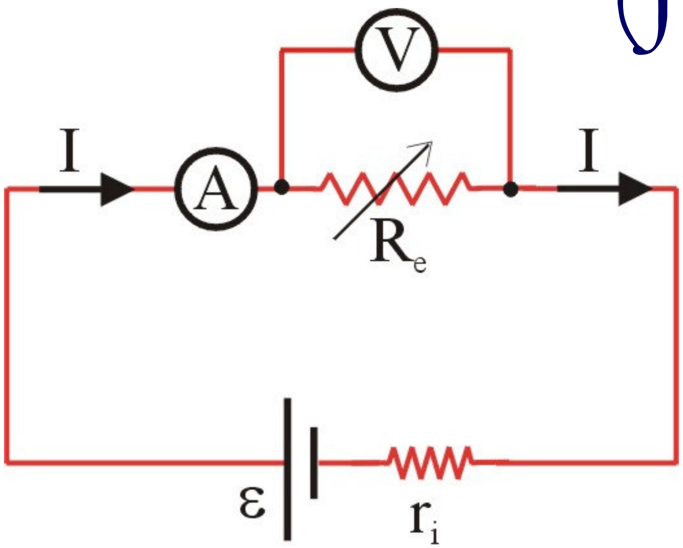
Power dissipated in the load: $P = I^2 R = I\left(V_b - V_c\right)$



$$\mathrm{I} = \frac{\varepsilon}{\mathrm{R_e + r_i}}$$

Power dissipated in R_e: $P_e = \dfrac{\varepsilon^2 R_e}{\left(r_i + R_e\right)^2} = V \cdot I$

Maximum Power Transfer Theorem (Jacobi's Theorem) (2/2)



$$P_e = \frac{\varepsilon^2 R_e}{(r_i + R_e)^2} = V \cdot I \qquad \frac{\partial P_e}{\partial R_e} = 0 \Rightarrow R_e = r_i$$

Maximum Power Transfer Theorem:

Maximum power is transferred when the internal resistance of the source equals the resistance of the load (when the external resistance can be varied and internal resistance is constant)

$$I = \frac{\varepsilon}{R_e + r_i} \Longrightarrow R_e = \frac{\varepsilon}{I} - r_i$$

To obtain r_i: linear regression, R_e vs. $1/I$

Experimental procedure

1. Find the nominal value of a pair of resistors using colour codes

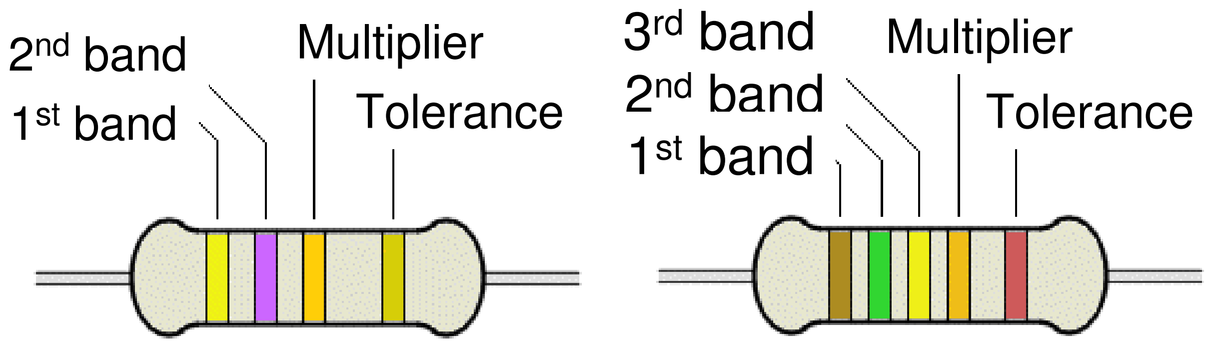
2. Measure their resistance with a multimeter and their association in series and in parallel

3.1. "Short" arrangement for only one of the resistors (vary the voltage from 1 V to 10 V in steps of 1 V): table $\varepsilon(I)$, plot and least-squares fit, determination of R

3.2. "Long" arrangement (same procedure)

4. Maximum power transfer theorem: emf = 1V, rheostat (variable resistor) R_e=2-9 Ω, steps of 1Ω, measure rheostat's resistance with ohmmeter (<u>always disconnect power from resistor</u>), plot and fit, determination r_i, plots of P_e, P_i, η.

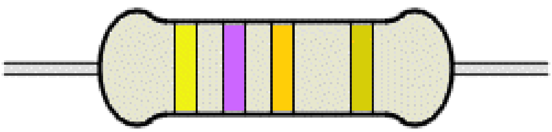
Resistors

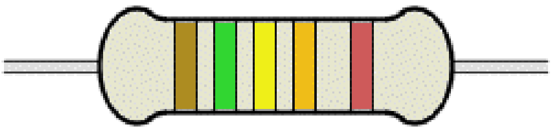


COLOUR	1st band	2nd band	3rd band	Multiplier	Tolerance
Silver				x 0.01	10%
Gold				x 0.1	5%
Black	0	0	0	x 1	
Brown	1	1	1	x 10	1%
Red	2	2	2	x 100	2%
Orange	3	3	3	x 1000	
Yellow	4	4	4	x 10000	
Green	5	5	5	x 100000	0.5%
Blue	6	6	6	x 1000000	
Violet	7	7	7		
Grey	8	8	8		
White	9	9	9		
--None--	-	-	-		20%

How to read resistor colour codes

COLOUR	1st band	2nd band	3rd band	Multiplier	Tolerance
Silver				x 0.01	10%
Gold				x 0.1	5%
Black	0	0	0	x 1	
Brown	1	1	1	x 10	1%
Red	2	2	2	x 100	2%
Orange	3	3	3	x 1000	
Yellow	4	4	4	x 10000	
Green	5	5	5	x 100000	0.5%
Blue	6	6	6	x 1000000	
Violet	7	7	7		
Grey	8	8	8		
White	9	9	9		
--None--	-	-	-		20%





Left resistor:

yellow – violet – orange – gold

4 – 7 – 3 zeros, 5% tolerance

47000 Ω = 47 kΩ

Real value between 44650 Ω and 49350 Ω

(47 kΩ ± 5%)

Right resistor (one more band)

precision resistor: tolerance 2%

brown – green – yellow – orange

1 – 5 – 4 – 3 zeros, 2% tolerance

154000 Ω = 154 kΩ = 0.154 MΩ

Real value between 150.9 KΩ and 157.1 KΩ

(154 kΩ ± 2%).

Multimeter measurement accuracy

Uncertainty of the multimeter (digitising error and instrument precision):

% measurement + (digits · resolution)

Multimeter HP E2378A

Function	Range	Resolution	Accuracy ± (% rdg + number of digits) E2373A	Accuracy ± (% rdg + number of digits) E2377A E2378A
dc voltage	300 mV	100 μV	0.5% + 2	0.3% + 2
	3 V	1 mV	0.5% + 1	0.3% + 2
	30 V	10 mV	0.5% + 1	0.4% + 1
	300 V	100 mV	0.7% + 1	0.4% + 1
	1000 V	1 V	0.7% + 1	0.4% + 1
ac voltage	3 V	1 mV	1.2% + 4	1.0% + 3
	30 V	10 mV	1.2% + 4	1.0% +3
	300 V	100 mV	1.2% + 4	1.0% + 3
	750 V	1 V	1.2% + 4	1.0% + 3
dc current	300 μA	100 nA	—	1.0% + 2
	3 mA	1 μA	—	1.0% + 2
	30 mA	10 μA	1.0% + 2	1.0% + 2
	300 mA	100 μA	1.5% + 2	1.5% + 2
	10 A	10 mA	1.5% + 2	1.5% + 2
ac current	300 μA	100 nA	—	2.0% + 5
	3 mA	1 μA	—	2.0% + 5
	30 mA	10 μA	2.0% + 5	2.0% + 5
	300 mA	100 μA	2.0% + 5	2.0% + 5
	10 A	10 mA	2.0% + 5	2.0% + 5
Resistance	300 Ω	100 mΩ	0.7% + 2	0.7% + 2
	3 kΩ	1 Ω	0.7% + 1	0.7% + 1
	30 kΩ	10 Ω	0.7% + 1	0.7% + 1
	300 kΩ	100 Ω	0.7% + 1	0.7% + 1
	3 MΩ	1 kΩ	1.5% + 1	0.7% + 1
	300 MΩ	10 kΩ	3.0% + 1	2.0% + 1

Multimeter Promax PD751

Voltage

Range	Resolution	DC Accuracy	AC Accuracy*	Input Impedance	Max. Input
400.0 mV	0.1 mV	±(0.3% meas+5 dig)	±(1.5% meas+5dig)	100 MΩ	1000 V DC or AC peak <10 s
4.000 V	1 mV	±(0.1%meas+5 dig) PD-751 ±(0.5% meas+5 dig) PD-750	±(1.0% meas+5dig) (40 – 1 kHz) PD-751 (40 – 500 Hz) PD-750	10 MΩ	
40.00 V	10 mV				
400.0 V	100 mV		±(1.5% meas+5dig) (700V)		
1000 V	1 V	±(0.5%meas.+5 dig)			

Current

Range	Resolution	DC Accuracy	AC Accuracy*	Max. Input	Overload Protection
400.0 µA	0.1 µA	±(1.2% meas+10dig)	±(1.5% meas+10dig) (40 – 1 kHz) PD-751 (40 – 500 Hz) PD-750	400 mA	fuse 0,5 A/250 V
4000 µA	1 µA				
40.00 mA	10 µA				
400.0 mA	100 µA				
20.00 A	1 mA	±(2% meas+10dig)	±(2% meas+10dig)	20 A, < 30 s (every 15 min.)	fuse 20 A/250 V

Frequency

Range	Resolution	Accuracy	Max. Input
5.000 Hz	0.001 Hz	±(0.1% meas+2dig) (250 mVac peak minimum)	250 V DC or CA peak
50.00 Hz	0.01 Hz		
500.0 Hz	0.1 Hz		
5.000 kHz	1 Hz		
50.00 kHz	10 Hz		
500.0 kHz	100 Hz		
5.000 MHz	1 KHz		
10.00 MHz	10 KHz		

Resistance

Range	Resolution	Accuracy	Max. Input
400 Ω	0.1 Ω	± (0.5%meas + 10dig)	250V DC or AC peak
4.000 kΩ	1 Ω		
40.00 kΩ	10 Ω		
400.0 kΩ	100 Ω		
4000 kΩ	1 kΩ		
40 MΩ	10 kΩ	±(1% meas+5dig)	

Questions

1.- Discuss why equations (2) and (3) in the lab manual provide the resistances measured for the 'short' and 'long' arrangement.

Justify why $R_{short} < R < R_{long}$.

Estimate the internal resistances of the ammeter and the voltmeter.

2.- Compare your experimental results with the series and parallel combination rules for resistors.

3.- Show that the maximum of the function $P_e=P_e(R_e)$ is obtained when $R_e=r_i$.

4.- Describe qualitatively how P_i and η change when we vary R_e.

5.- Which value of R_e gives a performance of 0.5?. What happens with P_i and P_e for this value of R_e?