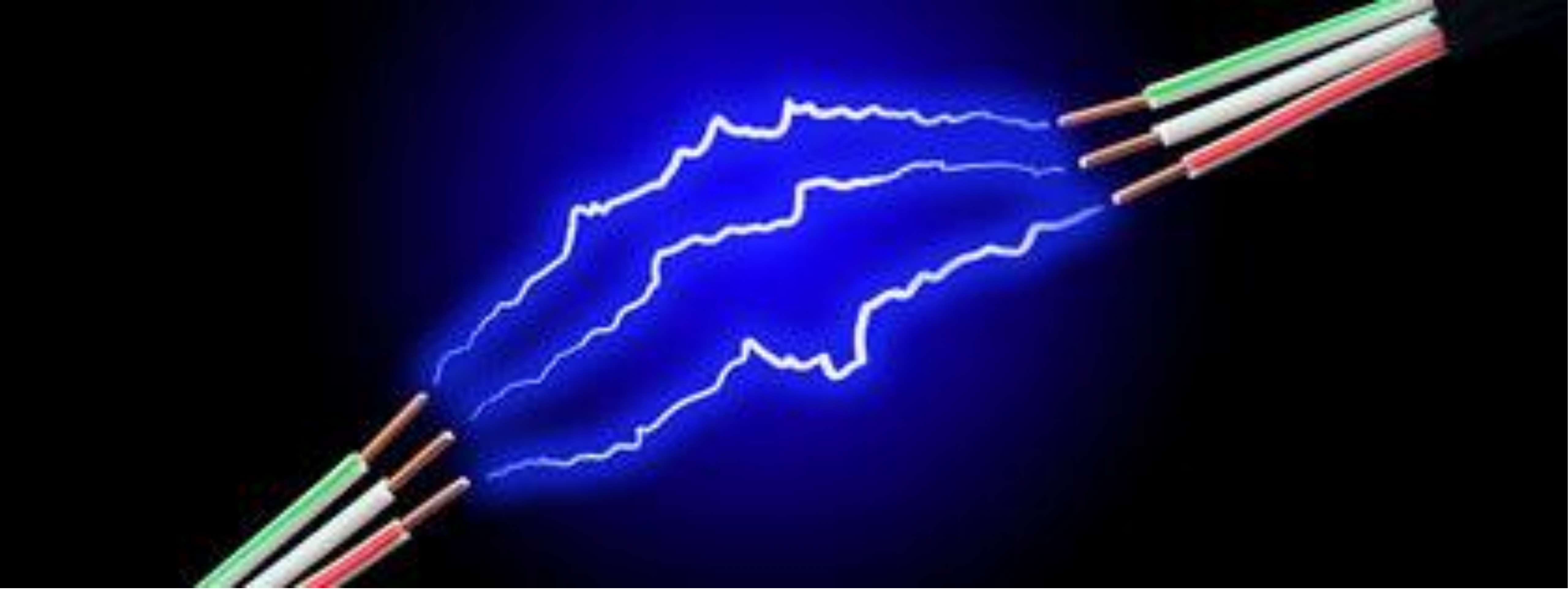
TECNOLOGIAS PARA SISTEMAS DE ENERGIA ESPACIAIS

Nuno Borges Carvalho



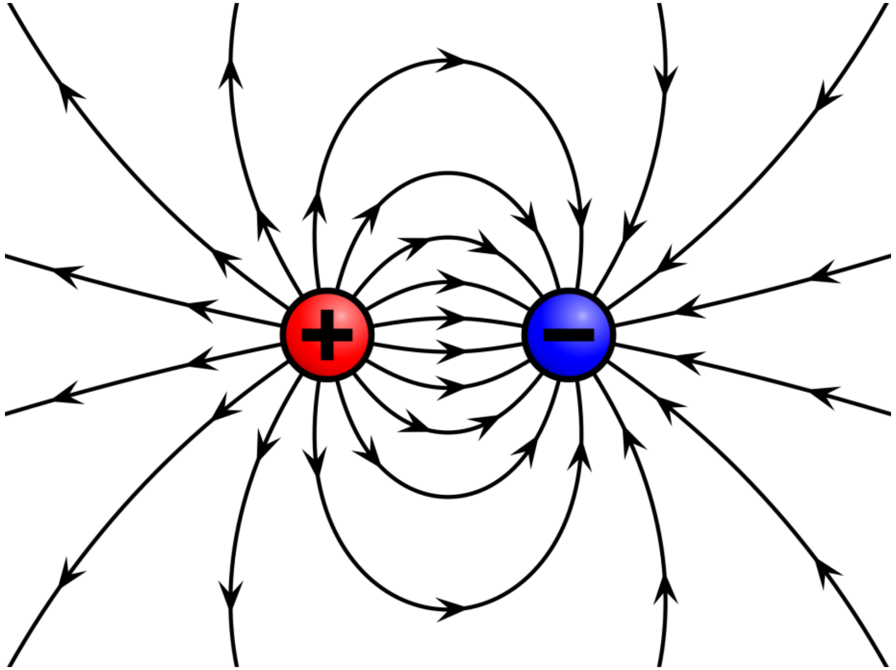
ELECTRICAL CURRENT

Aula 3

ELECTRICAL CURRENT

Coulomb's Law for electrostatics

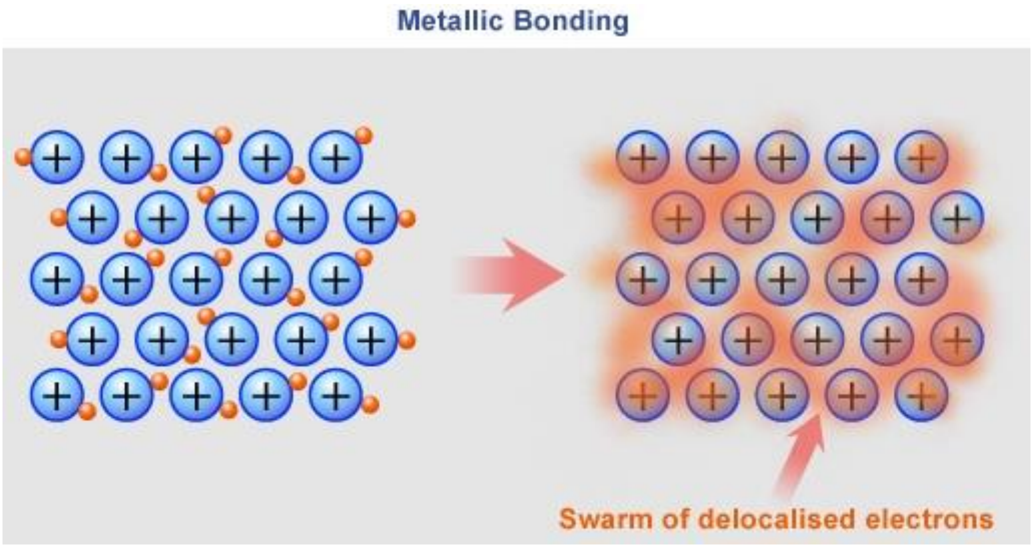
$$\vec{\boldsymbol{E}} = k_1 \frac{q}{r^2} = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2} \quad \text{and } \vec{\boldsymbol{F}} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}, \; k_1 \text{ is the Coulomb constant}$$



ELECTRICAL CURRENT

Assume that inside a conductor we have an uniform and constant charge flux, which creates a current, the amount of charge during a period of time traversing this surface is:

$$\boldsymbol{Q = I\,t}$$



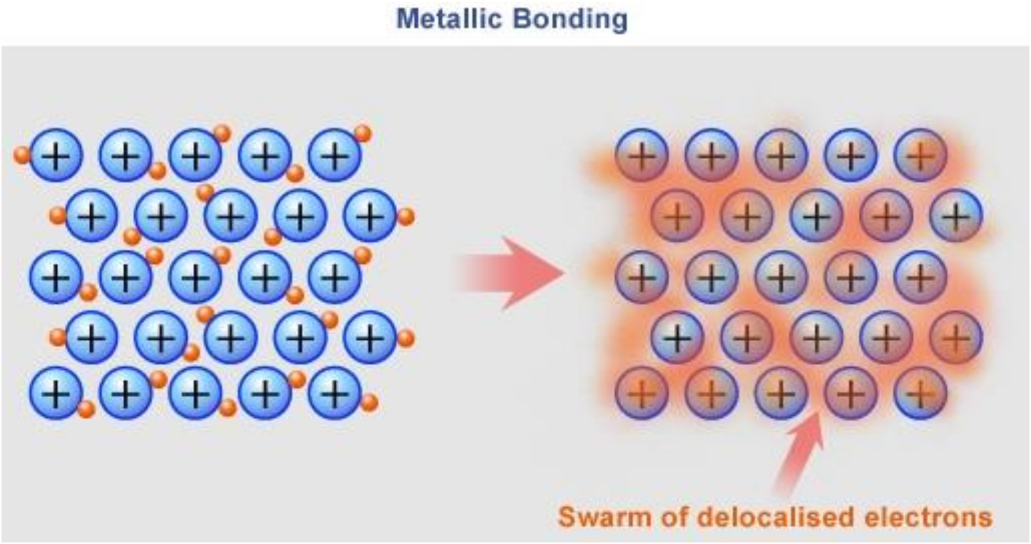
If the current is not constant over time, we should defined it as:

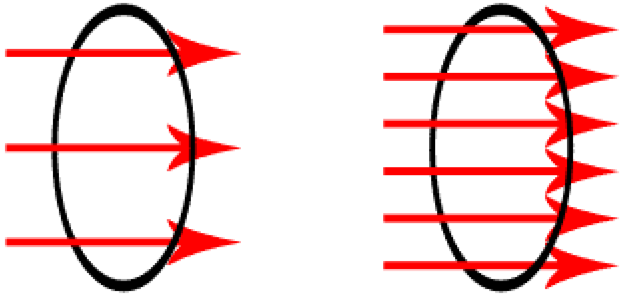
$$\boldsymbol{i = \frac{dq}{dt}}$$

ELECTRICAL CURRENT

If the current is not uniform inside the conductor, we can always divide it in infinitesimal pieces where the current is uniform, and the total current can be calculated as an integral of these pieces:

$$\boldsymbol{I} = \iint_{\boldsymbol{A}} \vec{\boldsymbol{J}}\, \overrightarrow{\boldsymbol{dA}}$$

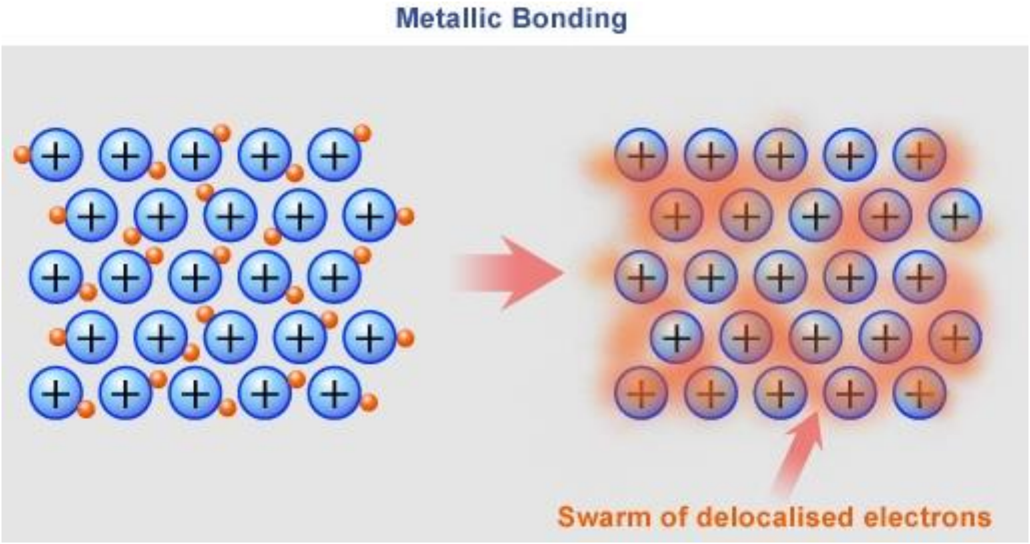




ELECTRICAL CURRENT

Assuming that the charge density inside a conductor is $\boldsymbol{\rho_c = A/m^2}$, and assuming that in this infinitesimal piece the charge velocity is constant and equal to $\vec{\boldsymbol{v}}$, we can then write the current density as:

$$\vec{J} = \boldsymbol{\rho_c}\vec{\boldsymbol{v}}$$



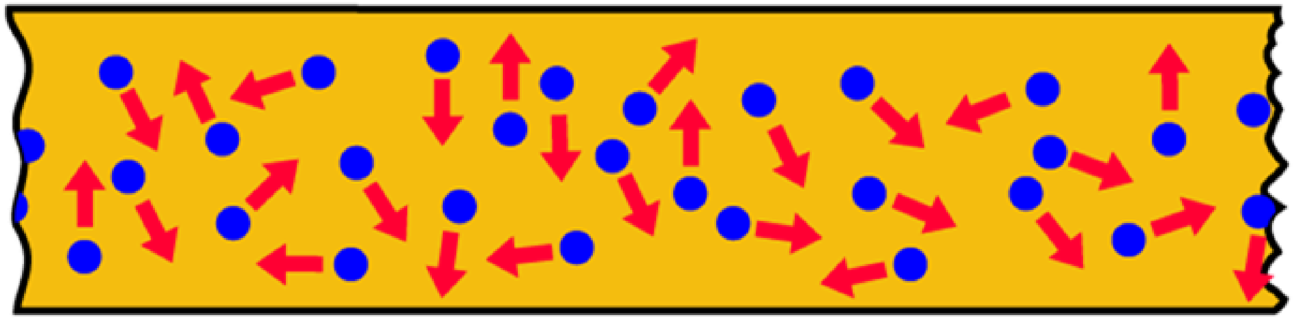
In the case that no force (or any electrical field) is applied the current should be zero, so:

$$\vec{J} = \boldsymbol{\rho_c}\vec{\boldsymbol{v}} = \mathbf{0}$$

ELECTRICAL CURRENT

In the case that no force (or any electrical field) is applied the current should be zero, so:

$$\vec{J} = \rho_c \vec{v} = 0$$



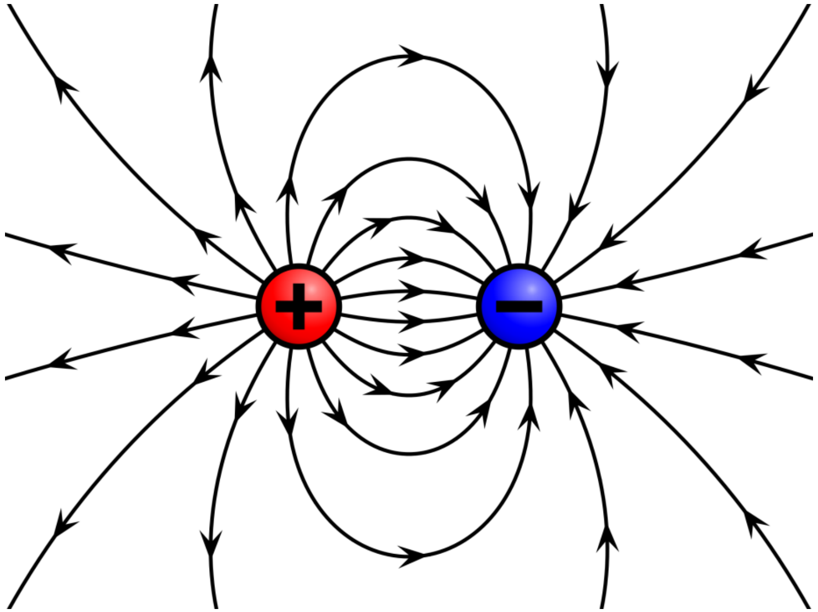
In fact there will be charge movement, due to thermal agitation, but macroscopically, the number of electrons traversing a surface in one direction is equal to the one traversing it on a different direction and thus:

$$\vec{J} = 0$$

ELECTRICAL CURRENT

The minimum charge that we can find in nature is the electron charge and has a value of:

$$\boldsymbol{e = 1.602 \cdot 10^{-19}\ C}$$



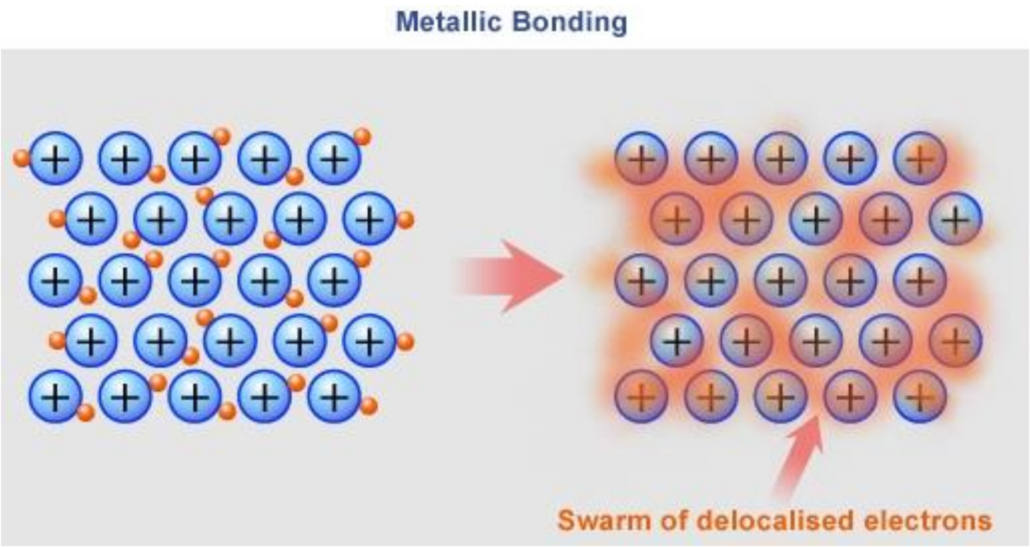
ELECTRICAL CURRENT

Despite the charge is small, its concentration in metals is very high, the number of atoms that exist in a mole is equivalent to the Avogrado number, which is:

$$N_A = 6.022 \cdot 10^{23}\ mol^{-1}$$

q=96 472,44 C/mol

ELECTRICAL CURRENT



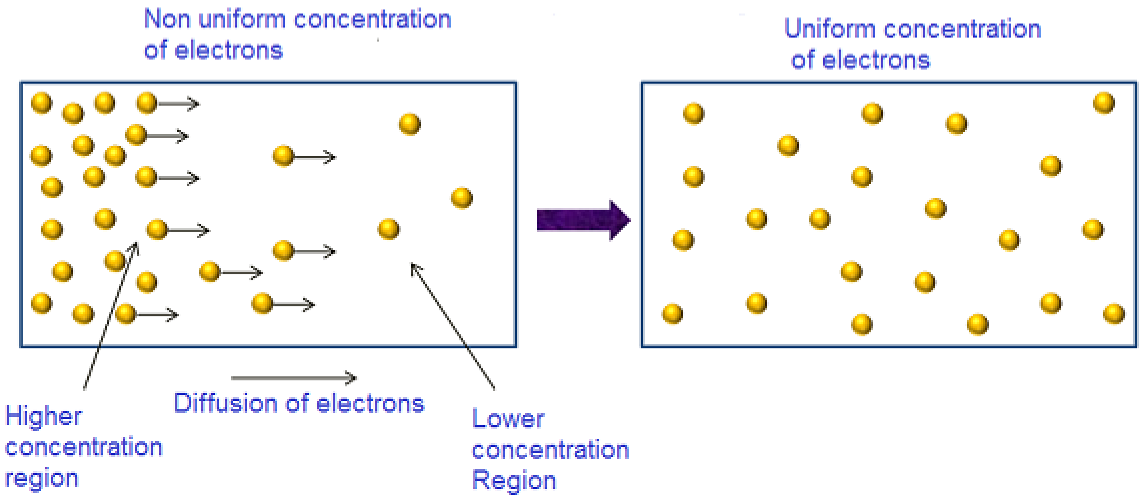
For copper the volumetric charge density is $\mathbf{13.5 \cdot 10^3 \, C/cm^3}$, and assuming a current density of $\mathbf{2.5 \, A/mm^2}$, the charge electron velocity will be:

$$\vec{v} = \frac{\boldsymbol{J}}{\boldsymbol{\rho_c}} = \frac{\mathbf{2.5 \cdot 10^{-6}}}{\mathbf{13.5 \cdot 10^3 \cdot 10^{-6}}} = \mathbf{185 \cdot 10^{-6}} \ \mathrm{m/s}$$

Very slow

ELECTRICAL CURRENT

Current in a conductor can be divided into two mechanism: diffusion and drift



In the case of diffusion, the current appears since if in there is a charge gradient, where in one zone there is a high concentration of charges and on another a low concentration, the charge will diffuse from the higher to the lower concentration, and this effect creates a current:

$$\vec{J} = -eD_e\vec{\nabla}\rho_c$$

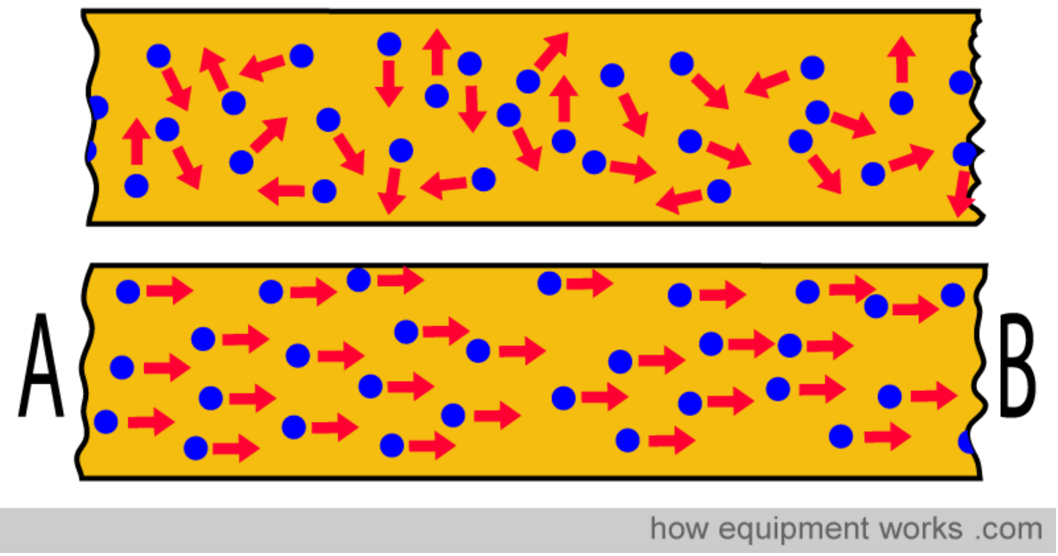
In semiconductors this mechanism is very important, but in conductors it can be ignored since we have an uniform flow of electrons

ELECTRICAL CURRENT

Drift Current is the one that results from the application of a electrical field to the conductor. In this case the force that is applied in each charge carrier is also constant. Inside a conductor the velocity for the drift current is:

$$\vec{v} = \mu\vec{E}$$

Where μ is the mobility.



ELECTRICAL CURRENT

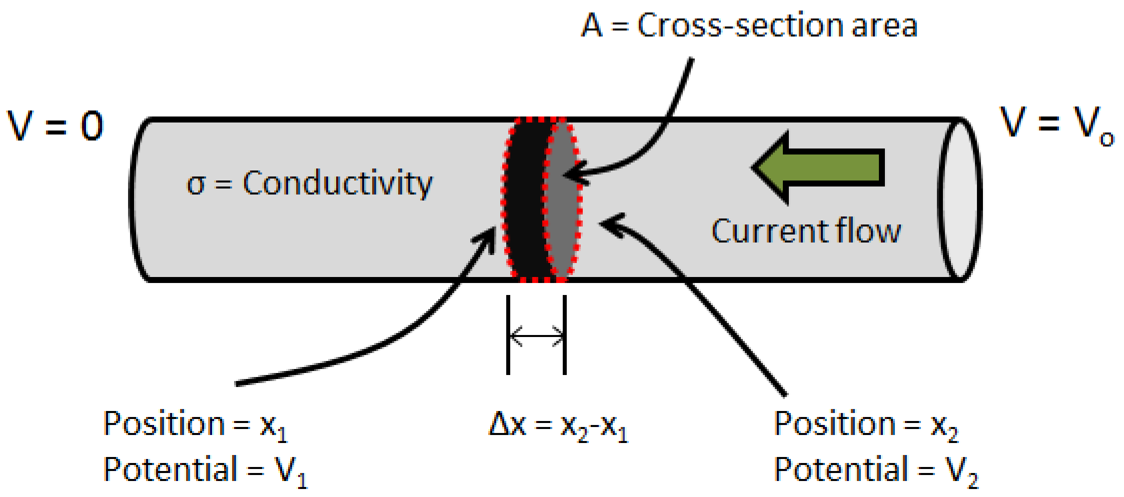
If the last formula is combined with $\vec{J} = \rho_c \vec{v}$, we can define a relationship between the applied field and the current density as:

$$\vec{J} = \sigma \vec{E}$$

Where σ is called conductivity, inversely we can also define:

$$\vec{E} = \rho \vec{J}$$

In this case ρ is called resistivity.



ELECTRICAL CURRENT

For the case where the applied field and the charge density are uniform, the electrical field is proportional to the current, and the current density is proportional to the voltage and current, thus:

$$\boldsymbol{U = RI}$$

Which is the ohms law

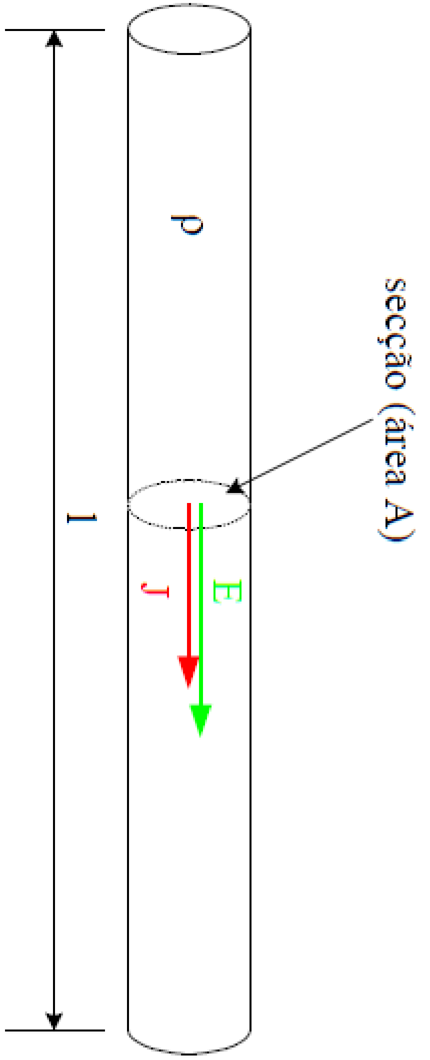
ELECTRICAL CURRENT

If the electrical field is constant and collinear with the conductor in all its extension we can write:

$\boldsymbol{U = El}$ and we also know that the current is $\boldsymbol{I = \iint_A \vec{J}\,\overrightarrow{dA}}$, and for charge conservation reasons, the current is equal in all transversal section, so:

$\boldsymbol{I = JA}$, we can combine these equations and get a final solution of:

$\boldsymbol{U = \rho \frac{l}{A} I}$, and $\boldsymbol{R = \rho \frac{l}{A}}$



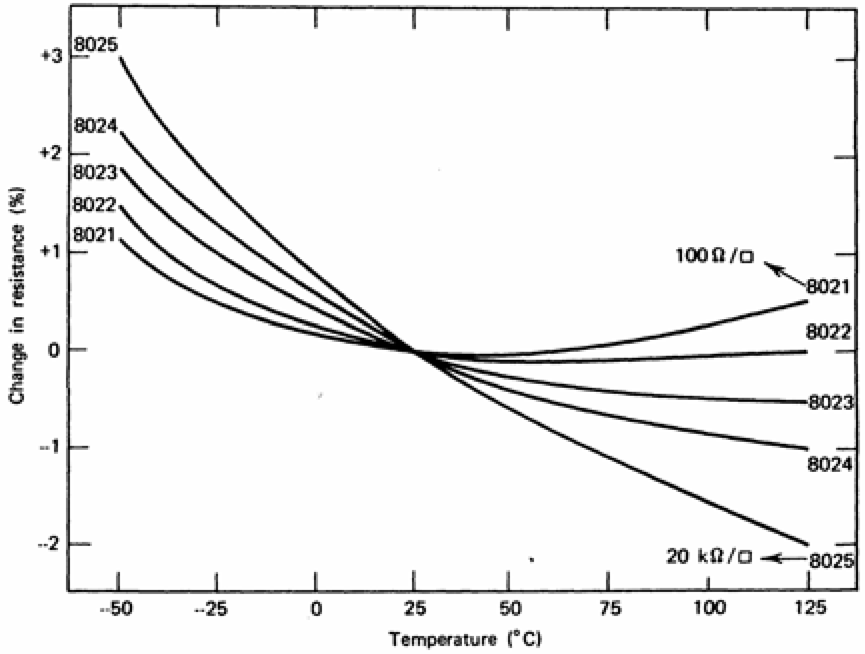
ELECTRICAL CURRENT

Nevertheless the resistivity of the materials change with temperature in a nonlinear way, and for simplification issues we can say that :

$$\rho = \rho_0\big(1 + \alpha(\theta - \theta_0)\big)$$

Where α is the temperature coefficient, and can be defined as:

$$\alpha = \frac{1}{\rho}\frac{d\rho}{d\theta}$$



ELECTRICAL CURRENT

Material	Resistividade, ρ ($\Omega\cdot$m)		Coeficiente de temperatura a 25°C
Prata	15.9	$\times 10^{-9}$	.0061
Cobre	16.8	$\times 10^{-9}$	.0068
Alumínio	26.5	$\times 10^{-9}$	.00429
Tungsténio	56	$\times 10^{-9}$	.0045
Ferro	97.1	$\times 10^{-9}$	.00651
Ouro	24.4	$\times 10^{-9}$	.0035
Platina	106	$\times 10^{-9}$	.003927

For copper the resistivity is $\boldsymbol{\rho} = \mathbf{16.8 \cdot 10^{-9}}$, and the resistance for a copper conductor with 1mm^2 of section and 1 m of length will be:

R= 16.8 mΩ

CONDUCTORS AND INSULATORS

In isolators charges move also, but the resistivity is on the order of 10^{12} and 10^{14} Ωm. Conduction can happen if there are very huge fields applied to it, these fields are normally specified by what is called disruption voltage.

Papel impregnado	10 a 100 kV/cm
Pertinax[16]	100 a 150 kV/cm
Nylon	140 kV/cm
Polistireno[17]	240 kV/cm
Polietileno[18]	500-900 kV/cm
Quartzo	80 kV/cm
Porcelana	150 a 250 kV/cm
Teflon (PTFE)[19]	600 kV/cm

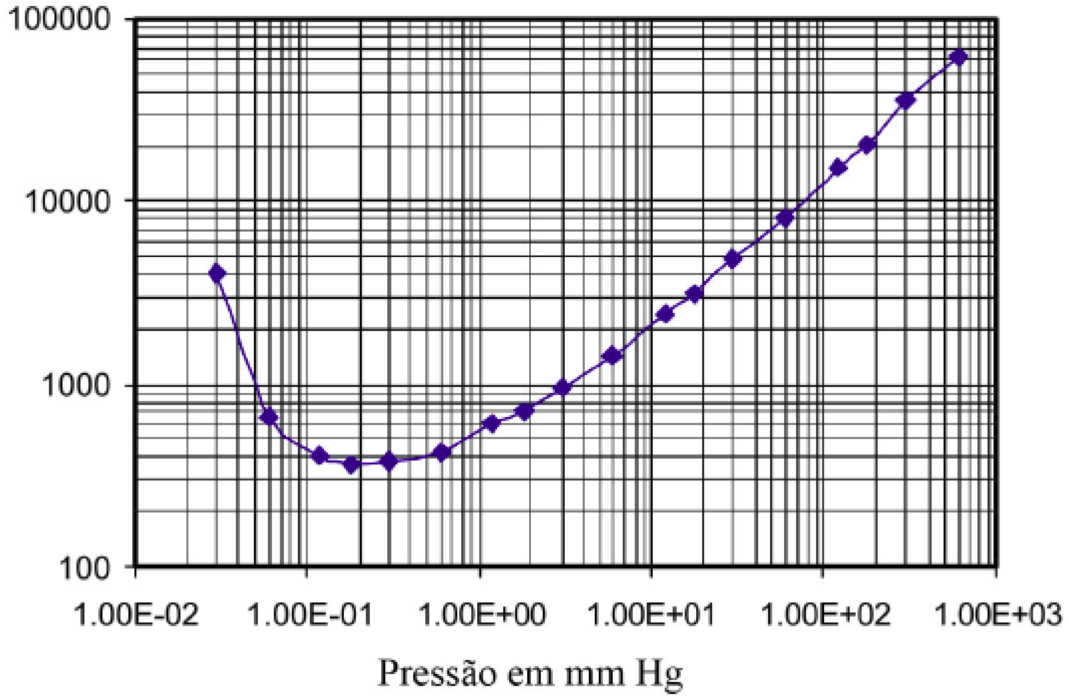
GAS CONDUCTION

Similar mechanisms exist in gases, as the well know thunder storm. In this case there exists a disruption voltage very high….

GAS CONDUCTION

Nevertheless there are some gases that present a lower disruption voltage for a certain bar pressure.

In this case conduction can appear is gases, this is the principle of fluorescent lamps. The color of the lamp is related with the type of the gas inside the lamp.

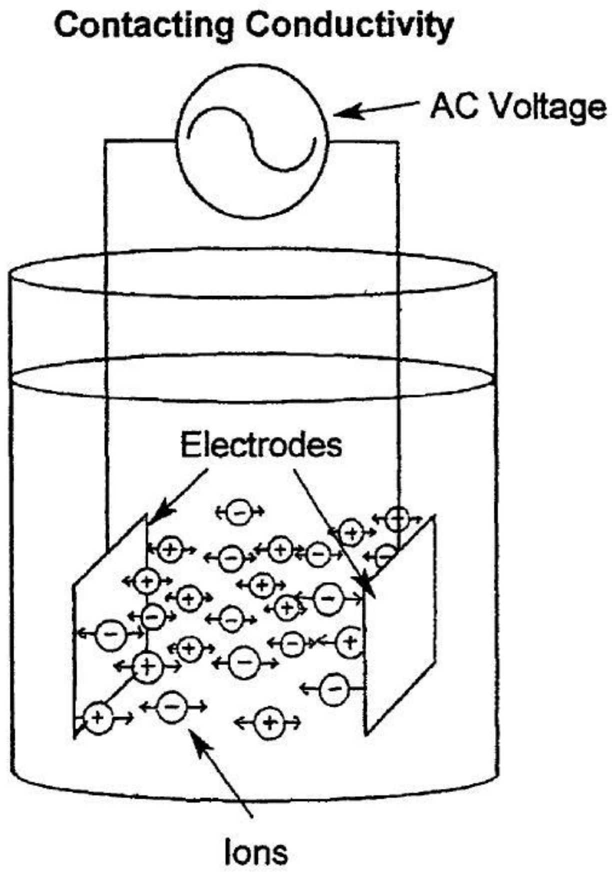


VACUOUS CONDUCTION

Conduction can also happens in vacuous, and this will give rise to the construction of valves and other electronic equipment's.

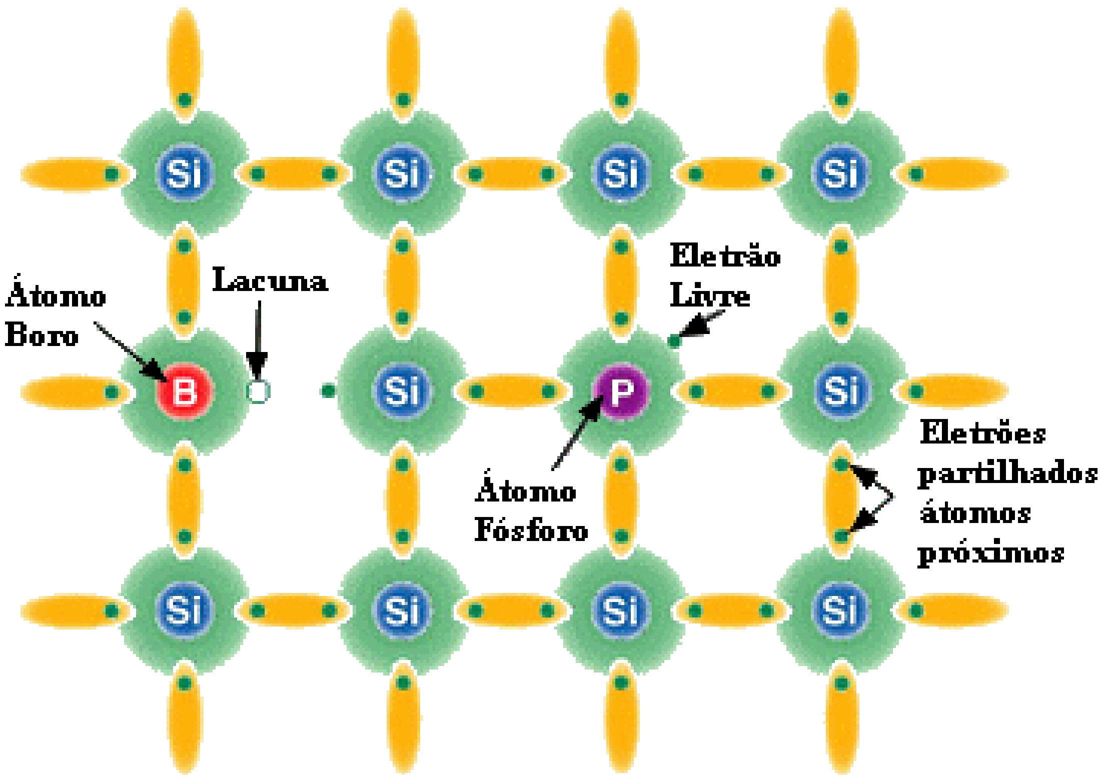
LIQUID CONDUCTION

In case of liquids, conduction does not exists in organic fluids, as oil, gasoline, alcohol, olive oil, but can happen in non-organic fluids as in salted water or body fluids, this can be attributed to the fact that organic fluids do not dissolve themselves…



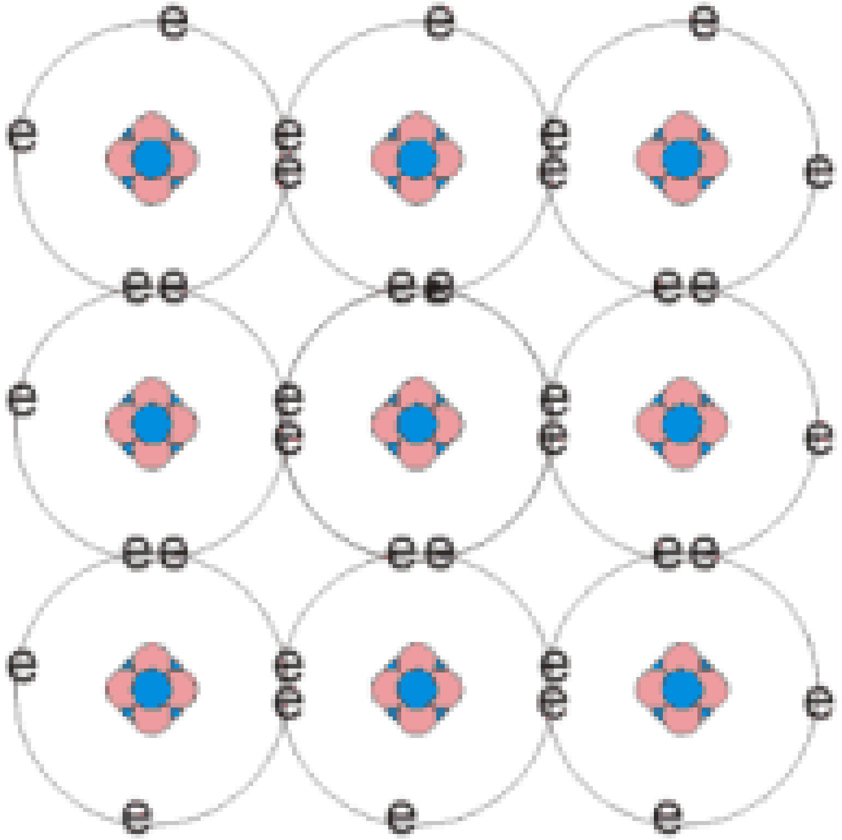
SEMICONDUCTORS

There are also a middle situation called semiconductors …



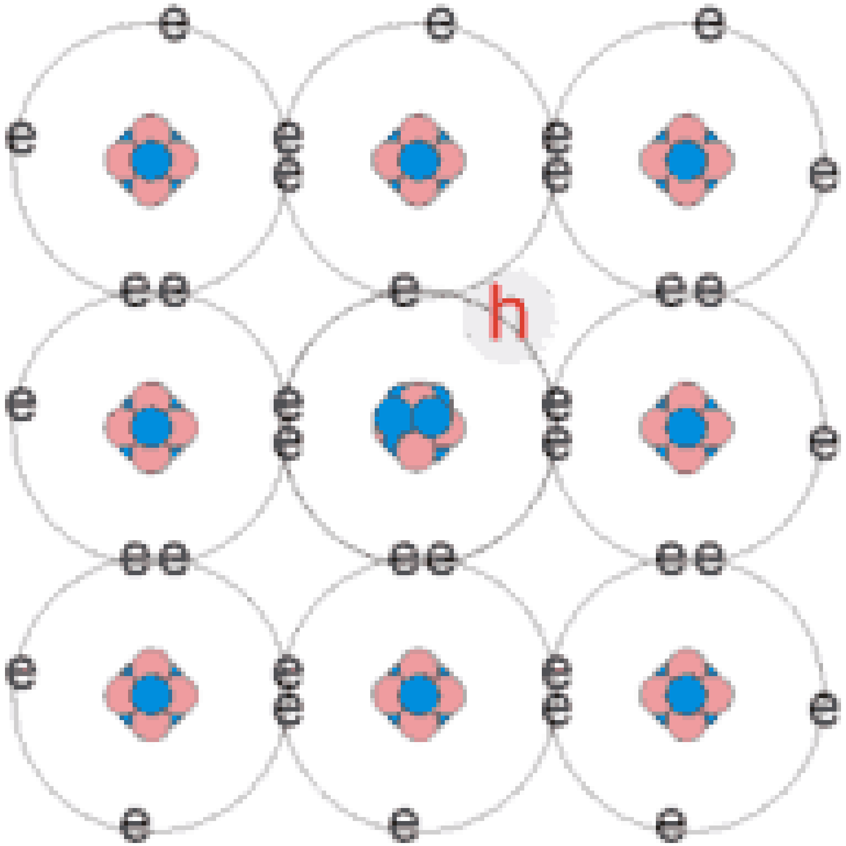
SEMICONDUCTORS

Intrinsic Semiconductor



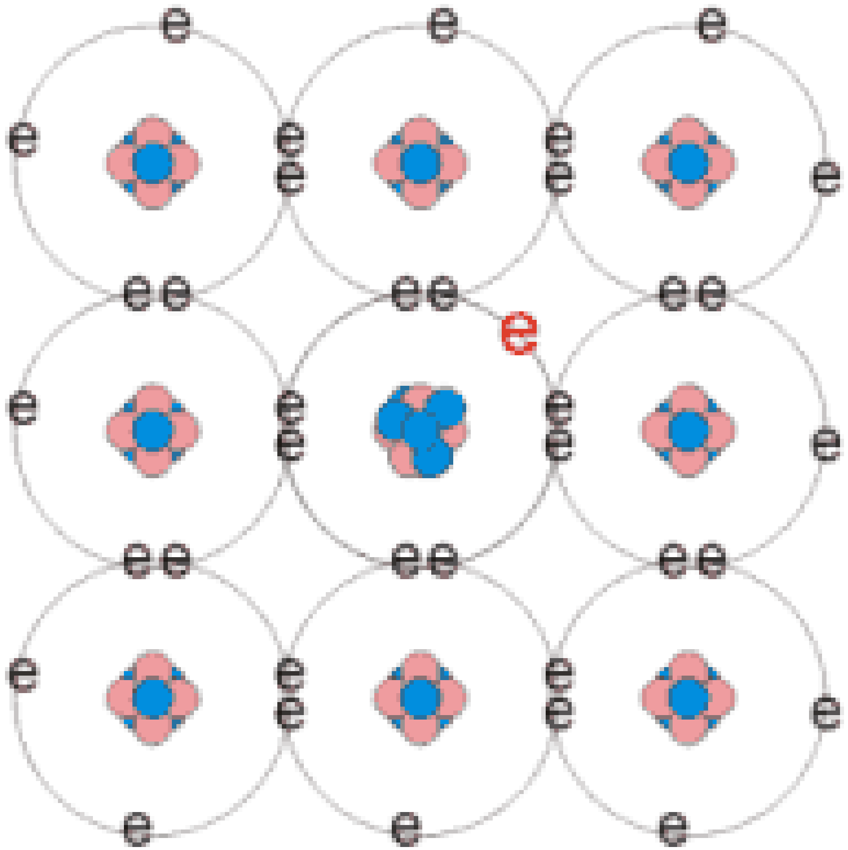
SEMICONDUCTORS

Doped Semiconductor



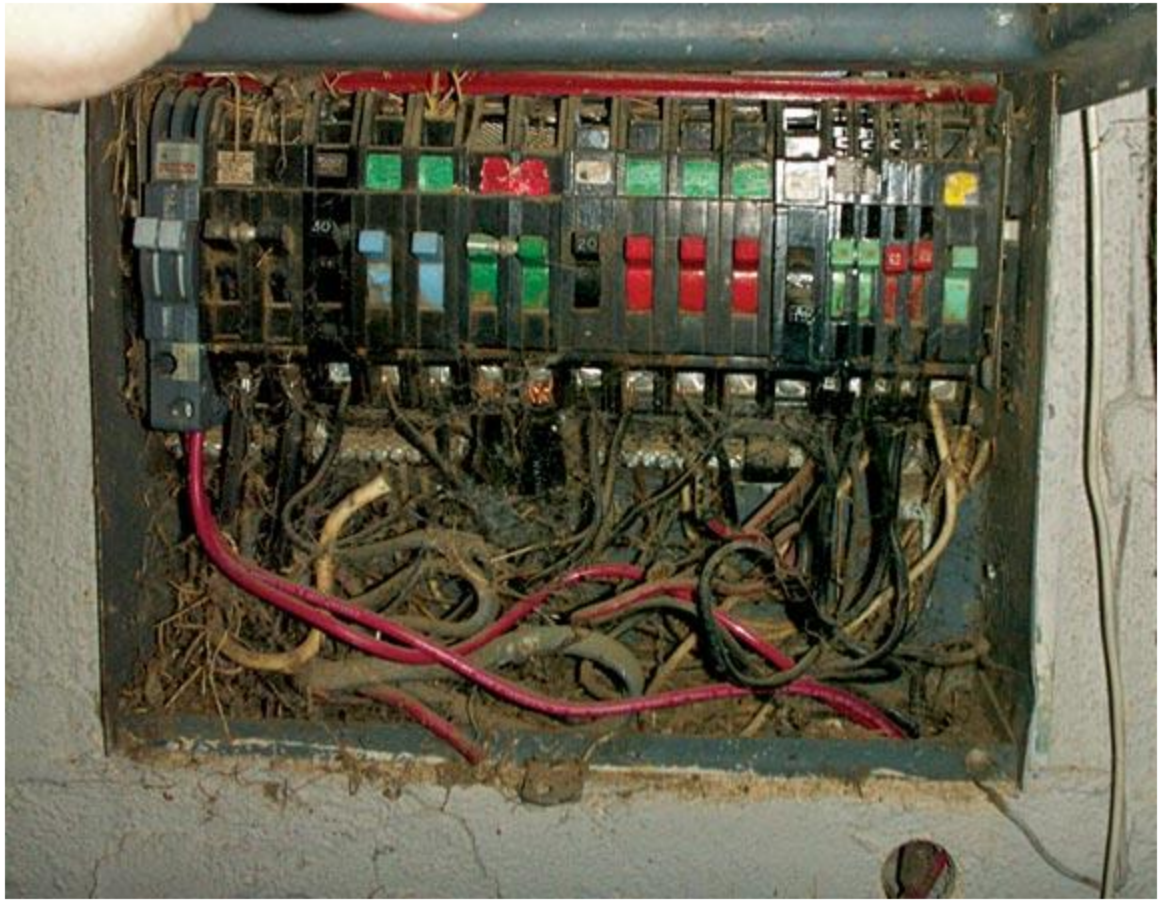
SEMICONDUCTORS

Doped Semiconductor



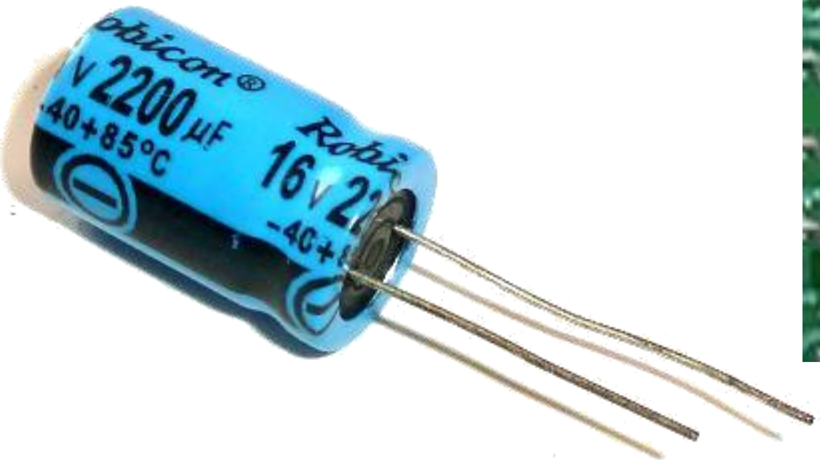
TECHNOLOGICAL ASPECTS

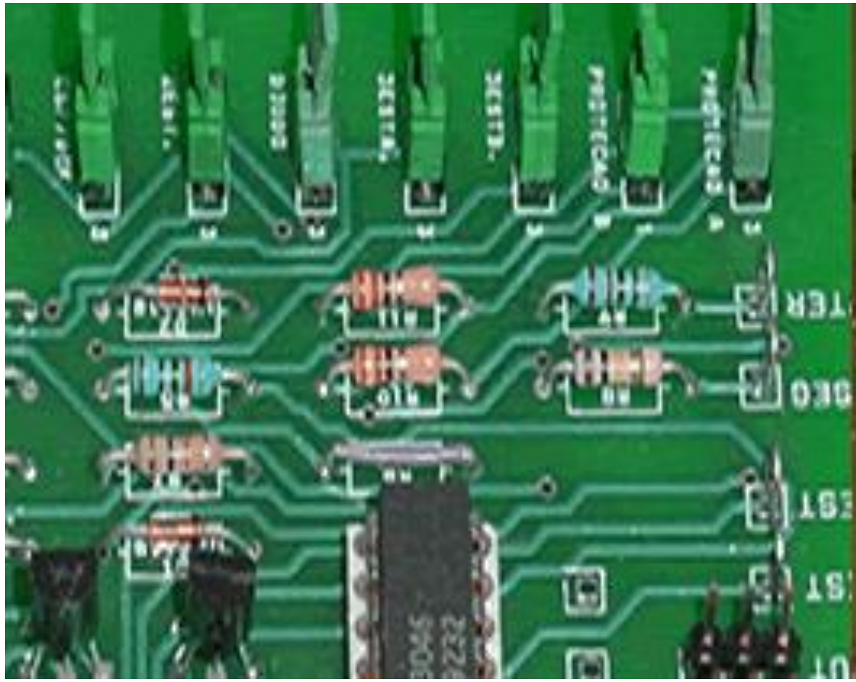
Copper based circuits

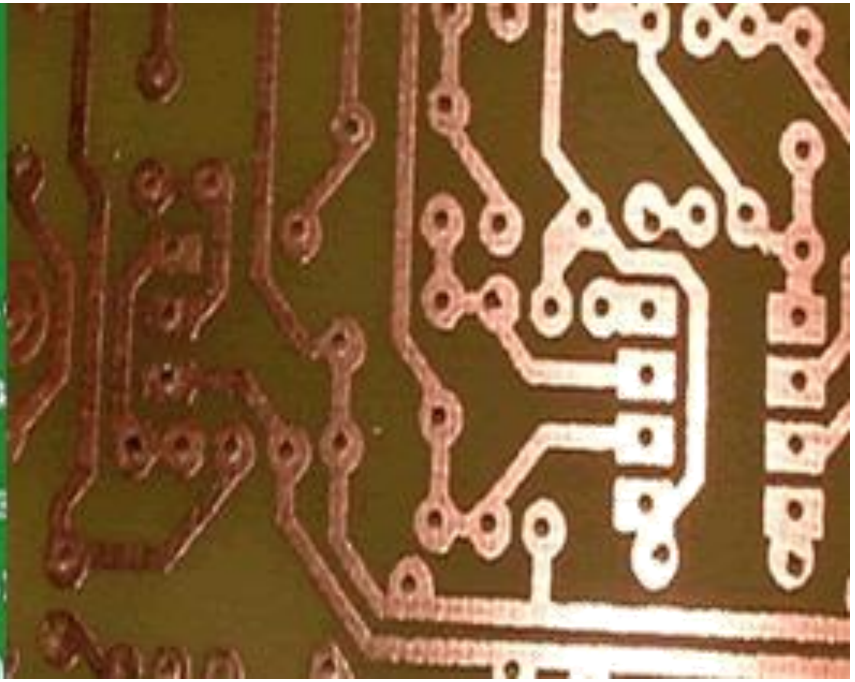


TECHNOLOGICAL ASPECTS

Printed circuit boards

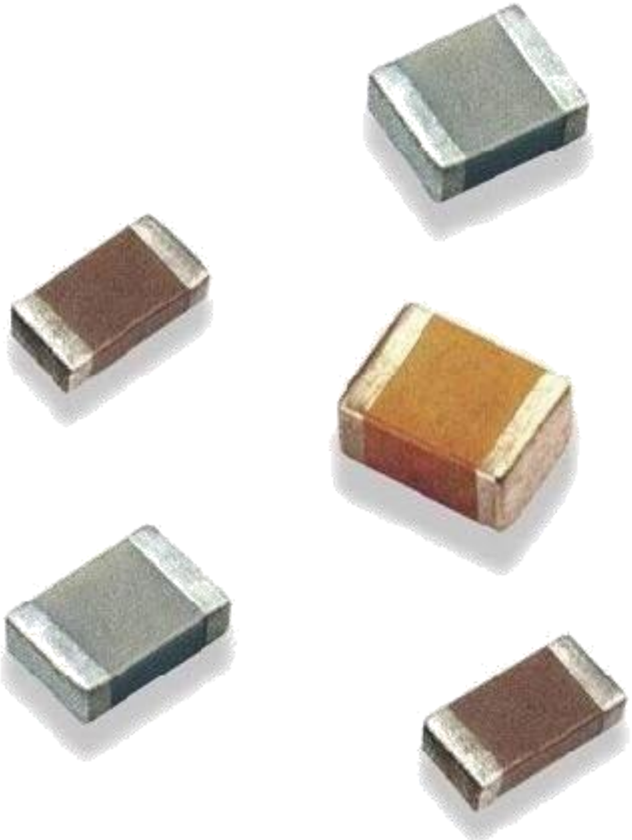


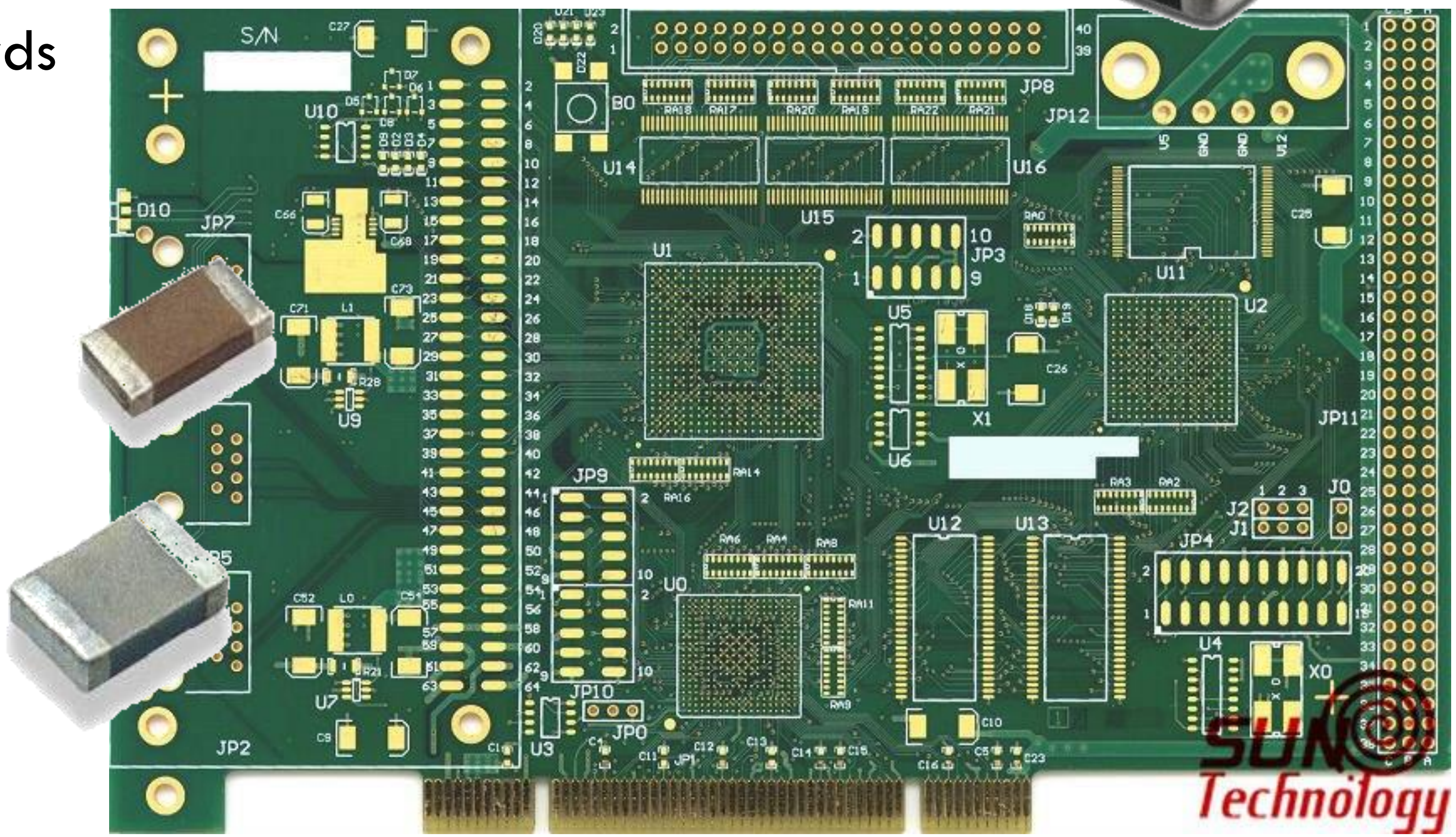




TECHNOLOGICAL ASPECTS

SMD circuit printed boards

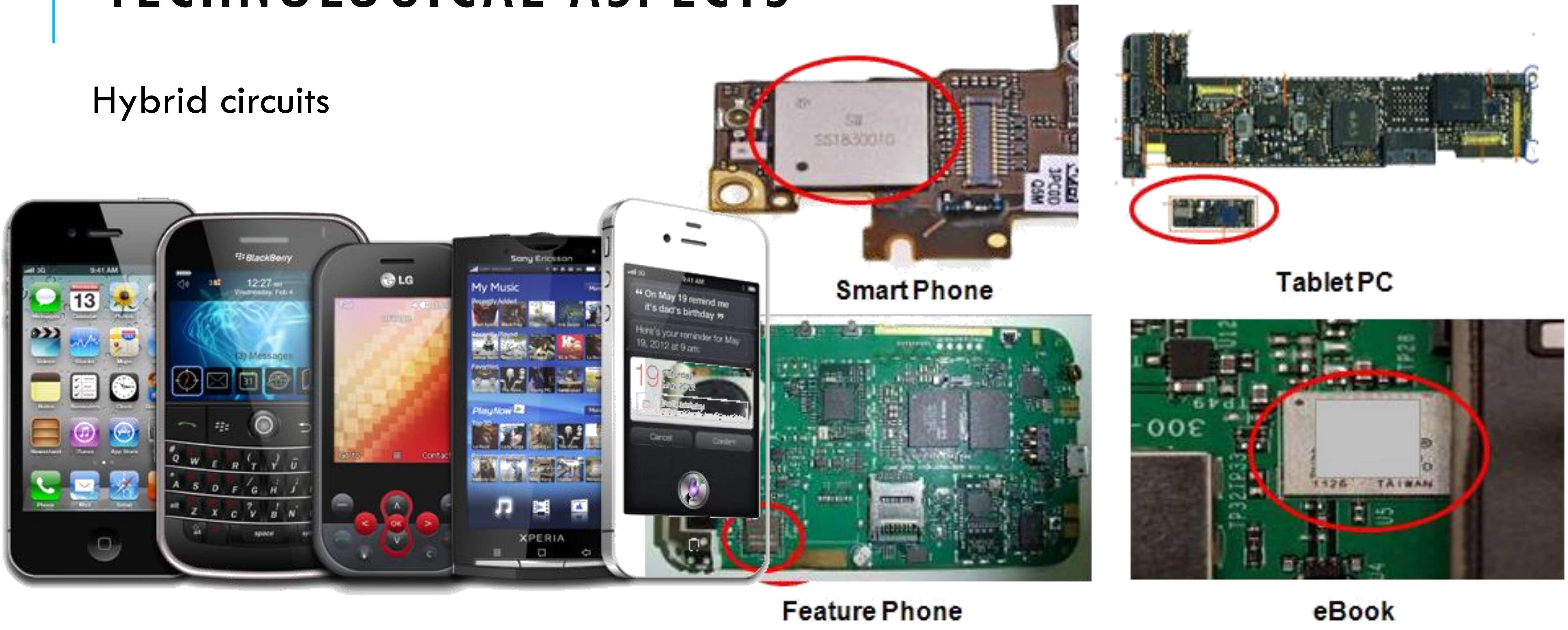




https://www.youtube.com/watch?v=CRSLbo_8nTQ

TECHNOLOGICAL ASPECTS

Hybrid circuits



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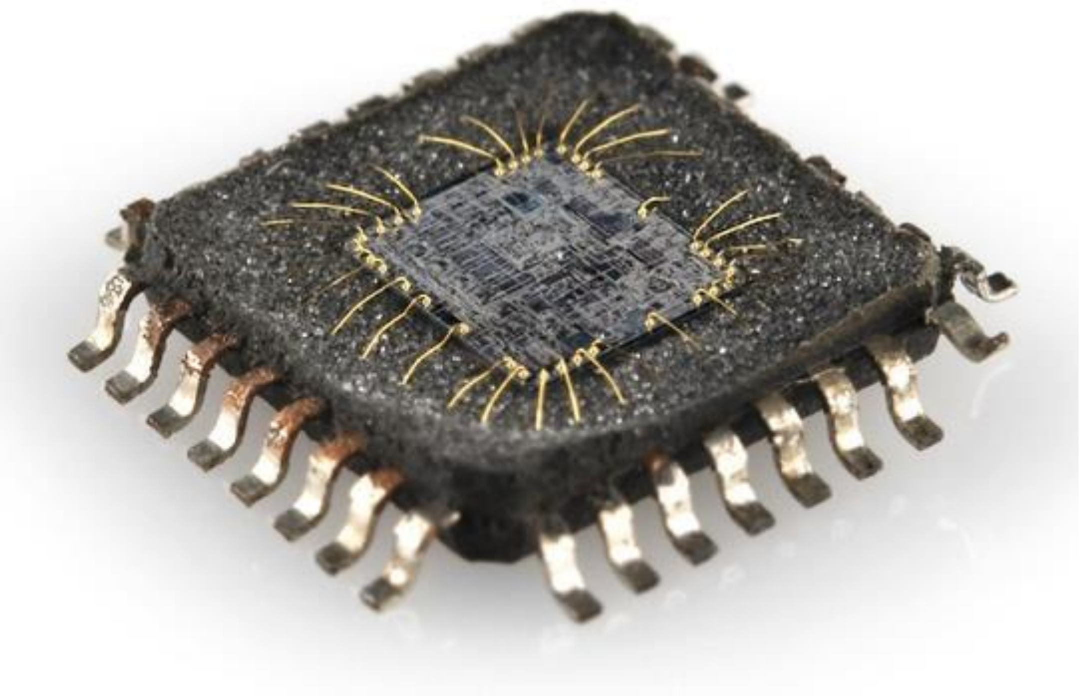
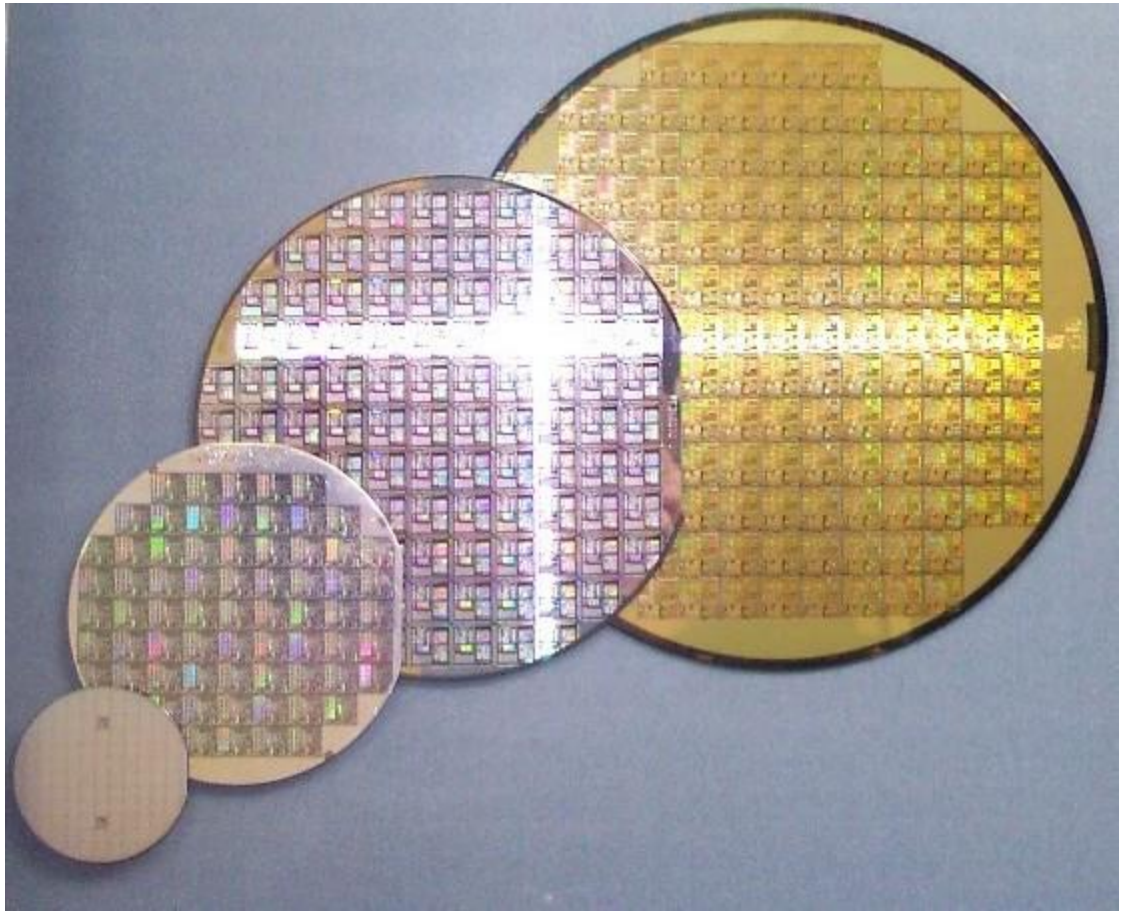
TECHNOLOGICAL ASPECTS

Integrated circuits





https://www.youtube.com/watch?v=WVLGKq9An28

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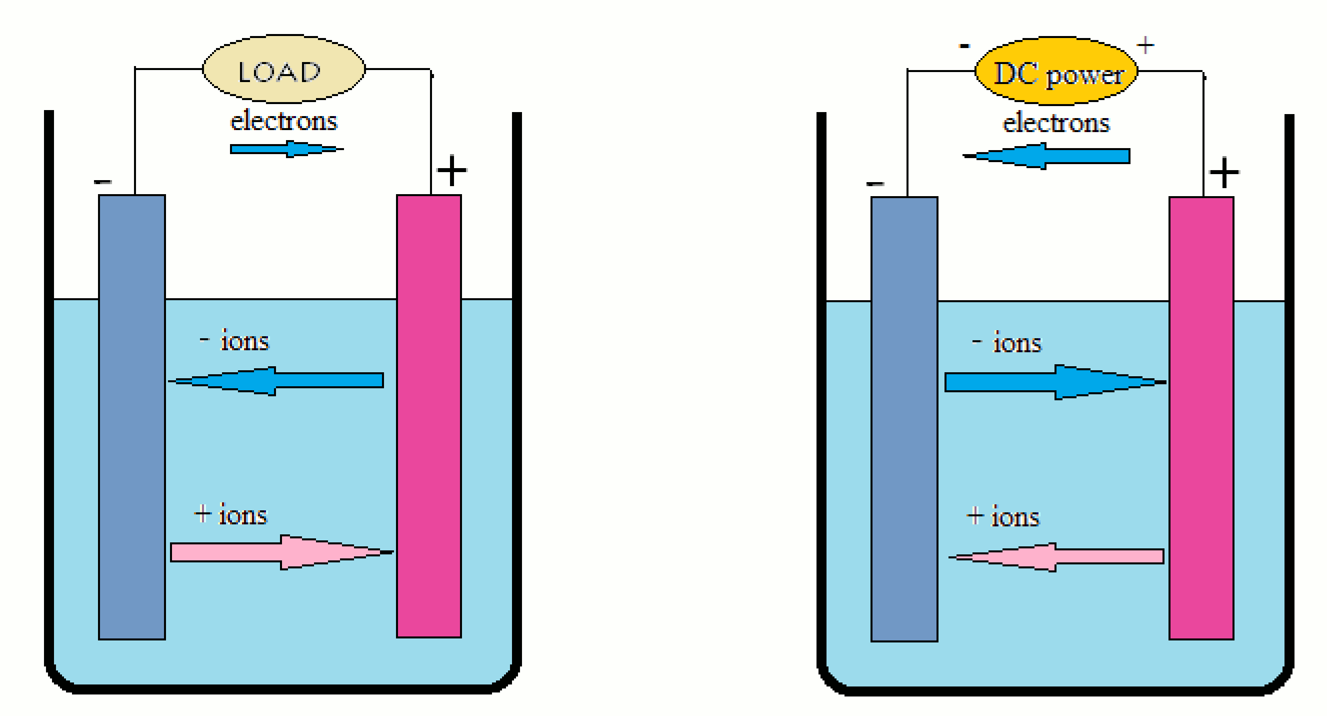
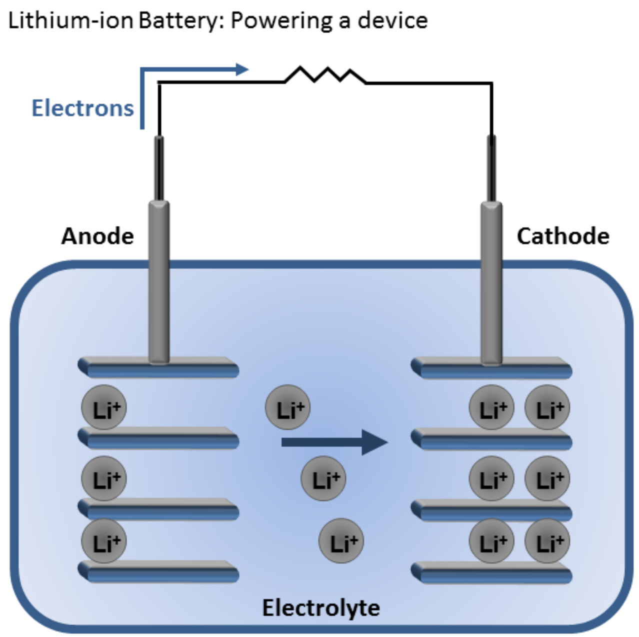
TECHNOLOGICAL ASPECTS

Battery

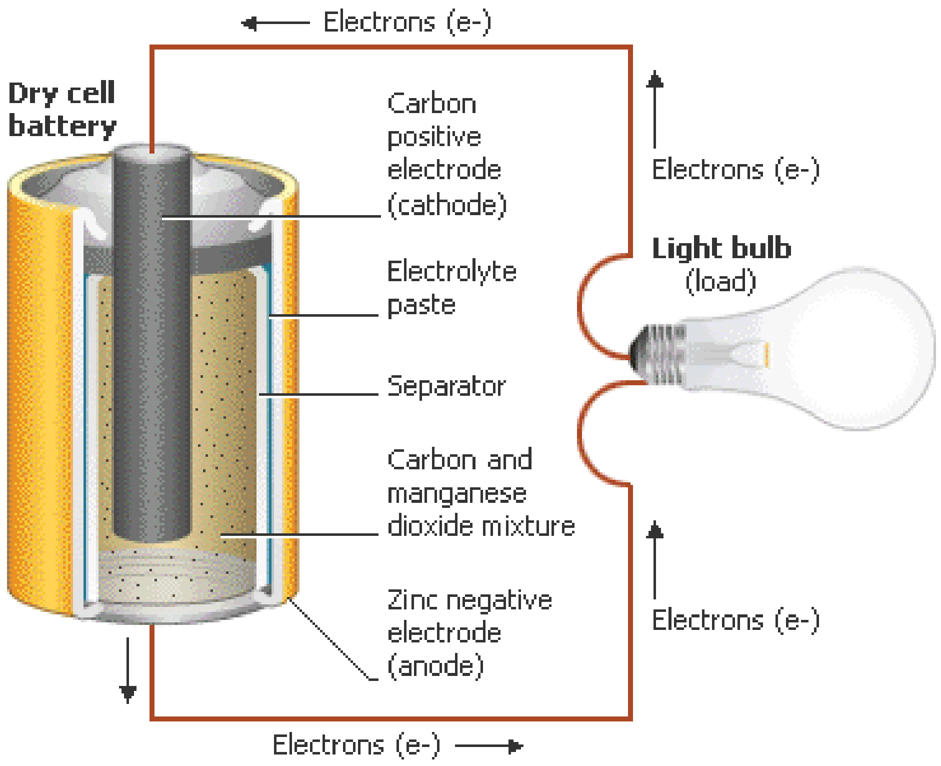


(a) Discharging (b) Charging



TECHNOLOGICAL ASPECTS

Battery



Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	± 0.5% (D)
Blue	6	6	6	1MΩ	± 0.25% (C)
Violet	7	7	7	10MΩ	± 0.10% (B)
Grey	8	8	8		± 0.05%
White	9	9	9		
Gold				0.1Ω	± 5% (J)

RESISTOR

Aula 4

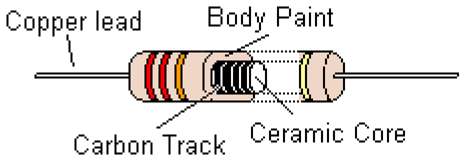
RESISTORS

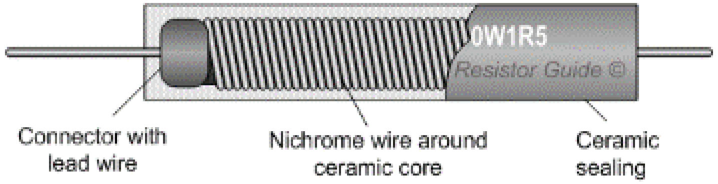
Resistors are normally built with carbon conductors, and they consist in a ceramic cylinder where carbon is deposited. The circuit is then closed by two metallic terminals.

Carbon thin film

Metal thin film

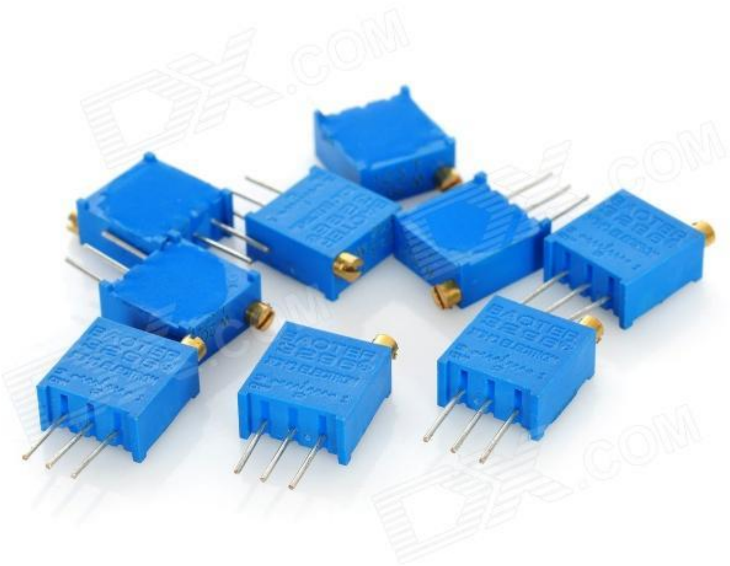
Wirewound resistor

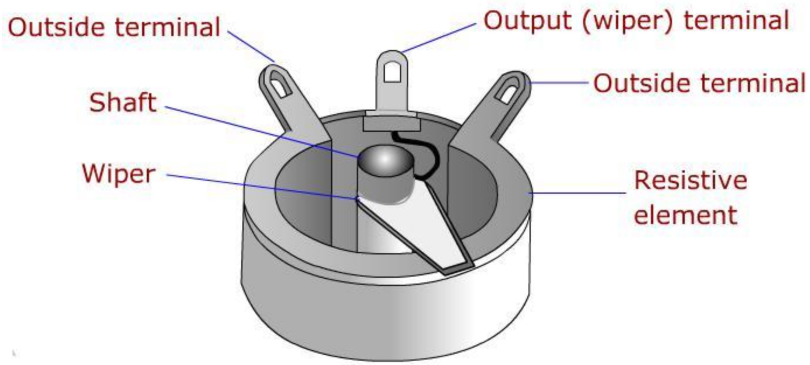




VARIABLE RESISTORS

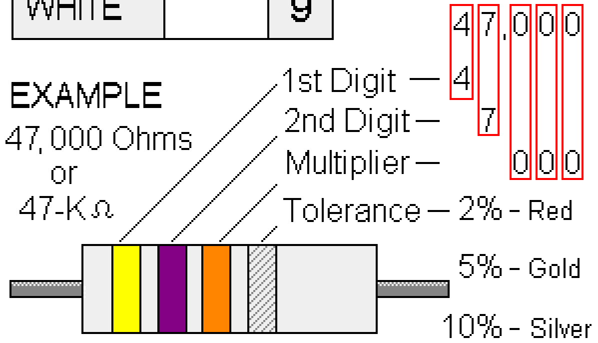
Resistors can also be vary with some mechanical change

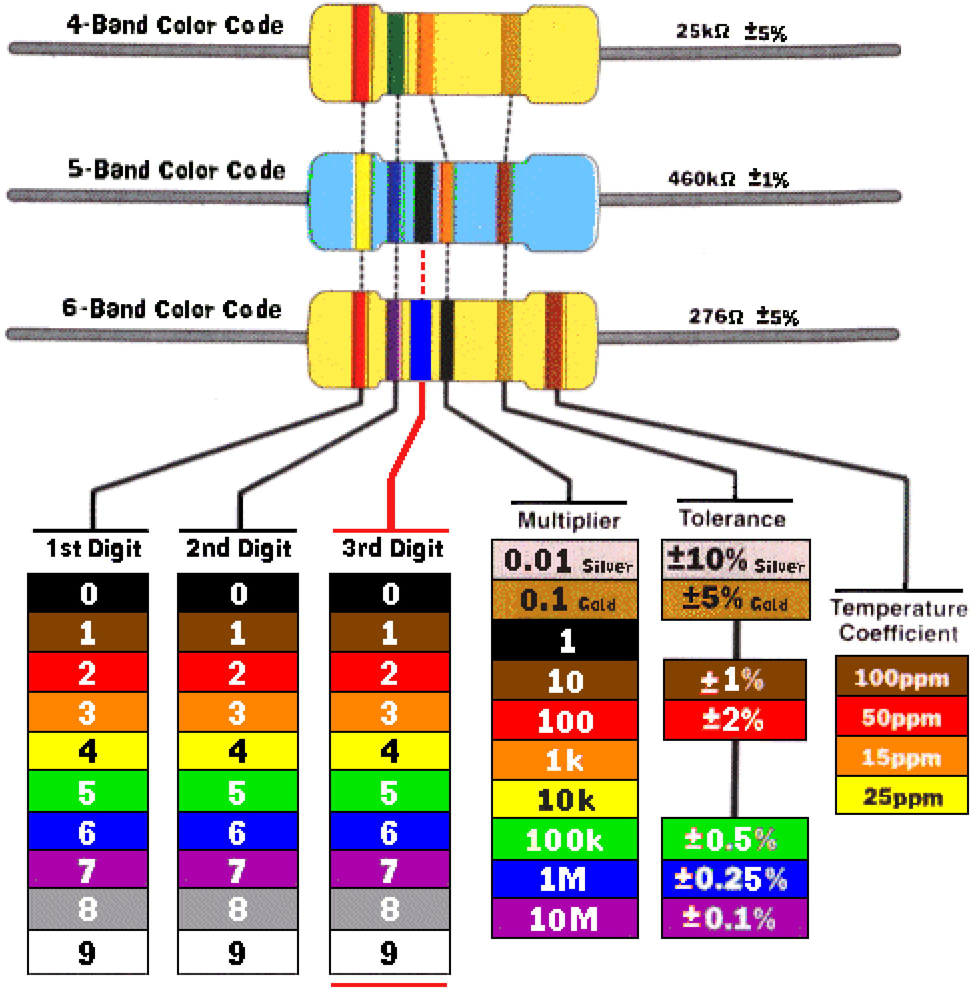




RESISTOR COLOUR CODE

			Multiplier
BLACK		0	________
BROWN		1	_______0
RED		2	______00
ORANGE		3	_____000
YELLOW		4	__0, 000
GREEN		5	_00, 000
BLUE		6	000, 000
VIOLET		7	
GRAY		8	
WHITE		9	





RESISTOR STANDARD

Standard EIA Decade Resistor Values Table

The EIA "E" series specify the preferred values for various tolerances. The number following the "E" specifies the number of logarithmic steps per decade. The table is normalized for the decade between 100 and 1,000. The values in any decade can be derived by merely dividing or multiplying the table entries by powers of 10. The series are as follows:

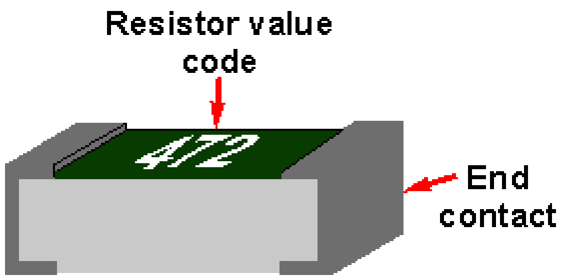
E3 50% tolerance (no longer used)
E6 20% tolerance (now seldom used)
E12 10% tolerance
E24 5% tolerance
E48 2% tolerance
E96 1% tolerance
E192 0.5, 0.25, 0.1% and higher tolerances

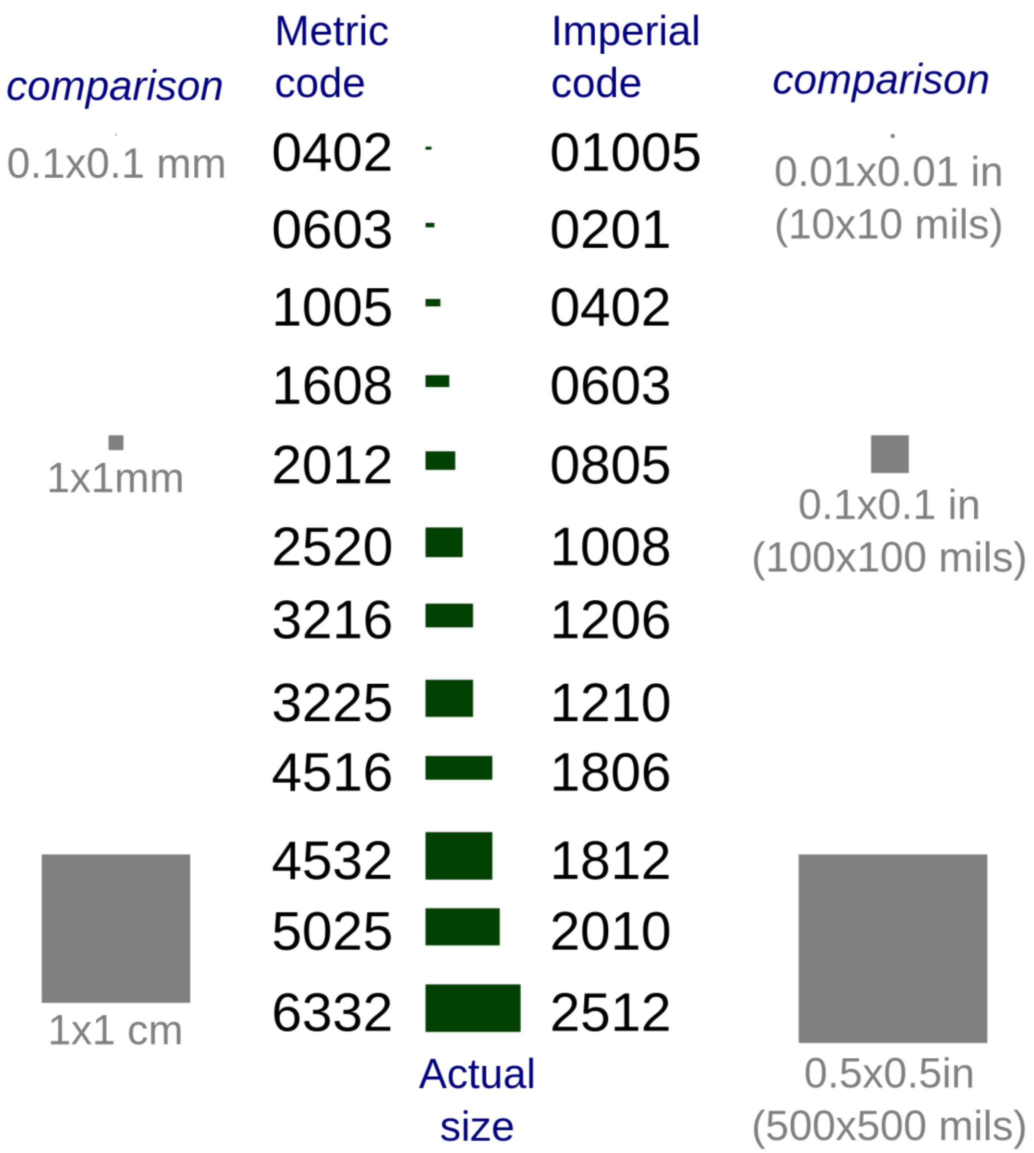
E6	E12	E24	E48	E96	E192	E6	E12	E24	E48	E96	E192	E6	E12	E24	E48	E96	E192
100	100	100	100	100	100	220	220	220	215	215	215	470	470	470	464	464	464
					101						218						470
				102	102					221	221					475	475
					104						223						481
			105	105	105				226	226	226				487	487	487
					106						229						493
				107	107					232	232					499	499
					109						234						505
		110	110	110	110			240	237	237	237			510	511	511	511
					111						240						517
				113	113					243	243					523	523
					114						246						530
			115	115	115				249	249	249				536	536	536
					117						252						542
				118	118					255	255					549	549
					120						258						556
	120	120	121	121	121		270	270	261	261	261		560	560	562	562	562
					123						264						569
				124	124					267	267					576	576
					126						271						583
			127	127	127				274	274	274				590	590	590
					129						277						597
				130	130					280	280					604	604
					132						284						612
		130	133	133	133			300	287	287	287			620	619	619	619
					135						291						626
				137	137					294	294					634	634
					138						298						642
			140	140	140				301	301	301				649	649	649
					142						305						657
				143	143					309	309					665	665
					145						312						673
150	150	150	147	147	147	330	330	330	316	316	316	680	680	680	681	681	681
					149						320						690
				150	150					324	324					698	698
					152						328						706
			154	154	154				332	332	332				715	715	715
					156						336						723
				158	158					340	340					732	732
					160						344						741
		160	162	162	162			360	348	348	348			750	750	750	750
					164						352						759
				165	165					357	357					768	768
					167						361						777
			169	169	169				365	365	365				787	787	787
					172						370						796
				174	174					374	374					806	806
					176						379						816
	180	180	178	178	178		390	390	383	383	383		820	820	825	825	825
					180						388						835
				182	182					392	392					845	845
					184						397						856
			187	187	187				402	402	402				866	866	866
					189						407						876
				191	191					412	412					887	887
					193						417						898
		200	196	196	196			430	422	422	422			910	909	909	909
					198						427						920
				200	200					432	432					931	931
					203						437						942
			205	205	205				442	442	442				953	953	953
					208						448						965
				210	210					453	453					976	976
					213						459						988

RESISTOR STANDARD SMD

An SMD resistor with the figures 472 as a resistance of 47 x 10^2 ohms, or 4.7kΩ. However beware of resistors marked with figures such as 100.

Where resistance values less than ten ohms are used, the letter "R" is used to indicate the position of the decimal point. As an example, a resistor with the value 4R7 would be 4.7Ω.

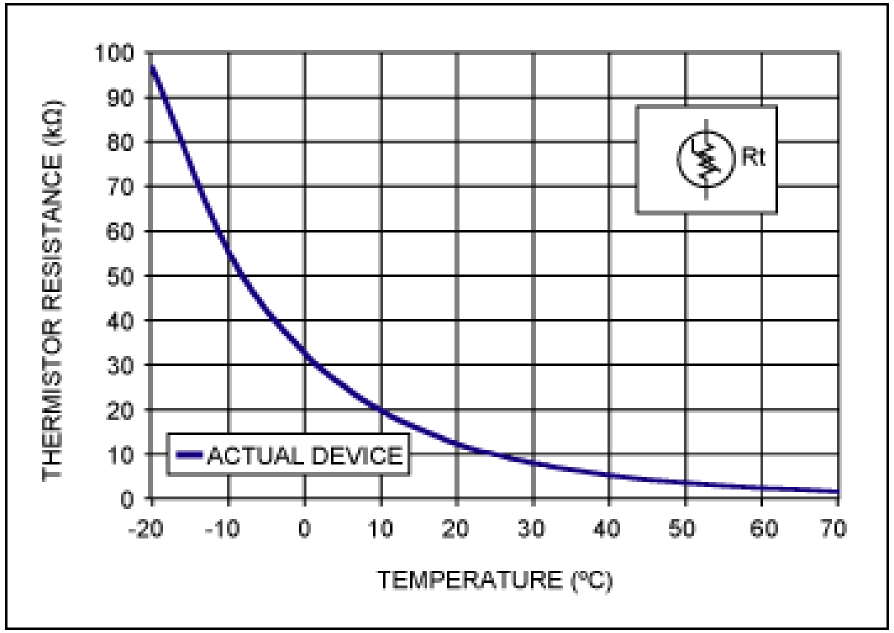




RESISTORS

Other resistors can also be used in certain applications as :

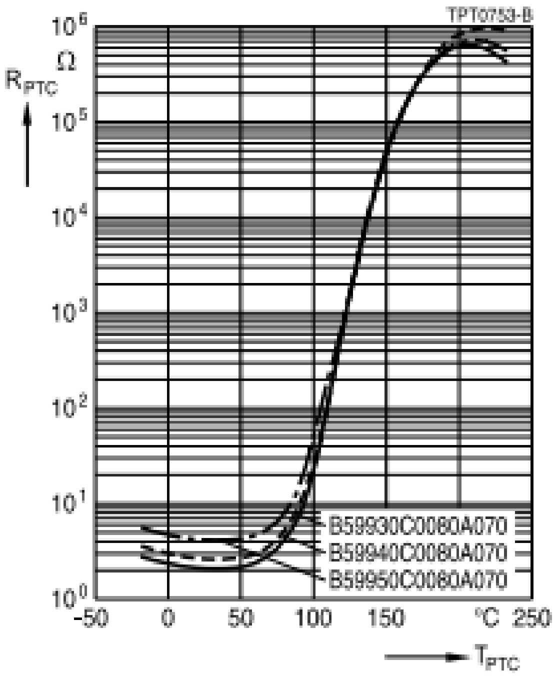
NTC (Negative temperature coefficient)



RESISTORS

Other resistors can also be used in certain applications as :

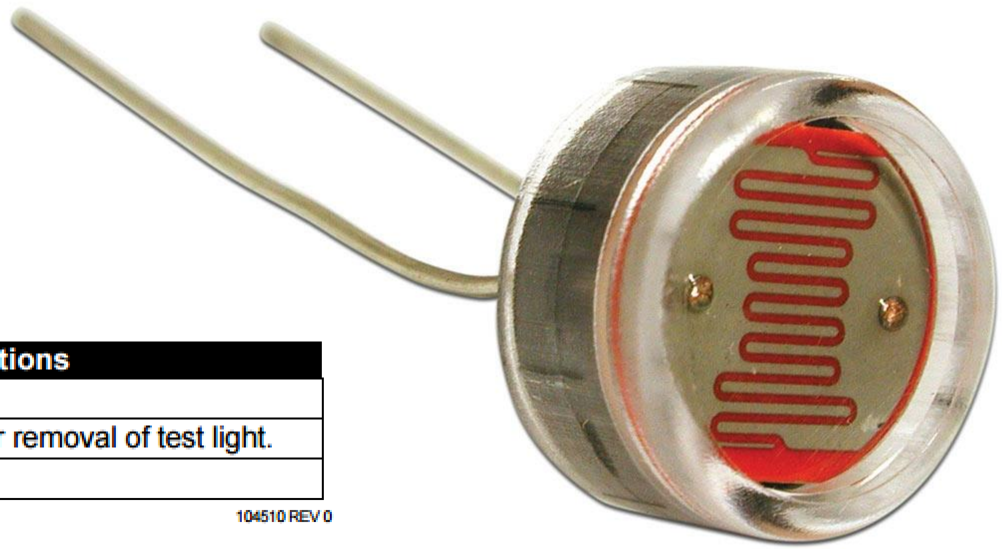
PTC (Positive temperature coefficient)



RESISTORS

Other resistors can also be used in certain applications as :

LDR (Light Dependent Resistor)



Electrical Characteristics (T_A=25°C unless otherwise noted)

Symbol	Parameter	Min.	Typ.	Max.	Units	Test Conditions
R_L	Light Resistance	5.4		12.6	kΩ	1 ftc. (1)
R_D	Dark Resistance			2.5	MΩ	15 sec. after removal of test light.
λ_P	Spectral Peak		550		nm	

Specifications subject to change without notice

104510 REV 0

Notes: (1) Cells light adapted at 30 to 50 Ftc for 16 hrs minimum prior to electrical tests.
(2) Derate linearly to zero at 75°C.

RESISTORS

Other resistors can also be used in certain applications as :

VDR (Voltage Dependent Resistor)

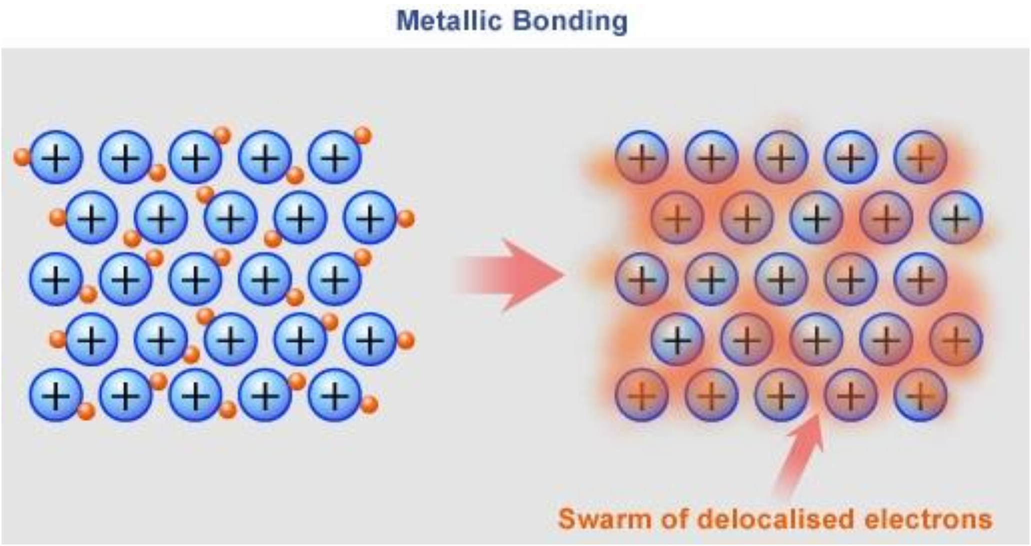
RESISTOR


MAGNIFYING GLASS USED TO SEE DEFLECTION OF MAGNET
COLD JUNCTION

ELECTRICAL CURRENT

Assume that inside a conductor we have an uniform and constant charge flux, which creates a current, the amount of charge during a period of time traversing this surface is:

$$Q = I\,t$$



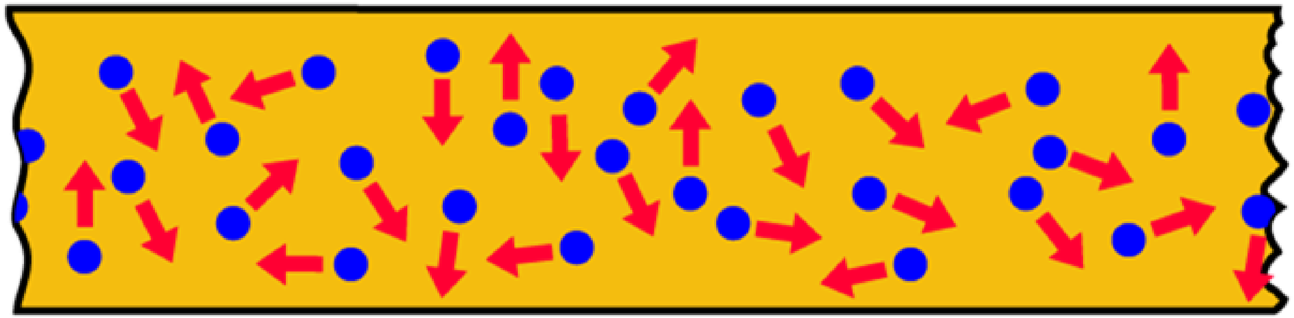
If the current is not constant over time, we should defined it as:

$$i = \frac{dq}{dt}$$

ELECTRICAL CURRENT

In the case that no force (or any electrical field) is applied the current should be zero, so:

$$\vec{J} = \rho_c \vec{v} = 0$$



In fact there will be charge movement, due to thermal agitation, but macroscopically, the number of electrons traversing a surface in one direction is equal to the one traversing it on a different direction and thus:

$$\vec{J} = 0$$

ELECTRICAL CURRENT

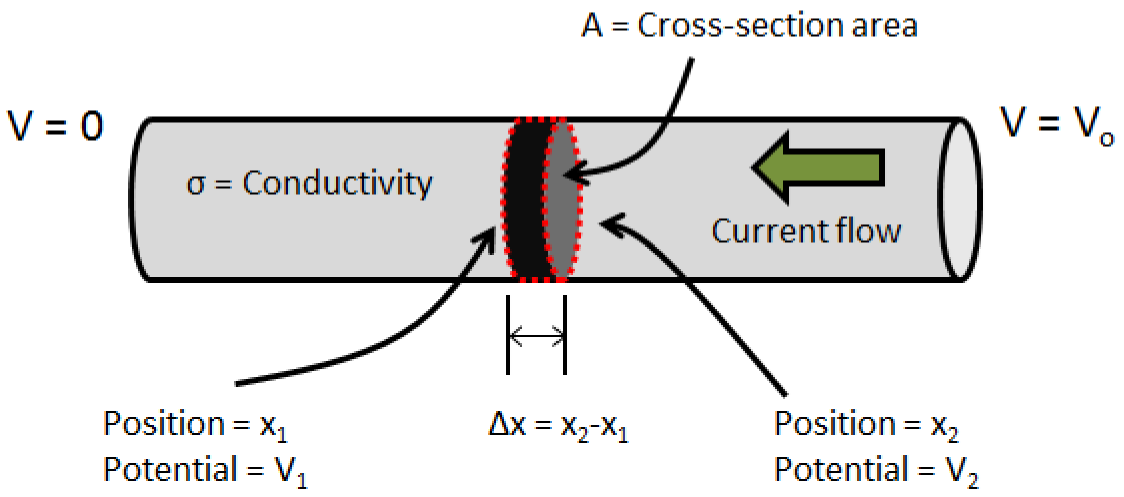
If the last formula is combined with $\vec{J} = \rho_c \vec{v}$, we can define a relationship between the applied field and the current density as:

$$\vec{J} = \sigma \vec{E}$$

Where σ is called conductivity, inversely we can also define: $\rho = 1/\sigma$

$$\vec{E} = \rho \vec{J}$$

In this case ρ is called resistivity.



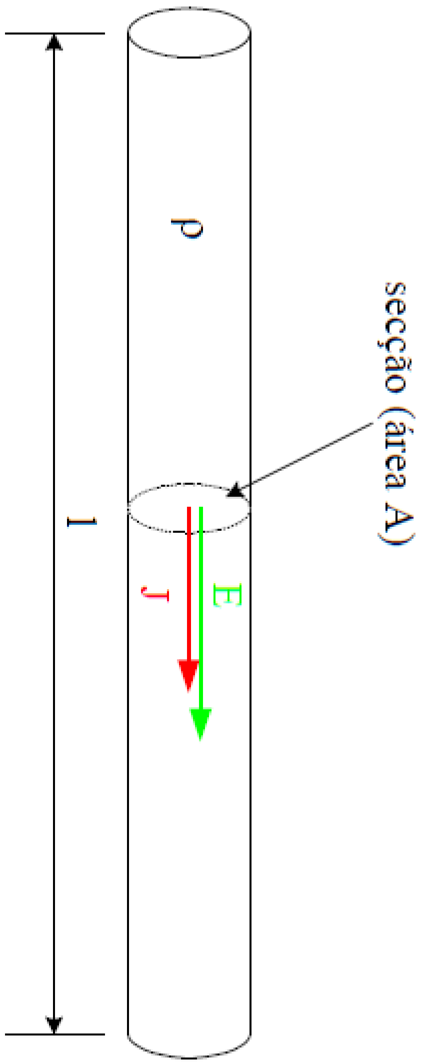
ELECTRICAL CURRENT

If the electrical field is constant and collinear with the conductor in all its extension we can write:

$\boldsymbol{U = El}$ and we also know that the current is $\boldsymbol{I = \iint_A \vec{J}\,\overrightarrow{dA}}$, and for charge conservation reasons, the current is equal in all transversal section, so:

$\boldsymbol{I = JA}$, we can combine these equations and get a final solution of:

$\boldsymbol{U = \rho \frac{l}{A} I}$, and $\boxed{\boldsymbol{R = \rho \frac{l}{A}}}$



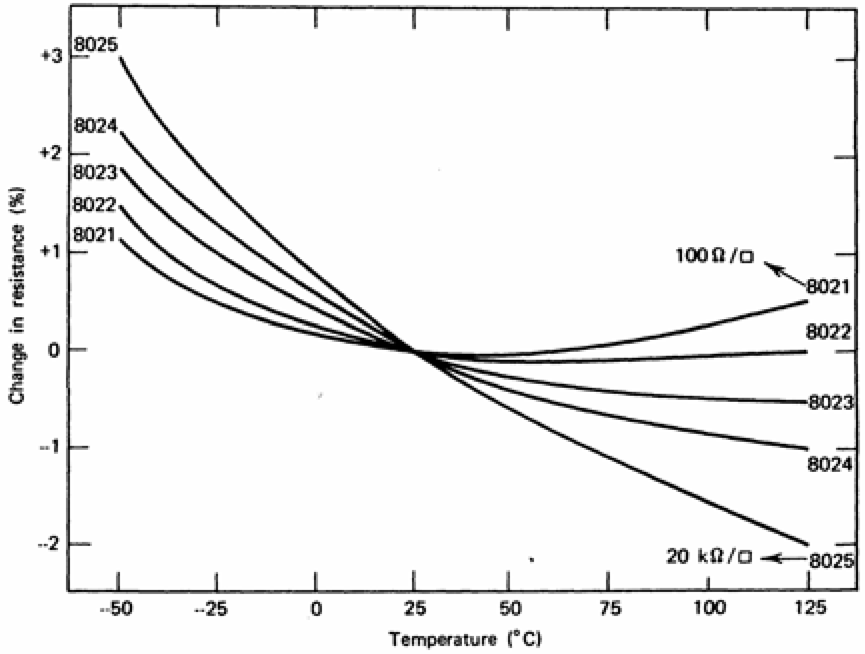
ELECTRICAL CURRENT

Nevertheless, the resistivity of the materials change with temperature in a nonlinear way, and for simplification issues we can say that :

$$\boldsymbol{\rho = \rho_0\left(1 + \alpha(\theta - \theta_0)\right)}$$

Where α is the temperature coefficient, and can be defined as:

$$\boldsymbol{\alpha = \frac{1}{\rho}\frac{d\rho}{d\theta}}$$



EXERCICIO

Numa habitação, devido a um erro de construção, um gerador elétrico foi indevidamente ligado a um tudo de alumínio de uma canalização existente.

1. Assumindo que no terminal desse tubo a 10m de distância do gerador, temos uma torneira, calcule qual a tensão que existirá entre essa torneira e a massa a 25ºC, neste caso assuma que não temos nenhuma interligação entre essa torneira e a massa.

2. Assumindo agora que está uma pessoa a abrir a torneira e que pode ser representada por uma resistência de 300Ω, calcule qual a corrente que a vai atravessar.

3. Explique o que acontece se a temperatura ambiente diminuir para -30ºC, assumindo um coeficiente de temperatura do alumínio, a 0ºC, de 0.43%$ºC^{-1}$.

Diâmetro interno do tubo: 2 cm, diâmetro externo: 3 cm, resistividade do alumínio a 25ºC é $28 \cdot 10^{-9} \Omega \cdot m$.
Tensão do gerador: 240V