Polipirrolo: La plastica che conduce la corrente elettrica

Partendo dal confronto della struttura atomica, la lezione illustrerà la differenza tra un metallo capace di trasportare la corrente elettrica e i materiali plastici (o polimerici) che normalmente sono isolanti. Quindi spiegherà come può una “plastica” avere la proprietà di condurre la corrente elettrica.

In laboratorio verrà sintetizzato il polipirrolo, un polimero che è in grado di condurre la corrente elettrica, con cenni alle reazioni chimiche di polimerizzazione. Il polimero verrà depositato sui tessuti e verranno condotte delle misurazioni per calcolare la resistenza elettrica, applicando la legge di Ohm, su tessuti trattati con il polipirrolo.

Infine attraverso una telecamera ad infrarossi, si potrà apprezzare il calore generato per effetto Joule dal tessuto attraversato dalla corrente elettrica.

Destinatari: *Scuola Secondaria I e II grado*

Esperienza di Laboratorio: *Sintesi del polipirrolo, Misurazioni di resistenza elettrica e termografie su tessuti trattati*

Discipline Scolastiche: *Fisica, Scienze Naturali, Chimica*

Durata: *3 h*

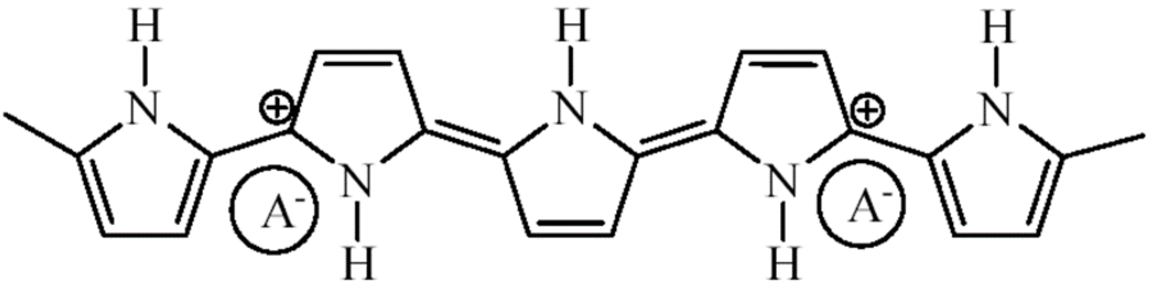
Documentazione: *Presentazione Powerpoint*

Materiali: *videoproiettore, cappa da laboratorio, agitatore magnetico, generatore elettrico, morsetti, termocamera.*

MAKING AN ELECTRICALLY CONDUCTIVE FABRIC
(for the teacher)

Objective: Synthesis and deposition of polypyrrole on a fabric

Introduction:
Polypyrrole is an intrinsically conducting polymer, *i.e.* it is an organic polymer able to conduct electricity. This property is related to its chemical configuration: it has a conjugated structure and it contains positive charges along the polymer chain.



Polypyrrole can be easily synthesised from the monomer (pyrrole) in water with an oxidant (e.g. $FeCl_3$) by a redox reaction.

$n\ C_4H_4NH + 2\ FeCl_3 \rightarrow (C_4H_2NH)_n + 2\ FeCl_2 + 2\ HCl$

During the synthesis, positive charges are formed by oxidation and anions (A^-) present in the solution are embedded into the polymer (counter-ions) by ionic bonds.
As the polymerization reaction takes place and the molecular weight of polypyrrole increases, polypyrrole becomes water insoluble and tends to deposit on solid surfaces. If a fabric is placed in the solution, a uniform layer of polypyrrole will coat it in 1-4 h.
Polypyrrole is black.

Materials required:

- White cotton fabric, about 1 g (it must be untreated and undyed in order to prevent treatments from altering the result)
- Ferric chloride ($FeCl_3$) 
- Pyrrole  (it must be handled under a fume hood)
- Beaker
- Sealed plastic container
- Laboratory spoon
- Pasteur pipettes
- Gloves
- Safety glasses
- Plier
- Fume hood
- Oven (if available)

Procedure:

Wear gloves and safety glasses.
Make a $FeCl_3$ 0.2 M solution in water.
Put the fabric into the plastic container and cover it with 50 ml of $FeCl_3$ solution.
Be sure that the fabric is completely soaked with the solution.
Put 8-10 drops of pyrrole in the plastic container. Handle pyrrole under fume hood.
Check that the weight of 8-10 drops should be ~200 mg.
Seal the container and gently shake it to spread pyrrole in the solution for at least 2 minutes.
Let it stand for a few hours (1-4 hours).
The indicated times should ensure the reaction is completed. Higher the time, more polypyrrole should be deposited on the fabric.
Pull out the fabric from the polymerization solution with plier.
The fabric must be completely and uniformly black.
Rinse the fabric under running water and dry it.
Drying would be completed in about 1 h at 60°C in oven, or 10-15 h at room temperature (overnight).
Observe the colour of the fabric and touch it.

Results:

Colour and touch sensation of the fabric before polypyrrole polymerization	*Colour: white. Touch: flexible/soft*
Colour and touch sensation of the fabric after polypyrrole polymerization	*Colour: black. Touch: rigid and dry sensation* *The dry sensation is due to the ability of polypyrrole to adsorb humidity.*

Discussion:

• Do you think that the polypyrrole deposition has modified the fabric structure?
The changes observed in terms of colour variation revealed that a thin layer of polypyrrole deposited on the fibres, and the rigidity of the fabric is due to some bonding of the polypyrrole layer between fibre to fibre.
• Are you able to explain why polypyrrole is black?
Polypyrrole, being a polymer, has an extremely wide conjugated structure that is able to absorb almost all the frequencies of visible light.
• Other oxidizing chemicals can be used to produce polypyrrole, for instance ferric nitrate, ferric sulphate, ammonium persulfate. Can you write the chemical equations with these oxidants?
Increasing the difficulty, the chemical equations are:

$n\ C_4H_4NH + 2\ Fe(NO_3)_3 \rightarrow (C_4H_2NH)_n + 2\ Fe(NO_3)_2 + H_2NO_3$

$n\ C_4H_4NH + Fe_2(SO_4)_3 \rightarrow (C_4H_2NH)_n + Fe_2(SO_4)_2 + H_2SO_4$

$n\ C_4H_4NH + (NH_4)_2S_2O_8 \rightarrow (C_4H_2NH)_n + (NH_4)_2SO_4 + H_2SO_4$

• For each of the three oxidants above, what anions have been embedded into polypyrrole as counter-ions?
For the first reaction, the anion is NO_3^{2-}. For the second and the third reactions is SO_4^{2-}.

USING AN ELECTRICALLY CONDUCTIVE FABRIC
(for the teacher)

Objective: Evaluate the electrical properties of a polypyrrole-coated fabric

Introduction:
Conjugated structure and positive charges make polypyrrole able to transport electricity as a voltage is applied. So, the coated fabric has this property. Moreover, the passage of an electric current through a conductor produces heat by Joule heating (or resistive heating). Joule heating is caused by interactions between charge carriers and the atoms of the conductor.

To evaluate electrical property and heating generation of the polypyrrole-coated fabric, an electrical circuit is required.
A parallel probes configuration is suggested. The scheme of the basic electrical circuit is reported in the following. It consists of a 9V battery, an ammeter and 12-16 crocodile clips.

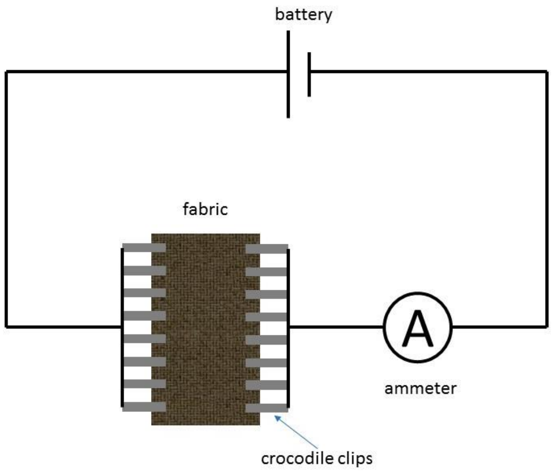


Figure 1. *Scheme of the electrical circuit*

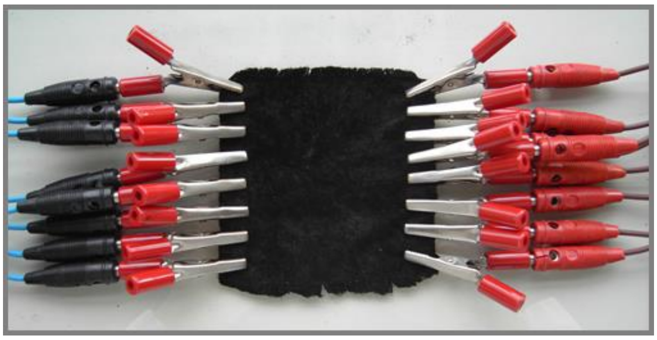
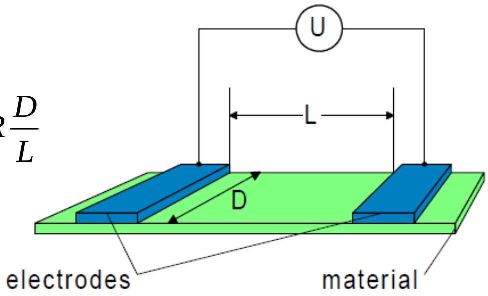


Figure 2. *Picture of the electrical connections of the fabric by crocodile clips*

The ohm law ($V = RI$) is used to calculate the electrical resistance (R) of the fabric by measuring the current (I) flowing through the fabric. If a 9V battery is used, the voltage (V) is 9 V.
As resistance depends on the sizes of the fabric, <u>surface resistivity</u> (ρ_s) is usually calculated by the following equation:

$$\rho_s(\Omega/\text{square}) = R\frac{D}{L}$$



were:
D is the width of the fabric
L is the sample length (distance between electrodes)

ρ_s is often expressed as Ω/square (or Ω/sq. or Ω/□) to differentiate surface resistivity and resistance. Actually, "square" (or "sq." or "□") is not a unit, for instance it means "cm/cm".

As the current flows through the fabric, its temperature increases by Joule heating. Heating could be measured by a thermometer (suggested an infrared thermometer) or a thermal imaging camera. An example of a picture shoot by a thermal imaging camera is reported in the following.

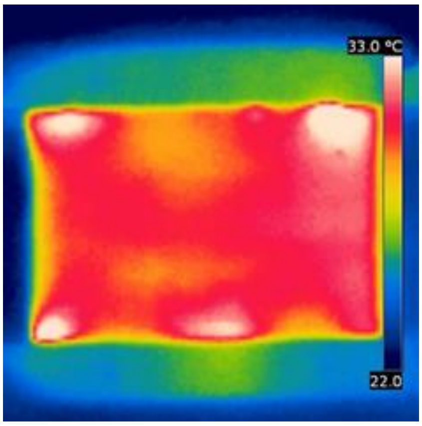


Figure 3. *Picture by a thermal imaging camera of a polypyrrole-coated fabric during electrical tests*

Instead of a 9V battery, at CNR-ISMAC, an electrical generator is used in order to change voltages.

Materials required:

- 9V battery
- Ammeter (*suitable to measure ~250 mA*)
- 12-16 crocodile clips
- Electric wires
- Thermometer (*suggested infrared thermometer; if a bulb thermometer is used, be sure that it is sensitive enough to measure temperature just above room temperature*)

Procedure:
Cut the fabric about 4 x 8 cm (if larger).

Connect the fabric to the (open) electrical circuit by means of the crocodile clips. About one clip each cm for each side (see Figure 2, as example). Pay attention to avoid short circuit not to discharge battery.
Measure the temperature (at time 0).
If a bulb thermometer is used, be sure that the bulb has a good contact with the fabric.
Connect the battery to the circuit (close the circuit).
Measure current and temperature after 10-30 seconds until a steady state is reached.
The expected conditions at 9V are: current 150-200 mA (depending on the weight of the fabric) and temperature 28 °C (initial temperature of 24 °C).

Results:

Measurements of current and temperature. *Note when the fabric reach steady conditions*

Discussion:

• Calculate the resistance and surface resistivity of the fabric.
Use the equation above reported with values of voltage, current, width and length.
• Theoretically, what happens to surface resistivity connecting the fabric along the short sides (4 cm) instead the longer ones?
In theory, surface resistivity should be constant. Actually, it will be not constant because resistance is also temperature-dependent (as L increases, current decreases and, in turns, temperature decreases, too).