Universidad Politécnica de Cartagena

Development of self-sensing systems comprising polymeric artificial muscles

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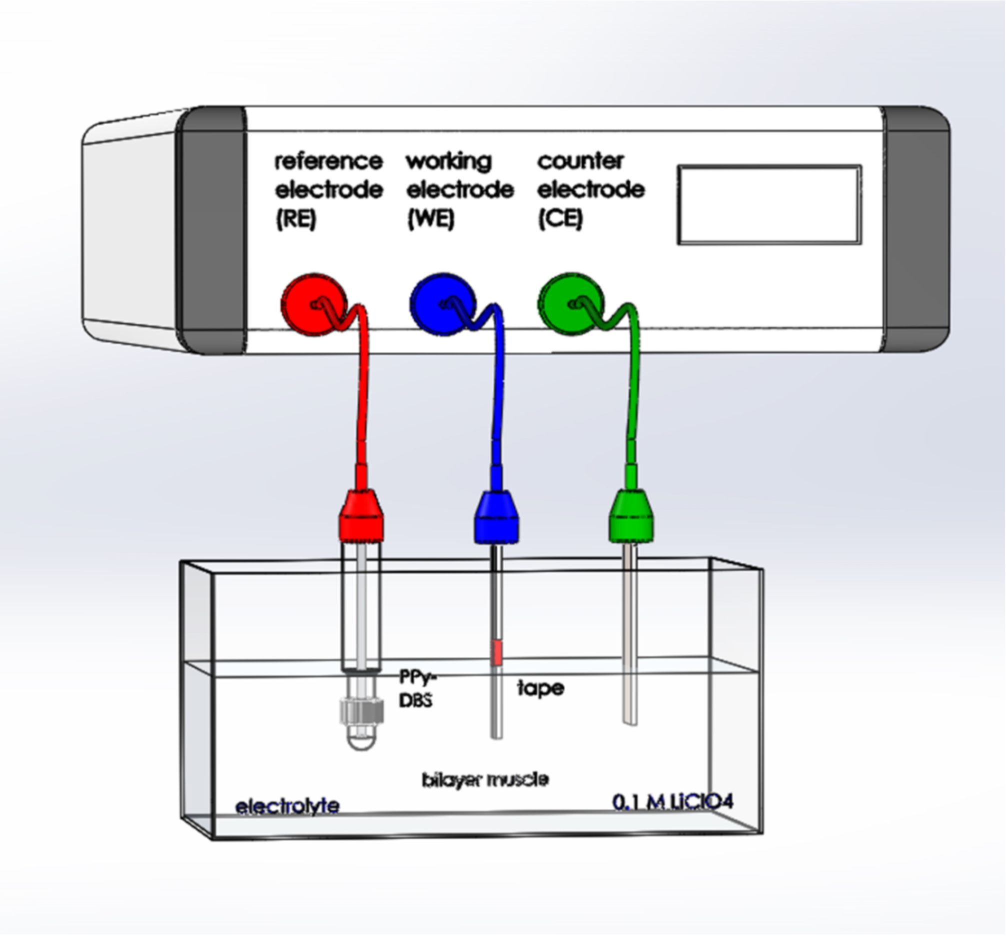
Outline

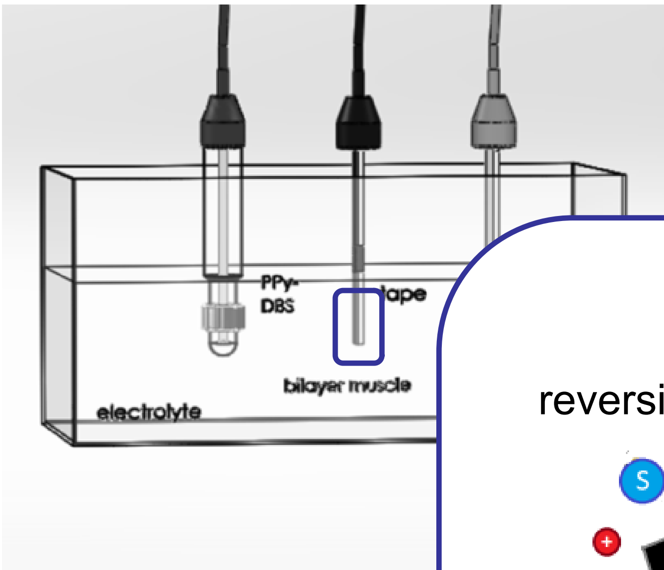
1. Polymeric artificial muscles
2. Self-sensing artifical muscles
3. Motivation
4. Objectives
5. Working Plan
6. Training
7. Communication
8. Publication

Electrochemical motors based on conducting polymers



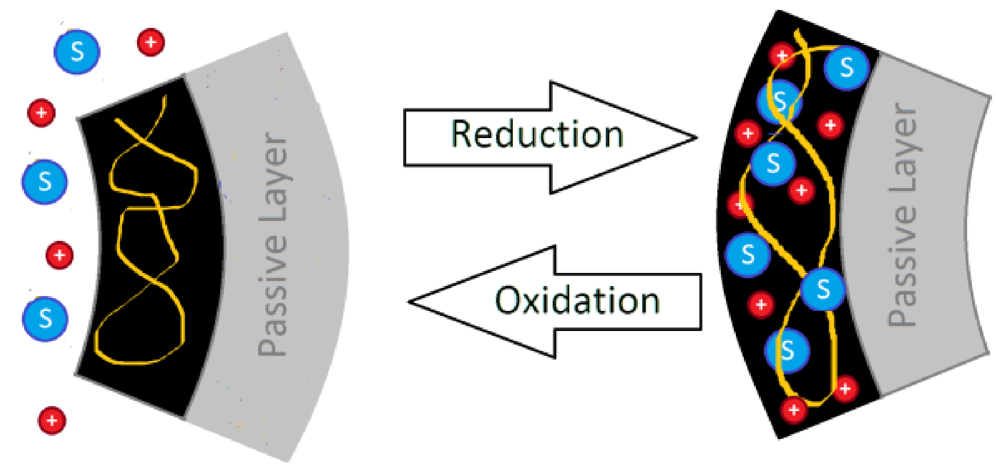
1. Polymeric artifical muscles

Electrochemical motors based on conducting polymers are **actuators.**



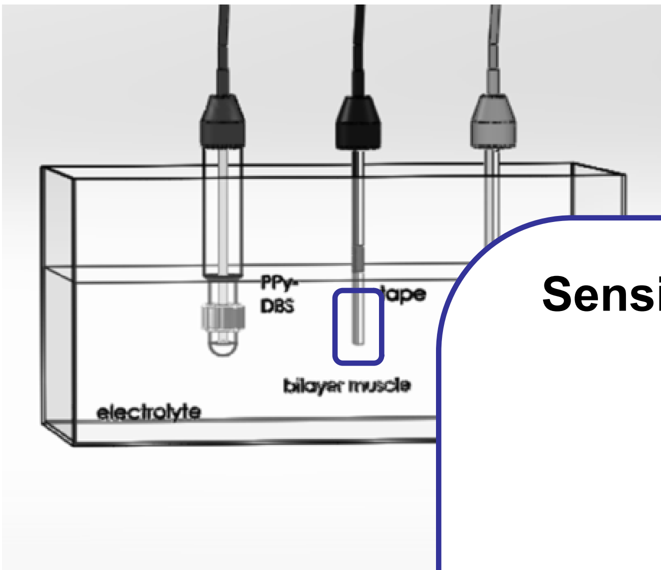
Actuation

reversible volume changes driven by redox reaction

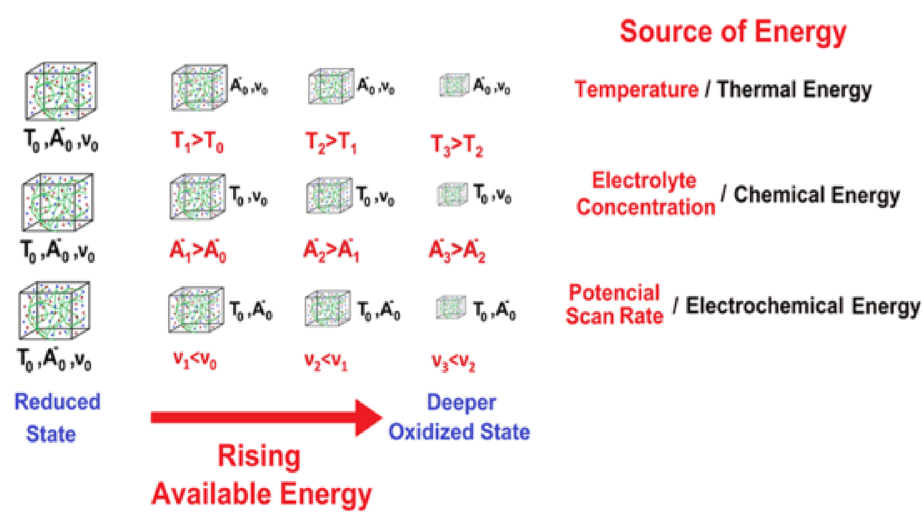


$$[(Pol^{n+})(MA^-)_n]_s + n(C^+)_{aq} + m\ (Solv) + n(e^-)_{metal} \leftrightarrow (Pol)_s + n(A^-)_{aq} + m(Solv)$$

Electrochemical motors based on conducting polymers are **sensors**.

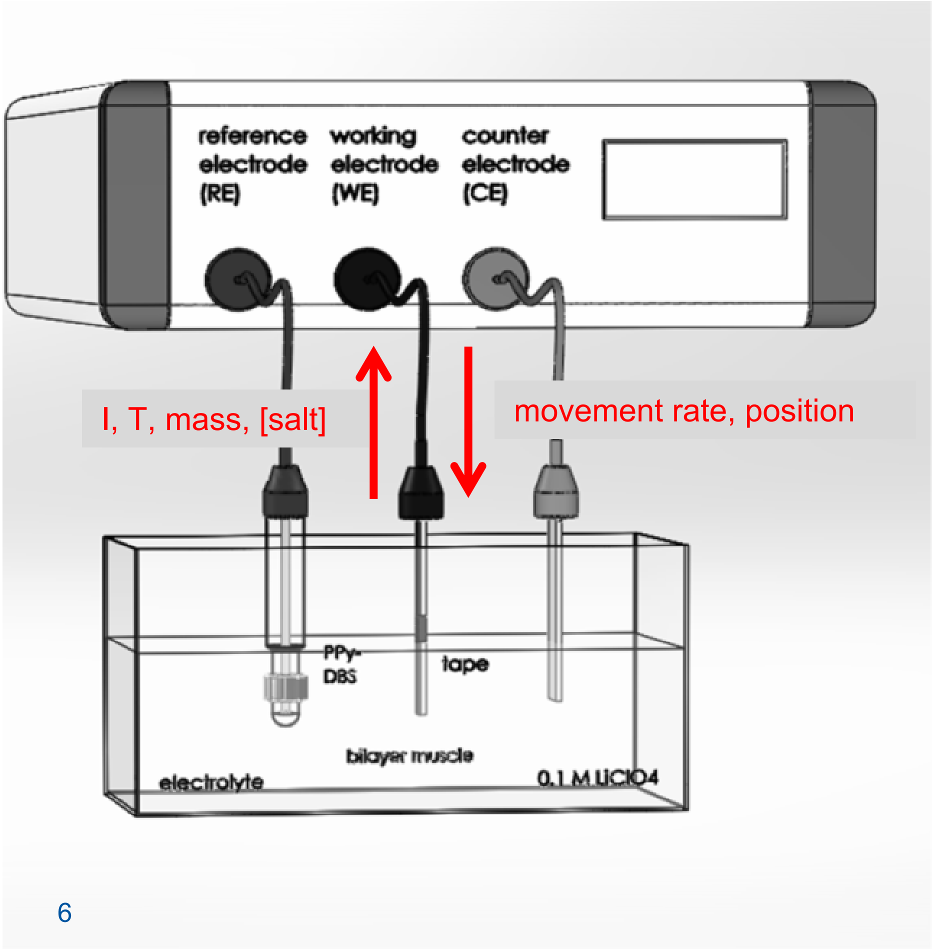


Sensing electrochemical working conditions



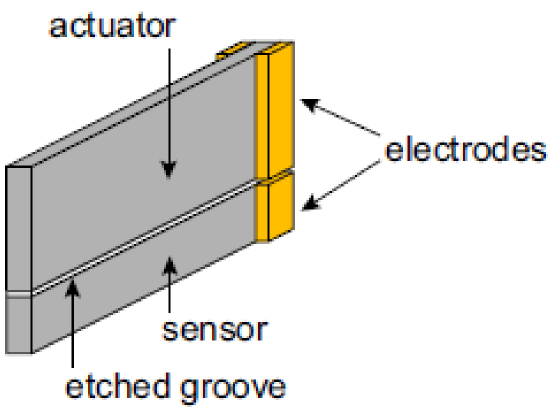
$$[(Pol^{n+})(MA^-)_n]_s + n(C^+)_{aq} + m\,(Solv) + n(e^-)_{metal} \leftrightarrow (Pol)_s + n(A^-)_{aq} + m(Solv)$$

Electrochemical motors based on conducting polymers are **self-sensing artificial muscles**.



Electromechanical actuators

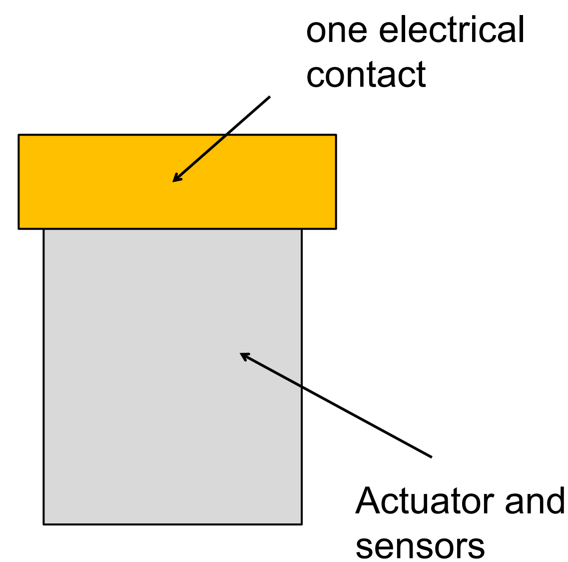
Partial separation of actuation and sensing region



John, S. W., Alici, G., & Cook, C. D. (2009, July). Towards the position control of conducting polymer trilayer bending actuators with integrated feedback sensor. In *Advanced Intelligent Mechatronics, 2009. AIM 2009. IEEE/ASME International Conference on* (pp. 65-70). IEEE.

Electro-chemo-mechanical actuators

Simultaneous sensing and actuation

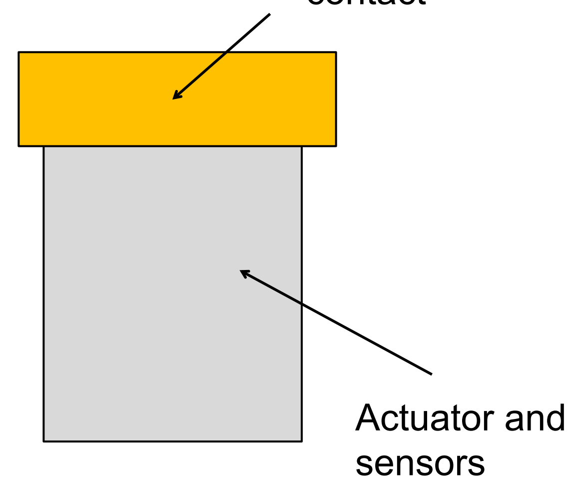


Otero, T. F., "Biomimetic conducting polymers: synthesis, materials, properties, functions, and devices," Polym. Rev. **53**(3), 311–351 (2013).

Only reactions originate dual sensing-actuation functions

Electro-chemo-mechanical actuators

Simultaneous sensing and actuation

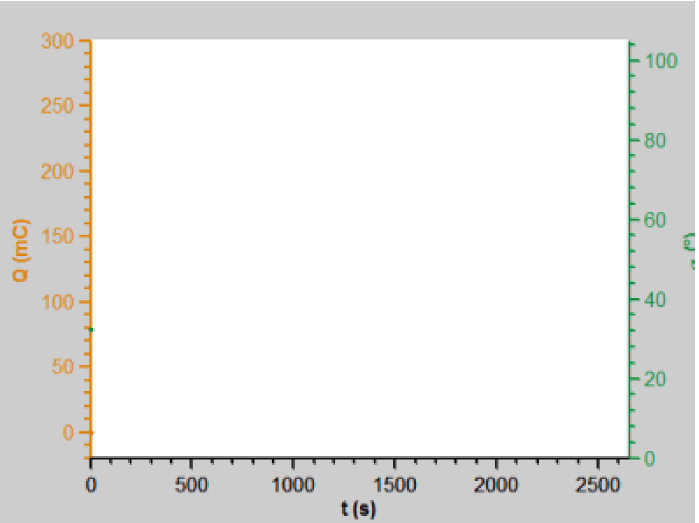


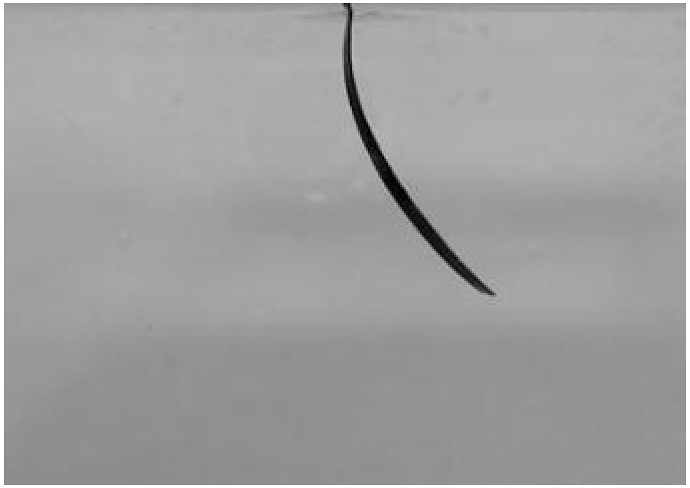
Otero, T. F., “Biomimetic conducting polymers: synthesis, materials, properties, functions, and devices,” Polym. Rev. **53**(3), 311–351 (2013).

The driving electrochemical reaction allows the faradaic movement rate and position control

$$\omega(t) = k \cdot i(t)$$

$$\alpha(t) = k \cdot I \cdot t = k \cdot Q(t)$$



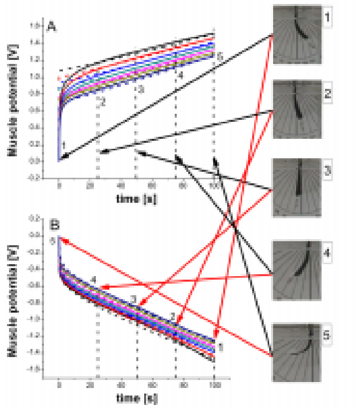


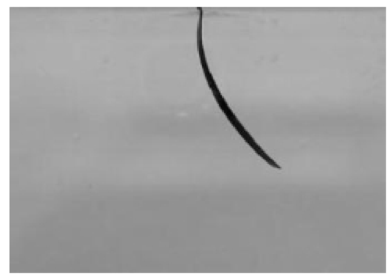
Otero, T. F.., Cortes, M. T., "Artificial muscle: movement and position control," Chem. Commun.(3), 284–285 (2004).
Otero, T. F., Conducting Polymers, The Royal Society of Chemistry (2016).

2. Self-sensing artificial muscles

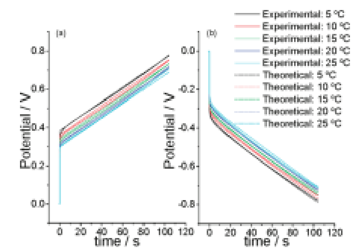
Self-awareness of the energetic working conditions during actuation

Trailed mass

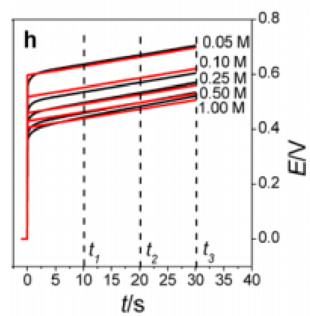




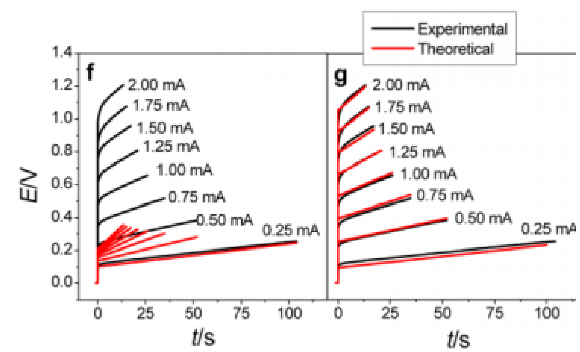
Temperature



electrolyte concentration



Driving current



Otero, T. F., Sanchez, J. J.., Martinez, J. G., Biomimetic dual sensing-actuators based on conducting polymers. Galvanostatic theoretical model for actuators sensing temperature,J. Phys. Chem. B 116(17), 5279–5290 (2012).
Martinez, J. G.., Otero, T. F., Biomimetic dual sensing-actuators: theoretical description. Sensing electrolyte concentration and driving current, J. Phys. Chem. B 116(30), 9223–9230 (2012).
Martinez, J. G.., Otero, T. F., Mechanical awareness from sensing artificial muscles: Experiments and modeling,Sens. Actuators B Chem. 195, 365–372 (2014).

2. Self-sensing artificial muscles

From the Butler-Volmer basic equation of the Electrochemical Kinetics, the evolution of the muscle potential during the movement, driven by a constant current, gives the **sensing-actuating dual Equation**.

$$E(t) = E_0 + \underbrace{i_a Z}_{\text{Current Sensor}} - \underbrace{\frac{\Delta PV}{(1-\alpha)nF}}_{\text{Mechanical Sensor}} + \underbrace{\frac{RT}{(1-\alpha)nF}}_{\text{Thermal Sensor}} \left(\ln\left(\overbrace{\frac{\omega}{KFV}}^{\text{movement rate } \omega} \right) - \underbrace{a \ln[A^-]}_{\text{Chemical Sensor}} - b \ln\left([Pol^*]_{initial} - \overbrace{\frac{\alpha}{KFV}}^{\text{Angle } \alpha} \right) - \ln k_0 \right)$$

Otero, T.F., Martinez, J.G., 2015. Physical and chemical awareness from sensing polymeric artificial muscles. Experiments and modeling. Prog. Polym. Sci. 44, 62–78. doi:10.1016/j.progpolymsci.2014.09.002

- Development of biomimetic devices (Replication of haptic muscles)
- Reduction of complexity, the size and the control effort of nowadays technology
- Self-awareness can enable closed loop control for soft self-sensing actuators without external sensors

- Investigation of novel materials for self-sensing artificial muscles
- Implementation of self-sensing model for controlling self-sensing systems
- Development of a proof of concept for industrial applications
- Demonstration of the potential of dual sensing-actuating polymeric artificial muscles for future technology

1st year

- State of the art of the field
- Material synthesis and characterization
- Fabrication and testing of proprioceptive motors under different experimental conditions
- Writing manuscripts for publications

2nd year

- Choice of a material to develop a control system
- Improvement of the theoretical model for artificial proprioception
- Development of control system for dual sensing and actuation devices
- Writing manuscripts for publications

3rd year

- Design and fabrication of demonstrator for functional device for industrial applications comprising sensing and actuation properties as proof-of-concept
- Writing and presentation of the thesis

"MICACT Training School on Dielectric Elastomer Transducers". École Polytechnique Fédérale de Lausanne(Switzerland) 8th,9th&10th September 2015 (30 hours)

"MICACT Training School on Modelling and Ionic EAPs". University of Tartu (Estonia) 25th-29th January 2016 (35 hours)

"MICACT Training School on Microapplications". Linköping University (Sweden) 16th-20th January 2017 (35 hours)

VI International Conference on Electrochemically Active Polymer (EAP) transducers and artificial muscles 2016

XXXVII Reunión del Grupo de Electroquímica de la Real Sociedad Española de Química. 2016

SPIE, Electroactive Polymer Actuators and Devices (EAPAD) 2017

EuroEAP 2017, 7th international conference on Electromechanically Active Polymer (EAP) transducers & artificial muscles

Otero, T. F., Schumacher, J., & Pascual, V. H. (2016). Construction and coulodynamic characterization of PPy-DBS-MWCNT/tape bilayer artificial muscles. RSC Advances,6(72), 68538-68544

Otero, T. F., & Schumacher, J. (2016). Electrochemical synthesis and characterization of self-supported polypyrrole -DBS-MWCNT electrodes. Journal of Electroanalytical Chemistry, 782, 182-191.

Otero, T. F., Martinez - Soria, L. X., Schumacher, J., Valero, L., & Pascual, V. H. (2017). Self - Supported Polypyrrole/Polyvinylsulfate Films: Electrochemical Synthesis, Characterization, and Sensing Properties of Their Redox Reactions. ChemistryOpen.

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