Supporting Information

Design of an Extended Experiment with Electrical Double Layer Capacitors: Electrochemical Energy Storage Devices in Green Chemistry

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Associate Content

1 Teaching plan

1.1 Teaching Aims

1.1.1 Knowledge & skills

(i) Understanding the working principle, assembly, and factors affecting the performance of supercapacitors, based on electrochemical experiments.

(ii) Forming a complete concept of supercapacitors, understanding the conditions required for fabricating a supercapacitor, and examining the effects of different electrolytes on supercapacitor performance.

1.1.2 Process & steps

(i) Further understanding of the significance of inquiry, learning basic methods of scientific inquiry, and enhancing scientific inquiry capabilities through experimental exploration of energy storage devices.

(ii) Planning, reflecting, evaluating, and controlling the learning process of exploring concepts related to supercapacitors and their fabrication conditions, to improve the ability to develop chemistry skills independently.

(iii) Playing the role of a supervisor and assistant and leaving the initiative of learning to the students in the course to allow the students to understand that chemistry is based on experiments and collaborative exploration activities.

1.1.3 Emotional attitude & values

(i) Developing interest in chemistry and exposing students to energy storage devices, letting them experience the hardships and joys of scientific inquiry and feel the wonders and harmony of the world of chemistry.

(ii) Appreciating the contribution of chemical science to the students' personal life and social development, bringing attention to energy problems and possible solutions, and gradually forming the correct view of energy.

(iii) Cultivating green chemistry literacy of students through understanding, practice, and forming green feelings during the energy experiments.

1.2 Main & Difficult Points

(i) Working principle and performance test of the double-layer capacitor.

(ii) Drawing of test data into graphs using the drawing software and analyzing the images

(iii) Calculating specific capacitance.

(iv) Cultivation of the scientific method.

1.3 Teaching Method

Teaching, writing, and presentation.

1.4 Teaching Procedures

The teaching process can be divided into three parts: before class, during class, and after class. Uploading learning plans and related videos on the teaching platform for students to watch before class is essential. A total of 4 academic hours are required for the laboratory (during class), as shown in Table S1. Students should complete the experiment report after class. The contents of the experimental report include the purpose of the experiment, basic principle(s) of the experiment, content of the experiment, equipment and materials, analysis of experimental results, and problems and suggestions for the experiment.

Table S1 Teaching Arrangements in the Laboratory

Teaching link	Contents of Teaching
Explanation (30 min)	(i) Asking students about the preparatory content: working principle, assembly, and testing methods of the supercapacitor as well as the advantages and disadvantages of the three electrolytes used in the supercapacitor. (ii) Emphasizing the assembly and testing methods.
Package (30 min)	Each group is required to assemble three types of buckle capacitors, which are bilayer capacitors with KOH, Li_2SO_4, and $LiPF_6$ electrolytes. The two capacitors using aqueous systems can be assembled faster, and the capacitors using the organic electrolyte must be completed in the glove box, which takes a long time. The operation of the glove box will be demonstrated

	to the students by the experimental assistant.
Test (150 min)	Cyclic voltammetry and constant current charge-discharge tests are to be conducted at the electrochemical workstation. The scanning voltage gradient of 5, 10, 20, 30, 40, and 50 mV/s was measured by cyclic voltammetry. Contents of constant current charge-discharge test: drawing the graph of the constant current charge and discharge according to the experimental data after 3 cycles with current densities of 0.5, 1, 2, 3, and 4 A/g and the specific capacitance is calculated according to the constant current charge-discharge curve.

1.5 Teaching Evaluation

The standards of evaluation of this experiment are listed in Table S2.

Table S2 Evaluation standards

<table>
<tr><td>Experiment Name</td><td colspan="4">Assembly and performance testing of a double layer supercapacitor</td></tr>
<tr><td rowspan="2">Evaluating Indicator</td><td colspan="4">Evaluation standard description（Total score: 100 points）</td></tr>
<tr><td>Excellent
(90-100)</td><td>Good
(80-90)</td><td>Pass
(60-80)</td><td>Need to Improve<60</td></tr>
<tr><td>Preparation
(20 Points)</td><td colspan="4">Experimental purpose
Experimental principle (basic principles, main concepts, laws for experimental testing, important formulas, etc.)
Experimental reagents and instruments (main instruments and chemical reagents)
Main points of experimental operation
Precautions (caused damage to the instrument, commonly encountered dangers, and operations that have a significant influence on the experimental results)</td></tr>
<tr><td>Operation</td><td colspan="4">Very familiar with the experimental principles, very skilled</td></tr>
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(50 Points)	experiment operation, and lighting the diode (40-50 points)
	Familiar with the experimental principles, skilled experiment operation, lighting the diode (30-40 points)
	Familiar with the basic experimental principles, able to perform basic experimental operations, lighting the diode (20-30 points)
	Unfamiliar with experimental principles, unable to perform experimental operations (0-20 points)
Data Processing (20 Points)	Draw CV and GCD graphs, fully analyze the graph, calculate the specific capacitance, and complete the experimental report. (15-20 points)
	Draw CV and GCD graphs, simply analyze the graph, calculate the specific capacitance, and complete the experimental report. (10-15 points)
	Draw CV and GCD graphs, calculate the specific capacitance, and complete the experimental report. (5-10 points)
	Draw CV and GCD graphs without calculating the specific capacitance and complete the experimental report. (0-5 points)
Awareness of Safety and Environmental Protection (10 Points)	A strong awareness of safe operation and environmental protection and good awareness of green chemistry was demonstrated (8-10 points)
	A certain awareness of safe operation and environmental protection and good awareness of green chemistry was demonstrated (5-8 points)
	No safety operation or environmental awareness was demonstrated (0-5 points)
Remarks	
Summary	

2 Learning Plan

2.1 Purpose

1.1 Comprehend the working principles of electric double layer capacitors (EDLCs);

1.2 Learn how to assemble an EDLC;

1.3 Understand the testing methods for EDLC performance;

1.4 Become familiar with the effects of the KOH, Li_2SO_4, and $LiPF_6$ electrolytes on EDLC performance.

2.2 Theory

2.2.1 Electric Double Layer Capacitor

Supercapacitors are electrical energy storage devices with high specific power and specific energy, which act as intermediates between capacitors and batteries as part of a larger apparatus. They fall into two categories, electrical double layer capacitors (EDLCs) and faradaic pseudocapacitors.

The polarization process consists of transfer polarization and Ohmic resistance polarization. When applying the electric field, the anions and cations in the solution migrate toward the positive and negative electrodes, respectively, and form a double layer on the surface of the wire. After the electric field is moved, the positive and negative charges on the electrode attract the oppositely charged ions in solution, which maintains the stability of the double electrical layer and a constant potential difference is generated. When connected to an external circuit, the charge on the electrodes migrates to create a current, while the ions migrate into the solution and become electrically neutral.

2.2.2 Electrolyte

Supercapacitor electrolytes are classified into aqueous electrolytes, organic electrolytes, and ionic electrolytes. Aqueous electrolytes include acidic, alkaline, and neutral electrolytes, and are widely used in supercapacitors due to their high electrical conductivity, ability to fully infiltrate the electrode pores, and low cost. Organic electrolytes generally exhibit high decomposition voltage, weak corrosion, and a wide operating temperature range. Common organic electrolytes include acetonitrile and lithium hexafluorophosphate. Ionic electrolytes with non-flow properties, low conductivity, and large internal resistance require special preparation conditions but result in an excellent performance of the supercapacitor.

The electrolytes used in this experiment were potassium hydroxide (KOH), lithium sulfate (Li_2SO_4), and lithium hexafluorophosphate ($LiPF_6$) to investigate the effect of different electrolytes on EDLC performance.

2.3 Materials and Apparatus

2.3.1 Materials

Activated carbon, Cr2032 coin cell case, spacer disk (16.2mm×0.8mm), wave washer (15.4mm×1.2mm), Celgard separator, tweezer, pipette, electric wire, clip connector, light emitting diode, 6.0 mol/L KOH, 1.0 mol/L Li_2SO_4, and 1.0 mol/L $LiPF_6$.

2.3.2 Apparatus

Punching machine (SY-160, Shenzhen Yongxingye Precision Machinery Mould Co., Ltd, China), sealing machine (SZ-50-10, Shenzhen Yongxingye Precision Machinery Mould Co., Ltd, China) for coin cell crimping, glove box (Etelux Lab 2000, Etelux Inertgas-System (Beijing) Co., Ltd., China), and electrochemical workstation (CHI760E, CH Instruments, Inc., USA).

2.4 Procedure

2.4.1 Assemble the EDLC

Figure 1b shows the EDLC assembly sequence. The sequence is negative electrode shell, shrapnel, gasket, electrode, separator, electrode, gasket, and positive electrode shell. The samples must undergo sealing with a sealing machine after assembly, and the capacitor should be placed in the center of the carrier tablet.

2.4.2 Performance Test

The electrochemical performance of the EDLC was tested using cyclic voltammetry (CV), and galvanostatic charge-discharge (GCD) using a CHI760E electrochemical workstation. CV can rapidly provide a diverse range of information, including the reversibility and mechanism of the electrode reactions and adsorption of the electrochemical material. The scanning voltage gradient was 5, 10, 20, 30, 40, and 50 mV/s and was measured by CV.

GCD is another essential method for investigating electrode materials via specific capacitance and cycle performance. Analysis of the capacitance via charge-discharge curves and calculation of the specific capacitance of the electrode material based on the continuous current discharge curve and Eq. (1) was performed:

$$C_m = \frac{4It}{m \cdot \Delta\bar{V}} \tag{1}$$

Where m is the weight of the electrode material in the electrode layer (g), I is the constant current value (A), t is the discharge time (s), and is the average voltage drop of the discharge curve (V).

$\Delta\bar{V}$ was calculated using available discharge curve points as follows :

$$\Delta\bar{V} = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} V dt \tag{2}$$

Where t_1 is the discharge start time and t_2 is the time of discharge termination (s).

The contents of the constant GCD test: drawing the graph of the constant current charge and discharge according to the experimental data after 3 cycles with current densities of 0.5, 1, 2, 3, and 4 A/g and the specific capacitance was calculated according to the constant current charge-discharge curve.

2.4.3 Lighting the Diode

The fabricated EDLC was placed in the electrochemical workstation for charging. The diode was connected to the EDLCs with different electrolytes, and the diode brightness was observed and recorded.

2.5 Matters Requiring Attention

First, the electrolyte must be added to the gap between the separator and gasket. The edge of the spacer is prone to roll up when it meets the electrolyte, so tweezers are required to smooth the separator. The battery center of the two electrodes should then be closed with the tweezers and carefully controlled to prevent the separator from breaking during this process.

2.6 Questions

(i) List some differences between the working principles of EDLCs and batteries.

(ii) Why are the EDLCs with organic electrolytes isolated from the air when they are assembled?

2.7 Experimental Report Requirements

Experimental report must include purpose, principles, materials, process, results and discussion, questions and suggestions.