

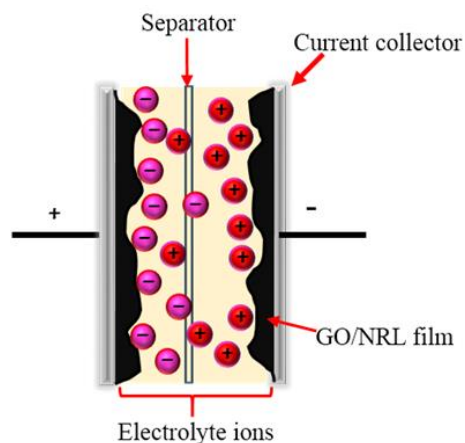


UNIVERSITI
PENDIDIKAN
SULTAN IDRIS
اونڤوسيتي قنڤديدين سلطان ادريس

SULTAN IDRIS EDUCATION UNIVERSITY

TEACHING INOVASION:

**CUSTOM MADE *SUPERCAPACITOR*
(Home Made Battery)
AS TEACHING AID FOR
ELECTROMAGNETISM - SFT3013**



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1. Introduction

Basically, supercapacitors or electrochemical double-layer capacitor (EDLC) applications play a role as a storage energy device with a low rate of energy density. In contrast, batteries have higher capacity of energy storage with a low rate of power density. The high porosity of carbon easily grabs the ion transfer in the devices. Carbon allotropes such as carbon nanotubes (CNTs), carbon black and graphene (GE) are chosen due to exceptional electrical and mechanical properties and unique structures. However, the high cost of CNTs and low performance of active carbon has introduced GE to this application. The Ragone plot in Figure 1 illustrates the typical energy and power densities of portable energy storage devices consumption nowadays [1].

Now, GE is seen to have a wide potential in supercapacitor applications where previous studies have shown the best electrode come from carbon family. According to the Simon P, et al. [2] groups of carbon, metal oxides, and conducting polymer are the fundamental electrode for supercapacitor applications. This is because carbon-based materials have the advantages of possessing extremely high conductivity, electrochemical stability, and high surface area with high porosity percentage [3] (see Figure 2).

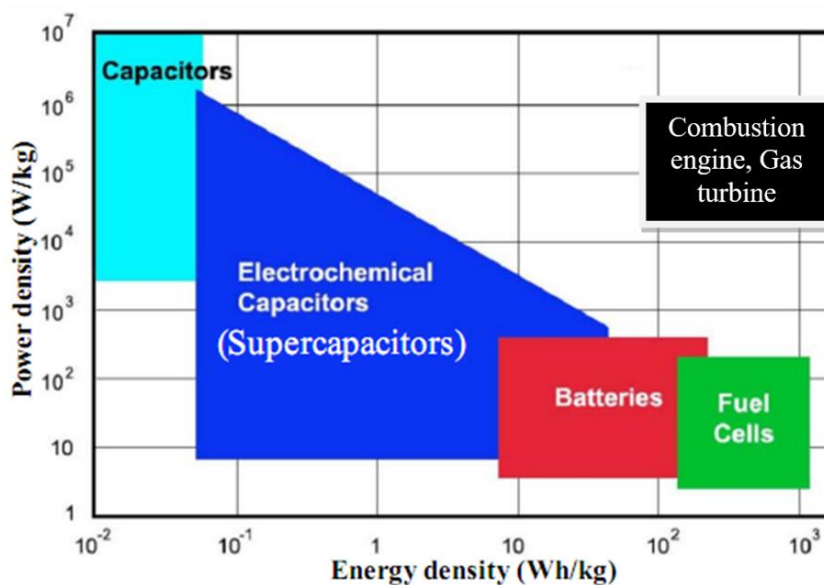


Figure 1. Ragone plot illustrating typical energy and power densities of portable energy storage devices [1].

The use of GE-based materials as an electrode material was first reported by Vivekchand and his co-workers. They found that by introducing functionalized GE sheets in the EDLC system, the value of capacitance can be achieved similar to activated carbons. Stoller et al. [4] have proved that the capacitance is nearly constant over a large range of scan rates in aqueous electrolyte system.

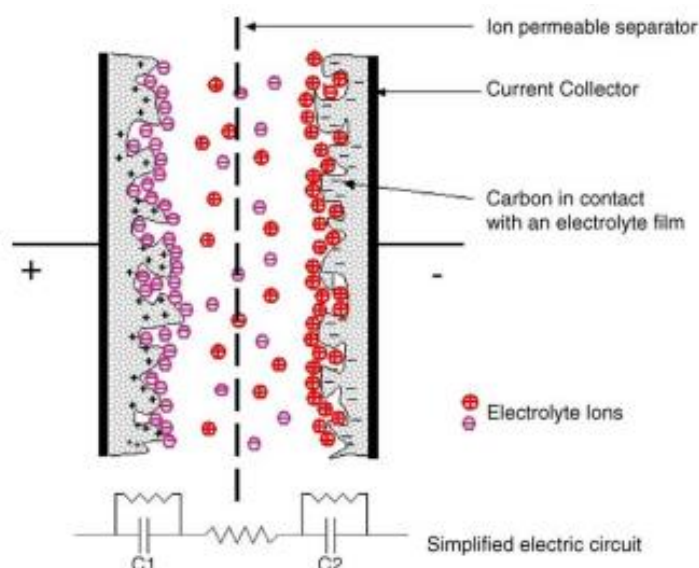


Figure 2. A diagram of a symmetric EDLC in charged and discharged states [5].

As CNTs and GE have good properties in terms of high surface area, Fan et al. [6] sparked ideas in his research to produce a CNTs and GE layer sandwich in the use of a supercapacitor through CVD process. In this method, the CNTs/GE sandwich is further used in supercapacitor as an electrode with an extremely high specific capacitance of 385 F g^{-1} at a scan rate of 10 mV s^{-1} in KOH aqueous solution. In addition, Chen J, et al. [7] also reported the combination between GE and CNTs in b-PEDOT polymer to form hybrid nanocomposite. Through this work, the nanocomposite possessed a high specific capacitance of 225 F g^{-1} as compared to the individual b-PEDOT, multi walled CNTs and rGO, where the improved capacitive performances of nanocomposite obtained was mainly contributed to from high surface area of the GE structure itself.

The combination of GE-based materials with conducting polymers has also lead to evolution in capacitance enhancement. As reported by Luo Z, et al. [8] improved capacitive properties (797 F g^{-1}) are presented by GO/PANI nanocomposite. The

results show that well-arranged PANI nanoparticles and GO sheets have mainly contributed to the improvement of charge transport in the composites. However, PANI shows poor stability during the charge/discharge process. Moreover, polypyrrole (Ppy) as another conducting polymer also contributed to the increase in specific capacitance about 633 F g^{-1} when incorporated the small amount of GO nanosheets [9]. In that work, they have used facile chemical method to grow Ppy on layered GO, resulting a good electrochemical stability. In recent, the high conductivity of GE/PPy nanocomposite was supported by Zuo X et al. [10] where they found the higher capacitance value up to $\sim 310 \text{ F g}^{-1}$. However, these conducting polymers had similar drawbacks which were low cycling stability where the structures were easily being destroyed during redox processes [11].

GE-based materials always show re-stacking properties when forming an agglomeration structures. Due to the inaccessible site for ions diffusion in restacking agglomerate GO, the use of so-called non-functionalization of surfactants were demonstrated to encounter the excess agglomerated sheets in the nanocomposite electrode materials. With the addition of surfactants for stabilizing GO or rGO sheets during fabrication process in the nanocomposite, researchers have found the effective SDBS as stabilized agent in the nanocomposite which performed the highest stability using C-V measurement [12]. Yuan K et al. (2015) also demonstrated the higher specific capacitance of 690 F g^{-1} in the presence of SDBS-stabilized GE with PANI as electrodes materials in supercapacitor. In addition, Jothi PR et al. [13] obtained 1312 F g^{-1} of capacitance performance by applying pluronic P123 in the hybridization between rGO and nanoporous nickel sulphide.

They reported three main factors which contribute to the high capacitance performance, including:

- (i) high porous structure of material,
- (ii) uniform surface coating and
- (iii) reduced stacking effects of of the materials (rGO sheets).

Thus, it is crucial to properly select the interfacial interaction molecule to assist the dispersion of GE-based materials. The surfactant has stabilized GO sheets more in the nanocomposite and thus can increase the effective platform for ion kinetics movements between the electrodes and the electrolyte. Moreover, the tail group at the hydrophobic part of the surfactant was also responsible for the specific capacitance increment. Therefore, the increasing number of tail groups might believe to help and assist carbon group more effective in the NRL polymer then led to improved capacitive behavior.

Instead of using GO, the use of rGO in the nanocomposite has clearly shown an interesting increment of capacitive behavior in the electrochemical supercapacitor due to outstanding properties contained in the GE structure. Previous work by Hu et al. [14] reported the fabrication of GE nanosheets-polystyrene nanocomposite via in situ emulsion polymerization. In addition, the addition of hydrazine as a reducing agent recovered the quality of single layer GE and therefore increased the properties of the nanocomposite (i.e. high electrical conductivity, increase in glass-transition temperature and good thermal stability). As summarized, reduction of GO to form single layer GE has advantages in terms of nanocomposite properties.

Along with these, Jin and their team [15] introduced a green and efficient synthesis route with sodium carbonate (Na_2CO_3) as reducing agent rather than hydrazine, which has a detrimental effect on the environment. From the results, the nanocomposites have shown a high electrical conductivity (10 S m^{-1}) and specific capacitance (228 F g^{-1} at current densities of 5 mA cm^{-2}). Jin Y et al. [16] also reported a green and efficient method to reduce GO by the same reducing agent of Na_2CO_3 for use in electrode materials of supercapacitor. C-V measurement is shown in the typical rectangular curve which indicates the electrodes have good charge propagation. Moreover, the conductivity measured for a thin film of Na_2CO_3 -GE sheets is 10 S m^{-1} , better than the GO without Na_2CO_3 treatment. As mentioned above, the use of green and soft reducing agent gives a significant low conductivity as compared to the reduction of rGO using hydrazine hydrate, also affecting the capacitive behavior. GE-based materials in energy storage have been researched extensively due to their unique properties.

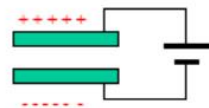
Recently, functionalized GE has extremely used as electrodes for supercapacitor due to its high performances. RGO composites made by functionalized GE nanosheets require an effective surface area for charge-discharge transferring process through electrochemical supercapacitor in order to improve the capacitive behavior. According to the Karthika P et al. [16], a simple chemical method for functionalized exfoliated GO based from exfoliated graphite as a precursor was proposed. Through this method, it shows a specific capacitance of 146 F g^{-1} and energy density of 20 W h kg^{-1} . In addition, they have proven the degree of agglomeration that could be reduced by using this method in producing the mono- or bi-layer of GO sheet. Results also shown that the specific capacitance in aqueous KOH was found to be 135 and 117 F g^{-1} in H_2SO_4 electrolyte [5]. In view of this findings, almost no work reported on the use of GO/NRL polymer nanocomposite as electrode materials for supercapacitor application. Therefore, a study according to the GE-filled NRL as conductive electrode as well as capacitance enhancement should be carried out in order to meet the multifunctional with superb properties of nanocomposite.

THE BASIC CONCEPT OF CAPASITOR, CAPACITANCE, DIAELECTRIC MATERIALS

Capacitance

When a voltage V is applied to two parallel conducting plates, the plates are charged by $+Q$, $-Q$, and an electric field E develops between the plates.

The charge remains on the plates even after the voltage has been removed.



The ability to store charge is called **capacitance** and is defined as a charge Q per applied voltage V :

$$C = Q / V \text{ [Farads]}$$

For a parallel-plate capacitor, C depends on **geometry of plates and material between plates**

$$C = \epsilon_r \epsilon_0 A / L = \epsilon A / L$$

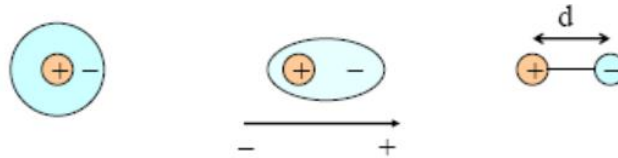
where A is the area of the plates, L is the distance between plates, ϵ is the **permittivity** of the dielectric medium, ϵ_0 is the permittivity of a vacuum (8.85×10^{-12} F/m²), and ϵ_r is **relative permittivity (or dielectric constant) of the material**, $\epsilon_r = \epsilon / \epsilon_0 = C / C_{\text{vac}}$

Dielectric Materials

The dielectric constant of vacuum is 1 and is close to 1 for air and many other gases. But when a piece of a dielectric material is placed between the two plates in capacitor the capacitance can increase significantly.

$$C = \epsilon_r \epsilon_0 A / L \quad \text{with } \epsilon_r = 81 \text{ for water, } 20 \text{ for acetone, } 12 \text{ for silicon, } 3 \text{ for ice, etc.}$$

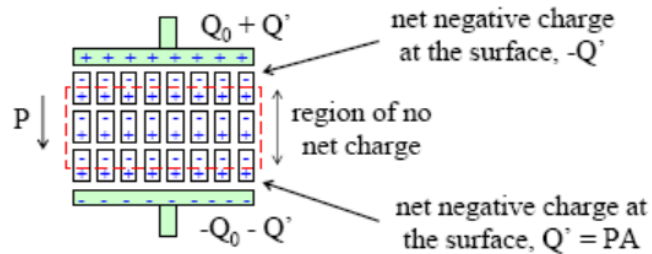
A **dielectric material** is an **insulator** in which **electric dipoles** can be induced by the electric field (or permanent dipoles can exist even without electric field), that is where positive and negative charge are separated on an atomic or molecular level



Magnitude of electric dipole moment is $\mathbf{p} = q \mathbf{d}$

Dielectric Materials

Dipole formation and/or orientation along the external electric field in the capacitor causes a charge redistribution so that the surface nearest to the positive capacitor plate is negatively charged and vice versa.



Dipole formation induces additional charge Q' on plates: total plate charge $Q_t = |Q + Q'|$.

Therefore, $C = Q_t / V$ has increased and dielectric constant of the material $\epsilon_r = C / C_{vac} > 1$

The process of dipole formation/alignment in electric field is called **polarization** and is described by $P = Q' / A$

Dielectric Materials

In the capacitor **surface charge density** (also called **dielectric displacement**) is

$$\mathbf{D} = \mathbf{Q}/\mathbf{A} = \epsilon_r \epsilon_0 \mathbf{E} = \epsilon_0 \mathbf{E} + \mathbf{P}$$

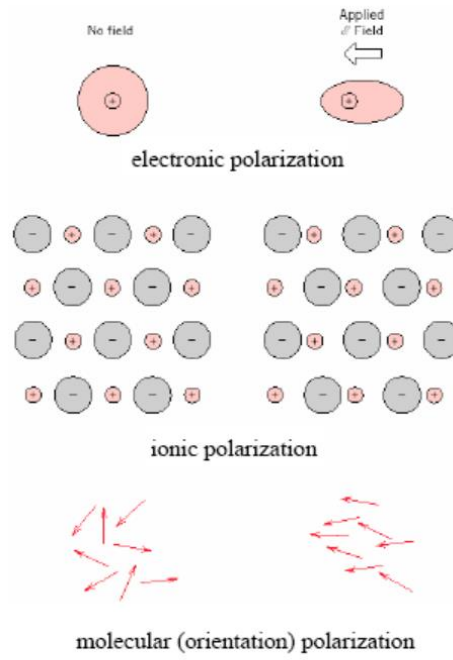
Polarization is responsible for the increase in charge density above that for vacuum

Mechanisms of polarization (dipole formation/orientation)

- **electronic** (induced) polarization: Applied electric field displaces negative electron “clouds” with respect to positive nucleus. Occurs in all materials.
- **ionic** (induced) polarization: In ionic materials, applied electric field displaces cations and anions in opposite directions
- **molecular** (orientation) polarization: Some materials possess **permanent electric dipoles** (e.g. H₂O). In absence of electric field, dipoles are randomly oriented. Applying electric field aligns these dipoles, causing net (large) dipole moment.

$$\mathbf{P}_{\text{total}} = \mathbf{P}_e + \mathbf{P}_i + \mathbf{P}_o$$

Mechanisms of polarization



DIFFERENCE BETWEEN CAPACITORS AND SUPERCAPACITORS

What is the difference between Capacitors and Super-capacitors?

- Super-capacitors have a very high energy density than normal capacitors.
- Super-capacitors use two layers of the dielectric material separated by a very thin insulator surface as the dielectric medium, whereas normal capacitors use only a single layer of dielectric material.
- Normal capacitors are much cheaper than the super-capacitors in general.

(<http://www.differencebetween.com/difference-between-capacitors-and-vs-supercapacitors/>)

Capacitors vs Supercapacitors

Capacitors are very useful components and are widely used in electronic and electrical circuits. Capacitor is a component capable of storing charges and thereby energy. A super-capacitor is a component capable of storing more charges than a normal capacitor. Both of these components have wide applications and are very useful in constructing complex circuits. Capacitors are used in fields such as electrical engineering, electronic engineering, computer designing, energy storage and various other fields. It is very important to have proper knowledge in the theories behind capacitors and super-capacitors in order to excel in such fields. In this article, we are going to discuss what capacitors and super-capacitors are, their applications, how capacitors and super-capacitors are

made, different types of capacitors and super-capacitors, their similarities and finally differences between capacitors and super-capacitors.

Capacitors

Capacitors are components that are used to store charges. Capacitors are also known as condensers. Commercially used capacitors are made of two metal foils rolled into a cylinder with a dielectric medium in between them. The capacitance is the main property of a capacitor. The capacitance of an object is a measurement of the amount of charges that object can hold without discharging. Capacitance is a very important property in both electronics and electromagnetism. Capacitance is also defined as the ability to store energy in an electric field. For a capacitor, which has V voltage difference across the nodes and the maximum amount of charges that can be stored in that system is Q , the capacitance is Q/V , when all are measured in SI units. The unit of the capacitance is farad (F). However, it is inconvenient to use such a large unit. Therefore, most of the capacitance values are measured in nF, pF, μ F and mF ranges. The energy stored in the capacitor is equal to $(QV^2)/2$. This energy is equal to the work done on each and every charge by the system summed up. The capacitance of a system depends on the area of the capacitor plates, the distance between the capacitor plates, and the medium between the capacitor plates. The capacitance of a system can be increased by increasing the area, decreasing the gap or having a medium with higher dielectric permittivity.

Supercapacitors

Electric double layer capacitors or EDLCs are generally known as super-capacitors. Super-capacitors in general have a very high capacitance compared to normal capacitors. The capacitance of a super-capacitor is usually two or three orders of that of a normal capacitor. The main property that matters in a capacitor is the capacitance density or the energy density. This refers to the amount of charges that can be stored per unit mass.

A supercapacitor is also known as an ultracapacitor or a double-layer capacitor. A supercapacitor tends to differ from an ordinary capacitor due to its very high capacitance. These capacitors have very high energy density in comparison to common capacitors. They are quite beneficial for hybrid vehicles. A supercapacitor was developed on a double layer mechanism in 1957. A supercapacitor can be used in the applications where batteries are used. They can be charged and discharged continuously. The main difference that exists between a capacitor and a supercapacitor is that supercapacitors are based on carbon technology. Due to this carbon technology, these capacitors are able to create a very large surface area. This area exists even with an extremely small separation distance. The effective thickness of the “dielectric” in a supercapacitor is exceedingly thin. Due to the porous nature of the carbon, the surface area remains to be extremely high and provides a very high capacitance.

Comparison between Capacitor and Supercapacitor:

	Capacitor	Supercapacitor
Definition	In capacitors, energy is stored in their electric field.	A supercapacitor is also known as ultracapacitor or double-layer capacitor. A supercapacitor tends to differ from an ordinary capacitor due to its very high capacitance.
Energy Density	Comparatively low	Comparatively very high
Dielectric materials	Dielectric material like ceramic, polymer films or aluminum oxide are used for the separation of the electrodes.	Activated carbon is used as a physical barrier between the electrodes so that when an electrical charge is applied to the material a double electric field is generated. This electric field acts like a dielectric.
Cost	Comparatively cheap	Comparatively expensive
Advantages	<ul style="list-style-type: none"> • Less Battery Drain – A car’s battery does 	<ul style="list-style-type: none"> • High energy storage - Compared to conventional

	<p>not deplete due to a capacitor.</p> <ul style="list-style-type: none"> • Powerful stereos-Amplifiers and subwoofers working mechanism is based on the capacitors • Less Damaged equipment – It helps to avoid the excessive drawing of power. 	<p>capacitor technologies, it possesses orders of magnitude higher energy density.</p> <ul style="list-style-type: none"> • Low Equivalent Series Resistance (ESR) - Compared to batteries, they have a low internal resistance. Thus, providing high power density capability. • Fast charge/discharge – they can be charged and discharged without damaging to the parts.
<p>Applications</p>	<ul style="list-style-type: none"> • High Voltage Electrolytic used in power supplies. • Axial Electrolytic; lower voltage smaller size for general purpose where large capacitance values are needed. • High Voltage disk ceramic; small size and capacitance value, excellent tolerance characteristics. • Metalised Polypropylene; small size for values 	<ul style="list-style-type: none"> • CMOS RAM, IC for clocks • CMOS micro computer • Micro computer, RAM • Driving motor • CMOS RAM, IC for clocks • CMOS micro computer, IC for Clocks • Micro computer, RAM • Driving motor • Power source of toys, LED, buzzer • High current supply for a short amount of time

	<p>up to around 2μF good reliability.</p> <ul style="list-style-type: none">• Sub-miniature Multi layer ceramic chip (surface mount) capacitor. Relatively high capacitance for size achieved by multiple layers. Effectively several capacitors in parallel.	
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(<http://www.differencebetween.info/difference-between-capacitor-and-supercapacitor>)

2. HOW TO MAKE YOUR OWN SUPERCAPACITOR

HOW TO MAKE SUPERCAPACITOR (HOME MADE BATTERY)

- A. Synthesis of GO
- B. Physical characterizations of GO:

C. Fabrication of GO: Natural Rubber Latex (NRL) composite via simple one and two step of electrochemical exfoliation Method. Next dry it in the oven for 24 hrs at 60°C. Cut the film into 0.5 x0.5 cm². Place on the aluminum foil as current collector

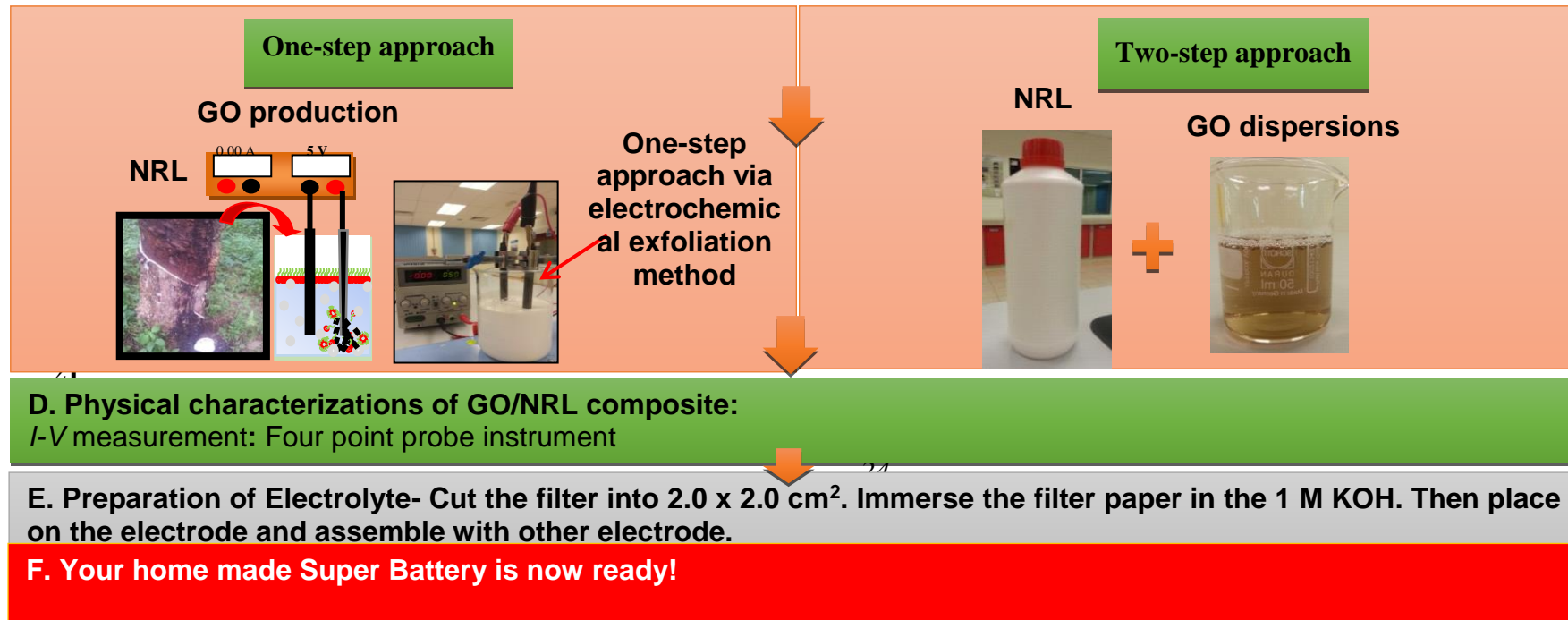


Figure 3. The flow chart of the methodology to build the supercapacitor.

Synthesis of Graphene Oxide (GO) Using Electrochemical Exfoliation

GO is synthesized by electrochemical exfoliation in an electrolyte solution assisted by surfactants. The electrolyte solution was prepared by dissolving surfactant into DI water to obtain 0.1 M concentration. Two graphite rods (Goodfellow, 99.5% purity) is used as electrodes and connected to 7 V potential (DC power supply GW Instek GPS-3030DD) for 24 hours to perform electrochemical exfoliation. Surfactant is intercalated into the graphite interlayer thus exfoliate it which yields graphene sheets. The schematic diagram and experimental procedures to synthesize GO are shown in Figure 4.

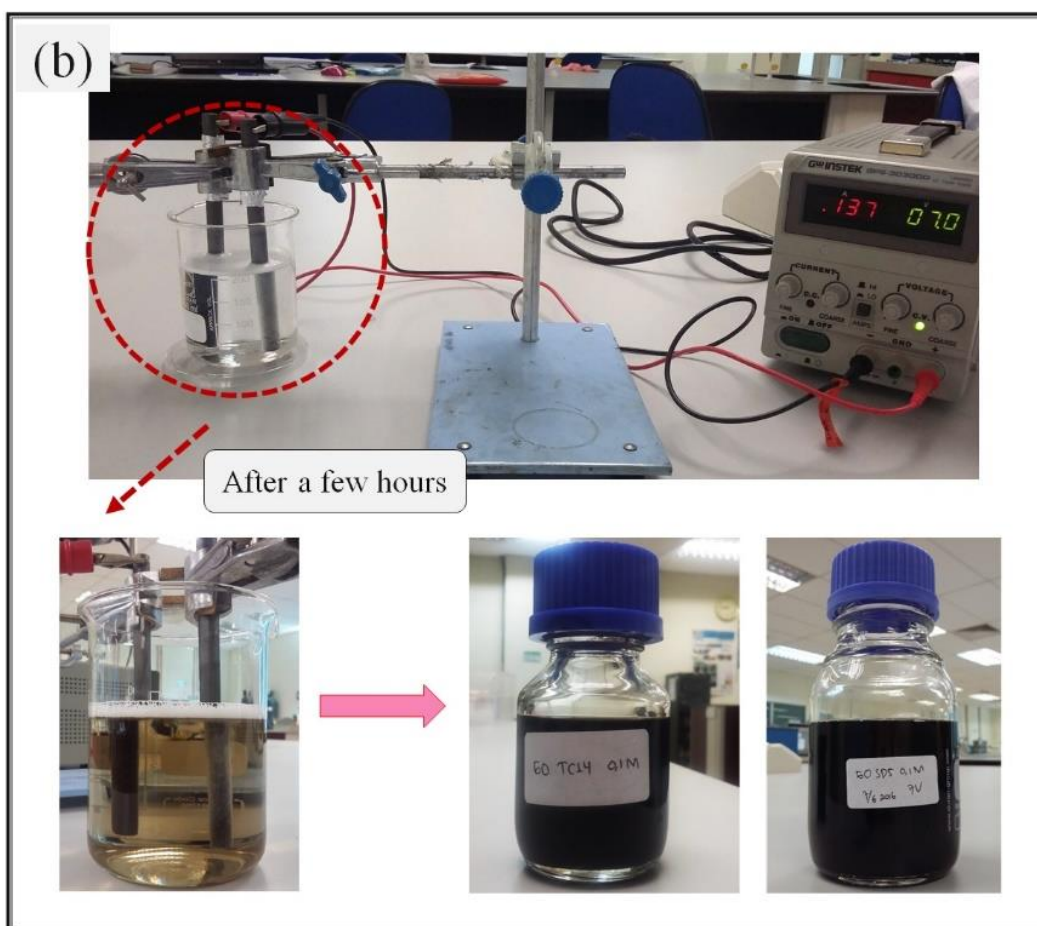
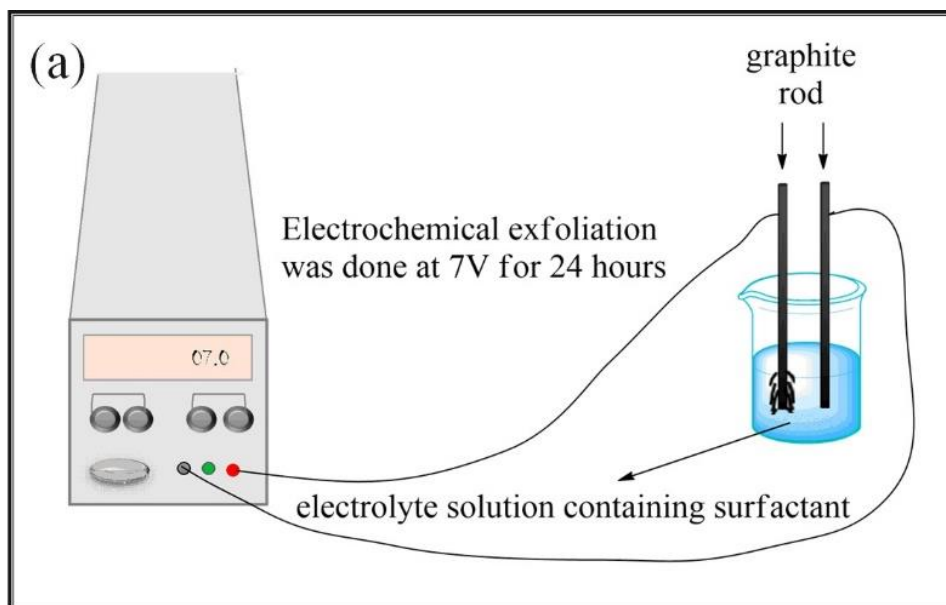


Figure 4. (a) The schematic diagram and (b) experimental procedures of electrochemical exfoliation method to synthesize GO.

Production of reduced Graphene Oxide (rGO)

The reduction process is done in order to reduce the oxygen content and avoid the agglomeration of GO solution. Hydrazine hydrate (80% in water) as reducing agent was added to GO solution with the ratio 1:100. The reduction process is carried out for 24 hours at $\sim 95^{\circ}\text{C}$ temperature. The schematic diagram and experimental procedures to produce rGO are shown in Figure 5.

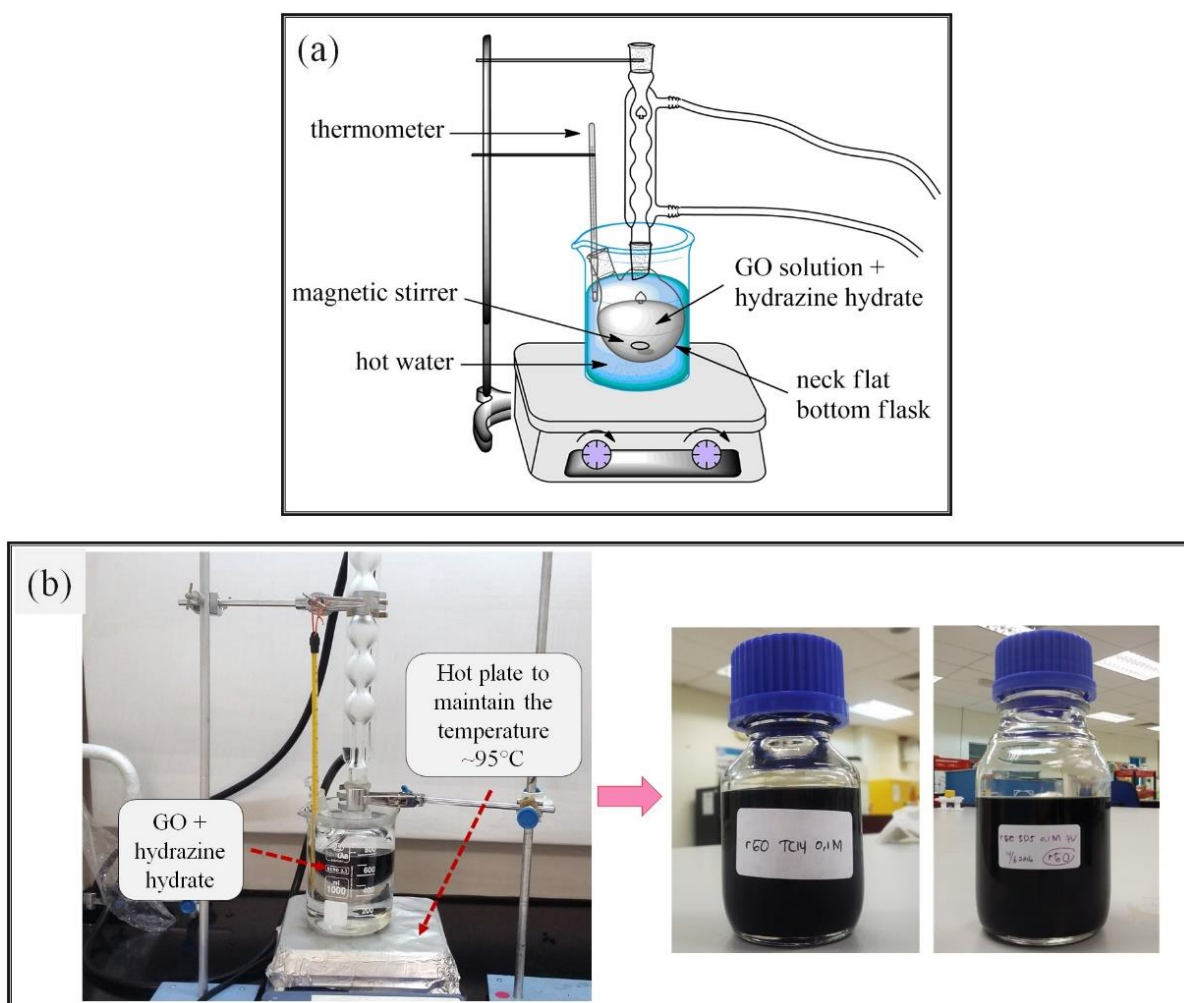


Figure 5. (a) The schematic diagram and (b) experimental procedure of reduction process using hydrazine hydrate as reducing agent.

FABRICATION OF SUPERCAPACITOR ELECTRODES

Fabrication of Graphene Oxide/Natural Rubber Latex Composite using One and Two-step Method

The fabrication of GO/NRL polymer nanocomposite is done using one- and two-step methods. The fabrication parameters included the use of different type of polymers and the reducing of GO to rGO using hydrazine hydrate. Two different types of NRL polymers, namely low ammonia NRL and RVNRL polymers, were fabricated via one-step method. Meanwhile, the ENRL 25 polymer are fabricated via two-step method. Further investigations on the capacitance performance of GO/NRL polymer nanocomposite produced are also done.

Fabrication of Graphene Oxide/Natural Rubber Latex Polymer Nanocomposite Using One-Step Method

GO is synthesized through an electrochemical exfoliation method assisted by a surfactant. The one-step method to fabricate GO/NRL polymer nanocomposite is achieved via intermixing GO into the NRL polymer at a volume ratio of 1:1. The dispersions obtained are then subjected to mechanical stirring and bath sonication for 2 hours. The dispersions are drop-casted into a 5 × 5 cm² container and dried in an oven overnight. The work flow of the one-step method is shown in Figure 6.

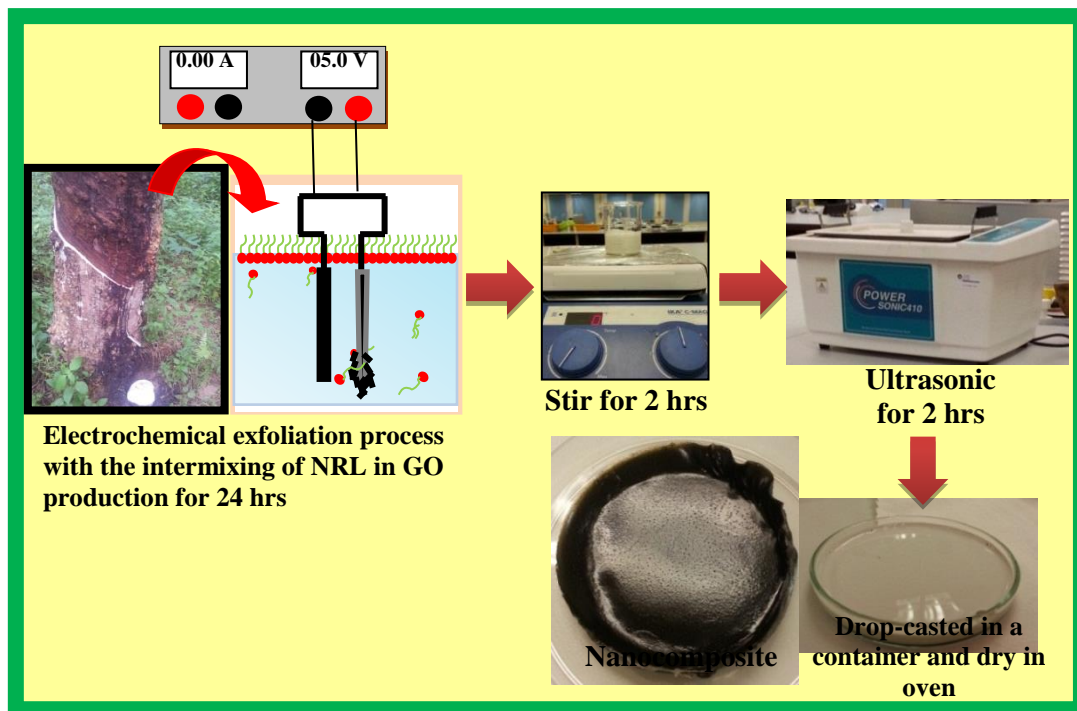


Figure 6. Diagram of the synthesis method of GO/NRL polymer nanocomposite produced via one-step method.

Fabrication of Graphene Oxide/Natural Rubber Latex Polymer Nanocomposite Using Two-Step Method

For comparison, the two-step method of GO/NRL polymer nanocomposite production is also carried out. The fabrication of GO/NRL polymer nanocomposite via two-step method is involved two steps, which are (i) the production of GO; and (ii) the fabrication of 1:1 volume ratio GO/NRL polymer nanocomposite via similar stirring and ultrasonication processes. The work flow of the two-step method is shown in Figure 7.

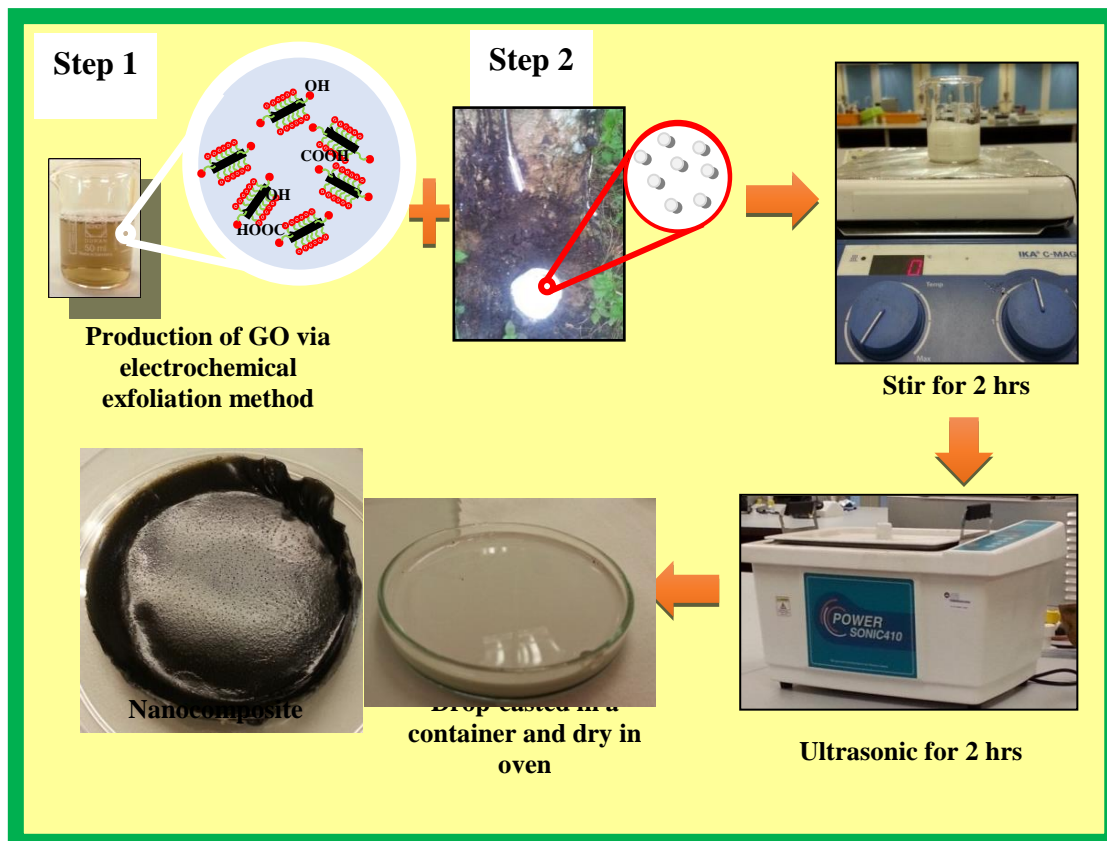


Figure 7. Diagram of the synthesis method of GO/NRL polymer nanocomposite produced via two-step method.

Fabrication of Graphene Oxide/Natural Rubber Latex Polymer Nanocomposite Using Different Type of Natural Rubber Latex Polymers

Three different types of NRL polymers are used which were low ammonia NRL, RVNRL and ENRL 25. The polymers are collected from Malaysian Institute of Nuclear Technology Research, Bangi, Malaysia (MINT). The RVNRL polymer is irradiated at RAYMINTEX plant with doses up to 12 kGy using γ -rays from ^{60}Co gamma ray source at a constant dose rate (2 kGy/hour) for 6 hours of radiation time. Meanwhile, the determination values for total solid content (TSC) and dry rubber content (DRC) of low ammonia NRL are determined per ISO numbers ISO 124: 1997 (E) and ISO 126: 1995 (E), respectively. The TSC and DSC values obtained are $33.87 \pm 0.01 \%$ and $32.51 \pm 0.08 \%$, respectively. Meanwhile, 25 mol % of epoxidation is performed to the ENRL 25 polymer. The TSC of ENRL 25 polymer is determined to be $47.28 \pm 0.01 \%$. These three NRL polymers are used without any purification.

Preparation Procedure for the Fabrication of another Type of Carbon Based Materials such as Carbon Nanotubes/Polymers Nanocomposites as an Electrodes in Supercapacitor Application

The preparation of nanocomposites is illustrated as in Figure 8 where CNTs from waste cooking palm oil (WCPO) is directly used as nanofiller in nanocomposites as an electrode for supercapacitor application.

Firstly, 10 mL of distilled water was mixed with the surfactant and placed into the flask. Then, 5 wt% of CNTs from WCPO is added to the aqueous surfactant. The resulting mixtures are ultrasonicated for 3 h at room temperature. The homogenous dispersion of CNTs/surfactant in aqueous solution is then added to the NRL solution. The mixtures of CNTs/NRL/surfactant are stirred for 1 h followed by ultrasonication for 3 h. Finally, the nanocomposites is dried overnight in an oven at 80 °C. Further study on the capacitance performance are also done using commercial polymers (such as PEDOT:PSS, PS and etc).

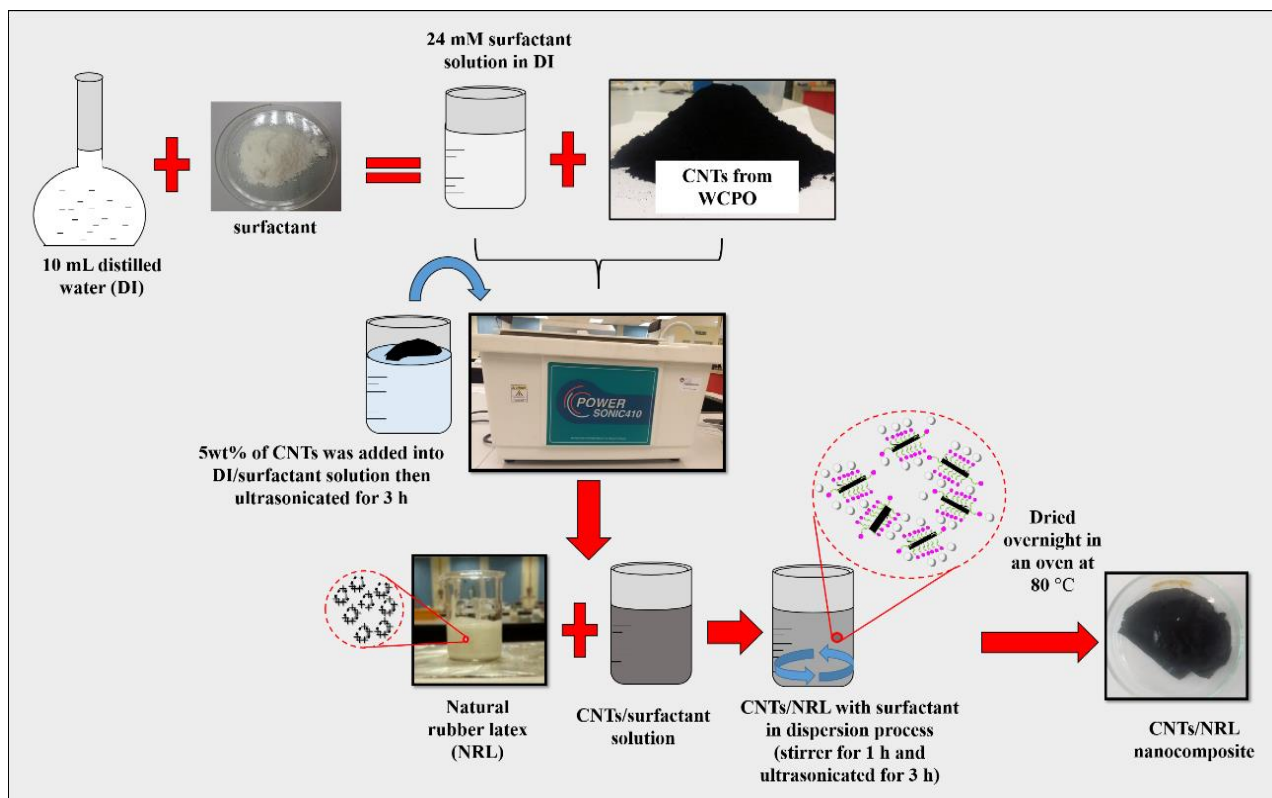


Figure 8. Fabrication of CNTs/polymers nanocomposites as an electrode for supercapacitor application.

How to Make SUPERCAPACITOR

Stage 1

- Fabrication of graphene/natural rubber latex nanocomposite via **one**-step method
- Dry in the oven for 24 hours at 60 °C

Stage 2

Preparation of **electrodes** materials

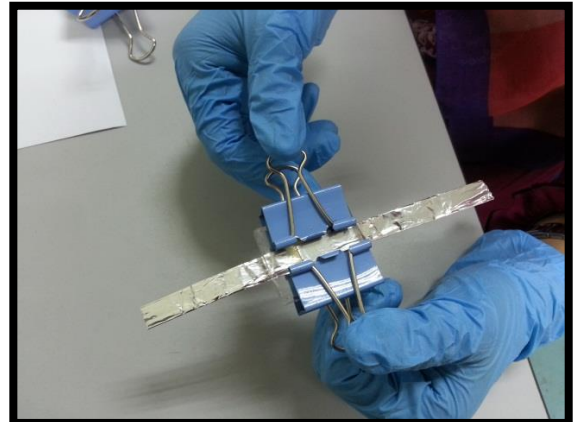
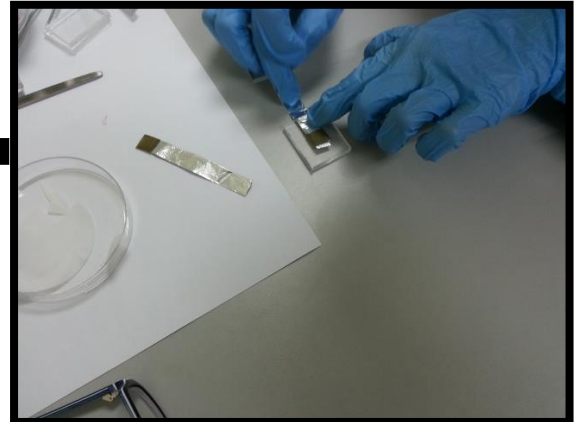
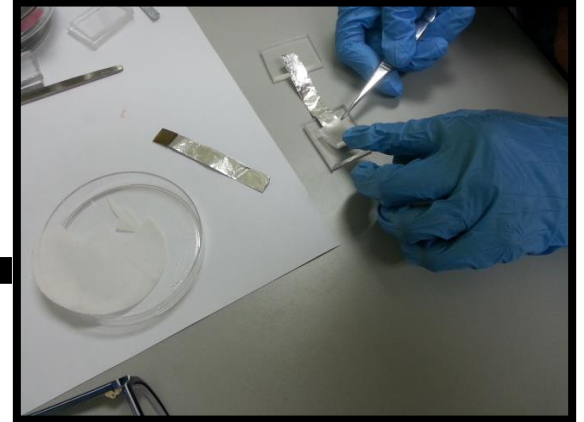
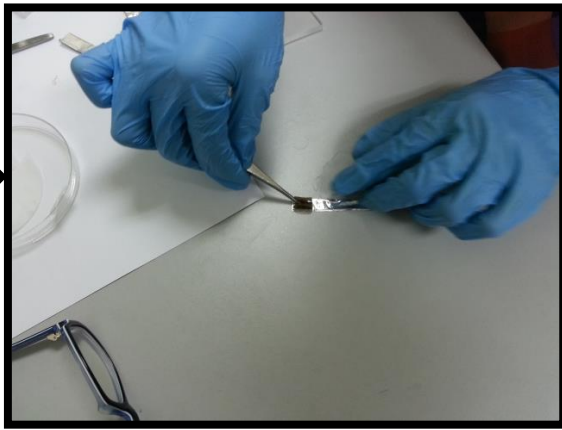
- Cut the thin films into 0.5 x 0.5 cm²
- Place on the aluminum foil as current collector

Stage 3

Preparation of **electrolyte**

- Cut the filter paper into 2.0 x 2.0 cm²
- Immerse the filter paper in the 1 M KOH
- Then, place on the electrode and assembled with another electrode

**PREPARATION
OF
SUPERCAPACITOR**



A Gamry potentiostat series-G750, USA instrument is used at Department of Chemistry, Universiti Pendidikan Sultan Idris and Gamry software is used for capacitance measurement. Prior to the *C-V* analysis, the densities of the GO dispersions have been measured using densitometer (shown in Figure 9 (a)). The readings are taken for three times in room temperature. The mass of $1 \times 1 \text{ cm}^2$ GO/NRL polymer nanocomposite electrode is measured. The samples are assembled side by side with 1 M KOH of aqueous electrolytes. Then, the assembled samples are connected to the positive terminal (working and sensing electrode cables) and negative terminal (reference and counter electrode cables). The measurements are recorded at potential window of 0 to 1 mV with scan rate of 10, 50 and 100 mV s^{-1} . The capacitance value is calculated using the formula as written below:

$$C = \frac{I}{\left(\frac{dv}{dt}\right) \times m} \quad (1)$$

where *C* is defined as specific capacitance (F g^{-1}), *I* is defined as maximum response current, *m* is defined as effective mass of an electrode (g) and $\frac{dv}{dt}$ is defined as the gradient of the slope (mV s^{-1}).

Figure 9 (b) shows the Gamry potentiostat series-G75 instrument. In addition, two electrodes testing of potentiogalvanostat (*C-D*, WonATech Korea) is used at Institute of Science, Universiti Teknologi MARA, Shah Alam for electrochemical testing as presented in Figure 9 (c). Figure 9 (d) shows the standard assembled samples for capacitance measurement.

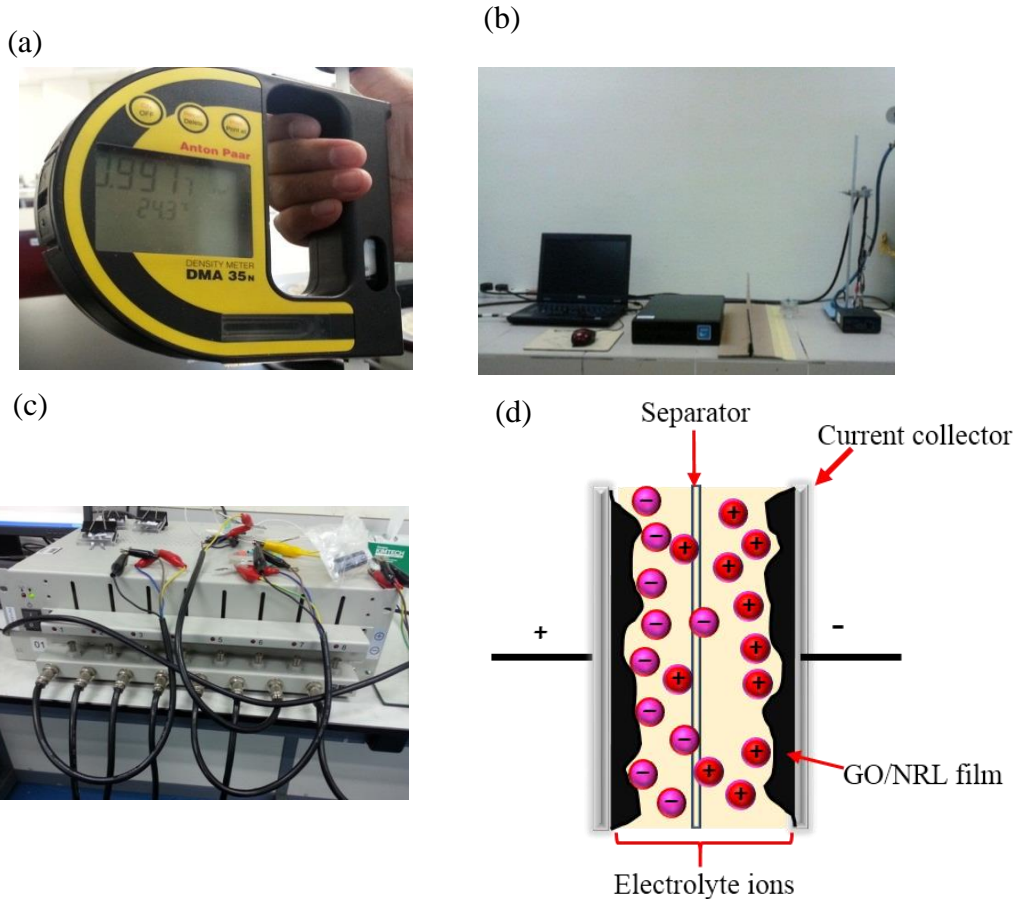


Figure 9 (a) Densitometer, (b) C-V, (c) C-D measurement and (d) assembled samples for capacitance measurement.

Four Point Probe Measurement

The electrical properties are measured by four-point probe instrument at Department of Physics, Universiti Pendidikan Sultan Idris. The measurement is done in room temperature using the samples with dimension of $10 \times 10 \text{ mm}^2$. Source meter (Kiethely 2636A) is connected to PC and the data are analysed with Leios TMXpert computer program (see Figure 10). Three measurements of resistivity are taken and then the electrical conductivity is calculated using the following equation:

$$\sigma = \frac{1}{\rho} \quad (3.2)$$

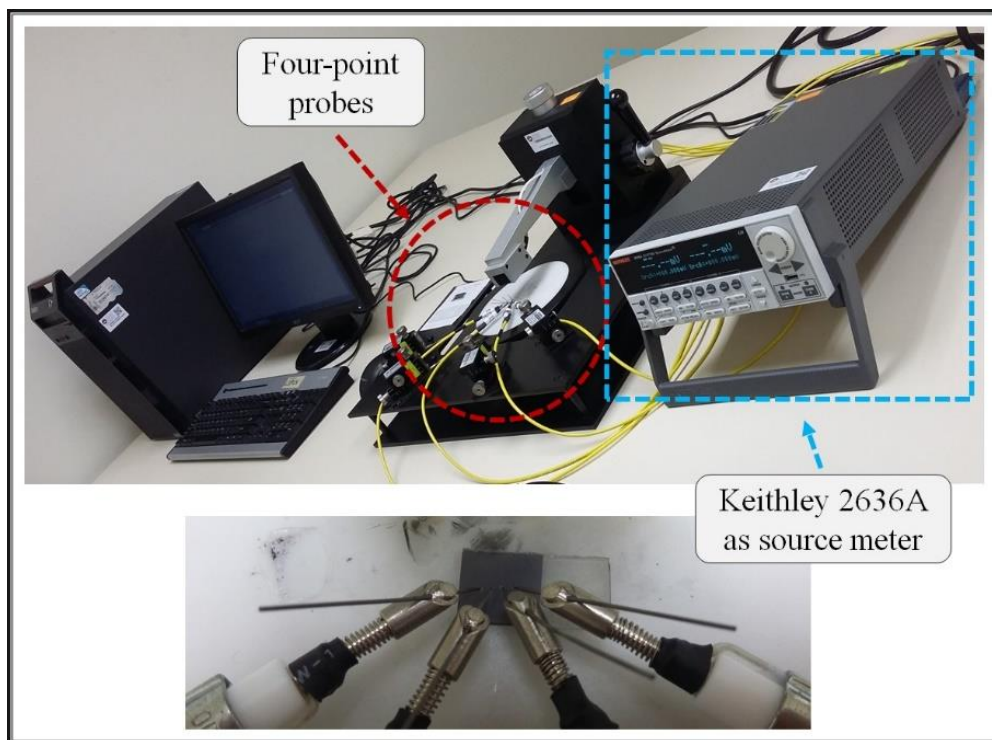


Figure 10. Four-point probe – Keithley 2636A equipment for I-V measurement.

3. Finding and Discussion

The electrical properties of the nanocomposite samples are presented in Figure 11. A higher conductivity was measured in the sample produced by the one-step method ($7.12 \times 10^{-5} \text{ S cm}^{-1}$) than in the sample prepared via the two-step method ($3.62 \times 10^{-7} \text{ S cm}^{-1}$). This is suggested to be due to the better dispersion of GO throughout the NRL. The conductivity value of the one-step GO/NRL nanocomposite was found to be higher than stated in a previous report [14]. This shows that the GO stabilization by a surfactant plays a role in the formation of percolating pathways between GO particles, which is necessary to render an

insulating NRL to conduct the electricity of nanocomposite [15]. In addition, a high specific capacitance obtained in the C - V curve indicates a good number of charge-transfer ions between the electrolyte and nanocomposite electrodes [16].

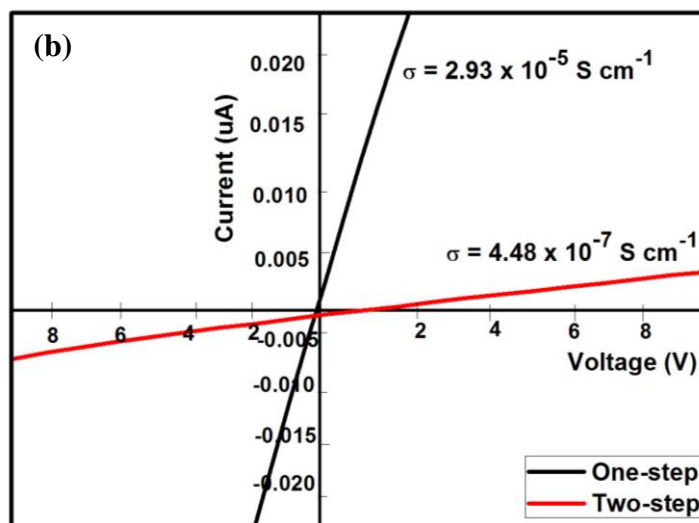


Figure 11. I - V analyses of GO/NRL nanocomposite produced via one- and two-step methods.

Figure 12 (a)-(b) shows the C - V curves of the nanocomposite electrodes. The leaf-like shape observed indicates the good capacitive behaviour of the redox reaction. The calculated specific capacitance of nanocomposite prepared via the one-step method was found to be 103.7 Fg^{-1} , which is higher than that of the two-step method (32.6 Fg^{-1}). The result obtained for the one-step method was comparable to that of a previous study [12]. These results were also consistent with the I - V analysis, in which a higher conductivity value was measured for the one-step method ($7.12 \times 10^{-5} \text{ Scm}^{-1}$) than for the two-step method ($3.62 \times 10^{-7} \text{ Scm}^{-1}$). This result paves the way to the development of new supercapacitor applications based on GO/NRL nanocomposite.

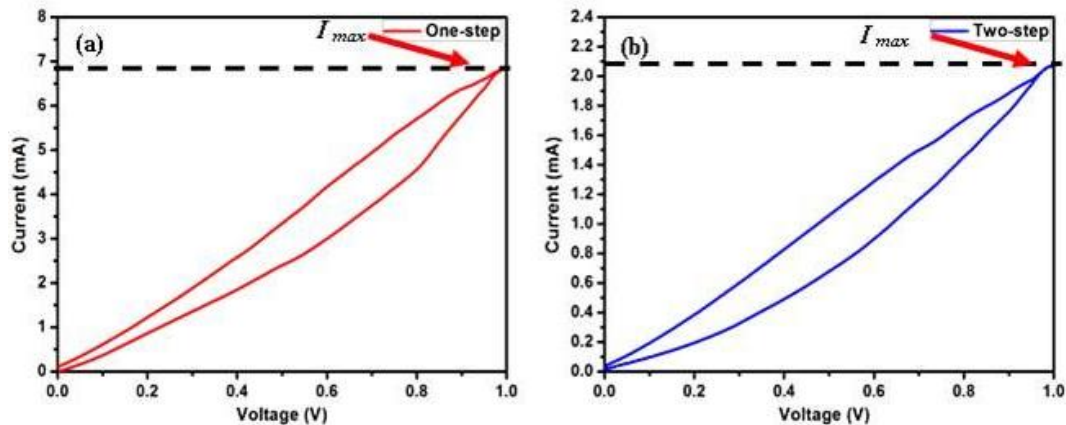


Figure 12.(a)-(b) C-V characteristics of GO/NRL nanocomposite.

4. Conclusion

A new and simple fabrication of GO/NRL nanocomposite for supercapacitor electrodes have been successfully done via a one-step method. The specific capacitance of 103.7 Fg^{-1} was also measured (103.7 Fg^{-1}) for one-step GO/NRL nanocomposite than that of the nanocomposite produced via a two-step method (32.6 Fg^{-1}). Thus, the produced GO/NRL nanocomposites have potential applications in energy storage devices, such as supercapacitors and it also offers a great exposure to the students to make their own supercapacitor and home-made battery.

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6. Appendix A: SIMPLE HOMEMADE BATTERY

Brief Description of Activity:

The lesson uses an activity to help students learn about how batteries function in relation to ions, electrolytes, voltage, and current. The lesson additionally helps students apply the knowledge of batteries that they accumulated in class to the real world. These goals are achieved by the students watching a demonstration of a coin battery being made, constructing a coin battery individually, and discussing how and where in their daily lives batteries help.

Learning Goals:

Students will test the voltage of coin batteries using a voltmeter to see how to a battery can be assembled.

Students will observe the coin battery to see how a battery can be assembled using coin, cardboard and copper wire.

Students will understand

- the way a battery functions
- batteries' applications to the real world

This project is hope to give students an understanding on how a battery is made. Students should be able to further understand the working principle of batteries and electricity.

In the modern era, electrical energy is normally converted from mechanical energy, solar energy, and chemical energy etc. A battery is a device that converts chemical energy to electrical energy. The first battery was developed by Alessandro Volta in the year of 1800. In the year 1836, John Frederic Daniell, a British chemist developed the Daniell cell as an improved version of the voltaic cell. From that time until today, the battery has been the most popular source of electricity in many daily life applications. In our daily life, we generally use two types of battery, one of them is which can be used once before it gets totally discharged. Another type of battery is rechargeable which means it can be used multiple times by recharging it externally. The former is called primary battery and the later is called secondary battery.

Batteries are devices that convert chemical energy into electrical energy. When two different metals are connected by an electrolyte, a chemical reaction occurs at each metal surface, called *electrodes*, that either releases or uses electrons. When these electrodes are connected by a wire, electrons will move from one surface to the other, creating an electric current.

The cardboard cut-out soaked in salty vinegar water serves as the electrolyte between the two terminals.

Each coin-cardboard stack represents one individual cell. By stacking additional coin-cardboard, you've created a battery, which is a series of electrochemical cells. This is also called a *voltaic pile*, which is named after Alessandro Volta, who created the first battery by alternating zinc and copper electrodes with sulfuric acid between them. In Volta's battery and our coin battery, an oxidation reaction occurs at the zinc electrode that releases electrons and a reduction reaction occurs at the copper electrode that uses them. With a voltmeter, you can see that each cell can generate over 0.3 volts.

WORKING PRINCIPLES

A battery can be useful in producing a small amount of volts. To make a homemade battery it is crucial that there are two different kinds of metals with a substance in between them. It is beneficial to have at least 5 coins so that enough volts can be created. Then cut 5 circle pieces as big as the coin of cardboard. Soak the cardboard cut-out in an acid solution. An acid as simple as vinegar and water, or lemon juice could be used. Stack the pennies on top of one another with a piece of cardboard cut-out in between them. Use a coin that has not been scratched on either side and place it on top.

First, make sure that the cardboard cut-out are moist. Less electrical energy will be produced if less electrolytes are available. Second, ensure that none of the coins are touching one another and that each cardboard cut-out only touches two coin and does not overlap onto other coin. This would create a short and little to no electrical energy will be produced. Third, check the acidity of the solution that is being used to soak the cardboard cut-out. The greater the acidity, the greater number of electrolytes, and the greater amount of electricity that can be conducted.

KEY CONCEPTS AND DEFINITIONS OF TERMS

Battery: a container consisting of one or more cells, in which chemical energy is converted into electricity and used as a source of power in an electrochemical reaction.

Electricity: the flow of electrons through a conductive path like a wire. This path is called a circuit.

Voltage: an electromotive force, a force that tends to produce an electrical current, or potential difference expressed in volts. The greater the voltage, the greater the flow of electrical current, the quantity of charge carriers that pass a fixed point per unit of time.

Current: a flow of electric charge. In electric circuits this charge is often carried by moving electrons in a wire.

Electrolyte: a chemical compound that ionizes when dissolved or molten to produce an electrically conductive medium. This solution can be salt water, vinegar, fruit juice, ect.

Anion: a negatively charged ion.

Cation: a positively charged ion.

Ion: an atom or a molecule in which the total number of electrons is not equal to the total number of protons, giving the atom or molecule a net positive or negative electrical charge.

Prepare the equipment as below:

Equipments

1. Cardboard cut-out x5

To be used as electrode

2. Multimeter

To measure voltage produced by the battery

3. 1 cent coins x5

To be used as conducting material

4. Toy fan

To demonstrate the batteries capability

5. Copper wire

To be used as anode and cathode

6. Insulating tape

To hold the coin, electrode and copper wire together

7. Vinegar

Cardboard cut-out will be soak in vinegar.

8. Tweezer

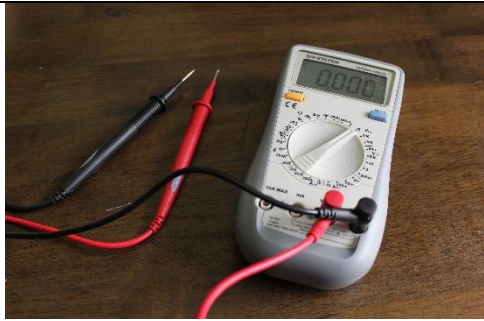
To easily hold the soaked cardboard cut-out

9. Glass plate

To put the soaked cardboard cut-out

10. Tissue paper

Absorb excess vinegar, avoid dripping



MULTIMETER



VINEGAR



CARDBOARD CUT-OUT



INSULATING TAPE



TWEEZER AND GLASS PLATE



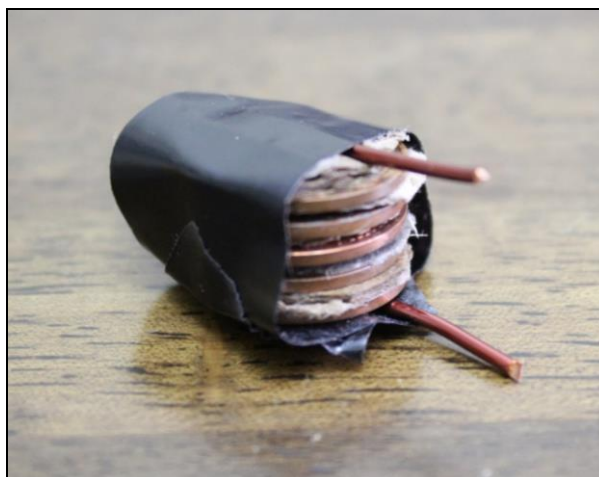
COPPER WIRE



TOY FAN



1 CENT COIN x5



Completed Battery

Challenge Questions

1. How can you make a more powerful battery?
2. Can you use this same battery to light different-colored LEDs or other things that require power?
3. What other metals could you use in an activity like this?

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