ELECTRO-ORGANIC SYNTHESIS: ADDING NEW DIMENSIONS TO SYNTHETIC ORGANIC CHEMISTRY

Abstract

In comparison to conventional methods, organic electro-synthesis produces less waste, uses fewer chemicals, and frequently requires fewer stages in the reaction process. This has garnered a lot of attention as a potent green tool for synthesis. Even with all the benefits, there is still a hurdle preventing the broad use of this knowledge-based technology. This has led to a knowledge gap between experienced electrochemists and those new in the field. This chapter therefore focuses on providing a general overview of the new emerging research field and motivating researchers to investigate this topic, since it deserves more exploration in today's green movement. The authors believe that the readers will develop a keen interest of the topic after reading the chapter.

Keywords: Electrochemical cell, electrodes, cyclic voltametry, Single Electron Transfer (SET), current, potential.

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I. INTRODUCTION

The development of new and clean energy is receiving significant importance due to scarcity resources, excessive use of fossil energy, and severe environmental pollution in the current century. Electricity is considered an alternative fuel under the Energy Policy Act of 1992, therefore in most cases electricity can be considered as a greener fuel or fuel for future. However, the broader use of electricity will gain increasing influence due to sustainable transformations when electricity is obtained from renewable resources like wind-, solar-, or hydropower. Considering the vital applications of electricity in the modern era, synthetic chemists had made a progressive application in developing new methodologies for the synthesis of organic compounds using electricity. Hence, **Electro-organic synthesis** had become one of the most promising topics for research in organic synthesis. It has received a remarkable importance in last few decades due to its mild, green and atom efficient synthetic routes. It nulifies the stoichiometric use of many oxidising and reducing agents which are used widely in organic synthesis reactions. Due to its intensive advantages, electro-synthesis has gained lots of attraction in pharmaceutical science, medicinal chemistry and future industrial applications in energy storage and conversion.

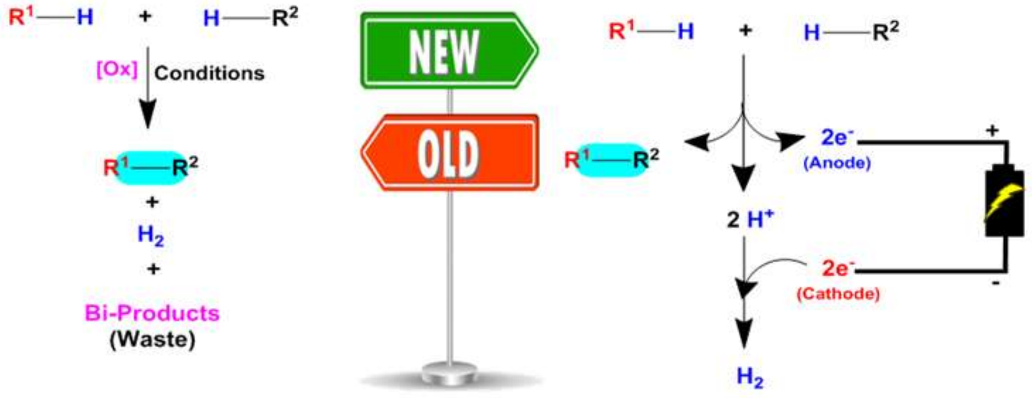


Figure 1: Comparison of conventional and electrochemical methods with an example of a coupling reaction.

Although the process of electro-synthesis was common in inorganic transformations including production of chemicals in industrial scale, like chlor-alkali electrolysis for manufacturing basic inorganic chemicals or aluminium production by the Hall-Héroult process. The organic synthetic community was not so aware or did not accept this technique even though it was already used by Kolbe over 170 years ago. However, a number of organisations from all over the world have recently developed a strong interest in this topic and investigated it in order to gather enough information for additional research. Despite the fact that electro organic transformations make it possible to access novel structures because of their special reactivity and selectivity, their widespread application in organic synthesis is still limited. Therefore, the current chapter focuses on the fundamental ideas of electro-organic synthesis and aims to inform the readers about the most recent developments in this field of study.

II. PRINCIPLES OF ELECTRO-ORGANIC SYNTHESIS

A simple electrochemical setup consists of a reaction vessel with an external power supply (A), a reaction solution (D) and two electrodes (C & D) which is connected to the power supply as shown in figure 2. The reaction solution or reaction mixture consists of the place in the anode (B, Red) while reduction reaction takes place on the cathode (C, Blue). The arrows on the wire of the electrodes show the direction of electron flow (Figure 2). The oxidation or the reduction e in further sections.

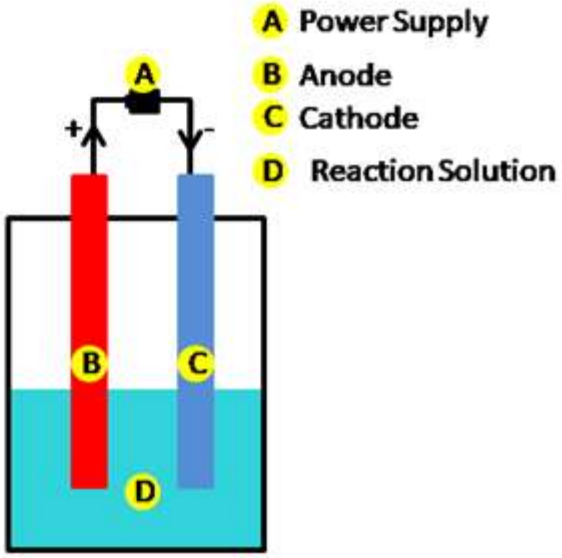


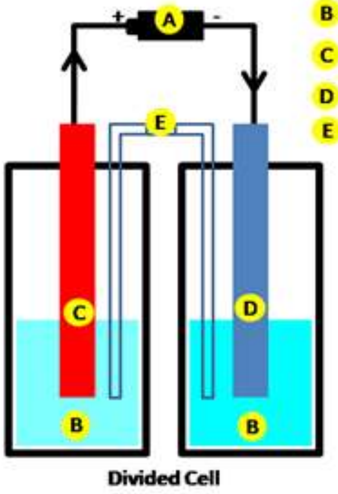
Figure 2: A simple electrochemical setup

The versatile method of electro-organic synthesis relies on the fundamental principles of redox reactions using electric current as the starting material or substrate, suitable solvent, a supporting electrolyte and additives (if necessary). At the time of an electrochemical reaction, both the electrodes (viz. Anode & Cathode) undergoes separate electrochemical reactions. An important reagent is replaced by the oxidation process. When an electron is added to a substrate, reductive processes called single electron transfers (SET) take place at the cathode, whereas oxidations happen during anodic transformations. As a result, the electrodes play a key role in electro-organic conversions, which occur as heterogenous chemical reactions between a substrate and a commonly solid electrode in a liquid electrolyte system. A solvent that is electrochemically inert and supporting electrolytes that enable adequate electrical conductivity make up this electrolyte system. The creation of an electrochemical double layer at the electrode surface (see section Electrodes) is aided by this supporting electrolyte, which may be a salt, acid, or base. It is common practice, inert ions that are highly soluble in organic solvents, such as tetraalkylammonium, hexafluorophosphate, or tetrafluoroborate are used.

III. BASIC CONCEPTS OF ELECTROLYTIC REACTION

1. **Types of Electrolytic cells:** In electrolysis, there are two possibilities of operation, either in divided cell (Figure 3a) or in undivided cell (Figure 3b). In un-divided cell, both the

electrodes viz. anode and cathode are placed in a same reaction vessel. In divided cells, the semiporous membrane used to separate the cathode and anode chambers is typically made of sintered glass, porous porcelain, poly-tetrafluoroethene, or polypropylene. The divided cell's function is to allow ion diffusion while limiting the flow of products and reactants. The separation makes the workup easier. In many of the divided cells, both the anodic compartment and cathodic compartments are separated via salt bridge (See E in figure 3a).



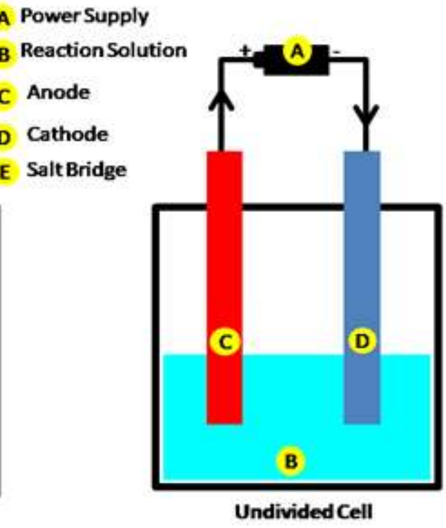


Figure 3a: Divided cell **Figure 3b:** Undivided Cell

A salt bridge or ion bridge is a laboratory device used to connect the oxidation and reduction half-cells. It maintains electrical neutrality within the internal circuit. In the absence of salt bridge, the solution in one-half cell would accumulate a negative charge and the solution in the other half cell would accumulate a positive charge as the reaction proceeded, quickly preventing further reaction. Considering the electrochemical process implementation, the main influence of efficiency comes from the electrochemical reactions. In divided cell, the advantage is that there is the possibility to avoid decomposition of oxidants at anode or cathode which increases the faradic yield.

2. **Electrodes:** In electrochemical reactions, any conducting substance can normally be employed as an electrode. However, the electrode's material, size, and shape have a significant impact on how the reaction turns out. The basic role of an electrode is to transfer electrons and facilitate heterogeneous reaction. Depending on the homogeneity of the electrochemical reaction, electrodes are classified into sacrificial and non-sacrificial electrodes. Sacrificial electrodes takes part in the reaction and gets dissolved in the reaction mixture (e.g. Al, Zn, Mg, etc) while non-sacrificial electrodes are inert, highly durable and stable under oxidative conditions (e.g. Graphite, glassy carbon, RVC). Hence, favourable electrode materials are (electro-) chemically inert facilitating easy handling, and ecologically and economically beneficial use.

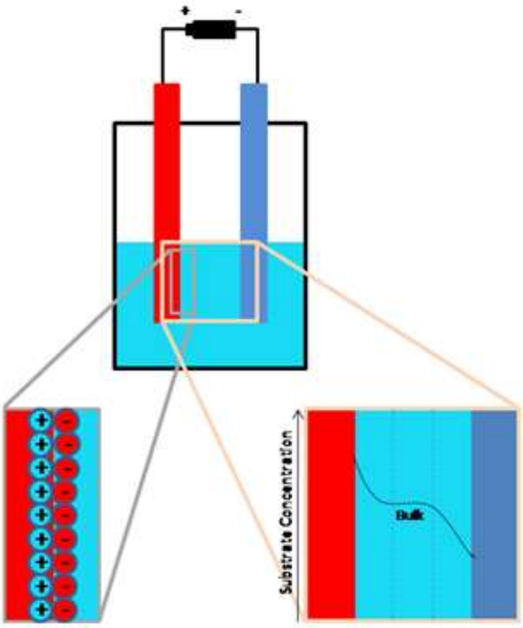


Figure 4: Helmholtz layer(Left) and Nernst diffusion layer (right)

In electrochemical reactions, the reactions takes place on the surface of the electrodes, therefore the surface area of electrodes which is in contact with the reaction mixture, plays an important role on the rate of an electrochemical reaction. Since electrode materials that are foams or meshes often have more surface area than electrode materials that are plates or rods, they can be advantageous for a reaction by speeding up the reaction rate. Both oxidation and reduction reactions are connected during redox reactions in an electrolytic cell, which makes both electrode surfaces crucial.

As discussed in earlier sections that an electrochemical reaction occurs via Single Electron Transfer (SET) to the substrate which results into a radical species that reacts further to form the desired product. During an electrochemical reaction, two layers of opposite polarities are formed when the electrode comes in contact with the electrolyte. This electrochemical double layer is called Helmholtz layer (Figure 4-left). A positively charged layer on the electrode's surface and a negatively charged layer of the solvated electrolyte covering the first layer make up the anodic double layer. The applied voltage and electrolyte concentration have a significant impact on the double layer's thickness, which is normally measured in a few nanometers. In addition to the double layer, the Nernst diffusion layer (Figure 4-right), which describes the concentration of substrate close to the electrode, also forms. As the substrate is used up, its concentration at the electrode decreases relative to that in the bulk solution, causing more substrate to diffuse toward the electrode. The concentration at the electrode rises if the substrate is produced rather than consumed. This is the general mechanism followed by nearly all the electrochemical reactions.

- **Working Electrode (WE):** The most significant element of an electrochemical cell is the working electrode. This is due to the fact that the reaction of interest occurs at the point where the WE and the reaction solution meet. The choice of WE has a significant impact on how an electrochemical reaction turns out. It is made of redox-inert material and varies from experiment to experiment to provide different potential windows or to decrease or promote the target species' adsorption onto the surface. The working electrode's surface is exceedingly clean, and its surface area is clearly defined, which is another crucial characteristic. Platinum, gold, carbon, and mercury are the most used working electrode materials. Platinum is the most advantageous of these since it exhibits good electrochemical inertness and can be produced. Platinum is the most advantageous of these due to its superior electrochemical inertness and versatility in fabrication. The main drawback of using Pt electrodes, despite the fact that they are expensive to use, is that even small amounts of water or acid in the electrolyte solution cause hydrogen gas to evolve at relatively low negative potentials (E = -0.059 x pH) due to the reduction of hydrogen ions to form hydrogen gas. Any valuable analytical signal is obscured by this reduction.

- **Counter Electrode (CE).** At the electrode surfaces, electrochemical reactions are inextricably coupled. Current starts to flow when a voltage is given to the working electrode that allows reduction (or oxidation) of the reaction mixture to happen. The reaction occurring at the counter electrode is the counter reaction. The electrons removes at the anode are driven to the cathode by power supply ensuring a net neutral system. Thus, the fundamental purpose of the counter electrode is to complete the electrical circuit. Current is recorded as electrons flow between the WE and CE. An oxidation reaction is observed at the CE when investigating a reduction in WE. Therefore, it is necessary to select the CE to be as inert as possible. Due to their potential for producing waste products in response to an experiment, these electrodes may occasionally be placed in a fritted compartment and kept isolated from the rest of the system. One such is the THF oxidative polymerization that can take place in the CE when studying the THF (Tetrahydrofuran) reductive process in the WE.

- **Reference Electrode (RE):** In order to accurately measure the voltage applied at the WE, a reference electrode is typically utilized in addition to a working and counter electrode. It has a steady and clearly defined equilibrium potential. It will be used as a baseline when calculating the potential of additional electrodes in an electrochemical cell. As a result, the applied potential is often expressed as "vs" a specific reference. A few frequently used (and typically readily accessible commercial) electrode assemblies feature an electrode potential that is unrelated to the electrolyte that is utilized in the cell. The saturated calomel electrode (SCE), standard hydrogen electrode (SHE), and the AgCl/Ag electrode are a few examples of reference electrodes frequently employed in aquatic media. Typically, a porous frit separates these reference electrodes from the fluid. By matching the solvent and electrolyte in the reference compartment to the one used in the experiment, junction potentials should always be kept to a minimum. Reference electrodes based on the Ag+/Ag pair are frequently used in non-aqueous liquids. These are composed of a silver wire in an Ag+ salt solution, usually AgNO3. However, extreme caution must be used while converting potentials because various factors, like solvent and electrolyte content, might have an impact. For constant potential reactions (see section Applied Current and Potential) and cyclic voltammetry (see section Cyclic voltammetry), the use of a reference electrode is crucial for consistency.

3. **Electrolytes and Supporting Electrolytes:** An electrochemist's primary priority is to eliminate the inhibition (resistance) and so increase the rate of an electrochemical reaction because resistance is vital in reducing the rate of an electrochemical reaction. Therefore, the majority of electrochemical reactions include an electrolyte to lower the potential of the system and reduce resistance in order to increase the rate of the reaction. The electrochemical inertness of an electrolyte is the most important criterion. A supporting electrolyte must be electrochemically inert in order to be used in a process. It cannot experience a redox reaction while the applied potential is present. In the reaction mixture, it must be completely soluble. Short alkyl groups normally have the lowest resistance, and as they get longer, the resistance rises. For inorganic electrochemistry studies carried out in organic solvents, ammonium salts are the preferred electrolyte since they meet all the criteria for an electrolyte. Tetrabutylammonium (+NBu4) salts for processes in dichloromethane or acetonitrile are frequently utilized. Tetrahexylammonium salts are useful for less polar solvents like benzene because of their excellent solubility in these solvents. The choice of counteranion is less standardized since anions frequently react more strongly with transition metal analytes than ammonium salts, which are regarded as standard cations. The five anions that are most frequently employed are [B(C6F5)4], [B(C6H5)4], [PF6], [BF4], and [ClO4]. The likelihood of unfavorable interactions between the anion and the cation, solvent, or analyte increases with the anion's degree of coordination. In acetonitrile, [NBu4][PF6] salts have been shown to be the best supporting electrolytes because to their stability, non-coordinating nature, simplicity in purification, and solubility. The cleanliness of the electrolyte is another crucial factor since even the smallest impurity can accumulate to a level where it interferes with measurements and throw off the electro-organic synthesis process as a whole.

   To further improve the performance of the process, additives can be employed in addition to the supporting electrolytes. Utilizing an additive is mostly done to stabilize intermediates or to encourage the counter reaction. Acid is frequently advantageous when added to oxidation reactions because it serves as a source of protons for the reductive release of hydrogen that occurs as the counterreaction. Metal salts may also be added since they decrease and deposit on the cathode. Radical intermediates can be stabilized by adding fluorinated alcohols, such as hexafluoroisopropanol (HFIP).

IV. MODES OF OPERATION

1. **Applied Current and Potential:** Current (I) and potential (V) are the most important parameters for an electrochemical reaction. The current describes the movement of electrons, the potential describes the energy by which they are moved. The current controls the rate at which electrons are transferred to the reaction medium and hence the reaction rate. The charge (Q) is the current in a unit time, which means that it corresponds to the amount of electrons released into the reaction medium corresponding to an analogous reagent stoichiometry. It is necessary to adjust the energy of electrons, the potential, in accordance with the desired process. It is observed that the majority of synthetic reaction occurs at 2 V, with the reaction not occurring if the potential is too small and it may lead to selectivity problems. The current and potential are related by the resistance (R) in a process. The resistance in a electrochemical cell can be offered by various components such as wiring and the electrodes but the biggest contributor is the reaction solution (discussed in supporting electrolyte section). Therefore, all the three

parameters, the current, the potential and the resistance are related to each other by the Ohms law, which is given by-

$$V = R\ .I$$

V: Potential in Volt (V); R: Resistance in ohm (Ω) ; I: Current in Ampere (A)

An electrochemical reaction can run in two modes viz. Galvanostatic mode (if it runs under constant current) and Potentiostatic mode (if it runs under constant potential). It is not practically possible to control both the current and the potential separately without changing the resistance of the setup.

2. **Galvanostatic Mode:** Galvanostatic setup is a simplest setup since it uses only the working electrode and counter electrode. It does not use any reference electrode for its operation and the exact stoichiometry of electrons is known. In galvanostatic mode, the system is run under constant current, which is dependent on the amount of substrate present in the reaction solution. The electrode potential decreases on the consumption of starting material. The main advantage of galvanostatic setup is that it is easy to assemble and the exact equivalents of electrons are known i.e; Fmol^{-1} . The only drawback of this system is that the voltage range in not under control. It is the most common mode generally employed in maximum number of electro-organic transformations.

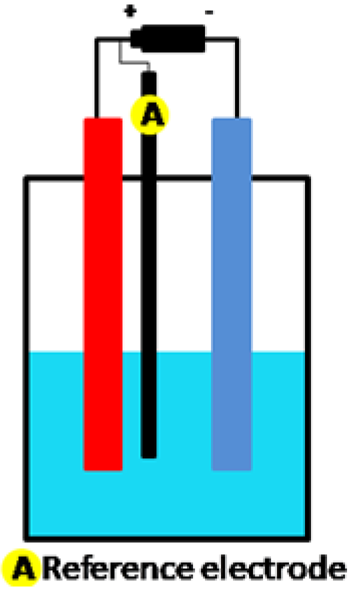


Figure 5: Electrochemical cell indicating reference electrode.

3. **Potentiostatic Mode:** The energy required to move electrons from the anode into the cathode in order to create potential differences is commonly referred to as Potential, also known as voltage. The electrons may then be moved from the cathode to the reaction solution if this difference is sufficiently large. At the same time electrons shall be removed from a reaction solution at an anode, which will lead to current flow. Correspondingly, the current cannot be actively controlled under potentiostatic conditions and may vary to maintain a constant potential. Due to the fact that the current is not always constant, it is not possible to calculate the electron equivalents directly. A multimeter that records currents over time must be included in the setup if an electron

equivalent is to be calculated. Therefore, a reference electrode is required in potentioststic mode (Figure 5). Hence, this setup is only used in case of highly selective reactions of for reaction mechanism clarification.

Figure 6 shows the variation of current potentials and concentration of the substrate during the galvanostatic and potentiostatic conditions.

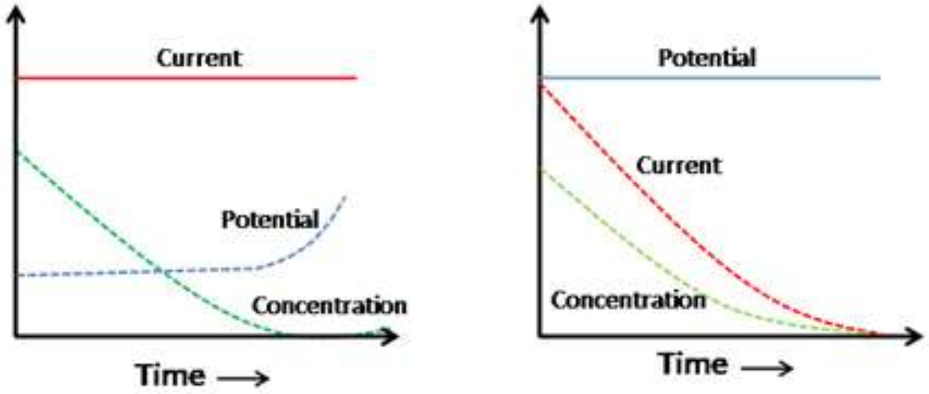


Figure 6: Graphical representation of galvanostatic(left) and potentiostatic (right) conditions.

V. CYCLIC VOLTAMETRY

An analytical tool used in electrochemical reactions called cyclic voltammetry (CV) is used to look into the oxidation and reduction potential of a chemical species. A CV setup, consisting of a CV working electrode, a CV counter electrode, and a reference electrode, is prepared for the measurement of CV. The working electrode differs from the one used for synthetic purposes, it must be recognized. A cyclic voltammogram (Figure 7b) is produced during a CV experiment by measuring the current while the potential at the working electrode is scanned in a cyclic fashion using a triangular waveform (Figure 7a). Current will not increase if the potential is increased without any reaction taking place. An electric current must run until it has been completely used up at the electrode surface, causing a peak, if a species is present that can be oxidized or reduced within the range of the applied voltage. Based on the potential, solvent oxidation and reduction can also be seen. Ea and Ec for anodic and cathodic, respectively, refer to the potential at which the highest current is observed. At the middle of the peaks, the chemical reaction's redox potential ($E^{1/2}$) may be seen. As a result, CV also aids in comprehending the redox system and the minimal potential necessary for a redox reaction to take place.

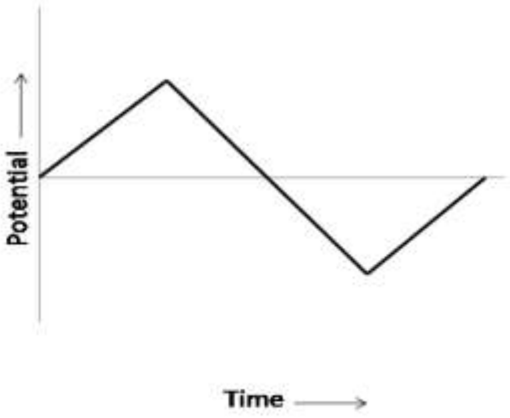


Figure 7a: Triangular waveform

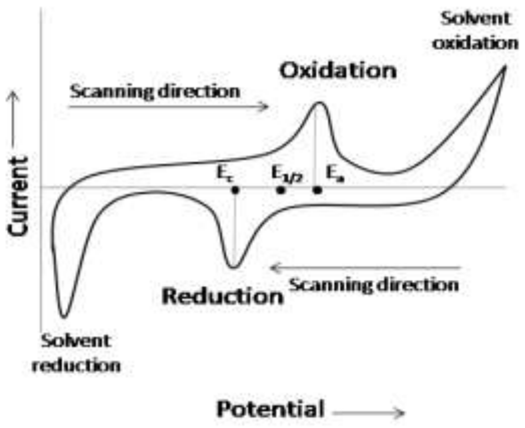


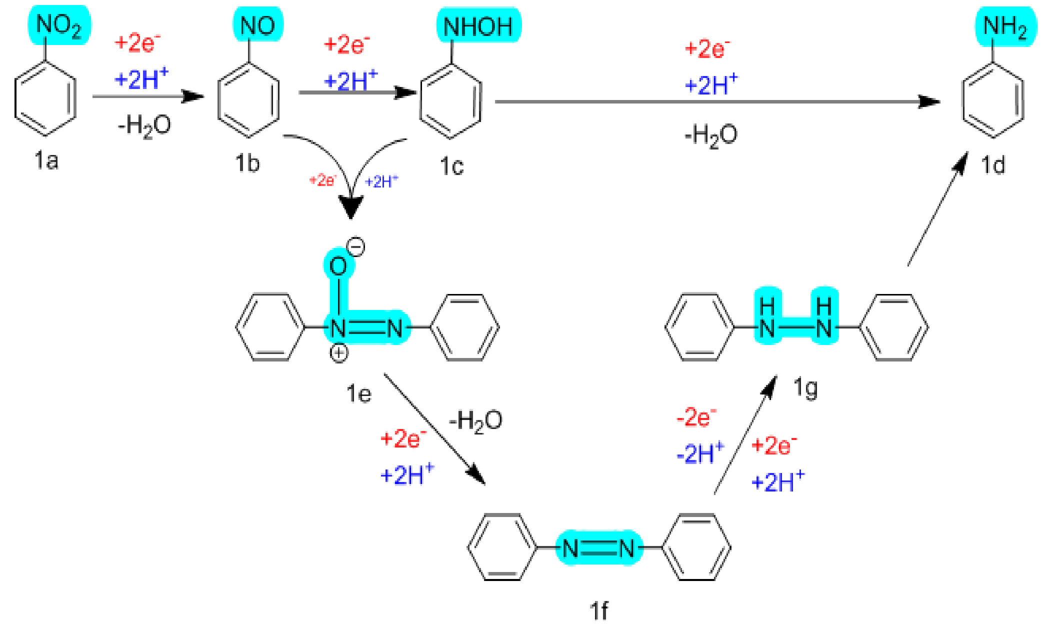
Figure 7b: Cyclic Voltammogram

VI. TYPES OF ELECTROCHEMICAL REACTIONS

There are many electro-organic transformations that are reported till-date, which can be classified into various ways. However, in this chapter a general classification few electro-organic reactions is discussed below-

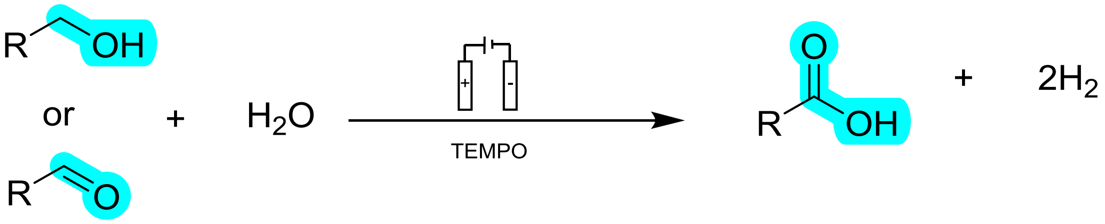
1. **Transformation of Functional Groups:** There are many electro-organic reactions known which deals in functional group inter-conversions. The general functional group transformation reaction include, $NH_2 \rightarrow NO_2$, $NO_2 \rightarrow NHOH$, $NO_2 \rightarrow NH_2$, $S \rightarrow SO_2$, $CH_2OH \rightarrow CHO$, $CH_2OH \rightarrow COOH$, $CHO \rightarrow CH_2OH$, $CHO \rightarrow COOH$, $CH_2NH_2 \rightarrow CN$, etc.

   Reducing nitroaryles(1a) electrochemically can yield nitroso compounds (1b), hydroxylamines(1c) and anilines(1d) as products. Since the nitroso group is more easily reducible than the nitro group, obtaining nitroso derivatives by directly reducing a nitro group is difficult and it demands specific conditions like selective electrode materials. On the other hand, hydroxylamines usually form straight from the nitro reduction It is significant to note that the hydroxylamines rapidly form the 2 e/2 H+ redox-pair with the corresponding nitroso system and are very susceptible to oxidation. This is one of the factors contributing to the difficulty of the final reduction to the aniline and the frequent requirement of divided cells in order to produce anilines or nitroso compounds on a preparative scale. Azoxybenzenes (1e), which can then be electroreduced to azobenzenes (1f) or further to hydrazobenzenes (1g), can be produced by condensing nitroso intermediates and hydroxylamines. Additionally, reversible 2 e/2 H+ redox-pairs are formed by azobenzenes and hydrazobenzenes. Additionally, under acidic or basic circumstances, hydrazobenzenes can be electroreduced to anilines, but in the former case, competition from rearrangement to 1,1-biphenyl-4,4′-diamines hampers the electroreduction process. This could have complicated results.



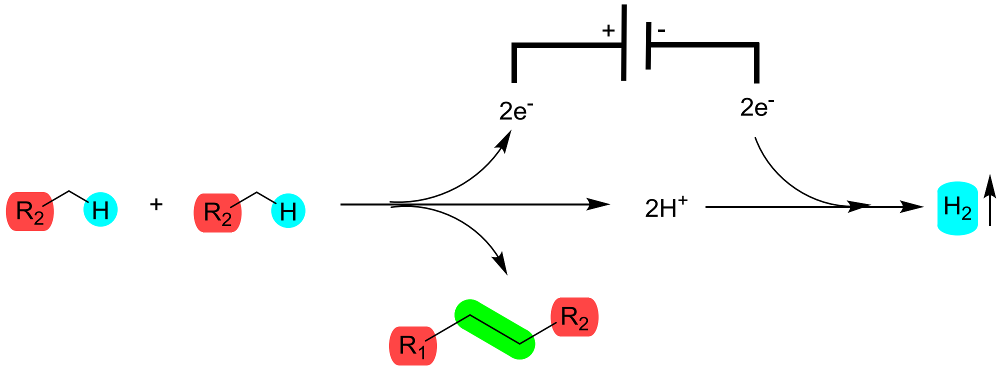
Scheme 1; Reduction of aryl nitro compounds and possible reaction pathways

The use of organic electrocatalysts in electrochemical alcohol oxidation processes has attracted a lot of attention recently and offers a strong substitute for the more conventional chemical processes. These techniques are appealing in part because the only result of the process is hydrogen gas (Scheme 2). Mono/polysaccharides and other precursors produced from biomass have been converted using electrochemical techniques for the oxidation of primary alcohols to carboxylic acids.



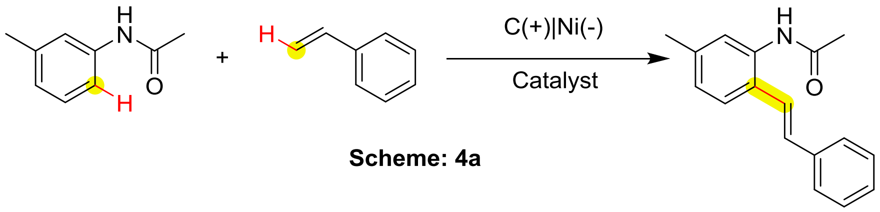
Scheme 2; Electrolytic oxidation of alcohols and aldehydes

2. **Coupling Reactions:** For many coupling processes, electrochemistry has long been acknowledged as an environmentally acceptable synthesis method. Through coupling, both cathodic reduction and anodic oxidation have been used to create complex compounds. A potential technique for establishing oxidative R1-H/R2-H cross-coupling with hydrogen gas evolution has evolved over the past ten years: electrochemical anodic oxidation in conjunction with cathodic proton reduction (Scheme 3). In a perfect scenario, the entire transformation uses only electric energy and does not include any sacrificial reagents. Recent research has demonstrated that electrochemical dehydrogenative cross-coupling can be used to create carbon-carbon and carbon-heteroatom connections.

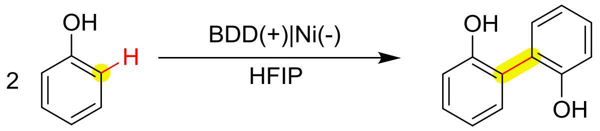


Scheme 3; A general electrochemical coupling reaction

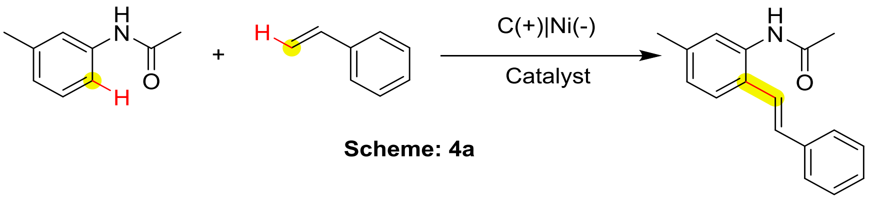
Many electrochemical coupling reactions are explored in last decades which includes cross coupling of anilines and alkenes reported by Waldvogel and group at year 2000. they used Carbon electrode at the working (anode) and nickel (Cathode) as the counter electrode. The reaction used 1,4-benzoquinone as catalyst (4a). Then at 2006, the same group explored the homo coupling of phenols under oxidative condition using Boron Dopped Diamond (BDD) at the anode and simple Nickel electrode at the cathode.They also used florinated alcohols like hexafluoroisopropanol (HFIP) as solvent with supporting electrolytes(4b). Under same reaction conditions or by slight modifications, the dehydrogenative cross coupling between Phenols and arenes (4c), dehydrogenative cross coupling between two phenols (4d), etc were also studied.



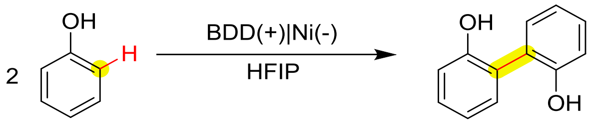
Scheme: 4a



Scheme: 4b

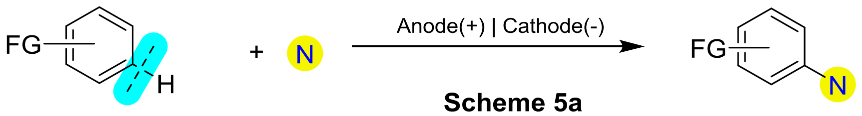


Scheme: 4a

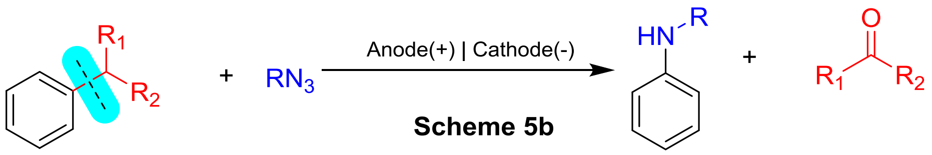


Scheme: 4b

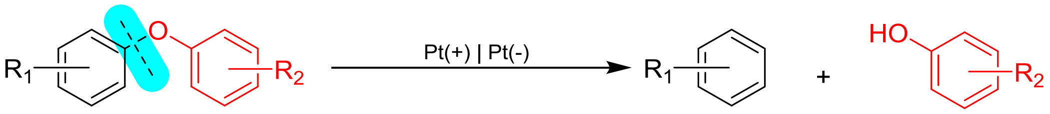
3. **Cleavage:** Electrochemical reactions resulting in cleavage of bonds are synthetically useful in many respects such as deprotonation of functional groups and generation of reactive intermediates. The electrochemical approach may be applied for the cleavage of bond, i.e. Carbon-carbon bond, carbon-hydrogen bond, carbon-sulphur bond, carbon-phosphorous bond, carbon – oxygen bond, carbon-halogen bond, oxygen-oxygen bond, sulphur-sulphur bonds, oxygen-nitrogen bonds, sulphur-nitrogen bonds and sulphur-halogen bonds. Scheme 5a shows the electrochemical C-N bond formation through C-H cleavage, scheme 5b shows the C-N bond formation through C-C bond cleavage while scheme 5c shows C-O cleavage using platinum as anode and cathode.



Scheme 5a

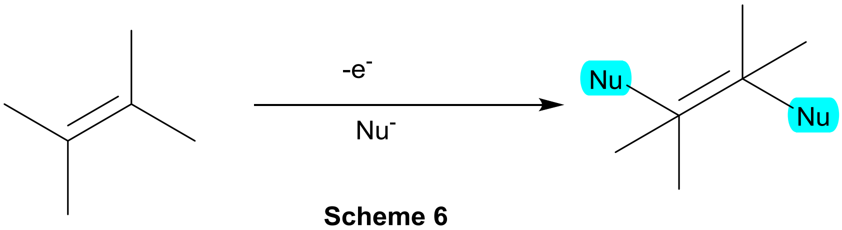


Scheme 5b



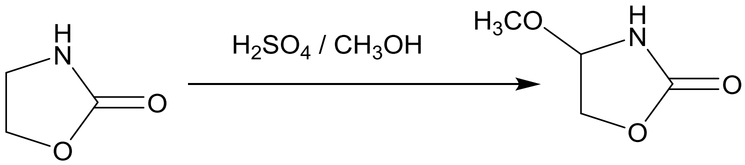
Scheme 5c

4. **Addition:** Products from anodic addition include propylene oxide, diols, and 1,4-dimethoxyfuran, some of which are of to industry. Sometimes, mediators like Ti3+, Pd2+, Ce4+, or Ru3+ are utilized to increase selectivity. Cathodically, the hydrogenation of the C=C bond is possible. The following is a possible representation for anodic additions at double bonds Scheme 6).-



Scheme 6

Methoxylation of organic compounds received the greatest attention in recent years among anodic addition reactions. A class of antibacterial substances called oxyazolidinones is efficient against gram-positive pathogenic bacteria. Using graphite or boron-doped diamond (BDD) as the anode, Saravanan and colleagues reported on the methoxylation of a 2oxazolidinone (Scheme 7). For BDD, higher yields were attained; the highest value of 88% was attained at a current density of 50 mAcm2. Beyond that current density, yields begin to drop as a result of the solvent oxidizing and the starting material deteriorating electrochemically.

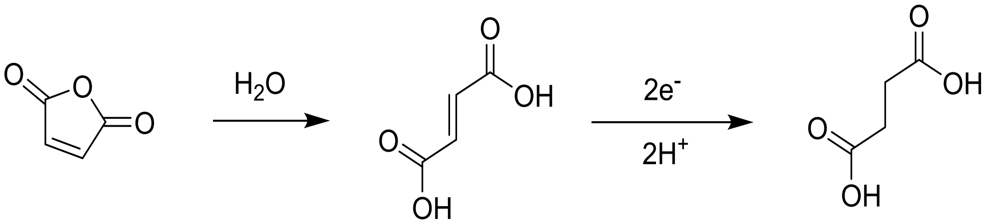


Scheme 7

VII. ELECTRO-ORGANIC SYNTHESIS FOR INDUSTRY

In the fields of fine chemicals, environmental mitigation, pharmaceuticals, agrochemicals, and other fields, organic electrosynthesis has garnered a lot of attention due to its high versatility and ability to replace harmful and toxic chemicals with electric current, or "clean" electrons. The yield of the intended product, the rate of production, and the amount of energy used during the synthesis process are the key factors at an industrial scale. Due to (a) high energy costs, (b) environmental restrictions, and (c) poor product selectivity, many electro-organically produced goods do not make it to official commercialization. In India, the Central Electrochemical Research Institute (CECRI) and other institutes has been playing an important role in developing many industrially viable products over decades, which includes p-amino benzoic acid, p-aminophenol, p-nitobenzoic acid, succinic acid, benzyl alcohol, benzaldehyde, salicylaldehyde, benzidine, saccharin and many other chemicals which have vital application in medicinal and agrochemical fields . In order to comprehend the idea of electrosynthesis as a real-world application, let's have a look at an example of industrial production of succinic acid.

Georgius Agricola initially refined butanedioic acid in 1546, often known as amber acid or succinic acid. Due to its reactivity, this dicarboxylic acid can be utilized in the production of nanomaterials, food and cosmetic items, and even anti-cancer medications. Due to the limited supply of fossil fuels, other sources, such as bacterial or other microbial derivative products, have taken a prominent role in the manufacture of succinic acid. Large amounts of wastewater would need to be produced from microbial sources, which is one of the main drawbacks. There are also issues with the effectiveness of the extraction process and the price of production. In order to overcome the disadvantages, a method of producing succinic acid via electrosynthesis has been proposed in which maleic anhydride hydrolysis is usually performed with further electroreduction under acidic conditions.(Scheme 6)



Scheme 8

The electrosynthesis techniques that resulted in better yields of succinic acid utilizing various types of reactors have been patented during the course of the previous few years by a number of writers. Gao and coworkers have described a technique for coupling the maleic anhydride electroreduction with concurrent iodide ion oxidation to produce paired electrosynthesis, which lowers the overall cell voltage and lowers production costs. 95% current efficiency was achieved using Pb alloy as the cathode and Ti supported RuO_2TiO_2 as the anode.

VIII. CONCLUSION

Herein, we discussed the general overview of electro-organic synthesis which will help the readers as a guide to electrosynthesis. The use of various aspects in the electro-organic synthesis describes an exciting method that makes several discoveries but contains a great many unknown treasures, which will lead to more advanced developments. In particular, in future chemical operations the use of fluctuating and abundant electricity to produce value added chemicals is going to be a game changer. The proper control of the working electrode potential, or the cell voltage (especially in the cases of paired electrolysis), or of the cell current that is applied to the terminals of the electrolytic cell reactor vessel, is all that is needed for electrochemical synthesis to be carried out in the majority of cases in a benign environmental condition, at moderate or low temperature and pressures, and with simple cheap facilities. In industrial synthesis, the galvanostatic mode is typically utilized, and the potential automatically adjusts to the compound having the least positive oxidation potential (anode) or the least negative reduction potential (cathode). This eliminates the need to test several redox reagents and allows one to examine the oxidation (or reduction) chemistry of a range of different substances essentially under the same conditions.. The fundamental focus of the book chapter was to motivate and make the readers aware of the general concept practical applications of electrochemical pathways for organic synthesis, from bench to industrial scale. It is believed that electro-organic synthesis will occupy a more prestigious positions on the fields like science and engineering, contributing to the specific, efficient and widespread commercialization of organic electrode processes.

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