RESEARCH ARTICLE

# Understanding the voltaic cell-like nature of moist cellulose thread through the development of a modified version of J.C. Bose's strain cell: A crucial property for cellulose-based biomedical sensors

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## ABSTRACT

Cellulose is considered an important material for biomedical sensor development. In the recent past, several experiments have been conducted to explore several advantageous properties of cellulose for use in biomedical engineering. To investigate the electrical properties of a material, using laboratory-based electrochemical cells is considered a simple technique. It is known that ideally, there should not exist any potential difference (P.D.) between two identical wires obtained from the same piece of metal when connected in the form of an electrochemical cell, with water as the electrolyte. However, in the year 1900, Acharya J.C. Bose had experimentally proved through his Strain Cell instrument that even when two identical metallic pieces, in the form of electrodes obtained from the same metal wire (immersed in water), are connected to a sensitive galvanometer, there exists a minute P.D. between them. In recent times, various experiments have been conducted to develop low-cost modified galvanic cells using cotton salt bridges. In view of this, first, a modified strain cell setup was developed in the laboratory to repeat J.C. Bose's experiment, and then a single electrode was replaced with moist cotton thread as a stable source of cellulose, connected from electrode to electrolyte to check if there is any qualitative variation in the phenomenon. A similar stable peak voltage, though of a different value as compared to that obtained in the original modified Strain Cell setup, was recorded, thereby confirming a voltaic-cell-like property of the moist cotton thread as well. Identification of such peculiar properties of cellulose in the form of moist cotton-based voltaic cells may help in the development of various types of cellulose-based biomedical sensors.

**Keywords:** Cellulose, Biomedical sensor, Moist cotton thread, Voltaic cell, Modified strain cell.

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## INTRODUCTION

A galvanic or electrochemical cell consists of two electrodes made up of two dissimilar metals, each immersed in a solution containing a dissolved salt of the corresponding metal[1]. The two solutions are connected by a tube containing a porous barrier that prevents them from rapidly mixing but allows diffusion of ions. If an ammeter is placed in the external circuit, the amount of electric charge that passes through the electrodes, and thus the number of moles of reactants that get transformed into products in the cell reaction, can be measured. Therefore, it can be stated that ideally, there should not exist any potential difference (P.D.) between two identical wires obtained from the same piece of metal, with water as the electrolyte. However, in the year 1900, Acharya J.C. Bose experimentally proved that even when two identical metallic pieces, in the form of electrodes obtained from the same metal wire (immersed in water), are connected to a sensitive galvanometer, there exists a minute P.D. between them[2]. To study the scientific basis of such a phenomenon, J.C. Bose invented the Strain Cell. In view of this, at first, a modified Strain Cell setup has been developed in the laboratory to repeat J.C. Bose's experiment.

In the recent past, there has been a rising trend in the development of modified Voltaic cells for use in experimental research, biomedical engineering, nature-inspired technology and the like. In the era of nanotechnology, various research works have been conducted on the development of nano-scale voltaic cells to understand the microscopic working principle of the Voltaic Cell[3]. Other studies have focused on the development of low-cost galvanic cells

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comprising electrodes of various metals like copper, zinc and so on, and a salt bridge made up of cotton thread that reduces the amount of electrolyte usually used to develop conventional galvanic cells[4]. In view of this, in the present study, in the next step, a single electrode was replaced with a moist cotton thread immersed in the electrolyte to find out a qualitative variation in the phenomenon, if any. The objective of choosing a cotton thread for the experiment is that cotton threads are a solid and cost-effective source of cellulose. Cellulose is a considerable biopolymer that has gained attention in the past few years owing to its widespread use in numerous domains, like the development of environmental sensors, medical diagnostic tools, forensic science, the food processing industry and many more[5]. It is considered an important material for biomedical sensor development due to its enhanced biocompatibility and biodegradability. It is considered as a 'smart' material for use in biomedical engineering because of several properties like transparency, dimensional stability, low thermal expansion and so on[6]. The two most important properties of cellulose, making it a suitable material for biomedical applications are low toxicity and high mechanical strength. It is known that the toxicity of materials is a matter of concern when it comes to biomedical applications. Cellulose particles are extracted from sources with no or low toxicity, making it safe for use in biomedical setups[7]. Previous studies have reported that, in general, cellulose crystals and its derivatives have high intrinsic stiffness and strength. It has also been reported that if cellulose crystals are arranged properly then they can exhibit extraordinary mechanical properties like high specific modulus and strength[8]. Other studies have shown that the enhanced mechanical strength of cellulose comes from its high crystallinity and strong intermolecular interactions like hydrogen bonding between cellulose chains[9]. In the recent past, certain electrochemical peculiarities of cellulose has also been reported. A study has shown that when electric voltage is applied to the electrodes, cellulose behaves like an actuator by generating a bending displacement[10]. Other studies have reported that a cellulose matrix exhibits metal oxide immobilization properties, thereby making it an ideal material for use in bioelectronics production. The same study also established other advantageous characteristics of cellulose like acquired mechanical properties, chemical steadiness, photosensitivity, and conductivity[11]. It is known that to understand the electrochemical properties of a material, the development of electrochemical cells can serve as a simple experimental approach because it allows fine control and measurement of the cell reaction. In light of the mentioned scenario, the present study aimed at the development of a modified Voltaic cell based on the working principles of J. C. Bose's Strain Cell by using cellulose (in the form of cotton thread) for use in biomedical research in the near future. Such property identification of cellulose through the modified strain cell may facilitate its further use in other types of biomedical sensors.

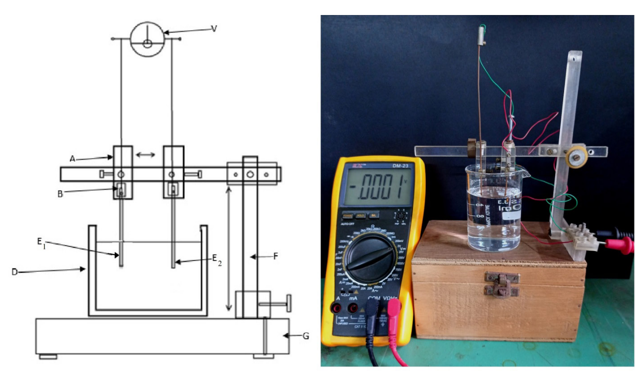
## MATERIALS AND METHODS

In accordance with J.C. Bose's Strain Cell setup, a similar setup was constructed in the laboratory (Figure 1). The setup was made up of 2 electrodes (diameter around 0.93 mm), comprising copper obtained from the same strip of metal[2]. In order to vary the distance (horizontal movement) and length (vertical movement) between the said electrodes, a mechanical structure was designed. The whole electrode setup was placed inside a 100 mL beaker containing electrolytes (drinking water, 90 mL) and was connected to a sensitive voltmeter (HTC DM-23 Digital Multimeter). The physical parameters of the drinking water used have been tabulated below in Table 1. The electrodes were immersed in electrolyte and the change in voltage in between the two electrodes was noted using the voltmeter.

To identify the factors influencing the generation of voltage the character of one of the electrodes was changed at a time. As demonstrated in Figure 2, a single electrode was connected to the electrolyte through a moist cotton thread (diameter 0.43 mm), keeping the other electrode unchanged. The cotton thread was primarily composed of ≈ 92–96% cellulose and ≈ 4–8 % natural impurities[12]. A further effort was made to check whether the voltage generated changes with the length of the dipped cotton thread and in the presence of externally applied mechanical load when connected with the electrode (Figure 2). For studying the effect of mechanical load on the voltage pattern an attempt was made to maintain the length of the dipped cotton thread at a fixed value. Then the cotton thread was manually pulled (force applied in a downward direction along the thread length) in a secure manner using a non-metal clamp-like tweezer for application of tension (mechanical load) and then released for withdrawal of the tension. Each test set was replicated thrice by three different operators and every time, the pattern of the results obtained was similar.

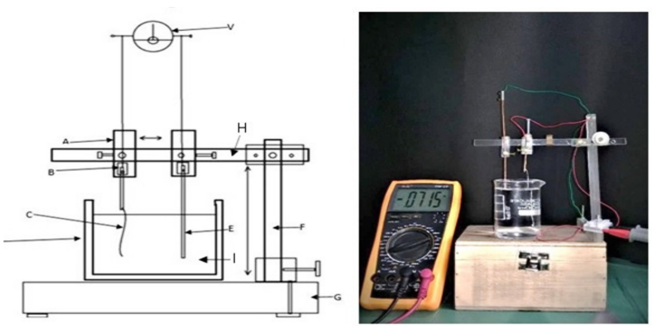
## RESULTS

In the case of the modified Strain Cell with Cu (0.93 mm) electrodes, when the identical metal electrodes were




V – Voltmeter, A – Vise mounter, B – Electrode vise, $E_1$ and $E_2$ – Identical Copper Electrodes, D – Beaker, F – Vertical Mechanical Stand, G – Wooden Base, H – Horizontal Mechanical Stand, I – Electrolyte

**Figure 1:** Images of the Modified Strain Cell Set up




V – Voltmeter, A – Vise mounter, B – Electrode vise, C – Moist cotton (cellulose) thread, D – Beaker, E – Copper Electrode, F – Vertical Mechanical Stand, G – Wooden Base, H – Horizontal Mechanical Stand, I – Electrolyte

**Figure 2:** Images of the Cotton-Mediated Voltaic Cell Set up

**Table 1:** Tabular representation of details of the relevant physical parameters of the drinking water used for the experimentation

| *Parameters* | *Values* |
|---|---|
| Temperature (°C) | 24.5 |
| pH | 6.8 |
| Salinity (% PPT) | 0.1 |
| Specific gravity | 1.000 |
| Turbidity (N.T.U) | 0.5 |

**Table 2:** Tabular representation of maximum saturated voltage (mV) at different lengths (cm) of moist cotton thread

| | *Max. saturated voltage (mV) at different lengths (cm) of moist cotton thread* | | | |
|---|---|---|---|---|
| *No. of readings* | *1 cm* | *2 cm* | *3 cm* | *4 cm* |
| 1 | -73.5 | -63.7 | -65.3 | -51.1 |
| 2 | -76.1 | -66.5 | -65.9 | -57.8 |
| 3 | -74.0 | -67.0 | -61.0 | -58.0 |
| AM ± SD | -74.5 ± 1 | -65.7 ± 1 | -64.1 ± 2 | -55.6 ± 3 |

**Table 3:** Tabular representation of maximum saturated voltage (mV) under variable mechanical disturbances: Vi (N) – initial voltage, T1 – Increased Thread Tension and T2 – Decreased Thread Tension

| | Max. saturated voltage (mV) | | |
|---|---|---|---|
| *No. of Readings* | *Vi (N)* | *V (T1)* | *V (T2)* |
| 1 | -51.2 | -54.3 | -35.4 |
| 2 | -51.0 | -56.3 | -39.8 |
| 3 | -44.3 | -53.1 | -39.4 |
| AM ± SD | -48.9 ± 4 | -54.6 ± 1 | -38.2 ± 2 |

immersed in electrolyte, a P.D. was noted in the voltmeter. The mean value of the order of magnitude of the P.D. was around -111 mV, which reduced to 0 within a few seconds.
In the case of the modified strain cell with moist cotton thread and Cu electrode, when one of the Cu electrodes was replaced with a moist cotton thread (0.43 mm) it was found that the maximum saturated voltage reached around -62.1 mV. In the study on varying the length of immersion of the moist cotton thread into the electrolyte it was found that there was a prominent variation in the intensity of the peak voltage. The change in the maximum saturated voltage with varying lengths of immersion of the cotton thread has been shown in Table 2 below. From the study, it was also noted that in the presence of an external mechanical disturbance (T1 and T2) there was a visibly prominent alteration in the maximum saturated voltage, as demonstrated in Table 3.

## DISCUSSION

Bose had reported in his experiment on strain cells that when similar metal electrodes were dipped in water within the Strain Cell, a P.D. was present. Bose had also stated that the presence of such P.D. even with similar metal wires, was due to the slight differences in the surface molecular orientation (condition)[2]. In the study, a P.D. of -111 mV was noted when identical electrodes were immersed in water, but this maximum saturated voltage was reduced to 0 within a short period of time (45 seconds).
Now, upon connecting one of the electrodes to the electrolyte through a moist cotton thread (diameter 0.43 mm), keeping the other electrode unchanged, a new feature was observed. The cotton-connected electrode showed a stable negative voltage (in the order of - 62.1 mV). The presence of a stable voltage (in the order of -62.1 mV) using moist cotton thread as one of the electrodes coincides with research reported by Khattiyavong *et al*., where they similarly reported the presence of a stable cell potential obtained from a galvanic cell developed using metals like Cu, Zn and so on and a low-cost salt bridge made up of 18 cm long cotton thread[13]. In the present study, the voltage pattern remained unaltered when the cotton was removed from the earlier electrode and fitted with the other one. The magnitude of the voltage (as shown in Table 2) varied with the alteration in the thread length. In the present experiment, readings were taken with different lengths of the moist cotton, viz. 1 to 4 cm.
In addition to this, another phenomenon was studied by applying mechanical disturbance (tension) to the moist cotton thread externally. As shown in Table 3, under the conditions of the presence and absence of the externally applied mechanical disturbance, there was a prominent change in the maximum saturated voltage (mV). The present finding is almost identical to that of Bose's experiments on strain cells. Bose had shown through his experiments on strain cells that when one of the wires was continuously twisted, a marked variation in the induced P.D. was noted during torsion between the acted and the unacted wires. Bose also stated that the probable basis behind such a variation in the P.D. was due to the generation of a temporary disturbance on the surface molecular arrangement that, in turn, alters the solid-state matter, resulting in variation of

conductivity and electromotive force (EMF)[2].

Sir J. C. Bose, in his experiment on strain cells, demonstrated that the voltaic cell property continues to exist even when two identical metal wires are used. The novelty of the present study lies in the fact that even if one of the electrodes in the modified strain cell apparatus is replaced by a non-metal material there occurs no qualitative change in the phenomenon. The non-metal electrode used in the present experiment was a cotton (moist) thread comprised mostly of cellulose. Since cellulose is considered an important material for biosensor development, the developed Strain Cell may serve as a novel setup for studying the electro-mechanical properties of cellulose at a laboratory scale in a stable and cost-effective manner. These constitute the novelty of the present study.

To summarize, some peculiar electrical and mechanical properties of cellulose, when used in the form of moist cotton thread inside a strain cell, have been identified, which may facilitate its use in biomedical sensor development in the future. From the present study, it may also be inferred that a moist cotton thread exhibits a voltaic cell-like pattern, as evident from the stable peak voltage (in the order of - 62.1 mV) generated after connecting the moist thread to the metal electrode through the electrolyte. The study also indicated that there may be a role of mechanical disturbance as observed from the variation in EMF when different strengths of mechanical disturbance were imposed.

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## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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## PEER-REVIEWED CERTIFICATION

During the review of this manuscript, a double-blind peer-review policy has been followed. The author(s) of this manuscript received review comments from a minimum of two peer-reviewers. Author(s) submitted revised manuscript as per the comments of the assigned reviewers. On the basis of revision(s) done by the author(s) and compliance to the Reviewers' comments on the manuscript, Editor(s) has approved the revised manuscript for final publication.